January 2004

CERP MONITORING AND ASSESSMENT PLAN:

PART 1

MONITORING AND SUPPORTING RESEARCH

REstoration COordination and VERification (RECOVER)

the journey to restore America's Everglades

COMPREHENSIVE EVERGLADES RESTORATION PLAN

CENTRAL AND SOUTHERN FLORIDA PROJECT

EXECUTIVE SUMMARY

The Monitoring and Assessment Plan (MAP) is the primary tool by which the REstoration COordination and VERification (RECOVER) program will assess the performance of the Comprehensive Everglades Restoration Plan (CERP). The scientific and technical information generated from the MAP implementation will be organized to provide a process for RECOVER to evaluate CERP performance and system responses and to produce assessment reports describing and interpreting the responses. The Adaptive Assessment Team of RECOVER has the lead responsibility for developing, implementing, and updating the MAP. The overarching goal for implementation of the MAP is to have a single, integrated, system-wide monitoring and assessment plan that will be used and supported by all participating agencies and tribal governments as the means of tracking and measuring the performance of the CERP.

This document, Part 1 of the MAP, describes in detail the monitoring components and supporting research of the MAP and briefly summarizes the assessment process. A detailed assessment process for interpreting the information collected by the implementation of this plan is under development at this time by the Adaptive Assessment and Water Quality Teams. This process will be documented in Part 2 of the MAP. As initial monitoring and research efforts facilitate new understandings, modifications to the monitoring components and supporting research of the MAP will be developed as needed and will be documented in the first MAP update and in subsequent updates. As CERP implementation advances and RECOVER evaluates and assesses its performance, the MAP will be further supplemented and refined, and this document will be updated as necessary.

OBJECTIVES

In general, the MAP has four broad objectives:

1. Establish a pre-CERP reference state including variability for each of the performance measures

2. Provide the assessment of the system-wide responses of CERP implementation

3. Detect unexpected responses of the ecosystem to changes in stressors resulting from CERP activities

4. Support scientific investigations designed to increase ecosystem understanding, establish cause-and-effect relationships, and interpret unanticipated results

OVERVIEW

The RECOVER program, as one of the major programmatic components of the CERP, has a threefold mission:

- **Evaluation –** to work with CERP project teams prior to construction to evaluate projects through predictive modeling and maximize the contribution made by each project to the system-wide performance of the CERP

- **Assessment –** to measure, by the use of data collected through monitoring, and interpret responses in the natural and human systems as CERP projects are constructed and implemented

- **Planning and Integration –** to identify potential improvements in the design and operation of the CERP, consistent with CERP objectives, and to strive for consensus among agencies regarding the scientific and technical aspects of the CERP

To support these mission areas, RECOVER is responsible for the coordination and application of an Applied Science Strategy (Ogden and Davis 1999) during CERP implementation. This strategy outlines a process for organizing current scientific understanding of wetland and estuarine ecosystems into formulations that can effectively support restoration efforts. The major components of the Applied Science Strategy are the development of regional and total system conceptual ecological models, identification of performance measures and restoration targets, development and implementation of a system-wide monitoring program, and development of an assessment strategy (see Figure ES-1). Natural and human system responses will be assessed relative to stated hypotheses for these systems and evaluated relative to the trends or targets established for the CERP performance measures consistent with the Applied Science Strategy and the objectives of the MAP.

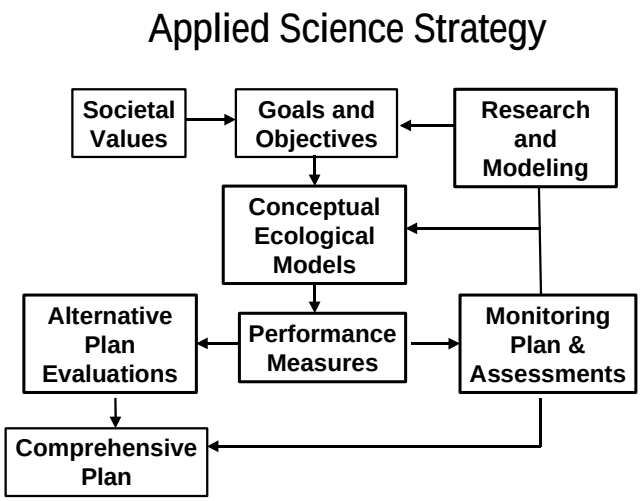


Figure ES-1: Applied Science Strategy

Comparisons of system responses to predicted performance will serve as a basis for evaluating how the implementation of the CERP projects, both individually and collectively, are meeting the overall goals and objectives of the CERP. Monitoring data collected by the MAP will be used for six broad purposes in support of the CERP:

1. Assess and document progress towards meeting performance measure targets and interim and long-term goals

2. Detect undesirable system responses as early as possible in order to minimize the adverse effects of these responses

3. Provide a basis for identifying options for improvements in the design and operation of CERP projects and components

4. Develop reports on the status and progress of the CERP for the agencies involved, the public, Congress, the Florida Legislature, and stakeholders

5. Evaluate CERP hypotheses and performance measures and revise conceptual ecological models as appropriate

6. Enhance predictive ability through improvements in simulation models before and after project construction

In summary, the MAP is designed to help establish the framework for measuring and understanding system responses to the CERP, to help determine how well the CERP is meeting its goals and objectives, and to help identify opportunities for improving the performance of the CERP where needed.

This monitoring plan does not encompass all of the measurements necessary to document the long-term restoration of all of the South Florida ecosystems. The monitoring identified in the MAP includes monitoring already being conducted by one or more agencies or institutions and identifies a large body of new monitoring required for a complete interpretation of CERP responses.

Successful implementation of the MAP is dependent on two key assumptions:

1. **Existing Monitoring Programs -** Existing monitoring will continue with existing funding sources (i.e., the MAP should not replace ongoing agency efforts that are essential to the plan implementation)

2. **Partnering Agencies -** Partnering agencies will contribute funding and/or will participate in implementation of the MAP

The RECOVER program recognizes that the MAP is a key component of a system-wide adaptive management strategy that is essential for the success of the CERP. Basic components and purposes of the CERP Adaptive Management Program are described in the Programmatic Regulations for the Comprehensive Plan (DOD 2003). The Adaptive Management Program is designed to maximize the success of the CERP by refining the Plan during its implementation to respond to new information or technologies to ensure that the goals and purposes of the Plan are fulfilled. These uncertainties include unpredicted and undesired responses and events in the natural and human systems of South Florida that result from CERP implementation or from non-CERP projects and programs. A successful adaptive management program will provide early warnings of undesired impacts and a process that will allow decision makers 1) to effectively integrate science and management to ensure that the CERP goals and purposes are fulfilled and 2) to seek continuous improvements of the CERP.

The monitoring components and supporting research described in the MAP are designed to answer adaptive management questions. For example, will the natural system respond to the implementation of the CERP as the working hypotheses indicate it should? If not, how can the design and/or operation of the CERP be modified to achieve desired ecosystem responses?

Implementation of the MAP will require rigorous Quality Assurance and Quality Control (QA/QC) programs for the data management program for the CERP. RECOVER has adopted the following principles in developing these programs. The QA/QC programs must do the following:

- Withstand scientific review and legal scrutiny

- Be used to develop and support scientific and technical consensus

- Be fully integrated into the CERP

This QA/QC effort will provide consistency to the information collected by the many different agencies and tribal governments involved in the implementation of the CERP. This effort will also establish operating standards for the design, collection, and analyses of a variety of data types recommended in this MAP and for all of the CERP project and components. The QA/QC Program is designed to meet the following requirements:

- **Standardized Procedures** – ensure the consistency and comparability of data using standardized procedures across agencies or organizations

- **Accuracy and Precision Criteria** – provide guidance to those involved in the CERP monitoring activities to establish accuracy and precision criteria for each data type

- **Degree of Confidence** - provide for the efficient and effective analysis of data collected by the various organizations in South Florida and provide users of these data with some degree of confidence that the data were collected with similar accuracy and processing standards across agencies

- **Guidance for New Monitoring Stations** – provide guidance on accuracy and precision requirements to agencies and organization involved with establishing new monitoring stations

DOCUMENT ORGANIZATION

The MAP presents the monitoring and supporting research that is required to measure the responses of the South Florida ecosystem that the CERP is explicitly designed to improve, correct, or directly affect.

The MAP is organized into five main sections:

- **Section 1. Purpose and Scope of the CERP Monitoring and Assessment Plan**

- **Section 2. Development of the CERP Monitoring Plan and Adaptive Management Program**

- **Section 3. Integrated Monitoring Requirements** – Integrated monitoring plans have been developed for six monitoring modules covering the CERP project area and are contained in the following subsections:

  3.1 Greater Everglades Wetlands
  3.2 Southern Estuaries (Florida Bay, Biscayne Bay, and Southwest Florida Coast)
  3.3 Northern Estuaries (Caloosahatchee Estuary, St. Lucie Estuary, Indian River Lagoon, Loxahatchee River Estuary, and Lake Worth Lagoon)
  3.4 Lake Okeechobee
  3.5 South Florida Hydrology Monitoring Network
  3.6 South Florida Mercury Bioaccumulation

- **Section 4. Quality Assurance/Quality Control and Data Validation, Management, Evaluation, and Reporting**

- **Section 5. Implementation Strategy for the CERP Monitoring and Assessment Plan**

- **Appendix A. Draft Conceptual Ecological Models –** this section contains eleven conceptual ecological models covering the major physiographic regions of South Florida

- **Appendix B. Project Influence on Monitoring and Assessment Plan Modules**

DEVELOPMENT AND REFINEMENT OF THE PLAN

The development and refinement of the MAP is a continuous and iterative process. Earlier drafts of this document have undergone extensive agency coordination and public scrutiny. Formal reviews of the MAP will occur no less frequently than once every three years, with informal reviews occurring annually.

The Adaptive Assessment Team has the lead responsibility for developing and updating the MAP and providing guidance for its implementation. In addition, the Adaptive Assessment Team has the lead responsibility for using the information provided by the monitoring program to assess system responses. RECOVER is responsible for preparing a technical assessment report at least every five years. This report presents an assessment of whether the goals and purposes of the CERP are being achieved.

The MAP consists of numerous biologic, hydrologic, and water quality components. No single agency can carry out the full suite of monitoring tasks due to logistic challenges, budgetary constraints, and distribution of interagency expertise. Although lead responsibility for funding and implementing this monitoring program is held by the United States Army Corps of Engineers and the South Florida Water Management District, the success of the program will depend on the long-term participation of a number of South Florida federal and state agencies and non-governmental organizations that are currently conducting monitoring programs in South Florida.

MAP IMPLEMENTATION ORGANIZATION

The conceptual organizational structure proposed for implementation of the MAP is composed of four tiers (Figure ES-2). This structure provides an approach for RECOVER to implement a successful monitoring and assessment program. This chart shows the hierarchical relationship of this proposed functional management unit to RECOVER and the Adaptive Assessment and Water Quality Teams. This also illustrates the linkage to the MAP module subteams.

Central to the success of MAP implementation is the establishment of a MAP coordinator. This position is responsible and accountable for the overall coordination and implementation of the MAP. The MAP Coordinator is expected to ensure that there is overall consistency and standardization of processes, common systems and technology, and programmatic practices among the regional monitoring program participants. Although the MAP implementation organization as currently proposed involves a strong centralization of data management, data analysis, and reporting functions, it is proposed that data collection activities be conducted largely through intra- and interagency agreements as well as contractual arrangements with universities and private sector contractors.

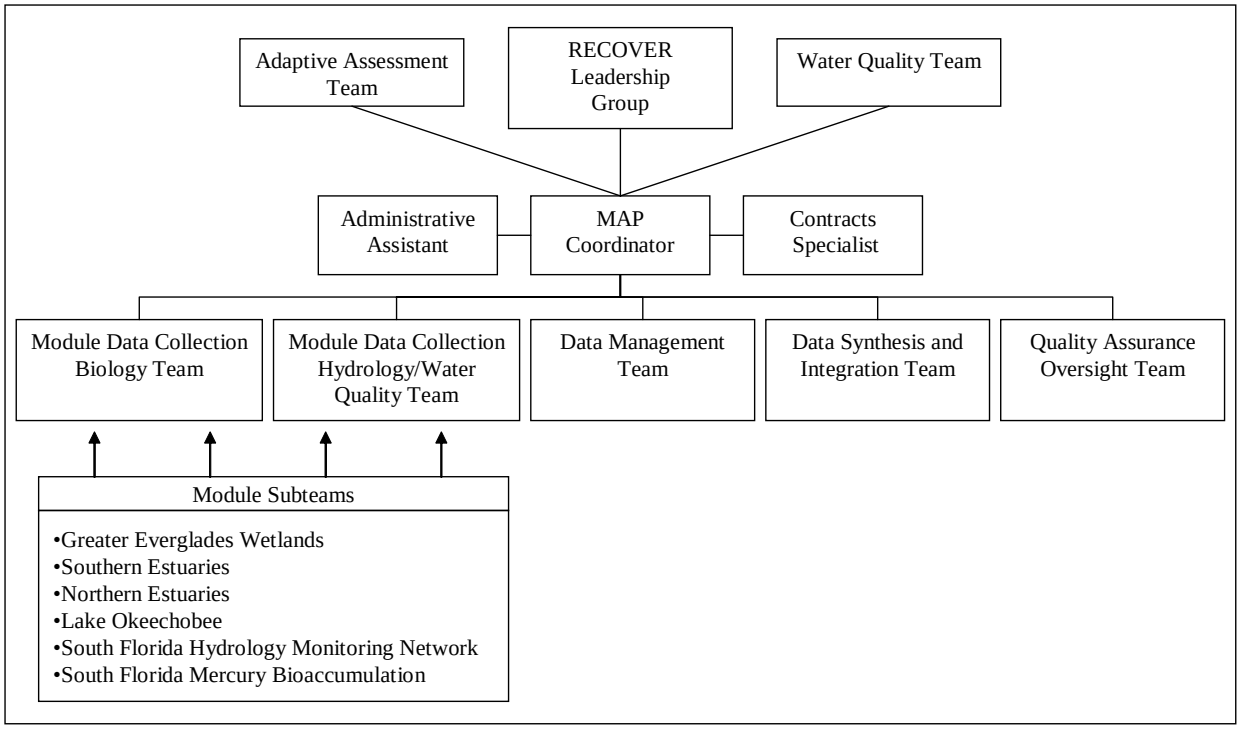


Figure ES-2: Conceptual Organization for the Implementation of the MAP

SEQUENCING OF MONITORING COMPONENTS

Implementation of the MAP is expected to be phased-in over a two-year period, with the initial focus on filling gaps in the existing condition (baseline) data. Four goals have been established to help provide logic for sequencing the implementation of the various MAP monitoring components:

- Establish stations or projects necessary to measure stressors identified in the simplified conceptual ecological models
- Close the gaps in biologic, hydrologic, and water quality monitoring components in existing programs
- Initiate priority baseline research to address uncertainties in system response as determined by the Adaptive Assessment Team
- Initiate priority baseline monitoring components for the MAP as determined by the Adaptive Assessment Team

Additional details on implementation and sequencing are contained in Section 5 of the MAP.

CONCLUSION

The long-term success of the CERP depends on the effective implementation of the MAP through the RECOVER Program. It is essential that stakeholders, agencies, managers, and elected officials understand

how RECOVER will evaluate the ecosystem responses with the implementation of the CERP and assess whether this implementation is producing the intended benefits.

REFERENCES

Ogden, J.C., and S.M. Davis. 1999. The Use of Conceptual Ecological Landscape Models as Planning Tools for the South Florida Ecosystem Restoration Programs. South Florida Water Management District, West Palm Beach, Florida.

DOD. 2003. Programmatic Regulations for the Comprehensive Everglades Restoration Plan; Final Rule. Federal Register, Volume 68, Number 218, pp. 64200-64249. Department of Defense, Department of the Army, Corps of Engineers, 33 CFR Part 385, November 12, 2003, Washington, D.C.

TABLE OF CONTENTS

Section **Page No.**

EXECUTIVE SUMMARY ..... **i**
OBJECTIVES i
OVERVIEW i
DOCUMENT ORGANIZATION iv
DEVELOPMENT AND REFINEMENT OF THE PLAN v
MAP IMPLEMENTATION ORGANIZATION v
SEQUENCING OF MONITORING COMPONENTS vi
CONCLUSION vi
REFERENCES vii

LIST OF TABLES ..... **xiii**

LIST OF FIGURES ..... **xv**

ACRONYMS AND ABBREVIATIONS ..... **xix**

1.0 PURPOSE AND SCOPE OF THE CERP MONITORING AND ASSESSMENT PLAN **1-1**
1.1 INTRODUCTION 1-1
1.2 SCOPE AND ORGANIZATION OF THE MONITORING AND ASSESSMENT PLAN 1-7
1.3 BACKGROUND 1-9
1.4 RECOVER 1-11
1.5 CONTACTS FOR THE MONITORING AND ASSESSMENT PLAN 1-14
1.6 REFERENCES 1-14

2.0 DEVELOPMENT OF THE CERP MONITORING PLAN AND ADAPTIVE MANAGEMENT PROGRAM **2-1**
2.1 INTRODUCTION 2-1
2.2 DEVELOPMENT OF CONCEPTUAL ECOLOGICAL MODELS AND PERFORMANCE MEASURES 2-1
2.3 DEVELOPMENT OF INTEGRATED MONITORING MODULES 2-4
2.4 ASSESSMENT OF MONITORING DATA 2-5
2.5 CERP ADAPTIVE MANAGEMENT PROGRAM 2-6
2.6 REFERENCES 2-8

3.0 INTEGRATED MONITORING REQUIREMENTS **3-1**
3.1 GREATER EVERGLADES WETLANDS MODULE 3-3
3.1.1 Introduction 3-3
3.1.2 Ecological Premises and CERP Hypotheses as the Basis for Monitoring Components and Supporting Research 3-9
3.1.3 Monitoring Components 3-19
3.1.4 Key Uncertainties and Supporting Research 3-42
3.1.5 References 3-53
3.2 SOUTHERN ESTUARIES MODULE 3-59
3.2.1 Introduction 3-59
3.2.2 Ecological Premises and CERP Hypotheses as the Basis for Monitoring Components and Supporting Research 3-63

TABLE OF CONTENTS (Continued)

Section **Page No.**

3.2.3 Monitoring Components 3-69
3.2.4 Key Uncertainties and Supporting Research 3-89
3.2.5 References....3-100
3.3 NORTHERN ESTUARIES MODULE 3-105
3.3.1 Introduction....3-105
3.3.2 Ecological Premises and CERP Hypotheses as the Basis for Monitoring Components and Supporting Research 3-110
3.3.3 Monitoring Components 3-115
3.3.4 Key Uncertainties and Research Topics 3-141
3.3.5 References....3-146
3.4 LAKE OKEECHOBEE MODULE 3-149
3.4.1 Introduction....3-149
3.4.2 Ecological Premises and CERP Hypotheses as the Basis for Monitoring Components and Supporting Research 3-151
3.4.3 Monitoring Components 3-155
3.4.4 Key Uncertainties and Supporting Research 3-168
3.4.5 References....3-170
3.5 SOUTH FLORIDA HYDROLOGY MONITORING NETWORK MODULE 3-173
3.5.1 Introduction....3-173
3.5.2 Ecological Premise and CERP Hypotheses as the Basis for Monitoring Components and Supporting Research 3-174
3.5.3 Monitoring Components 3-178
3.5.4 Key Uncertainties and Supporting Research 3-184
3.5.5 References....3-185
3.6 SOUTH FLORIDA MERCURY BIOACCUMULATION MODULE 3-187
3.6.1 Introduction....3-187
3.6.2 Ecological Premise and CERP Hypotheses as the Basis for Monitoring Components and Supporting Research 3-190
3.6.3 Monitoring Components 3-194
3.6.4 Key Uncertainties and Potential Research Questions (to be developed) 3-196
3.6.5 References....3-197

4.0 QUALITY ASSURANCE/QUALITY CONTROL AND DATA VALIDATION, MANAGEMENT, EVALUATION, AND REPORTING....4-1
4.1 INTRODUCTION 4-1
4.2 DATA QUALITY OBJECTIVES 4-1
4.3 QUALITY ASSURANCE/QUALITY CONTROL 4-1
4.3.1 Need for Standardized Protocols 4-2
4.3.2 CERP Quality Assurance Systems Requirements 4-2
4.3.3 CERP Quality Assurance Oversight Team 4-4
4.3.4 Water Quality Monitoring 4-5
4.3.5 Hydrologic Monitoring 4-5
4.3.6 Biological Monitoring....4-6
4.3.7 Remote Sensing 4-6
4.4 DATA VALIDATION AND ASSESSMENT 4-7
4.5 DATA MANAGEMENT 4-8
4.5.1 System Requirements 4-9

TABLE OF CONTENTS (Continued)

Section **Page No.**

4.5.2 Data Management Standards 4-9
4.6 IMPLEMENTATION OF QA/QC AND DATA VALIDATION REQUIREMENTS....4-10
4.7 EVALUATION AND REPORTING 4-10
4.8 REFERENCES 4-11

5.0 IMPLEMENTATION STRATEGY FOR THE CERP MONITORING AND ASSESSMENT PLAN 5-1
5.1 INTRODUCTION 5-1
5.2 COMPONENTS OF A MONITORING AND ASSESSMENT IMPLEMENTATION PROGRAM....5-1
5.2.1 Data Collection 5-2
5.2.2 Data Management 5-3
5.2.3 Data Analysis 5-3
5.2.4 Reporting 5-4
5.2.5 Quality Assurance 5-4
5.3 REQUIREMENTS OF MAP IMPLEMENTATION 5-4
5.4 MAP IMPLEMENTATION ORGANIZATION 5-5
5.4.1 MAP Coordinator and Supporting Organization 5-6
5.4.2 Module Subteams of the Adaptive Assessment Team 5-7
5.4.3 Sequencing of Monitoring Components 5-8
5.4.4 Characterizing Existing Conditions 5-10
5.4.5 Progress to Date 5-11
5.5 REFERENCES 5-12

APPENDIX A. DRAFT CONCEPTUAL ECOLOGICAL MODELS A-1

APPENDIX B. PROJECT INFLUENCE ON MONITORING AND ASSESSMENT PLAN MODULES B-1

LIST OF TABLES

Table **Page No.**

Table 1-1: Summary of Existing Monitoring and Responsible Agencies 1-2
Table 2-1: Draft Assessment System-Wide Performance Measures 2-2
Table 3-1: Summary List of Monitoring Components and Key Uncertainties and Supporting Research for the Greater Everglades Wetlands 3-18
Table 3-2: Greater Everglades Water Quality Monitoring at Water Control Structures 3-23
Table 3-3: Greater Everglades Water Quality Monitoring at Marsh Stations (Transects and Fixed Stations) 3-23
Table 3-4: Landscape Units of Greater Everglades Wetlands to be used for Stratified Random Sampling Design 3-36
Table 3-5: Monitoring Components and Key Uncertainties and Supporting Research for the Southern Estuaries 3-69
Table 3-6: Recommended Biscayne Bay Water Quality Monitoring (Nutrient Loads and Canal/River Quality) 3-73
Table 3-7: Recommended Biscayne Bay Water Quality Monitoring (Estuarine) 3-74
Table 3-8: Recommended Florida Bay Water Quality Monitoring (Estuarine and Southwestern Coast) 3-79
Table 3-9: Monitoring Components and Key Uncertainties and Supporting Research for the Northern Estuaries 3-115
Table 3-10: Recommended Water Quality Monitoring for Nutrient Loads and Canal/River Quality 3-123
Table 3-11: Recommended Estuarine Water Quality Monitoring 3-124
Table 3-12: SAV Monitoring Stations for the Caloosahatchee River and San Carlos Bay 3-127
Table 3-13: Preliminary Site Locations for Macroinvertebrate Sampling Sites in the St. Lucie Estuary 3-140
Table 3-14: Monitoring Components and Supporting Research for Lake Okeechobee 3-154
Table 3-15: Recommended Lake Okeechobee Water Quality Monitoring – (Nutrient Loads and Inflow/Outflow Quality) 3-158
Table 3-16: Lake Okeechobee Inflow and Outflow Monitoring Station Summary 3-158
Table 3-17: Lake Okeechobee In-Lake Water Quality Monitoring Parameters 3-161
Table 3-18: Summary List of Monitoring Components and Key Uncertainties and Supporting Research for the South Florida Hydrology Monitoring Network 3-177
Table 3-19: Monitoring Components and Key Uncertainties and Supporting Research for South Florida Mercury Bioaccumulation 3-193

LIST OF FIGURES

Figure **Page No.**

Figure ES-1: Applied Science Strategy ii
Figure ES-2: Conceptual Organization for the Implementation of the MAP vi
Figure 1-1: The Physical Scope of the MAP 1-8
Figure 1-2: Applied Science Strategy 1-12
Figure 1-3: Current Organization of RECOVER Teams 1-13
Figure 2-1: The CERP Adaptive Management Process 2-7
Figure 3-1: Boundary of Greater Everglades Wetlands within the Influence of CERP 3-4
Figure 3-2: Simplified Conceptual Ecological Model to Reflect Expected CERP Influences in Everglades Ridge and Slough 3-5
Figure 3-3: Simplified Conceptual Ecological Model to Reflect Expected CERP Influences in Everglades Southern Marl Prairies 3-6
Figure 3-4: Simplified Conceptual Ecological Model to Reflect Expected CERP Influences in Everglades Mangrove Estuaries 3-7
Figure 3-5: Simplified Conceptual Ecological Model to Reflect Expected CERP Influences in Big Cypress Basin 3-8
Figure 3-6: Diagram Depicting Relationships between the Ecological Premise, CERP Hypotheses, Monitoring Components, and Supporting Research for Interior Gradients of Flow and Water Quality in the Greater Everglades Wetlands 3-10
Figure 3-7: Diagram Depicting Relationships between the Ecological Premise, CERP Hypotheses, Monitoring Components, and Supporting Research for Coastal Gradients of Flow, Salinity, and Nutrients in the Greater Everglades Wetlands 3-11
Figure 3-8: Diagram Depicting Relationships between the Ecological Premise, CERP Hypotheses, Monitoring Components, and Supporting Research for Wetland Landscape Patterns in the Greater Everglades Wetlands 3-12
Figure 3-9: Diagram Depicting Relationships between the Ecological Premise, CERP Hypothesis, Monitoring Components, and Supporting Research for Primary Producer Trophic Levels of Food Chains Supporting Higher Vertebrates in the Greater Everglades Wetlands 3-14
Figure 3-10: Diagram Depicting Relationships between the Ecological Premise, CERP Hypothesis, Monitoring Components, and Supporting Research for Secondary Producer Trophic Levels of Food Chains Supporting Higher Vertebrates in the Greater Everglades Wetlands 3-15
Figure 3-11: Diagram Depicting Relationships between the Ecological Premise, CERP Hypotheses, Monitoring Components, and Supporting Research for Wading Birds as Upper Trophic Level Consumers in the Greater Everglades Wetlands 3-16
Figure 3-12: Diagram Depicting Relationships between the Ecological Premises, CERP Hypotheses, Monitoring Components, and Supporting Research for the American Alligator and American Crocodile in the Greater Everglades Wetlands 3-17
Figure 3-13: Greater Everglades (North) Water Quality Monitoring Stations as of September 2002 – Water Control Structures and Interior Marsh 3-20
Figure 3-14: Greater Everglades (South) Water Quality Monitoring Stations as of September 2002 – Water Control Structures and Interior Marsh 3-21
Figure 3-15: Stratified Random Sampling Design for Soil Nutrient Concentration Monitoring in Greater Everglades Wetlands 3-25
Figure 3-16: Spatial Distribution of Surface Soil (0-10 centimeters) Phosphorus Concentrations throughout the Everglades 3-26

LIST OF FIGURES (Continued)

Figure **Page No.**

Figure 3-17: Coastal Gradient Transects of Flow, Salinity, and Nutrients for Monitoring Flow.....3-28
Figure 3-18: Marl Prairie/Slough Vegetation Transects Across the Southern Everglades.....3-30
Figure 3-19: Everglades Prey-Availability Hypothesis.....3-33
Figure 3-20: Landscape Units of Greater Everglades Wetlands to be Used for Stratified Random Sampling Design.....3-38
Figure 3-21: Landscape Subregions Aggregated into Regional Groups to be Used for Stratified Sampling Design.....3-39
Figure 3-22: Southern Estuaries within the Influence of CERP.....3-59
Figure 3-23: Simplified Conceptual Ecological Model of Florida Bay to Reflect Expected CERP Influences.....3-61
Figure 3-24: Simplified Conceptual Ecological Model for Biscayne Bay to Reflect Expected CERP Influences.....3-62
Figure 3-25: Diagram Depicting Relationships between the Ecological Premise, CERP Hypotheses, Monitoring Components, and Supporting Research for Freshwater Inflows and Salinity in the Southern Estuaries.....3-65
Figure 3-26: Diagram Depicting Relationships between the Ecological Premise, CERP Hypotheses, Monitoring Components, and Supporting Research for Water Quality in the Southern Estuaries.....3-66
Figure 3-27: Diagram Depicting Relationships between the Ecological Premise, CERP Hypotheses, Monitoring Components, and Supporting Research for Epibenthic and Shoreline Communities in the Southern Estuaries.....3-68
Figure 3-28: Biscayne Bay Water Quality and Phytoplankton Monitoring Network.....3-71
Figure 3-29: Florida Bay and Southwest Florida Coast Water Quality Monitoring Network.....3-77
Figure 3-30: Offshore transect monitoring sites used by NOAA.....3-78
Figure 3-31: Biscayne Bay Salinity Monitoring Network.....3-81
Figure 3-32: Florida Bay Salinity Monitoring Network.....3-83
Figure 3-33: Current and Proposed SAV and Seagrass Fish and Invertebrate Monitoring and Assessment Network.....3-85
Figure 3-34: Northern Estuaries Module Boundary on the West Coast of Florida – Caloosahatchee Estuary.....3-105
Figure 3-35: Northern Estuaries Module Boundary on the East Coast of Florida – St. Lucie Estuary, Indian River Lagoon, Loxahatchee River Estuary, and Lake Worth Lagoon.....3-106
Figure 3-36: Simplified Conceptual Ecological Model of the Caloosahatchee Estuary to Reflect Expected CERP Influences.....3-107
Figure 3-37: Simplified Conceptual Ecological Model of the St. Lucie Estuary and Indian River Lagoon to Reflect Expected CERP Influences.....3-108
Figure 3-38: Simplified Conceptual Ecological Model of the Loxahatchee River Estuary to Reflect Expected CERP Influences.....3-109
Figure 3-39: Simplified Conceptual Ecological Model of the Lake Worth Lagoon to Reflect Expected CERP Influences.....3-110
Figure 3-40: Diagram Depicting Relationships between the Ecological Premise, CERP Hypotheses, Monitoring Components, and Supporting Research for Freshwater Flows and Salinity Regimes in the Northern Estuaries.....3-111
Figure 3-41: Diagram Depicting Relationships between the Ecological Premise, CERP Hypotheses, Monitoring Components, and Supporting Research for Water Quality in the Northern Estuaries.....3-112

LIST OF FIGURES (Continued)

Figure **Page No.**

Figure 3-42: Diagram Depicting Relationships between the Ecological Premise, CERP Hypotheses, Monitoring Components, and Supporting Research for Estuarine Epibenthic Communities in the Northern Estuaries 3-114
Figure 3-43: Continuous Salinity Recorder Sites in the Caloosahatchee Estuary 3-116
Figure 3-44: Caloosahatchee River Estuary Water Quality Monitoring Stations 3-119
Figure 3-45: St. Lucie Estuary and Indian River Lagoon Water Quality Monitoring Stations 3-120
Figure 3-46: Loxahatchee River Estuary Water Quality Monitoring Stations 3-121
Figure 3-47: Lake Worth Lagoon Water Quality Monitoring Stations 3-122
Figure 3-48: SAV mapping boundary and three transect monitoring locations for the Central Embayment of the Loxahatchee River 3-126
Figure 3-49: SAV Monitoring Sites within the Caloosahatchee Estuary 3-129
Figure 3-50: Existing and Proposed SAV Monitoring Locations within the St. Lucie Estuary and Southern Indian River Lagoon 3-131
Figure 3-51: SAV Monitoring Locations Near the Mouth of the St. Lucie River 3-132
Figure 3-52: SAV Transect Locations for Lake Worth Lagoon 3-134
Figure 3-53: Oyster Monitoring Stations in the Caloosahatchee Estuary 3-135
Figure 3-54: Oyster Beds for Oyster Spat and Adult Monitoring within the St. Lucie Estuary 3-137
Figure 3-55: St. Lucie Estuary Macroinvertebrate Sample Collection Sites 3-139
Figure 3-56: Loxahatchee River Estuary Benthic Monitoring Study Sites (Loxahatchee River District) 3-141
Figure 3-57: Simplified Conceptual Ecological Model to Reflect Expected CERP Influences in Lake Okeechobee 3-149
Figure 3-58: Diagram Depicting Relationships between the Ecological Premise, CERP Hypotheses, Monitoring Components, and Supporting Research for Water Quality in Lake Okeechobee 3-152
Figure 3-59: Diagram Depicting Relationships between the Ecological Premise, CERP Hypotheses, Monitoring Components, and Supporting Research for Ecological Communities and Effects of Water Stages in Lake Okeechobee 3-153
Figure 3-60: Map of Lake Okeechobee, Showing the Locations of 32 Inflow and Outflow Water Quality and Flow Monitoring Stations 3-157
Figure 3-61: Map of Lake Okeechobee, Showing Names and Locations of 33 In-Lake Water Quality Monitoring Stations 3-160
Figure 3-62: Three Major Physiographic Regions of Lake Okeechobee 3-162
Figure 3-63: Map of Lake Okeechobee, Showing the Location of Transects for Quantitative Evaluation of SAV, Water Depth, Secchi Transparency, and Total Suspended Solids 3-164
Figure 3-64: Map of Lake Okeechobee, Showing the 1,000 by 1,000 Meter Sampling Grid for 2002 Evaluation of SAV Spatial Extent 3-165
Figure 3-65: Diagram Depicting Relationships between the Ecological Premise, CERP Hypotheses, Monitoring Components, and Supporting Research for Increased Water Storage Capacity as it Relates to the Natural Systems 3-175
Figure 3-66: Diagram Depicting Relationships between the Ecological Premise, CERP Hypotheses, Monitoring Components, and Supporting Research for Increased Water Storage Capacity as it Relates to Water Supply 3-176
Figure 3-67: Diagram Depicting Relationships between the Ecological Premise, CERP Hypotheses, Monitoring Components, and Supporting Research for Increased Water Storage Capacity as it Relates to Flood Protection 3-176

LIST OF FIGURES (Continued)

Figure **Page No.**

Figure 3-68: Selected Stage Monitoring Sites 3-178
Figure 3-69: Selected Ground Water Monitoring Sites 3-179
Figure 3-70: Selected Flow Monitoring Sites 3-181
Figure 3-71: Selected Weather Monitoring Sites 3-181
Figure 3-72: Selected Rainfall Monitoring Sites 3-183
Figure 3-73: Diagrammatic representation of the Everglades Mercury Cycling Model showing multimedia nature of the problem 3-188
Figure 3-74: Graphic representation of factors influencing mercury bioaccumulation 3-189
Figure 3-75: Conceptual model of mercury biogeochemistry and factors affecting methylation efficiency 3-189
Figure 3-76: Diagram Depicting Relationships between the Ecological Premise, CERP Hypotheses, Monitoring Components, and Supporting Research for Water Storage Components and Mercury Biogeochemistry 3-191
Figure 3-77: Diagram Depicting Relationships between the Ecological Premise, CERP Hypotheses, Monitoring Components, and Supporting Research for Mercury Methylation and Sulfur Biogeochemistry 3-192
Figure 3-78: Diagram Depicting Relationships between the Ecological Premise, CERP Hypothesis, Monitoring Components, and Supporting Research for Mercury Releases and Soil Hydrological Conditions 3-193
Figure 5-1: Components of Successful Monitoring Plan Implementation 5-2
Figure 5-2: Conceptual Organization for the Implementation of the MAP 5-6

ACRONYMS AND ABBREVIATIONS

ATLSS	Across Trophic Level Systems Simulation
ASR	Aquifer Storage and Recovery
C&SF Project	Central and Southern Florida Project
CERP	Comprehensive Everglades Restoration Plan
FDEP	Florida Department of Environmental Protection
FMRI	Florida Marine Research Institute
FWC	Florida Fish and Wildlife Conservation Commission
GIS	geographic information system
GPS	global positioning system
MAP	Monitoring and Assessment Plan
NOAA	National Oceanic and Atmospheric Administration
NSM	Natural Systems Model
PAH	polycyclic aromatic hydrocarbons
PAR	photosynthetically-active radiation
PCB	polychlorinated biphenyls
QA/QC	quality assurance and quality control
QASR	Quality Assurance Systems Requirement Manual
RECOVER	REstoration COordination and VERification Program
SAV	submerged aquatic vegetation
SFWMD	South Florida Water Management District
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WRDA	Water Resource Development Act

1.0 PURPOSE AND SCOPE OF THE CERP MONITORING AND ASSESSMENT PLAN

1.1 INTRODUCTION

The overall purposes of the Comprehensive Everglades Restoration Plan (CERP) Monitoring and Assessment Plan (MAP) are to establish the framework for measuring and understanding system responses to the CERP, to determine how well the CERP is meeting its goals and objectives, and to identify opportunities for improving the performance of the CERP where needed.

The MAP is a key component of the Applied Science Strategy being used by the REstoration COordination and VERification (RECOVER) Program. RECOVER is a programmatic component of the CERP. This document, Part 1 of the MAP, describes in detail the monitoring components and supporting research of the MAP and briefly summarizes the assessment process. A detailed assessment process for interpreting the information collected by the implementation of this plan is under development at this time by the Adaptive Assessment and Water Quality Teams. This process will be documented in Part 2 of the MAP.

The development and refinement of the CERP MAP is a continuous iterative process. A first draft of the MAP, released in March 2001 (RECOVER 2001), underwent public and agency comment throughout the summer of 2001. The second draft, released in March 2003, was substantially revised as a result of comments received and further consideration of how the monitoring plan for the CERP should be designed (RECOVER 2003). This document is a result of a second public and agency review from March through June 2003. Additionally, as new information becomes available, periodic reviews and revisions of the MAP will ensure the technical soundness of the plan and the continuing support of the participating agencies. The best available science and technical expertise will continue to be incorporated into the MAP through these periodic updates. While formal reviews of the MAP will occur no less frequently than at three-year intervals, efforts will be made annually to adjust the plan and address deficiencies.

The MAP references the system-wide performance measures of the natural and human systems in South Florida that will be evaluated to help determine the success of the CERP. The system-wide performance measures address the responses of the South Florida ecosystem that the CERP is explicitly designed to improve, correct, or directly affect. A separate Performance Measure Documentation Report being prepared by RECOVER will provide the scientific, technical, and legal basis for the performance measures (RECOVER In prep). The Performance Measure Documentation Report will also describe the restoration targets, endpoints or restoration objectives that have been established for each performance measure.

The goal in developing and implementing the MAP is to have a single, integrated, system-wide monitoring and assessment plan that will be used and supported by all participating agencies and tribal governments to track and measure system-wide responses to the implementation of the CERP. In general, monitoring has four broad objectives:

1. Establish a pre-CERP reference state including variability for each of the performance measures

2. Provide the assessment of the system-wide responses of CERP implementation

3. Detect unexpected responses of the ecosystem to changes in stressors resulting from CERP activities

4. Support scientific investigations designed to increase ecosystem understanding, establish cause-and-effect relationships, and interpret unanticipated results

Addressing these objectives will help determine how CERP's implementation affects the physical, biological, and chemical components of the South Florida ecosystem and will increase scientific understanding of how this system works. Knowledge of how the South Florida ecosystem is changing in response to CERP implementation combined with investigations of cause-effect relationships will contribute to the refinement of CERP projects through the adaptive management program. In this way, restoration objectives set by the performance measures have a greater opportunity to be met.

This monitoring plan does not include all of the measures necessary to document the long-term restoration of the South Florida ecosystem. It is not within the scope of the CERP to contain all the elements necessary to achieve full restoration. CERP's primary focus is the restoration of the natural system's hydrology, while continuing to provide for water supply and flood protection for the built (human) system. This MAP provides a focused, critical set of measures for those systems directly affected by CERP and seeks to supplement and fill the gaps in ongoing relevant monitoring efforts. Other important anthropogenic factors that interact with the South Florida ecosystem, including population growth, water demand increases, and land use changes, will be tracked through RECOVER planning processes. Additionally, each CERP project implementation report will contain a separate, project-specific monitoring plan to assess the local responses to the implementation of individual CERP projects.

During the development of the MAP, the Adaptive Assessment Team relied upon two key assumptions that are critical to the success of the performance assessment process:

- Existing monitoring will continue with existing funding sources (i.e., the MAP should not replace ongoing agency efforts that are essential to the plan implementation). These monitoring efforts are presented in Table 1-1.

- Partnering agencies will contribute funding and/or will participate in implementation of the MAP

RECOVER is cognizant of the uncertainty inherent in these assumptions, due to the annual cycles of agency budgeting and funding constraints. Since these ongoing monitoring efforts are recognized as a critical foundation for the MAP, cooperative agreements and other mechanisms will need to be developed to ensure critical linkages within and among participating agencies.

Table 1-1: Summary of Existing Monitoring and Responsible Agencies

Map Component	Activity	Funding Source
Greater Everglades Wetlands		
Interior Gradients of Water Quality (3.1.3.1)	Water Conservation Area (WCA) Water Quality Monitoring Network	South Florida Water Management District (SFWMD)
	404 Permit Monitoring	SFWMD
	Everglades National Park Water Quality Monitoring Network	Everglades National Park
Coastal Gradients of Flow, Salinity, and Nutrients (3.1.3.3)	Tidal Creek Monitoring Stations Established. Prior to 2003	United States Geological Survey (USGS)

Table 1-1: Summary of Existing Monitoring and Responsible Agencies (Continued)

Map Component	Activity	Funding Source
Mangrove Forest Soil Accretion (3.1.3.9)	Sediment Elevation Sites In Mangrove Estuary Established. Prior to 2005	USGS
Aquatic Fauna Regional Populations (3.1.3.10)	Throw-trap sampling and Electrofishing at Long-term Sites in Shark River and Taylor Sloughs and WCA3A&B	Everglades National Park
	Drop-trap Sampling at Long-term Sites in Florida Bay Mangrove Zone	United States Army Corps of Engineers (USACE)/ Everglades National Park
	Drop-trap Sampling at Long-term Sites in Biscayne Bay Mangrove Zone	SFWMD/ National Marine Fisheries Service (NMFS)
Wading Bird Foraging Distribution and Abundance (3.1.3.12)	ENP Systematic Reconnaissance Flight	Everglades National Park
	WCA and Big Cypress Systematic Reconnaissance Flights	USACE
Wading Bird Nesting Colony Location, Size, and Timing (3.1.3.13)	Aerial Surveys in ENP	Everglades National Park
Productivity in Coastal Ecotone: Sea Level and CERP Influences (3.1.4.3)	Florida Coastal Long-term Ecological Research Program (LTER)	National Science Foundation /SFWMD
Ridge and Slough Landscape Sustainability (3.1.4.4)	Tree Island Research in ENP	Everglades National Park
	Tree Island Research in WCA3A and 3B	SFWMD
	Everglades Landscape Model (ELM)	SFWMD
	Loxahatchee Impoundment Landscape Assessment (LILA)	SFWMD
Southern Estuaries		
Water Quality and Phytoplankton Monitoring Network (3.2.3.1)	Water Quality Monitoring Network	SFWMD
Water Quality and Phytoplankton Monitoring Network (3.2.3.1) and Salinity Monitoring Network (3.2.3.2)	Interdisciplinary Sustained Coastal Observations (CTD casts/synoptic surveys/in situ instruments)	NOAA
	Florida Bay Salinity Platform Network	Everglades National Park
South Florida Fish Habitat Assessment Program (3.2.3.3)	South Florida Habitat Assessment Program	Critical Ecosystems Studies Initiatives
Seagrass Fish, Pink Shrimp, and Invertebrate Assessment Network (3.2.3.5)	Pink Shrimp Fisheries Assessment (CPUE/Model)	National Oceanic and Atmospheric Administration (NOAA)

Table 1-1: Summary of Existing Monitoring and Responsible Agencies (Continued)

Map Component	Activity	Funding Source
Northern Estuaries		
Salinity Monitoring Network (3.3.3.1)	Salinity Monitoring Network	SFWMD/ RECOVER[1]
Water Quality and Phytoplankton Monitoring Network (3.3.3.2)	Caloosahatchee Estuary	SFWMD/ RECOVER
	Indian River Lagoon, and, St. Lucie Estuary	SFWMD/ RECOVER[1]
	Loxahatchee River Estuary	SFWMD and Loxahatchee River District
	Lake Worth Lagoon	SFWMD, Palm Beach County Environmental Resource Management (PBCERM), and Florida Department of Environmental Protection (FDEP)
SAV Mapping from Aerial Photography (3.3.3.3)	Caloosahatchee Estuary and Loxahatchee River Estuary	SFWMD
	St. Lucie Estuary and Indian River Lagoon	SFWMD[2]
	Lake Worth Lagoon	PBCERM
SAV Monitoring for Caloosahatchee Estuary (3.3.3.4)	SAV Monitoring for Caloosahatchee Estuary	RECOVER
SAV Transects/Visual Surveys for St. Lucie Estuary/Indian River Lagoon, Lake Worth Lagoon, and Loxahatchee River Estuary (3.3.3.5)	St. Lucie Estuary and Indian River Lagoon	SFWMD/ RECOVER[2]
	Loxahatchee River Estuary	SFWMD/ RECOVER
	Lake Worth Lagoon	PBCERM
Oyster Monitoring Network (3.3.3.6)	Caloosahatchee Estuary	RECOVER
	St. Lucie Estuary, Indian River Lagoon, and Loxahatchee River Estuary	SFWMD/ RECOVER[3]
Juvenile Fish Community Monitoring Network (3.3.3.7)	Caloosahatchee Estuary	Florida Fish and Wildlife Conservation Commission (FWC)
	St. Lucie Estuary and Indian River Lagoon	RECOVER
Benthic Macroinvertebrate Monitoring (3.3.3.8)	St. Lucie Estuary and Loxahatchee River Estuary	RECOVER
Reconnaissance Study of Caloosahatchee (3.3.4.1)	Reconnaissance Study of Caloosahatchee	RECOVER

[1]Previous funding totally from SFWMD Surface Water Improvement and Management (SWIM) and ad valorem funds; funded in fiscal year (FY) 2004 by RECOVER.
[2]Previous funding from SFWMD SWIM and ad valorem funds; partially funded in FY 2003 and FY 2004 by RECOVER.
[3]Previous work funded by SFWMD, but long-term future monitoring will be funded by RECOVER.

Table 1-1: Summary of Existing Monitoring and Responsible Agencies (Continued)

Map Component	Activity	Funding Source
Fish Health and Pathology in the St. Lucie Estuary (3.3.4.2)	Fish Health and Pathology in the St. Lucie Estuary	NOAA and FDEP/FWC-Florida Marine Research Institute (FMRI)
Bottlenose Dolphin Health Assessment in St. Lucie Estuary (3.3.4.3)	Bottlenose Dolphin Health Assessment in St. Lucie Estuary	NOAA/NMFS
Manatee Abundance and Distribution Relative to Changes in Freshwater Flows and Seagrass Distribution as a Result of Implementation of CERP Projects (3.3.4.4)	Manatee Monitoring	RECOVER
Lake Okeechobee		
Water Quality and Phytoplankton (3.4.3.1)	Inflow nutrient loads, lake water nutrients, water clarity, and algal blooms	SFWMD
Littoral Zone Plant Communities (3.4.3.2)	Aerial photography, photo-interpretation, ground-truthing, and GIS map development at 6-year intervals for entire littoral zone, and at 2-year intervals for selected components of the community with unique performance measures (e.g., bulrush)	SFWMD
Submerged Aquatic Vegetation (3.4.3.3)	Yearly mapping to determine acreage of dominant taxa of submerged plants; quarterly transect surveys to determine plant biomass	SFWMD/ RECOVER[4]
Fish Condition and Population Structure (3.4.3.6)	Largemouth bass and black crappie population size structure (yearly)	FWC
Zooplankton Biomass and Taxonomic Structure (3.4.3.4)	Quarterly sampling of pelagic plankton community	SFWMD
Submerged Plant/Periphyton Interrelationships with Light, Nutrients, and Water Depth (3.4.4.4)	Submerged Plant/Periphyton Interrelationships with Light, Nutrients, and Water Depth	SFWMD
Fish and Wildlife Relationships to Food Abundance and Composition (3.4.4.2)	Fish and Wildlife Relationships to Food Abundance and Composition	SFWMD
South Florida Hydrology Monitoring Network		
Stage Monitoring Network (3.5.3.1)	Stage Monitoring Network	SFWMD, USGS, USACE, and Everglades National Park
Ground Water Monitoring Network (3.5.3.2)	Ground Water Monitoring Network	SFWMD and USGS
Water Flow Monitoring Network (3.5.3.3)	Water Flow Monitoring Network	SFWMD, USGS, and USACE
Meteorology Monitoring Network (3.5.3.4)	Meteorology Monitoring Network	SFWMD
Monitoring Specific to Water Supply (3.5.3.5)	Monitoring Specific to Water Supply	SFWMD
Monitoring Specific to Flood Protection (3.5.3.6)	Monitoring Specific to Flood Protection	SFWMD

[4]SFWMD funds reduced to zero for FY 2004; these items presently are funded by RECOVER.

Table 1-1: Summary of Existing Monitoring and Responsible Agencies (Continued)

Map Component	Activity	Funding Source
Mercury Bioaccumulation		
Mercury Bioaccumulation (3.6.3.1)	Monitoring of water/sediment / mosquitofish (Greater Everglades Wetlands)	United States Environmental Protection Agency (USEPA)
	Monitoring of estuarine fish (Southern and Northern Estuaries)	FMRI
	Monitoring of freshwater fish (Greater Everglades Wetlands)	FWC and FDEP
	Monitoring of wading birds (Greater Everglades Wetlands)	USACE and FDEP
	Monitoring of surface water/rain/sediment /fish/birds (Greater Everglades Wetlands)	SFWMD
	Monitoring water, sediment, fish (Greater Everglades Wetlands)	SFWMD
	Monitoring water (system-wide)	SFWMD
Mercury Bioaccumulation (3.6.3.1) and Relationship between CERP-Related Changes in Stage Duration and Water Chemistry (Including Quantity and Quality of Carbon) and Flux Rate of Inorganic Mercury and Net Methylmercury Production (3.6.4.1)	Cause-effect monitoring of water/sediment /fish (Greater Everglades Wetlands)[1]	SFWMD
Relationship between CERP-Related Changes in Stage Duration and Water Chemistry (Including Quantity and Quality of Carbon) and Flux Rate of Inorganic Mercury and Net Methylmercury Production (3.6.4.1) (and Potential to Reduce Rates of Mercury Methylation through a Reduction in Sulfur Inputs (3.6.4.4))	Research on mercury biogeochemistry (Greater Everglades Wetlands)	USGS / Academy of Natural Sciences Environmental Research Center, FDEP, and USEPA
Relationship between CERP-Related Changes in Stage Duration and Water Chemistry (Including Quantity and Quality of Carbon) and Flux Rate of Inorganic Mercury and Net Methylmercury Production (3.6.4.1)	Model development (Greater Everglades Wetlands)	FDEP
	Monitoring of sediment accumulation (Greater Everglades Wetlands)	FDEP
Relationship between CERP-Related Changes in Stage Duration and Water Chemistry (Including Quantity and Quality of Carbon) and Flux Rate of Inorganic Mercury and Net Methylmercury Production (3.6.4.1) and Relationship between CERP-Related Changes in Food Web Dynamics and Biomagnification of Mercury to Top-Level Predators (3.6.4.2)	Monitoring and research on food-web studies – fish (Florida Bay)[5]	NOAA and SFWMD
	Research on food-web dynamics – fish (Greater Everglades Wetlands)[5]	FWC, FDEP, and USGS
	Research on food-web – fish and other biota (Greater Everglades Wetlands)[5]	USGS
	Research on toxicological effects – birds (lab – system-wide)[5]	USGS, with field support by SFWMD
	Research on toxicological effects – birds (lab – system-wide)[6]	University of Florida and FDEP

[5]Field work completed or nearly complete; final report pending.
[6]Study proposed.

Table 1-1: Summary of Existing Monitoring and Responsible Agencies (Continued)

Map Component	Activity	Funding Source
	Research on toxicological effects – fish (Greater Everglades Wetlands)	USGS
	Research of atmospheric transport / flux (system-wide)	FDEP
Relationship between the Use of Aquifer Storage and Recovery (ASR) Technology and Potential Changes in Surface Water Quality, Especially as it Relates to Sulfate, and Mercury Biogeochemistry (3.6.4.3)	Research on ASR effluent (lab – system-wide)[6]	USGS
	Characterization of ASR inflow / effluent (lab – system-wide)	USACE/ SFWMD

1.2 SCOPE AND ORGANIZATION OF THE MONITORING AND ASSESSMENT PLAN

This plan encompasses the geographic areas presented in Figure 1-1. Additional areas will be considered for inclusion into later versions of the MAP. To be included, monitoring components and supporting research for new areas must follow the same process used to develop those in this version of the MAP (see Section 2). This process includes the development and review of a conceptual ecological model, ecological premises, and CERP hypotheses upon which the monitoring components and supporting research are based.

[6] Study proposed.

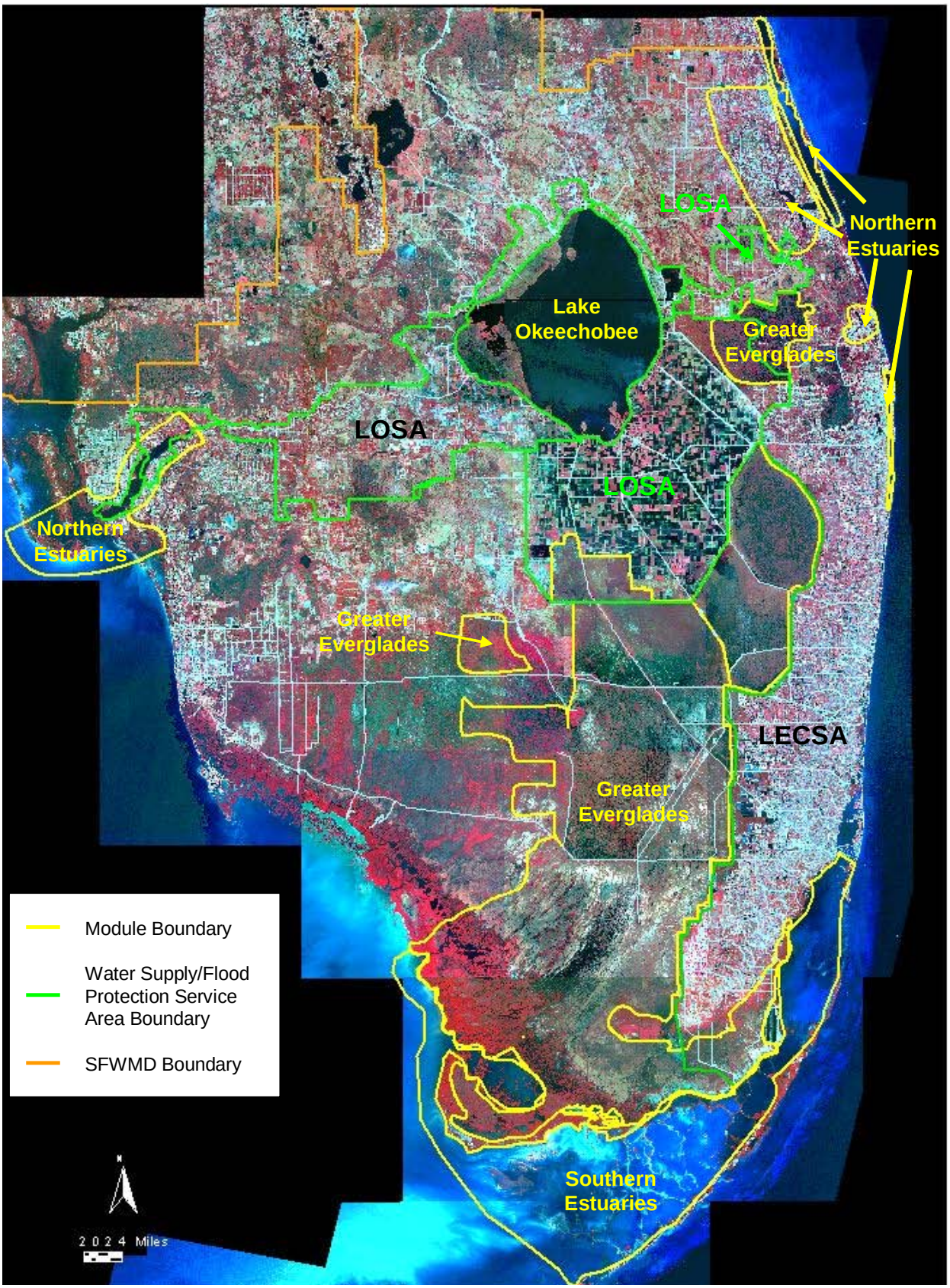


Figure 1-1: The Physical Scope of the MAP

The CERP MAP is organized into five main sections. Section 1, Purpose and Scope of the CERP Monitoring and Assessment Program, provides background information and a broad overview of the purpose of the monitoring plan. Section 2, Development of the Monitoring Plan, describes the processes through which the MAP was developed. Because much of the focus of this document is on the content and design of the system-wide monitoring program, Section 2 also describes the CERP Adaptive Management Program, which includes a performance assessment component. Section 3, Integrated Monitoring Requirements, describes the actual monitoring plan for the initial six integrated monitoring modules:

- Greater Everglades Wetlands
- Southern Estuaries (Florida Bay, Biscayne Bay, and Southwest Florida Coast)
- Northern Estuaries (Caloosahatchee Estuary, St. Lucie Estuary, Indian River Lagoon, Loxahatchee River Estuary, and Lake Worth Lagoon)
- Lake Okeechobee
- South Florida Hydrology Monitoring Network
- South Florida Mercury Bioaccumulation

These monitoring modules have been designed to evaluate the performance of the CERP as it is implemented and to test the working hypotheses in the conceptual ecological models. Section 4, Quality Assurance/Quality Control and Data Validation, Management, Evaluation and Reporting, describes proposed protocols for data management, quality assurance and/or quality control (QA/QC), and data reporting. This protocol will be further revised and formalized by the Adaptive Assessment Team.

Section 5, Implementation Strategy for the CERP Monitoring and Assessment Plan, contains an overview of a proposed implementation strategy for the MAP. This section of the MAP describes an implementation strategy that uses criteria to evaluate and sequence monitoring components and supporting research.

Appendix A contains the eleven conceptual ecological models covering the major physiographic regions of South Florida. Appendix B contains a summary of the direct and indirect effects of projects as they relate to the modules.

1.3 BACKGROUND

The Central and Southern Florida (C&SF) Project Comprehensive Review Study (Restudy) was authorized by Section 309(l) of the Water Resources Development Act (WRDA) of 1992 (Public Law 102-580). Section 528 of the WRDA of 1996 (Public Law 104-303) provided additional direction and guidance for the Restudy.

The Restudy's purpose was to re-examine the C&SF Project to determine the feasibility of modifying the project to restore the South Florida ecosystem and provide for other water-related needs of the region, including water supply and flood protection. As directed by the authorizing legislation in 1992 and 1996, the study specifically investigated making structural and operational modifications to the C&SF Project to meet the following goals:

- Improving the quality of the environment

- Protecting water quality in and reducing the loss of fresh water from the Everglades
- Improving the protection of the aquifer
- Improving the integrity, capability, and conservation of urban and agricultural water supplies
- Improving other water-related conditions

The Restudy culminated with the *Central and Southern Florida Project Comprehensive Review Study Final Integrated Feasibility Report and Programmatic Environmental Impact Statement* (USACE and SFWMD 1999), which was transmitted to Congress on July 1, 1999. Through the enactment of the WRDA of 2000, Congress approved the Comprehensive Plan presented in the Restudy as a framework for the modifications and operational changes to the C&SF Project needed to restore the South Florida ecosystem. This framework is generally referred to as the CERP.

The following principles guided the development of the Comprehensive Plan:

- The overarching objective of the Comprehensive Plan is the restoration, preservation, and protection of the South Florida ecosystem while providing for other water-related needs of the region.
- The Comprehensive Plan is based on the best available science, and independent scientific review will be an integral part of its development and implementation.
- The Comprehensive Plan was developed through an inclusive and open process that engaged all stakeholders.
- All applicable federal, state, and local agencies and tribal governments will be full partners, and their views will be considered fully.
- The Comprehensive Plan is a flexible plan that is based on the concept of adaptive assessment, recognizing that modifications will be made in the future based on new information.

In addition to the guiding principles, planning goals and study objectives were created to further sharpen the focus of the Comprehensive Plan. These goals and objectives are as follows (USACE and SFWMD 1999):

- Goal: Enhance Ecological Values
  - Increase the total spatial extent of natural areas
  - Improve habitat and functional quality
  - Improve native plant and animal species abundance and diversity
- Goal: Enhance Economic Values and Social Well-Being
  - Increase availability of fresh water (agricultural/municipal and industrial)
  - Reduce flood damages (agricultural/urban)
  - Provide recreational and navigation opportunities
  - Protect cultural and archeological resources and values

The CERP contains over 60 projects that will create approximately 217,000 acres of reservoirs and wetland-based water treatment areas. Implementation of the plan will vastly increase water storage and supply for the natural system and for urban and agricultural needs, while maintaining current C&SF Project purposes. The CERP will restore more natural flows of water, including sheetflow; improve water quality; and establish more natural hydropatterns in the South Florida ecosystem.

The CERP is a major contributor to the overall goal of restoration of the natural systems of South Florida (SFERTF 2000). As envisioned in the Restudy, the implementation of the CERP is projected to span over 30 years at a cost of $7.8 billion (in 1999 dollars). The scope, complexity, and importance of the CERP and the significant outlay of public funds necessary for implementation dictate the institution of a means to measure, assess, and report progress towards achieving the CERP's objectives. Section 601(b)(2)(C) of WRDA 2000 gives specific authorization for the first ten years of an adaptive assessment and monitoring program.

Section 601(h)(3)(C) of WRDA 2000 requires programmatic regulations to develop and implement adaptive management activities:

(i) In General -- Programmatic regulations promulgated under this paragraph shall establish a process --

(I) for the development of project implementation reports, project cooperation agreements, and operating manuals that ensure that the goals and objectives of the Plan are achieved;

(II) to ensure that new information resulting from changed or unforeseen circumstances, new scientific or technical information or information that is developed through the principles of adaptive management contained in the Plan, or future authorized changes to the Plan are integrated into the implementation of the Plan; and

(III) to ensure the protection of the natural system consistent with the goals and purposes of the Plan, including the establishment of interim goals to provide a means by which the restoration success of the Plan may be evaluated throughout the implementation process.

This Congressional direction makes it clear that an adaptive assessment and monitoring program is considered essential for ensuring the incorporation of new scientific and technical information into the Comprehensive Plan. An adaptive assessment and monitoring program will also help refine and improve the design and operation of the CERP throughout its implementation and determine whether the CERP achieves its primary objectives of recovering healthy and sustainable ecosystems throughout South Florida while providing for other water-related needs of the region.

1.4 RECOVER

RECOVER is a system-wide program of the CERP. A detailed description of RECOVER and its organization and responsibilities can be found in the RECOVER Program Management Plan (USACE and SFWMD 2001). RECOVER has three mission areas:

- ***Evaluation*** - to work with CERP project teams prior to construction to evaluate (through predictive modeling) and maximize the contribution made by each project to the system-wide performance of the CERP

- ***Assessment*** - to measure (by the use of data collected through monitoring) and interpret actual responses in the natural and human systems as CERP projects are constructed and implemented

- ***Planning and Integration*** - to identify potential improvements in the design and operation of the CERP, consistent with the Comprehensive Plan's objectives, and to strive for consensus among agencies regarding the scientific and technical aspects of the CERP

To support these mission areas, RECOVER is responsible for the coordination and application of an Applied Science Strategy (Ogden and Davis 1999) during CERP implementation. This strategy outlines a process for organizing current scientific understandings of wetland and estuarine ecosystems into formats that can effectively support restoration efforts. The major components of the Applied Science Strategy are conceptual ecological models, performance measures and restoration targets, a system-wide monitoring program, and a performance assessment protocol (Figure 1-2).

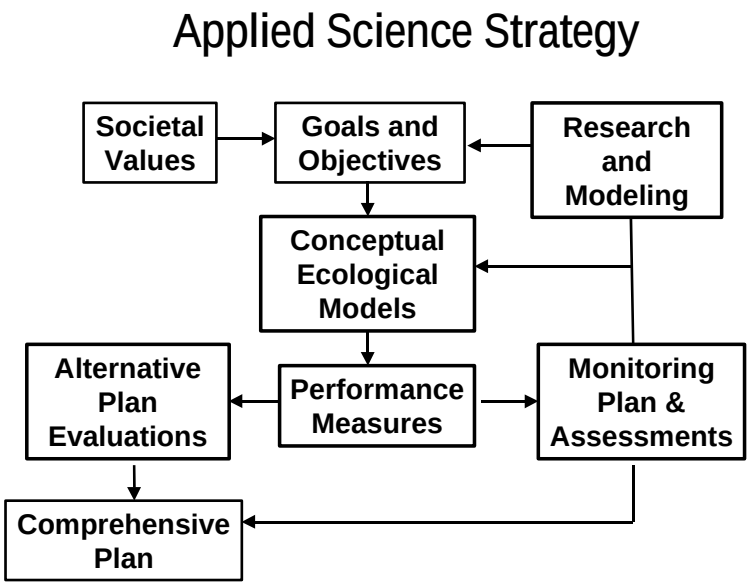


Figure 1-2: Applied Science Strategy

To ensure the successful application of the Applied Science Strategy, RECOVER is organized into technical teams and one leadership group, which is the coordinating body for the technical teams. Teams are comprised of individuals representing the two sponsoring agencies, the South Florida Water Management District (SFWMD) and the United States Army Corps of Engineers (USACE), and participating entities such as state and federal agencies and tribal governments. RECOVER affords the opportunity for all participants to engage in an ongoing process of assessment and refinement of the CERP. The current organization of the RECOVER teams is shown in Figure 1-3.

RECOVER teams have the responsibility to develop performance measures that will be used to help measure the progress and success of the CERP. For the natural system, performance measures are largely derived from the physical and chemical stressors and biological attributes and the working hypotheses contained in a set of conceptual ecological models (Appendix A) for the major wetland and estuarine physiographic regions of South Florida. The conceptual ecological models provide a means to develop consensus regarding a set of causal hypotheses that attempt to explain the effects of stressors on the ecological system. This consensus is the basis for developing specific hydrological and ecological performance measures and provides a means for converting policy-level statements of restoration goals into numerical measures of progress. For socio-economic objectives, performance measures are based on planning criteria consistent with current federal and state law and policy.

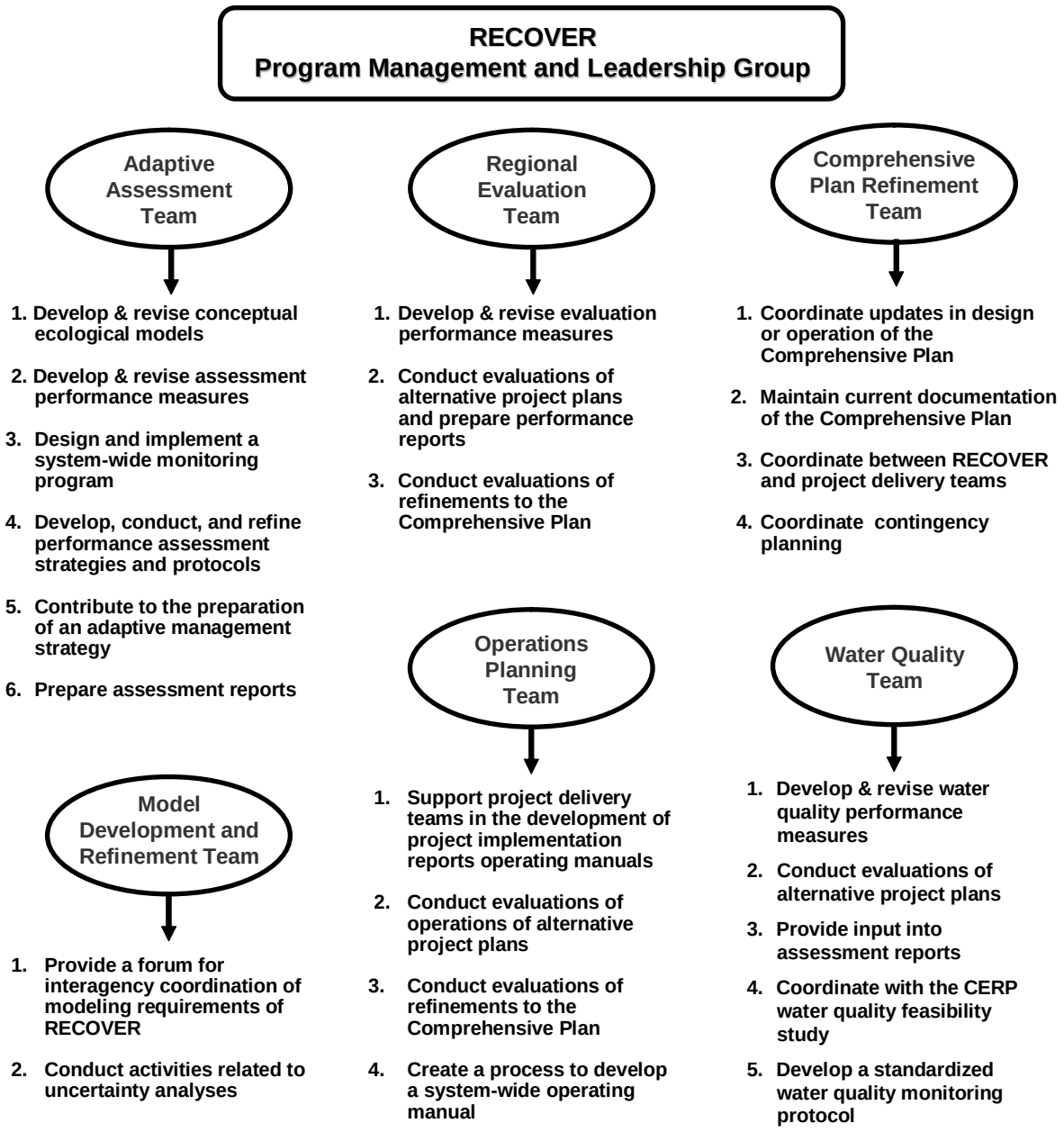


Figure 1-3: Current Organization of RECOVER Teams

The effects of each CERP project must be measured on both system-wide and local scales. RECOVER is responsible for the design and implementation of system-wide monitoring, while the design and implementation of monitoring to determine local responses is the responsibility of the individual CERP project delivery teams. This system-wide monitoring plan and the individual project monitoring plans must be closely coordinated to ensure that measures and targets selected by the project teams are compatible and consistent with the MAP and that duplication of effort is avoided.

1.5 CONTACTS FOR THE MONITORING AND ASSESSMENT PLAN

For additional information on the MAP, contact one of the Adaptive Assessment Team chairs, Elmar Kurzbach (elmar.g.kurzbach@saj02.usace.army.mil) , Steve Davis (sdavis@sfwmd.gov) , Betty Grizzle (betty_grizzle@fws.gov), or the RECOVER Program Managers, John Ogden (jogden@sfwmd.gov) and Stu Appelbaum (stuart.j.appelbaum@saj02.usace.army.mil).

1.6 REFERENCES

Ogden, J.C., and S.M. Davis. 1999. The Use of Conceptual Ecological Landscape Models as Planning Tools for the South Florida Ecosystem Restoration Programs. South Florida Water Management District, West Palm Beach, Florida.

RECOVER. 2001. Monitoring and Assessment Plan. REstoration COordination and VERification Program, c/o Jacksonville District, United States Army Corps of Engineers, Jacksonville, Florida, First Draft, March 2001.

RECOVER. 2003. Monitoring and Assessment Plan. REstoration COordination and VERification Program, c/o Jacksonville District, United States Army Corps of Engineers, Jacksonville, Florida, Second Draft, March 2003.

RECOVER. In prep. Performance Measure Documentation Report. REstoration COordination and VERification Program, c/o South Florida Water Management District, West Palm Beach, Florida, May 29, 2003 draft.

SFERTF. 2000. Coordinating Success. South Florida Ecosystem Restoration Task Force, Miami, Florida.

USACE and SFWMD. 1999. Central and Southern Florida Project Comprehensive Review Study Final Integrated Feasibility Report and Programmatic Environmental Impact Statement. Jacksonville District, United States Army Corps of Engineers, Jacksonville, Florida, and South Florida Water Management District, West Palm Beach, Florida.

USACE and SFWMD. 2001. Management Plan for REstoration COordination and VERification (RECOVER). Jacksonville District, United States Army Corps of Engineers, Jacksonville, Florida, and South Florida Water Management District, West Palm Beach, Florida.

U.S. Congress. 2000. Section 601 of the Water Resources Development Act of 2000 (Public Law 106-541). Washington, DC.

U.S. Congress. 1996. Section 528 of the Water Resources Development Act of 1996 (Public Law 104-303). Washington, DC.

U.S. Congress. 1992. Section 309(l) of the Water Resources Development Act of 1992 (Public Law 102-580). Washington, DC.

2.0 DEVELOPMENT OF THE CERP MONITORING PLAN AND ADAPTIVE MANAGEMENT PROGRAM

2.1 INTRODUCTION

The CERP Monitoring Program must be built upon a strong science foundation, be logistically and economically feasible, be sustainable over the long term, and provide data at appropriate spatial and temporal scales that support the Comprehensive Everglades Restoration Plan (CERP) Adaptive Management Program. The CERP Monitoring and Assessment Plan (MAP) was developed with these characteristics in mind, and it reflects the Monitoring Program Planning Guidelines presented in Section 9.5.3 of the Central and Southern Florida (C&SF) Project Comprehensive Review Study Final Integrated Feasibility Report and Programmatic Environmental Impact Statement (USACE and SFWMD 1999) and the Applied Science Strategy (Ogden and Davis 1999, Ogden et al. 2003). These guidelines were used to define the scope and focus of the MAP and to determine its major components.

2.2 DEVELOPMENT OF CONCEPTUAL ECOLOGICAL MODELS AND PERFORMANCE MEASURES

Conceptual ecological models are a key element of the Applied Science Strategy and provide a primary foundation for the development of the majority of the assessment performance measures. The models illustrate the links among societal actions, environmental stressors, and ecological responses and provide the basis for selecting and testing the set of causal hypotheses that best explain why the natural systems in South Florida have been altered (Gentile et al. 2001). Developed as a planning tool, conceptual ecological models are used in ecological risk assessment analysis worldwide (Rosen et al. 1995, Gentile 1996).

Conceptual ecological models developed for the major physiographic regions in South Florida (see Appendix A) provide the scientific basis for the development of the CERP system-wide monitoring design and adaptive assessment process. The conceptual ecological model process provides a planning tool for translating the overall restoration goals of the CERP into the specific performance measures that will be used to plan, design, and assess the success of the plan. Specifically, the process of developing the conceptual ecological models was designed to meet the following purposes:

1. Illustrate the ecological linkages between the physical, chemical, and biological elements in specific physiographic regions of South Florida

2. Develop a suite of causal hypotheses linking the most important physical stressors with the major ecological effects as a basis for predicting responses to the CERP's restoration projects and other restoration efforts

3. Create a set of measurable indicators of success (i.e., "performance measures") as a basis for assessing how well the projects achieve system-wide goals that have been established for the CERP

A Total System Conceptual Ecological Model is being developed by the Adaptive Assessment Team to represent the ecological linkages among the major working hypotheses and cause-and-effect relationships that explain the important consequences of system-wide stressors on the South Florida ecosystem. These stressors, which include altered hydropatterns, exotics and invasive species, excess nutrients, mercury contamination, compartmentalization, loss of spatial extent, sea level rise, water management practices, and changes in land use patterns, will be complementary to those stressors identified in the set of regional conceptual ecological models described above. The Total System Conceptual Ecological Model integrates

system-wide hypotheses that are common to several or all of the regional models, identifies stressors and ecological effects that have not been adequately characterized in the regional models due to their spatial and temporal scales, and identifies important downstream effects of altered hydrological conditions across the boundaries of adjacent regional models.

Performance measures have been defined and continue to be developed as a means to assess the system-wide performance of the CERP. They have been developed by the REstoration COordination and VERification's (RECOVER) Adaptive Assessment and Water Quality Teams primarily from the attributes and stressors in the conceptual ecological models, but also from input from the Restudy and direction provided by law, regulation, and policy. The performance measures have undergone several reviews using a series of criteria to ensure that they would measure system responses directly related to CERP implementation and could be interpreted in the context of the CERP. The performance measures are defined by indicators that are assessed using measurable parameters with quantitative targets or assessed by trends, i.e., directions of change.

The current level of development and refinement of assessment system-wide performance measures are presented in Table 2-1. These will be described in more detail in a separate RECOVER document, the Performance Measure Documentation Report (RECOVER In prep). Updates of this document will occur at least every three years to coincide with updates of the MAP. The initial documentation report is being prepared in cooperation with three RECOVER teams (Adaptive Assessment, Regional Evaluation, and Water Quality Teams) and will be available for review in early 2004.

The monitoring protocols that support this list of assessment performance measures are described in Section 3 of the MAP. The modules contained in Section 3 also describe monitoring components that are designed to provide supplemental information about the South Florida ecosystem to support RECOVER's assessment of the system responses as the CERP is implemented.

Table 2-1: Draft Assessment System-Wide Performance Measures

Number	Title
	Greater Everglades
GE-A1	Greater Everglades Wetlands Hydropattern
GE-A2	Wetland Landscape Patterns - Freshwater and Estuarine Vegetation Mosaics
GE-A3	Wetland Landscape Patterns - Ridge and Slough Community Sustainability
GE-A4	Wetland Landscape Patterns - Tidal Creek Sustainability
GE-A5	Wetland Landscape Patterns - Marl Prairie Cape Sable Sparrow Habitat
GE-A6	Wetland Trophic Relationships - Regional Populations of Fishes, Crayfish, Grass Shrimp, and Amphibians
GE-A7	Wetland Trophic Relationships - Wading Bird Foraging Patterns in Wetlands
GE-A8	Wetland Trophic Relationships - Wading Bird Nesting Patterns
GE-A9	Wetland Trophic Relationships - American Alligator Distribution, Size, Nesting, and Condition
GE-A10	Wetland Trophic Relationships - Periphyton Mat Production and Composition
GE-A11	Wetland Trophic Relationships -Mangrove Forest Production/Soil Accretion
GE-A12	Greater Everglades Wetlands Coastal Salinity Gradients
GE-A13	American Crocodile - Juvenile Growth and Survival
GE-A14	Greater Everglades Wetlands Nutrient Concentrations in Surface Water
GE-A15	Greater Everglades Wetlands Total Phosphorus Concentrations in Peat Soil

Table 2-1: Draft Assessment System-Wide Performance Measures (Continued)

Number	Title
GE-A16	Greater Everglades Wetlands Sulfate Concentrations in Surface Water
GE-A17	Greater Everglades Wetlands Conductivity in Surface Water
GE-A18	Roseate Spoonbill Nesting Patterns
	Southern Estuaries
SE-A1	Surface Water Discharges to Biscayne Bay
SE-A2	Southern Estuaries Salinity Pattern
SE-A3	Southern Estuaries SAV Distribution, Abundance, and Community Structure
SE-A4	Southern Estuaries Juvenile Pink Shrimp and Associated Epifauna
SE-A5	Southern Estuaries Shoreline Fish Community
SE-A6	Florida Bay Juvenile Spotted Seatrout
SE-A9	Southern Estuaries Nutrient Concentrations in Surface Water
SE-A10	Southern Estuaries Nutrient (TP and TN) Loads
SE-A11	Southern Estuaries Algal Bloom Frequency Intensity and Duration
SE-A12	Southern Estuaries Water Clarity/Light Penetration (PAR)
SE-A13	Contaminants (Toxicants and Pathogens) in Biscayne Bay Tributaries and Coastal Sediments
	Northern Estuaries
NE-A1	St. Lucie Estuary Salinity Envelope
NE-A2	Lake Worth Lagoon Salinity Envelope
NE-A3	Caloosahatchee Estuary Salinity Envelope
NE-A4	Loxahatchee River Estuary Salinity Envelope
NE-A5	Northern Estuaries Oysters
NE-A6	St. Lucie Estuary Macroinvertebrates
NE-A7	Northern Estuaries Fish Communities
NE-A8	Northern Estuaries Submerged Aquatic Vegetation
NE-A9	Caloosahatchee Estuary Nutrient Concentrations in Surface Water
NE-A10	St. Lucie Estuary Nutrient Concentrations in Surface Water
NE-A11	South Indian River Lagoon Nutrient Concentrations in Surface Water
NE-A12	Loxahatchee River Estuary Nutrient Concentrations in Surface Water
NE-A13	Lake Worth Lagoon Nutrient Concentrations in Surface Water
NE-A14	Northern Estuaries Algal Bloom Frequency
NE-A15	Northern Estuaries Contaminants (Toxicants and Pathogens)
NE-A16	Northern Estuaries Water Clarity
	Lake Okeechobee
LO-A1	Lake Okeechobee Extreme Low Lake Stage
LO-A2	Lake Okeechobee Prolonged Moderate Low Lake Stage
LO-A3	Lake Okeechobee Extreme High Lake Stage
LO-A4	Lake Okeechobee Prolonged Moderate High Lake Stage
LO-A5	Spring Recession for Lake Okeechobee
LO-A6	Lake Okeechobee Native Vegetation Mosaic - Littoral Plant Communities and Bulrush
LO-A7	Lake Okeechobee Native Vegetation Mosaic - SAV
LO-A8	Lake Okeechobee Fish and Aquatic Fauna (Fish and Invertebrates)
LO-A9	Lake Okeechobee Apple Snails and Snail Kite Population and Nesting
LO-A10	Lake Okeechobee Wading Bird Feeding Aggregations and Nesting

Table 2-1: Draft Assessment System-Wide Performance Measures (Continued)

LO-A11	Lake Okeechobee Fish Population Density, Age Structure and Condition
LO-A12	Lake Okeechobee Alligator Population and Condition
LO-A13	Lake Okeechobee Shoreline Organic Berm
LO-A14	Lake Okeechobee TP Concentration in Surface Water
LO-A15	Lake Okeechobee TN:TP Ratio in Surface Water
LO-A16	Lake Okeechobee Diatom:Cyanobacteria Ratio
LO-A17	Lake Okeechobee Algal Bloom Frequency
LO-A18	Lake Okeechobee Water Clarity
LO-A19	Lake Okeechobee Phosphorus Loads
LO-A20	Lake Okeechobee Class I Surface Water Quality Standards
	Water Supply and Flood Protection
WS-A1	Frequency, Severity, and Duration of Water Restrictions for the Lake Okeechobee Service Area
WS-A2	Frequency of Water Restrictions for the Lower East Coast Service Area
WS-A3	Potential for High Water Levels in South Miami-Dade Agricultural Area
WS-A4	Prevent Saltwater Intrusion of Biscayne Aquifer - Meet MFL Criteria for the Biscayne Aquifer
WS-A5	Prevent Saltwater Intrusion of Biscayne Aquifer in South Miami-Dade County
	Total System
TS-A1	Mercury Bioaccumulation

2.3 DEVELOPMENT OF INTEGRATED MONITORING MODULES

As a result of the MAP review process, specifics on sampling techniques and design and integration of monitoring throughout the system and across performance measures became the focus for discussions within a series of technical workshops conducted by members of the Adaptive Assessment Team. These workshops, held from October 2001 through February 2002, focused on the following:

- Identifying the stressors, ecological linkages, and biological attributes within the conceptual ecological models that the CERP is designed to affect
- Refining the monitoring and research topics necessary to improve evaluation of system-wide CERP performance
- Developing appropriate monitoring network designs for each module
- Identifying existing monitoring programs critical to the CERP that should continue
- Estimating approximate costs for each part of the monitoring plan

Concurrently, the RECOVER Water Quality Team developed a draft water quality monitoring portion for the plan, and a team at the South Florida Water Management District (SFWMD) developed a plan for addressing performance related to water supply and flood protection. A primary objective in the development of the water quality component of the plan was to identify a set of water quality parameters that would complement, support, and aid in understanding and interpreting results from the ecological monitoring. These water quality parameters can also be used to evaluate how the CERP will affect stressors related to nutrients and other pollutants as identified in the conceptual ecological models. Since this system-wide monitoring program is not intended to address all water quality issues in South Florida,

the water quality elements selected for monitoring are intended to 1) address changes that can reasonably be attributed to CERP activities and 2) either address factors that could be resolved through changes in the CERP and/or identify factors that may adversely affect the CERP but are not specifically a result of a failure or an inadequacy in the CERP. The water quality parameters have been integrated into each of the individual modules. A mercury bioaccumulation module is included in this version of the MAP. This module will be integrated into a Total Systems Module in later versions.

The South Florida Hydrology Monitoring Network Module addresses the surface and ground water monitoring needs of the four regional modules and provides information to evaluate progress towards other water-related needs of the region provided for in the CERP. These needs include water supply and flood control, which have been identified as stressors in the conceptual ecological models.

2.4 ASSESSMENT OF MONITORING DATA

Natural and human system responses during and following CERP implementation will be compared to the trends or targets established for each performance measure. These comparisons will serve as a basis for evaluating how the implementation of CERP projects, individually and collectively, are meeting the overall goals and objectives of the CERP. The combined responses from the full set of performance measures will determine CERP's overall success.

Once analyzed and interpreted, monitoring data will be used for six broad purposes in support of the CERP:

1. Assess and document progress towards meeting performance measure targets and interim and long-term goals

2. Detect undesirable system responses as early as possible in order to minimize the adverse effects of these responses

3. Provide a basis for identifying options for improvements in the design and operation of CERP projects and components

4. Develop reports on the status and progress of the CERP for the agencies involved, the public, Congress, the Florida Legislature, and stakeholders

5. Evaluate CERP hypotheses and performance measures and revise conceptual ecological models as appropriate

6. Enhance predictive ability through improvements in simulation models before and after project construction

RECOVER will periodically issue technical reports on CERP's progress based on comparisons between the measured performance of the CERP and the performance measure's restoration targets. These technical reports will identify where ecosystem responses to the CERP are on track to meet the goals of the plan and/or where performance does not meet expectations. Where undesirable responses occur or are anticipated based on initial interpretations of monitoring and research data, the technical reports will seek to identify whether these responses are due to some structural or operational component of the restoration plan or are external to the plan.

These technical reports will be consulted and referenced by the United States Army Corps of Engineers and the South Florida Water Management District when preparing assessment reports as required by the

Programmatic Regulations (DOD 2003). The technical reports and assessments of key indicators will be the source of information in preparing a proposed CERP Report Card to be issued to the public, stakeholders, and legislators.

2.5 CERP ADAPTIVE MANAGEMENT PROGRAM

One definition of Adaptive Management (Blann and Light 2003) is as follows: "Adaptive management applies scientific methods to complex resource management challenges with the objective of designing robust policies for dealing with uncertainty and surprise inherent in such context." The Committee on Restoration of the Greater Everglades Ecosystem (National Research Council 2003) further defines adaptive management as consisting of "(1) clear restoration goals and expectations, (2) a sound conceptualization of the system, (3) an effective process for learning about future management actions, and (4) explicit feedback mechanisms for refining and improving management based on the learning process."

Basic components and purposes of the CERP Adaptive Management Program are described in the Programmatic Regulations for the Comprehensive Plan (DOD 2003). The Adaptive Management Program is designed to maximize the success of the CERP by anticipating future uncertainties and responding to system responses. These uncertainties include unpredicted and undesired responses and events in the natural and human systems of South Florida that result from CERP implementation or from non-CERP influences (including "drivers" in the conceptual ecological models provided in Appendix A). A successful adaptive management program will provide early warnings of undesired impacts and a process that will allow decision makers to effectively integrate science and management to ensure that the CERP goals and purposes are fulfilled and seek continuous improvements of the CERP.

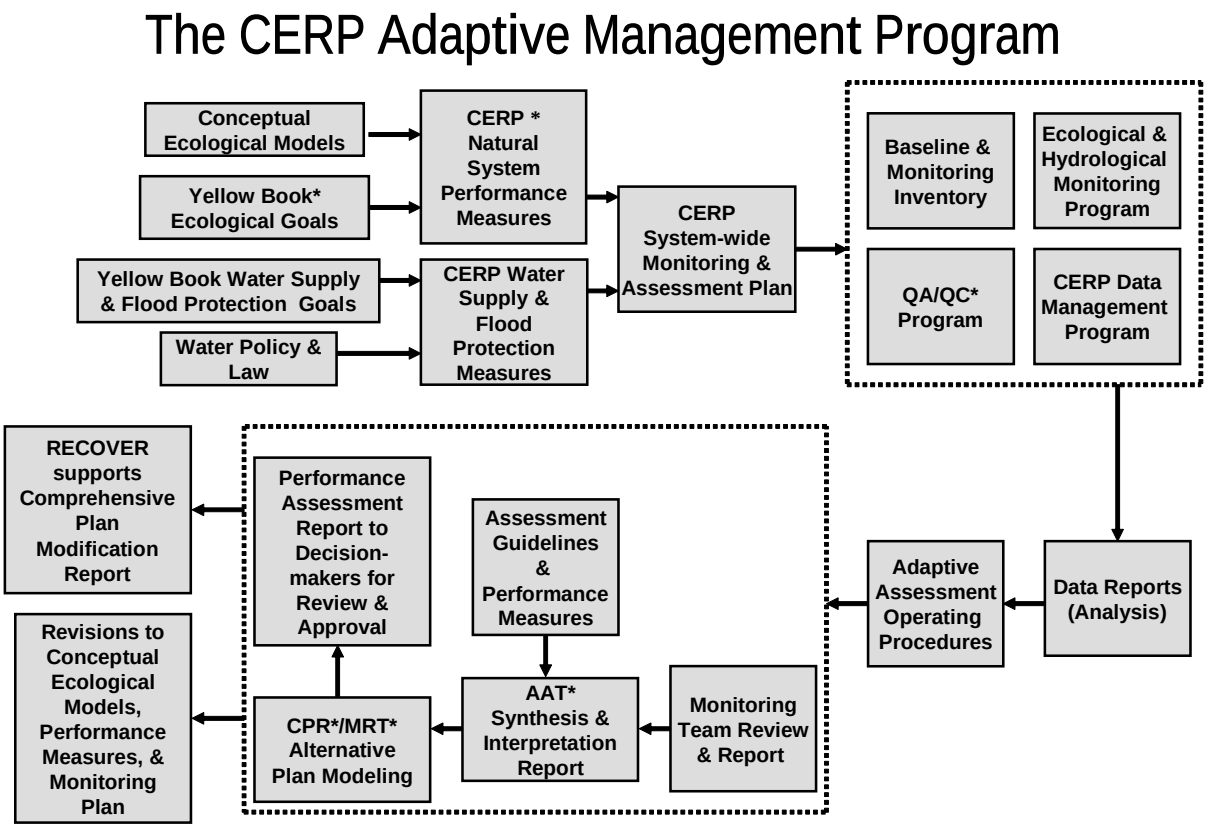
The MAP is a key component in the CERP Adaptive Management Program. The March 2003 draft of the MAP contained a section discussing the adaptive management program (Figure 2-1) (RECOVER 2003). The process described in that section and presented in Figure 2-1 is currently being revised. As of this writing, RECOVER is developing and then implementing the CERP adaptive management principles and process that will allow for science-based management adjustments to the implementation of CERP programs and projects. This process included planning and facilitating a series of workshops with the following objectives:

- Develop a collaborative approach that would establish a set of CERP Adaptive Management principles

- Enhance scientific inquiry and understanding relative to the CERP, allowing for adjustments to be made during the course of implementation

- Establish linkages between science and management that improve management's understanding of how ecosystem responses are affected by the design and operation of CERP projects

The first of the Adaptive Management Program workshops was held on June 18 and 19, 2003, and the second was held on October 22 and 23, 2003. As part of the overall CERP Adaptive Management Program, an assessment strategy will be developed and published in an assessment guidance memorandum, as required by the Programmatic Regulations (DOD 2003). The guidance memorandum will identify the process that will be used to actually conduct performance assessments based on data acquired through implementing the MAP.



*Yellow Book – Central and Southern Florida Project Comprehensive Review Study (USACE and SFWMD, 1999);
CERP – Comprehensive Everglades Restoration Plan; CPR – Comprehensive Plan Refinement;
MRT – Model Refinement Team; AAT-Adaptive Assessment Team; QA/QC – Quality Assurance/Quality Control

Figure 2-1: The CERP Adaptive Management Process

The components of the adaptive management program are and will be described in more detail in other documents currently being prepared by RECOVER or by RECOVER in cooperation with CERP managers. These documents include the following:

- **Conceptual Ecological Models**: These models provide a planning tool for translating the overall restoration goals of the CERP into the specific performance measures that will be used to plan, design, and assess the success of the plan. The draft models are provided in Appendix A of the MAP.

- **CERP Monitoring and Assessment Plan**: This document is designed as a planning framework for a system-wide monitoring and assessment program for the CERP. The focus of this document is describing where and how the CERP assessment performance measures are to be monitored.

- **Performance Measure Documentation Report**: This report is intended as a companion document to the MAP. The performance measure report provides the technical documentation for the approved set of CERP system-wide evaluation and assessment performance measures. A draft will be provided for agency and public review early in 2004.

- **Assessment Guidance Memorandum**: As required by the Programmatic Regulations for CERP (DOD 2003), this document will describe the system-wide assessment protocol for measuring and reporting system responses to the effects of the CERP. A draft will be distributed in 2004.

- **Interim Goals and Interim Targets Report**: Interim goals and targets will be used to periodically assess how well the CERP is meeting its objectives throughout its implementation. The initial report will provide the method to evaluate CERP performance at five-year intervals during implementation. This document will be available in 2004.

- **Adaptive Management Program Implementation Strategy**: This strategy will be based on the outcome of a set of collaborative workshops between RECOVER and participating agency management for the purpose of developing an implementation strategy for the principles of adaptive management for the CERP. A draft report will be available in 2004.

- **CERP Update Guidance Memorandum**: This document will describe the process for periodic updates and improvement to the CERP, including those improvements brought about by the adaptive management program. A draft document for the initial CERP update is currently being developed.

- **Project Formulation and Evaluation Guidance Memorandum**: This document is designed to provide CERP project delivery teams with guidelines for formulation and evaluation protocols for project implementation reports. Among other topics, the guidelines will address the application of adaptive management principles in the formulation and evaluation of projects. A draft memorandum will be available in 2004.

Because the specifics of these documents and protocols are currently being developed by RECOVER teams, each document should be consulted as it becomes available for additional information.

2.6 REFERENCES

Blann, K., and S. Light. 2003. Key Principles for Adaptive Management: Enhancing Scientific Inquiry and Policy Formulation for CERP. Unpublished report to RECOVER, c/o South Florida Water Management District, West Palm Beach, Florida.

DOD. 2003. Programmatic Regulations for the Comprehensive Everglades Restoration Plan; Final Rule. Federal Register, Volume 68, Number 218, pp. 64200-64249. Department of Defense, Department of the Army, Corps of Engineers, 33 CFR Part 385, November 12, 2003, Washington, D.C.

Gentile, J.H. 1996. Final Report: Workshop on South Florida Ecological Sustainability Criteria, April 25-26, 1996. University of Miami, Miami, Florida, 54 pp.

Gentile, J.H., M.A. Harwell, W. Cropper, Jr., C.C. Harwell, D. DeAngelis, S. Davis, J.C. Ogden, D. Lirman. 2001. Ecological Conceptual Models: A Framework and Case Study on Ecosystem Management for South Florida Sustainability. The Science of the Total Environment 274 (2001) 231-253.

National Research Council. 2003. Adaptive Monitoring and Assessment for the Comprehensive Everglades Restoration Plan. Committee on Restoration of the Greater Everglades Ecosystem Water Science and Technology Board, Board on Environmental Studies and Toxicology,

Division of Earth and Life Sciences, National Research Council of the National Academies, National Academies Press, Washington, D.C.

Ogden, J.C., and S.M. Davis. 1999. The Use of Conceptual Ecological Landscape Models as Planning Tools for the South Florida Ecosystem Restoration Programs. South Florida Water Management District, West Palm Beach, Florida.

Ogden, J.C, S.M. Davis, and L.A. Brandt. 2003. Science Strategy for a Regional Ecosystem Monitoring and Assessment Program: The Florida Everglades Example. In: Busch, D., and J. Trexler. Ecological Monitoring of Ecosystem Initiatives, Island Press, Covelo, California.

RECOVER. 2003. Monitoring and Assessment Plan. REstoration COordination and VERification Program, c/o Jacksonville District, United States Army Corps of Engineers, Jacksonville, Florida, Second Draft, March 2003.

RECOVER. In prep. Performance Measure Documentation Report. RECOVER c/o South Florida Water Management District, West Palm Beach, Florida.

Rosen, B.H., P. Adamus, and H. Lal. 1995. A Conceptual Model of the Assessment of Depressional Wetlands in the Prairie Pothole Region. Wetlands Ecology and Management 3:195-208.

U.S. Congress. 2000. Section 601 of the Water Resources Development Act of 2000 (Public Law 106-541). Washington, DC.

USACE and SFWMD. 1999. Central and Southern Florida Project Comprehensive Review Study Final Integrated Feasibility Report and Programmatic Environmental Impact Statement. Jacksonville District, United States Army Corps of Engineers, Jacksonville, Florida, and South Florida Water Management District, West Palm Beach, Florida.

3.0 INTEGRATED MONITORING REQUIREMENTS

This section describes the system-wide monitoring components and supporting research that will establish a framework for measuring the system responses to the Comprehensive Everglades Restoration Plan (CERP) implementation. Six modules are presented in this section:

- 3.1 Greater Everglades Wetlands
- 3.2 Southern Estuaries
- 3.3 Northern Estuaries
- 3.4 Lake Okeechobee
- 3.5 South Florida Hydrology Monitoring Network
- 3.6 South Florida Mercury Bioaccumulation

The description of each module contains the following subsections, with "X" being one of the six modules listed above (1-6):

- 3.X.1 Introduction
- 3.X.2 Ecological Premises and CERP Hypotheses as the Basis for Monitoring Components and Supporting Research
- 3.X.3 Monitoring Components
- 3.X.4 Key Uncertainties and Supporting Research
- 3.X.5 References

The process used to develop the modules is described in Section 2.0, Development of the CERP Monitoring Plan and Adaptive Management Program. The strategy for prioritizing and implementing monitoring components and research topics is discussed in Section 5.0, Implementation Strategy for the CERP Monitoring and Assessment Plan.

3.X.1 Introduction

The introduction defines the ecological and geographical scope of the module as well as the simplified conceptual ecological models from which the module is derived. These simplified conceptual ecological models were derived from draft conceptual ecological models to focus specifically on CERP restoration expectations. These models are provided in Appendix A.

3.X.2 Ecological Premises and CERP Hypotheses as the Basis for Monitoring Components and Supporting Research

This subsection, Ecological Premises and CERP Hypotheses as the Basis for Monitoring Components and Supporting Research, summarizes the rationale for choosing monitoring components and supporting research and provides an overview of the contents of each module. The rationale for choosing monitoring

components and supporting research is based on ecological premises and CERP hypotheses, which are derived from the simplified conceptual ecological models. Ecological premises describe the current, broad understanding of the causal factors that have led to a loss of the natural ecological characteristics of the South Florida ecosystem. Each ecological premise leads to CERP hypotheses, which state assumptions of how changes due to the implementation of the CERP will restore the ecological characteristics that have been lost. The CERP hypotheses are the bases for the monitoring components and supporting research in each module. Many hydrology monitoring components support all the modules and are described in Section 3.5, South Florida Hydrology Monitoring Network Module.

The monitoring components and supporting research are designed to answer adaptive management questions. For example, will the natural system respond to the implementation of the CERP as the premises indicate it should? If not, how can the design and/or operation of the CERP be modified to achieve desired ecosystem responses?

Supporting research is generally linked to monitoring components and is intended to support the interpretation of monitoring results. Where supporting research originates directly from a CERP hypothesis, research will be required to develop an appropriate monitoring component.

A summary list of monitoring components and supporting research is provided as a guide to the more detailed sections of the module. The table also indicates the performance measure or measures that correspond to each component. The system-wide assessment performance measures are being published in a separate document, the Performance Measure Documentation Report (RECOVER In prep). Each monitoring component has at least one corresponding performance measure. For reference, the performance measure identification number or numbers are provided.

3.X.3 Monitoring Components

The Monitoring Components section describes how monitoring will be conducted for each module.

3.X.4 Key Uncertainties and Supporting Research

This section describes key uncertainties that may impede the development of monitoring components and/or the interpretation of the monitoring results. Research topics are developed to reduce key uncertainties. The supporting research topics included are those identified during the development of the draft conceptual ecological models (Appendix A) and the current version of the Monitoring and Assessment Plan (MAP). This list has yet to be prioritized, and it is anticipated that additional research topics of equal or higher priority will be identified in the future, including those related to water quality.

3.X.5 References

A list of literature citations used in the development of the module is provided in this section.

3.0.1 References

RECOVER. In prep. Performance Measure Documentation Report. RECOVER c/o South Florida Water Management District, West Palm Beach, Florida.

3.1 GREATER EVERGLADES WETLANDS MODULE

3.1.1 Introduction

The remaining portion of the Greater Everglades Wetlands includes a mosaic of inter-connected freshwater wetlands and estuaries (Figure 3-1). A ridge and slough system of patterned, freshwater peatlands extends throughout the Water Conservation Areas (WCAs) into Shark River Slough in Everglades National Park. The ridge and slough wetlands drain into tidal rivers that flow through mangrove estuaries into the Gulf of Mexico. Higher elevation wetlands that are characterized by marl substrates and exposed limestone bedrock flank either side of Shark River Slough. The marl prairies and rocky glades to the east of Shark River Slough include the drainage basin for Taylor Slough, which flows through an estuary of dwarf mangrove forests into northeast Florida Bay. The Everglades marshes merge with the forested wetlands of Big Cypress National Preserve to the west of WCA 3 and Everglades National Park. Also included in the Greater Everglades Wetlands are the Lake Okeechobee littoral zone and the hydric pinelands and seasonal wetlands of the J.W. Corbett/Pal Mar Wildlife Management Area.

The Greater Everglades Wetlands Module combines four conceptual ecological models: 1) Everglades Ridge and Slough, 2) Everglades Southern Marl Prairies including the Taylor Slough basin, 3) Everglades Mangrove Estuaries including the mangrove estuaries of Florida Bay and the Gulf of Mexico westward to Lostman's River, and 4) Big Cypress Basin eastern portions that will be influenced by the Comprehensive Everglades Restoration Plan (CERP). These are presented in detail in Appendix A. Simplified conceptual ecological models (Figures 3-2, 3-3, 3-4, and 3-5) were derived from the above models to focus specifically on CERP restoration expectations. These four regions share interrelated hydrologic patterns and ecological restoration goals in CERP, and they are combined and integrated at the regional scale in the Monitoring and Assessment Plan (MAP).

The simplified conceptual ecological models reveal that most of the restoration expectations for the ecological attributes of the greater Everglades pertain to 1) the recovery of wetland landscape patterns shown as attributes encircled by dashed lines in Figures 3-2 through 3-5 and 2) the renewal of functional trophic relationships in wetland food webs shown as attributes encircled by solid lines in Figures 3-2 through 3-5. Arrows represent linkages within the conceptual ecological model. Additional species-specific expectations are for the American alligator, the American crocodile, and the Cape Sable seaside sparrow. Restoration expectations for the stressors to the Greater Everglades Wetlands pertain to hydrologic patterns, coastal gradients, and water quality.

A number of CERP projects are expected to influence the stressors and attributes described in the simplified conceptual ecological model. Some of these effects will be direct, others indirect. A summary of the projects expected to affect the Greater Everglades Wetlands is provided in Appendix B.

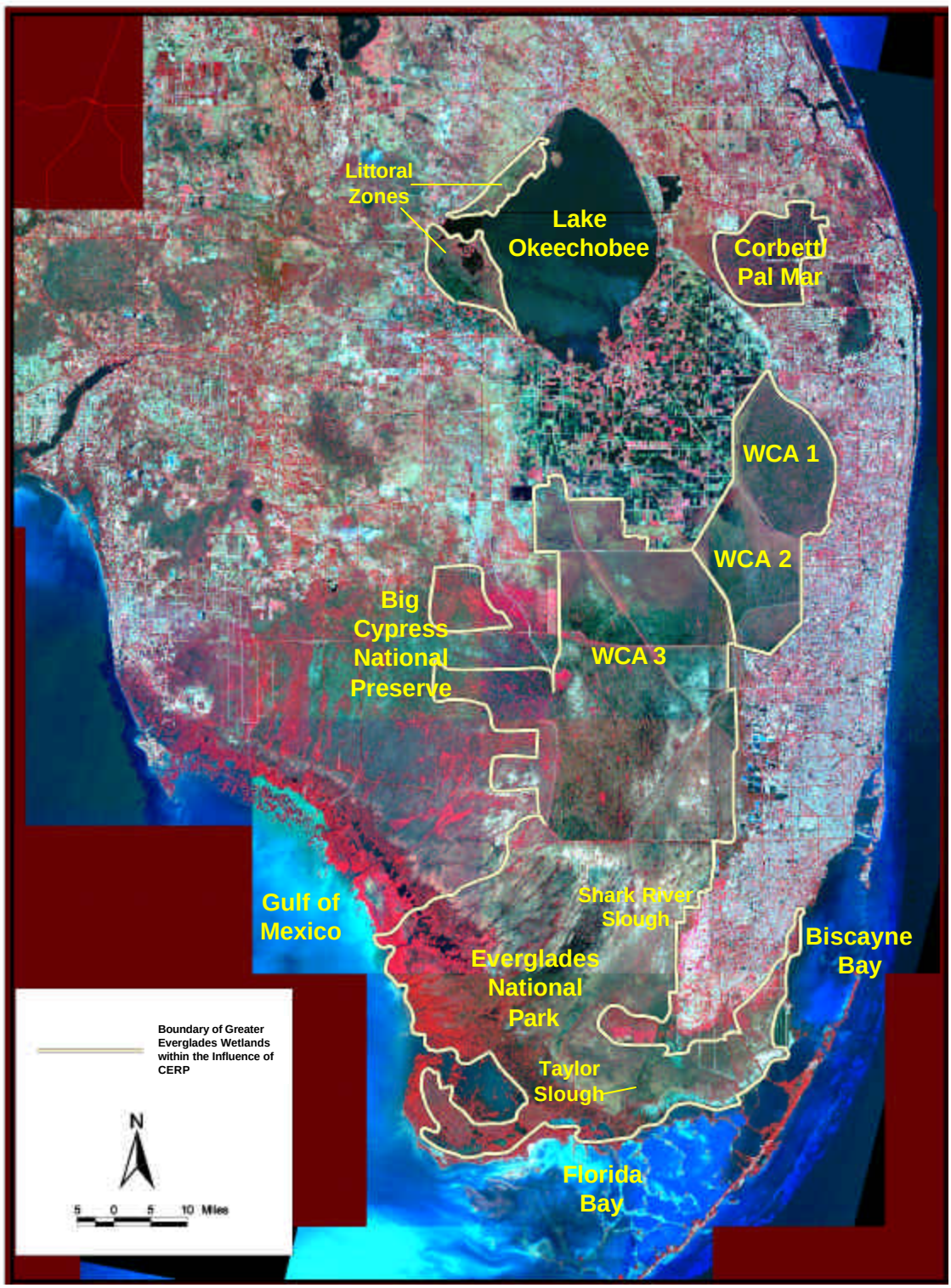


Figure 3-1: Boundary of Greater Everglades Wetlands within the Influence of CERP

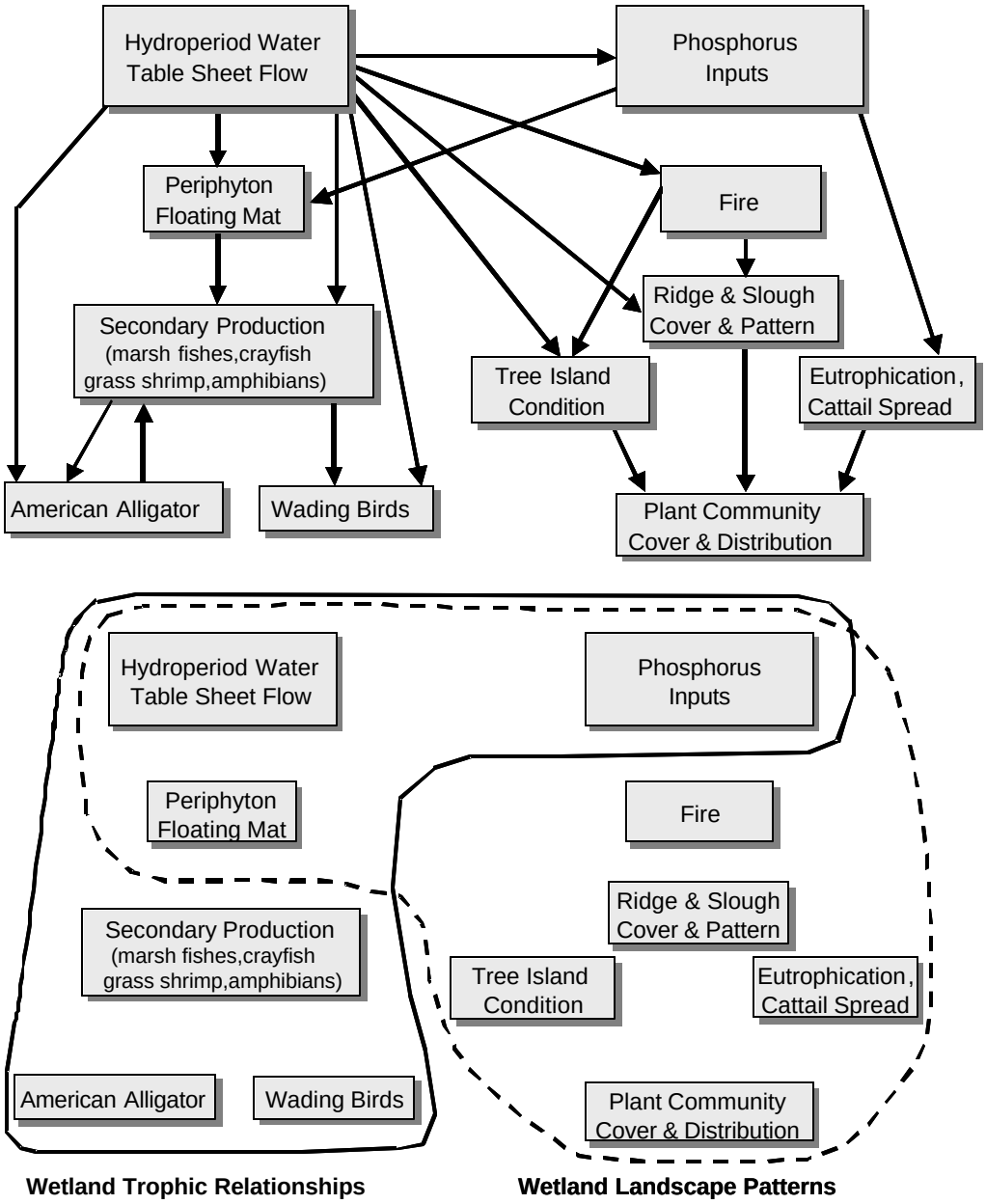


Figure 3-2: Simplified Conceptual Ecological Model to Reflect Expected CERP Influences in Everglades Ridge and Slough

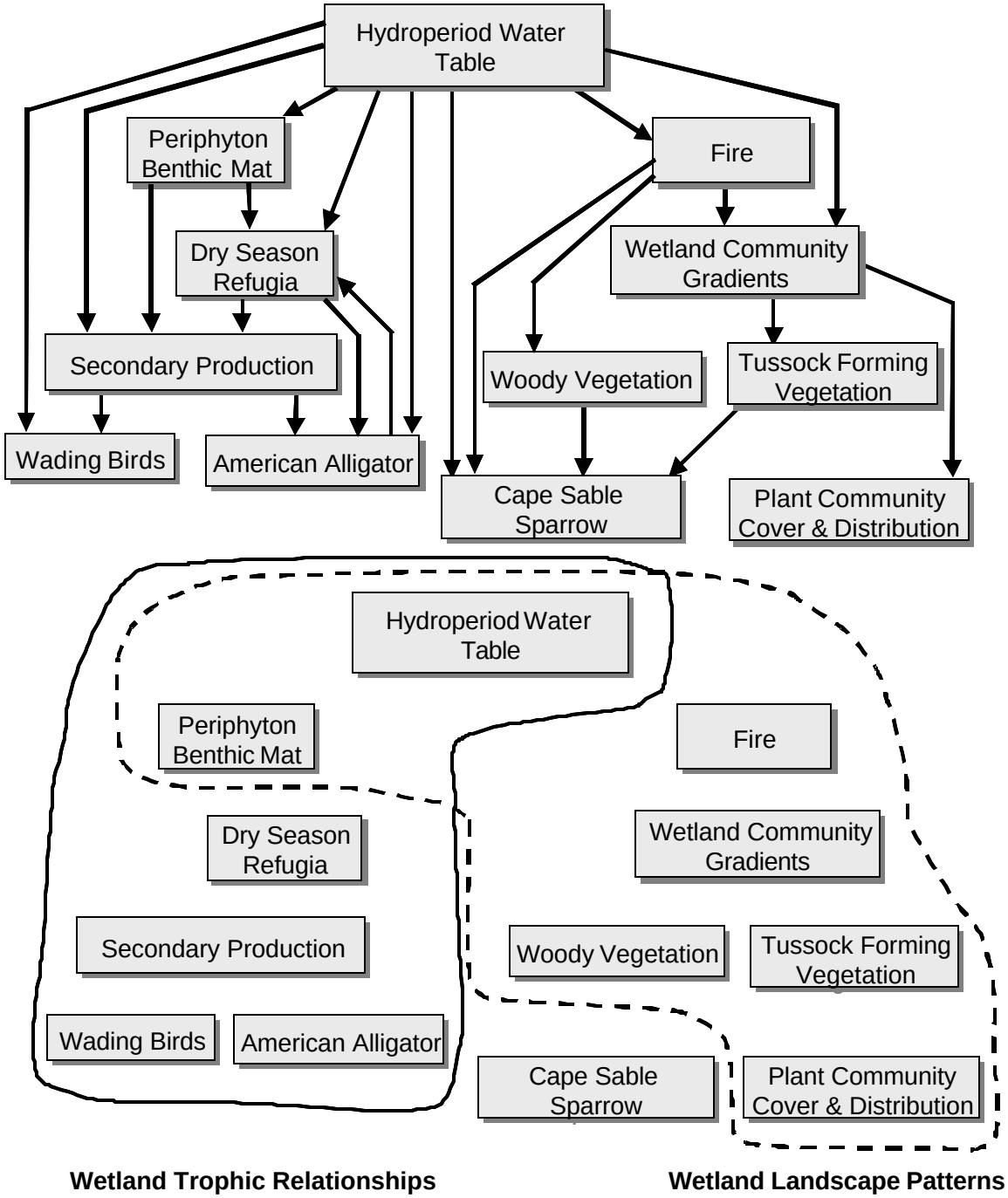


Figure 3-3: Simplified Conceptual Ecological Model to Reflect Expected CERP Influences in Everglades Southern Marl Prairies

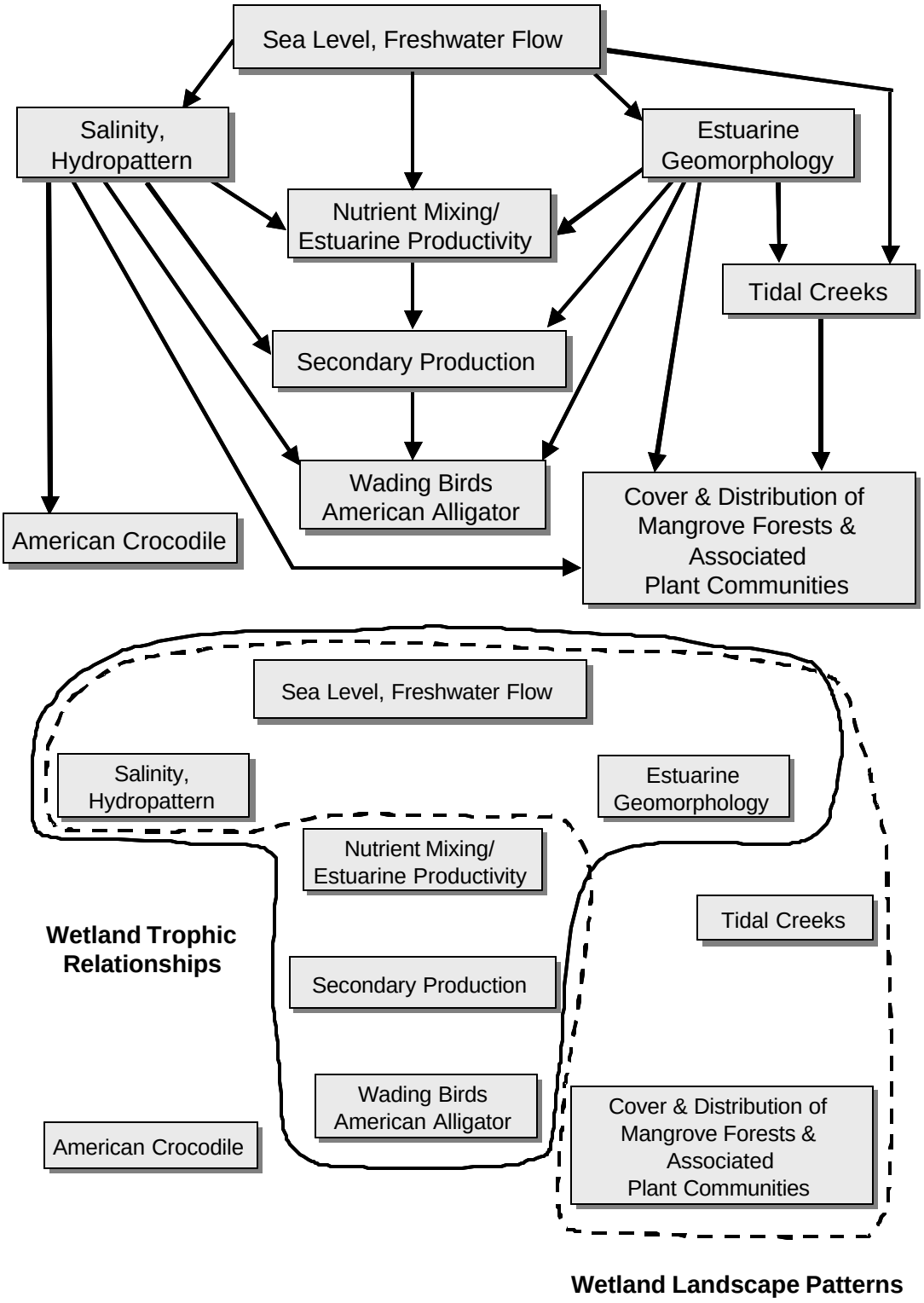


Figure 3-4: Simplified Conceptual Ecological Model to Reflect Expected CERP Influences in Everglades Mangrove Estuaries

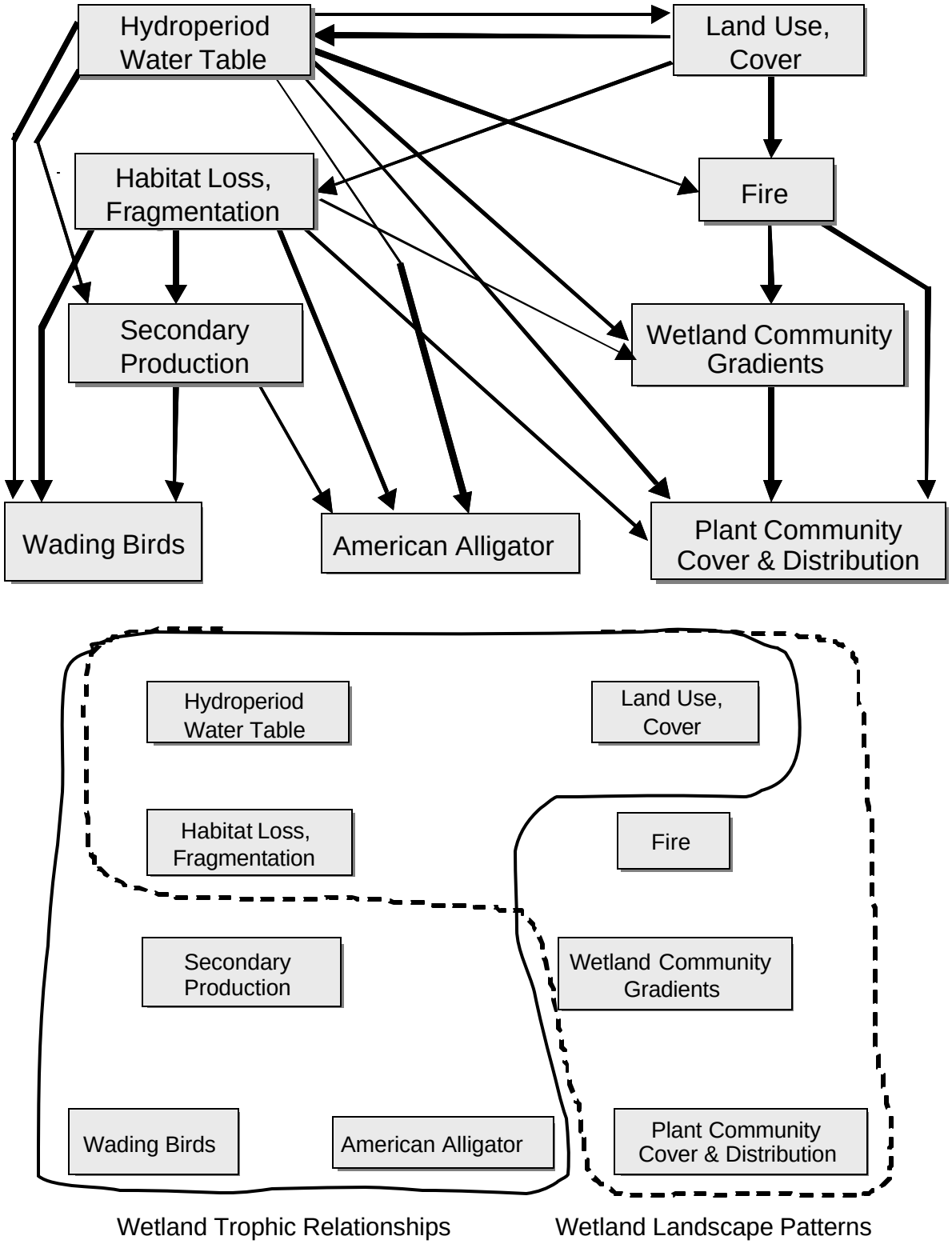


Figure 3-5: Simplified Conceptual Ecological Model to Reflect Expected CERP Influences in Big Cypress Basin

3.1.2 Ecological Premises and CERP Hypotheses as the Basis for Monitoring Components and Supporting Research

Four ecological premises form the basis for most of the CERP restoration goals and strategies for the Greater Everglades Wetlands. These pertain to the effects of hydrology on 1) interior gradients of water quality (i.e., rates of change of a parameter over distance) and the resulting distribution of soil nutrients; 2) coastal gradients of flow, salinity, and nutrients; 3) wetland landscape pattern and extent; and 4) trophic levels of food chains supporting higher vertebrates. Additional species-specific premises relate to the American alligator, the American crocodile, and the Cape Sable seaside sparrow. Monitoring and assessment associated with each of these premises is dependent on the South Florida Hydrology Monitoring Network (Section 3.5).

Figures 3-6 to 3-12 illustrate the linkages of ecological premises to CERP hypotheses, monitoring components, and key uncertainties and supporting research. Supporting research is generally linked to monitoring components, in which case research supports the interpretation of monitoring results. In some cases, supporting research originates directly from a CERP hypothesis, and research will be required to develop an appropriate monitoring component. These linkages are indicated by a red arrow. The resulting monitoring components and supporting research for the Greater Everglades Wetlands are listed in Table 3-1 and described in detail in the following sections. The list of research topics includes those identified during the development of the current version of the MAP. This list has yet to be prioritized, and it is anticipated that additional research topics of equal or higher priority will be identified in the future, including those related to water quality.

The process used to develop the monitoring plan for the Greater Everglades Wetlands Module, and all of the other modules, is described in Section 2.0, Development of the CERP Monitoring Plan and Adaptive Management Program. The strategy for prioritizing and implementing monitoring components and research topics is discussed in Section 5.0, Implementation Strategy for the CERP Monitoring and Assessment Plan.

3.1.2.1 Interior Gradients of Flow and Water Quality (Figure 3-6)

Ecological Premise: The pre-drainage Greater Everglades Wetlands system was characterized by hydrologic inputs (primarily from direct rainfall) and by extended hydroperiods. Natural conditions were characterized by oligotrophic conditions with low phosphorus and sulfur concentrations in surface waters having defined zones of low or high conductivity as compared to present conditions. An overriding expectation of CERP is that it will restore hydroperiods by providing freshwater inflows and restored hydropatterns to the Greater Everglades Wetlands without increasing nutrient loads or subjecting more of the system (particularly the more pristine areas) either to elevated concentrations of surface water phosphorus, nitrogen, and sulfur or to constituents that alter the natural zones of conductivity in the freshwater regions, thereby improving overall water quality throughout the wetland system.

CERP Hypothesis: The restoration of hydrology toward Natural Systems Model (NSM) conditions (a simulation of the pre-drainage Everglades) will result in the following:

- Maintenance or reduction of nutrient (phosphorus and nitrogen) loads from inflow structures and phosphorus and nitrogen concentrations in surface water and soils in the open marsh at levels that do not expand zones of eutrophication in Greater Everglades Wetlands and halt the loss of Everglades landscape patterns (i.e., spread of cattail) and the breakdown in aquatic trophic relationships

- No increases or expansion of sulfate/sulfide concentration gradients into near pristine areas so that aquatic fauna and flora are not subjected to sulfide toxicity and ensure that mercury methylation in the system is not exacerbated (as described in Section 3.6)

- Maintenance of a soft water, low conductivity surface water in the Arthur R. Marshall Loxahatchee National Wildlife Refuge and hard water, higher conductivity water in the remaining freshwater Everglades

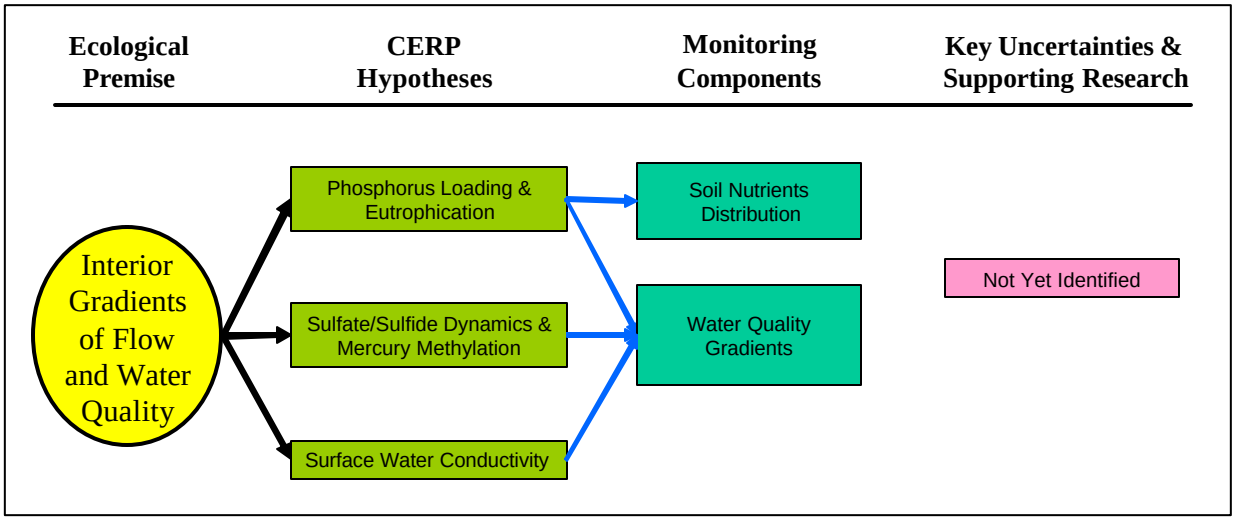


Figure 3-6: Diagram Depicting Relationships between the Ecological Premise, CERP Hypotheses, Monitoring Components, and Supporting Research for Interior Gradients of Flow and Water Quality in the Greater Everglades Wetlands

Adaptive Management Question: Will the restoration of NSM conditions achieve these objectives? If not, how and to what extent do we modify the physical structure and hydrology of the system to create desired trends toward pre-drainage water quality conditions? Will increased freshwater flows to the remaining Everglades bring higher or lower nutrient loads?

3.1.2.2 Coastal Gradients of Flow, Salinity, and Nutrients (Figure 3-7)

Ecological Premise: Pre-drainage hydrological conditions in the southern Everglades produced prolonged pooling of fresh water just upstream of the mangrove estuaries and prolonged patterns of freshwater flow into the mangrove estuaries. The freshwater pooling and inflow supported a wide salinity gradient, including a broad oligohaline zone, in the mangrove estuary. The freshwater inflows also provided nitrogen inputs that supported a highly productive estuarine transition zone without stimulating algal blooms in the downstream receiving estuaries.

CERP Hypotheses: The restoration of hydrology toward NSM conditions will result in the following:

- Prolong the pooling of fresh water in the region upstream of the southwest Florida shelf mangrove estuary, including the fertile crescent, and in the Craighead Basin region upstream of the Florida Bay mangrove estuary

- Expand the width and extend the seasonal duration of the oligohaline zone in the mangrove estuaries of the southwest Florida shelf, Florida Bay, and Biscayne Bay
- Slow the inland expansion of the "white zone" interface of marine and freshwater environments in coastal wetlands of Biscayne Bay and northeast Florida Bay
- Control nutrient inputs to Florida Bay and southwest Florida shelf that promote eutrophication and phytoplankton blooms
- Provide freshwater inflows, nitrogen inputs, and nutrient mixing to sustain a high-productivity salinity transition zone in the mangrove estuaries of the southwest Florida shelf

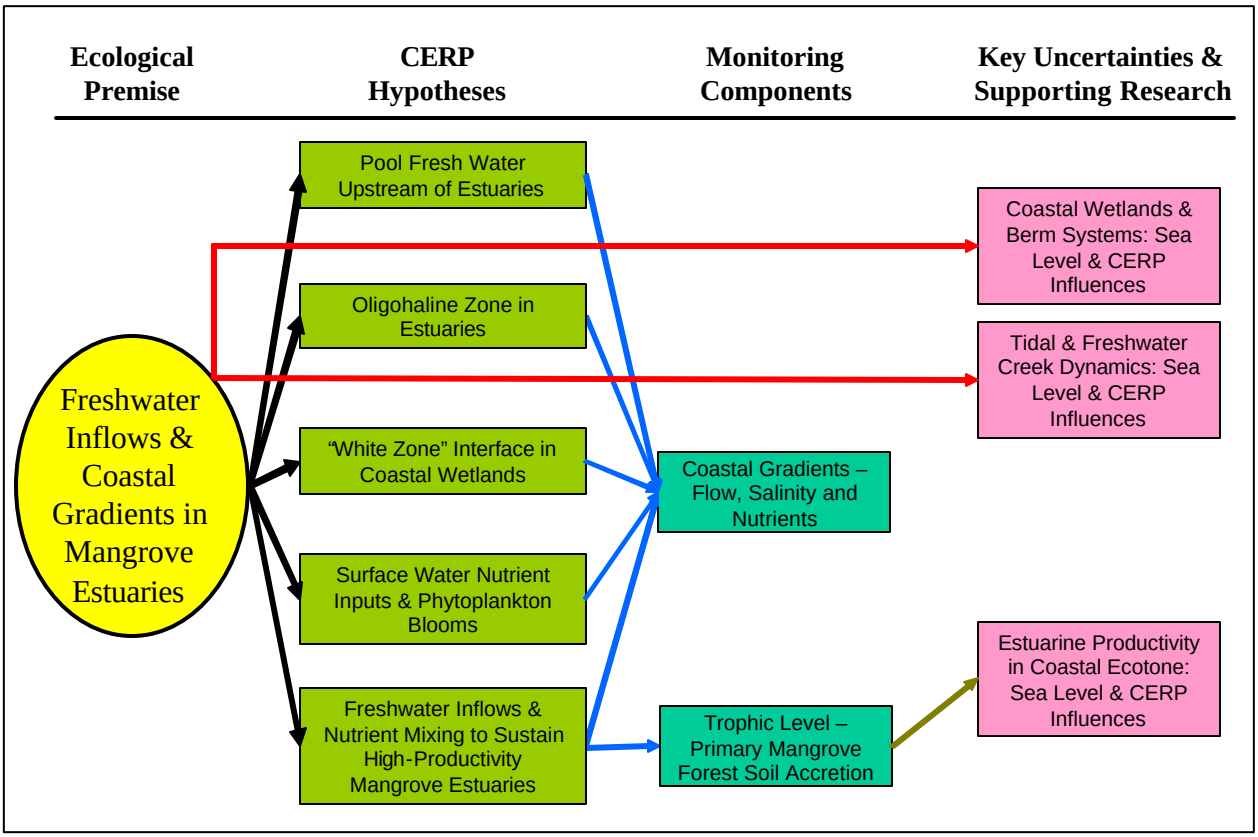


Figure 3-7: Diagram Depicting Relationships between the Ecological Premise, CERP Hypotheses, Monitoring Components, and Supporting Research for Coastal Gradients of Flow, Salinity, and Nutrients in the Greater Everglades Wetlands

Adaptive Management Question: Will the restoration of NSM achieve these objectives? If not, how and to what extent do we modify the physical structure and hydrology of the system to provide desired freshwater flow and salinity patterns in the coastal mangroves and basins of the southern Everglades without stimulating additional algal blooms in Florida Bay?

3.1.2.3 Wetland Landscape Pattern and Extent (Figure 3-8)

Ecological Premise: The loss of pattern and directionality in Everglades wetland landscapes has been caused by altered hydrologic conditions in combination with eutrophication.

CERP Hypotheses: The restoration of hydrology toward NSM conditions will result in the following:

- Sustain spatial extents and patterns of ridges and sloughs and the health of tree islands given the altered conditions now existing and restore patterns, where possible, through hydrologic restoration toward NSM conditions, in the ridge and slough landscape
- Achieve the above ridge and slough restoration objectives through hydrologic restoration without having negative impacts on vegetation communities due to excessive nutrient inputs and eutrophication
- Provide hydrodynamic conditions that will sustain patterns of tidal creeks in the mangrove estuaries
- Restore slough habitat in the southern Everglades while maintaining short hydroperiod, tussock-forming plant communities in the adjacent marl prairies

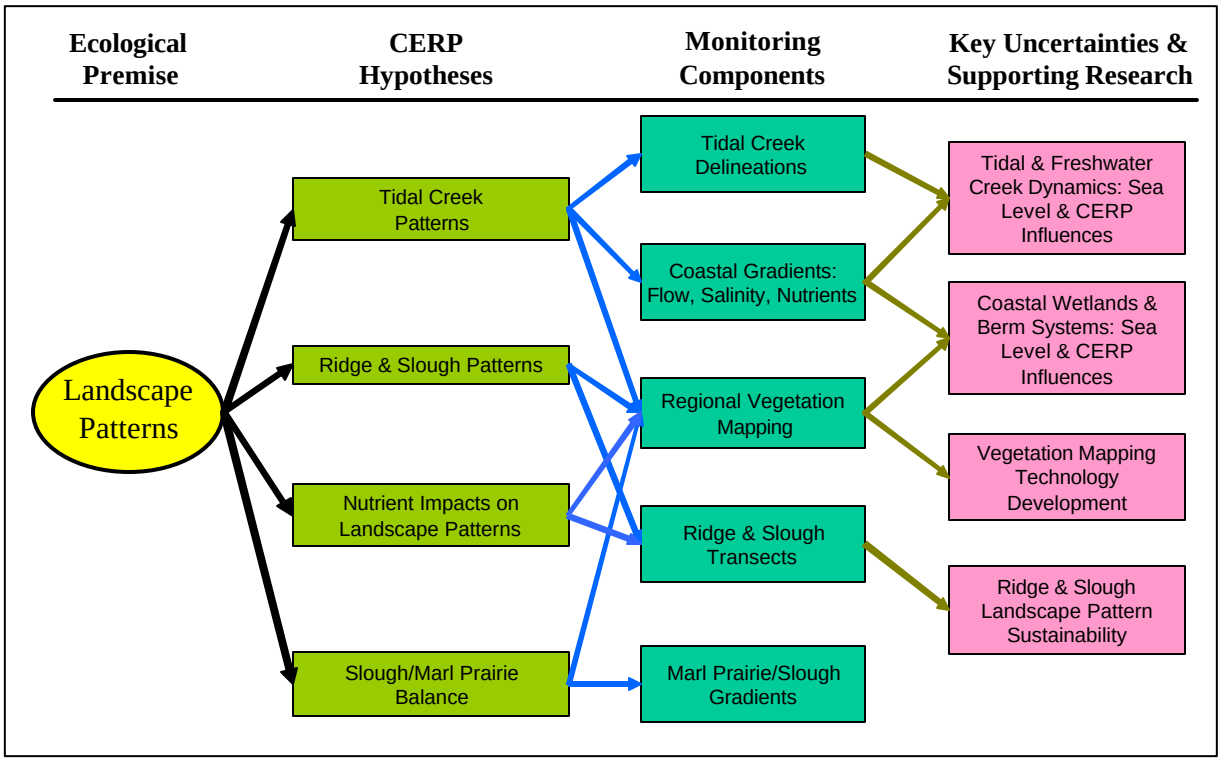


Figure 3-8: Diagram Depicting Relationships between the Ecological Premise, CERP Hypotheses, Monitoring Components, and Supporting Research for Wetland Landscape Patterns in the Greater Everglades Wetlands

Adaptive Management Question: Will the restoration of NSM conditions achieve these objectives? If not, how and to what extent do we modify the physical structure and hydrology of the system to restore pattern and directionality in Everglades landscapes?

3.1.2.4 Trophic Levels of Food Chains Supporting Higher Vertebrates (Figures 3-9, 3-10, and 3-11)

Ecological Premise: Reproduction of higher vertebrates that are dependent on aquatic food webs is food limited due to altered hydrologic and water quality conditions in the Greater Everglades Wetlands. As a result, the foraging distributions and nesting patterns of wading birds have been altered due to the redistribution of high concentrations of prey organisms.

CERP Hypotheses: The restoration of hydrology toward NSM conditions will result in the following:

- Enhance periphyton community characteristics and mangrove forest soil accretion rates as regional indicators of the functional bases of Everglades food webs
- Restore the density, seasonal concentration, size structure, and taxonomic composition of marsh fishes and other aquatic fauna to levels that support sustainable breeding populations of higher vertebrates
- Shift the distribution of high density populations of marsh fishes and other aquatic fauna from artificially-pooled areas (the Water Conservation Areas) to the restored pools in the southern Everglades
- Shift the foraging distribution of wading birds in response to expected trends in the density, distribution, and concentration of prey organisms
- Reestablish wading bird nesting colonies in the coastal regions of the southern Everglades and increase the numbers of nesting pairs and colony sizes in response to desired trends in populations of prey organisms
- Increase the nesting success/survival rate of wading birds in response to desired trends in populations of prey organisms

Adaptive Management Question: Will the restoration of NSM conditions achieve these objectives? If not, how and to what extent do we modify the physical structure and hydrology of the system to restore aquatic food webs that support reproducing populations of higher vertebrates and to shift the foraging distribution and nesting of wading birds to energetically sustainable breeding populations?

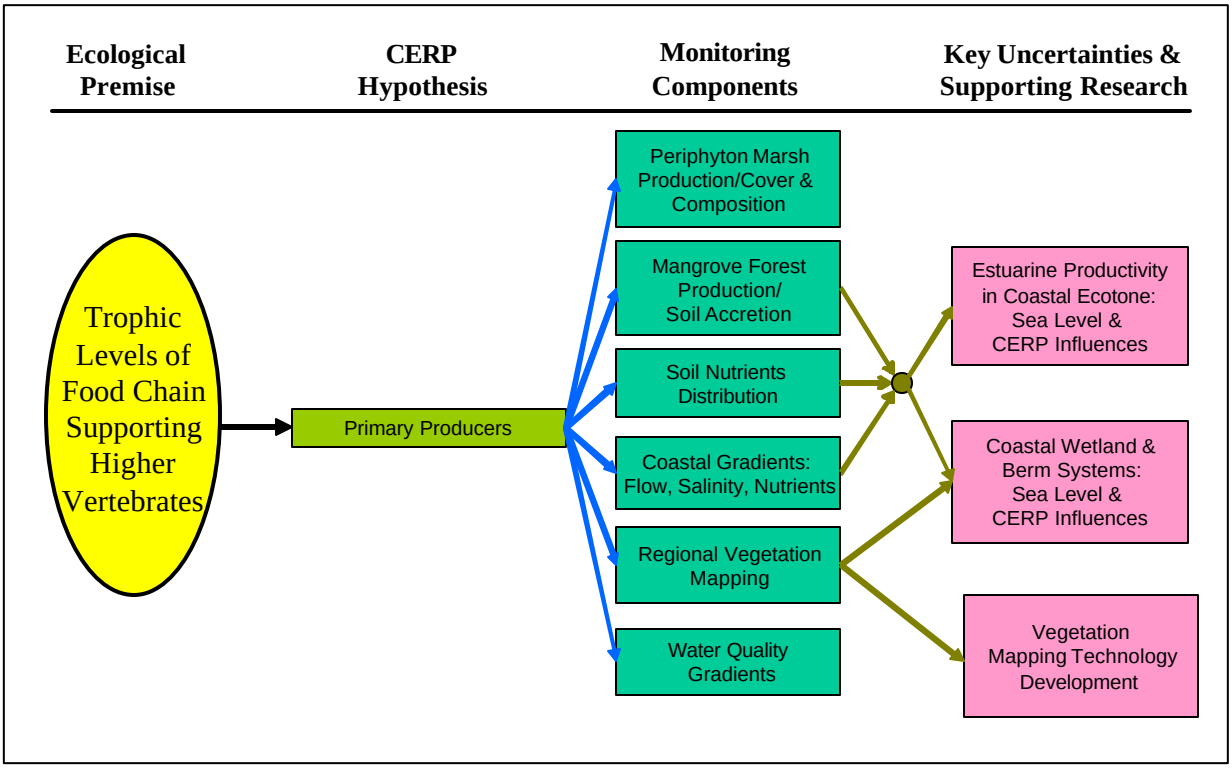


Figure 3-9: Diagram Depicting Relationships between the Ecological Premise, CERP Hypothesis, Monitoring Components, and Supporting Research for Primary Producer Trophic Levels of Food Chains Supporting Higher Vertebrates in the Greater Everglades Wetlands

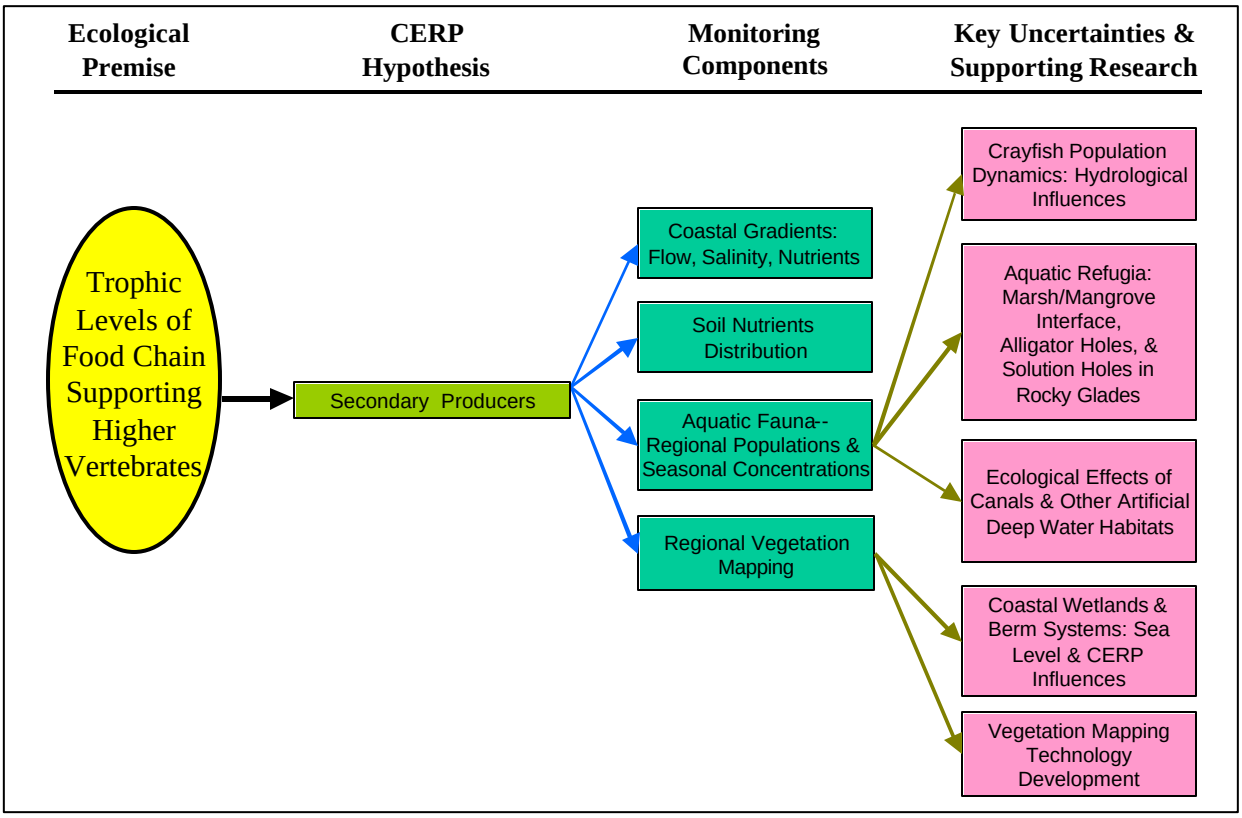


Figure 3-10: Diagram Depicting Relationships between the Ecological Premise, CERP Hypothesis, Monitoring Components, and Supporting Research for Secondary Producer Trophic Levels of Food Chains Supporting Higher Vertebrates in the Greater Everglades Wetlands

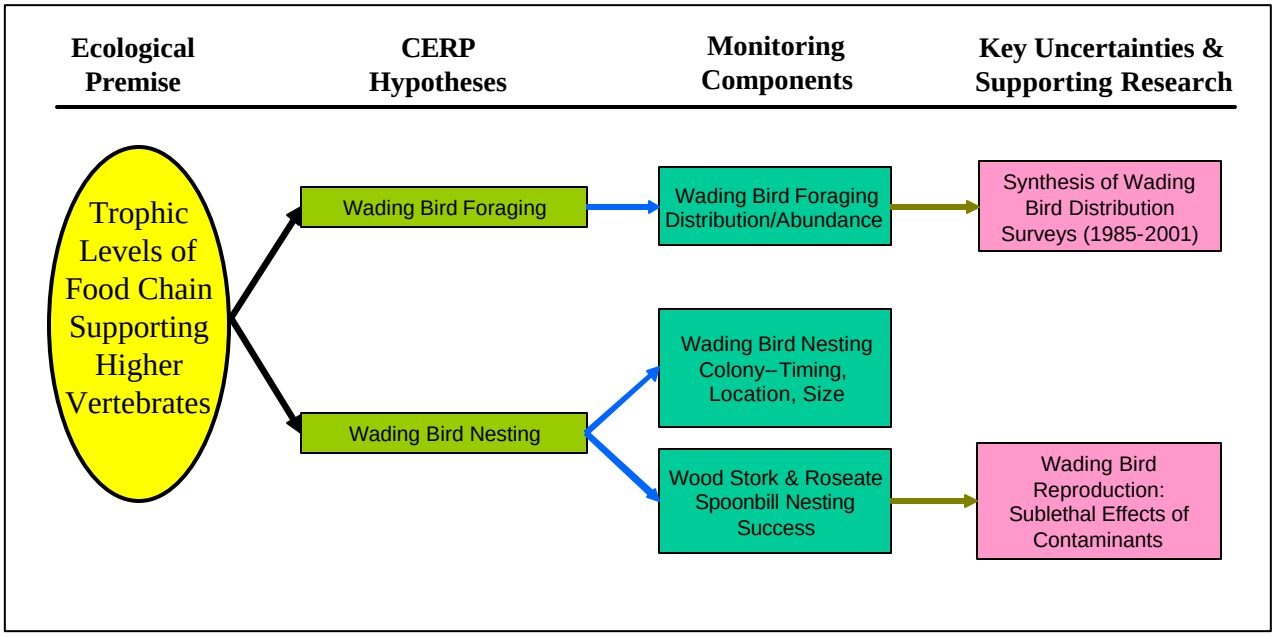


Figure 3-11: Diagram Depicting Relationships between the Ecological Premise, CERP Hypotheses, Monitoring Components, and Supporting Research for Wading Birds as Upper Trophic Level Consumers in the Greater Everglades Wetlands

3.1.2.5 American Alligator (Figure 3-12)

Ecological Premise: The distribution and reproduction of American alligator populations have been reduced as a result of altered hydrologic conditions and the reduced abundance and accessibility of prey organisms that accompany the hydrologic alterations.

CERP Hypotheses: The restoration of hydrology toward NSM conditions will result in the following:

- Expand the distribution of reproducing alligators and alligator holes to the southern marl prairies and restore the keystone role of alligator holes as drought refugia for aquatic fauna in that region
- Provide salinity regimes that are favorable for expansion of populations of reproducing alligators into the mangrove estuary
- Sustain current populations of reproducing alligators in the ridge and slough landscape

Adaptive Management Question: Will the restoration of NSM conditions achieve these objectives? If not, how and to what extent do we modify the physical structure and hydrology of the system to restore populations of the alligator in regions where they were formerly abundant by reestablishing both their wetland habitat requirements and the abundance and accessibility of their prey?

3.1.2.6 American Crocodile (Figure 3-12)

Ecological Premise: Growth and survival rates of juvenile American crocodiles have declined as a result of detrimental salinity ranges in coastal wetlands and tidal creeks of Biscayne and Florida Bays due to altered freshwater inflow regimes.

CERP Hypothesis: The restoration of hydrology toward NSM conditions will provide freshwater inflows and salinity regimes that will increase the growth and survival of juvenile crocodiles.

Adaptive Management Question: Will the restoration of NSM conditions achieve these objectives? If not, how and to what extent do we modify the physical structure and hydrology of the system to restore beneficial salinity ranges that will improve juvenile crocodile growth and survival rates?

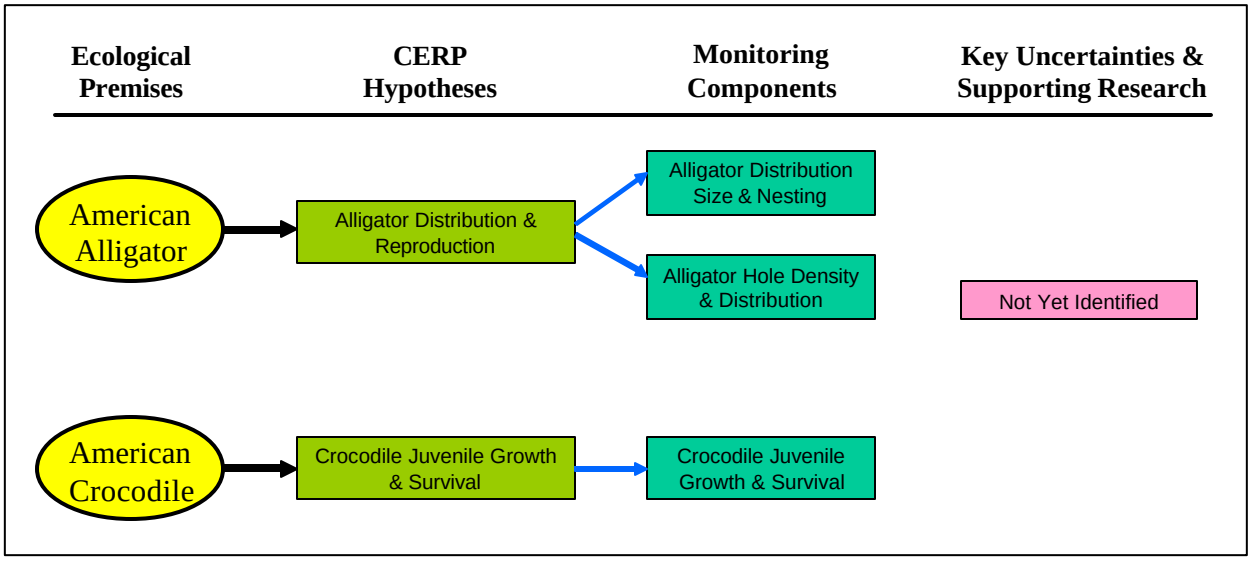


Figure 3-12: Diagram Depicting Relationships between the Ecological Premises, CERP Hypotheses, Monitoring Components, and Supporting Research for the American Alligator and American Crocodile in the Greater Everglades Wetlands

3.1.2.7 Summary of Monitoring Components and Key Uncertainties and Supporting Research

Table 3-1 summarizes the monitoring components and key uncertainties and supporting research for the Greater Everglades Wetlands Module. The section of this document where each monitoring component is discussed is provided in the second column of Table 3-1 for reference.

The systemwide assessment performance measures are being published in a separate document, the Performance Measure Documentation Report (RECOVER In prep). Each MAP monitoring component has at least one corresponding performance measure. For reference, the performance measure identification number or numbers are provided in the last column of Table 3-1.

Table 3-1: Summary List of Monitoring Components and Key Uncertainties and Supporting Research for the Greater Everglades Wetlands

Monitoring Components	MAP Section	Performance Measure Number
Interior Gradients of Water Quality	3.1.3.1	GE-A14 GE-A16 GE-A17
Regional Distribution of Soil Nutrients	3.1.3.2	GE-A15
Coastal Gradients of Flow, Salinity, and Nutrients	3.1.3.3	GE-A12
Landscape Pattern – Vegetation Mapping	3.1.3.4	GE-A2
Landscape Pattern – Marl Prairie/Slough Gradients	3.1.3.5	GE-A5
Landscape Pattern – Ridge, Slough, and Tree Island Mosaics	3.1.3.6	GE-A3
Landscape Pattern – Tidal Creek Delineation	3.1.3.7	GE-A4
Trophic Level – Primary – Periphyton Mat Cover, Structure, and Composition	3.1.3.8	GE-A10
Trophic Level – Primary – Mangrove Forest Soil Accretion	3.1.3.9	GE-A11
Trophic Level – Secondary – Aquatic Fauna Regional Populations	3.1.3.10	GE-A6
Trophic Level – Secondary – Aquatic Fauna Seasonal Concentrations	3.1.3.11	GE-A6
Trophic Level – Wading Bird Foraging Distribution and Abundance	3.1.3.12	GE-A7
Trophic Level – Wading Bird Nesting Colony Location, Size, and Timing	3.1.3.13	GE-A8
Trophic Level – Wood Stork and Roseate Spoonbill Nesting Success	3.1.3.14	GE-A8 GE-A18
American Alligator Distribution, Size, Nesting, and Hole Occupancy	3.1.3.15	GE-A9
American Crocodile Juvenile Growth and Survival	3.1.3.16	GE-A13
Key Uncertainties and Supporting Research		
Coastal Wetland Landscapes and Berm Systems: Sea Level and CERP Influences	3.1.4.1	
Tidal and Freshwater Creek Dynamics: Sea Level and CERP Influences	3.1.4.2	
Productivity in Coastal Ecotone: Sea Level and CERP Influences	3.1.4.3	
Ridge and Slough Landscape Pattern Sustainability	3.1.4.4	
Technology Development: Vegetation Mapping	3.1.4.5	
Crayfish Population Dynamics – Hydrological Influences	3.1.4.6	
Aquatic Refugia – Coastal Ecotone, Alligator Holes, and Solution Holes	3.1.4.7	
Ecological Effects of Canals and Other Artificial Deep Water Habitats	3.1.4.8	
Synthesis of Wading Bird Distribution Surveys 1985-2001	3.1.4.9	
Sub-Lethal effects of Contaminants on Wading Bird Reproduction	3.1.4.10	

3.1.3 Monitoring Components

3.1.3.1 Interior Gradients of Water Quality

The overall objective of water quality monitoring is to evaluate the impacts to the water quality in the Greater Everglades Wetlands system over time as a result of the altered routing, timing, quantity, and quality of fresh water entering the system and the resulting changes to the ecological indicators. Assessment performance measures have been developed for surface water nutrient and sulfate/sulfide concentrations as well as conductivity. The performance measures for total phosphorus concentrations in peat soils and periphyton mat production and composition are closely linked to water quality influences in this system. A nutrient loading assessment performance measure is currently being considered and developed by the REstoration COordination and VERification (RECOVER) Water Quality Team.

According to the work conducted by Stober et al. (2001a,b,c), there are significant north to south water quality gradients from Lake Okeechobee to Florida Bay in total phosphorus, sulfate, and total organic carbon that affect eutrophication as well as mercury contamination throughout the Everglades. These gradients are also apparent in the soil quality. All of these factors are interrelated and can be potentially affected by CERP efforts to change quantity, quality, timing, and distribution of the agricultural and urban stormwater runoff and Lake Okeechobee releases to various portions of the Everglades. An extensive mix of non-CERP, CERP, and critical restoration projects are underway or are planned that will have a cumulative impact on water quality in this region. Some of these projects include Modified Water Deliveries to Everglades National Park, C-111, WCA 3 Decompartmentalization, Everglades Agricultural Area Storage Reservoirs, Western C-11 Water Quality Improvement, C-9 Stormwater Treatment Area/Impoundment, Hillsboro Site 1 Impoundment and Aquifer Storage and Recovery, Lake Belt In-ground Reservoir Technology, and the C-111N Spreader Canal.

Conceptually, a network with a mix of transects and fixed sentinel sites will be designed to capture the interior water quality gradients that characterize the various subregions of the Everglades. The water quality transect and sentinel site design that is preliminarily described below will be designed 1) to distinguish project-level monitoring from the regional monitoring strategies and 2) to integrate the water quality sampling design with soil (Section 3.1.3.2), periphyton (Section 3.1.3.8), and vegetation mapping (3.1.3.4), as well as with the stratified random sampling design for monitoring trophic levels (Section 3.1.3.10).

The water quality monitoring program will quantify water quality performance measures in two different areas of the Everglades. The first area will be under the direct and immediate influence of the flows from South Florida Water Management District (SFWMD) structures and is referred to as near-field, short response-time areas. The quantification of nutrient loads or flow-weighted mean nutrient concentrations entering and leaving the greater Everglades area will be evaluated using this existing network of inflow and outflow stations currently operated by the SFWMD (Figures 3-13 and 3-14). As various CERP components are brought on-line, additional structure monitoring stations will be added to the network. Structures to be monitored will include those that 1) historically/currently manage flows into, within, and out of the Greater Everglades Wetlands and 2) will manage inflows in the future. Many, but not all, such structures will be affected by CERP implementation; however, it is estimated that approximately 20 additional sites will be required over time to characterize the new flow pathways that will eventually be created or modified by the CERP. Monitoring of flow volumes through structures is addressed in the South Florida Hydrology Monitoring Network Module (Section 3.5), and methodology for measurements is described in the CERP Quality Assurance Systems Requirements (QASR) Manual (RECOVER 2003).

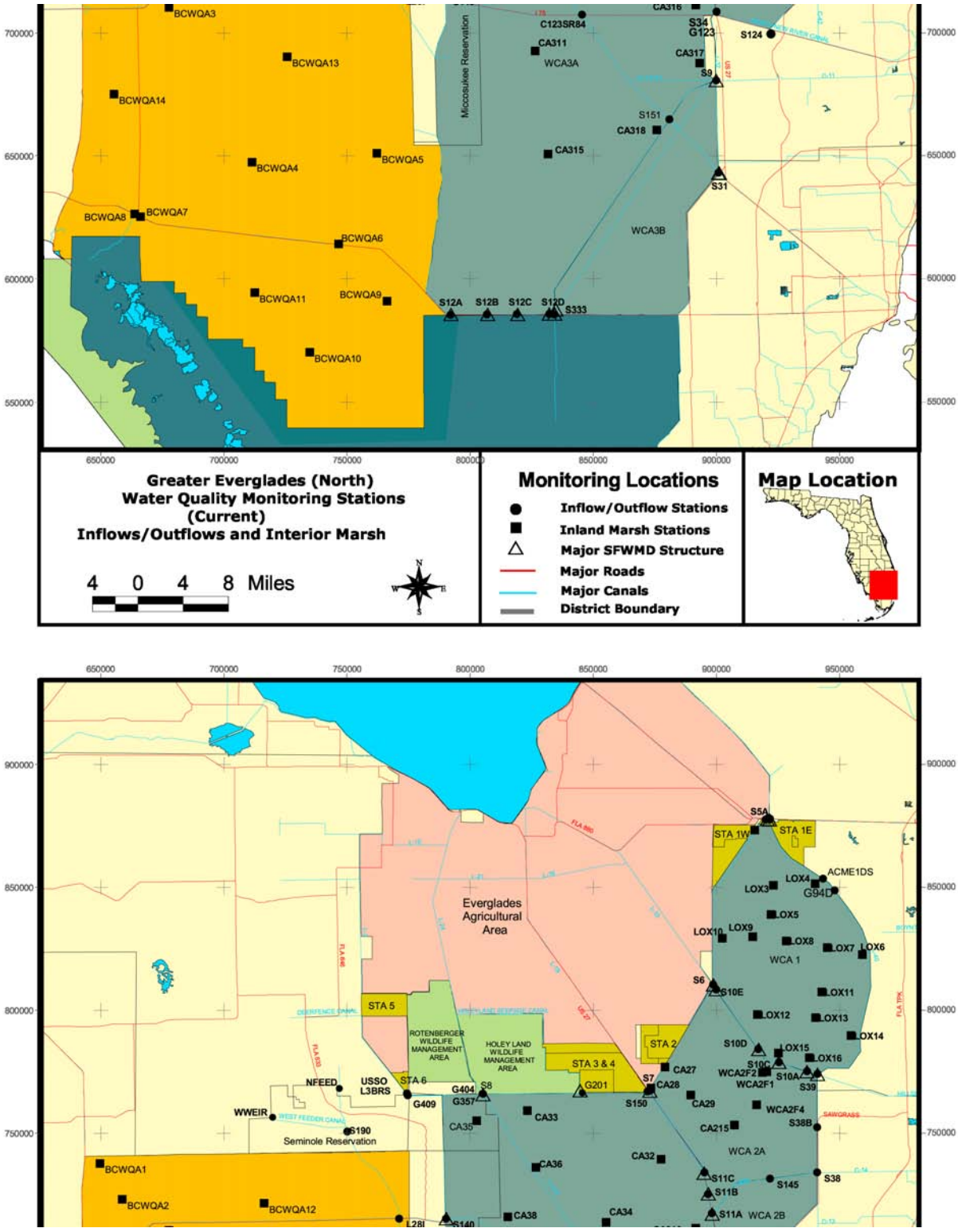


Figure 3-13: Greater Everglades (North) Water Quality Monitoring Stations as of September 2002 –Water Control Structures and Interior Marsh

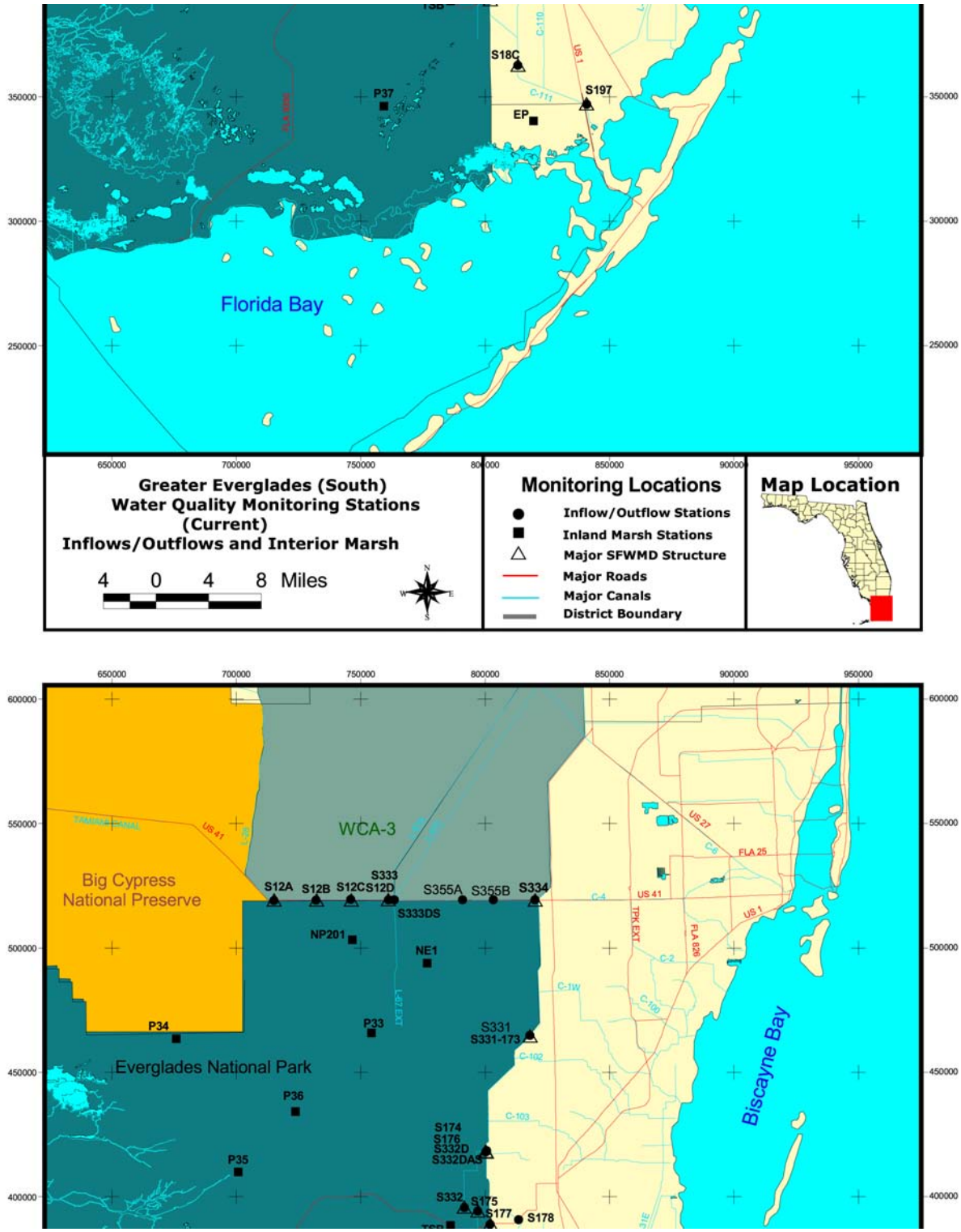


Figure 3-14: Greater Everglades (South) Water Quality Monitoring Stations as of September 2002 – Water Control Structures and Interior Marsh

The second distinct area will be under the delayed or indirect cumulative influence of multiple sources. These will be referred to as the far-field, long response-time areas that are located within the Greater Everglades Wetlands. For example, if nutrient or other contaminant loads are reduced at the inflows, there should a corresponding, longer-term response in the wetland systems. The existing network of far-field or marsh stations, shown in Figures 3-13 and 3-14, are primarily used to meet monitoring requirements under the 1992 Settlement Agreement/Consent Decree and the Everglades Forever Act and provide useful information for long-term trend tracking and a wealth of baseline information; however, this network is not necessarily structured or designed to address the documented water quality gradients and CERP-related scientific questions. RECOVER is proposing a monitoring design that calls for a suite of transects to be set up within current and expected hydrologic, nutrient, and habitat gradients that address several different but interrelated processes. Water quality and habitat gradients downstream of major inflow structures and along sheet flow paths that will be reconnected will be monitored to document potential water quality impacts resulting from the CERP. Monitoring water quality gradients will also help refine the regions of the Greater Everglades Wetlands for the stratified random sampling design based on eutrophication status.

Water quality monitoring in far-field, long response-time areas will consist of a mix of transects and fixed or sentinel sites distributed throughout the Greater Everglades Wetlands. Transect locations will be proposed to capture areas that are either currently impacted (geared to restoration) or where CERP plans significant changes to flows or depths (and nutrient loads) and thus are potential regions of ecological change. In addition, sentinel sites will be located to be representative of regionally significant ecotypes. Sentinel sites are intended to provide information for regions of interest either in impact areas or in reference, unimpacted regions. A number of the sentinel sites are existing fixed station monitoring sites with historical data. Transect alignments and sentinel sites will overlap with vegetation mapping cells and soil nutrient sites to the extent possible.

RECOVER intends to utilize the appropriate expertise to design and optimize a water quality monitoring network for the Greater Everglades Wetlands that will properly integrate with and complement the ecological and hydrological monitoring, adequately contribute to answering the CERP monitoring questions for this area, and be financially sustainable over the span of CERP implementation. Once the near-field and far-field monitoring program elements are finalized, they will be compared with the corresponding ongoing/current monitoring program elements (Figures 3-13 and 3-14) to identify opportunities for optimizing the number of sites, media, or frequencies of sampling or for reducing the number of analyses per sample.

Water quality parameters to be measured at near-field and far-field sites are listed in Tables 3-2 and 3-3, respectively. To estimate cost, approximately 65 near-field/water control structure monitoring sites and approximately 130 far-field or marsh stations are currently being used. The actual number of stations (whether new or existing) needed and sampling frequencies will be determined during the network design.

Physical parameters in the water column such as dissolved oxygen (DO), conductivity, pH, salinity, and temperature will be collected directly in the field on a monthly basis using water quality monitoring probes. Sampling for the other parameters will be conducted on a monthly basis using grab samples and subsequent laboratory analysis. The proposed monitoring program includes monitoring of additional core parameters, such as several major ions, total suspended solids, silicate, and calculated parameters, that will assist in interpreting monitoring results directly tied to the assessment of performance measures. Estimation of nutrient loading or flow-weighted mean concentrations requires the monitoring of water discharge (flow) and nutrient concentrations. Grab and flow-proportional autosampler assays will be conducted for surface water total phosphorus and total nitrogen concentrations at structures, along with the measurement of flow volumes. Such continuous monitoring equipment has already been deployed at

some flow structures, but instrumentation of additional sites may be necessary. Surface water and sediment sampling methodologies, associated quality control requirements, and methods used for subsequent laboratory analyses are described in the QASR Manual (RECOVER 2003).

Table 3-2: Greater Everglades Water Quality Monitoring at Water Control Structures

Medium	Group	Parameters	Sites	Frequency	Collection Method
Water	Physical parameters	DO, conductivity, pH, temperature, turbidity, alkalinity, TSS, color, DOC	Approx. 65 sites	Monthly	Water quality probe and grab
Water	Nutrients	TP, TKN, TOC, NO_2, NO_3, NH_4, NO_{2+3}, SRP, SiO_2	Approx. 65 sites	Monthly and continuous	Grab and flow-proportional autosampler
Water	Other core parameters	Cl, SO_4, S^{-2}	Approx. 65 sites	Monthly	Grab
Water	Nutrients	Flow	Approx. 65 sites	Continuous	Flow recorder

LEGEND:

Cl - chloride
DO - dissolved oxygen
DOC - dissolved organic carbon
NH_4 - ammonium nitrate
NO_2 - nitrate
NO_3 - nitrite
NO_{2+3} - nitrate-nitrite
S^{-2} - sulfide
SiO_2 - silicate
SO_4 - sulfate
SRP - soluble reactive phosphate
TKN - total Kjeldahl nitrogen
TOC - total organic carbon
TP - total phosphorus
TSS - total suspended solids

Table 3-3: Greater Everglades Water Quality Monitoring at Marsh Stations (Transects and Fixed Stations)

Medium	Group	Parameters	Sites	Frequency	Collection Method
Water	Physical parameters	DO, conductivity, pH, temperature, turbidity, alkalinity, TSS, color, DOC, depth	Approx. 130 sites	Monthly	Water quality probe and grab: transects and fixed stations
Water	Nutrients	TP, TKN, TOC, NO_2, NO_3, NH_4, NO_{2+3}, SRP, SiO_2	Approx. 130 sites	Monthly	Grab: transects and fixed stations
Water	Other core parameters	Cl, SO_4, S^{-2}	Approx. 130 sites	Monthly	Grab: transects and fixed station

LEGEND:

Cl - chloride
DO - dissolved oxygen
DOC - dissolved organic carbon
NH_4 - ammonium nitrate
NO_2 – nitrate
NO_3 - nitrite
NO_{2+3} - nitrate-nitrite
S^{-2} - sulfide
SiO_2 - silicate
SO_4 – sulfate
SRP – soluble reactive phosphate
TKN - total Kjeldahl nitrogen
TOC - total organic carbon
TP - total phosphorus
TSS - total suspended solids

3.1.3.2 Regional Distribution of Soil Nutrients

The distribution of soil nutrients will augment water quality transects to delineate zones of eutrophication and to further refine the regions of the Greater Everglades Wetlands for the stratified random sampling design. Nutrient concentrations in surface soils provide indicators of site nutrient status that show less temporal variability than surface water phosphorus concentrations. Site nutrient status is a potentially important determinant of fish populations and will aid the interpretation of changes in regional populations of marsh fishes and associated fauna.

A stratified random sampling design will produce maps of soil nutrient gradients across the Greater Everglades Wetlands (Figure 3-15). The model for the stratified random design will be based on that implemented in WCA 1 in the 1990s (DeBusk et al. 1994, Newman et al. 1997) with higher density strata based on current and anticipated soil, habitat, and flow gradients. Soil sampling locations will overlap water quality sites, vegetation mapping cells, and throw trap sites to the extent possible. The resulting sampling design will entail approximately 1,500 sample points to be sampled at five-year intervals corresponding to the years of vegetation mapping.

Surface soil (0-10 centimeters) and overlying floc will be collected from cores and analyzed for a standard suite of parameters including phosphorus and nitrogen concentration, bulk density, percent organic matter, and salinity using standard methods (USEPA 1983, 1986) that are documented in the CERP QASR Manual (RECOVER 2003). Figure 3-16 shows the spatial distribution of soil phosphorus concentrations based on the stratified random sampling design.

3.1.3.3 Coastal Gradients of Flow, Salinity, and Nutrients

Coastal gradients across the freshwater-marine interface of the mangrove estuaries of Florida Bay and the Southwest Florida shelf will be monitored to achieve the following:

- Track salinity gradients along historic flow paths that will be restored by the CERP and relate to freshwater flow volumes and sea level
- Delineate the boundaries of coastal regions for the stratified random sampling design
- Measure freshwater flow volumes and nutrient inputs into the high-productivity salinity transition zone of the mangrove estuary to support the evaluation of estuarine productivity in relation to freshwater inputs from the CERP
- Measure freshwater flow volumes and nutrient inputs from Greater Everglades Wetlands to Florida Bay and Gulf estuaries

Coastal gradients will be monitored along twelve transects extending from marine to freshwater conditions (Figure 3-17):

1. **Lostman's River.** Transect up Lostman's River, across the chain of bays, through the broad mainland mangrove fringe, and through Second (or Lostman's) Slough
2. **Broad River.** Transect up Broad River, through the broad mainland mangrove fringe, through the fertile crescent region, and into the marl wetlands below the Ochopee Marl Prairie
3. **Harney River.** Transect up Harney River, through the broad mainland mangrove fringe and the oligohaline wetlands, and into mid-Shark River Slough

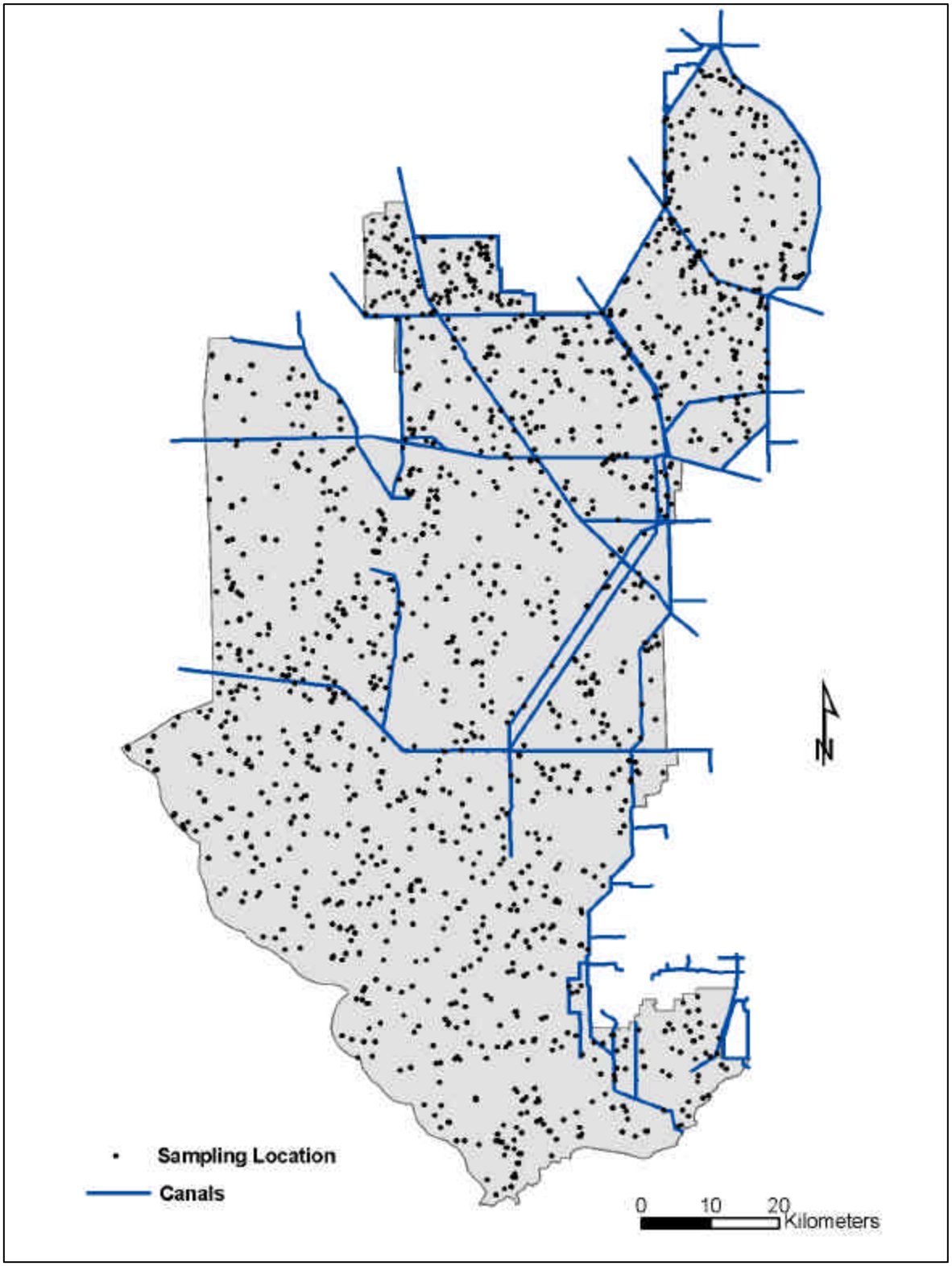


Figure 3-15: Stratified Random Sampling Design for Soil Nutrient Concentration Monitoring in Greater Everglades Wetlands

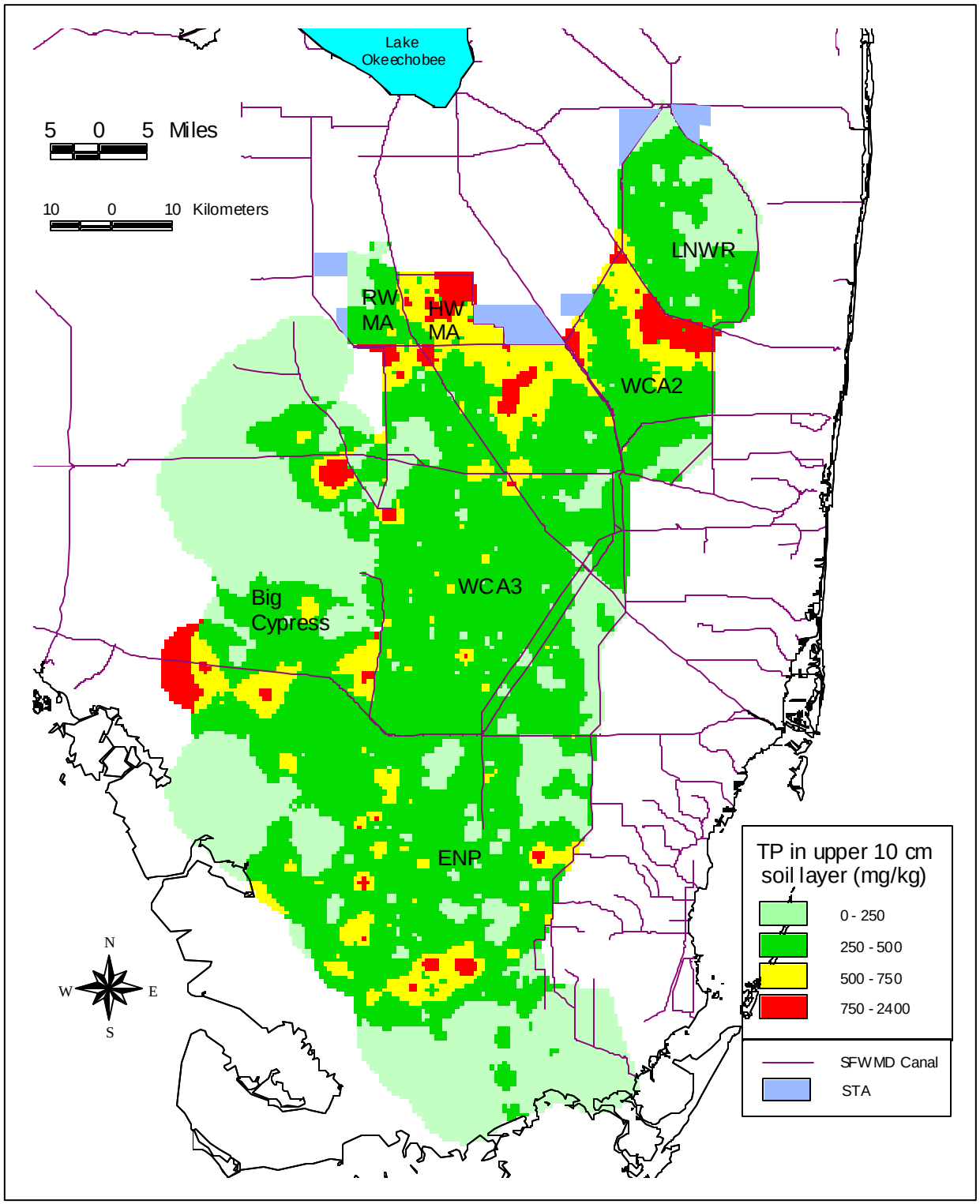


Figure 3-16: Spatial Distribution of Surface Soil (0-10 centimeters) Phosphorus Concentrations throughout the Everglades (Data sources: REMAP data from USEPA 2001, DeBusk et al. 2001, Smith unpublished data, Newman unpublished data)

4. **Ponce de Leon Bay.** Transect extending from Ponce de Leon Bay up Shark River into Shark River Slough

5. **North River.** Transect extending from the north shoreline of Whitewater Bay up the North River into mid-Shark River Slough

6. **McCormick Creek.** Transect extending from Terrapin Bay up McCormick Creek, through Seven Palm Lake, through Craighead Basin, and into Taylor Slough

7. **Little Madeira – Taylor Slough.** Transect extending from Little Madeira Bay up the Taylor River into Taylor Slough headwaters

8. **Joe Bay – C-111 Wetlands.** Transect extending from Trout Pass, through Joe Bay, through the dwarf mangroves, and through the East Perrine marl prairie to the location of the new C-111 spreader canal

9. **Barnes Sound – South Dade Wetlands.** Transect extending from Barnes Sound upstream into the pie-slice shaped area between US Highway 1 and Card Sound Road

10. **Card Sound – South Dade Wetlands.** Transect extending from Card Sound inland through the mangroves, oligohaline wetlands, and freshwater marl prairies of the South Dade Wetlands

11. **Biscayne Bay – L-31E – South Dade Wetlands.** Transect extending from near-shore western Biscayne Bay, west to levee L-31E, and ending just east of the Homestead Air Force Base

12. **Biscayne Bay – Black Point – South Dade Wetlands.** Transect extending from near-shore western Biscayne Bay through the Black Point coastal wetlands and westward to near the C-1 canal

Transects 1 through 8 will be adjusted to include seven existing salinity and stream flow monitoring stations at Trout, Taylor, and McCormick Creeks and along Shark, Harney, Broad, and Lostman's Rivers (Hittle et al. 2001, Patino et al. 2001). An eighth new stream flow monitoring station will supplement the existing salinity station at North River. Stream flow and salinity will be monitored using continuous recording stations at permanent, fixed platforms at the marine and oligohaline ends of Transects 1 through 8. Eight new continuous recording platforms at the upstream ends of these transects will supplement existing platforms at the downstream ends to provide continuous salinity records. Surface water will be collected at these sites using a flow proportioned automatic sampler and analyzed in the laboratory for phosphorus and nitrogen. Based on past studies by the SFWMD and Florida International University, composite sampling every three days (with four samples collected and pooled every 18 hours) is sufficient to capture nutrient pulses and smooth tidal variations, while at the same time minimizing laboratory costs. Conductivity, temperature, and flow meters at each platform will be needed in support of flow calculations and salinity monitoring. The monthly measurement of salinity and nutrients along the lengths of each coastal transect will supplement continuous flow, salinity, and nutrient records at the upstream and downstream ends. For Transects 9 through 12, where no flow channels exist, only monthly measurements will be made. Sediment elevation measurement stations along Transects 1 through 8, as described in section 3.1.3.9, will monitor soil accretion as an indicator of mangrove forest production as a function of flow, salinity, and nutrient inputs. As more advanced remote sensing techniques are developed during the next decade, the coastal gradient locations will be developed into belt transects to document changes and trends in substrate elevation, water quality, sediment characteristics, and vegetation.

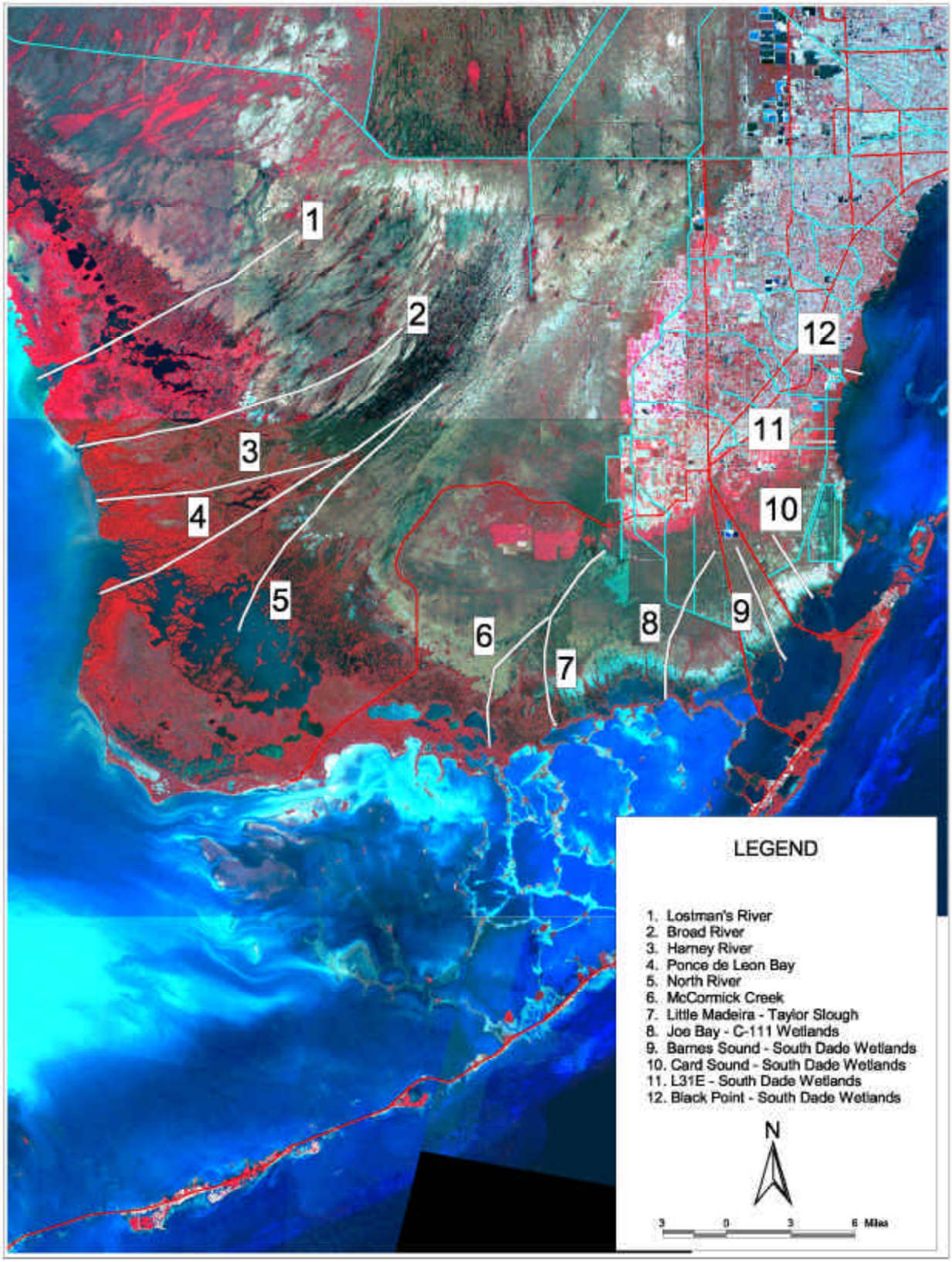


Figure 3-17: Coastal Gradient Transects of Flow, Salinity, and Nutrients for Monitoring Flow

3.1.3.4 Landscape Pattern – Vegetation Mapping

Vegetation mapping will monitor the spatial extent, pattern, and proportion of plant communities within major landscape regions of the Greater Everglades Wetlands. Specific landscape changes to be monitored that pertain to the CERP include the following:

- Changes in the extent and orientation of sloughs, tree islands, and sawgrass ridges as flow patterns, flow volumes, hydroperiods, and water quality are modified in the ridge and slough landscape

- Changes in the extent and distribution of cattail as flow patterns, flow volumes, hydroperiods, and water quality are modified in the ridge and slough landscape

- Changes in the extent and distribution of exotic plant communities

- Changes in the distribution and configuration of tidal creeks, salt marshes, and mangrove forests as changing flow patterns and volumes interact with sea level and salinity in the mangrove estuaries of Florida Bay and the Gulf of Mexico

- Changes in the distribution of plant communities in calcitic wetlands, including tussock-forming *Muhlenbergia* and sawgrass communities in the major breeding locations of the Cape Sable seaside sparrow, as hydrologic gradients change

- Changes in the distribution of plant communities of eastern Big Cypress with the removal of L-28 and hydroperiod restoration in the Kissimmee Billy Strand

Regional landscape patterns will be monitored using a combination of a transect and sentinel site sampling design (Section 3.1.3.1) and a stratified random sampling design (Section 3.1.3.10).

Aerial photo-interpretation is currently the best tool available to produce dependable and accurate maps of the Everglades (Welch et al. 1995, Doren et al. 1999, Rutchey and Vilchek 1999, Richardson and Harris 1995). Aerial photography of the greater Everglades wetland system at a scale of 1/24,000 will be purchased at three-year intervals. Photography will be interpreted and ground-truthed to produce vegetation maps at three-year intervals for the randomly selected cells. Additional cells will be mapped to supplement the stratified random cells along the alignments of the coastal, marl prairie-slough, and WCA gradients that are described above. The vegetation classification scheme of Jones et al. (unpublished report) will be used to identify major plant communities that are defined by typical dominant species. An all-embracing, multi-decade vegetation mapping program will require appropriate resources and a dedicated group with a high level of commitment and stability.

3.1.3.5 Landscape Pattern - Marl Prairie/Slough Gradients

Hydrologic and plant community gradients will supplement vegetation mapping to document the potential trade-off between slough habitat restoration and the extent and quality of habitat in adjacent marl prairies in the southern Everglades. The goal is to maintain the short-hydroperiod, tussock-growth habitats in the marl prairies while restoring long-hydroperiod habitats in adjacent sloughs.

Two east-west vegetation transects will run through southern marl prairies and adjacent sloughs (Figure 3-18), traversing the three marl prairie nesting habitats for the major breeding populations of the Cape Sable seaside sparrow:

1. Lostman's Slough - Ochopee Marl Prairie - Shark River Slough – Southern Rocky Glades
2. Shark River Slough - Western Perrine Marl Prairie - Taylor Slough

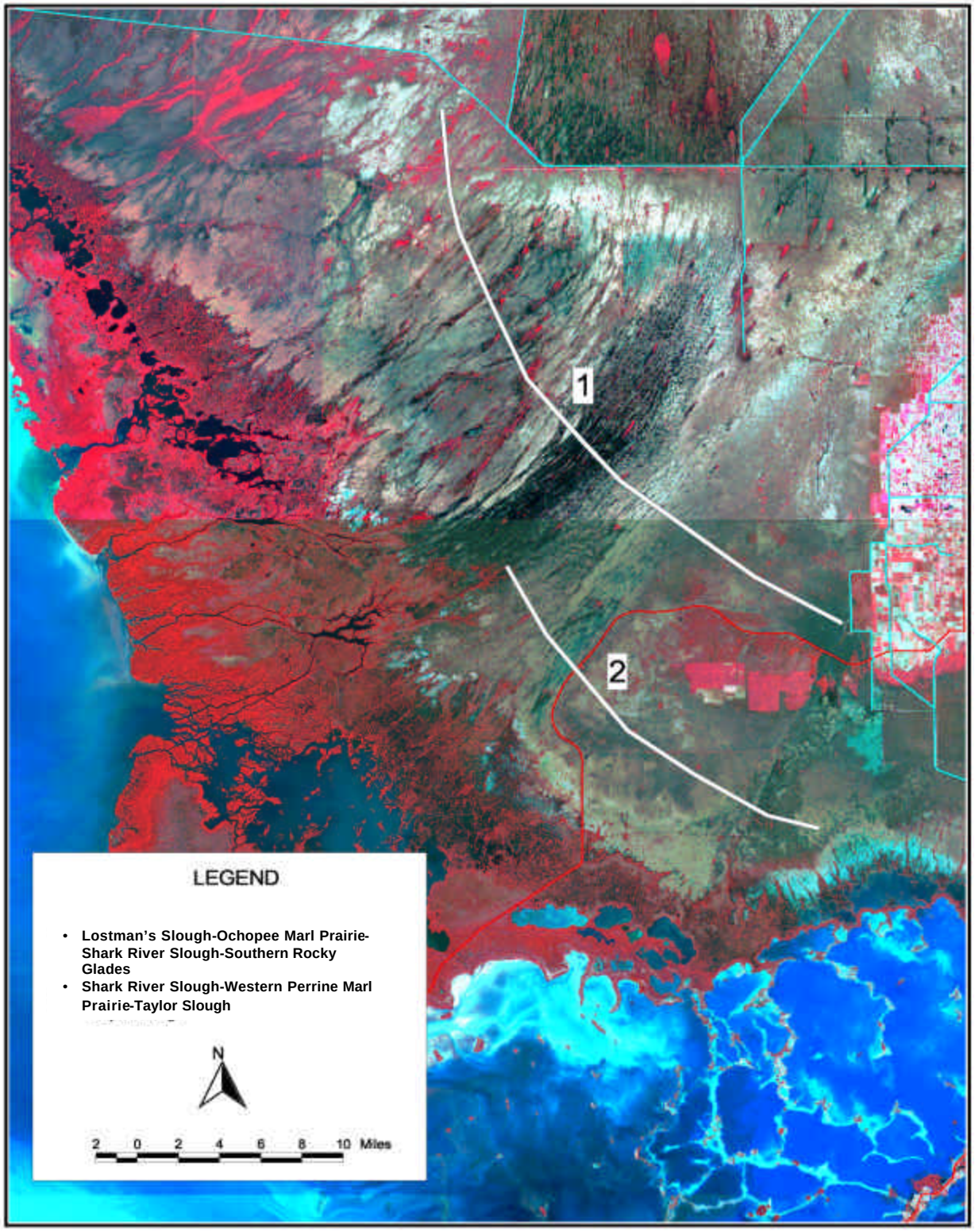


Figure 3-18: Marl Prairie/Slough Vegetation Transects Across the Southern Everglades

A preliminary monitoring design includes three replicate transects to be run through each of the marl prairies and into the adjacent sloughs. Plant community species composition, cover, and density will be monitored annually at approximately 100-meter intervals using a modified Braun-Blanquet technique (Braun-Blanquet 1964, Muller-Dombois and Ellenberg 1974, Peet et al. 1998) and at approximately 1,000-meter intervals in permanent 10x10-meter quadrants. The sampling design and frequency will be reviewed and refined during the development of a more detailed work plan for marl prairie/slough gradients.

3.1.3.6 Landscape Pattern – Ridge, Slough, and Tree Island Mosaic

A detailed sampling design for integrated sawgrass ridge, slough, and tree island landscape monitoring has yet to be completed. A preliminary sampling design includes ridge and slough transects perpendicular to the dominant flow vector to establish current microtopographic conditions. Additional transects are proposed for tree islands, running the length and width of each selected island from high and low island elevations. Tree island and ridge and slough parameters will be measured during the years of vegetation mapping. An initial set of parameters will include the following:

- Soil accretion
- Periphyton and flocculent characteristics in sloughs
- Macrophyte community characterization
- Tree island canopy cover
- Tree species richness
- Tree island tree and shrub species composition
- Surface elevation relative to water level and benchmark
- Soil depth to bedrock
- Bedrock elevation
- Tree species composition
- Tree seedling density and species composition
- Fern understory density and composition

3.1.3.7 Landscape Pattern - Tidal Creek Delineation

Channel bathymetry and volume measurements in representative tidal creeks of the mangrove estuaries of Florida Bay and the Gulf of Mexico will supplement vegetation mapping in cells and along coastal transects. The combined monitoring methodologies will be developed to delineate tidal creeks and to determine their status and evolution in relation to freshwater flow and sea level rise. The development of the tidal creek monitoring methodology is described under Section 3.1.4.2 Key Uncertainties and Research Topics in "Tidal and Freshwater Creek Dynamics: Sea Level and CERP Influences."

3.1.3.8 Trophic Level – Primary - Periphyton Mat Cover, Structure, and Composition

The monitoring of periphyton mats will track an important food base that supports the intermediate trophic level marsh fishes and macroinvertebrates in freshwater habitats of the Greater Everglades Wetlands. Periphyton mats will be sampled annually during the late wet season at the location of each throw trap sample and within each cell and each landscape unit when regional populations of marsh fishes

are sampled, as described in Section 3.1.3.10. Periphyton sampling in landscape regions will overlap water quality transect alignments and sentinel sites to the extent possible. Annual sampling may be supplemented by seasonal sampling at sentinel sites.

Periphyton sampling methodologies are described in Noe et al. (2002) and Childers et al. (2001). The cover of floating, epiphytic, and benthic periphyton within each of the one-meter square throw traps will be visually estimated and archived using a digital photograph, after which biovolume will be measured, and a relatively homogenized subsample will be collected for laboratory analysis.

Periphyton will be analyzed for chlorophyll *a*, biomass, percent organic matter, and tissue phosphorus, nitrogen, and carbon using standard methods (USEPA 1983, Soloranzo and Sharp 1980). Periphyton will be analyzed for dominant algal species, indicator diatom species, and percent of mat biovolume consisting of non-filamentous blue-greens. Counts, identifications, and biovolumes of soft algal species will be determined using standard methods (Bahls 1993, Stevenson and Lowe 1986, Porter et al. 1993, Klemm and Lazorchak 1994). Diatom counts, identifications, and biovolumes will be determined using standard methods (Gaiser and Johansen 2000, Stevenson and Bahls 1999).

Periphyton biovolume, biomass, percent organic matter, chlorophyll *a*, and tissue phosphorus will be measured annually, and possibly seasonally, at selected sentinel sites. Tissue nitrogen and carbon analyses and species identifications will be conducted every three to five years to correspond with the years of vegetation photography.

3.1.3.9 Trophic Level – Primary – Mangrove Forest Soil Accretion

Mangrove soil accretion will be monitored as an indicator of mangrove forest production in relation to flow, salinity, and nutrient inputs. Mangrove soil accretion also provides a measure of coastal substrate elevation relative to sea level rise.

Mangrove soil accretion will be measured at fixed stations along Transects 1 through 8 of the coastal gradients of flow, salinity, and nutrients (Section 3.1.3.3, Figure 3-17). Sediment elevation measurement stations will be added to supplement existing stations of the United States Geologic Survey Global Climate Change project and the Florida Coastal Everglades Long-Term Ecological Research Program. Sediment elevation will be measured periodically at each station.

3.1.3.10 Trophic Level – Secondary - Aquatic Fauna Regional Populations

Understanding the effects of the CERP on the prey bases for wading birds and other higher consumers requires knowledge of the regional populations of fishes and associated aquatic fauna that are produced during each wet season and the distribution of those populations across the Greater Everglades Wetlands (Figure 3-19) (Gawlik 2002). The aquatic fauna that are anticipated to channel most of the energy from primary production to higher vertebrates under restored conditions include marsh fishes, crayfish, grass shrimp, and aquatic amphibians.

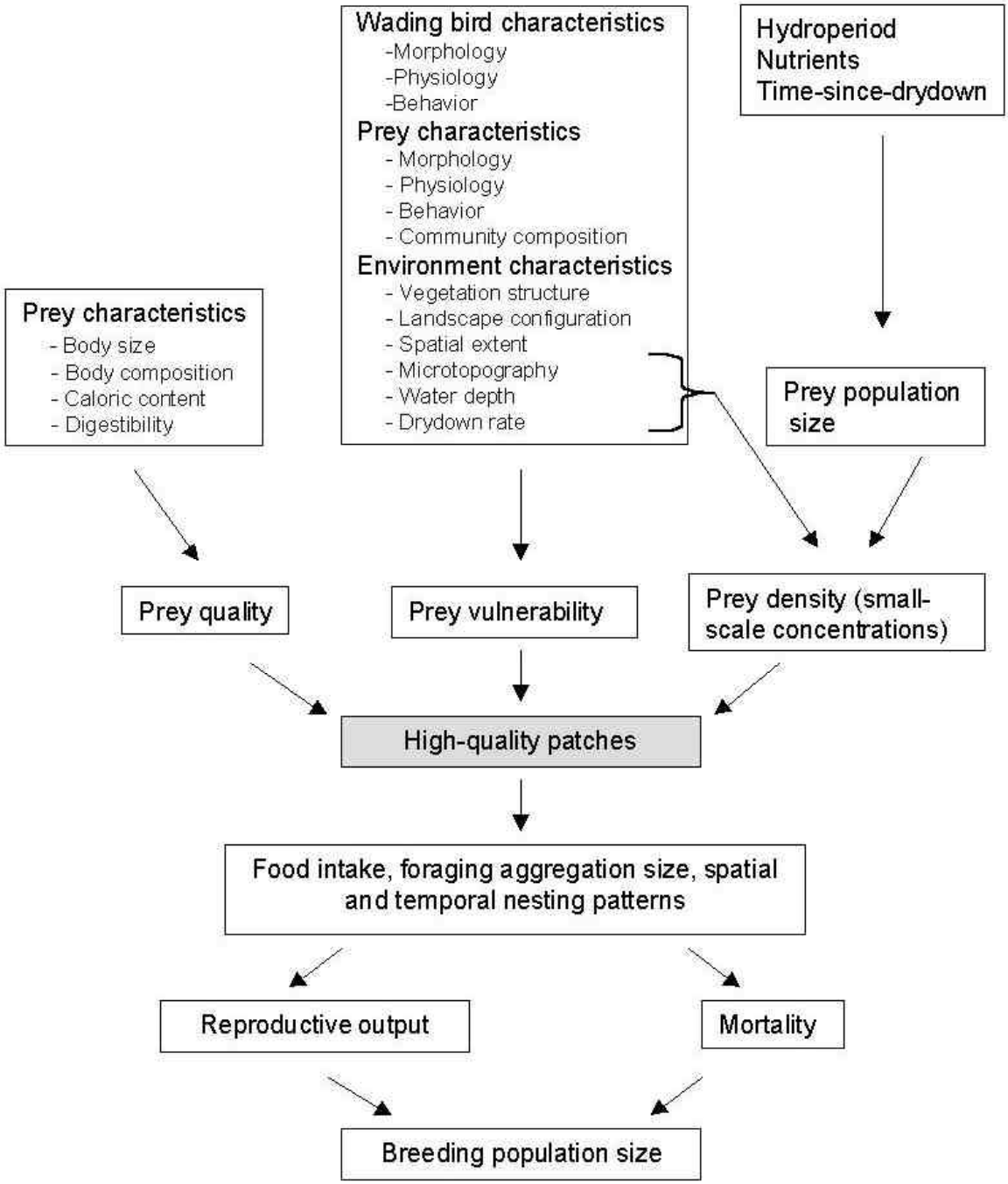


Figure 3-19: Everglades Prey-Availability Hypothesis

The regional population densities and distributions of marsh fishes and associated aquatic fauna will be monitored using a stratified random sampling design. The Greater Everglades Wetlands will be divided into landscape units (landscape subregions) representing distinct landscape patterns and/or management units. Figures 3-20 and 3-21 and Table 3-4 depict 52 such units that have been identified in the Greater Everglades Wetlands. Within each subregion, replicate cells will randomly be selected. The number and configuration of subregion, cell size, and number of replications are preliminary and will be revised during a more detailed statistical design of the sampling program. The stratified random approach will be designed to monitor system-level status and trends, trends within regions, and comparisons among regions (see Stoddard et al. 1998, Nusser et al. 1998, Dixon et al. 1998, Urquhart et al 1998, and Thompson 1992 for sampling design considerations).

Densities of marsh fishes, crayfish, grass shrimp, and aquatic amphibians will be monitored using one-meter square throw traps (Jordan et al. 1997, Chick et al. 1992, Kushlan 1981). Throw trap samples will be collected from the randomly selected sites within areas of sparse emergent macrophytes that will be delineated for each cell. These communities appear to be the most important habitats for marsh fishes and for wading bird foraging in the Greater Everglades Wetlands (Trexler et al. 2001, Loftus and Kushlan 1987). Parameters to be measured from throw trap samples include the density, species composition, and size class distribution of fishes and associated fauna. Electrofishing will supplement throw trap sampling at selected sites that are accessible by airboat to monitor fishes of larger size classes (Chick et al. 1999). Throw trap sampling is not effective in karst habitats, and this problem requires further development of sampling protocols. Drop trap sampling will be substituted for throw traps in estuarine areas where mangrove roots may prevent the use of throw traps (Lorenz et al. 1997).

Throw trap samples will be collected annually during the late wet season (September-November) to provide an estimate of the net production of marsh fishes and other fauna at the end of the wet season. This represents the prey base that is available for concentration and wading bird consumption as water levels recede during the dry season. Annual sampling may be supplemented by seasonal sampling at sentinel sites.

3.1.3.11 Trophic Level – Secondary – Aquatic Fauna Seasonal Concentrations

Understanding the effects of the CERP on marsh fishes as prey bases for wading birds also requires monitoring the concentration of the fishes in high-density patches where the birds can feed effectively as water levels recede during the dry season. There is a close relationship between high prey-availability patches and wading bird foraging patterns under experimental conditions, and it is hypothesized that there is a linkage between high prey-availability patches and foraging and nesting patterns in the ecosystem (Figure 3-19) (Gawlik 2002).

Seasonal concentrations of marsh fishes and associated fauna will be monitored to determine the following:

- The spatial distribution of maximum fish densities across the landscape
- The inter-annual variation of maximum fish densities among years
- The correlation between annual wading bird nesting and foraging patterns and maximum fish densities
- The correlation between annual hydrologic patterns and maximum fish density

Fish concentrations during the dry season will be monitored in the randomly selected cells in a selected subset of the landscape units where wet season fish populations are monitored (Figure 3-20, Table 3-4). The subset that is proposed includes landscape units representing contrasting fish populations, hydroperiods, and drying patterns (numbers refer to numbered areas on Figure 3-20):

- 7. Central WCA 1 Ridge & Slough
- 16. Central WCA 3A Ridge & Slough
- 29. Mid-Shark River Slough
- 36. Southern Rocky Glades
- 43. Fertile Crescent region of Coastal Oligohaline Wetlands
- 47. Central Florida Bay Oligohaline Wetlands

Each selected cell within a landscape unit will be examined monthly from January to May each year to determine the presence of a drying front, as indicated by a disconnected water surface. Drying fronts will be identified monthly from systematic reconnaissance flights to monitor wading bird foraging as described in detail in the next subsection. If a drying front is present within a cell, points will be randomly selected from that drying front every two weeks. If any of those points have target water-level conditions of disconnected surface water in sloughs, the slough or deep-water refugia nearest a given random point will be selected for throw trap sampling. Samples taken within each slough or deep-water refugium will include at least one in the estimated deepest point. A cursory look at drydown patterns for the South Florida Water Management Model indicates that for any month during the dry season, three to four landscape regions of the six considered for sampling will have cells that could potentially meet the drying front criterion. A one-year pilot study will be conducted to refine the logistics of sampling across such a large spatial area.

Table 3-4: Landscape Units of Greater Everglades Wetlands to be used for Stratified Random Sampling Design

Everglades Landscape Regions	Everglades Landscape Subregions
Lake Okeechobee Littoral Zone	1. Lake Okeechobee Littoral Zone Northwest 2. Lake Okeechobee Littoral Zone Southwest
Corbett/Pal Mar	3. Corbett/Pal Mar
Northern Everglades	4. Rotenberger 5. Holey Land 6. Northern WCA 1 Drained 7. Central WCA 1 Ridge & Slough 8. Southern WCA 1 Pooled 9. Northwest WCA 2A Drained 10. Northeast WCA 2A Cattail 11. Southern WCA 2A Ridge & Slough 12. WCA 2B 13. Northern WCA 3A Drained 14. Northeast WCA 3A S-11 Influence 15. Northeast WCA 3A Miami Canal Influence 16. Central WCA 3A Ridge & Slough 17. Southwest WCA 3A Dwarf Cypress/ Hammock 18. Southeast WCA 3A Pooled 19. Northern WCA 3B Drained 20. Southern WCA 3B Pooled 21. Pennsuco Wetlands
Eastern Big Cypress	22. Kissimmee Billy Strand 23. Mullet Slough 24. Dwarf Cypress 25. L-28 Cypress
Everglades Slough	26. Lostman's Slough 27. Lower Lostman's Slough 28. Northeast Shark River Slough 29. Mid-Shark River Slough 30. Southwest Shark River Slough 31. Taylor Slough
Southern Marl Prairies	32. Ochopee Marl Prairie 33. Western Shark River Slough Marl Transition 34. Eastern Shark River Slough Marl Transition 35. Northern Rocky Glades 36. Southern Rocky Glades 37. Western Perrine Marl Prairie 38. Craighead Basin 39. East Perrine Marl Prairie 40. Model Lands Marl Prairie 41. South Dade Marl Prairie

Table 3-4: Landscape Units of Greater Everglades Wetlands to be used for Stratified Random Sampling Design (Continued)

Everglades Landscape Regions	Everglades Landscape Subregions
Coastal Oligohaline Wetlands	42. Lostman's Slough Oligohaline 43. Fertile Crescent 44. Southeast Shark River Slough Oligohaline 45. Cape Sable Salt Prairie 46. Cape Sable Marsh Prairie 47. Central Florida Bay Oligohaline 48. Northeast Florida Bay Oligohaline 49. Barnes Sound/Model Lands Oligohaline 50. Biscayne Bay Oligohaline
Gulf Mangrove Wetlands	51. Lostman's Slough Mangroves 52. Shark River Slough Mangroves

3.1.3.12 Trophic Level - Wading Bird Foraging Distribution and Abundance

Experimental studies have demonstrated a close link between feeding aggregation size of wading birds and prey availability (Gawlik 2002). This relationship appears to be the mechanism that links fish populations and wading bird nesting patterns.

Wading bird distribution and abundances will be monitored with monthly systematic reconnaissance flights over the Greater Everglades Wetlands. These spatially explicit surveys have been conducted monthly from January to June since 1985 (Bancroft et al. 2002). They represent one of the most comprehensive and systematic databases available for evaluating biological responses to the Everglades restoration.

Systematic reconnaissance flights are designed as a means of recording variability in the numbers and spatial distribution of wading birds over time and linking them to variability in hydrology and other more static features of the landscape. The systematic reconnaissance flight protocol is a standard aerial transect counting technique employed within a systematic sampling design (Porter and Smith 1984, Bancroft et al. 2002). The systematic reconnaissance flights, which continue today, are conducted by the United States Army Corps of Engineers and Everglades National Park. These surveys cover the Water Conservation Areas, Everglades National Park, Big Cypress National Preserve, and other landscape units within the Greater Everglades Wetlands.

Figure 3-20: Landscape Units of Greater Everglades Wetlands to be Used for Stratified Random Sampling Design

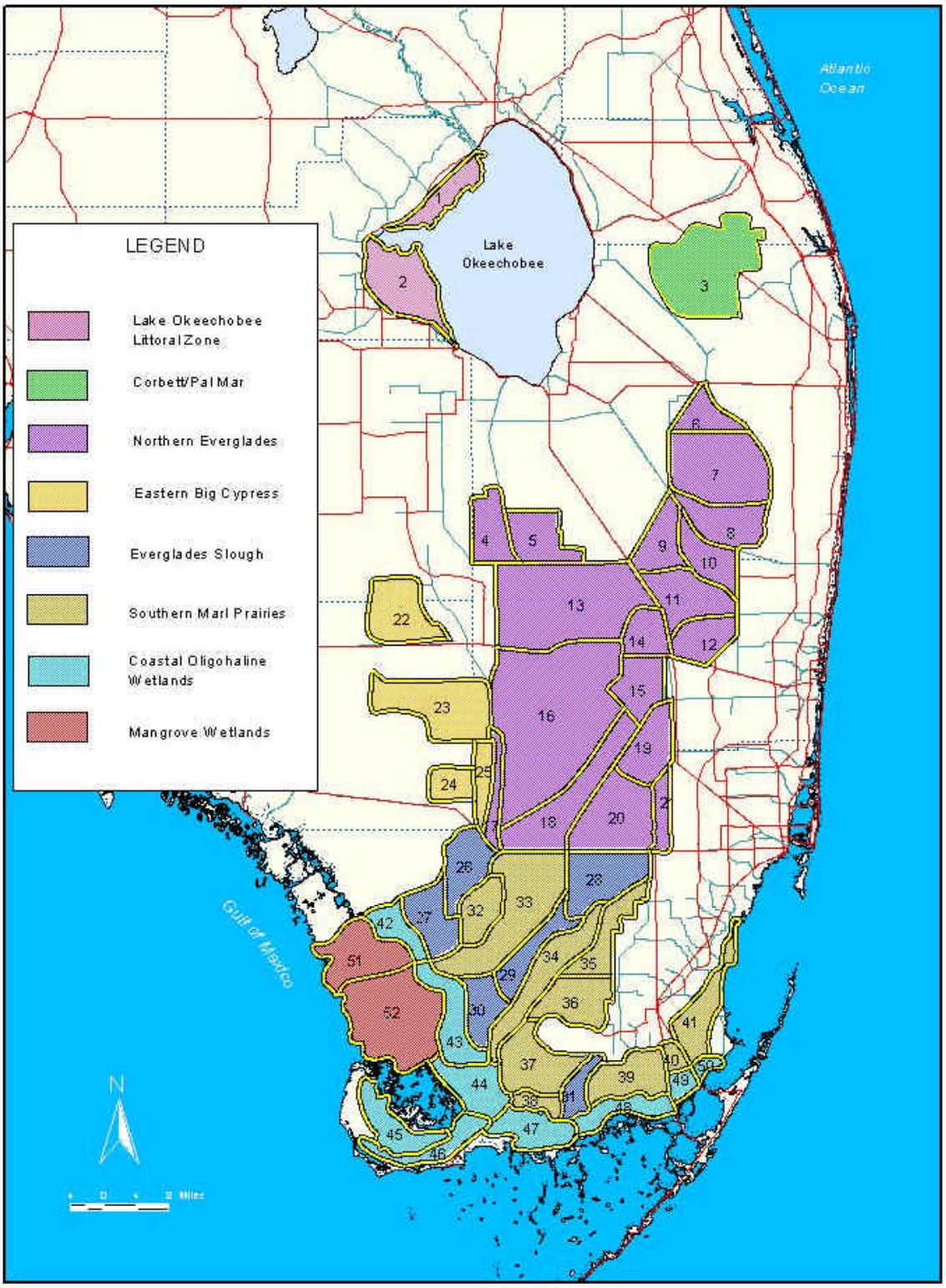


Figure 3-21: Landscape Subregions Aggregated into Regional Groups to be Used for Stratified Sampling Design

3.1.3.13 Trophic Level - Wading Bird Nesting Colony Location, Size, and Timing

A central prediction of the current Everglades restoration plan is that the return to natural flows and hydropatterns will result in large, sustainable breeding wading bird populations; return to natural timing of nesting; and restoration of nesting in the coastal zone. The timing, location, size, and productivity of wading bird nesting will be monitored over the geographic range of the Greater Everglades Wetlands. Monitoring methods will allow for comparison of historical and current information. The geographic regions monitored will include Florida Bay; mangrove estuaries and ecotone; freshwater marshes of Everglades National Park; Water Conservation Areas 1, 2, and 3; and Big Cypress National Preserve.

Nesting of six wading bird species will be monitored: wood stork, white ibis, roseate spoonbill, snowy egret, great egret, and great white heron. These are the species for which the best historical comparisons exist for one or more of the parameters of interest: range of trophic levels, prey sizes, and foraging techniques used (Ogden 1994, Frederick et al. 1996). Nesting will be monitored between January and late June of each year, with the exception of Florida Bay (November through June). However, there is the possibility that monitoring in the mainland areas will need to be expanded if wood storks begin nesting earlier than January. Evidence of early nesting (eggs or young) is likely to be discovered on January surveys, and timing of surveys will be adjusted accordingly.

The timing, location, and size of nesting events will be monitored using systematic aerial surveys followed by ground counts. Established techniques used in the freshwater marsh sections of the study area (Frederick et al. 2001) will be adapted to specific habitats in the Big Cypress National Preserve and the mainland mangrove estuary. Ground counts will focus on the largest colonies of each species based on the analysis of past years, which suggests that 90 percent of nesting birds are found on average in 3 to 33 colonies depending on the species (Frederick personal communication). Accuracy in aerial counts of large colonies will be improved through the use of aerial photography followed by later counts of those photos (Frederick et al. 2003).

Roseate spoonbill and white ibis nests in Florida Bay are generally located in dense red mangrove stands and are not generally visible from outside the colony. All islands that were previously reported to have had nesting colonies (Lorenz et al. 2001) will be surveyed monthly during the nesting season, and the number of nests will be counted. While traversing Florida Bay by boat, locations of roseate spoonbill and white ibis activity will be investigated for new nesting sites. The timing of colony surveys late in the incubation period and during mild climatic conditions and the limitation of time in an individual colony to less than one hour whenever possible will minimize impacts of surveys on colonies (Lorenz et al. 2001).

In order to use nesting effort and nesting success as criteria for ecosystem evaluation, the location of primary foraging grounds must be monitored for each colony group (Lorenz et al. 2001). In order to identify the direction of foraging grounds from nesting colonies, flight line counts similar to those described by Dusi and Dusi (1978) will be made at the two largest colonies in each colony group. Flight line counts will yield an estimate of the proportion of birds using general areas (e.g., eastern, middle, or western mainland sites; mainline keys; etc.). To get more specific foraging locations, individual birds will be followed using a fixed-wing aircraft from their nesting colonies to the first foraging location. Flight line observation and following flights will also greatly aid in identifying new colony sights locations throughout the bay.

Any periodic surveys are likely to lead to underestimates due to asynchronous nesting and the possibility that nests may start and fail between survey dates. Comparing typical monthly survey schedules with a large sample of known nesting histories of individual nests shows that the monthly survey schedule that has been followed in the central Everglades since 1986 has been associated with a known correction factor, with annual variation in that correction factor of 26 percent above and below any annual estimate

(Frederick et al. In prep.) Therefore, the resulting nesting population estimates are likely to be associated with this level of error. However, estimation of this error rate is based on only 2 to 4 years of information on marked nests, depending on species. The database of individual nest histories will be expanded in order to refine the estimation of error associated with monthly surveys. This involves close monitoring of individual nests at one or more colonies throughout the nesting season in order to measure both duration and seasonal timing of nesting attempts.

3.1.3.14 Trophic Level - Wood Stork and Roseate Spoonbill Nesting Success

Success of nesting for wood storks and roseate spoonbills will be measured as the number of young produced per nest start. This provides at minimum a relative measure that can be compared among years. If measured at enough colonies, the absolute number of fledglings produced may be estimated. Historical information exists for this parameter in both species, and techniques for these measurements are standardized in both species (Ogden 1994, Bjork and Powell 1994, Lorenz et al. 2001).

For wood storks, helicopter censuses will be performed at one or more points during the nestling period, and numbers of large, standing young per nest will be counted. This yields young per successful nest. Young per nest start will be calculated by using the total number of estimated starts as the denominator.

For roseate spoonbills, the two largest colonies within each subregion of Florida Bay will be used to estimate nesting success for each group. Survey transects will be established in each of these colonies so that representative samples of nests can be monitored. On the initial visit, 25 to 50 nests will be marked with numbered plastic tags (unless a colony has less than 25 nests, in which case all nests will be marked), and the number of eggs per nest will be counted. Each colony will be visited approximately every ten days, and the contents of each nest will be recorded. Information on clutch size, duration of nesting, reproductive success, and cause of nest failure will be collected for each nest. Nests will be monitored until failure or until all surviving chicks reach at least 21 days of age. Chicks reaching at least 21 days of age will be considered a successful nesting attempt (fledged). Subsequent counts of flying young of the year at other colonies within the same group will be used to corroborate results from this method.

3.1.3.15 American Alligator Distribution, Size, Nesting, and Hole Occupancy

The American alligator will be monitored using three approaches in the Greater Everglades Wetlands, each to determine if populations are recovering in expected ways as CERP is implemented. Methodologies are described in Rice et al. (2004 in press).

The recovery of a healthy range of alligator size classes and condition throughout the system, including increased occupancy on mangrove creeks, will be monitored by surveys at the end of the wet season and throughout the dry season. Eye shine surveys of freshwater wetlands will be supplemented by aerial and ground surveys of coastal creeks during September and throughout the dry season. Alligators will be captured, weighed, and measured in October and March-April. Survey and capture locations will be a combination of fixed and randomly selected routes in regions and cells where landscape patterns and marsh fish populations are monitored. Capture areas and survey areas will not overlap during a given sampling period. Alligator parameters will include the number of alligators per kilometer, size class distribution, and body condition of alligators greater than one meter in length. Habitat parameters will include water level, temperature, salinity, and vegetation type.

The return of reproducing alligator populations to the southern marl prairies and mangrove estuaries, while maintaining alligator nesting in Shark River Slough, will be monitored by systematic reconnaissance flight surveys supplemented by aerial surveys and ground checks. Annual systematic

reconnaissance flight surveys will be flown throughout Everglades National Park in July. Systematic reconnaissance flight methodology is described above for monitoring wading bird foraging. The number of alligator nests and the number of successful nests will be measured in addition to water level, salinity, and vegetation type.

Occupancy rate of alligator holes (with a goal of 75-100 percent occupation) and an increase in the number and distribution of alligator holes in areas of low density will be monitored by mapping alligator holes in combination with occupancy checks. The number and distribution of alligator holes will be mapped every three years in the regions and cells where landscape patterns and fish populations are monitored, using the aerial photography acquired for vegetation mapping. The number of mapped holes occupied by alligators 1.8 meters or longer will be monitored annually in a random sample of holes using helicopter and airboat surveys.

3.1.3.16 American Crocodile Juvenile Growth and Survival

American crocodile surveys will be conducted using methodologies described in Mazzotti and Cherkiss (2002). Surveys for crocodile nests will be conducted April through August in Biscayne Bay and Florida Bay from Crandon Park to Shark River. Nests will be monitored through incubation, and hatchlings will be captured, measured, and marked upon emergence. Surveys and captures of juvenile crocodiles will be conducted four times a year in the same areas (early nesting, late nesting, and twice in the winter dry season). All animals will be weighed, measured, sexed, and given an individual mark. Location (using a global positioning system), salinity, and temperature will be recorded at each capture.

3.1.4 Key Uncertainties and Supporting Research

3.1.4.1 Coastal Wetland Landscapes and Berm Systems: Sea Level and CERP Influences

Justification: With the projected future increase in the rate of rise in sea level over the coming century, dramatic changes in coastal landscapes of the Everglades are inevitable. It is critical to predict the resulting landscape changes in the lower Everglades because ecosystem restoration will succeed only by working in harmony with those inevitable changes. Ecological performance measures and project design features may require substantial modification given the projected changes resulting from this evaluation. It is recommended that the following research and evaluation be carried out early in the Everglades restoration program to permit its results to be incorporated into the restoration design and monitoring program.

Project Description: This project will include the following work activities:

- Determine the anticipated relative sea level rise over the next 50 and 100 years and select moderate and moderate-to-high scenarios to project the evolution of South Florida environments.

- Provide an integrated map of topography, sediments, and sediment influx/production for coastal and southern Everglades environments and assess the susceptibility of those sediments and environments to change due to rates of sea level rise, storm events, and changes in freshwater discharge and water level. Based on this information, define the sequences, patterns, and connectivity of environmental change in response to the anticipated sea level rise scenarios over the next 50 and 100 years.

- Develop understanding and consensus on the responses of lower Everglades environments and substrates to sea level rise and changes in freshwater discharge and water level through a series of

workshops bringing together experts on sea level stress to wetland systems, substrates, and ecosystem dynamics.

- Forecast the type, extent and patterns of environmental change and changes in flow and flooding patterns in the next 50 and 100 years based on the sea level rise scenarios. Identify freshwater flow conditions that should optimize stability of coastal wetland systems. Test the feasibility of landscape model forecasting. Identify gradient transects most likely to reveal the areas most and least susceptible to environmental and substrate change in response to future sea level and freshwater discharges.

3.1.4.2 Tidal and Freshwater Creek Dynamics: Sea Level and CERP Influences

Justification: Many tidal creeks through coastal wetlands of the Everglades have disappeared entirely during the past century because they have been filled in with sediments and with the vegetation of surrounding landscapes. Reduced freshwater flow volume and rising sea level are probable contributing factors. In the course of Everglades ecosystem restoration, there are two critical changes anticipated that may greatly influence the character of channeled flow and, in turn, the pattern of freshwater and saline water movement: 1) changes in the freshwater flow volume, timing, depth, and hydroperiod and 2) changes in sea level and associated changes in flow and sediment loads during prevailing storm conditions. Restored freshwater inflow from the Everglades is expected to sustain and open watercourses through the estuary that will more closely resemble historic patterns, yet the causal factors of flow and sea level remain poorly understood. This project defines causes for instability in flow channels, determines rates and patterns of change that can be expected in response to changing influences, and defines monitoring criteria that can be used as early warning indicators for channel system instability.

Project Description: This project will include the following work activities:

- Define the different types of natural channel/creek systems and networks along the coastal zone from central Biscayne Bay to Lostman's River. Determine the present and historical dynamic status and evolution of these systems. For channel systems with significant recent geologic and historical evolution, document the timing and assess the causes for observed changes.

- Select a suite of representative sites along freshwater and tidal channels for documenting and understanding stability and the evolution of channel form. These will include channels that are currently stable, enlarging, and constricting; channels cut through differing substrates and with differing margin topography; channels that have been filled because of presumed historical reduction in freshwater flow; and channels historically initiated through natural and human causes. For the selected channels, define and carry out a research program to determine the following:

  - Boundaries of hydrologic conditions necessary to maintain but not enlarge or constrict channel form

  - Nature and volume of sediment loads released in response to channel changes if stable flow conditions are exceeded

  - Rate and degree of channel constriction/infill in response to channel hydrology changes if stable flow conditions are not maintained

  - Influence of catastrophic event and post-event sediment redistribution on channel flow, stability, and evolution

- Input research results into workshops assessing effects of anticipated changing sea levels to evaluate anticipated changes in channel forms, changes in flow velocities, changes in sediment supply and load, and differing effects of catastrophic events in a time of rising sea level.

3.1.4.3 Productivity in Coastal Ecotone: Sea Level and CERP Influences

Justification: The salinity transition zone of the Everglades, along both the Florida Bay and Gulf of Mexico coastlines, is an ecotone of high productivity due to the retention of nitrogen that enters this region from the Everglades and phosphorus that enters from the Gulf of Mexico and Florida Bay. The estuarine productivity peak is hypothesized to have supported food webs that sustained the large colonies of wood stork, great egret, and white ibis that once nested in the ecotone region. The retention of nitrogen and phosphorus is also important in order to maintain water quality in the adjacent, more oligotrophic systems (the Everglades and Florida Bay) and to sustain soil accretion and thus minimize the effects of sea level rise. It is expected that implementation of the CERP will enhance productivity in the ecotone as a result of reduced salinity combined with the continued function of the transition zone as a "sink" for nitrogen and phosphorus. This study provides support to a comprehensive research program of the Florida Coastal Everglades Long-Term Ecological Research Program to address productivity in the estuarine ecotone in relationship to freshwater flow, sea level, and the associated variables of nutrient mixing and salinity.

Project Description: A series of simple experiments are proposed to provide information on the factors that control nutrient uptake, releases, and storage in the salinity transition zone:

- **Measure organic matter decomposition rates -** The release and uptake of nutrients during the decomposition of organic matter in the salinity transition zone is hypothesized to be tightly coupled so nutrients are retained. Rates of decomposition (leaching, carbon loss, and nutrient mineralization) will be measured for different sources of plant organic matter.

- **Measure belowground root production and decomposition -** Soil accretion in the transition zone may largely be a function of the production of decay-resistant root tissues. Production and decomposition rates will be estimated in transects through the salinity transition zone.

- **Measure controls of decomposition rates -** In order to understand the effect of restoration on the processes of organic matter decomposition and accretion in the transition zone, experiments on several factors that are likely to change in coming decades will be manipulated. These include salinity, wetting and drying patterns, and phosphorus and nitrogen concentrations.

- **Integrate with monitoring and modeling programs -** Results from these studies will help RECOVER understand the effects of restoration on central processes, such as the maintenance of patterns of productivity, water quality (including measurements of creek flow and nutrient loads), and soil elevation. All of these patterns will be monitored and are important components of any models of the region. Data from the proposed studies will be included in the refinement and further development of conceptual and numerical models.

3.1.4.4 Ridge and Slough Landscape Sustainability

Justification: An important restoration expectation for the ridge and slough landscape is to prevent further loss of tree islands and sloughs and to restore these features, if possible, through the restoration of sheet flow patterns, water depths, and hydroperiods that more closely resemble natural, pre-drainage hydrology (Science Coordination Team 2003). Sloughs have lost spatial extent and directionality and have been encroached by sawgrass, apparently as a result of a combination of reduced water flow and reduced depth.

Tree islands have experienced high-water stress and drowning, as well as burnout under low-water conditions. Hydrologic requirements for the sustainability of sloughs and tree islands have yet to be determined. Furthermore, in the current degraded system with widespread losses in peat elevation and depth, there is concern that the hydrologic conditions necessary to perpetuate sloughs and tree islands may be conflicting. The hydrological, geological, and ecological processes that control the origin and persistence of co-existing sloughs and tree islands must be understood to prevent their continued disappearance from the ridge and slough landscape. The role of climatic extremes, which produce peak flow velocities and depths at one extreme and peat-burning fires at the other, is critical to that understanding.

Project Description: The project description of a comprehensive research program to address ridge-slough-tree island mosaic sustainability has yet to be developed. The following ongoing and proposed research projects pertain to this question.

Processes Affecting Sheet Flow in Vegetated Wetlands of the Everglades

This project quantifies the magnitude, direction, and behavior of sheet flow in the major wetland communities of the Everglades. The external and internal processes that affect sheet flow behavior will be determined. Forcing mechanisms will include the immediate and long-term residual effects of fire on shallow surface-water flows. The project analyzes data from eight existing and two new flow monitoring stations located in the major wetland plant communities of the southern Everglades to provide the following information:

- Quantify, both temporally and spatially, the nature and behavior of sheet flows in vegetated wetlands
- Identify the external and internal processes that affect sheet flow behavior, both horizontally and vertically
- Contrast slough, spikerush, marl prairie, and tidal headwaters plant communities regarding sheet flow magnitudes and patterns
- Determine the effects of temperature on flow structure
- Determine forcing functions that govern the channeling of sheet flows from sloughs to the headwaters of tidal creeks
- Analyze data from flow monitoring stations in the Squawk Creek tributary headwaters of Everglades National Park to 1) quantify, both temporally and spatially, the effects that fires have on the nature and behavior of sheet flows; 2) identify the extent and duration of the residual effects of fires on external and internal flow-forcing mechanisms; 3) contrast flow magnitudes and directions in adjacent burned and unburned sites; and 4) investigate long-term recovery effects of vegetation regeneration on flow conditions.

Loxahatchee Impoundment Landscape Assessment

The Loxahatchee Impoundment Landscape Assessment (LILA) project defines hydrologic regimes that can sustain a healthy Everglades ridge and slough ecosystem. Specifically, this study quantifies the effects of water depth, hydroperiod, and flow rate on five of the seven CERP ridge and slough priority components: 1) wading birds, 2) tree islands, 3) marsh plant communities, 4) marsh fishes and invertebrates, and 5) peat soils. LILA also provides the public easy access to a site where construction

work that is so much a part of the CERP is visibly producing restored tree islands, restored ridge and slough habitats, increased wildlife use, and an obvious example of the integration of science into the restoration process.

"Macrocosms" will be constructed so that they are a large enough to include ridges and sloughs, tree islands, and free ranging wading birds, but small enough to allow for control of their hydrologic regimes. These macrocosms will be used to measure the responses to hydrologic manipulations at several trophic levels of the CERP priority components of the ridge and slough system. Four replicate macrocosms that total 32 hectares in size will be constructed in two impoundments at the Arthur R. Marshall Loxahatchee National Wildlife Refuge. Each impoundment will be divided into two macrocosms, each containing tree islands, ridges and sloughs, and deep-water refugia (representing alligator holes). These macrocosms will be used to study how different hydrologic treatments that are controlled, replicated, and defined a priori affect the ridge and slough system. The tree island and ridge and slough responses will be measured by examining biogeochemical, vegetative, and physical parameters. The wildlife response will come from changes in the distribution, abundance, and behavior of free-ranging wading birds and native fish communities.

Tree Island Assessment

This project will evaluate how best to quantify the overall health of tree islands and then use this quantification to monitor the performance of the CERP. The vegetation structure, plant succession, soil quality, elevation change, and wildlife diversity will be assessed on six tree islands in WCA 3B, 12 tree islands in WCA 3A, and 8 tree islands south of WCA 3B in Everglades National Park.

Vegetation will be sampled primarily using two intensive 10-by-10 meter (0.01 hectare) plots at the head, two at the near-tail, and one in the tail of each tree island. In each sampling unit, presence of all tree species with diameter breast height greater than 2.5 centimeters will be tagged. Height and canopy cover will be recorded for each tagged tree. Nested subplots will be employed to obtain estimates of plant species number and co-occurrence at spatial scales less than that of the 0.01 hectare plot.

Soil samples will be collected on each island in year 1 of this program and again in year 5. In the near-tail of each tree island, a water depth recorder capable of hourly measurements of both surface and ground water elevations will be established.

A sediment erosion table will be used to measure wetland elevation change to an accuracy of plus or minus 1 millimeter. This device, in conjunction with feldspar marker horizons, will measure deposition by monitoring vertical soil/peat accretion or erosion on the head of each tree island.

Ridge and Slough Flows Study

This study will quantify hydrologic processes (water flows, sediment flows, water depths, vegetation communities, and geometry of man-made conveyance structures) under actual field conditions that will provide the data needed both for development of mechanistic models and for objective evaluation of alternative restoration scenarios. Specifically, meteorological and biological conditions that affect the carbon balance in and topography of sloughs will be measured, as well as the anthropogenic influences that may alter carbon accumulation in sloughs.

The effects of sediment transport and water flows on marsh topography and habitat diversity will be measured using three parallel approaches: 1) continuous monitoring, 2) synoptic characterization, and 3) residual characterization. In particular, the threshold conditions (velocity, wind speed, temperature, bioturbation, etc.) needed to suspend and transport organic sediments (flocculent) will be quantified.

Effects of continuous, average flows and effects of infrequent, higher energy flows will be separated. Infrequent effects will be captured through continuous, automated monitoring of flows and sediment movement and of the meteorological driving forces at approximately 5-10 ridge and slough sites. The same autonomous monitoring stations transmitting continuous data back to SFWMD will also capture low energy, average flow effects. Synoptic studies of areas large enough to include 4 to 6 replicate ridges and sloughs will capture the variations in flow and sediment transport over representative portions of the ridge and slough landscape. The studies will include passive tracer monitoring (nonsorbing fluorescent dyes and/or lithium) and active sediment movement experiments in which flocculent layer movement will be artificially induced and monitored within sloughs and ridges. Residual studies will use before and after comparisons on either side of large meteorological events to further document sediment movement events and to act as a check on the continuous monitoring stations.

Fully Integrated, Multi-Scale Simulation Model(s) for Ecosystem Processes in Northern and Southern Everglades

As better temporal and spatial ecological data are becoming available, particularly in the southern Everglades, the Everglades Landscape Model (ELM) is being further evaluated and refined to best capture system dynamics in the southern and the northern extent of the system. Functional refinements include the following:

- Year 1: Complete version 3.0 refinement
- Year 2: Improve peat and marl soil responses to interactions of hydrology and nutrient dynamics
- Year 1, 2, and 3: Deploy fine scale ridge and slough implementations (including existing but unused sedimentation module) in 2 subregions of WCA 3A
- Year 1, 2, and 3: Incorporate simple net settling rate module for nitrogen transport and fate and further develop existing, process-based nitrogen module
- Year 1 and 2: Fully integrate data on topography and mangrove creek hydrography
- Year 1 and 2: Develop simple creek flow module based on existing canal module
- Year 2, 3, and 4: Enhance existing dynamics for mangrove (including dwarf) biomass and species responses to hydrology, salinity, and nitrogen and phosphorus interactions
- Year 1-5: Develop code and data-passing algorithms for enhanced collaboration with existing mangrove and seagrass modeling efforts

3.1.4.5 Technology Development: Vegetation Mapping

Justification: Many of the CERP projects are intended to directly affect vegetation mosaics and water quality characteristics in the Everglades wetlands. Currently, Everglades vegetation mapping is limited primarily to photo-interpretation of aerial photography, which is very time-consuming and costly but yields relatively accurate determinations of the cover vegetation. Water quality monitoring proposals using transects and grab samples are also costly. This project investigates the potential use of hyperspectral remote sensing technologies as a way to develop more cost-effective techniques for mapping Everglades landscape and water quality patterns. The anticipated results will be used to supply baseline information on the key attributes of the regional system, refine the calibration and validation of

the simulation models, and provide quasi-real time performance measure assessments as the restoration plan proceeds.

Project Description: The specifics for a project description are still being developed.

3.1.4.6 Crayfish Population Dynamics – Hydrological Influences

Justification: Native crayfish species appear to represent an important intermediate trophic level and a major prey base for wading birds in Everglades food webs (Frederick and Collopy 1988, Gibbs 1993, Hart and Newman 1995, Jordan et al. 1996, Kushlan and Kushlan 1979, Lodge et al. 1994, Momot et al. 1978, 1984, 1995, Nystrom et al. 1996). The Everglades are the only large wetland system in the Western Hemisphere where the predominant wading bird (white ibis) feeds largely on crayfish. Large nesting colonies (super colonies) comprised mostly of white ibis form during years following major droughts when marsh fish populations are diminished and when crayfish may provide the prey base supporting the nesting birds. Numbers of nesting white ibis in the Everglades have plummeted during the last century, apparently as a result of diminished prey population density and availability. Knowledge of crayfish population dynamics in relation to hydrology is essential to understanding why large breeding populations of white ibis and other wading birds return or do not return to the Everglades upon the hydrologic restoration implemented by the CERP. Presently there is little information on the population ecology of the two Everglades crayfish species, as affected by hydrology and water management. The crayfish population dynamics research, in combination with trophic level and water quality monitoring, will provide the foundation for future research on the causal factors leading to the formation of wading bird super colonies (large nesting colonies of white ibis and other wading birds that form after major droughts).

Project Description: This project will include the following work activities:

- Compare the capture efficiency and selectivity of sampling gear and mark/recapture techniques to determine the most effective combination of sampling methods across the diversity of regions listed below. Test traditional capture methods including throw traps, drop traps, minnow traps, and Breder traps. Conduct literature survey of other applicable sampling methods and compare with traditional methods. Devise an optimal method or combination of methods to monitor crayfish populations as prey bases for wading birds in the Everglades.

- Determine the basic life histories and population dynamics of *Procambarus alleni* and *P. fallax* in relation to season and hydrology at selected sites in the Everglades. Provide quantitative estimates of population density, growth, survival, recruitment, and dispersal through monthly sampling in six regions: Coastal oligohaline wetlands in the fertile crescent region, Florida Bay oligohaline wetlands, mid-Shark River Slough, southern Rocky Glades, central WCA 3A, and central WCA 1. The duration of this study may need to be extended or revised to include a major drought year and the year following the drought. Crayfish research will be coordinated with the throw trap monitoring program to compare the population dynamics of crayfish with those of marsh fishes and grass shrimp.

The crayfish research is the first in a series of studies on the life histories and population dynamics of groups of aquatic fauna that appear to play important but little understood roles in aquatic food webs in the Everglades. The importance of amphibians as environmental indicators and their abundance in the Everglades make them likely candidates for future research priorities.

3.1.4.7 Aquatic Refugia – Coastal Ecotone, Alligator Holes, and Solution Holes

Role of Marsh-Mangrove Interface Habitats as Aquatic Refuges for Marsh fishes and Other Aquatic Animals

Justification: The freshwater marsh/mangrove ecotone of the southern Everglades is considered to be essential in achieving the restoration goals of the CERP. Reductions in freshwater flows to this region have been implicated in the loss of secondary production and the departure of historical wading bird colonies from coastal areas. Aquatic habitats in this region are the most heterogeneous in the ecosystem and the most naturally productive, even under current conditions. They are also among the least understood in terms of their ecological function. The pools and swales and small creeks that coalesce to form larger river channels are thought to provide protection for aquatic fauna from adverse dry season conditions, although rising salinity and predatory fishes may diminish the functions of these habitats as drought refuges. How aquatic animals respond to present-day conditions in the marsh/mangrove ecotone and how the CERP will affect conditions are questions that are meshed tightly with wading bird responses and the restoration of coastal nesting colonies. Information from these studies will be critical in testing hypotheses about the management and recovery of the freshwater marsh/mangrove ecotone and in planning adaptive assessment actions during the implementation and operation of the CERP.

Project Description: This project will include the following work activities:

- Determine the dynamics of population density and movement of marsh fishes and other prey organisms within creek channels and between marshes and channels in response to cycles of tide and climate. Determine the upstream hydrologic factors that affect those dynamics, including upstream water management, freshwater inflows, and hydroperiod.

- Determine the effects of salinity as a factor limiting the survival of marsh fishes and other prey organisms in tidal creeks and rivers, pools, and swales during dry seasons and drought years. How significant are salinity and drying pattern as factors limiting species richness and density during the following wet season?

- Determine if the refuges in the freshwater wetland/mangrove ecotone provide a source of colonists for long-distance dispersal into the sloughs and peripheral wetlands. Quantify the direction and degree of dispersal by fishes and other aquatic prey organisms from this region during the wet season under different hydrologic conditions.

- Focus on ecotones at the North, Shark, Broad, and Lostman's Rivers' drainages in the fertile crescent region that historically supported intensive wading bird foraging and nesting. Establish replicate stations of creek/pool and marsh habitats within each river's drainage. Concentrate sampling during the dry season, especially as the marshes dry, with less frequent sampling during the wet season. Measure movement of fishes and other prey organisms to and from creeks to determine the temporal and spatial extent, direction, species composition, and size distribution of the individuals involved.

Role of Alligator Holes as Aquatic Refuges for Marsh Fishes and Other Aquatic Animals

Justification: An important restoration expectation of the CERP is to increase population densities of marsh fishes and other aquatic fauna that form the major prey bases for wading birds. The restoration of more natural hydrologic patterns is expected to increase prey populations due to prolonged hydroperiod and to increase survival rates in aquatic refuges during dry periods. Because alligator holes provide

permanently flooded habitats when surrounding marsh areas dry in the main Everglades sloughs, they are considered to be important aquatic refuges. Alligators and alligator holes are expected to increase in distribution and density as more natural hydrologic patterns are restored, thereby increasing survival rates for aquatic fauna during droughts and sustaining higher population densities during wet periods. A key uncertainty is whether these deeper aquatic habitats serve as sources or sinks for aquatic animals during dry periods.

Project Description: This project will include the following work activities:

- Determine the relationship between the density of alligator holes and numbers of fishes and other aquatic fauna available to colonize surrounding wetlands following a drought.

- Measure the survival of fishes and other aquatic fauna in alligator holes during the dry season.

- Measure the characteristics of alligator holes that affect their quality as refuges, i.e., vegetation cover, alligator occupancy, etc. Determine which characteristics favor the survival of particular groups of aquatic species.

- Determine if the numbers of fishes and other aquatic fauna that take refuge in alligator holes are adequate to explain the numbers of colonists found in adjacent wetlands during the following wet season. Is there reason to suspect that long-distance dispersal from other refuges is an important factor in repopulation of wetlands?

- Analyze evidence from refuges that droughts foster predator release for small-bodied fishes and other aquatic fauna, resulting in population increases that support high wading bird nesting in subsequent years.

A research plan to address these questions will involve sampling of fishes and other important prey species in holes and surrounding marshes within major sloughs (Lostman's, Shark, and Taylor) in the dry season, using multiple methods to assess animal populations and their use of the habitats.

Role of Solution Holes as Aquatic Refuges for Marsh Fishes and Other Aquatic Animals in Karst Wetlands: Pilot Study of Remote Sensing/Surveying Methods for Estimating Refuge Characteristics

Justification: An important restoration expectation of the CERP is to increase population densities of marsh fishes and other aquatic fauna that form the major prey bases for wading birds. The restoration of more natural hydrologic patterns is expected to increase prey populations due to prolonged hydroperiod and to increase survival rates in aquatic refuges during dry periods. Dry season refuges are particularly important determinants of fish population densities in the rocky glades, where water levels typically drop below the ground surface each dry season and where the ground surface is underlain by a complex karst network of solution holes that may retain water during the dry season.

Aquatic animals such as fish and crayfish are known to move onto the surface of the rocky glades at high water for feeding and reproduction. The source of these animals is still uncertain but involves both long-distance dispersal and local movement from solution holes. Reduction in ground water levels in the rocky glades since the 1960s has reduced the number of solution holes available as refuges. An objective of hydrologic restoration of the CERP is to raise ground water level in the rocky glades to inundate more solution holes and increase the abundance of re-colonizing aquatic fauna during wet seasons.

To relate the dynamics of aquatic animals to the characteristics of solution holes, data are presently collected from a sample of holes of various depths and diameters in several areas of the rocky glades. To

predict the consequences of regional increases in ground water levels on populations of marsh fishes and other prey species, however, it is necessary to extrapolate the data from the intensive, site-based studies to the greater rocky glades landscape. This requires measurement of the density of holes and their diameters and depth distributions. New technologies for remote sensing have recently been developed that may gather these physical data in a more rapid and cost-effective manner; however, these methods are untested in the rocky glades landscape.

Project Description: This project will include the following work activities:

- Conduct a pilot study to test alternative remote sensing methods to determine their resolution and accuracy in estimating hole density, areas, and depths in the rocky glades. Validate the methods by comparison to results from standard land surveying methods.

- Determine optimum study designs and survey methods to characterize the density, areas, and depth distributions of solution holes in the rocky glades in a spatially explicit manner.

3.1.4.8 Ecological Effects of Canals and Other Artificial Deep Water Habitats

Justification: Effects of canals on the physical and biological aspects of the Everglades ecosystem are widespread but, in some cases, poorly understood. They act as 1) corridors for the movement of nonnative animals and plants, 2) artificial deep water habitats for native and introduced aquatic predators in the dry season, and 3) refuges in which large native and introduced species achieve higher abundance than in natural deep-water habitats. During the dry season, those predators prey heavily on small marsh fishes and invertebrates that are attracted to the canals from adjacent wetlands. Since some canals will be filled by the CERP and a new set will be excavated, it is important to understand the consequences of this artificial habitat in light of restoration costs.

Project Description: This project will include the following work activities:

- Determine if canals act as sources of colonists after the dry season, as sinks for wetland production at the end of the wet season, or as both for different groups of animals

- Analyze the outstanding largemouth bass fishery in Everglades' canals in terms of the energy subsidy from adjacent wetlands, the effects on the ecology of adjacent wetlands, and the potential for a wetland-supported trophy fishery without canals given the lengthened hydroperiods that will result from CERP implementation

- Examine effects of canals on the distribution and abundance of the American alligator and alligator holes in adjacent wetlands

- Analyze canals as habitats and movement corridors for exotic fishes. Do canals result in higher colonization rates than wetlands? How far into wetlands do native and nonnative fishes move in relation to artificial habitats?

- Compare wetlands adjacent to filled canals before and after the canals are filled, in contrast to wetlands adjacent to canals that are unaffected. Sample two years before and three years after an infilling action

- Compare canals cut through natural wetlands with canals isolated from wetlands

3.1.4.9 Synthesis of Wading Bird Distribution Surveys 1985-2001

Justification: The decline of wading bird populations in the Everglades was one of the first and most visible signs that the Everglades ecosystem had been degraded. Currently, wading bird populations are used as an important indicator in the Everglades restoration effort. The CERP uses hypothesized relationships between wading birds and hydrology to shape hydrologic targets for the Everglades restoration. In addition, several performance measures based on wading birds will likely be used to gauge the progress and success of the Everglades restoration (e.g., the number of large flocks in the system, the number of nests in the system, the location of the nesting colonies, and the timing of nesting initiation). The results from this project will be used to fine-tune these hydrologic targets and performance measures to support the Everglades restoration.

Project Description: This project will include the following work activities:

- Determine the relative contribution of short- and long-term effects of hydrologic stressors and landscape variables on the variation and trends in wading bird feeding patterns and population sizes observed over the past 17 years

- Develop a wading bird performance measure based on relationships between wading bird spatial distributions, hydrology, and annual nesting effort

- Evaluate the systematic reconnaissance flight as a tool for wading bird monitoring

The primary data set consists of 17 years of spatially explicit aerial wading bird systematic reconnaissance flight surveys across the entire Everglades landscape with a suite of associated environmental variables. The ancillary data range from detailed observations on feeding behavior on experimental plots to long-term information on annual nesting patterns to data on habitat and hydrology.

The project will proceed in three stages: 1) collect the primary and ancillary data sets into a single data base, 2) perform an initial exploration of the assembled data sets, and 3) develop detailed empirical models and performance measures aimed at quantifying the effects of multiple hydrologic and landscape factors on wading bird populations.

3.1.4.10 Sub-Lethal Effects of Contaminants on Wading Bird Reproduction

Justification: Restoration of wading bird reproduction has been a centerpiece of the argument for restoring hydrology in the Everglades. However, the current nesting populations demonstrate reproductive anomalies that also appear to be consistent with contaminant effects. While reproductive failure is likely related to a hydrology-mediated problem with the production and availability of prey organisms, contaminants remain an important competing explanation. Thus, while hydrologic degradation may have been a primary cause of population and nesting declines, reproductive impairment due to contaminants may also be operating in the current, more polluted South Florida environment. Our lack of knowledge about the levels and specific effects of contaminants remains a key uncertainty in our ability to predict reproductive responses of wading birds.

Two major uncertainties have been identified in resolving effects of contaminants on wading bird reproduction in the Everglades. First is the identification of potential contaminants that might be of risk to the birds. Second, the effects of most contaminants on wading bird reproduction are poorly known, and the only useful information is that contaminants can have effects on reproduction in other bird groups.

Project Description: This project will include the following work activities:

- Conduct a survey of wading bird tissues for levels of possible contaminants, including regularly used pesticides, herbicides, heavy metals including mercury, polychlorinated biphenyls (PCBs), dioxins, and furans. The survey will be done via collection of pipped eggs or small young from Everglades nests. The survey may be the basis for a monitoring program at five-year intervals if contaminant levels appear to pose a risk to reproduction.

- Conduct aviary studies to experimentally investigate the effect of ecologically relevant concentrations of contaminants on willingness to breed, reproductive success, and other sub-lethal effects such as susceptibility to disease, parental behavior, endocrinology, and foraging behavior. Aviary studies will be conducted on breeding groups to include individual variation in stresses (planned food shortages, effects of normal dominance, disease) so that the mechanisms and patterns by which contaminant effects are manifested in the field can be inferred with confidence.

3.1.5 References

Bahls, L.L. 1993. Periphyton Bioassessment Methods for Montana Streams. Montana Water Quality Bureau, Department of Health and Environmental Science, Helena, Montana.

Bancroft, G.T., D.E. Gawlik, and K. Rutchey. 2002. Distribution of Wading Birds Relative to Vegetation and Water Depths in the Northern Everglades of Florida, USA. Waterbirds 25: 265-277.

Bjork, R.D., and G.V.N. Powell. 1996. Roseate Spoonbill. In: Rodgers, J.A., H.W. Kale, and H.T. Smith (eds). Rare and Endangered Biota of Florida, Volume 5: Birds. University of Florida Press, Gainesville Florida, 295-308.

Braun-Blanquet, J. 1964. Pflanzensoziologie. Springer-Verlang, New York.

Chick, J.H., S. Coyne, and J.C. Trexler. 1999. Effectiveness of Airboat Electrofishing for Sampling Fishes in Shallow Vegetated Habitats. North American Journal of Fisheries Management 19: 957-967.

Chick, J.H., F. Jordan, J.P. Smith, and C.C. McIvor. 1992. A Comparison of Four Enclosure Traps and Methods Used to Sample Fishes in Aquatic Macrophytes. Journal of Freshwater Ecology 7: 353-361.

Childers, D.L., R.D. Jones, J.C. Trexler, C. Buzzelli, S. Dailey, A.L. Edwards, E.E. Gaiser, K. Jayachandaran, A. Kenne, D. Lee, J.F. Meeder, J.H.K. Pechmann, A. Renshaw, J. Richards, M. Rugge, L.J. Scinto, P. Sterling, and W. Van Gelder. 2001. Quantifying the Effects of Low-Level Phosphorus Additions on Unenriched Everglades Wetlands with In Situ Flumes and Phosphorus Dosing. In: J. Porter and K. Porter (eds). The Everglades Hydroscape. St. Lucie Press, Delray Beach Florida.

DeBusk, W.F., K.R. Reddy, M.S. Koch, and Y. Wang. 1994. Spatial Distribution of Soil Nutrients in a Northern Everglades Marsh – Water Conservation Area 2A. Soil Sci. Soc. Am. J. 58(2): 543-552.

DeBusk, W.F., S. Newman, and K.R. Reddy. 2001. Spatio-temporal patterns of soil phosphorus enrichment in Everglades Water Conservation Area 2A. Journal of Environmental Quality 30:1438-1446.

Dixon, P.M., A.R. Olsen, and B.M. Kahn. 1998. Measuring Trends in Ecological Resources. Ecological Applications 8: 225-227.

Doren, R.F., K. Rutchey, and R. Welch. 1999. The Everglades: A Perspective on the Requirements and Applications for Vegetation Map and Database Products. Journal of Photogrammetric Engineering and Remote Sensing 65: 155-161.

Dusi, J.L., and R.D. Dusi. 1978. Survey Methods Used for Wading Birds in Alabama. In: A. Sprunt IV, J.C. Ogden and S. Winckler (eds). Wading Birds: Research Report No. 7 of the National Audubon Society. National Audubon Society, New York, pp 207-212.

Frederick, P.C., and M.W. Collopy. 1988. Reproductive ecology of wading birds in relation to water conditions in the Florida Everglades. Technical Report 30, Florida Cooperative Fish and Wildlife Research Unit, School of Forest Resources and Conservation, University of Florida.

Frederick, P.C., T. Towles, R.J. Sawicki, and G.T. Bancroft. 1996. Comparison of Aerial and Ground Techniques for Discovery and Census of Wading Bird (Ciconiiformes) Nesting Colonies. Condor 98: 837-840.

Frederick, P.C., J. Heath, B. Hylton, J.D. Semones, G. Babbitt, and M.G. Spalding. 2001. Factors Affecting Breeding Status of Wading Birds in the Everglades. 2001 Final Comprehensive Report to United States Army Corps of Engineers, Jacksonville Florida.

Frederick, P.C., B. Hylton, J.A. Heath, and M. Ruane. 2003. Accuracy and variation in estimates of large numbers of nesting birds by individual observers using an aerial survey simulator. Journal of Field Ornithology 74: 281-287.

Frederick, P.C., J.A. Heath, R.E. Bennetts, and H. Hafner. In preparation. Effects of Survey Frequency, Nest Success, and Nest Asynchrony on Probabilities of Detecting Nest Starts.

Frederick, P.C. Personal communication. University of Florida, Gainesville, Florida.

Gaiser, E.E., and J. Johansen. 2000. Freshwater Diatoms from Carolina Bays and Other Isolated Wetlands on the Atlantic Coastal Plain of South Carolina, U.S.A., with Descriptions of Seven Taxa New to Science. Diatom Research 15: 75-130.

Gawlik, D.E. 2002. The Effects of Prey Availability on the Numerical Response of Wading Birds. Ecological Monographs 72: 329-346.

Gibbs J.P. 1993. Importance of small wetlands for the persistence of local populations of wetland-associated animals. Wetlands 13(1):25-31.

Hart R., and J.R. Newman. 1995. The Importance of Isolated Wetlands to Fish and Wildlife in Florida. Project Report for Non Game Wildlife Project NG88-102, Florida Freshwater Fish and Game Commission, Sarasota, Florida.

Hittle, C., E. Patino, and M. Zucker. 2001. Freshwater Flow from Estuarine Creeks into Northeastern Florida Bay. Water Resource Investigations Report 01-4164.

Jones, D.M., M. Madden, J. Snyder, and K. Rutchey. Unpublished report. A Vegetation Classification System for Southern Florida's National Parks and Preserves. South Florida Natural Resources Center, National Park Service, Everglades National Park, Homestead, Florida.

Jordan, C.F., S. Coyne, and J.C. Trexler. 1997. Sampling Fishes in Heavily Vegetated Habitats: the Effects of Habitat Structure on Sampling Characteristics of the 1-m^2 Throw Trap. Transactions of the American Fisheries Society 126: 1012-1020.

Jordan, F., C. De Leon, and A. McCreary. 1996. Predation, habitat complexity, and distribution of the crayfish *Procambarus alleni* within a wetland habitat mosaic. Wetlands 16: 452-457.

Klemm, D.J., and J.M. Lazorchak. 1994. Environmental Monitoring and Assessment Program – Surface Waters and Region 3 Regional Environmental Monitoring and Assessment Program. 1994. Pilot Field Operation and Methods Manual for Streams. Report no. EPA/620/R-94/004, Environmental Monitoring Systems Lab, Office of Research and Development, United States Environmental Protection Agency, Cincinnati Ohio.

Kushlan, J.A. 1981. Sampling Characteristics of Enclosure Fish Traps. Transactions of the American Fisheries Society 110: 557-562.

Kushlan, J.A., and M.S. Kushlan. 1979. Observations on the crayfish in the Everglades, Florida, USA. Crustaceana, Supplement 5: 115-120.

Lodge, D.M., M.W. Kershner, J.E. Aloi, and A.P. Covich. 1994. Effects of an omnivorous crayfish (*Orocectes rusticus*) on a freshwater littoral food web. Ecology 75: 1265-1281.

Loftus, W.F., and J.A. Kushlan. 1987. Freshwater Fishes of Southern Florida. Bulletin of the Florida State Museums, Biological Sciences 31: 147-344.

Lorenz, J.J., C.C. McIvor, G.V.N. Powell, and P.C. Frederick. 1997. A Drop Net and Removable Walkway for Sampling Fishes over Wetland Surfaces. Wetlands 17: 346-359.

Lorenz, J.J., J.C. Ogden, R.D. Bjork, and G.V.N. Powell. 2001. Nesting Patterns of Roseate Spoonbills in Florida Bay 1935-1999: Implications of Landscape Scale Anthropogenic Impacts. In: J.W. Porter and K.G. Porter (eds). The Everglades, Florida Bay and Coral Reefs of the Florida Keys, an Ecosystem Sourcebook. CRC Press, Boca Raton Florida, pp 555-598.

Mazzotti, F.J., and M.C. Cherkiss. 2002. Status and Conservation of the American Crocodile in Florida: Recovering an Endangered Species While Restoring an Endangered Ecosystem. Final Report. National Park Service, Everglades National Park.

Momot, W., H. Gowing, and P. Jones. 1978. The dynamics of crayfish and their role in the ecosystem. American Midland Naturalist 99: 10-35.

Momot, W., H. Gowing, and P. Jones. 1984. Crayfish Production: A reflection of community energetics. J. of Crustacean Biology 4(1):35-54.

Momot, W., H. Gowing, and P. Jones. 1995. Redefining the Role of Crayfish in Aquatic Ecosystems. Reviews in Fisheries Sciences 3(1): 33-63.

Muller-Dombois, D., and H. Ellenberg. 1974. Aims and Methods of Vegetation Ecology. John Wiley and Sons, New York.

Newman, S., K. R. Reddy, W. F. DeBusk, Y. Wang, G. Shih, and M. M. Fisher. 1997. Spatial Distribution of Soil Nutrients in a Northern Everglades Marsh: Water Conservation Area 1. Soil Sci. Soc. Am. J. 61(4): 1275-1283.

Newman, S. 2002. Unpublished data. South Florida Water Management District, West Palm Beach, Florida.

Noe, G.B., D.L. Childers, A.L. Edwards, E. Gaiser, K. Jayachandaran, D. Lee, J. Meeder, J. Richards, L.J. Scinto, J. Trexler, and R.D. Jones. 2002. Short-Term Changes in Phosphorus Storage in an Oligotrophic Everglades Wetland Ecosystem Receiving Experimental Nutrient Enrichment. Biogeochemistry 59: 239-267.

Nusser, S.M., E.J. Breidt, and W.A. Fuller. 1998. Design and Estimation for Investigating the Dynamics of Natural Resources. Ecological Applications 8: 234-245.

Nystrom, P., C. Bronmark, and W. Graneli. 1996. Patterns in benthic food webs: a role for omnivorous crayfish? Freshwater Biology 36: 631-646.

Ogden, J.C. 1994. A Comparison of Wading Bird Nesting Colony Dynamics (1931-1946 and 1974-1989) as an Indication of Ecosystem Conditions in the Southern Everglades. In: Davis, S.M., and J.C. Ogden (eds). Everglades: The Ecosystem and Its Restoration. St. Lucie Press, Boca Raton, Florida, pp 533-570.

Patino, E., L. Soderqvist, and V. Levesque. 2001. Hydrodynamics of the Southwest Coast Estuaries. Poster presentation, 2001 Florida Bay Science Conference, Key Largo, Florida.

Peet, R.K., T.R. Wentworth, and P.S. White. 1998. A Flexible, Multipurpose Method for Recording Vegetation Composition and Structure. Castanea 63: 262-274.

Porter, K.M., and A.R.C. Smith. 1984. Evaluation of Sampling Methodology – Systematic Flight/Pilot Wading Bird Survey. Technical Report, Everglades National Park, Homestead, Florida.

Porter, S.D., T.F. Cuffney, M.E. Gurtz, and M.R. Meador. 1993. Methods for Collecting Algal Samples as Part of the National Water-Quality assessment Program. Report 93-409, United States Geological Survey, Raleigh, North Carolina.

RECOVER. 2003. Quality Assurance Systems Requirements (QASR). RECOVER, c/o South Florida Water Management District, West Palm Beach, Florida, June 23, 2003.

RECOVER. In prep. Performance Measure Documentation Report. RECOVER c/o South Florida Water Management District, West Palm Beach, Florida.

Rice, K.G., F.J. Mazzotti, and L.A. Brandt. 2004 in press. Status of the American Alligator (Alligator mississippiensis) in Southern Florida and its Role in Measuring Restoration Success in the Everglades. In: Meshaka, W.E., and K.J. Babbitt (eds). Status and Conservation of Florida Amphibians and Reptiles. Krieger Publishing, Melbourne, Florida.

Richardson, J.R., and T.T. Harris. 1995. Vegetation mapping and change detection in the Lake Okeechobee marsh ecosystem. Archiv fur Hydrobiologie, Special Issues Advancements in Limnology 45: 17-39.

Rutchey, K., and L. Vilchek. 1999. Air Photo-Interpretation and Satellite Imagery Analysis Techniques for Mapping Cattail Coverage in a Northern Everglades Impoundment. Journal of Photogrammetric Engineering and Remote Sensing 65: 185-191.

Science Coordination Team. 2003. The role of flow in the Everglades ridge and slough landscape. South Florida Ecosystem Restoration Task Force, c/o Florida International University, Miami, Florida.

Smith, S.M. Unpublished data. Steve M. Smith, South Florida Water Management District, West Palm Beach, Florida.

Soloranzo, L., and J.H. Sharp. 1980. Determination of Total Dissolved P and Particulate P in Natural Waters. Limnology and Oceanography 25: 754-758.

Stevenson, R.J., and L.L. Bahls. 1999. Periphyton Protocols. In: Barbour, M.T., J. Gerritsen, B.D. Snyder and J.B. Stribling (eds). Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition. EPA 841-B-99-002, United States Environmental Protection Agency, Office of Water, Washington D.C.

Stevenson, R.J., and R.L. Lowe. 1986. Sampling and Interpretation of Algal Patterns for Water Quality Assessments. In: Isom, B.G. (ed). Rationale for Sampling and Interpretation of Ecological Data in the Assessment of Freshwater Ecosystems. American Society of Testing and Materials. ASTM STP 894.

Stober, Q.J., K. Thorton, R. Jones, J. Richards, C. Ivey, R. Welch, M. Madden, J. Trexler, E. Gaiser, D. Scheidt, and S. Rathbun. 2001a. South Florida Ecosystem Assessment: What Did We Learn? EPA-904-R-01-004, Science and Ecosystem Support Division and Office of Research and Development, Region 4, United States Environmental Protection Agency, Athens, Georgia.

Stober, Q.J., K. Thorton, R. Jones, J. Richards, C. Ivey, R. Welch, M. Madden, J. Trexler, E. Gaiser, D. Scheidt, and S. Rathbun. 2001b. South Florida Ecosystem Assessment: Phase 1/II Summary Everglades Stressor Interactions: Hydropattern, Eutrophication, Habitat Alteration and Mercury Contamination. EPA-904-R-01-002, Science and Ecosystem Support Division and Office of Research and Development, Region 4, United States Environmental Protection Agency, Athens, Georgia.

Stober, Q.J., K. Thorton, R. Jones, J. Richards, C. Ivey, R. Welch, M. Madden, J. Trexler, E. Gaiser, D. Scheidt, and S. Rathbun. 2001c. South Florida Ecosystem Assessment: Phase 1/II Technical Report - Everglades Stressor Interactions: Hydropattern, Eutrophication, Habitat Alteration and Mercury Contamination. EPA-904-R-01-003, Science and Ecosystem Support Division and Office of Research and Development, Region 4, United States Environmental Protection Agency, Athens, Georgia.

Stoddard, J.L., C.T. Driscoll, J.S. Kahl, and J.P. Kellogg. 1998. Can Site-Specific Trends Be Extrapolated to a Region? An Acidification Example for the Northeast. Ecological Applications 8: 288-299.

Thompson, S.K. 1992. Sampling. John Wiley & Sons, New York.

Trexler, J.C., W.F. Loftus, C.F. Jordan, J. Chick, K.L. Kandl, T.C. McElroy, and O.L. Bass. 2001. Ecological Scale and its Implications for Freshwater Fishes in the Florida Everglades. In: Porter , J.W., and K.G. Porter (eds). The Everglades, Florida Bay and Coral Reefs of the Florida Keys: an Ecosystem Sourcebook. CRC Press, Boca Raton Florida, pp 153-181.

USEPA. 1983. Methods for Chemical Analysis of Water and Wastes. United States Environmental Protection Agency, Cincinnati, Ohio.

USEPA. 1986. Test Methods for Evaluating Solid Waste, Physical and Chemical Methods. United States Environmental Protection Agency, Cincinnati, Ohio.

USEPA. 2001. South Florida Ecosystem Assessment: Phase I/II, Everglades Stressor Interactions: Hydropatterns, Eutrophication, Habitat Alteration, and Mercury Contamination Technical Report, Appendix D Data Files. EPA 904-R-01-003, United States Environmental Protection Agency Region 4, Science and Ecosystem Support Division, Athens, Georgia and Water Management Division, Atlanta, Georgia.

Urquhart, N.S., S.G. Paulsen, and D.P. Larson. 1998. Monitoring for Policy-Relevant Regional Trends Over Time. Ecological Applications 8: 246-257.

Welch, R., M. Remillard, and R.F. Doren. 1995. GIS Database Development for South Florida's National Parks and Preserves. Journal of Photogrammetric Engineering and Remote Sensing 61: 1371-1381.

3.2 SOUTHERN ESTUARIES MODULE

3.2.1 Introduction

The Southern Estuaries influenced by the Comprehensive Everglades Restoration Plan (CERP) include Florida Bay, the coastal lakes inland from Florida Bay, Biscayne Bay, and estuaries within southwest Florida's mangrove zone from Whitewater Bay to Lostman's River (Figure 3-22). Altered freshwater inflows have affected circulation and salinity patterns of the Southern Estuaries, in turn altering the structure and function of these ecosystems. Changes in habitat structure and distribution have been of particular concern because of their effects on animal populations.

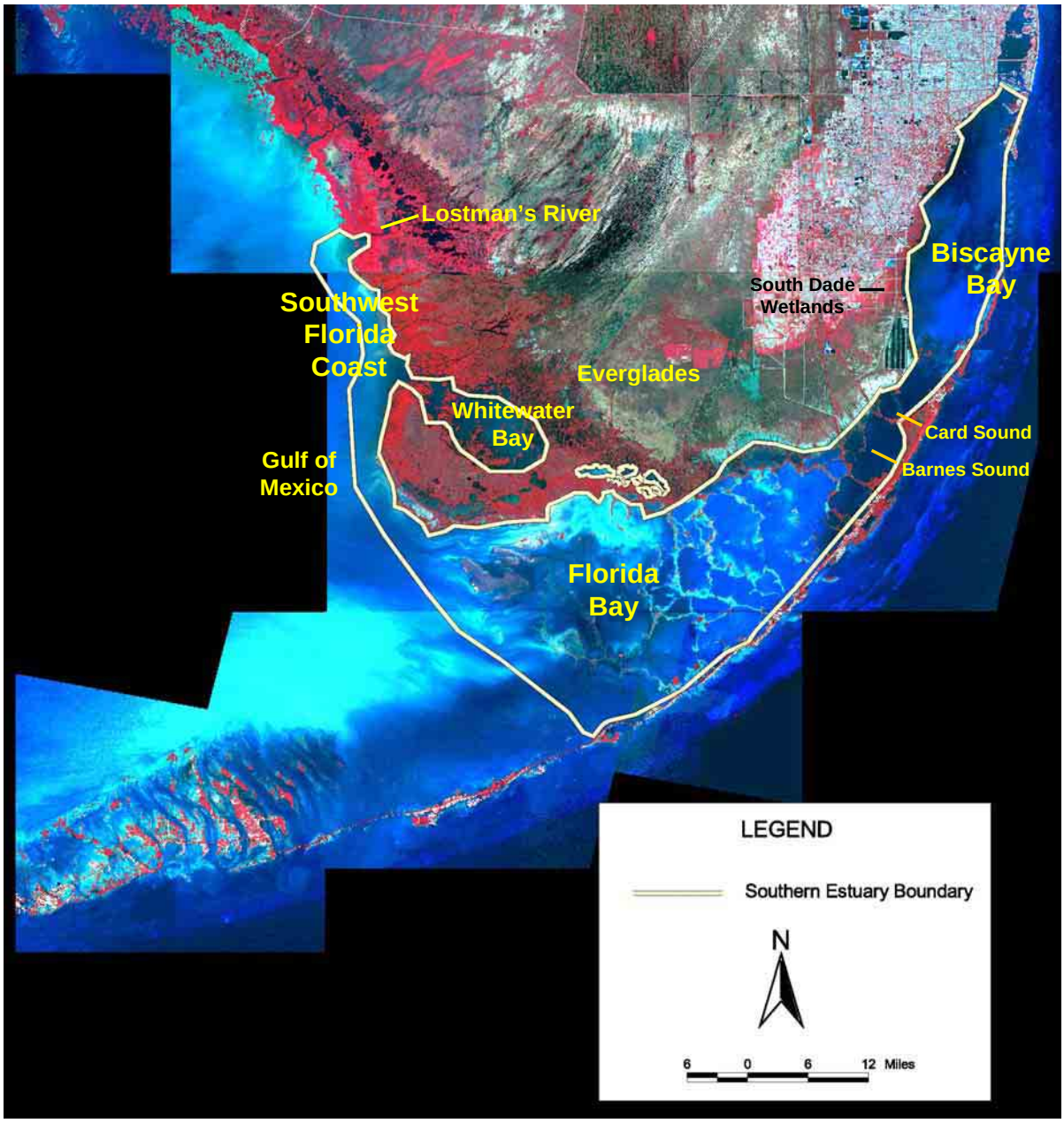


Figure 3-22: Southern Estuaries within the Influence of CERP

Altered freshwater flow is also linked to water quality changes. This flow transports nutrients, toxicants such as pesticides, and other materials to coastal systems. Material transport varies as a function of flow quantity, timing, and distribution. The loading of anthropogenic nutrients and other contaminants can strongly affect coastal ecosystem structure and function. The stimulation of algal blooms, with subsequent effects on light penetration and seagrass habitat, is of particular concern.

The Southern Estuaries Module is based on both the Florida Bay and Biscayne Bay Conceptual Ecological Models (Appendix A). Simplified conceptual ecological models (Figures 3-23 and 3-24) were derived from the above models to focus specifically on CERP restoration expectations. Restoration expectations in the simplified conceptual ecological models focus on effects of changing patterns of freshwater inflow, salinity, and water quality in the estuaries. The specific nature of hydrologic and water quality restoration differs among estuaries, but a common restoration goal is to establish and sustain natural and diverse epibenthic and shoreline communities that support desired groups of estuarine fauna. Because the estuaries are sensitive to sea level rise and the quality of freshwater inputs, those two elements must be factored into any restoration expectation.

A number of CERP projects are expected to influence the stressors and attributes described in these simplified conceptual ecological models. Some of these effects will be direct, others indirect. A summary of the projects expected to affect Florida Bay, Biscayne Bay, and the southwest Florida coast is provided in Appendix B.

3.2.1.1 Florida Bay

The restoration of a natural volume, distribution, and timing of freshwater inputs to Florida Bay is expected to provide salinity patterns that will sustain seagrass beds covering most of the bay bottom (Figure 3-23). The northeast bay is expected to experience less abrupt and less extreme decreases in salinity, while hypersaline conditions are expected to be less frequent, less extreme, and less extensive in the central and western bay. Seagrass recovery is expected to include decreased dominance by *Thalassia* and more cover by a mix of *Thalassia* and *Halodule* through most of the bay and the expansion of *Ruppia* near the northern coastline. The recovery of seagrass beds in combination with restored salinity regimes is expected to enhance nursery ground habitat values, as indicated by increased populations of juvenile pink shrimp, juvenile spotted seatrout, and other fish species that inhabit seagrass beds. Recovery of seagrass beds should also sequester nutrients and stabilize sediments to reduce algal blooms and turbidity in areas of Florida Bay that have experienced seagrass die-off.

Baseline studies have documented that little phosphorus is exported from the Everglades, and it is likely that coastal wetlands import phosphorus from the Gulf of Mexico (Rudnick et al. 1999). In contrast, large quantities of nitrogen and organic carbon are exported from the Everglades. The extent to which this export will change with Everglades' restoration is unknown, but it is possible that nitrogen export will increase and that this could stimulate algal blooms (Brand 2001).

Current conditions in Florida Bay are characterized by the occurrence of turbid water in many parts of the bay. In the eastern bay, most of this turbidity is caused by resuspended sediments, while in the central and western bay, turbidity is caused by both resuspended sediments and algal blooms. Sediment resuspension and associated turbidity is strongly affected by seagrass density. The dense monoculture of *Thalassia* that existed in Florida Bay prior to die-off in the 1980s resulted in clear water, but this condition is not considered to be natural (Fourqurean and Robblee 1999) and is not a restoration target. Rather, the target of moderate and diverse seagrass cover will likely be associated with moderate turbidity and light penetration sufficient to support net production of seagrass.

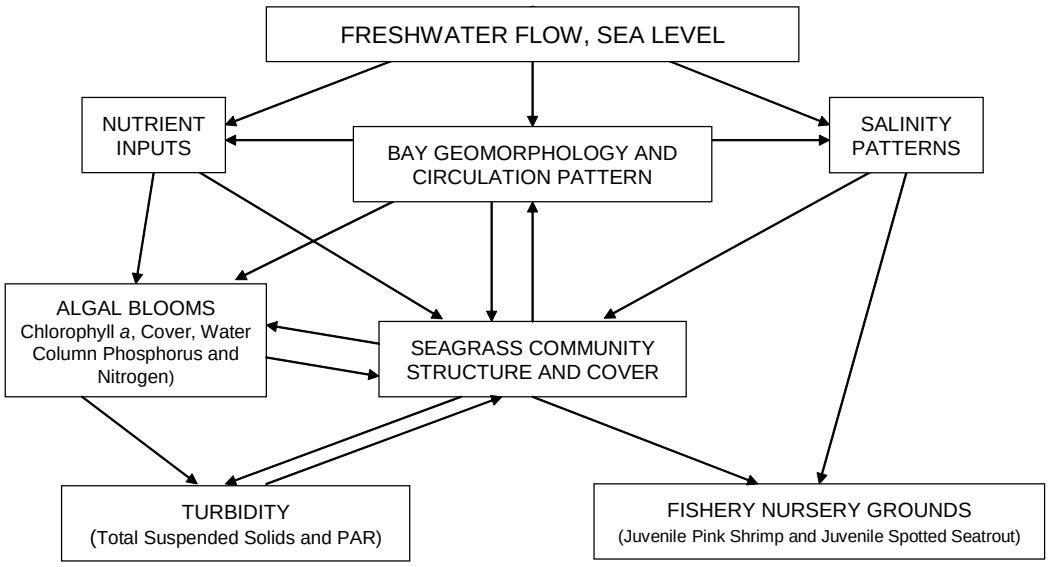


Figure 3-23: Simplified Conceptual Ecological Model of Florida Bay to Reflect Expected CERP Influences

Plankton blooms regularly occur in Florida Bay. The Central and Southern Florida (C&SF) Project caused hydrological and land use alterations that may have increased nutrient availability either directly via nutrient inputs from the Everglades or indirectly via changes in seagrass community structure and function. The increased frequency, magnitude, duration, and spatial extent of algal blooms in central and western Florida Bay during the 1990s may thus be related to water management. Cyanophytes dominate the blooms occurring in the central bay, and diatoms dominate those occurring in the western bay and Gulf of Mexico transition region.

Restoration of freshwater inputs to Florida Bay is also expected to lower salinity to oligohaline levels in the coastal lakes immediately upstream with the mangrove estuary. Submerged aquatic vegetation (SAV) in the coastal lakes and along the northern Florida Bay shoreline should respond in turn with increases in the cover and seasonal duration of *Ruppia*, *Chara*, *Najas*, and *Utricularia*.

3.2.1.2 Biscayne Bay

Benefits of the CERP to the epibenthic communities of Biscayne Bay are expected primarily in the near-shore environment of the southern bay, including Barnes and Card Sounds. Increased freshwater inflows to the bay through the tidal creeks and herbaceous marshes of the South Dade Wetlands are expected to lower salinity at mouths of the creeks to levels favorable for establishment of mesohaline salinity patterns supporting seagrass beds, consisting primarily of *Halodule*, in near-shore areas that are presently devoid of seagrasses (Figure 3-24). The delivery of water to the bay across the South Dade Wetlands should reduce the accompanying nutrient inputs, which might otherwise support growth of benthic algae rather than seagrass. The establishment of these patterns and associated SAV is expected to restore oyster bars and estuarine fish communities and to increase densities of juvenile pink shrimp in the near-shore environment of southern Biscayne Bay.

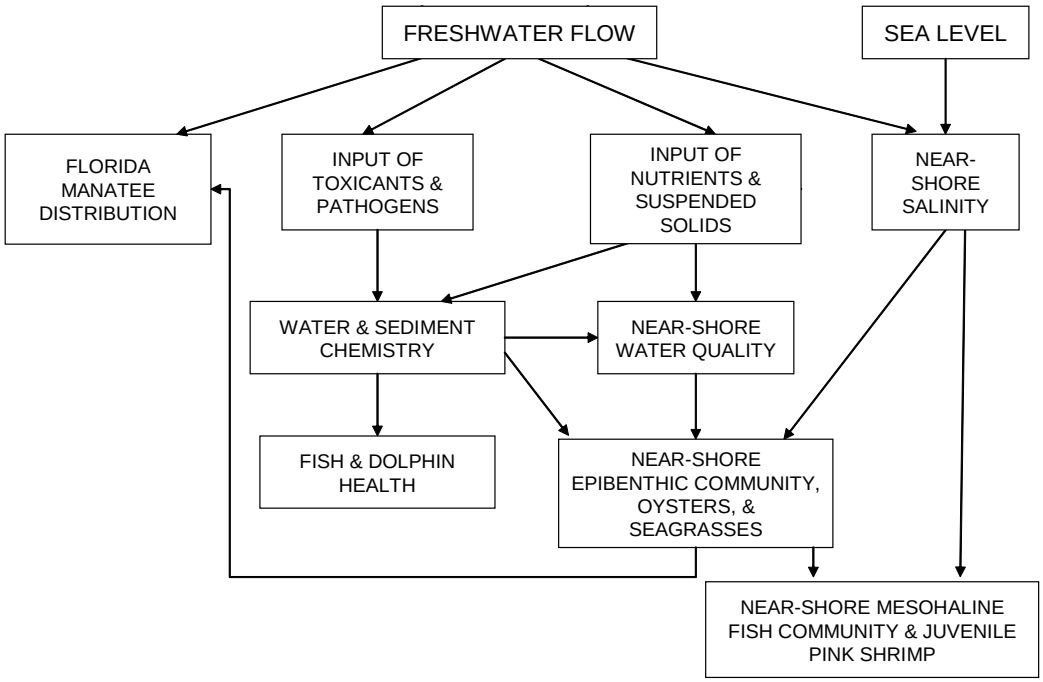


Figure 3-24: Simplified Conceptual Ecological Model for Biscayne Bay to Reflect Expected CERP Influences

Open areas of Biscayne Bay exhibit low nutrient concentrations; however, near-shore areas, affected by discharges from major flood control and drainage canals, have higher nutrient concentration. This is especially true for regions that drain older, more urbanized, or agricultural areas. In northern Biscayne Bay, while nutrient and chlorophyll *a* concentrations are generally higher, this region does not have a history of persistent algal blooms as is commonly reported in Florida Bay. Southern and central Biscayne Bay are usually oligotrophic (nutrient and chlorophyll concentrations are very low) and do not support algal blooms.

Although CERP projects were not formulated to address sediment quality and toxicant/pathogen input, it is considered to be a stressor in the Biscayne Bay simplified ecological model and a constraint on the restoration effort. It is linked to dissolved and suspended solids inputs and sediment contamination. These stressors are particularly significant in urban and agricultural portions of the bay, where contaminants such as sewage-related pathogens, ammonium, heavy and/or trace metals, and synthetic organic chemicals may enter the system through stormwater runoff, sewage or industrial discharges, and agricultural practices. CERP projects that result in redistribution of water may affect fate and transport of existing contaminants (both in the water column and the sediments) already present in the Biscayne Bay system. CERP projects proposing to meet water quality goals with alternative water sources, such as wastewater reuse, may introduce or alter potential for release of contaminants to previously uncontaminated sensitive areas. Also, modifications of flow regimes through the canals and into the near-shore area as a result of the CERP may affect transport and distribution of these contaminants and sediments or change exposure pathways. Therefore, these contaminants must be measured and assessed, and corrective action must be taken if the geographic extent or degree of sediment toxicity increased as a

result of CERP implementation. Additionally, incidences of abnormalities in fish in Biscayne Bay correspond to high inputs and sediment concentrations of toxic substances.

Because of the low solubility of some contaminants in water, they may not be detected in the water column, but associate (bind) with fine sediments and particulates in the water column, settle, and accumulate in the canal and bay sediments. Multiple contaminants have been documented to accumulate at levels known to cause biological effects (Long et al. 2002).

The occurrence of fish abnormalities in the Biscayne Bay estuarine system (commonly identified by fin abnormalities and scale disorientation) has been shown to be highest in areas directly exposed to human inputs (from canal discharges and outfalls). Planned modifications in the volume, timing, and spatial distribution of freshwater flows to the estuary are expected to reduce the anthropogenic stress on the fish health by restoring salinity patterns characteristic of estuaries, reducing contaminant loads, and reducing the input and resuspension of sediments, which sequester and concentrate available toxicants. The initial target in the Biscayne Bay is a reduction in prevalence of abnormalities to reference levels defined in Gassman et al. (1994).

3.2.2 Ecological Premises and CERP Hypotheses as the Basis for Monitoring Components and Supporting Research

Three ecological premises form the basis for most of the CERP restoration goals and strategies for the Southern Estuaries. These pertain to the effects of hydrology on freshwater inflow and salinity regime, water quality, and epibenthic and shoreline communities. Monitoring and assessment associated with each of these premises is dependent on the South Florida Hydrology Monitoring Network (Section 3.5).

Figures 3-25, 3-26, and 3-27 illustrate the linkages of ecological premises to CERP hypotheses, monitoring components, and key uncertainties and supporting research. Supporting research generally originates from monitoring components, and the supporting research facilitates the interpretation of monitoring results. In some cases, supporting research originates directly from a CERP hypothesis, and research will be required to develop an appropriate monitoring component. These linkages are indicated by a red arrow. Research that does not link to monitoring components or to CERP hypotheses has also been identified in this module. However, this research may not be the responsibility of this monitoring program.

A summary of the resulting monitoring components and supporting research for the Southern Estuaries is listed in Table 3-5 and described in detail in the following sections. The list of research topics include those identified during the development of the current version of the Monitoring and Assessment Plan (MAP). This list has yet to be prioritized, and it is anticipated that additional research topics of equal or higher priority will be identified in the future, including those related to water quality.

The process used to develop the monitoring plan for Southern Estuaries Module, and all of the other modules, is described in Section 2.0, Development of the CERP Monitoring Plan and Adaptive Management Program. The strategy for prioritizing and implementing monitoring components and research topics is discussed in Section 5.0, Implementation Strategy for the CERP Monitoring and Assessment Plan.

3.2.2.1 Freshwater Inflows and Salinity Regimes (Figure 3-25)

Ecological Premise: Prior to water management, the Natural Systems Model (NSM) and palaeo-ecological studies indicate that patterns of freshwater inflow to Biscayne Bay, Florida Bay, and the

southwest Florida coast resulted in more sustained mesohaline salinity conditions in coastal areas with fewer high and low salinity extremes.

CERP Hypotheses: The restoration of more natural upstream hydrological conditions and the expansion and/or addition of flow pathways will result in the following:

- Provide additional overland and ground water flow into south Biscayne Bay
- Provide more natural patterns of freshwater flow volume, timing, and distribution to Biscayne Bay, Florida Bay, and the near-shore environments along the southwest Florida coast
- Expand areas of mesohaline conditions in near-shore regions of southern Biscayne Bay, Florida Bay, and the southwest Florida coast, shifting seaward and possibly expanding the polyhaline zone
- Decrease the intensity and duration of hypersalinity events in Florida Bay and Biscayne Bay
- Reduce the magnitude, duration, and frequency of pulsed, low salinity events in northeastern Florida Bay and southern Biscayne Bay

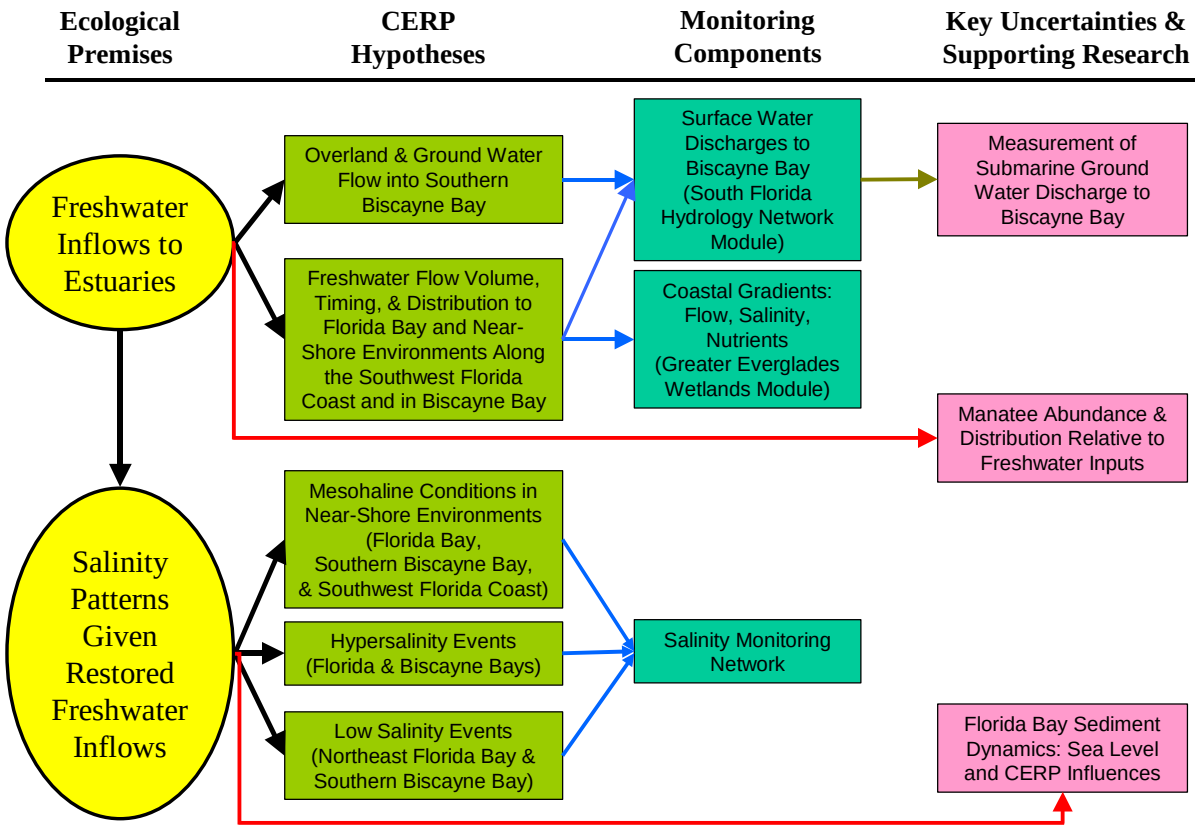


Figure 3-25: Diagram Depicting Relationships between the Ecological Premise, CERP Hypotheses, Monitoring Components, and Supporting Research for Freshwater Inflows and Salinity in the Southern Estuaries

Adaptive Management Questions: Will the restoration of more natural upstream hydrological conditions and the expansion and/or addition of flow pathways achieve the salinity regime objectives? What further actions may be required to accomplish these objectives?

3.2.2.2 Water Quality (Figure 3-26)

Ecological Premise: Prior to upstream water management and watershed development, natural freshwater inputs to Biscayne Bay and Florida Bay sustained highly oligotrophic (low nutrient) conditions in these estuarine ecosystems and high productivity along the southwest Florida mangrove zone and shelf. Surface water and sediment associated with natural freshwater flows into Biscayne Bay were essentially free of toxicants and pathogens.

CERP Hypotheses: The restoration of more natural patterns of water delivery to Biscayne Bay, Florida Bay, and the southwest Florida coast will provide beneficial patterns of freshwater inflows without providing harmful inputs of nutrients and toxicants so the following will occur as a result of CERP implementation:

- Restoration of more natural freshwater flow will not significantly stimulate phytoplankton blooms, benthic micro-algae, or epiphyte cover on seagrasses or harm seagrasses in Biscayne Bay, Florida Bay, or along the southwest Florida coast

- The geographic extent or degree of sediment toxicity in Biscayne Bay or fish abnormalities will not increase

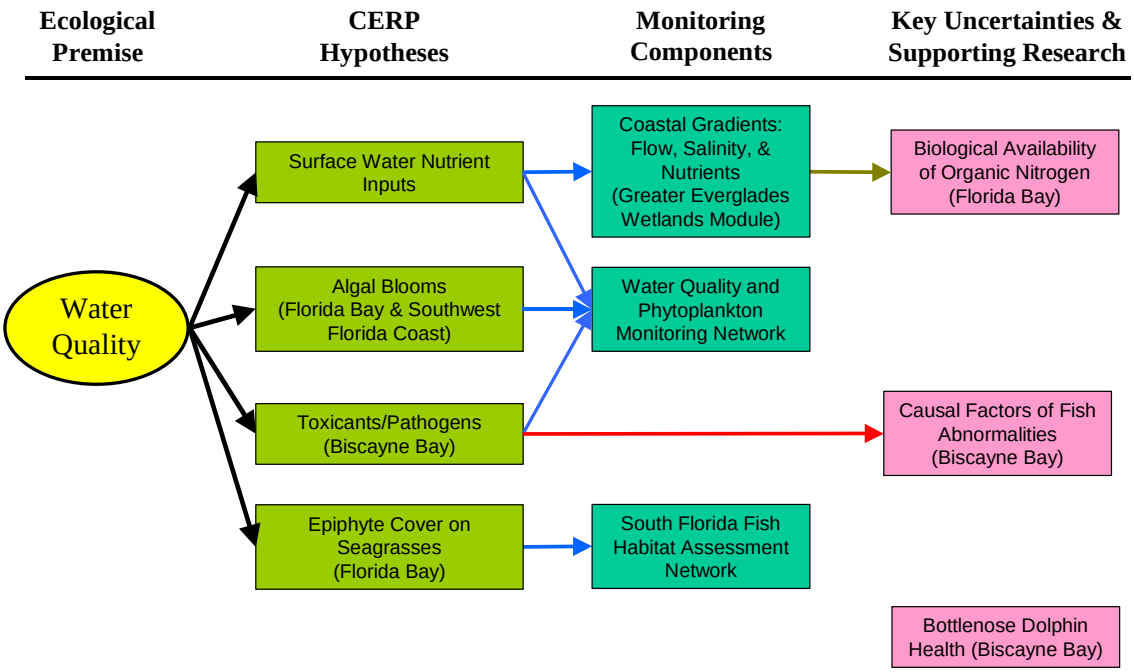


Figure 3-26: Diagram Depicting Relationships between the Ecological Premise, CERP Hypotheses, Monitoring Components, and Supporting Research for Water Quality in the Southern Estuaries

Adaptive Management Questions: Will the restoration of more natural patterns of water delivery to Biscayne Bay, Florida Bay, and the southwest Florida coast result in ecologically significant additional inputs of nutrients and toxicants? If so, how can freshwater inflows be modified or treated to reduce inputs of nutrients and/or toxins to non-harmful levels? This leads to the following more specific inquiries:

- In regard to the linkage of mainland hydrology to freshwater inflow and to the resulting distribution of salinity and nutrients in the estuaries: What is the quantitative relationship between mainland hydrology and nutrient dynamics, between freshwater inflow to the estuaries, nutrient loading, and resulting patterns of salinity and nutrient availability in the estuaries? What are these same relationships for toxic contaminants?

- In regard to the fate and ecological consequences of increased nutrient inputs that may accompany restored freshwater flows to the estuaries: Will inputs of dissolved organic nitrogen increase because of the restoration of natural water inflows of the Everglades and result in an increase in phytoplankton blooms in Florida Bay? What is the functional importance of Florida

Bay as a source or sink of nitrogen? Is there a net loss of nitrogen in Florida Bay via denitrification? Will the reduced incidences of hypersalinity yield greater phosphorus retention within the sediments of Florida Bay, and what will be the net effect on seagrass communities?

- In regard to the relationships between fish abnormalities and water management, as it affects salinity patterns and contaminant loading: What is the functional relationship of toxic concentrations and fish exposure to the type of abnormalities observed in Biscayne Bay?

3.2.2.3 Epibenthic and Shoreline Communities (Figure 3-27)

Florida Bay and Biscayne Bay support large areas of seagrass and healthy seagrass communities that require good light penetration and oligotrophic nutrient conditions. These seagrass communities provide food and habitat for animal species and stabilize bay sediments, helping to maintain and improve water clarity. Modifications of water management via CERP may alter not only salinity, but also light penetration, both of which strongly affect seagrass communities. This effect on light can be caused by water color (from dissolved organic matter) or algae, which may be affected by changing nutrient inputs. Turbidity resulting from nutrient loading (algal blooms) must be distinguished from that caused by resuspension of sediments or dissolved organic matter. Phytoplankton absorb light more efficiently than other particles. The link between seagrass and hydrological restoration cannot be made without light field monitoring.

Ecological Premise: Prior to upstream water management, mesohaline salinity conditions with fewer extremes in the coastal environments of Biscayne Bay, Florida Bay, and the southwest Florida coast supported broader coverage and higher diversity of seagrass and other epibenthic communities. These communities, in combination with prop-root habitats of mangrove shorelines, provided habitat for higher densities of valued estuarine fauna, including juvenile and adult stages of several economically important fisheries species.

CERP Hypotheses: The restoration of favorable flow and salinity regimes will result in the following:

- Extend the range of *Halodule* seaward into the near-shore environment of Biscayne Bay

- Increase seagrass cover and diversity in Florida Bay, reduce the region of *Thalassia* over-dominance, and increase both *Halodule* and *Ruppia* cover

- Enhance the productivity of near-shore mesohaline fish and invertebrates in south Biscayne Bay, resulting in higher abundances of mesohaline forms and lower abundances of purely marine forms such as some reef fishes

- Extend the spatial extent of high concentrations of pink shrimp further south in Biscayne Bay

- Enhance the function of Florida Bay, the mangrove estuaries of the southwest coast, and Biscayne Bay as nursery grounds for fishery species, increasing the distribution and density of juvenile pink shrimp, spotted seatrout, and other species and resulting in higher yields in the pink shrimp fishery

- Restore habitat for the endangered American crocodile

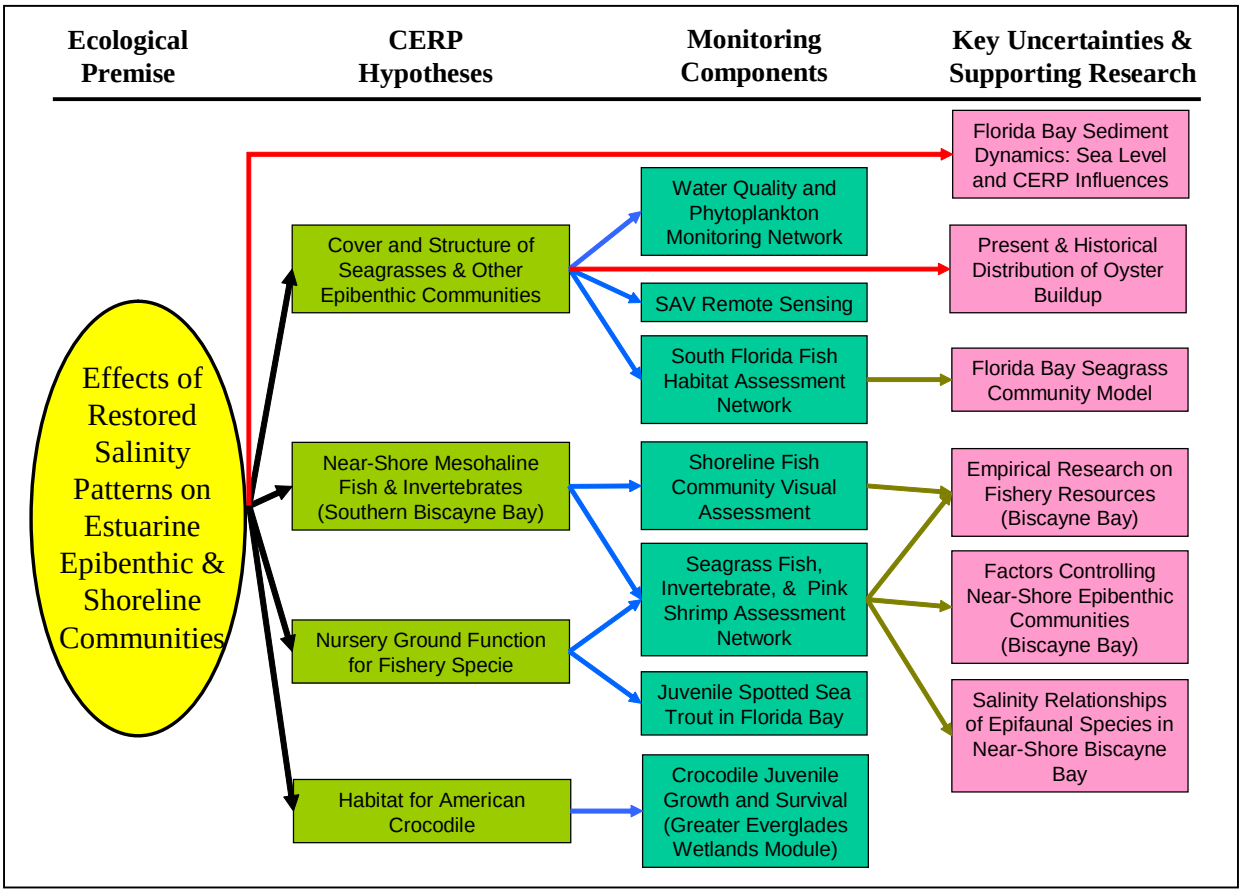


Figure 3-27: Diagram Depicting Relationships between the Ecological Premise, CERP Hypotheses, Monitoring Components, and Supporting Research for Epibenthic and Shoreline Communities in the Southern Estuaries

Adaptive Management Question: Will the restoration of favorable flow and salinity regimes achieve restoration objectives for epibenthic and shoreline habitats, thereby increasing the distribution and density of representative estuarine fauna, including juvenile and adult stages of several economically important fisheries species? If not, what additional changes in flow and salinity regimes are necessary?

3.2.2.4 Summary of Monitoring Components and Key Uncertainties and Supporting Research

Table 3-5 summarizes the monitoring components and key uncertainties and supporting research for the Southern Estuaries Module. The section of this document in which the item is discussed is provided in the second column of Table 3-5 for reference.

The system-wide assessment performance measures will be published in a separate document, the Performance Measure Documentation Report (RECOVER In prep). Each MAP monitoring component has at least one corresponding performance measure. For reference, the performance measure identification number or numbers are provided in the last column of Table 3-5.

Table 3-5: Monitoring Components and Key Uncertainties and Supporting Research for the Southern Estuaries

Monitoring Components	MAP Section	Performance Measure Number
Water Quality and Phytoplankton Monitoring Network	3.2.3.1	SE-A9 SE-A10 SE-A11 SE-A12 SE-A13
Salinity Monitoring Network	3.2.3.2	SE-A1 SE-A2
South Florida Fish Habitat Assessment Program	3.2.3.3	SE-A3
Large-Scale Remote Sensed SAV Monitoring Program	3.2.3.4	SE-A3
Seagrass Fish, Pink Shrimp, and Invertebrate Assessment Network	3.2.3.5	SE-A4,SE-A14
Shoreline Fish Community Visual Assessment	3.2.3.6	SE-A5
Juvenile Spotted Seatrout Monitoring in Florida Bay	3.2.3.7	SE-A6
Key Uncertainties and Supporting Research		
Florida Bay Sediment Dynamics: Sea Level and CERP Influences	3.2.4.1	
Measurement of Submarine Ground Water Discharge to Biscayne Bay	3.2.4.2	
Biological Availability of Organic Nitrogen in Florida Bay	3.2.4.3	
Present and Past Distribution of Oysters in South Florida Coastal Complex	3.2.4.4	
Factors Controlling Epibenthic Communities of Near-Shore Biscayne Bay	3.2.4.5	
Salinity Relationships of Epifaunal Species in Near-Shore Biscayne Bay	3.2.4.6	
Empirical Research on Fishery Resources of Biscayne Bay	3.2.4.7	
Causal Factors of Fish Abnormalities in Biscayne Bay	3.2.4.8	
Bottlenose Dolphin Health Assessment in Biscayne Bay	3.2.4.9	
Manatee Abundance and Distribution Relative to Freshwater Inputs	3.2.4.10	

3.2.3 Monitoring Components

Monitoring proposed in this module is intended to support a quantitative assessment to determine if restoration of patterns of freshwater inflow to the Southern Estuaries is resulting in the desired patterns of salinity, water quality, and benthic habitat (SAV and oyster beds). It will, in turn, permit assessment of the degree to which the restoration of these habitats is resulting in the desired structure and productivity of associated estuarine faunal communities. Lastly, it is intended to support assessment of the degree to which any changes observed are attributable to the CERP. If the desired changes in estuarine condition are not achieved, the assessment and accompanying research is intended to support recommendations regarding additional modification of freshwater flow, salinity, or water quality to achieve restoration objectives.

3.2.3.1 Water Quality and Phytoplankton Monitoring Network

Biscayne Bay

The modification of volume, timing, and spatial distribution of freshwater inflow and the restoration of more natural freshwater delivery regimes are the objectives of the CERP projects that are to be implemented in the upstream and coastal regions of Biscayne Bay. This will be accomplished by removing certain canals and related structures or replacing them with structures and flow paths that can modify the timing of the flow release, distributing the flow along a broader front through historic or recreated coastal creeks.

The proposed water quality monitoring is intended to document and evaluate the effects of CERP implementation on both changes in nutrient and pollutant loads transported into Biscayne Bay and changes in water quality in estuarine waters that might occur as a cumulative result of several CERP and non-CERP projects. These projects include the proposed modification of water deliveries, the South Dade Wastewater Reuse facility, the Biscayne Bay Coastal Wetland Project, the C-111 Canal Spreader Project, and modified flows from the twelve canals that discharge directly into Biscayne Bay. Water quality performance measures for Biscayne Bay include nutrient (total phosphorus and total nitrogen) loads from major tributaries and canals to the estuarine system, water clarity, and toxicants and pathogens (pollutants) in sediment (RECOVER In prep). Major nutrient species concentrations will also be added as a performance measure.

The water quality monitoring plan for Biscayne Bay will be comprised of two types of monitoring: one to evaluate nutrient loads and characterize water quality of the major tributaries and canals and the other to document trends and changes within the bay. Presently Miami-Dade Department of Environmental Management (DERM), in partnership with the South Florida Water Management District (SFWMD), monitors 105 stations throughout the Biscayne Bay and its watershed canals. Water quality samples are collected and analyzed for a variety of physical, chemical, and biological parameters at monthly, bi-monthly, and/or quarterly intervals. Approximately 14 sites of the 105 fixed-station water quality monitoring network (Figure 3-28) will be used to measure the nutrient loads from major canals and tributaries, while 35 other stations will be used for monitoring water quality within Biscayne Bay. Additional stations (New1, New2) will be needed within the bay to accommodate changes in freshwater input patterns and changes in water treatment (e.g., South Dade Wastewater Reuse facility). However, the number and location of the stations will depend on the outcome of the Wastewater Reuse Pilot Project and ultimate reuse water entry point(s) into the bay. Sediment sampling at near-shore stations for various pollutants will also need to be added as a component to the existing Miami-Dade DERM monitoring to measure influx of toxicants and pathogens into the system. The estuarine water and sediment quality sites will be co-located with seagrass, oyster, and fish monitoring wherever possible.

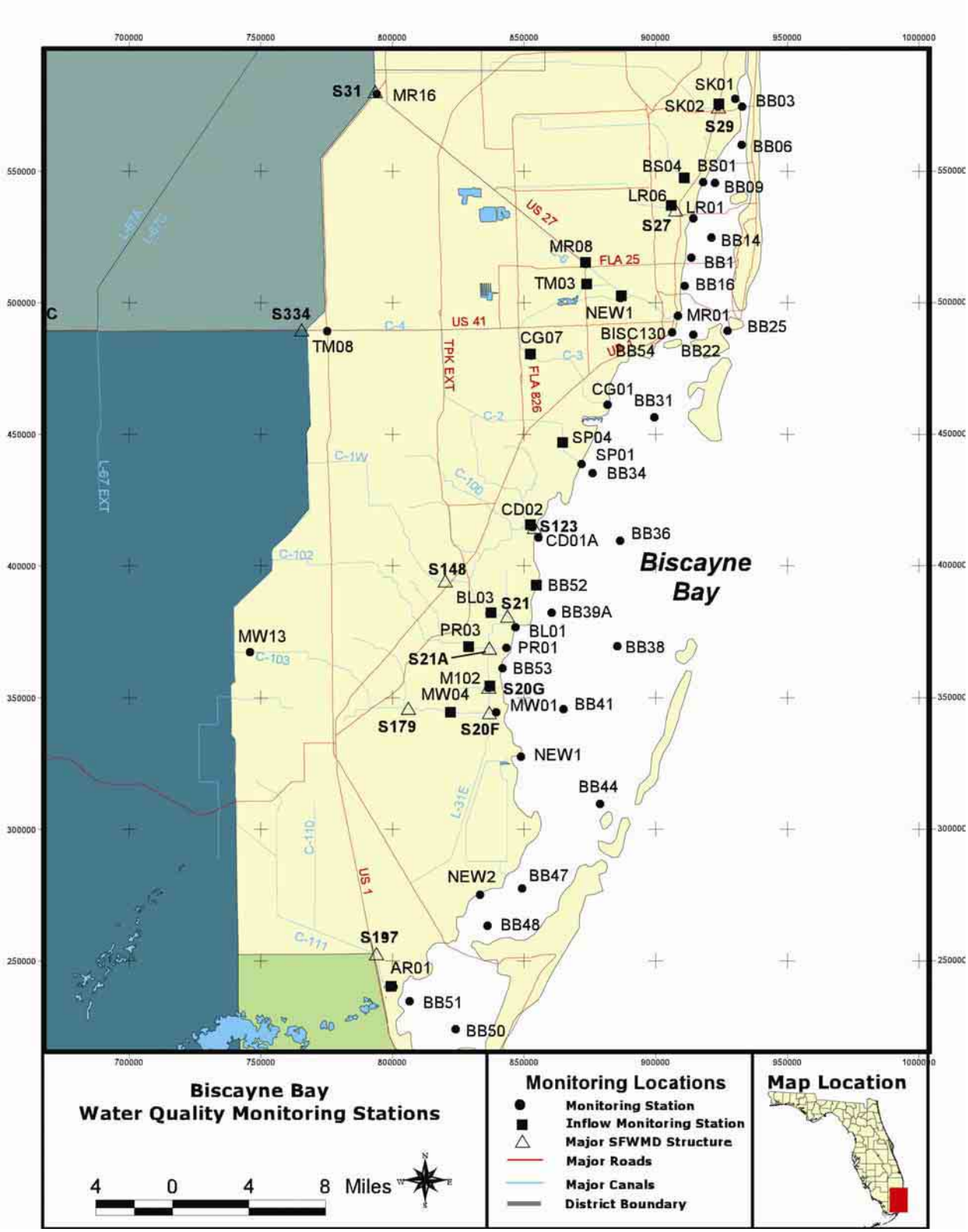


Figure 3-28: Biscayne Bay Water Quality and Phytoplankton Monitoring Network

In the current sampling program, parameters measured in situ include temperature, pH, dissolved oxygen, conductance, salinity, and photosynthetically-active radiation (PAR) (only bay sites). Laboratory analyses of grab samples include total and fecal coliforms, total phosphorus, soluble reactive phosphorus (canal sites only), ammonium nitrogen, nitrate/nitrite, total Kjeldahl nitrogen (canal sites only), color, turbidity, total suspended solids (quarterly, only canal sites), chlorophyll *a*, phaeophytin (at 12 bay sites only), hardness (quarterly, only canal sites), and metals (cadmium, copper, lead, and zinc; quarterly, all canal sites and 6 of the 22 bay sites).

Modifications necessary to the present program to meet the REstoration COordination and VERification (RECOVER) program's recommended water quality monitoring (Table 3-6 and Table 3-7) include the addition of three parameters to the monitoring suite for canal stations (dissolved organic matter florescence, alkalinity, and ions); addition of four parameters to the monitoring suite for the bay (dissolved organic carbon, silicate, total Kjeldahl nitrogen, and soluble reactive phosphate); inclusion of additional stations for chlorophyll *a* and metals monitoring; and increased frequency of collection for some parameters.

To capture the effects of seasonal variation and minimize serial correlation, a monthly sampling frequency has been recommended in several published studies on monitoring strategies (Loftis and Ward 1980, Spooner et al. 1990, and Robertson and Roerish 1999) as the appropriate monitoring frequency for surface water quality parameters in such situations. The in situ parameters, along with monthly measurements of other core parameters, are essential to interpretation of the grab sample data.

Estimation of nutrient loading to Biscayne Bay requires the monitoring of water discharge (flow) and nutrient concentrations. Because water discharge is highly variable, continuous monitoring with flow recorders and flow-proportional automatic samplers will be conducted at the outflow points of canals, rivers, and creeks following protocols outlined in the draft CERP Quality Assurance System Requirements (QASR) Manual (RECOVER 2003) and using agreed upon protocols to calculate loads. At present, the 14 canal/tributary locations for Biscayne Bay are not instrumented with these devices; however, the feasibility of conducting nutrient sampling at these sites using flow recorders and automatic samplers at weekly and bi-weekly frequencies is being investigated. Regardless, nutrient monitoring in the open estuary will continue through the existing monthly sampling program with grab samples collected at parameter specific frequencies from the fixed stations identified in Table 3-7.

For sediment contaminants, monthly monitoring of ammonia and sewage-related bacteriological indicators (total and fecal coliforms) will be conducted at inflow stations and select estuarine sites where modified water deliveries may affect the spatial distribution and concentration of these contaminants. Bi-annual long-term sediment chemistry and toxicity testing will be conducted at these same sites to document spatial and temporal patterns in contaminant levels throughout the watershed, with emphasis on canals and adjoining coastal waters. Sediment sampling methodologies, associated quality control requirements, and methods used for subsequent laboratory analyses are described in the draft CERP QASR Manual (RECOVER 2003) and will follow those currently used by National Oceanic and Atmospheric Administration (NOAA), Florida Department of Environmental Protection (FDEP), and Miami-Dade DERM monitoring programs. Parameters will include trace metals using the total digestion analytical method, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and pesticides. Bioassays will include standard whole sediment and pore water toxicity protocols. No sampling of bay sediments per se is currently in the DERM program; however, canal sediments are assessed once every five years.

Table 3-6: Recommended Biscayne Bay Water Quality Monitoring (Nutrient Loads and Canal/River Quality)

Medium	Group	Parameters	Sites	Frequency	Collection Method
Water	Physical parameters	DO, conductivity, pH, temperature, salinity, turbidity, depth, DOM fluorescence	SK02, BS04, LR06, MR08, TM03, CG07, CD02, BL03, PR03, MI02, MW04, MR15, TM08, MW13 New 1, New 2	Monthly	Water quality probe and grab
Water	Nutrients	TP, SRP, TKN or TN, NH_4, NO_{2+3}	See above	Weekly/ bi-weekly composite and/or monthly	Grab (monthly) and/or flow-proportional autosampler (weekly/ biweekly composite)
Water	Other core parameters	TSS, SiO_2, DOC, alkalinity, Cl, Ca, Mg	See above	Monthly	Grab
Water	Trace metals	Trace metals- Cd, Cu, Pb, Zn	See above	Quarterly	Grab
Water	Pathogens	Total and fecal coliform	See above	Monthly	Grab
Sediment	Pathogens	Total and fecal coliforms, NH_3	See above	Monthly .	Core
Sediment	Toxicants	Trace metals – total digestion (As, Ag, Al, Cd, Cr, Cu, Fe, Mg, Mn, Ni, Pb, and Zn), pesticides, PAHs and PCBs, acid volatile sulfide	See above	Bi-annually if possible, at a minimum every 5 years	Core
Water	Flow	Flow	See above	Continuous	Flow recorder

LEGEND

Ag - silver
Al - aluminum
As - arsenic
Ca - calcium
Cd - cadmium
Cl - chloride
Cr - chromium
Cu – copper
DO - dissolved oxygen
DOC - dissolved organic carbon
DOM - dissolved organic matter
Fe - iron
Mg - magnesium
Mn - manganese
NH_4 – ammonium nitrogen
Ni - nickel
NO_{2+3} - nitrite + nitrate
PAHs - polycyclic aromatic hydrocarbons
Pb – lead
PCBs - polychlorinated biphenyls
SRP - soluble reactive phosphate
TKN - total Kjeldahl nitrogen
TN – total nitrogen
TP - total phosphorus
TSS - total suspended solids
Zn - zinc

Table 3-7: Recommended Biscayne Bay Water Quality Monitoring (Estuarine)

Medium	Group	Parameters	Sites	Frequency	Collection Method
Water	Physical parameters	DO, conductivity, pH, salinity, depth, temperature, PAR, turbidity	SK01, BB03, BB06, BB09, BS01, LR01, BB14, BB16, MR01, BB25, BB54, BB22, BB31, CG01, SP01, BB34, CD01A, BB36, BB52, BL01, BB39A, BB38, BB53, BB41, MW01, BB44, BB47, BB48, BB51, AR01, BB50, FLAB 1-4	Monthly (see above)	Water quality probe and grab
Water	Nutrients	TP, SRP, TKN or TN, NH_4, NO_{2+3} , SiO_2,	See above	Monthly (see above)	Grab
Water	Other core parameters	TSS, DOC	See above	Monthly (see above)	Grab
Water	Biological	Chlorophyll *a*, phaeophytin	See above; at present Chlorophyll *a* is assessed at only 12 of the proposed stations: BB06, BB09, BB14, SP01, CD01A, BB52, BB39A, BB38, BB53, BB47, BB51, BB50	Monthly	Grab
Water	Trace metals	Cu, Pb, Zn, Cd	Near-shore stations	Quarterly	Grab
Water	Pathogens	Total and fecal coliforms	Near-shore stations	Monthly	Grab
Sediment	Pathogens	Total and fecal coliforms; NH_3	Near-shore stations	Monthly (see above)	Core
Sediment	Toxicants	Trace metals – total digestion (As, Ag, Al, Cd, Cr, Cu, Fe, Mg, Mn, Ni, Pb, and Zn); pesticides; PAHs and PCBs, acid volatile sulfide	Near-shore stations	Bi-annually (see above)	Core

LEGEND

Ag - silver
Al - aluminum
As - arsenic
Cd - cadmium
Cr - chromium
Cu – copper
DO - dissolved oxygen
DOC - dissolved organic carbon
Fe - iron
Mg - magnesium
Mn - manganese
NH_3 - ammonia
NH_4 - ammonium nitrogen
Ni - nickel
NO_{2+3} - nitrite + nitrate
PAHs - polycyclic aromatic hydrocarbons
PAR - photosynthetically-active radiation
Pb -lead
PCBs - polychlorinated biphenyls
SiO_2 - silicate
SRP - soluble reactive phosphate
TKN - total Kjeldahl nitrogen
TN – total nitrogen
TP - total phosphorus
TSS - total suspended solids
Zn - zinc

For water clarity, monitoring will include not less than monthly measurements of chlorophyll *a* and PAR depth profiles permitting calculation of attenuation coefficients at strategic locations. Secchi disk depth measurements will also be performed where Secchi depth measurements have historically been used to measure light penetration. Light monitoring will follow protocols outlined in draft CERP QASR Manual (RECOVER 2003).

In addition to fixed point sampling, regular synoptic surveys of fine-scale spatial variability from shipboard instrument arrays using global positioning satellites (GPS) will continue to be performed by NOAA vessels to characterize changing spatial patterns (e.g., salinity, light transmittance, in-vivo chlorophyll and accessory pigment fluorescence, and dissolved organic matter fluorescence mapping) and episodic event effects following freshwater pulses from tropical storms. These data are obtained en route to the monthly Florida Bay survey (see below).

Florida Bay and Southwest Florida Coast

The water quality monitoring program for Florida Bay and the adjacent southwest Florida estuaries and coast will evaluate status, quantify changes, and document trends in water quality within and near the estuaries as a result of CERP implementation. These estuaries are the downstream recipients of most freshwater flow through the Greater Everglades. The adjacent shelf is affected by the water quality of the estuaries that discharge into it. The estuaries and adjacent coastal shelf are then influenced by almost all the CERP projects. The primary (most direct) CERP projects that potentially affect the water quality of Florida Bay include the C-111N Spreader Canal, Water Conservation Area 3 Decompartmentalization, Florida Keys Tidal Restoration, the southern Water Preserve Area projects, and South Dade Wastewater Reuse.

The most important parameter with regard to estimating nutrient loading to Florida Bay is freshwater discharge into the bay. CERP-related changes in estuarine water quality may result from changes in upland water quality and nutrient loads from coastal creeks and rivers. The United States Geological Survey (USGS) will be evaluating water quality and nutrient loads at several of the main coastal creeks and rivers where they discharge fresh water into Florida Bay and the southwest coast of Everglades National Park. This monitoring program is described in Section 3.1.3.3, Coastal Gradients of Flow, Salinity, and Nutrients, in the Greater Everglades Wetlands Module. The coastal gradient monitoring is the only part of the water quality monitoring for this subregion for which RECOVER will have to assume financial responsibility. Outside those sites, all the monitoring has been underway for some time, establishing a baseline with which to compare CERP-related changes.

The monitoring network described herein is, in its innermost extent, the coastal portion of the coastal gradient transects described in the Greater Everglades Wetlands Module. The network will also include water quality sites along the Florida Bay coastline and in the bay's relatively isolated basins. It will also include stations in Whitewater Bay and along rivers (Shark, Harney, Broad, and Lostman's) of the southwest coastal mangrove zone. These are the primary recipients of Everglades' waters. Finally, it will include offshore sites on the Florida coast, where these Everglades waters mix with Gulf of Mexico waters and are then transported toward Florida Bay and the Florida Keys.

This plan also calls for continued complementary monitoring in offshore areas outside of the Southern Estuaries Module's boundary (north, west, and south) since the areas are hydrographically connected to this region. It will encompass the approximate boundaries in these directions adopted by the Florida Bay Florida Keys Feasibility Study since oceanographic data have clearly shown that riverine plumes of Everglades' waters discharged into the southwest Florida coastal waters mix with marine waters and are transported toward Florida Bay and the Florida Keys. The coastal monitoring is currently being conducted by NOAA (offshore) and SFWMD (nearer shore). Continued access to the data from these efforts will

enable RECOVER to assess the fate and effect of Everglades' nutrients on Florida Bay and the Florida Keys ecosystems, including the keys' coral reefs. In particular, this portion of the network is essential if RECOVER is to identify the origins of recurrent algal blooms and determine whether Everglades' nutrients contribute to bloom formation.

A network of 56 estuarine and near-shore fixed stations will be initially used to monitor the water quality of Florida Bay and the southwest Florida estuaries (Figure 3-29). This is a subset of the network currently managed by the SFWMD. Data from the current network will be analyzed to determine whether the 56 stations selected here, based on best professional judgment, are likely to optimally serve CERP needs. Estuarine water quality sites will be co-located with seagrass and fish monitoring wherever possible. Offshore sites are those already used by NOAA to define marine boundary conditions and assess the transport, fate, and effects of freshwater plumes from the Everglades as they mix with marine waters (Figure 3-30). This portion of the monitoring network uses a transect design and relies on a combination of continuous along track, shipboard measurements; vertical in situ profiles of physical parameters; and water samples from depths selected on the basis of real-time analysis of water column stratification.

Water quality performance measures for Florida Bay and the southwest Florida coast include total phosphorus and total nitrogen loads from major tributaries; total phosphorus, total nitrogen, and inorganic nitrogen concentrations; frequency and dynamics of algal blooms; and water clarity (RECOVER In prep). The coastal gradients monitoring detailed within the Greater Everglades Wetlands Module (Section 3.1.3.3) will provide nutrient loading estimates.

Monitoring in estuarine and coastal marine waters is currently being conducted via a combination of three approaches: 1) grab sampling from fixed stations, 2) in situ measurements from instruments on platforms, and 3) rapid, shipboard ("on the fly"), along track measurements that provide fine-scale spatial mapping of water quality parameters. In situ parameters measured on both platforms and shipboard instruments include temperature, pH, salinity, dissolved oxygen, and PAR (Table 3-8). Additional shipboard continuous measurements include light transmittance, dissolved organic matter fluorescence, and chlorophyll fluorescence (along with GPS coordinates). Grab samples are analyzed for nutrients, biological parameters, turbidity, silicate and calculated parameters, and total suspended solids (Table 3-8). Standard operating procedures for all sampling methods and associated quality assurance/quality control (QA/QC) protocols are described in the CERP QASR Manual (RECOVER 2003).

Bloom dynamics will be evaluated not only by measuring chlorophyll *a* concentrations, but also by estimating taxonomic identity and assessing bloom dynamics at appropriate temporal and spatial scales. Algal bloom measurements (chlorophyll *a* and in-vivo fluorescence) will be conducted by monthly grab samples at fixed water quality sampling stations, platform instruments for fine temporal scale data, and shipboard mapping (especially to assess episodic events, such as runoff from tropical storms) (Table 3-8). Continuous shipboard (track) optical measurements are essential as a guide to determine when pigment analysis is appropriate. If deemed appropriate, the pigment analysis will then be used to select samples for further phytoplankton community analysis and the enumeration of cell types (at least for large taxonomic groupings). NOAA is also measuring fluorescence at a limited number of fixed sites and using sea-viewing wide field-of-view sensor (SeaWIFS) data to analyze the distribution and intensity of algal blooms. NOAA cruise tracks are supplemented where necessary to monitor algal blooms, and extra cruises are scheduled to assess the impact of unusual discharge events (e.g., as a result of tropical storm flooding).

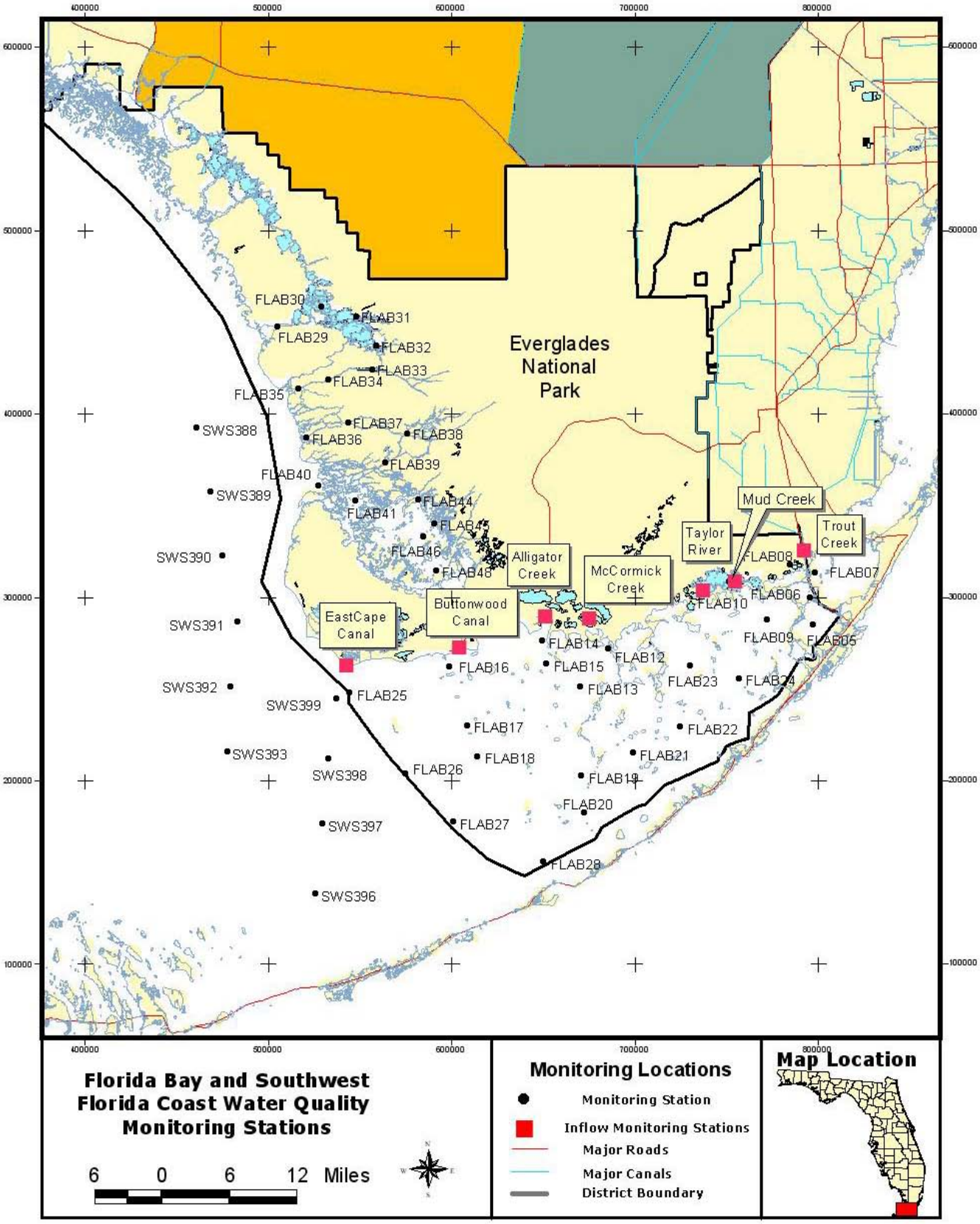


Figure 3-29: Florida Bay and Southwest Florida Coast Water Quality Monitoring Network

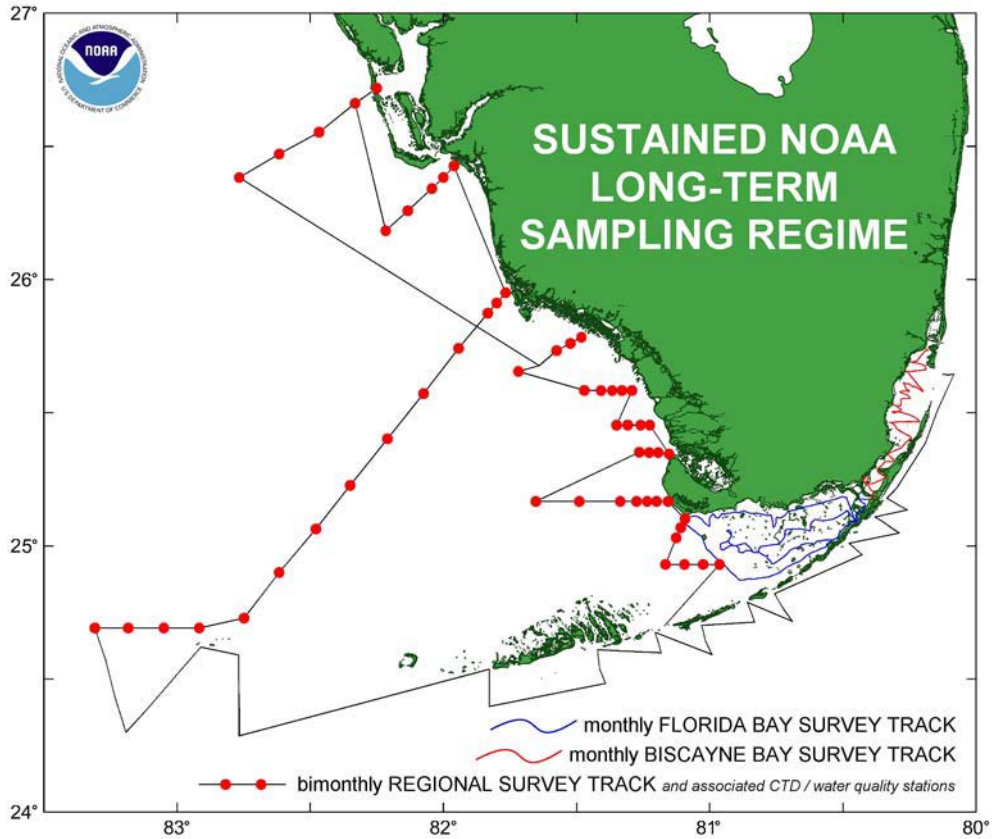


Figure 3-30: Offshore transect monitoring sites used by NOAA

Field measurements of water clarity and light penetration through the water column are needed to establish linkage between seagrass development, water quality conditions, and hydrologic and upland CERP project implementation. Monitoring will include no less than monthly measurements of the vertical profiles of PAR to permit calculation of the attenuation coefficient at strategic locations (Table 3-8). Platform-based PAR sensors and transmissometers will be added at seagrass monitoring sites to supplement those already established by the Florida Marine Research Institute (FMRI).

In Florida Bay, in addition to PAR (light attenuation), monitoring will include measurements of total suspended solids, phytoplankton (with chlorophyll *a* as a surrogate), and dissolved organic matter (with direct measurement of dissolved organic carbon and fluorescence) (Table 3-8). These measurements need to be made at proper spatial and temporal scales that are coincident with other water quality and seagrass measurements. In addition to fixed point sampling, regular synoptic surveys of fine-scale variations from ship-board instrument arrays with GPS are used to characterize changing spatial patterns (e.g., salinity, light transmittance, in-vivo chlorophyll and accessory pigment fluorescence, and dissolved organic matter fluorescence) and episodic event effects following freshwater pulses from tropical storms. Such surveys are presently conducted by NOAA and SFWMD. NOAA is currently producing and will continue to produce monthly maps of integrated water column light attenuation at PAR wavelengths (and areas of potential light limitation for seagrass growth) using a statistical model relying upon an underway data stream (dissolved organic matter, transmittance, chlorophyll *a*, temperature, and salinity).

Table 3-8: Recommended Florida Bay Water Quality Monitoring (Estuarine and Southwestern Coast)

Medium	Group	Parameters	Sites	Frequency	Collection Method
Water	In situ parameters	temperature, pH, salinity, DO PAR, light transmittance, DOM fluorescence, chlorophyll fluorescence	FLAB 5 – 28 WWB29-41, 45, 46, 48; SWS288-391, 393, 396, 298 in conjunction with shipboard mapping tracks in Florida Bay and along southwest coast	Monthly grabs, continuous at platforms, and monthly/ bimonthly (and event based) shipboard continuous surveys	Water quality probe and grab
Water	Nutrients Calculated parameters	TP, TN, NH_4, NO_2, NO_{2+3}, SiO_2, SRP, TOC NO_3, DIN, TON	FLAB 5 – 28 WWB29, 30, 32-41, 45, 46, 48; SWS288-391, 393, 396, 298 in conjunction with shipboard mapping tracks in Florida Bay and along southwest coast	Monthly, bimonthly, and event based	Grab
Water	Other core parameters	TSS	FLAB 5 – 28 WWB29, 30, 32-41, 45, 46, 48; SWS288-391, 393, 396, 298 in conjunction with shipboard mapping tracks in Florida Bay and along southwest coast	Monthly, bimonthly, and event based	Grab
Water	Biological	Chlorophyll *a*	FLAB 5 – 28 WWB29, 30, 32-41, 45, 46, 48; SWS288-391, 393, 396, 298 in conjunction with shipboard mapping tracks in Florida Bay and along southwest coast	Monthly, bimonthly, and event based	Grab
Water	Biological	Phytoplankton community composition	FLAB 5 – 28 and southwest coast or offshore sites where blooms observed	Quarterly or bloom-event based	Grab

LEGEND

DIN - dissolved inorganic nitrogen
DO - dissolved oxygen
DOM - dissolved organic material
NH_4 - ammonium nitrogen
SRP - soluble reactive phosphate
NO_2 - nitrite
NO_{2+3} - nitrite + nitrate
NO_3 - nitrate
PAR - photosynthetically-active radiation
SiO_2 - silicate
TN - total nitrogen
TOC - total organic carbon
TON - total organic nitrogen
TP - total phosphorus
TSS - total suspended solids

3.2.3.2 Salinity Monitoring Network

Biscayne Bay

Currently, 12 canals discharge fresh water directly into Biscayne Bay, seven of which discharge directly and indirectly into Biscayne National Park waters. One of the most profound changes anticipated to occur with CERP implementation is the alteration of salinities within Biscayne Bay and the park, especially in the near-shore habitats along the mainland coast. Specific regions anticipated to be affected by CERP projects are the Miami River/Rickenbacker-McArthur Causeway basin (affected by the proposed modification of water deliveries), the Little River/Dumbfoundling Bay/Oleta River basin (affected by the proposed modification of water deliveries), the Biscayne Coastal Wetland area of South Biscayne Bay (affected by the Biscayne Bay Coastal Wetland Project and the Water Reuse Project), and the Manatee Bay/Card Sound region (affected by the C-111 Spreader Canal Project). The areas most sensitive to the changes are shallow areas (less than one-meter deep) along the mainland shoreline, which account for about 10 percent of the park in Biscayne Bay. These areas are critical nursery habitats for pink shrimp and commercial and recreational fishes such as gray snapper and spotted seatrout.

Biscayne National Park has collected continuous (hourly) water quality data using benthic-mounted Yellow Springs Instruments (YSI) "datasonde" packages at a few deeper sites (greater than one-meter deep) in the bay for more than 20 years, but no data are collected in the shallow areas (less than one-meter deep). Many researchers have observed vertical stratification in the bay, but no one can report quantitatively the extent, frequency, and duration of vertical stratification due to the lack of well-planned continuous water quality data. While it is difficult to predict the consequences of the restoration plan, it is important to document the current hydrographic status in the very shallow near-shore areas of Biscayne Bay. Miami-Dade County and the State of Florida (via the SFWMD and the FDEP) have collected water quality data throughout Biscayne Bay for more than 20 years. These county/state data will augment the Biscayne National Park continuous data collection to assist in documenting and characterizing the long-term modifications of conditions within the bay. Continuous recording conductivity, temperature, and depth (CTD) instruments with both surface and bottom mounted meters will be installed in critical regions of the bay (i.e., shallow areas and those regions with projected modified conditions) to obtain CTD data that be used establish a pre-CERP condition; monitor change in salinity patterns over time; determine whether and under what circumstances stratification exists; and, in combination with canal discharge data and other environmental data (i.e., wind and rainfall), quantify the relationship between freshwater inflow volume and salinity patterns in the near-shore bay. In addition, these data will be used to define the habitat requirements (especially salinity and bottom type) of valued components of the epibenthic and planktonic communities in order to relate faunal changes to water management changes. Station locations have been selected and coincide with established, long-term water quality stations where possible.

The salinity monitoring network for the Biscayne Bay plan consists of 13 existing continuous stations throughout the bay that were established by the United States Army Corps of Engineers (USACE) and Biscayne National Park and will provide continuity with historical data. An additional 18 RECOVER salinity monitoring sites and 5 Biscayne National Park (BNP in Figure 3-31) salinity monitoring sites have been identified to provide coverage in critical areas not included in the present fixed-station monitoring network and to document the extent and stability of the CERP-related effects in the bay. Some specific sites are proposed in areas where there will be no anticipated CERP effect to provide comparison or control data. The locations of the stations (existing and new) are shown in Figure 3-31. Spatially continuous fine-scale salinity data are obtained by NOAA oceanographers on a monthly basis in Biscayne Bay (Figure 3-30) and will be important to interpreting these time series data.

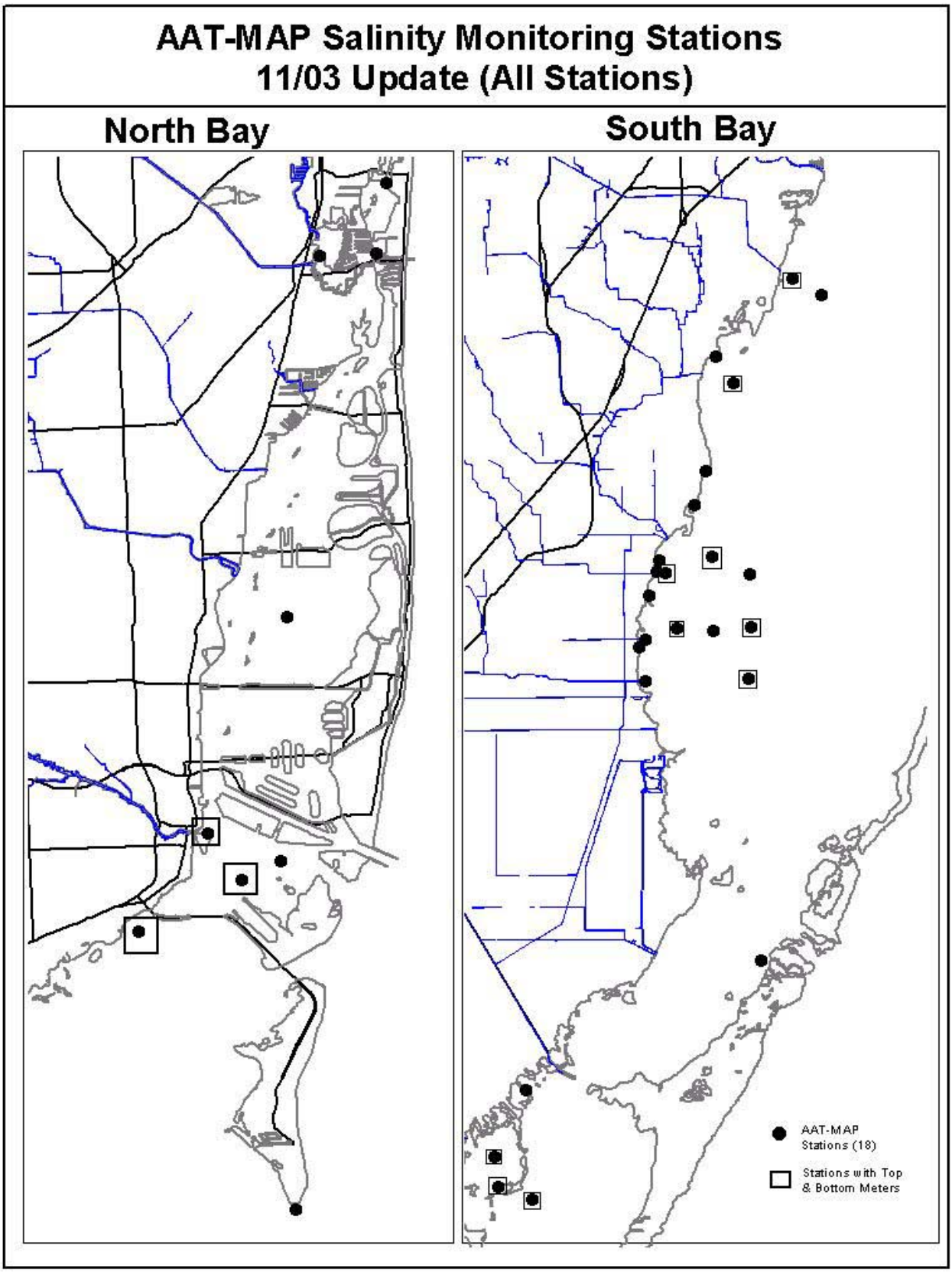


Figure 3-31: Biscayne Bay Salinity Monitoring Network

Florida Bay and Southwest Florida Coast

Salinity is measured nearly continuously at a set of National Park Service platforms, at all fixed water quality stations (from grab samples) on a monthly basis, and by conductivity meters included in shipboard arrays for fine-scale track mapping (monthly). Salinity values are needed to interpret all water quality and habitat monitoring data and are low cost, thus justifying this extensive set of measurements. The current National Park Service salinity monitoring network in Florida Bay will continue with the addition of four telemetered stations to the fourteen already in place (Figure 3-32). The locations to be added are Snake Bight, West Lake, Seven Palm Lake, and east of Cape Sable. This would be a one-time expense to RECOVER because after installation, the four additional stations would be integrated into the National Park Service network upkeep, maintenance, and operation budget. No additional salinity stations are required along the southwest coast. Spatially continuous fine-scale salinity data are obtained by NOAA oceanographers on a monthly basis in Florida Bay and a bimonthly basis offshore (Figure 3-30) and will be critical to important to interpreting these time series data.

3.2.3.3 South Florida Fish Habitat Assessment Program

The Florida Bay Fish Habitat Assessment Program (FHAP) (Durako et al. 2001) has provided spatially explicit data on the distribution, abundance, and population dynamics of seagrasses and benthic algae in Florida Bay since the spring of 1995. Using Braun-Blanquet cover measurements and coring to produce estimates of aboveground biomass, FHAP has quantified changes in distribution and abundance in macrophyte communities through the production of distribution and abundance maps, change maps, and summary graphic and tabular products. Miami-Dade DERM presently uses FHAP protocols in Biscayne Bay and at stations in northeastern Florida Bay, and the Florida Keys National Marine Sanctuary seagrass monitoring program also uses FHAP protocols (Fourqurean et al. 2002). The use of compatible sampling protocols among these three large-scale programs has resulted in the establishment of a regional management-oriented database of unprecedented scale (Fourqurean et al. 2002).

The proposed FHAP program will 1) build on the existing map data and associated data accumulated since 1995, providing information for spatial assessment and resolution of inter-annual variability in seagrass-macro-algae communities; 2) largely eliminate the destructive core sampling component; and 3) expand the focus to provide process-oriented physiological-based eco-indicator data, such as optical water quality, photosynthetic quantum yields, sexual reproduction, and epiphyte loads at scales ranging from individual seagrass shoots to the regional landscape.

FHAP will be based on a four-tiered sampling design (shoot, core, quad, area). Sampling will be conducted once per year at the end of the dry season (May-June). Salinity stress on seagrasses may be highest at this time, and this is the period when the dominant seagrass of the region, *Thalassia testudinum*, exhibits maximum shoot-specific and areal-specific leaf areas, increasing the ability to detect changes in cover. Reproductive effort (flowering and fruit development) can also be assessed at this time. A grid of approximately 30 tessellated hexagonal cells will be defined for each area. Sampling stations will be randomly chosen each year from within each grid cell and then revisited on a three-year cycle. Area grids and sampling stations will be generated using algorithms developed by the United States Environmental Protection Area's Environmental Monitoring and Assessment Program (EMAP) (Kevin Summers personal communication). This type of sampling design scales the sampling effort to the size of the area, and although sample-point locations are doubly randomized (the grid is randomly placed and sample stations are randomly located within each grid cell), they are also quasi-evenly distributed across the sampled area. At each station, seagrass cover will be visually quantified within each of four replicate 0.25-square meter quadrants using a modified Braun-Blanquet frequency/abundance scale (Mueller et al. 1974, Fourqurean et al. 2002). Optical water quality will be determined by diffuse attenuation coefficients (Kd, m-1) using paired scalar quantum sensors separated by 0.5 meters. Maps of seagrass distribution,

abundance, and changes in abundance will be produced using an appropriate contouring and mapping program. Spatial distribution of sexual reproduction will also be mapped.

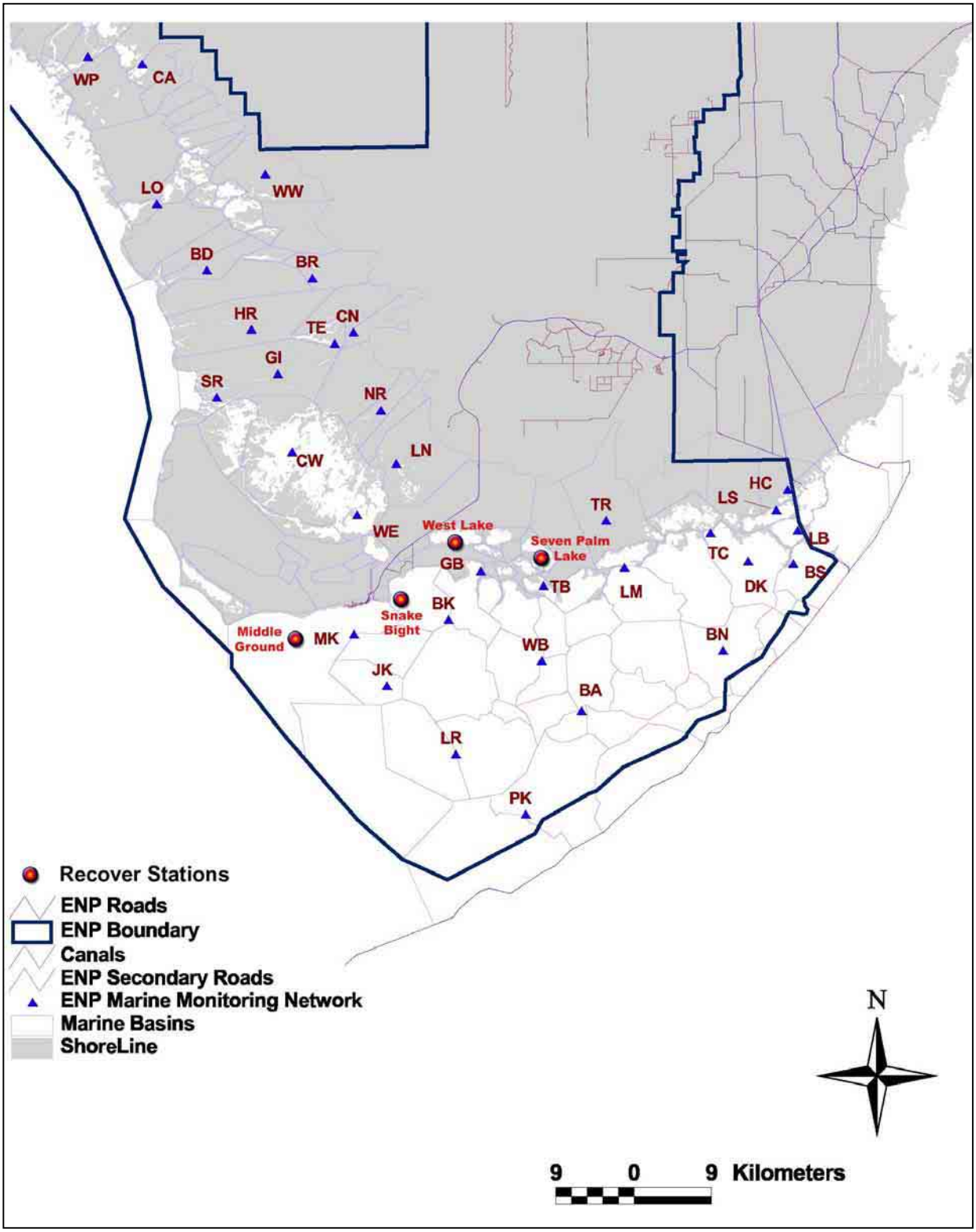


Figure 3-32: Florida Bay Salinity Monitoring Network

The standing crop and density element of the study provides an assessment of the spatial and temporal variability of seagrass and macro-algae habitat structure. Annual density and standing crop (aboveground biomass) measurements will be obtained from 15-centimeter diameter core samples from the first quadrant for each of the springtime measurements at the Braun-Blanquet stations. At sites where *Ruppia* is present, seed densities will be determined by sieving the contents of a 15-centimeter diameter core at each site using a 1.0-millimeter mesh. At sites where seagrasses are present, ten short-shoots will be collected for the determination of leaf epiphyte biomass.

Photosynthetic efficiency will be measured for 4 short-shoots of *Thalassia* at each station where it is observed using chlorophyll pulse-amplitude modulated (PAM) techniques (Ralph et al. 1998, Ralph 1999). PAM fluorescence is highly correlated with both oxygen evolution (Beer and Bjork 2000) and carbon 14 uptake (Hartig et al. 1998). PAM fluorescence has been used to assess both light stress (Ralph and Burchett 1995) and salinity stress (Kamermans et al. 1999). Photosynthetic characteristics are short-response indicators of the physiological status of seagrasses.

The proposed South Florida FHAP will maintain current monitoring efforts and expand the current program in approximately 18 new areas for sampling. A final form of the South Florida FHAP will be determined following an initial sampling effort when overlap with existing stations and redundancy among areas can be considered.

Figure 3-33 shows the locations in South Florida where current and proposed SAV and seagrass associated fish and invertebrate sampling will occur. Dashed boxes indicate areas where SAV and throw-trap animal sampling will overlap; solid boxes indicate current Florida Bay FHAP stations; solid circles indicate current Miami-Dade DERM stations; and open boxes indicate proposed new SAV monitoring stations. Specific information regarding the sites is provided for each area below.

Biscayne Bay. Miami-Dade DERM presently samples 100 SAV stations in Biscayne Bay between Rickenbacker Causeway and Card Sound using Braun-Blanquet cover estimates. An expanded FHAP program will include seven additional areas in the bay: BB01 – North Biscayne Bay, BB02 – Port of Miami, BB03 – North Black Point, BB04 - South Black Point, BB05 - Card Sound, BB06 - Barnes Sound, and BB07 - Manatee Bay. New SAV monitoring stations in Biscayne Bay will be restricted to the western third of the bay as appropriate since it is along the bay's western shore that effects of CERP modifications are most likely. Current Miami-Dade DERM sampling will continue and be incorporated to the extent possible into FHAP grids in each area.

Everglades-Florida Bay Ecotone. This region, a series of hydrologically linked creeks and lakes, is a broad estuarine zone between the freshwater Everglades and Florida Bay and Manatee Bay. Florida Bay FHAP currently samples SAV in two areas of north-central Florida Bay: FB01 - Madeira Bay and FB02 - Rankin Lake. Miami-Dade DERM currently samples seven areas: FB03 - Little Madeira Bay, FB04 - Joe Bay, FB05 - Trout Cove, FB06 - Long Sound, FB07 - Little Blackwater Sound, FB08 - Highway Creek, and BB07 - Manatee Bay. Five additional sampling areas are needed to characterize the full extent of this ecotone: FB09 - Terrapin Bay, FB10 - Garfield Bight, FB11 - Coot Bay, FB12 - Slagle Lake, and a station on the coastal lakes inland from Florida Bay (station not on Figure 3-33).

Florida Bay. Florida Bay FHAP has sampled ten areas (basins) within Florida Bay representing a range of conditions across the bay since the spring of 1995. The sampled basins include the following: FB13 - Blackwater Sound, FB14 - Eagle Key Basin, FB01 - Madeira Bay, FB15 - Calusa Key Basin, FB16 - Crane Key Basin, FB17 - Whipray Basin, FB02 - Rankin Lake, FB18 - Twin Keys Basin, FB19 - Rabbit Key Basin, and FB20 - Johnson Key Basin. Because of the extensive FHAP database regarding these basins and the fact that their locations are representative of the range of conditions across the bay, this sampling needs to be continued. Duck Key Basin (FB21), an area that receives freshwater inflow through

the Everglades-Florida Bay Ecotone at Trout Cove, Shell Creek, and the Boggies, may have recently changed to *Thalassia* dominance and needs to be added as an eleventh sampled basin.

Southwest Florida Estuaries and Coast. No monitoring of SAV currently occurs on the southwest mangrove coast. The Coastal Gradient Transects (described in the Greater Everglades Wetlands Module, Section 3.1.3.3) and the Southern Estuaries Module are attempting to assess the response of plant communities to CERP implementation along gradients from freshwater sloughs to coastal ecosystems. Sampling in the southwest coast's estuaries is thus needed. Sampling areas will be established at the following points near several coastal river mouths and within Whitewater Bay: SW01 - Lostman's River, SW02 - Broad River, SW03- Ponce de Leon Bay, SW04 - Oyster Bay, SW05 - North River, and SW06 - Midway Pass.

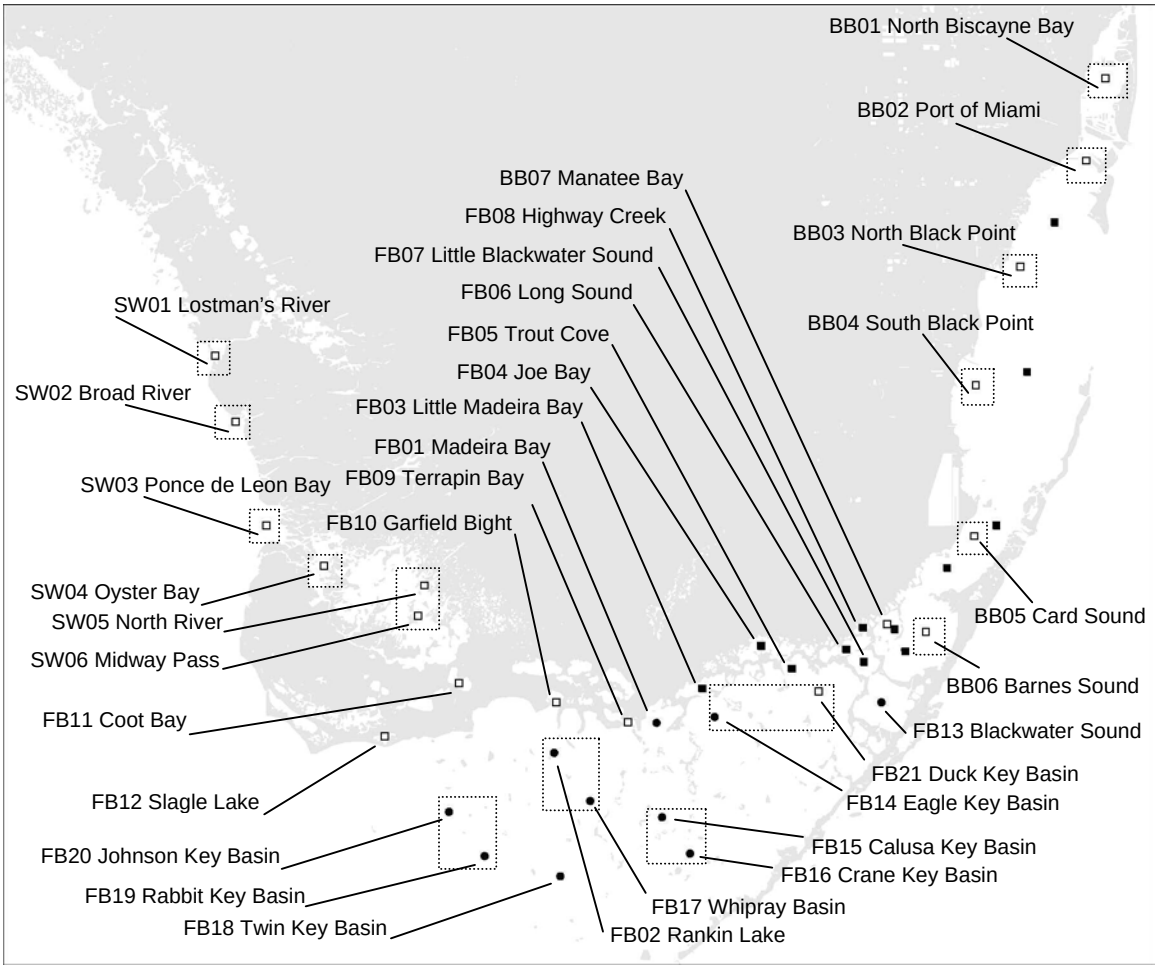


Figure 3-33: Current and Proposed SAV and Seagrass Fish and Invertebrate Monitoring and Assessment Network (small filled symbols are existing SAV monitoring stations and open small open squares are proposed SAV stations; larger dashed rectangles are proposed fish and invertebrate sampling sites)

3.2.3.4 Large-Scale Remote Sensed SAV Monitoring Program

Remote sensing will be used to evaluate spatial patterns of abundance and distribution of seagrass communities within Biscayne Bay and Florida Bay and along the southwest Florida coast. Color aerial photographs will be obtained and analyzed to create high-resolution digital benthic maps to 1) assess the present-day extent and distribution of seagrass communities; 2) determine, through repetitive sampling, patterns of change in seagrass abundance and distribution as restoration efforts proceed; and 3) develop a suite of landscape-level indicators of seagrass condition as a monitoring tool to evaluate the effects of management decisions on seagrass resources in the region.

Aerial photographs will be obtained (minimum scale 1:12,000) following parallel flight lines within the areas to be surveyed. The resulting images will be scanned, ortho-rectified, and classified to generate a basic set of classes with the spectral signatures of the common benthic habitats (e.g., seagrasses, hard-bottom, macro-algae).

Ground-reference data will be collected for each spectral category following a stratified random sampling scheme to ensure enough samples are gathered for each spectral category. The information recorded for each sample site will consist of differential GPS coordinates, depth, and bottom type based on visual observations. The reference data will be used to assign bottom type classes to the spectral categories. The high-resolution (i.e., sub-meter pixel size) digital maps thus generated will be used to evaluate the spatial extent of seagrass resources and other benthic categories. Similarly, these maps can be incorporated into a geographic information system (GIS) framework for data visualization and overlaid with other spatial data sets (e.g., satellite images or water quality data) to evaluate spatial correlations between biological and physical parameters.

The applicability of relevant landscape-level metrics such as those developed by O'Neill (1999) will be tested as indicators of present state and future patterns of change in the condition and function of seagrass habitats in South Florida. Metrics that describe landscape pattern such as patch perimeter-to-area ratio, contagion, relative patch area, and fractal dimensions will be determined explicitly from the high-resolution digital maps to be developed here and will provide important additional indicators of seagrass condition within Biscayne Bay and Florida Bay.

3.2.3.5 Seagrass Fish, Pink Shrimp, and Invertebrate Assessment Network

Seagrass habitat is critical as shelter or feeding ground, or both, for many juveniles of commercial or sport fishery value. Such species include the pink shrimp (*Farfantepenaeus duorarum*), the spotted seatrout (*Cynoscion nebulosus*), and the grouper or snapper species found on South Florida coral reefs as adults.

Pink shrimp spawn near the Dry Tortugas, migrate shoreward as larvae/postlarvae, and spend their juvenile stage as part of the Florida Bay epibenthic fauna. They recruit to the fishery when they return to the Dry Tortugas area for spawning. Several statistical analyses link catch-per-unit-of-effort (CPUE) in the Tortugas fishery to indices of freshwater inputs to Florida Bay and the southwest coast (Browder 1985, Sheridan 1996, Browder 1999). Remarkably, the relationship is sufficiently robust to serve as a basis for annual fisheries management purposes in predicting annual abundance (Sheridan 1996). Laboratory experiments have demonstrated that salinity affects juvenile pink shrimp growth and survival (Browder et al. 2002). Predicted pink shrimp CPUE was an ecological indicator used in the plan formulation stage of the CERP, where “natural system” flows, followed by the preferred alternative, consistently generated the highest predicted annual CPUE over the 31-year simulation period (USACE and SFWMD 1999). Predictions were based on a general linear model that related observed CPUE to observed flow volume across the Tamiami Trail during certain months (Browder 1999). The structure of

the predictive equation suggested an importance of flow timing as well as volume. In simulations of alternatives, the timing and volume of the NSM consistently provided the most productive conditions for pink shrimp. CPUE is an accepted index of abundance in fishery biology, especially in fisheries such as the Tortugas pink shrimp fishery that have been shown to be relatively insensitive to the level of effort. The National Marine Fisheries Service has collected pink shrimp catch and effort data on the Tortugas fishery since 1960, and a long-time series exists with which to determine variability. These data will continue to be collected and analyzed by the National Marine Fisheries Service/Southeast Fisheries Science Center (SEFSC) as part of their responsibilities under the Magnuson-Stevens Fisheries Wildlife Conservation Act without cost to the CERP or RECOVER. Because the connection between adult CPUE and freshwater input, however statistically robust, remains indirect, integrating a number of potential causative factors and relationships, a more direct pink shrimp recruitment performance measure (i.e., juvenile abundance) will also be employed (RECOVER In prep).

Throw-trap fish and invertebrate monitoring coupled with SAV monitoring will provide valuable data for development and verification of current and future pink shrimp and other higher-trophic-level ecological modeling and for interpreting faunal responses to changes in salinity and water quality. In Florida Bay, quantitative estimates of juvenile pink shrimp abundance across the bay will support one of the pink shrimp performance measures (RECOVER In prep).

Seagrass-associated fish and invertebrates have been quantitatively monitored in the Johnson Key Basin of western Florida Bay since 1983 (Robblee and DiDomenico 1991). Using a one-square meter throw-trap, the seagrass associated fish, caridean shrimp, pink shrimp, and crabs have been quantified in relation to bank, basin, and near-key habitats and in relation to microhabitat (water and sediment depth, seagrass standing crop and blade density by species, algae, etc.). Other detailed studies using the throw-trap have characterized these communities on bank-tops in relation to the loss of seagrass habitat associated with seagrass die-off and to salinity patterns across Florida Bay (Matheson et al. 1999, Matheson et al. 2001). In studies in Florida Bay, the throw trap proved substantially more efficient than either a one-meter roller-frame trawl or a sled net (Robblee and DiDomenico 1991) for catching pink shrimp.

The Seagrass Fish and Invertebrate Assessment Program will maintain the current monitoring in Johnson Key Basin. The Johnson Key Basin effort will be expanded into areas that are not currently monitored, but are likely to be affected by the CERP, by establishing throw-trap sampling in 14 new areas of Florida Bay, Biscayne Bay, and along the southwest mangrove coast. New areas will encompass 20 current or proposed FHAP sampling areas. The dashed boxes in Figure 3-33 identify the areas proposed for throw-trap sampling.

Environmental data to be collected with each throw-trap sample include salinity, temperature, and turbidity. Standard measures of seagrass habitat (water depth, sediment thickness and compaction, seagrass standing crop, blade density by species, epiphyte biomass, and species) will be collected adjacent to each throw trap sample. In addition, Braun-Blaunquet cover estimates will be made in the immediate vicinity of each throw trap sample.

Florida Bay

Expanded sampling in Florida Bay will capture a typical salinity gradient in Florida Bay and serve as elements of the current pink shrimp performance measure (RECOVER In prep). Two FHAP areas will be sampled in each of the four locations: western bay - FB19 and FB20; north-central bay – FB02 and FB17; south-central bay – FB16 and FB15; and eastern bay – FB14 and FB21. In Johnson Key Basin, throw-trap samples will be collected using both current sampling protocols (fixed point repeated measures) and FHAP-derived protocols (random sampling of 30-cell grid) for the purpose of establishing a relationship

between the existing long-term Johnson Key Basin record and a FHAP-based sampling of the 30-cell grid.

Biscayne Bay

At present, throw-trap sampling is ongoing in Biscayne Bay between Chicken Key and Turkey Point with random sampling within salinity strata in near-shore seagrass beds. Proposed throw-trap sampling will include three areas in Biscayne Bay - BB01, BB03, BB04; one area in Card Sound - BB05; and one area in Barnes Sound - BB06. A comparison between salinity strata-based sampling and 30-cell grid-based sampling will be made following initial sampling.

Southwest Florida Shelf

Throw trap sampling will be established at the following points adjacent to and in several coastal river mouths and within Whitewater Bay: SW01 - Lostman's River; SW02 - Broad River; SW03 - Ponce de Leon Bay; SW04 - Oyster Bay; SW05 - North River; and SW06 - Midway Pass.

Twenty FHAP areas will be sampled twice annually: in May-June at the end of the dry season and in September-October at the end of the wet season. In each area, throw-trap samples will be collected in a subset of cells of the 30-cell sampling grid established for FHAP and at the same location within a cell as sampled in FHAP. Sampling effort will be adjusted from an initial 10 samples per area following the first scheduled sampling. Sampling effort will be distributed among the areas as appropriate based on sample variability with the objective of detecting similar differences among areas.

Long-term throw-trap sampling in Johnson Key Basin has been stratified around sampling of bank, basin, and near-key habitats. This is appropriate in Florida Bay where these "macrohabitats" generally characterize the system. In Biscayne Bay, along the southwest mangrove coast, and in Whitewater Bay, these strata are less important due to the absence of extensive bank-top habitats. FHAP samples are collected in water greater than about 0.5 meters in depth, and it is proposed to limit throw-trap sampling similarly. This eliminates sampling the extensive banks in Florida Bay but will not limit sampling in Biscayne Bay or along the southwest coast.

3.2.3.6 Shoreline Fish Community Visual Assessment

Because of their unique position at the land-sea interface, it is within mainland mangrove habitats that CERP-related impacts are likely to be the strongest and most easily discerned from other effects. Previous studies in Florida Bay (e.g., Thayer et al. 1987, Ley et al. 1999) as well as Biscayne Bay (Faunce et al. in press, Serafy et al. in review) indicate that these mangrove habitats support high densities of juvenile and adult stages of several economically important fishes, including snappers, grunts, great barracuda, and snook, and even higher densities of their prey (e.g., silversides, killifishes and mojarras). If the CERP can realize a return of more natural salinity regimes along the mainland shoreline, bay-wide increases in fish diversity and density will be apparent in mangrove-fish assemblages.

Bi-annual monitoring of the fish assemblages that utilize Biscayne Bay mangrove-lined shorelines, which was initiated in 1998, will be continued and expanded into Florida Bay. Emphasis will be placed on evaluating relationships between the fish assemblages and variation in salinity/freshwater flow. Fish use of prop-root habitats along the mainland is compared with that along the leeward side of the northernmost Florida Keys. This has been pursued by examining seasonal and spatial variation in fish taxonomic composition and diversity as well as variation in the density and size-structure of dominant taxa that occupy these mangrove shorelines (Serafy et al. in review).

Mangrove-fish assemblages will be characterized and quantified using a modification of the visual "belt-transect" census method of Rooker and Dennis (1991). This will entail snorkeling 30-meter-long transects parallel to the shore and recording the identity, number, and the size-structure (minimum, mean, and maximum total length) of fishes observed. Measured landward from the prop-root edge, belt-transect width is 2 meters. Thus, the area censused per transect will be 60 square meters. All visual surveys will be conducted between 0900 and 1700 hours to minimize problems of low light. Although a variety of sources can be used to identify fish to species, identification of all individuals to the species level is not possible. Therefore, following Rooker and Dennis (1991), identification of problematic taxa will be done to the genus or family level (e.g., *Eucinostomus* or *Scaridae*), and following Humann (1994), small, silvery, fork-tailed fishes that tend to inhabit the water-column in large schools (e.g., *Engraulidae*, *Atherinidae*, and *Clupeidae*) will be grouped. Measurements of water temperature, salinity, dissolved oxygen, water quality, and depth will be obtained during each fish census.

The monitoring protocol compares fish assemblages associated with two mangrove shoreline types. The two shorelines correspond to those described by Lindeman et al. (1998): mangrove shorelines along the mainland and those on the leeward side of the major keys that define the eastern-southern boundaries of Biscayne and Florida Bays. Censuses are conducted during consecutive wet and dry seasons (i.e., July to September and January to March, respectively). Exact transect locations are chosen based on previous fish density and diversity information as well as measured and modeled salinity variation. Mainland census locations depend on visibility at time of sampling, but include the mangrove shorelines at the mouth of the Oleta River (north Biscayne Bay), south of Matheson Hammock (south Biscayne Bay), and then extend southwest from Card and Barnes Sounds to Cape Sable (Florida Bay). Statistical testing is for shoreline differences (mainland versus leeward side of the major keys) within each season, seasonal differences within each shoreline type, and fish-habitat relationships with emphasis on salinity and salinity variation. In addition, length-frequency distribution plots are constructed and compared for the dominant fish taxa within stable versus variable-salinity zones. Following Ley et al. (1999), literature values of minimum length-at-maturity, when available, are indicated on each length-frequency plot to reveal the life-stage(s) utilizing various mangrove shoreline areas.

3.2.3.7 Juvenile Spotted Seatrout Monitoring in Florida Bay

Spotted seatrout monitoring will determine if there is a consistent pattern of juvenile spotted seatrout distribution and abundance in the north central area of Florida Bay during restoration, thereby providing the basis to predict distribution as a function of salinity. The monitoring of juvenile spotted seatrout in Florida Bay will expand an existing program to sampling bimonthly at 18 stations in the central and western portion of the bay (from Madeira Bay to Sandy Key), ensuring that sampling occurs in the north central bay where hypersaline conditions often occur. Sampling is conducted with a small otter trawl, previously used in the NOAA Center for Coastal Fish Habitat Research monitoring program in Florida Bay (Powell et al. 2002, Powell et al. in press). The existing draft performance measure (RECOVER In prep) for spotted seatrout will be refined based on a detailed analysis of FDEP data and our collections. Salinity, turbidity, and temperature also will be measured between the predetermined 18 stations. The sampling approach will also include the following metrics at each station: seagrass standing crop and composition, salinity, sediment and water depth, turbidity, and temperature. Further, sub-sampling of seatrout collections will be evaluated for age, growth, and mortality using otolith microstructure analysis.

3.2.4 Key Uncertainties and Supporting Research

3.2.4.1 Florida Bay Sediment Dynamics: Sea Level and CERP Influences

Justification: The four South Florida sedimentary environments are 1) carbonate mud banks of Florida Bay and Biscayne Bay; 2) the coastal marl berm extending along the northern shore of Florida Bay and

within Cape Sable and the Mangrove Coast from Highland Beach north to Chatham River; 3) coastal mangrove forests with an organic substrate; and 3) transitional and freshwater wetlands with an organic peat substrate. These sedimentary environments are dynamic topographic/bathymetric features and can rapidly evolve under the stress of rapid sea level rise, changing salinity regimes, and changing freshwater depth. This project focuses on the carbonate mud banks and the coastal marl berm. It is possible to document the short-term rates of subsidence/erosion/dissection of these sediment bodies and assess their long-term evolution when destabilized.

Mudbanks of Florida Bay

The carbonate mudbanks of Florida Bay and Biscayne Bay are evolving features that have built to, or nearly to, inter-tidal level. In doing so, they have become a strong influence on circulation; residence time; salinity and nutrient patterns; zonation of floral and faunal communities; and the production, dispersal, and dissolution of sediment.

Since 1930, Florida Bay and Biscayne Bay have been subjected to a 0.7-feet relative rise in sea level and are forecast to experience an additional 1.5-2.0 feet rise in the coming century. How the carbonate/organic mudbanks within the bays are responding to the historic increased rate of sea level rise and how they will respond to additional future rise will determine the very essence of these valuable coastal bays. With available sediment loads, the mud banks can only keep up with the past and future rapid rise in sea level by building on the crest and narrowing. At some point, the bank top will be unable to keep up with sea level rise. When this occurs, increased circulation across bank top and through newly formed channels will create new circulation patterns and initiate a phase of rapid bank erosion and modification.

Coastal Marl Berm

The northern coast of Florida Bay is bordered by a nearly continuous, supratidal, storm-washover berm made of carbonate mud compacted into dense marl. From Cape Sable to Flamingo, in the west, this berm is several kilometers wide and has expanded bayward over the past 2,400 years. It is commonly referred to as the Buttonwood embankment. To the east, the berm progressively thins, is lower in elevation, and has progressively stepped landward through breaching over the past 2,400 years. Only in a few places in central and eastern Florida Bay do channels extend through the mud berm, connecting Florida Bay with the landward transitional marshes and the Everglades.

The historical and future response of this shoreline berm to rising sea level will determine the fate of the southern Everglades. It is critical to determine whether storms will build the supratidal berm upwards, keeping pace with rising sea level, or whether the sea will inundate and breach this shoreline, exposing the adjacent Everglades to increasing marine influences.

<u>Project Description:</u> The research would encompass the following specific projects:

Mudbanks of Florida Bay

- Document the vertical and lateral response (accretion and erosion) and changes in morphology that have occurred on the mudbanks in eastern, central, and western Florida Bay during the past 70 years of increased relative sea level rise and compare to the previous bank form and dynamics. Using representative banks areas in eastern central and western Florida Bay, define changes in the bank crest width and elevation, patterns and rates of flank growth, changes in vegetative cover and benthic community character, changes in the texture and composition of accreting sediment, and lateral continuity of banks.

- Determine the physical processes responsible for the growth and erosional changes observed and the role that vegetation and benthic communities (or lack thereof) have played in historical mudbank changes.

- Assess the fate of these banks over the next 50 and 100 years with anticipated accelerated sea level rise, changes in freshwater discharge into the bay, and expected stress events (i.e., hurricanes, prolonged high or low salinity conditions, nutrient stress).

Coastal Marl Berm

- Document the historical vertical and lateral growth/erosion of the coastal storm mud berm along the Everglades coast of western, central, and eastern Florida Bay and compare historical rates.

- Monitor growth/erosion along a total of 18 profiles across the berm in western, central, and eastern Florida Bay. In eastern Florida Bay, where new berms are forming landward from former, now breached, seaward berms, monitor history and growth of each berm. Design these monitoring stations so they can be used for long-term monitoring.

- Document any historical changes in form or evidence of weakening of the continuity of the coastal marl berm along its length.

- Determine the role that vegetation has played in the growth, stability, and evolution of the berm.

- Determine under what conditions earlier breaching, channel dissection, and landward overstepping of the berms occurred.

- Assess the continuity, persistence, and effectiveness of the coastal marl storm berms over the next 50 and l00 years in response to anticipated rising sea level.

Projects will involve aerial photographic analyses, field observation, and sampling, including dating of historical growth in core sequences using radiometric or other accurate historical dating methods. Projects will also establish baseline sites and berm levels (with dye marker layers or other suitable methods) from which long-term monitoring can be made of coastal berm levels. A total of at least 18 total sites in western, central, and eastern Florida Bay will be documented in the field.

3.2.4.2 Measurement of Submarine Ground Water Discharge to Biscayne Bay

Justification: Submarine ground water discharge appears to be an important component of the water budget for Biscayne Bay. Compared to rates of surface water discharge, submarine ground water discharge is relatively constant throughout the year, providing critical seagrass communities and other marine habitats with a continuous supply of fresh or brackish water, even during the dry season. Changes in the rate of ground water discharge resulting from the implementation of the CERP may also affect marine organisms that can only survive in a narrow range of salinity.

Rates and patterns of submarine ground water discharge into Biscayne Bay have been estimated by the USGS by calibrating a numerical model to the measured water levels and salinities in the monitoring wells. However, numerous attempts to measure seepage using seepage meters installed on the bottom of the bay were unsuccessful. Because the simulated estimates of submarine ground water discharge could not be compared with measured rates of submarine ground water discharge, the model results are less certain than what is needed by CERP planners.

Project Description: This project will include the following work activities:

- Directly measure submarine ground water discharge to Biscayne Bay by utilizing two advancements. First, seepage meters have been redesigned to continuously measure seepage rates using ultrasonic and heat pulse methods. These new methods substantially improve the traditional seepage meter, which recorded the cumulative seepage into a plastic bag. Second, tracer tests with sulfur hexafluoride offer a significant improvement over older methods and could refine our estimate of submarine ground water discharge to Biscayne Bay. The ground water monitoring wells already installed as part of the USGS project could be used for the tracer test.

- Evaluate the numerical model and recalibrate if necessary based on the direct measurements of submarine ground water discharge.

3.2.4.3 Biological Availability of Organic Nitrogen in Florida Bay

Justification: One hypothesis of concern to RECOVER is that algal blooms in Florida Bay are stimulated by nitrogen from the Everglades and that nitrogen loading to the bay will increase as freshwater flow increases. The spatial and temporal development of large algal blooms in Florida Bay correlate well with the runoff of water from the Everglades watershed into Florida Bay. The size of the algal blooms correlates well with the long-term, yearly, and seasonal changes in runoff. Phytoplankton production is thought to be nitrogen limited in western Florida Bay and phosphorous limited in eastern Florida Bay (Fourqurean and Robblee 1999). Loading/freshwater flow relationships have shown that nitrogen inputs to Florida Bay (in the form of dissolved organic nitrogen) increase as a function of water discharge.

Organic nitrogen could become available to microalgae through a number of different pathways. In addition to microalgae taking up organic nitrogen directly as a nutrient, bacteria oxidize organic nitrogen compounds as energy sources and release inorganic nitrogen that can then be taken up by microalgae. Furthermore, bacteria take up organic nitrogen compounds. The bacteria can be digested by protozoa that then excrete inorganic nitrogen that is available to microalgae. In addition to the enzymatic conversion of organic nitrogen to inorganic nitrogen by bacteria and/or protozoa, ultraviolet radiation photochemically breaks refractory organic nitrogen molecules down to bioavailable compounds. All these processes have been documented to occur in other ecosystems. Another possible transformation pathway is for the organic nitrogen to be processed by the benthic community in shallow Florida Bay and converted to inorganic nitrogen that is then released back into the water column. For these processes to be relevant to Florida Bay, they must occur on a time scale of months, the approximate time scale of the residence time of water in Florida Bay.

One of the objectives of the CERP is to increase the freshwater runoff into Florida Bay. This may increase organic nitrogen loading in Florida Bay. To determine if this is a potential problem, it is critical to learn how much of the organic nitrogen in the Everglades runoff into Florida Bay is biologically available.

Project Description: This project will include the following work activities:

Phase I

- Assess whether the main nitrogen source from the Everglades, dissolved organic nitrogen, can influence Florida Bay either directly or through decomposition processes

- Conduct experiments in combination with field investigations to assess the direct bioavailability of the organic nitrogen to microalgae

- Compare the abilities of different microalgae species to utilize organic nitrogen compounds
- Evaluate the role of bacteria and protozoa in making the organic nitrogen more bioavailable
- Conduct experiments on factors controlling dissolved organic material decomposition rates such as phosphorus availability, carbon:nitrogen ratio of the dissolved organic material, light intensity, temperature, salinity, sediment, or seagrass characteristics at sites of decomposition

Phase II

- If the results of these studies support the hypothesis that organic nitrogen from the Everglades stimulates algal blooms, identify the sources of nitrogen inputs to the Everglades and Florida Bay (via budgets, isotopes, organic geochemical markers)
- Measure the variation between seasons and between wet and dry years in the array of organic nitrogen molecules and the degree of refractivity and bioavailability among different organic molecules along the Everglades watershed-Florida Bay gradient
- Evaluate the role of changing salinity in affecting organic nitrogen bioavailability in Florida Bay
- Compare the variation in bioavailable nitrogen in Everglades' runoff with the variation in the algal blooms in Florida Bay
- Measure rates of nitrogen processing, especially nitrogen fixation and coupled nitrification-denitrification

3.2.4.4 Present and Past Distribution of Oysters in South Florida Coastal Complex

Justification: The historical coastal complex of South Florida was distinctly estuarine with freshwater discharging through natural channels, as sheet flow across coastal wetlands and ground water flow, as general pore seepage, and as individual artesian springs emerging from karst pipes. As a result, conditions were favorable for the oyster, *Crassostrea virginica*, to flourish and build small to extensive oyster banks and bars.

With reduction and redirection of freshwater Everglades discharge (along with many other changes to the coastal wetlands), many of these historical oyster bars and banks have been lost. Because of the abrupt episodic channelized discharge of redirected freshwater discharge, new banks have tended not to form in other locations. In a few areas on the southwest coast, new oyster growths have shifted further inland along channels and interior bays. The shell buildups of historical oyster banks and bars are mostly preserved, and these provide both critical information on the pre-modification patterns of estuarine conditions and a record of the nature of estuarine conditions in these locales.

An important part of the CERP is the reestablishment of viable estuarine conditions at the margins of Biscayne Bay and Florida Bay and along the southwest Mangrove Coast. Understanding the historical, pre-modification distribution of oyster buildups is a critical baseline to guide Everglades freshwater flow restoration.

In addition, stable isotopes in an oyster shell contain valuable information on the nature of water conditions under which the organism grew (salinity) that can likely be resolved to monthly intervals. This provides the opportunity for characterization of the historical estuarine conditions under which historical oyster bars and banks existed.

The design of the following research is to provide 1) a baseline of the distribution and nature of oyster buildups, both historical (pre-freshwater flow modification) and current; 2) a characterization of the nature of estuarine conditions under which historical oyster buildups grew, and 3) projections as to how and where habitat suitable for oysters could be reestablished under different Everglades flow restoration conditions.

Project Description: This project will include the following work activities:

- Document the historical and current distribution of oyster (*Crassostrea virginica*) buildups in the coastal and coastal wetland zone of South Florida from Biscayne Bay and Florida Bay and along the southwest coast north to the Lostman's River area

- Use a combination of historical and current aerial photographs combined with field observations and samplings (including probing and coring) and locate each area of oyster buildup both with GPS and on a GIS map data base

- For each historical and current oyster buildup occurrence, document the local distribution, geomorphological form, relation to historical or current channels, thickness, and whether the buildups are composed of oysters or are a capping veneer of preexisting topography. Define other environmental controls associated with oyster buildups

- Conduct stable isotope analysis on oyster shells from the various types of buildups in the various mapping sectors to assess the variation in freshwater influence on the mapped oyster buildups

- Correlate historical and current oyster buildups with salinity and flow characteristics of localities and historical changes therein

- Document style and rate of feedback modification of coastal systems by oyster buildups in areas where significant historical oyster buildups occurred (i.e., modification of circulation/flow patterns, reduced circulation in adjacent bay areas, and rates of accumulation on and adjacent to buildups)

- Determine flow conditions and salinities necessary for establishment and maintenance of oyster beds

- Document the research results including, but not limited to, a report summarizing observations, conclusions, and recommendations; regional maps showing the locales of historical and current oyster buildups; and local maps showing morphology and distribution of historical and current oyster buildups.

3.2.4.5 Factors Controlling Epibenthic Communities of Near-Shore Biscayne Bay

Justification: The western near-shore zone of south Biscayne Bay is expected to be especially vulnerable to change in freshwater inflow and to provide the most promising opportunities for restoration. This region of the bay provides habitat for fish and macroinvertebrates, including many species found on the reef tract and fished recreationally and commercially both on the reef tract and in the bay. Two estuarine species with pelagic larvae, pink shrimp and blue crab, use the bay as nursery grounds and support commercial and recreational fisheries within the bay. This study determines the distribution and abundance of key faunal species and communities in relation to salinity patterns, habitat, and other major influencing factors. It also aids in defining the sampling design of the monitoring plan by addressing questions about the appropriate gear, sampling frequency, and sampling strategy.

The gear proposed in the CERP monitoring effort for the epibenthic community needs special consideration. The one-meter throw trap has been the principal sampling gear used in Florida Bay since 1984 (Robblee and DiDomenico 1991, Rice 1997). In studies in Florida Bay, throw traps were substantially more efficient at catching pink shrimp than either trawl net or sled net sampling (Robblee and DiDomenico 1991). The commercial roller-frame trawl has the advantage of being able to sample a relatively large area within a short period. Furthermore, compared to the throw trap, there is less handling time for the samples from the trawl relative to the area covered (Robblee and DiDomenico 1991). However, coverage of a relatively large area is a handicap where the cover of bottom vegetation is not continuous or is heterogeneous or where salinity patterns are not exactly known and contours are complex. One disadvantage of the commercial roller-trawl gear for the present application is that it cannot operate in waters less than 1-meter deep. For this reason, Diaz (2001) developed a smaller trawl for use in less than 1-meter deep water. Because there has not been any exact quantitative comparison of the throw trap to a roller-frame trawl fitted with a hood or to the miniature trawl previously used in Biscayne Bay, gear comparisons are needed, both to help select the most appropriate gear for monitoring and to enable past data from Biscayne Bay to be examined in relation to new data collected with the throw trap.

Project Description: During the first year of the study, the most appropriate gear, frequency, and approach will be determined for use in monitoring the effect of the CERP on the epibenthic fauna of Biscayne Bay and other South Florida estuaries. The commercial roller-frame trawl, equipped with 3-millimeter hood, will be compared to the smaller, shallow-water trawl with the throw trap in comparable habitat. In each comparison, the throw trap will be used in the same water depth and habitat as the gear with which it is being compared. The relative efficiency and appropriateness of throw trap gear will be analyzed for use in sampling the shallow-water epibenthic fauna of Biscayne Bay in relation to gear previously used in Biscayne Bay. The various gear types will be standardized in relation to each other to take full advantage of past and future work. Sample size will be evaluated with respect to variance for throw trap sampling in Biscayne Bay habitat to ensure that the initial sample size, selected based on Florida Bay work, is adequate for the new habitat. During the second and third years of the study, the sampling protocol will be fine-tuned if results of gear comparisons, variance tests, and initial application of the recommended protocol suggest the necessity.

Once the appropriate gear, frequency, and approach are determined, the project will include the following activities:

- Determine the spatial and temporal variation in density and composition of epibenthic fauna and their relation to salinity and other recognized influencing factors, especially water depth and bottom type and cover.

- Sample epibenthic communities of seagrass habitat in the shallow near-shore zone (less than 1 meter and 1-2 meters) periodically using the throw trap gear and methods of Robblee and DiDomenico (1991). Emphasize the less than 1-meter zone, but include the 1-2-meter zone to better relate results to the pink shrimp fishery and to the previous work of Ault et al. (1999) and Diaz (2001).

- Position sampling transects and sites to best detect the effects of long-term water management changes and in proximity to salinity recording sites.

- Distribute sampling to distinguish faunal composition and density along gradients of water depth and canal influence and include north and south of Black Point.

- Measure salinity and other potentially influencing factors at each sampling site in order to determine their relationship to faunal density and community composition. Possible influencing

factors include salinity and temperature; sediment depth and type; and percent cover, density, type, and dominant taxa of bottom vegetation.

- Analyze faunal density and composition in relation to possible influencing factors, including recent (1 week, 2 week, 3 week, 4 week) salinity history.

- Sample fauna at a frequency of every other month initially to determine annual patterns of variation.

3.2.4.6 Salinity Relationships of Epifaunal Species in Near-Shore Biscayne Bay

Justification: Tolerance of individual species to salinity and salinity fluctuation will influence the response of the epifaunal community in Biscayne Bay to CERP implementation. Serafy et al. (1997) reported that tolerances of several fish species to salinity fluctuation in Biscayne Bay differed markedly among species, and several were intolerant of rapid salinity change. Significant species-specific differences in invertebrate fauna are also likely.

For example, survival and growth experiments with pink shrimp from Florida Bay suggested intolerance to low salinity of 2-15 parts per thousand (Browder et al. 2002) and that the highest densities of shrimp in Florida Bay are nearest to the Gulf of Mexico, rather than in close proximity to freshwater outflow. In Biscayne Bay, the density of pink shrimp is greater on the western side than eastern side (Diaz 2001). Salinity is lower and more variable on the western side of Biscayne Bay due to the presence of canals. Therefore, Biscayne Bay pink shrimp may be more tolerant of low and fluctuating salinity than Florida Bay shrimp.

Project Description: This project will conduct a series of experiments with juveniles of key epifaunal species from Biscayne Bay to determine their range of tolerance to salinity and salinity fluctuation.

3.2.4.7 Empirical Research of Fishery Resources of Biscayne Bay

Justification: Biscayne Bay contains a mosaic of interconnected habitats that are essential for a wide diversity of fishes and invertebrates, many of which support economically-important commercial and recreational fisheries. These species include pink shrimp, pinfish, bluestriped grunt, gray snapper, common snook, and spotted seatrout. Most of these fishery organisms require a sequence of habitats to complete their life cycles, with seagrass and mangrove habitats playing critical roles in the first year(s) of their lives. Among the objectives of the CERP is the modification of freshwater flows into Biscayne Bay so more natural, mesohaline salinity regimes are reestablished across its western shoreline and adjacent near-shore habitats. The habitats most likely to be affected by the CERP are the mangroves that line much of Biscayne Bay's southwestern shoreline and the near-shore seagrass beds that abut them.

Project Description: Three empirical research activities on Biscayne Bay's fishery organisms will be conducted as they relate to the CERP: 1) trophic studies that incorporate gut contents analyses and field sampling of revealed prey; 2) aging studies to determine growth trajectories in the wild; and 3) laboratory-based bioassay studies that examine the effects of salinity and salinity variation on animal foraging, growth, mortality, and/or reproduction. All three research elements will be coordinated (e.g., a focus on the same life stages of the same species).

3.2.4.8 Causal Factors of Fish Abnormalities in Biscayne Bay

Justification: Numerous studies have demonstrated the usefulness of biological markers of stress in aquatic animal populations as sensitive warning systems of adverse impacts of environmental degradation

on natural populations. Biscayne Bay's fishes have received moderate attention due to the apparently high prevalence of individuals with external abnormalities (Skinner and Kandrashoff 1988, Browder et al. 1993, Gassman et al. 1994, Alleman et al. 1995, Corrales et al. 2000). The major types of deformities observed in experimental hook-and-line and rollerframe trawl surveys in Biscayne Bay were stunted or missing fin rays, depressions in the dorsal profile, jaw deformities, and scale disorientations. The cause of these abnormalities is currently unknown, but if contaminants in the water column and/or sediments play a role, then this area of research is highly relevant to the CERP.

Species in which the above abnormalities are particularly evident are sea bream (*Archosargus rhomboidalis*), bluestriped grunt (*Haemulon sciurus*), pinfish (*Lagodon rhomboides*), and gray snapper (*Lutjanus griseus*). Gassman et al. (1994) found a significant correlation between abnormality prevalence (all fish combined) and historical aliphatic hydrocarbon concentrations in nearby sediments, but significant correlations between specific contaminants (i.e., PCBs, cadmium, copper, lead, mercury, and zinc) and specific abnormalities in specific fish species were few (e.g., the correlation between copper and fin ray abnormalities in bluestriped grunt). Gassman et al. (1994) stated that more recent data on the distribution and type of anthropogenic contaminants were needed to “implicate or eliminate” pollution as a cause of deformities found in Biscayne Bay fishes. Serafy et al. (2001) concurred, but suggested mechanical damage due to net entanglement and hook-and-line fishing may also play a role, especially as causative agents for fin ray and jaw deformities, respectively. Serafy et al. (2001) recommended further field studies, but suggested initial focus will be placed on laboratory research that examines the extent to which mechanical and toxicant stresses, both singly and in combination, are responsible for the two major abnormalities encountered in fish in the bay, namely scale disorientation and fin ray deformities.

Project Description: The long-term goal is to increase our understanding of the distribution, etiologic agents, and mechanisms of development of these abnormalities and the acquisition of more recent data on contaminant levels in the sediments and water column. Specific study objectives include the following:

- Further sampling to characterize and quantify morphological abnormalities in the most common fishes in Biscayne Bay. Determination of contaminant levels in the water column and sediments will accompany such sampling. These surveys will include prevalence estimates of the following syndromes at selected locations in the bay: a) scale abnormalities in several species of fish, particularly pinfish; b) fin ray abnormalities in gray snapper and/or bluestriped grunt; c) new types of abnormalities or previously rare abnormalities at higher levels (i.e., ulcers, saddleback, tumors, etc.).

- Conduct laboratory studies to determine mechanisms responsible for the two major abnormalities encountered in finfish in the bay, scale disorientation and fin ray deformity, using experimental approaches. Laboratory exposure experiments will be executed using fishes collected in the bay. Initial experiments will be designed to allow determination of cause-and-effect relationships. Additional protocols would then be designed to permit investigation of the mechanisms by which these agents induce deformities.

3.2.4.9 Bottlenose Dolphin Health Assessment in Biscayne Bay

Justification: Redistribution of water flow, in both quantity and timing, is anticipated for several major estuarine systems for the South Florida ecosystem and for smaller tidal creek systems as part of the implementation of the CERP. Salt marsh and sea-grass communities are examples of habitats that will be affected by changes in water flows. Changes in the introduction of toxins to both large estuarine and smaller tidal systems as a result of changes to patterns of freshwater flows may influence the health of and toxin accumulation in resident bottlenose dolphin populations.

Bottlenose dolphins are appropriate indicator animals with which to monitor quality of estuarine habitat in terms of animal health for several reasons. They are long-lived animals that accumulate contaminants in their fatty issues. Small amounts of subcutaneous blubber can be biopsied from living animals for contaminant analysis. Contaminant content can be examined in relation to the health, as reflected in histopathology, blood profiles, and other medical diagnostics. Health assessment projects using methods based on marine mammal veterinary standards have been conducted by NOAA and other entities to determine the status of bottlenose dolphin in a number of estuaries of the southeastern United States. Research has shown that groups of bottlenose dolphins are resident to particular estuaries. Since individual dolphins can be identified (primarily from dorsal fin shape or coloration) through pattern recognition methods, it has been possible to identify resident individuals in both Biscayne Bay and Florida Bay. By following the health of identifiable resident individuals, it is possible to assess the quality of estuarine habitat with respect to contaminants and their effects.

The objective of this research proposal is to monitor the health of resident dolphins in estuarine systems of South Florida. An integrated program of performance measure monitoring needs to be applied to dolphin populations in order to develop health assessment indices, including body burden analysis for toxins. Photo identification techniques are used to identify individual bottlenose dolphins in order to monitor movements and use patterns in conjunction with health assessment measurements. This project is an ongoing NOAA/National Marine Fisheries Service responsibility related to the Marine Mammal Protection Act and requires no RECOVER funding.

Project Description: This project will include the following work activities:

- Photo-ID Program - Conduct resident population studies for abundance and distribution using photographic identification of individuals by distinguishing marks along the dorsal fin. Material costs for boat and accommodations can vary.

- Biopsy Program - Blubber samples are collected via projectile dart biopsy system. The blubber sample will be used for lipophilic contaminant analysis. Collateral skin samples can be used for genetic analyses (and subsequent stock identification) and gender determination.

- Health Assessment Survey - Conduct a health assessment profile analysis, which is a combination of veterinary medical diagnostics, zoological body fat condition quantification, and toxicological analysis including physical examination, diagnostic ultrasonography, clinicopathology, urinalysis, microbiology, serologic evaluation, specimen cytologic examination, fecal analysis, milk sampling, and skin/blubber biopsy. Veterinary medical diagnostics can be truncated into a preliminary veterinary health assessment that is based on marine mammal veterinary standards, including physical examination (e.g., vital signs, sex, weight, and body temperature), urinalysis, hematology, serum chemistries, and diagnostic ultrasonography.

3.2.4.10 Manatee Abundance and Distribution Relative to Freshwater Inputs

Justification: The range of the Florida manatee (a subspecies of the West Indian manatee) varies seasonally. During summer months, manatees are widely dispersed at the lower reaches of rivers and canals and in estuaries, lagoons, and bays. During the winter, when water temperatures drop below 20 degrees Celsius, manatees typically seek natural and artificial warm waters of South Florida. Important habitat requirements for the Florida manatee include access to submerged, floating, and emergent vegetation (e.g., seagrasses and mangroves); natural freshwater sources; proximity to channels 1-2 meters deep; and access to natural springs or man-made warm water refugia during winter (Hartman 1978).

Changes in manatee populations and distribution related to changes in freshwater flows to coastal areas are anticipated to occur with the implementation of CERP projects. The redistribution of these flows (in both quantity and timing) to estuarine systems is expected to influence manatee behavior in these areas. It is important that a baseline be established relative to manatee habitat and behavioral patterns for important estuarine areas (i.e., portions of southwest Florida, Florida Bay, and Biscayne Bay).

As part of their research contribution to the CERP, the USGS initiated a study on the impacts of hydrological restoration on manatees in the Everglades National Park/Ten Thousand Islands region in June 2000. The major objectives of the study are to determine distribution, movements, and habitat use of manatees associated with coastal waters and rivers and to develop an Across Trophic Level Systems Simulation (ATLSS) model to predict manatee response to changes in hydrology achieved by the Southern Golden Gate Estates project specifically and more broadly by the CERP. Comprehensive field studies in southwest Florida involving satellite-based tracking and aerial surveys will provide data for the model and document the current distribution and status of the manatee population prior to implementation of restoration activities. Telemetry data from tagged manatees provide a valuable means of documenting the response of manatees to fluctuations in freshwater inflow and changes in distribution, abundance, and type of SAV. Strip-transect methods are proving to be a successful tool for statistically determining manatee population trends in this previously unstudied region. These findings and their integration with the manatee ATLSS model effort address specific CERP objectives:

- Develop relationship between salinity/water quality and manatee use of tidal rivers, creeks, and aquatic refugia for obtaining fresh water for drinking and sheltering from cold

- Develop relationship between hydrology (quantity, quality, and timing) on use by manatees as indicators of status of several communities, including estuaries, bays, creeks, and rivers

- Monitor the status of manatees, as an indicator species and a species of special concern

These project objectives can be used to provide supporting information for this research topic and further refine the project description for inclusion of a manatee monitoring component in the MAP.

Manatee distribution is also influenced by interactions with physical structures. The United States Fish and Wildlife Service is currently developing a scope of work with the USACE to investigate the distribution of manatees within the C&SF Project canal system. In addition to addressing causal factors related to entrapment, injury, or mortality of manatees, this effort is also expected to provide information on movements of manatees within inland coastal areas.

<u>Project Description:</u> This project will include the following work activities:

- Radio-tag a representative number of manatees within the South Florida coastal ecosystem and investigate annual movements of these tagged animals through satellite telemetry, focusing on the fall and spring migration patterns. Three to four manatees will be tagged per subregion, which include Biscayne Bay, Florida Bay, and the Ten Thousand Islands. If it is determined that the tag needs to be replaced and the animal needs to be captured, then a health assessment will be conducted for that animal during the course of tag replacement.

- Investigate the correlations between manatee distribution and abundance and seagrass habitat and freshwater flows within Florida Bay, Biscayne Bay, and southwest Florida. Develop baseline summary analysis.

This research proposal assumes that hydrological monitoring and collection of data relative to seagrass distribution proposed within other sections of this monitoring plan will provide supporting information for addressing this research topic.

3.2.5 References

Alleman, R.W., S.A. Bellmund, D.W. Black, S.E. Formati, C.A. Gove, and L.K. Gulick. 1995. An Update of the Surface Water Improvement and Management Plan for Biscayne Bay, Technical Supporting Document and Appendices. South Florida Water Management District, West Palm Beach, Florida.

Ault, J.S., G.A. Diaz, S.G. Smith, J. Luo and J.E. Serafy. 1999. An Efficient Sampling Survey Design to Estimate Pink Shrimp Population Abundance in Biscayne Bay, Florida. North American Journal of Fisheries Management 19: 696-712.

Beer, S. and M. Bjork. 2000. Measuring Rates of Photosynthesis of Two Tropical Seagrasses by Pulse Amplitude Modulated (PAM) Fluorometry. Aquatic Botany 66, 69-76.

Brand, L.E. 2001. An evaluation of the scientific basis for "restoring" Florida Bay by increasing freshwater runoff from the Everglades. South Florida Ecosystem Research and Monitoring Program, National Oceanic and Atmospheric Administration, Miami, Florida.

Browder. J.A. 1985. Relationship between pink shrimp production on the Tortugas grounds and water flow patterns in the Florida Everglades. Bulletin of Marine Science 37: 830-856.

Browder. J.A., V.R. Restrepo, J.K. Rice, M.B. Robblee, and Z. Zein-Eldin. 1999. Environmental influences on potential recruitment of pink shrimp, *Farfantepenaeus duorarum*, from Florida Bay nursery grounds. Estuaries 22: 484-499.

Browder, J.A, D.B. McClellan, D.E. Harper and M.G. Kandrashoff. 1993. A Major Developmental Defect in Several Biscayne Bay, Florida, Fish Species. Environmental Biology of Fishes 37:181-188.

Browder, J.A., Z. Zein-Eldin, M. M. Criales, M. B. Robblee, S. Wong, T. L. Jackson, and D. Johnson. 2002. Dynamics of pink shrimp (Farfantepenaeus duorarum) recruitment potential in relation to salinity and temperature in Florida Bay. Estuaries 25(6B):1355-1371.

Corrales, J., L.B. Nye, S. Baribeau, N.J. Gassman and M.C. Schmale. 2000. Characterization of Scale Abnormalities in Pinfish, *Lagodon rhomboides*, from Biscayne Bay, Florida. Environmental Biology of Fishes 57:205-220.

Diaz. G.A. 2001. Population Dynamics and Assessment of Pink Shrimp (*Farfantepenaeus duorarum*) in Subtropical Nursery Frounds. Ph.D Dissertation. University of Miami, Coral Gables Florida.

Durako, M.J., M.O. Hall, and M. Merello. 2001. Patterns of Change in the Seagrass Dominated Florida Bay Hydroscape. In: Porter, J.W., and K.G. Porter (eds). The Everglades, Florida Bay, and Coral Reefs of the Florida Keys: An Ecosystem Sourcebook. CRC Press, Boca Raton, Florida, pp. 523-537.

Faunce, C.H., J.J. Lorenz, J.E. Ley, and J.E. Serafy. In press. Size Structure of Gray Snapper (*Lutjanus griseus*) Within a Mangrove "No-Take" Sanctuary. Bulletin of Marine Science.

Fourqurean, J.W., M.J. Durako, M.O. Hall and L.N. Hefty. 2002. Seagrass Distribution in South Florida: A Multi-Agency Coordinated Monitoring Program. In: Porter, J.W., and K.G. Porter (eds), The Everglades, Florida Bay, and Coral Reefs of the Florida Keys: An Ecosystem Sourcebook. CRC Press, Boca Raton, Florida, pp. 497-522.

Fourqurean, J.W., and M.B. Robblee. 1999. Florida Bay: A History of Recent Ecological Changes. Estuaries 22(2B): 345-357.

Gassman, N.J., L.B. Nye, and M.C. Schmale. 1994. Distribution of Abnormal Biota and Sediment Contaminants in Biscayne Bay, Florida. Bulletin of Marine Science 54:929-943.

Hartig, P., K. Wolfstein, S. Lippemeier, and F. Colijn. 1998. Photosynthetic Activity of Natural Microphytobenthos Populations Measured by Fluorescence (PAM) and 14C-Tracer Methods: A Comparison. Marine Ecology Program Series 166: 53-62.

Hartman, D.S. 1978. West Indian Manatee. In: Layne, J.N. (ed). Rare and Endangered Biota of Florida. Volume 1. Mammals. University Presses of Florida, Gainesville, Florida, pp. 27-39.

Humann, P. 1994. Reef Fish Identification: Florida, Caribbean, Bahamas. New World Press, Jacksonville Florida.

Kamermans, P., M.A. Hemminga, and D.J. De Jong. 1999. Significance of salinity and silicon levels for growth of a formerly estuarine eelgrass (*Zostera marina*) populations (Lake Grevelingen, The Netherlands). Marine Biology 133: 527-539.

Ley, J.A., C.C. McIvor, and C.L. Montague. 1999. Fishes in Mangrove Prop-Root Habitats of Northeastern Florida Bay: Distinct Assemblages Across an Estuarine Gradient. Estuarine, Coastal and Shelf Science 48: 701-723.

Lindeman, K.C., G.A. Diaz, J.E. Serafy, and J.S. Ault. 1998. A spatial framework for assessing cross-shelf habitat use among newly settled grunts and snappers. Proceedings of the Gulf and Caribbean Fisheries Institute 50: 385-416.

Loftis, J.C., and R.C. Ward. 1980. Sampling Frequency Selection for Regulatory Water Quality Monitoring. Water Resources Bulletin 16 (3): 501-507.

Long, E.R., M.J. Hameedi, G.M. Sloane, and L.B. Read. 2002. Chemical contamination, toxicity, and benthic community indices in sediments of the lower Miami River and adjoining portions of Biscayne Bay, Florida. Estuaries 25(4A):622-637.

Matheson, R.E., Jr., D.K. Camp, S.M. Sogard, and K.A. Bjorgo. 1999. Changes in seagrass-associated fish and crustacean communities on Florida Bay mud banks: the effects of recent ecosystem changes. Estuaries 22(2B): 534-551.

Matheson, R.E., D.K. Camp, M.B. Robblee, G.W. Thayer, L.P. Rosas, and D.L. Meyer. 2001. Distribution and Abundance of Seagrass-Associated Fauna in Florida Bay: The effects of salinity and other habitat variables on resident fish and selected decapod crustaceans. In: Proceedings 2001 Florida Bay Science Conference, Key Largo, Florida, April 23-26, 2001, p.192-194.

Mueller-Dombois, D. and H. Ellenberg. 1974. Aims and Methods of Vegetation Ecology. John Wiley and Sons, New York.

O'Neill, R.V. 1999. Recovery in complex ecosystems. Journal of Aquatic Ecosystem Stress and Recovery 6:181-187.

Powell, A.B., R.T. Cheshire, E.H. Laban, J. Colvocoresses, P. O'Donnell, and M. Davidian. In press. Growth, mortality and hatchdate distributions of larval and juvenile spotted seatrout, *Cynoscion nebulosus*, in Florida Bay, Everglades National Park. Fishery Bulletin.

Powell, A.B., M.W. Lacroix, and R.T. Cheshire. 2002. An evaluation of northern Florida Bay as a nursery area for red drum, *Sciaenops ocellatus*, and other juvenile and small resident fishes. Technical Memorandum NMFS-SEFSC-485, National Oceanic and Atmospheric Administration (NOAA), Miami, Florida.

Ralph, P.J. 1999. Photosynthetic response of *Halophila ovalis* (R. Br.) Hook. f. to combined environmental stress. Aquatic Botany 65: 83-96.

Ralph, P.J., and M.D. Burchett. 1995. Photosynthetic responses of the seagrass *Halophila ovalis* (R. Br.) Hook. f. to high irradiance stress, using chlorophyll *a* fluorescence. Aquatic Botany 51: 55-66.

Ralph, P.J., R. Gademan, and W. C. Dennison. 1998. In situ seagrass photosynthesis measured using a submersible, pulse amplitude modulated fluorometer. Marine Biology 132:367-373.

RECOVER. 2003. Quality Assurance Systems Requirements (QASR). RECOVER, c/o South Florida Water Management District, West Palm Beach, Florida, June 23, 2003 draft.

RECOVER. In prep. Performance Measure Documentation Report. RECOVER c/o South Florida Water Management District, West Palm Beach, Florida.

Rice, J.K. 1997. An analysis of environmental factors influencing juvenile pink shrimp (*Penaeus duorarum*) abundance in southwest Florida. Masters Thesis, University of Miami, Coral Gables Florida.

Robblee, M.B., and W.J. DiDomenico. 1991. Seagrass die-off threatens ecology of Florida Bay. Park Science 11(4):21-23.

Robertson, D.M., and E.D. Roerish. 1999. Influence of various water quality sampling strategies on load estimates for small streams. Water Resources Research 35 (12): 3747-3759.

Rooker, J.R., and G.D. Dennis. 1991. Diel, lunar, and seasonal changes in a mangrove fish assemblage of southwestern Puerto Rico. Bulletin of Marine Sciences 49:684-689.

Rudnick, D.T., Z. Chen, D. Childers, J. Boyer, and T. Fontaine. 1999. Phosphorus and nitrogen inputs to Florida Bay: the importance of the Everglades watershed. Estuaries 22:398-416.

Serafy, J.E., K.C. Lindeman, T.E. Hopkins, and J.S. Ault. 1997. Effects of freshwater canal discharge on fish assemblages in a subtropical bay: field and laboratory observations. Marine Ecology Progress Series 160: 161-172.

Serafy, J.E., J.S. Ault, P. Ortner, and R. Curry. 2001. Coupling Biscayne Bay's natural resources and fisheries to environmental quality and freshwater inflow management. In: Biscayne Bay Partnership Initiative, Science Team Final reports, Miami, Florida, pp 163-174.

Serafy, J.E., C.E. Faunce, and J.J. Lorenz. In review. Mangrove Shoreline Fishes of Biscayne Bay, Florida. Bulletin of Marine Science.

Sheridan, P.F. 1996. Forecasting the fishery for pink shrimp, *Penaeus duorarum*, on the Tortugas grounds, Florida. Fishery Bulletin 94: 743-755.

Skinner, R.H., and W. Kandrashoff. 1988. Abnormalities and diseases observed in commercial fish catches from Biscayne Bay, Florida. In: J. Browder (ed.) Aquatic Organisms as Indicators of Environmental Pollution. AWRA monograph series #12, Water Resources Bulletin 24, pp. 961-966.

Spooner, J.D., A. Dickey, and J.W. Gilliam. 1990. Determining and increasing the statistical sensitivity of nonpoint source control grab sample monitoring programs. In: Proceedings: Design of Water Quality Information Systems, Information Series No. 61, Colorado Water Resources Research Institute, Ft. Collins, Colorado.

Summers, K. Environmental Monitoring and Assessment Program, United States Environmental Protection Agency, Region IV, Atlanta, Georgia.

Thayer, G.W., D.R. Colby, and W.F. Hettler. 1987. utilization of the red mangrove prop root habitat by fishes in South Florida. Marine Ecology Progress Series 35: 25-38.

USACE and SFWMD. 1999. Central and Southern Florida Project Comprehensive Review Study Final Integrated Feasibility Report and Programmatic Environmental Impact Statement. Jacksonville District, United States Army Corps of Engineers, Jacksonville, Florida, and South Florida Water Management District, West Palm Beach, Florida.

3.3 NORTHERN ESTUARIES MODULE

3.3.1 Introduction

The Northern Estuaries Module includes the Caloosahatchee Estuary (Figure 3-34), St. Lucie Estuary, Indian River Lagoon, Loxahatchee River Estuary, and Lake Worth Lagoon (Figure 3-35). Figures 3-36 through 3-39 illustrate the simplified conceptual ecological models relative to the Comprehensive Everglades Restoration Plan (CERP) for each ecosystem. The models describe a minimum set of ecological indicators for each estuary to be monitored (boxes) and the hypothesized relationships of these indicators to identified stressors (arrows). Appendix A presents a more complete description of these regional models.

A number of CERP projects are expected to influence the stressors and attributes described in these simplified conceptual ecological models. Some of these effects will be direct, others indirect. A summary of the projects expected to affect each estuary is provided in Appendix B.

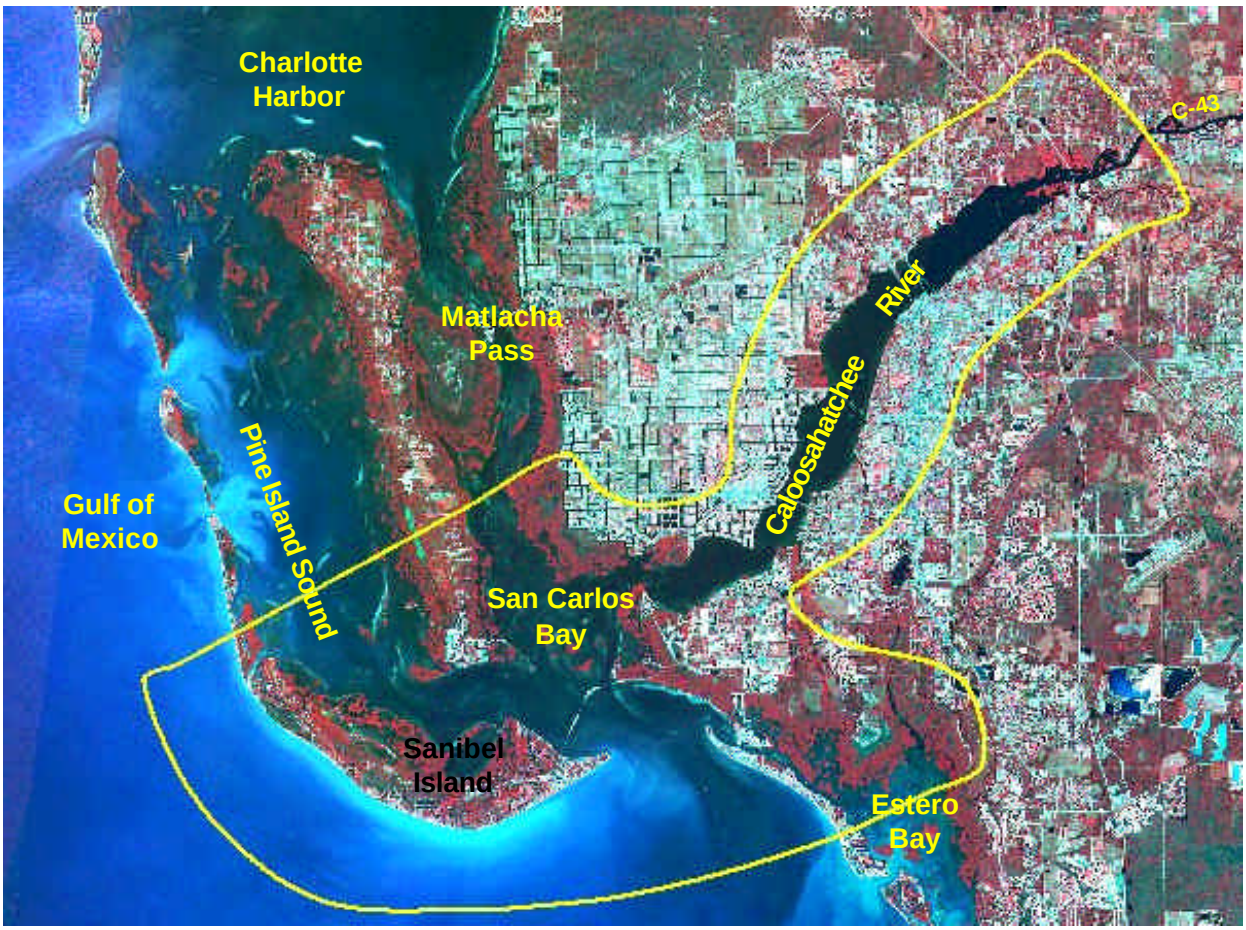


Figure 3-34: Northern Estuaries Module Boundary on the West Coast of Florida – Caloosahatchee Estuary

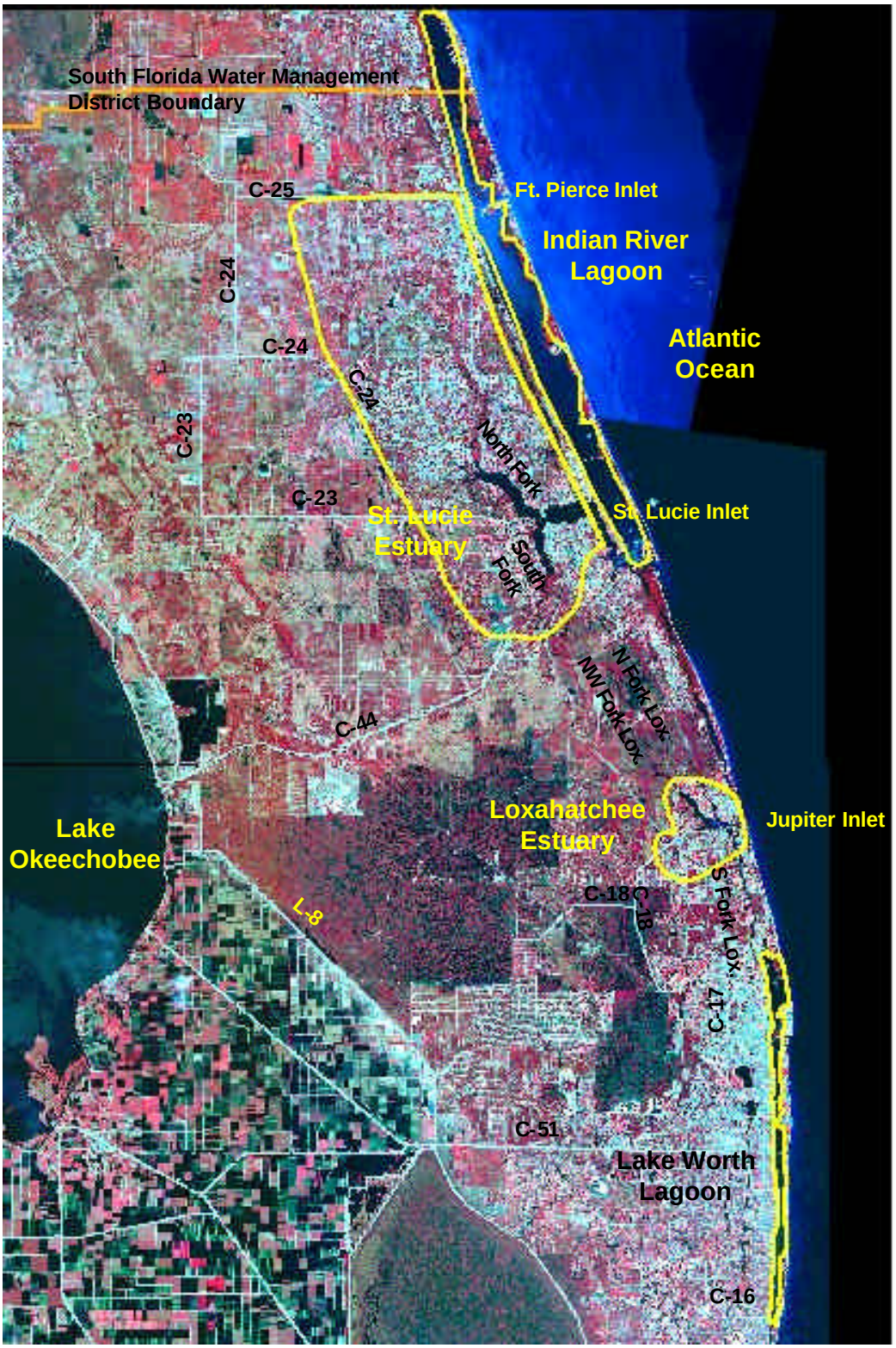


Figure 3-35: Northern Estuaries Module Boundary on the East Coast of Florida – St. Lucie Estuary, Indian River Lagoon, Loxahatchee River Estuary, and Lake Worth Lagoon

3.3.1.1 Caloosahatchee Estuary

The primary source of freshwater inflow to the Caloosahatchee Estuary is the highly altered Caloosahatchee River. In the Caloosahatchee Estuary, the alteration of flows has altered or eliminated upstream oligohaline habitat (Chamberlain and Doering 1998). CERP projects proposed for this watershed are designed to provide more natural freshwater flow regime from the basin to restore and support a healthy estuarine community.

The eastern oyster (*Crassostrea virginica*), several species of submerged aquatic vegetation (SAV), and fishes have been identified as important indicators for the Caloosahatchee Estuary. Oyster bars and seagrass beds provide important habitat for estuarine organisms. Fish are an integral component of the estuarine food web and have a significant societal value for sport and commercial fishing (Stickley 1984).

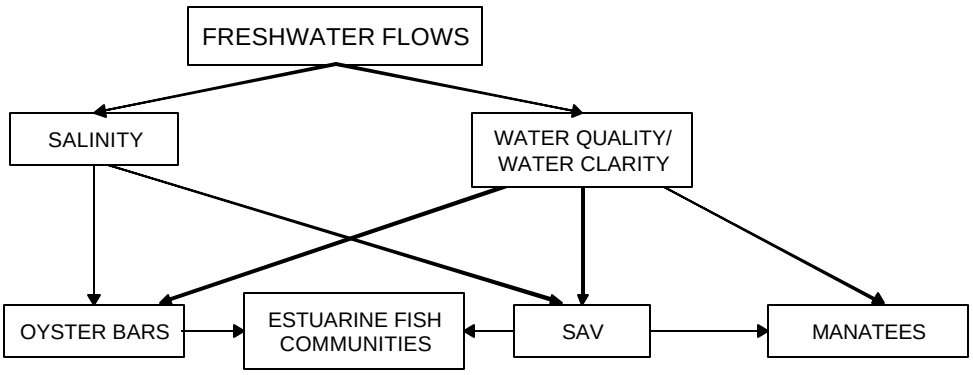


Figure 3-36: Simplified Conceptual Ecological Model of the Caloosahatchee Estuary to Reflect Expected CERP Influences

3.3.1.2 St. Lucie Estuary and Indian River Lagoon

The St. Lucie Estuary has been significantly altered by human activities. These activities include the construction of major canals (C-23, C-24, and C-44) that rapidly drain their watersheds into the St. Lucie Estuary and ultimately the southern Indian River Lagoon. Additionally, the C-44 canal provides an outlet for Lake Okeechobee water to be discharged to the estuary. As a result, freshwater inflows are extremely variable and tend to be too great in the wet season and too little in the dry season to support healthy, sustainable estuarine communities.

Oyster and SAV beds provide important habitat for numerous organisms and, along with juvenile fishes, are indicators of a healthy estuary. CERP efforts focus on establishing inflow regimes that will provide appropriate salinity ranges to reestablish and maintain these key organisms in the St. Lucie Estuary and the Indian River Lagoon.

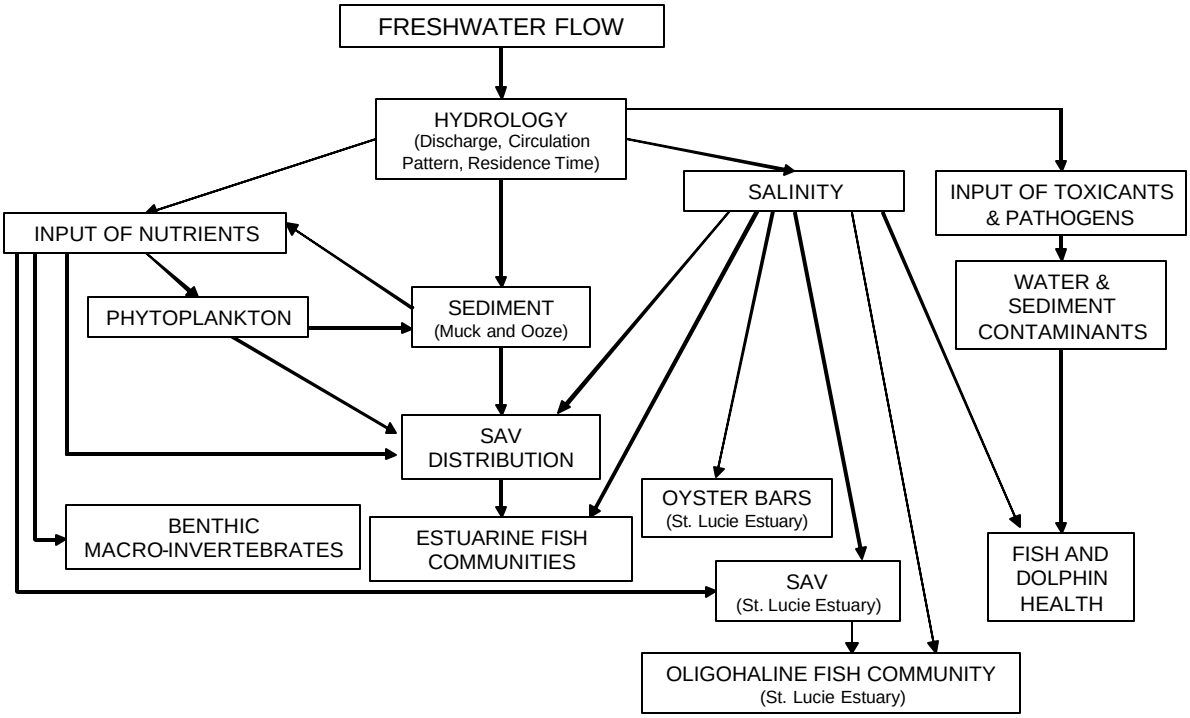


Figure 3-37: Simplified Conceptual Ecological Model of the St. Lucie Estuary and Indian River Lagoon to Reflect Expected CERP Influences

3.3.1.3 Loxahatchee River Estuary

The hydrologic conditions of the Loxahatchee Basin have been extensively altered by the construction of canals, channelization of natural waterways, drainage and/or impoundment of wetlands, and stabilization of Jupiter Inlet to the Atlantic Ocean. Construction of the G-18 canal resulted in severance of the Northwest Fork of the Loxahatchee River from its headwaters, the Loxahatchee Slough. This has resulted in periodic shortages of water for the Northwest Fork and extreme flows into the Southwest Fork during storm events. Saltwater intrusion upstream into the Northwest Fork of the Loxahatchee River has resulted in the loss of six river miles of cypress swamp.

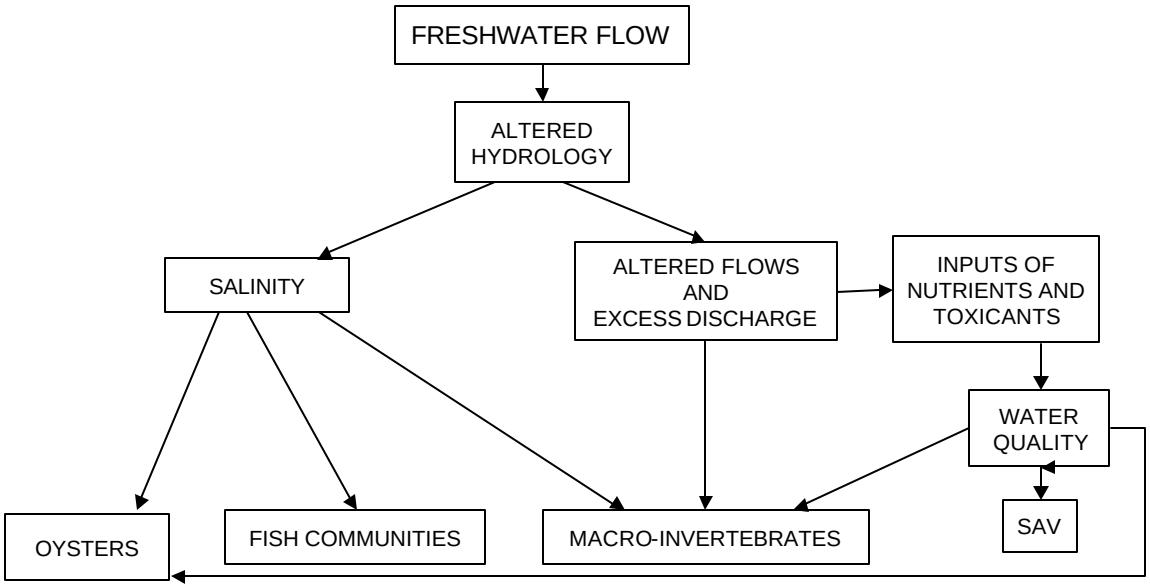


Figure 3-38: Simplified Conceptual Ecological Model of the Loxahatchee River Estuary to Reflect Expected CERP Influences

3.3.1.4 Lake Worth Lagoon

Historically, Lake Worth Lagoon was a freshwater lake with drainage from swamps along the western edge. Creation of permanent inlets to the lagoon has changed its character from freshwater to estuarine. Cumulative impact of the anthropogenic activities over the past 100 years has significantly altered the Lake Worth Lagoon environment, although regionally important natural resources remain. Alterations affecting the hydrology of the lagoon include construction and development of major drainage canals (C-51, C-17, and C-16), shoreline bulkhead construction, filling, causeway construction, channel dredging, and port development. In particular, discharges from the C-51 canal to the lagoon have produced episodic releases of large amounts of fresh water that have adversely impacted estuarine biological communities within the lagoon.

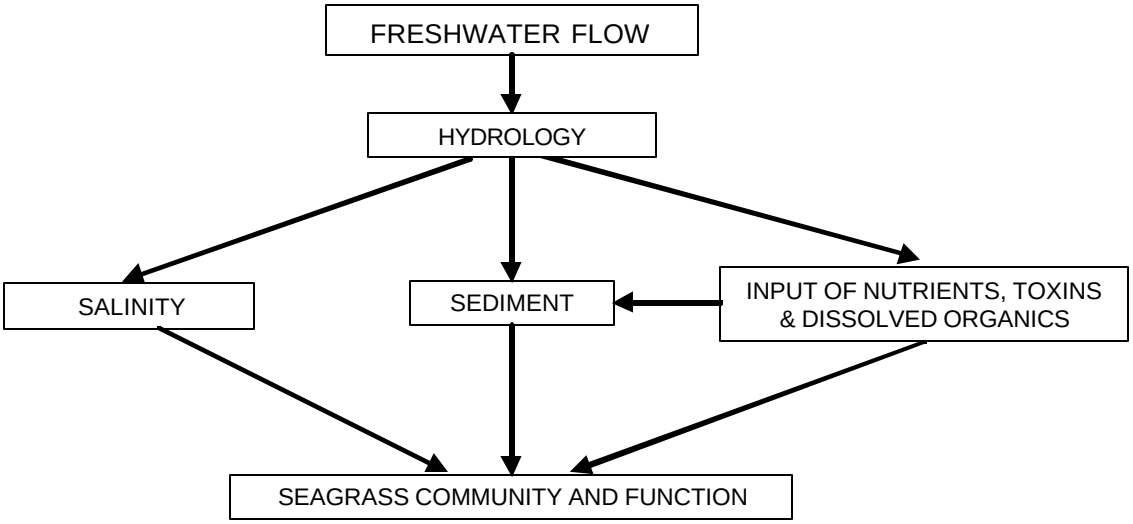


Figure 3-39: Simplified Conceptual Ecological Model of the Lake Worth Lagoon to Reflect Expected CERP Influences

3.3.2 Ecological Premises and CERP Hypotheses as the Basis for Monitoring Components and Supporting Research

Three overarching hypotheses form the basis for most of the CERP restoration goals and strategies for the Northern Estuaries. These relate to the effects of hydrology on 1) freshwater flows and salinity regimes, 2) water quality, and 3) estuarine epibenthic communities. Monitoring and assessment associated with each of these premises is dependent on the South Florida Hydrology Monitoring Network (Section 3.5).

Figures 3-40 through 3-42 illustrate the linkages of the ecological premises to CERP hypotheses, monitoring components, and key uncertainties and supporting research. Supporting research generally originates from monitoring components, in which case research supports the interpretation of monitoring results. In some cases, supporting research originates directly from a CERP hypothesis, and research will be required to develop an appropriate monitoring component. These linkages are indicated by a red arrow. Research that does not link to monitoring components or to CERP hypotheses has also been identified in this module. However, this research may not be the responsibility of this monitoring program.

A summary of the monitoring components and supporting research for the Northern Estuaries Module is listed in Table 3-9 and described in detail in the following sections. The list of research topics include those identified during the development of the current version of the Monitoring and Assessment Plan (MAP). This list has yet to be prioritized, and it is anticipated that additional research topics of equal or higher priority will be identified in the future, including those related to water quality.

The process used to develop the monitoring plan for the Northern Estuaries Module, and all of the other modules, is described in Section 2.0, Development of the CERP Monitoring Plan and Adaptive Management Program. The strategy for prioritizing and implementing monitoring components and research topics is discussed in Section 5.0, Implementation Strategy for the CERP Monitoring and Assessment Plan.

3.3.2.1 Freshwater Inflows and Salinity Regimes (Figure 3-40)

Ecological Premise: Prior to water management, natural patterns of freshwater inflow to Caloosahatchee Estuary, St. Lucie Estuary, Loxahatchee River Estuary, and Lake Worth Lagoon sustained an ecologically appropriate range of salinity conditions in coastal areas with fewer high and low salinity extremes.

CERP Hypothesis: The construction and operation of water storage and treatment facilities in the Northern Estuaries regions will provide salinity envelopes that avoid ecologically damaging high and low salinity extremes.

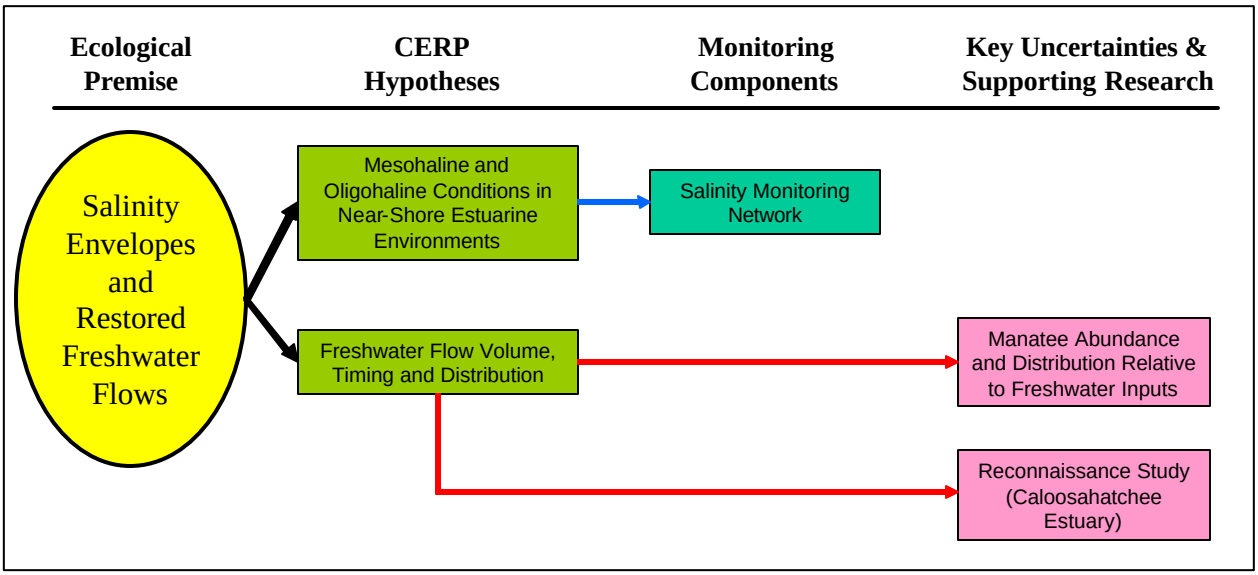


Figure 3-40: Diagram Depicting Relationships between the Ecological Premise, CERP Hypotheses, Monitoring Components, and Supporting Research for Freshwater Flows and Salinity Regimes in the Northern Estuaries

Adaptive Management Question: Will the restoration of more natural upstream hydrological conditions achieve the above physical system objectives? What further actions may be required to accomplish these objectives?

3.3.2.2 Water Quality (Figure 3-41)

Ecological Premise: The predrainage Caloosahatchee, St. Lucie, Indian River Lagoon (post-inlet construction), Lake Worth Lagoon (post-inlet construction), and Loxahatchee River estuarine systems were characterized by freshwater inflow primarily from direct rainfall and basin runoff that resulted in low nutrient inputs within the estuaries compared to present conditions.

CERP Hypothesis: The restoration of hydrology toward Natural Systems Model (NSM) conditions within the Northern Estuaries will result in a reduction in nutrient concentrations and loads from inflow structures at levels that provide water quality conditions that reduce the frequency and intensity of algal blooms and epiphytic plant growth and improve water clarity sufficient to promote establishment of oysters, seagrasses, and other SAV in the estuaries. Additionally, restoration of volume, timing, and spatial distribution of freshwater flows will provide for conditions within the Caloosahatchee, St. Lucie,

Loxahatchee River and Lake Worth Lagoon estuarine systems that result in reducing the anthropogenic stress on fish health and/or dolphin populations (where applicable) by reducing contaminant loads and reducing the input, transport, resuspension, and accumulation of sediments/muck and ooze, which sequester and concentrate available toxicants, to further improve water quality and enhance the abundance and diversity of estuarine epibenthic communities, such as benthic macroinvertebrates.

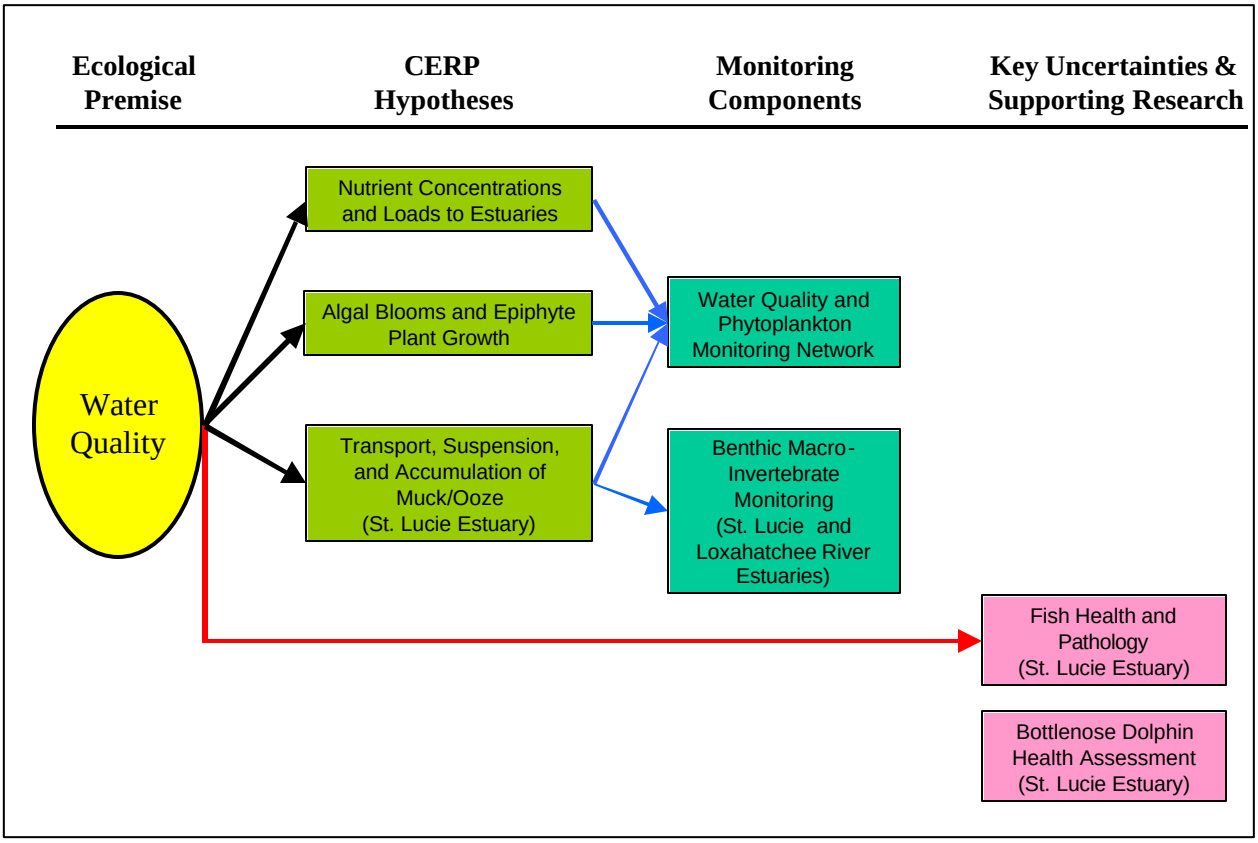


Figure 3-41: Diagram Depicting Relationships between the Ecological Premise, CERP Hypotheses, Monitoring Components, and Supporting Research for Water Quality in the Northern Estuaries

Adaptive Management Question: Will the restoration of more natural patterns of water delivery to the Northern Estuaries achieve these objectives? What further actions may be required to achieve these water quality objectives?

3.3.2.3 Estuarine Epibenthic Communities (Figure 3-42)

Ecological Premise: Prior to upstream water management (and post-inlet construction), the Northern Estuaries exhibited an ecologically appropriate range of salinity conditions, with fewer salinity extreme events, and supported broader coverage and higher diversity of SAV and other epibenthic communities.

CERP Hypotheses:

Caloosahatchee Estuary

The restoration of hydrology toward NSM conditions will provide estuarine habitat conditions so as to 1) improve the spatial and structural characteristics of submerged plant communities, particularly *Vallisneria americana*, 2) improve the recruitment and survivorship of the eastern oyster, and 3) promote the recovery of the relative abundance and distribution of fish communities.

St. Lucie Estuary and Indian River Lagoon

The restoration of hydrology toward NSM conditions will provide estuarine habitat conditions so as to 1) improve the spatial and structural characteristics of submerged plant communities, 2) promote desired shifts in fish community structure and composition, and 3) promote the expansion of eastern oyster bar communities where ecologically appropriate.

Loxahatchee River Estuary

Improved management of hydrologic conditions in the Loxahatchee River watershed will provide for protection and enhancement of SAV and benthic macroinvertebrate communities in the estuary.

Lake Worth Lagoon

The restoration of hydrology toward NSM conditions will provide estuarine habitat conditions so as to 1) improve the spatial and structural characteristics of submerged plant communities and 2) promote the recovery of the abundance and distribution of fish communities appropriate for salinity conditions.

Adaptive Management Question: Will the restoration of favorable flow and salinity regimes achieve restoration objectives for estuarine epibenthic habitats, thus providing for an increase in the distribution and density of representative estuarine fauna? If not, what additional changes in the flow and salinity regimes are necessary?

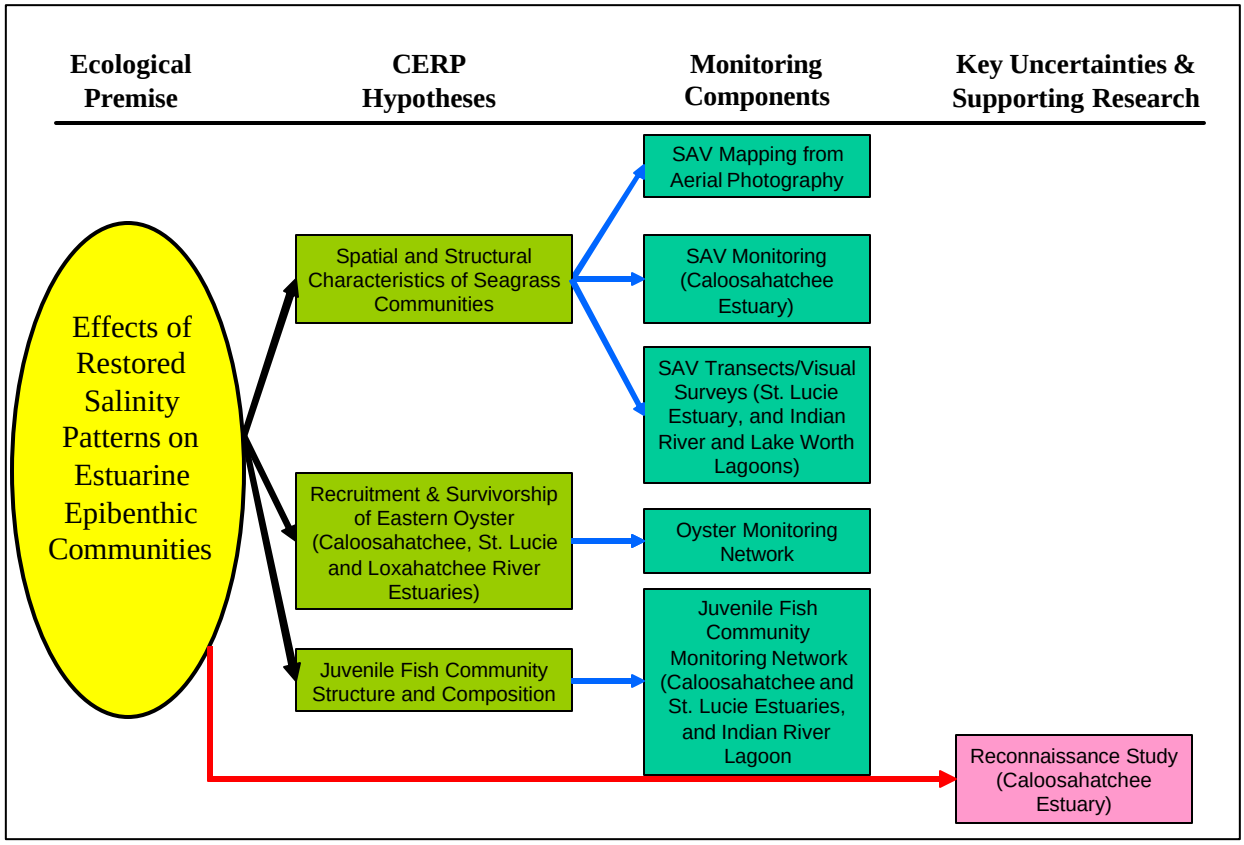


Figure 3-42: Diagram Depicting Relationships between the Ecological Premise, CERP Hypotheses, Monitoring Components, and Supporting Research for Estuarine Epibenthic Communities in the Northern Estuaries

3.3.2.4 Summary of Monitoring Components and Key Uncertainties and Supporting Research

Table 3-9 summarizes the monitoring components and key uncertainties and supporting research for the Northern Estuaries Module. The section of this document in which the item is discussed is provided in the second column of Table 3-9 for reference.

The system-wide assessment performance measures will be published in a separate document, the Performance Measure Documentation Report (RECOVER In prep). Each MAP monitoring component has at least one corresponding performance measure. For reference, the performance measure identification number or numbers are provided in the last column of Table 3-9.

Table 3-9: Monitoring Components and Key Uncertainties and Supporting Research for the Northern Estuaries

Monitoring Components	MAP Section	Performance Measure Number
Salinity Monitoring Network	3.3.3.1	NE-A1 NE-A2
Water Quality and Phytoplankton Monitoring Network	3.3.3.2	NE-A10 NE-A11 NE-A12 NE-A13 NE-A14 NE-A15 NE-A16 NE-A17
SAV Mapping from Aerial Photography	3.3.3.3	NE-A8
SAV Monitoring for Caloosahatchee Estuary	3.3.3.4	
SAV Transects/Visual Surveys for St. Lucie Estuary/Indian River Lagoon, Lake Worth Lagoon, and Loxahatchee River Estuary	3.3.3.5	
Oyster Monitoring Network	3.3.3.6	NE-A5
Juvenile Fish Community Monitoring Network (Caloosahatchee Estuary, St. Lucie Estuary/Indian River Lagoon)	3.3.3.7	NE-A7
Benthic Macroinvertebrate Monitoring (St. Lucie Estuary, Loxahatchee River Estuary)	3.3.3.8	NE-A6
Key Uncertainties and Supporting Research		
Reconnaissance Study of Caloosahatchee	3.3.4.1	
Fish Health and Pathology in the St. Lucie Estuary	3.3.4.2	
Bottlenose Dolphin Health Assessment in St. Lucie Estuary	3.3.4.3	
Manatee Abundance and Distribution Relative to Changes in Freshwater Flows and Seagrass Distribution as a Result of Implementation of CERP Projects	3.3.4.4	

3.3.3 Monitoring Components

3.3.3.1 Salinity Monitoring Network

Caloosahatchee Estuary

The salinity envelope for the Caloosahatchee Estuary will be monitored using data collected from six continuous salinity recorders, operated by the South Florida Water Management District (SFWMD), distributed throughout the estuary (Figure 3-43).

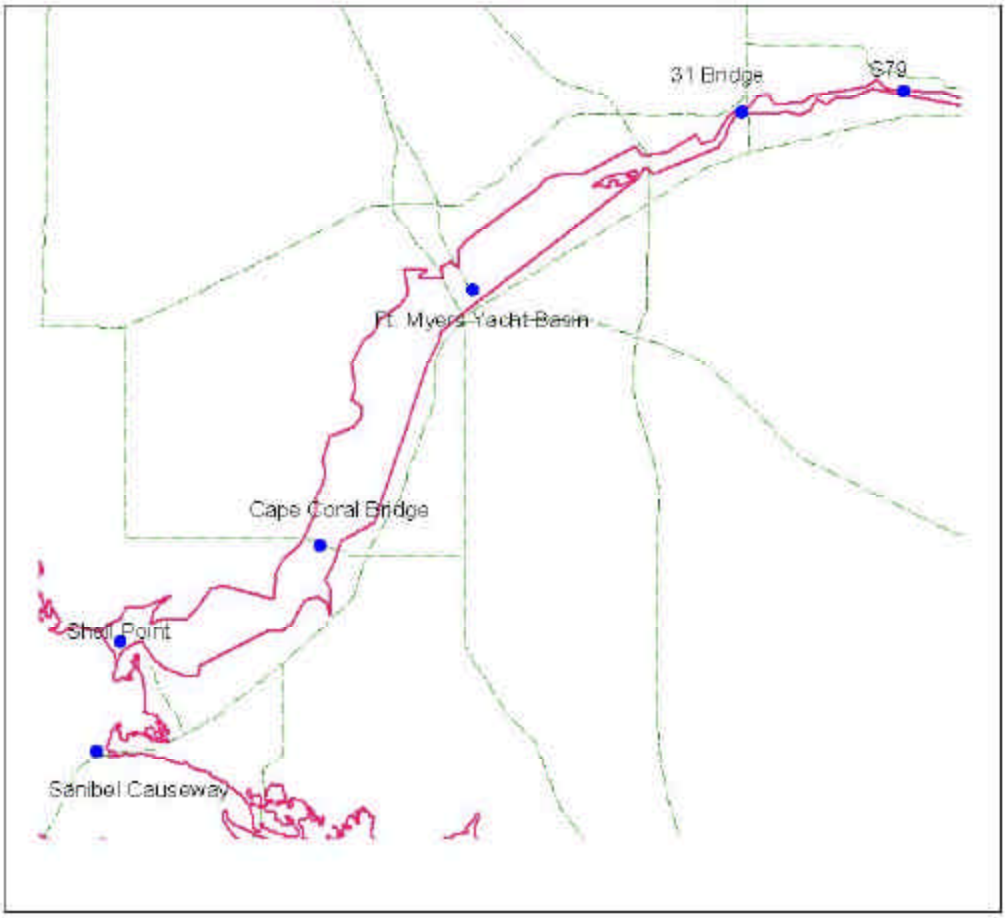


Figure 3-43: Continuous Salinity Recorder Sites in the Caloosahatchee Estuary

St. Lucie Estuary

The REstoration COordination and VERification (RECOVER) Water Quality Team has proposed a number of new sites to include an additional flow station and two salinity stations in the south fork of the St. Lucie Estuary (SE sites in Figure 3-45 in the next section). These would be fixed telemetry stations.

Lake Worth Lagoon

The Florida Department of Environmental Protection (FDEP) currently monitors salinity on a monthly basis at the eight water quality sampling locations depicted in Figure 3-47 (see the next section). Continuous salinity recorders will need to be installed at key locations throughout the lagoon in order to provide information to define an appropriate salinity envelope for the lagoon that will support a more stable and persistent natural biological community.

3.3.3.2 Water Quality and Phytoplankton Monitoring Network

Increases in the quantity and decreases in the quality of water released to the Caloosahatchee Estuary, St. Lucie Estuary, Indian River Lagoon, Loxahatchee River Estuary, and Lake Worth Lagoon due to the modifications inherent in the original Central and Southern Florida (C&SF) Project have resulted in

degradation of water quality in the estuaries. Urban and agricultural development in these watersheds has increased nutrient loading rates and concentrations to these estuaries, which has resulted in increased incidence and severity of algal blooms; degradation in water clarity; loss of extent and density of seagrass beds; increased rate of detrital accumulation of reducing estuarine sediments, which have in turn resulted in hypoxia; failure to meet Class III marine dissolved oxygen standards; and degradation of benthic faunal communities. Future CERP projects that will be constructed upstream from the estuaries and include reservoirs to retain wet season runoff, modification of drainage and/or canal discharge patterns, or changes in sources of fresh water to the estuaries may also affect water quality nutrient concentrations and loads to the estuaries.

CERP projects were not formulated to address toxicants, but these pollutants are considered constraints on the restoration effort. CERP projects that redistribute water may affect fate and transport of existing contaminated sediments already present in the Northern Estuaries and may introduce or alter potential for release of contaminants to previously uncontaminated sensitive areas. Also, changes in water management practices may affect conveyance of contaminated sediments or change exposure pathways. Therefore, these pollutants must be measured and assessed, and corrective action must be taken if the geographic extent or degree of sediment toxicity increases as a result of CERP implementation.

CERP Projects Influence

Water quality monitoring is intended to 1) document and evaluate changes in nutrient and pollutant loads transported to the Caloosahatchee Estuary, the St. Lucie Estuary and Indian River Lagoon, Loxahatchee River Estuary, and Lake Worth Lagoon and 2) document water quality trends of the estuarine and lagoon waters that are anticipated to occur as a result of upstream CERP projects.

Caloosahatchee Estuary. For the Caloosahatchee Estuary, the CERP C-43 Storage Reservoir and the Caloosahatchee River Basin Aquifer Storage and Recovery projects will be designed to capture runoff from C-43 basin and releases from Lake Okeechobee. It is anticipated that the reservoir will provide some improvements in water quality in conjunction with water supply benefits, some flood attenuation, and environmental water supply deliveries to the Caloosahatchee Estuary. Water quality benefits expected from the cumulative effect of these projects include reduced salinity fluctuations and reduced nutrient loads to the estuary.

St. Lucie Estuary and Indian River Lagoon. In the watersheds of the St. Lucie Estuary and Indian River Lagoon, the CERP features that will be constructed in the region include a system of reservoirs, storm water treatment areas, and natural wetland areas (Ten-Mile Creek Critical Project and projects resulting from the Indian River Lagoon Feasibility Study, such as Allapattah Ranch). These projects will reduce peak flows, restore an acceptable salinity regime, and reduce nutrient loads delivered to tide. These will operate in combination with agricultural and urban best management practices in the area and will affect water quality in the C-23, C-24, C-44, and C25 canals. Other monitoring is underway by the SFWMD to estimate nutrient loading from the local tidal basin and urban areas into the St. Lucie Estuary.

Loxahatchee River Estuary. For the Loxahatchee River Estuary, the proposed monitoring plan is intended to document improvement in freshwater deliveries and monitor pollutant loading and overall water quality within the estuary. The Loxahatchee Slough Ecosystem Restoration project will substantially increase water storage in the Loxahatchee Slough and the C-18 canal and should facilitate increased freshwater deliveries to the estuary. The North Palm Beach County Project - Part 1 has several projects that will potentially impact the hydrology and water quality within this system: the Pal Mar and J.W. Corbett Water Management Area Hydropattern Restoration Project, the L-8 Basin Modifications Project, the C-51 and L-8 Reservoir Project, and the C-51 Backpumping and Treatment Project.

Lake Worth Lagoon. Reductions in loadings of nutrients, excess fresh water, and contaminants are expected for the Lake Worth Lagoon due to the implementation of several of the North Palm Beach County CERP projects, including the L-8 Basin Modifications Project, the G-17 Backpumping and Treatment Project, the G-51 Backpumping and Treatment Project, and the G-51 and L-8 Reservoir Project, along with a number of the Water Preserve Area projects. These projects will enable retention of water that currently is discharged to the Lake Worth Lagoon with damaging ecological, water quality and sediment contamination impacts. These discharges cause ecological imbalance due to wide salinity swings, nutrient enrichment, and contaminant impacts. The Lake Worth Restoration Project will address contaminated sediments from the lower C-51 canal and its associated channel at the confluence with the Lake Worth Lagoon.

Performance Measures

Performance measures include nutrient concentrations from major tributaries and canals to the estuarine system and in the open water estuaries, frequency of algal blooms, water clarity, and toxicants (pollutants) in sediment as listed in Table 3-9. A performance measure is currently under development for nutrient loads into each of the estuaries. The water quality monitoring for the Northern Estuaries will be comprised of two types of monitoring: one to evaluate nutrient loads and characterize water quality of the major tributaries and canals and the other to document trends and changes within the estuaries and lagoons.

Water Quality Monitoring Sites

Caloosahatchee Estuary. For the Caloosahatchee Estuary, the existing water quality monitoring at S-78 and S-79 by the SFWMD that measures nutrient loads may be sufficient to measure nutrient loads to the estuary from the Caloosahatchee River. However, the number of monitoring sites may be modified so that loads from local wastewater treatment plants that discharge into Caloosahatchee Estuary will be taken into consideration when calculating changes in nutrient loads from upstream of S-79, which will be influenced by upstream CERP projects. The fixed-station estuarine water quality monitoring network (Figure 3-44) currently administered by the SFWMD and Lee County will be sufficient to measure nutrient loads to the estuary from the Caloosahatchee River, as well as water quality within the estuary and Pine Island Sound. Four of the stations dropped from the original eight-station Caloosahatchee Estuary network several years ago will be reactivated at the request of RECOVER.

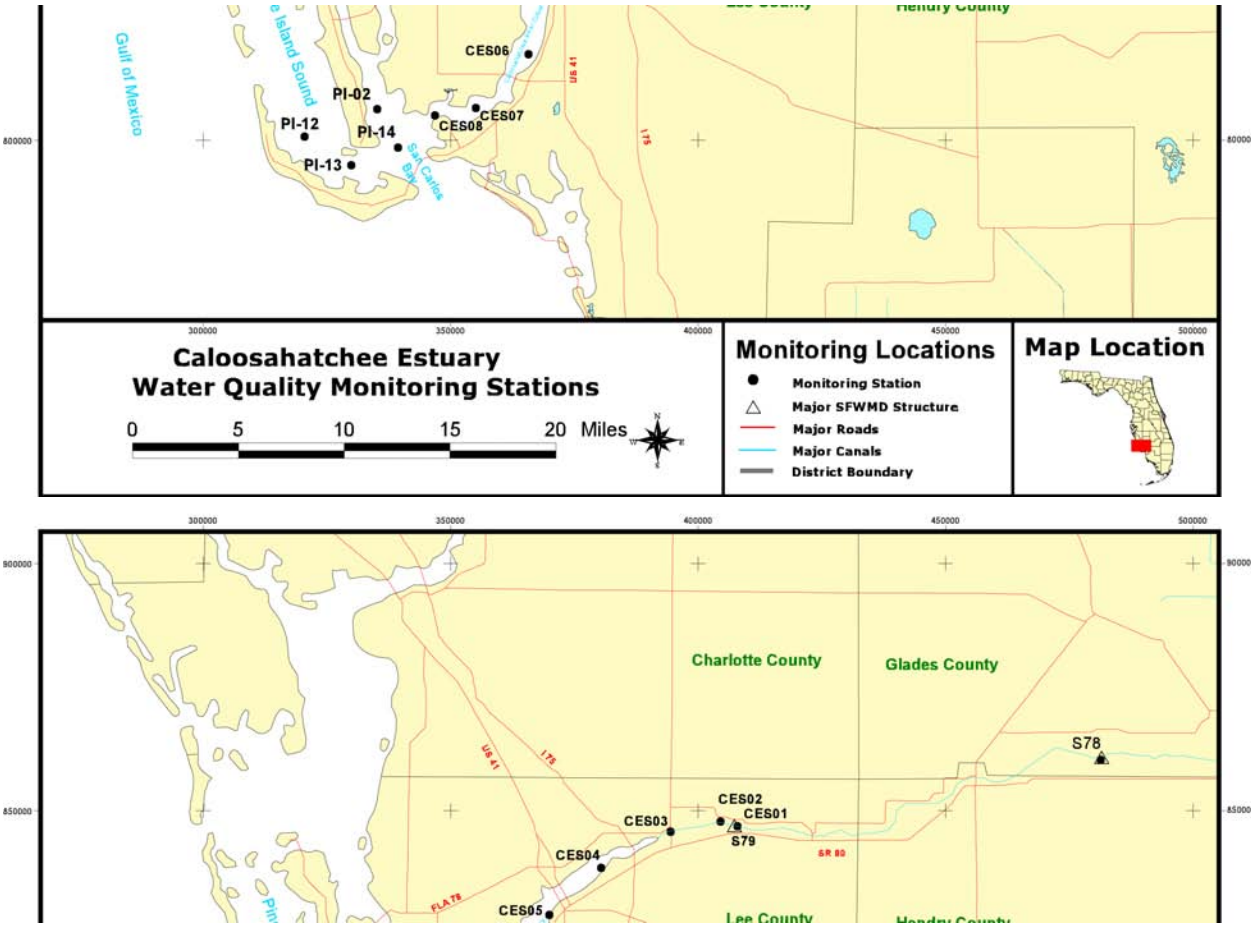


Figure 3-44: Caloosahatchee River Estuary Water Quality Monitoring Stations

St. Lucie Estuary and Indian River Lagoon. For the St. Lucie Estuary and the Indian River Lagoon region, the existing fixed station water quality monitoring network (Figure 3-45) administered by the SFWMD will be used to measure both the nutrient loads from major canals and tributaries into the estuary and lagoon and the water quality within the tributaries, lagoon, and estuary. There are currently 13 stations being monitored at inflows to and open water sites in the St. Lucie Estuary, along with 21 open-water stations in the Indian River Lagoon (two of which are near the Loxahatchee River Estuary) for physical parameters, nutrients, and chlorophyll using grab samples. The St. Lucie Estuary sites are sampled monthly, while the Indian River Lagoon sites are sampled 7 out of 12 months a year (weighted toward wet season months). It is recommended that site SE08, which currently sits on a sand bar, be moved slightly northwestward into deeper water of the south fork of the St. Lucie Estuary. Five inflow structures to the St. Lucie Estuary are currently monitored with flow proportional automatic samplers. Three additional sites, including a non-tidally influenced site (NEW 1) at an inflow point from the South Fork area, will be equipped with equivalent instrumentation (i.e., continuous flow recorders and automatic samplers), if feasible, to obtain more accurate load estimates. Much of the entire surface water monitoring network for this system has been recently optimized (spatially, temporally, and selection of parameters) to monitor the future effects of the CERP and will require little modification.

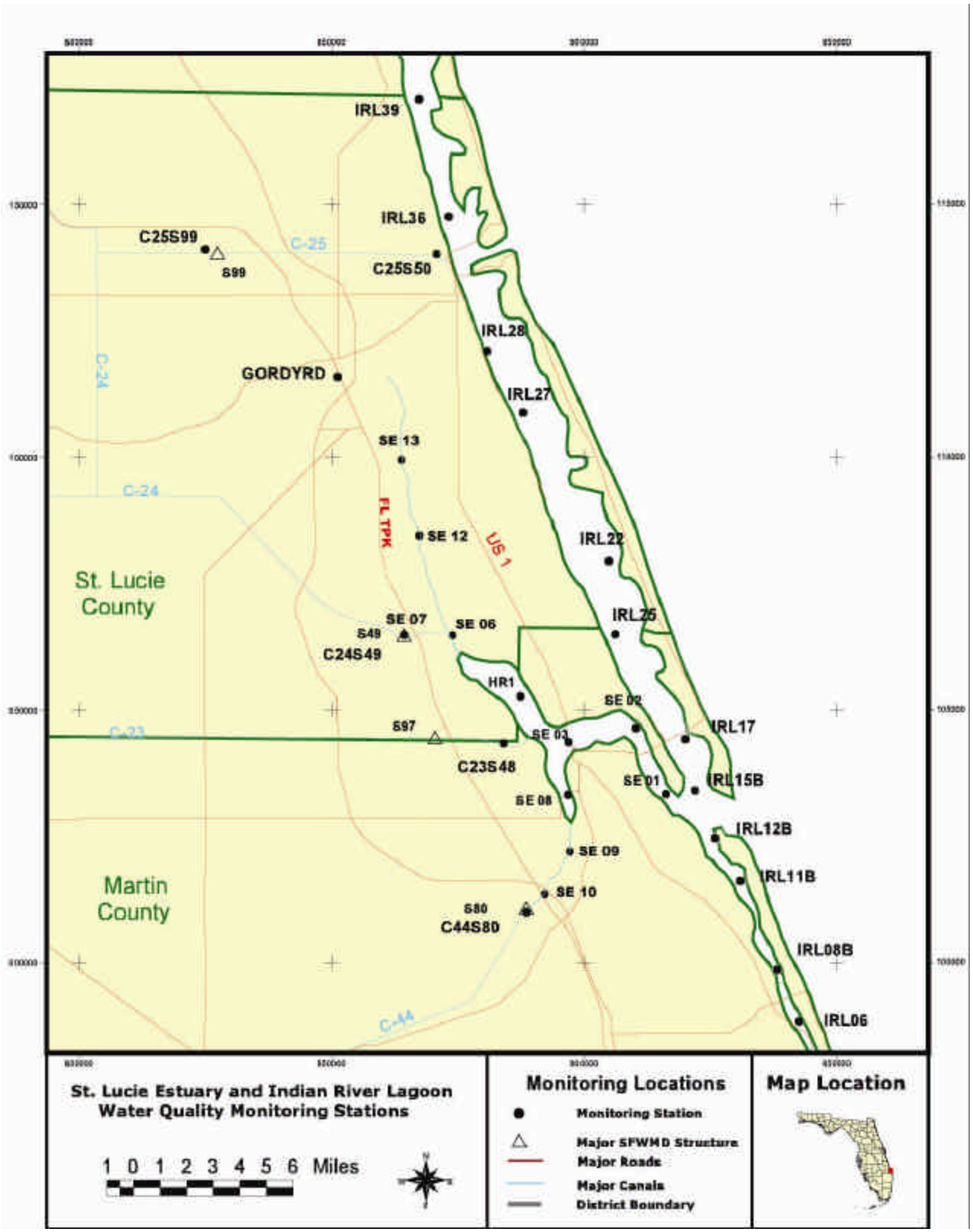


Figure 3-45: St. Lucie Estuary and Indian River Lagoon Water Quality Monitoring Stations

Loxahatchee Estuary. Within the Loxahatchee Estuary, the existing fixed-station water quality monitoring network (Figure 3-46) that is currently administered by the SFWMD and Loxahatchee River District will be sufficient to measure nutrient loads to the estuary from all major tributaries, as well as water quality within the estuary. However, some added parameters and increases in sampling frequencies (from bi-monthly to monthly) will need to be included in the sampling scheme as indicated in Tables 3-10 and 3-11.

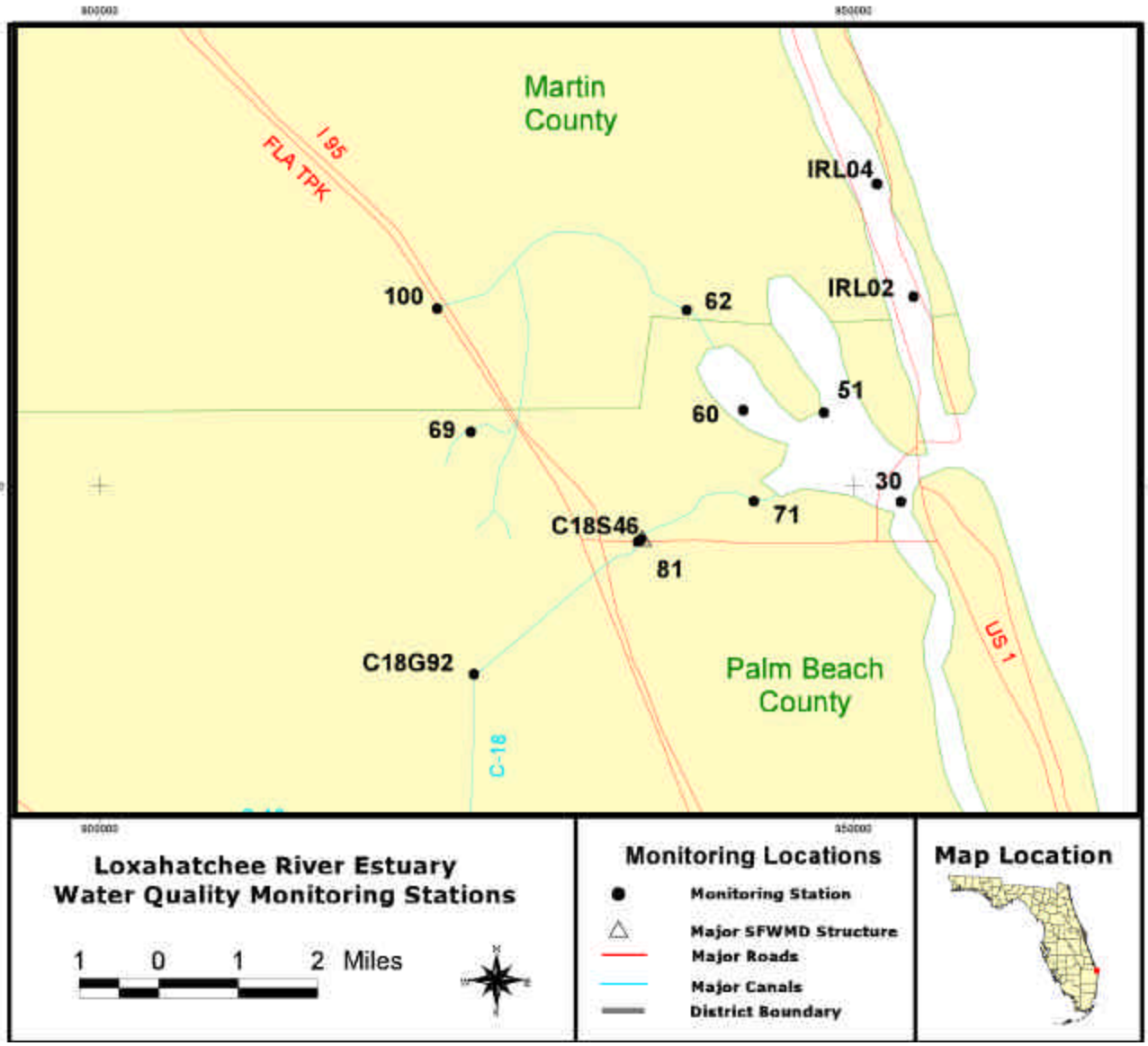


Figure 3-46: Loxahatchee River Estuary Water Quality Monitoring Stations

Lake Worth Lagoon. The existing water quality monitoring networks for the Lake Worth Lagoon (Figure 3-47), currently administered by the SFWMD and Palm Beach County Environmental Resource Management (PBCERM), will be sufficient to measure nutrient loads to the estuary from all major canal inflows to the lagoon. Due to the need to generate adequate baseline data with which to compare anticipated future changes in water quality in existing conditions, interim open water lagoon monitoring is

currently being administered by the FDEP Southeast District Water Quality Section at the eight sites depicted in Figure 3-47. Parameter coverage is according to Table 3-11, except for photosynthetically-active radiation (PAR) and phytoplankton community composition, which the FDEP currently lacks ability to perform. Continuance of the FDEP monitoring of Lake Worth Lagoon is dependent upon development of an appropriate agreement or assimilation of monitoring by another entity.

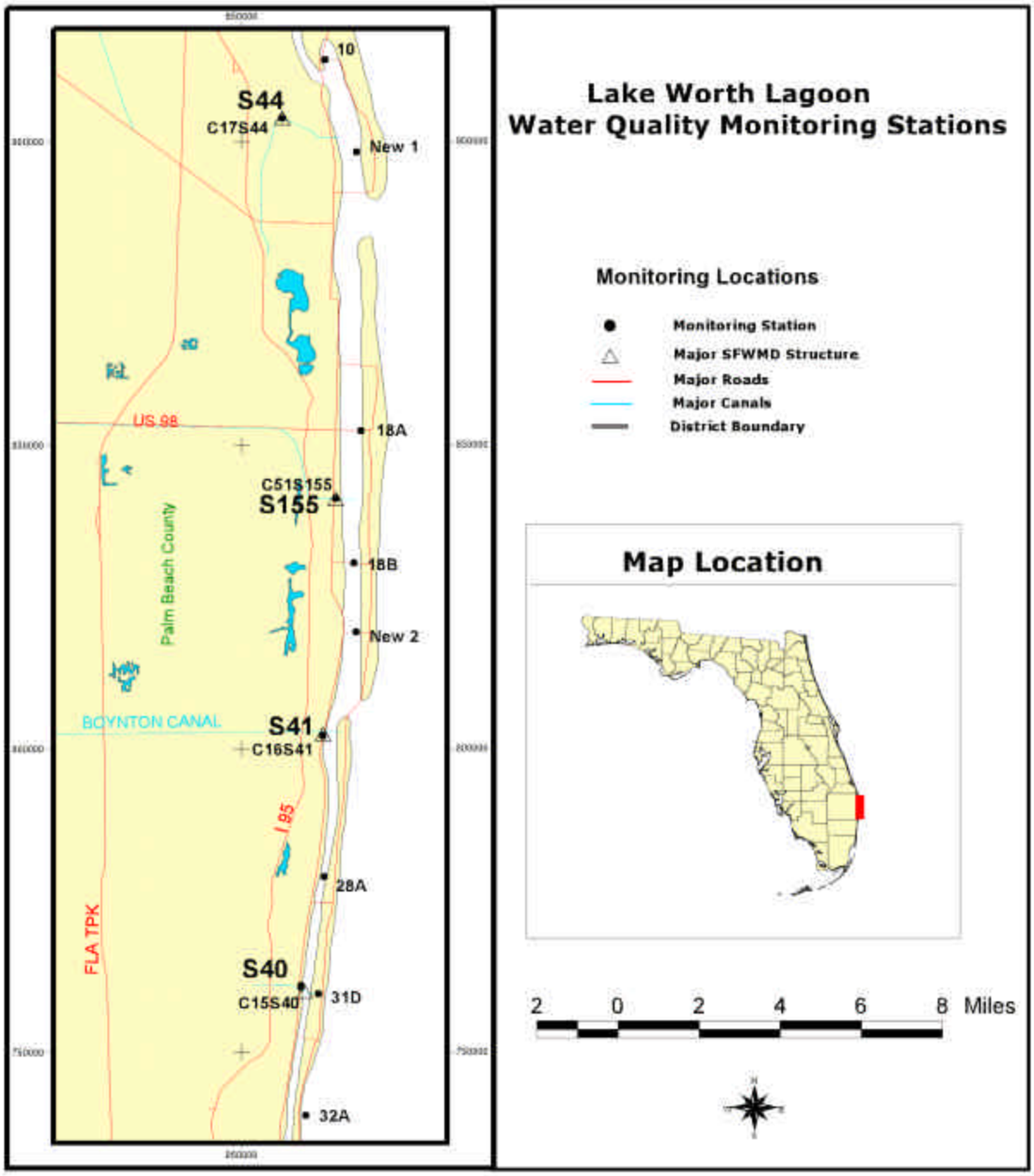


Figure 3-47: Lake Worth Lagoon Water Quality Monitoring Stations

Sediment Monitoring Sites

Sediment sampling for pollutants will be added to the monitoring scheme for many of the stations, with the exception of the Indian River Lagoon sites, to measure influx of toxicants into the northern estuarine systems. The estuarine water and sediment quality sites will be co-located with seagrass, oyster, and fish monitoring wherever possible. Some changes in parameter coverage and/or sampling frequency may be required as new information is obtained and the networks undergo further optimization.

Sampling Frequency and Collection Methods

Tables 3-10 and 3-11 summarize recommended sampling frequency and collection methods for all water quality parameters. Table 3-10 summarizes recommendations for nutrient loads and canal/river quality monitoring. Table 3-11 summarizes recommendations for estuarine water quality monitoring.

Table 3-10: Recommended Water Quality Monitoring for Nutrient Loads and Canal/River Quality

Medium	Group	Parameters	Sites	Frequency	Collection Method
Water	Physical parameters	DO, conductivity, pH, temperature, alkalinity, turbidity, TSS, color (DOC)	**Caloosahatchee** S78, S79	Monthly	Water quality probe and grab
Water	Nutrients	TP, OPO_4, TKN, NO_2, NH_3, NO_{2+3}, SiO_2	**St. Lucie Estuary** C25S99, C25S50, GORDYRD, C24S49, C23S48, C44S80, NEW 1	Weekly and monthly	Flow-proportional autosampler and grab (upstream and downstream)
Water	Other core parameters	SO_4, Cl, Ca, Mg, Na, K	**Loxahatchee River Estuary** 69,81, 100 (C18S46), C18G92	Monthly/ quarterly	Grab
Water	Trace metals	Trace metals - As, Cr, Cu, Fe		Monthly/ quarterly	Grab
Sediment	Toxicants	Trace metals – complete digestion (As, Ag, Al, Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn); pesticides; PAHs and PCBs.	**Lake Worth Lagoon** C17S44, C51S155, C16S41, C15S40	Bi-annually	Core
Water	Flow	Flow		Continuous	Flow recorder

LEGEND

Ag - silver
Al - aluminum
As - arsenic
Ca - calcium
Cd - cadmium
Cl - chloride
Cr - chromium
Cu - copper
DO - dissolved oxygen
DOC - dissolved organic carbon
Fe - iron
K - potassium
Mg - magnesium
Mn - manganese
Na - sodium
NH_3 - ammonia
Ni - nickel
NO_2 - nitrite
NO_{2+3} - nitrite + nitrate
OPO_4 - ortho-phosphate
PAHs - polycyclic aromatic hydrocarbons
Pb – lead
PCBs - polychlorinated biphenyls
SiO_2 - silicate
SO_4 - sulfate
TKN - total Kjeldahl nitrogen
TP - total phosphorus
TSS - total suspended solids
Zn - zinc

Table 3-11: Recommended Estuarine Water Quality Monitoring

Medium	Group	Parameters	Sites	Frequency	Collection Method
Water	Physical parameters	DO, conductivity, pH, salinity, temperature, PAR/Secchi, Turbidity, TSS, VSS, Color (DOC)	**Caloosahatchee Estuary** CES01, CES02, CES03, CES04, CES05, CES06, CES07, CES08, PI02, PI12, PI13, PI14 **St. Lucie Estuary** SE 01, SE 02, SE 03, SE 04, SE 06, SE 07, SE 08, SE 09, SE 10, SE 11, SE12, SE 13, HR1 **Indian River Lagoon** IRL06, IRL08B, IRL11B, IRL12B, IRL15B, IRL7, IRL18B, IRL21, IRL22, IRL24, IRL25, IRL27, IRL28, IRL29, IRL31, IRL34B, IRL36, IRL39, IRL40 **Loxahatchee River Estuary** IRL04, IRL02, 30, 51, 60, 62, 71 **Lake Worth Lagoon** 10, NEW 1, 18A, 18B, NEW 2, 28A, 31D, 32A	Monthly	Water quality probe and grab
Water	Nutrients	TP, TKN, NO_2, OPO_4, NH_3, NO_{2+3}		Monthly	Grab
Water	Biological	Chlorophyll *a*, *b*, *c*, corrected-*a*, pheophytin, and carotinoids		January, February, April, May, June, July, August, October Monthly Monthly	Grab
Water	Biological	Phytoplankton community composition	Same as above	Quarterly or event driven	Grab
Sediment	Toxicants	Trace metals – total digestion: (As, Ag, Al, Cd, Cr, Cu, Fe, Mg, Mn, Ni, Pb, and Zn); pesticides; PAHs and PCBs.	Same as above except no Indian River Lagoon sites included	Bi-annually	Core

LEGEND

Ag - silver
Al - aluminum
As - arsenic
Cd - cadmium
Cr - chromium
Cu – copper
DO - dissolved oxygen
DOC - dissolved organic carbon
Fe - iron
Mg - magnesium
Mn - manganese
NH_3 – ammonia
Ni - nickel
NO_2 - nitrite
NO_{2+3} - nitrite + nitrate
OPO_4 - ortho-phosphate
PAHs - polycyclic aromatic hydrocarbons
PAR – photosynthetically-active radiation
Pb -lead
PCBs - polychlorinated biphenyls
TKN - total Kjeldahl nitrogen
TP - total phosphorus
TSS - total suspended solids
VSS - volatile suspended solids
Zn - zinc

To capture the effects of seasonal variation and minimize serial correlation, a monthly sampling frequency has been identified in several published studies on monitoring strategies (Loftis and Ward 1980, Spooner et al. 1990, Robertson and Roerish 1999) as being an appropriate monitoring frequency for most surface water quality parameters. Sampling for the majority of the parameters will be conducted on a monthly or quarterly basis using grab samples and subsequent laboratory analysis.

Estimation of nutrient loading to estuaries requires the monitoring of water discharge (flow) and nutrient concentrations. Because water discharge is highly variable, continuous monitoring with flow meters and automatic samplers will be conducted at the outflow points of canals, rivers, and creeks. Continuous flow monitoring at all major tributary structures where water enters the estuaries will be conducted where feasible. Measure of inflows to estuaries can also be estimated by stage (headwater/tailwater). Such continuous monitoring equipment has already been deployed at some inflow points. Nutrient loading estimates could be based on occasional (e.g., monthly) grab samples, but such sampling is likely to miss pulses of nutrients associated with high flow events. Accurate estimates thus require automatic sampling. Less frequent grab sampling is still required for inorganic nutrients because these nutrient species cannot be preserved in the field over periods of weeks. Based on past studies of inflow points in estuaries, composite sampling on a weekly basis is adequate to capture nutrient pulses and tidal variations and minimize analytical costs.

Physical parameters such as dissolved oxygen, conductivity, pH, salinity, and temperature will be collected directly in the field using water quality monitoring probes. The measurement of PAR is preferred over Secchi disk depth, which is the method currently being used to measure water clarity in many areas. Measurement for both PAR and Secchi disk depth are recommended throughout the monitoring plan. However, Secchi measurements will be performed where 1) Secchi disk depths have historically been used to measure light penetration or 2) equipment to measure PAR cannot be obtained. Secchi disk depth and PAR measurements within strategic areas of estuaries will monitor improvements due to reduction in suspended solids released to tide and reestablishment of hydroperiods that more naturally mimic the historic, natural conditions.

Sediment samples will be collected bi-annually and analyzed for trace metals, pesticides, polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs). Surface water and sediment sampling methodologies used to collect parameter information, as well as hydrologic measurements, associated quality control requirements, and methods used for subsequent laboratory analyses, are described in the CERP Quality Assurance Systems Requirements (RECOVER 2003).

3.3.3.3 SAV Mapping from Aerial Photography

Caloosahatchee Estuary

SAV in the Caloosahatchee Estuary is being monitored through the use of mapping from aerial photography. The SFWMD contracted for an aerial photo survey of SAV in the Lower West Coast region (including the Caloosahatchee Estuary) during 1999, and another survey is underway. Geographic information system (GIS) maps prepared from the photographs provide a system-wide depiction of SAV. Subsequent routine mapping will allow evaluation of SAV acreage trends and distribution changes. This mapping effort will be continued by the SFWMD at two-year intervals.

St. Lucie Estuary and Indian River Lagoon

The SFWMD regularly evaluates SAV in the southern Indian River Lagoon by mapping SAV distribution using aerial photography. Southern Indian River Lagoon SAV mapping has been conducted every two to three years since 1986 and includes downstream portions of the St. Lucie Estuary. The mapping data are used to identify SAV acreage trends and distribution changes. This aerial mapping will continue.

Loxahatchee River Estuary

General seagrass maps of the Loxahatchee Central Embayment have been prepared by various agencies using numerous mapping methodologies. The mapping methods and accuracy of the maps are not consistent with methods and accuracies being used for similar efforts in adjacent water bodies (Southern Indian River Lagoon and Lake Worth Lagoon). Since seagrasses have been selected as valued ecosystem components for the Loxahatchee River, it is important to obtain current and accurate maps to document existing conditions and to monitor changes in seagrass coverage over time. The SFWMD began mapping seagrasses in the Central Embayment (see project boundary in Figure 3-48) of the Loxahatchee in spring/summer of 2003. The mapping will be conducted every two to three years using the same mapping techniques (mapping from aerial photography using an analytical stereoplotter) that are being used in the Southern Indian River Lagoon.

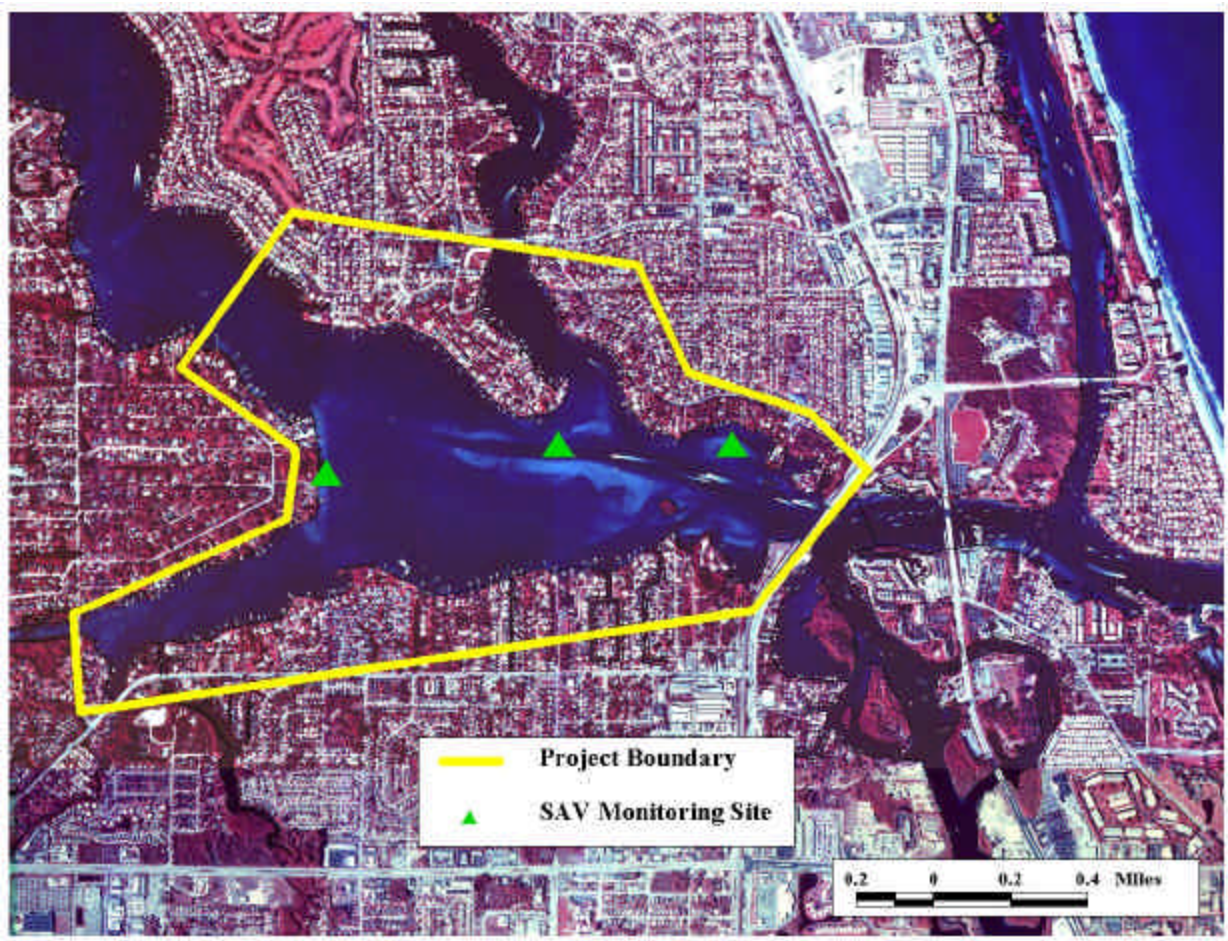


Figure 3-48: SAV mapping boundary and three transect monitoring locations for the Central Embayment of the Loxahatchee River

Lake Worth Lagoon

SAV in the Lake Worth Lagoon is being monitored by PBCERM through the use of mapping from aerial photography. A baseline condition for seagrasses in the lagoon was established in 2001. A GIS coverage of Lake Worth Lagoon seagrasses was produced using a combination of the 2001 aerial photography, field checking, and photo-interpretation. The aerial photography is to be converted to digital orthophotography in 2003. The lagoon seagrasses will be photographed every three to five years to document large-scale trends. Currently, the next scheduled flight is in the spring of 2006.

3.3.3.4 SAV Monitoring for Caloosahatchee Estuary

SAV beds provide important habitat for numerous organisms and are indicators of a healthy estuary. The status of SAV beds in the Caloosahatchee Estuary is represented in a performance measure that will assess the system responses of the CERP in this region.

The main objective of this monitoring component is to initiate and develop long-term programs for monitoring SAV in the Caloosahatchee Estuary. These programs include monitoring seagrass species using transects and hydroacoustic technology and monitoring habitat use of the SAV beds.

Transects

An important estuarine species within the Caloosahatchee Estuary is *Vallisneria americana*, a salt-tolerant freshwater plant that occurs in fresh to mesohaline portions of the Caloosahatchee Estuary. The SFWMD has conducted a continuing monitoring program for *Vallisneria* in the Caloosahatchee since January 1998. This monitoring program, with the addition of downstream SAV monitoring, will be continued. These data will provide valuable pre-project documentation for CERP efforts. The SFWMD intends to continue this monitoring indefinitely, pending annual budget approval, thus providing a long-term data set for evaluating CERP project success. The SAV will be monitored at seven sites in the upper and lower Caloosahatchee River and San Carlos Bay. Table 3-12 shows the individual species to be sampled at each site.

Table 3-12: SAV Monitoring Stations for the Caloosahatchee River and San Carlos Bay

Area	Station Number	Species Sampled
Upper Caloosahatchee	1	*Vallisneria america* *Ruppia maritima*
	2	*Vallisneria americana* *Ruppia maritima*
	3	*Vallisneria americana* *Ruppia maritima*
Lower Caloosahatchee	4	*Halodule wrightii,* *Ruppia maritima*
	5	*Halodule wrightii,* *Ruppia maritima*
San Carlos Bay	6	*Halodule wrightii* *Thalassia testudinum*
	7	*Halodule wrightii* *Thalassia testudinum*

Upper Caloosahatchee River. *Vallisaneria americana* and *Ruppia maritime* will be sampled in the Upper Caloosahatchee River. Three previously established stations (Station 1: 26º41'23" N, 81º49'48" W; Station 2: 26º40'21" N, 81º 51'52" W; Station 3: 26º 38'37" N, 81º 54'8" W) will be monitored in the upper Caloosahatchee River. Each station has two sites: one upstream and one downstream. Each site consists of two 100-meter transects, one perpendicular to shore and one parallel to shore. The sites are separated from each other by 100 – 200 meters. The intersection (midpoint) of each pair of transects is 50 meters from shore. Each transect has five intervals: 1-20 meters, 21-40 meters, 41-60 meters, 61-80 meters, and 81-100 meters. Thus, a total of 20 discrete samples are possible at each location. At each sampling, a different specific distance within each interval will be selected using a random number generator without replacement. A one square-meter quadrat will be placed on the river bottom at the randomly selected locations within the five interval increments. Within each quadrat, the following measurements will be made: percent coverage, estimate of abundance, shoot count, canopy height, blade length and width, water depth, and biomass.

Lower Caloosahatchee River and San Carlos Bay. *Ruppia maritima* and *Halodule wrightii* will be sampled in the Lower Caloosahatchee River and *Halodule wrightii* and *Thalassia testudimum* will be sampled in San Carlos Bay. The two shallow water stations located in the lower Caloosahatchee River and the two in San Carlos Bay shall be sampled bimonthly. At the start of the monitoring, a 6 six-feet tall, three-quarter inch-diameter PVC pole will be hammered into the approximate middle of the seagrass bed at least 50 meters offshore at each of the stations. This pole will serve as a visual marker for the station and also as the permanent mid-point of a cross-design transect. A pair of 100-meter transects, one parallel to shore and one perpendicular to shore, will be established at the two stations, with the permanent PVC pole being the 50-meter mark on each transect. On each sampling date, five 1-square-meter quadrats (divided into 100 10-by-10 centimeter squares) will be placed randomly along each transect. A total of five samples will be taken per transect and ten samples per site. For each quadrat, the following measurements will be determined: percent coverage, estimate of abundance, shoot count, and canopy height for all species; biomass of *Rupia*; and water depth.

Concurrent with the above sampling schedules, vertical profiles of dissolved oxygen, salinity, temperature, pH, conductivity, chlorophyll *a*, turbidity, and PAR will be measured using standard electronic sensors calibrated to manufacturer's specifications.

Hydroacoustic Technology

The SFWMD is also using hydroacoustic technology to monitor SAV in the Caloosahatchee Estuary under a contract with the United States Army Corps of Engineers (USACE). This effort has been underway since 1996 and is anticipated to continue until 2004. After 2004, additional hydroacoustic monitoring equipment will be required in order for the SFWMD to continue these efforts. The hydroacoustic project is used to monitor *Vallisneria* in the freshwater-mesohaline portion of the estuary (near sites 1 and 2, Figure 3-49) and seagrasses in the mesohaline-euryhaline portions of the estuary (sites 4-9, Figure 3-49). The hydroacoustic monitoring is currently conducted three times per year and provides the following data: percent cover, average plant height, and edge of bed location.

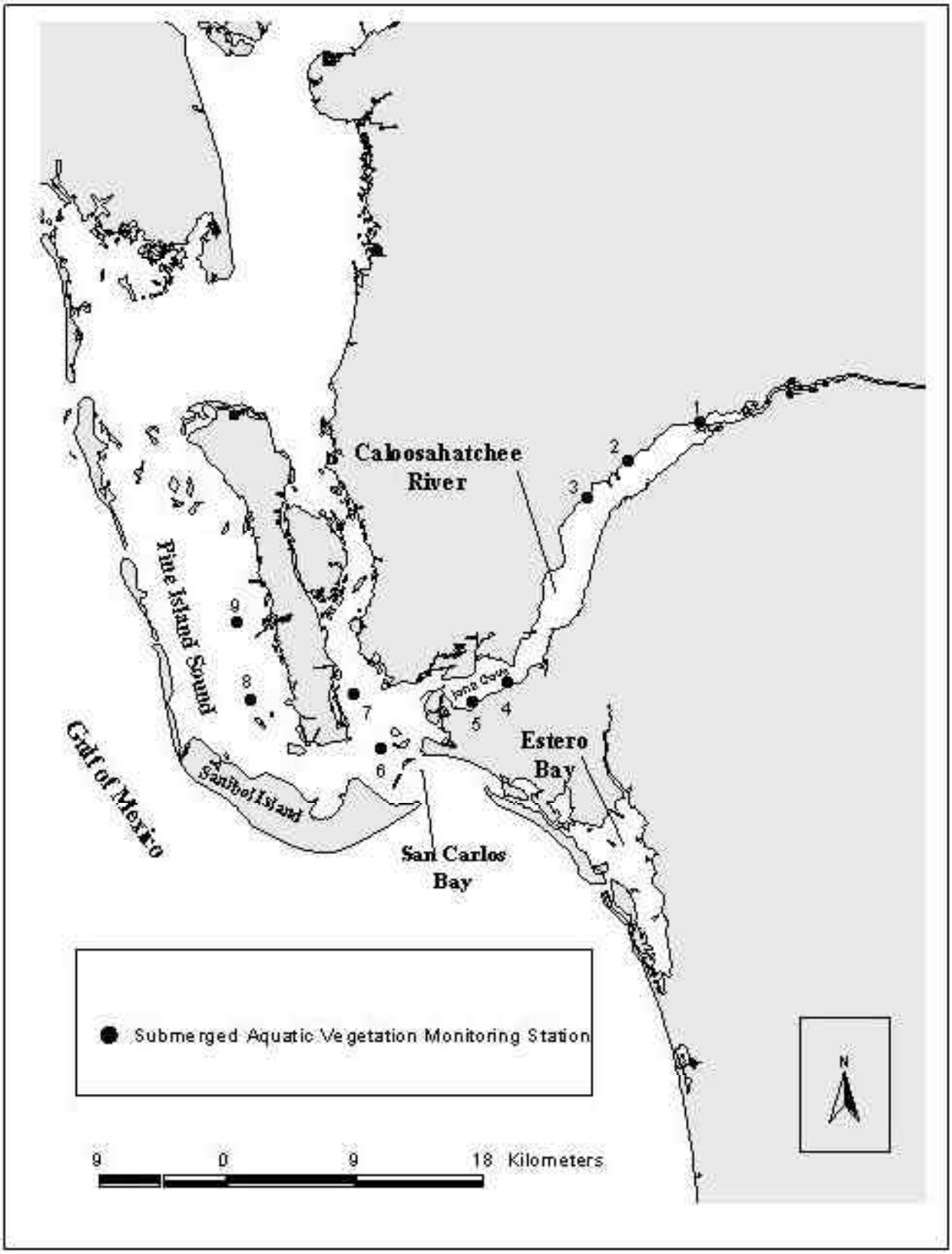


Figure 3-49: SAV Monitoring Sites within the Caloosahatchee Estuary

Habitat Use

Additionally, the SFWMD has contracted a private firm to monitor habitat use of Caloosahatchee Estuary *Vallisneria* beds from 2001 to 2004. Data gathered from this study will identify which organisms use *Vallisneria* habitat in the Caloosahatchee River and how season, salinity, and plant/bed morphometry affect habitat use. This information will be used to support minimum flows and levels criteria development by identifying times (season and ambient salinity) for releasing fresh water to the Caloosahatchee River to benefit not only *Vallisneria*, but also the key organisms that occupy this plant community.

3.3.3.5 SAV Transects/Visual Surveys for St. Lucie Estuary and Indian River Lagoon, Lake Worth Lagoon, and Loxahatchee River Estuary

St. Lucie Estuary and Indian River Lagoon

SAV beds in the St. Lucie Estuary were mapped under contract to the SFWMD in 1997, although very little SAV was present in the estuary at that time. Subsequent spot checks conducted by SFWMD support this finding.

SAV beds have been observed within the southern Indian River Lagoon. Transect monitoring of SAV within the southern Indian River Lagoon began in 1994, is conducted twice a year (winter and summer), and includes 18 transects, two of which are just inside the mouth of the St. Lucie Estuary (Figure 3-50). Parameters monitored include species present, percent cover, canopy height, edge of bed location, species depth profiles, and shoot counts. Virnstein and Morris (1996) contains a detailed description of the monitoring methods.

The Indian River Lagoon SAV transect monitoring discussed above will continue with the addition of six new permanent transects in the St. Lucie Estuary. Prior to CERP implementation, it is unlikely that significant areas of SAV will be present in the St. Lucie Estuary based on the 1997 survey and subsequent spot checks. Detailed transect monitoring, therefore, is not warranted until salinity and water clarity conditions improve sufficiently to allow SAV recruitment and growth. Prior to and during CERP implementation, general surveys for SAV will be conducted annually (spring/summer). These surveys will require divers to visually inspect the nearshore estuary bottom (areas less than one-meter deep) to look for SAV. Six general monitoring locations are suggested for these surveys: two sites each in the North Fork, South Fork, and mid-estuary (Figure 3-50). Once SAV begins to recruit and grow in the estuary, the general surveys will be modified to provide a more detailed transect monitoring design. Actual transect locations will be determined in the field based on SAV distribution observed during the general surveys.

In the summer of 2002, the SFWMD began monitoring seasonal trends in seagrass and macro-algae in the southern Indian River Lagoon near the mouth of the St. Lucie River to better understand 1) the natural seasonal variability of seagrass and macro-algae in the study area and 2) the response of the seagrass community to freshwater discharge. Transect monitoring is conducted at four study sites: two north and two south of the St. Lucie Inlet (Figure 3-51). The monitoring is conducted once a month and includes shoot counts, canopy height, percent cover, species diversity, species shifts, and species depth distribution. This project is expected to continue for a minimum of three years and will incorporate biomass monitoring for use with a mass-based seagrass model to help determine appropriate freshwater management strategies for restoring and protecting SAV in the St. Lucie Estuary and the Indian River Lagoon.

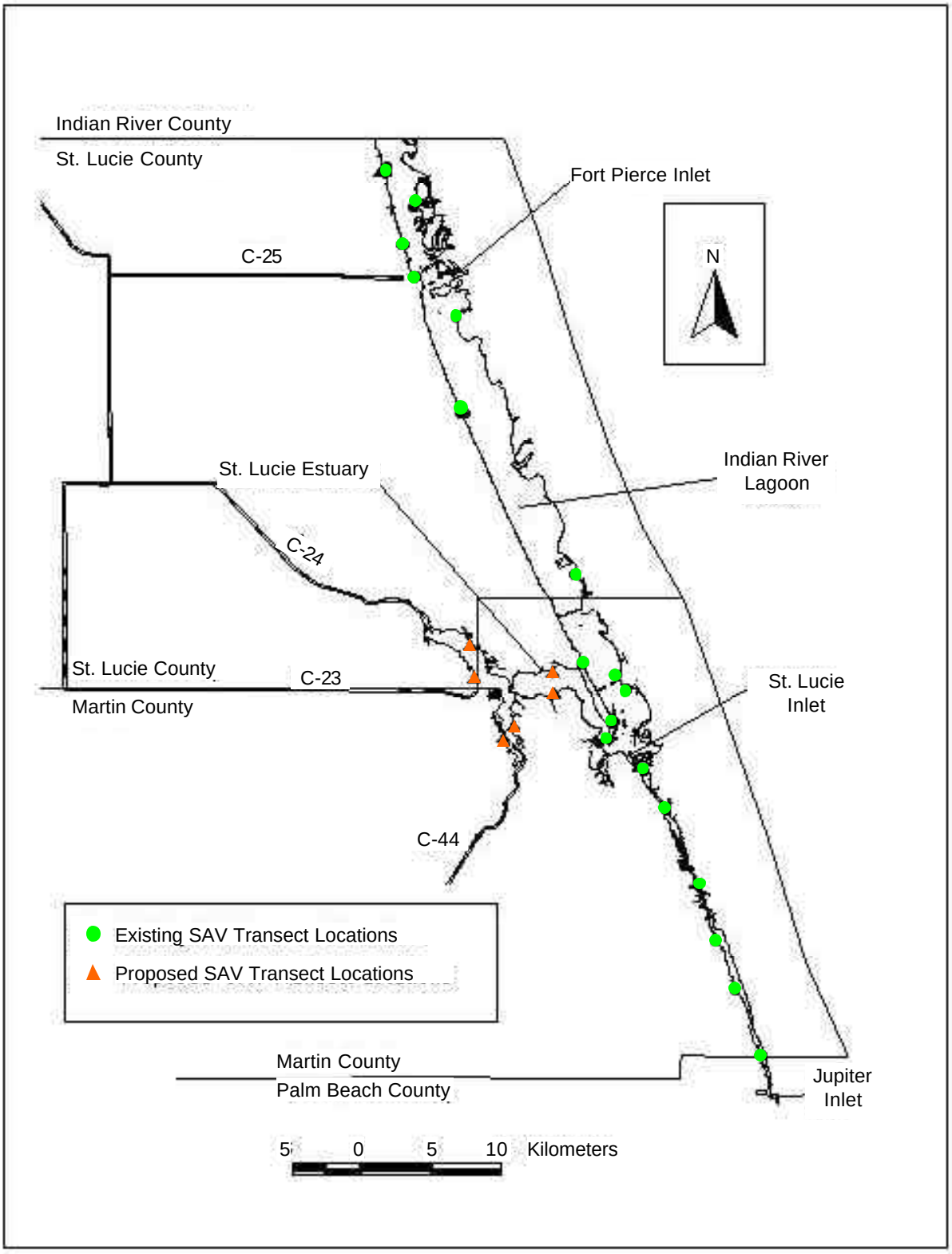


Figure 3-50: Existing and Proposed SAV Monitoring Locations within the St. Lucie Estuary and Southern Indian River Lagoon

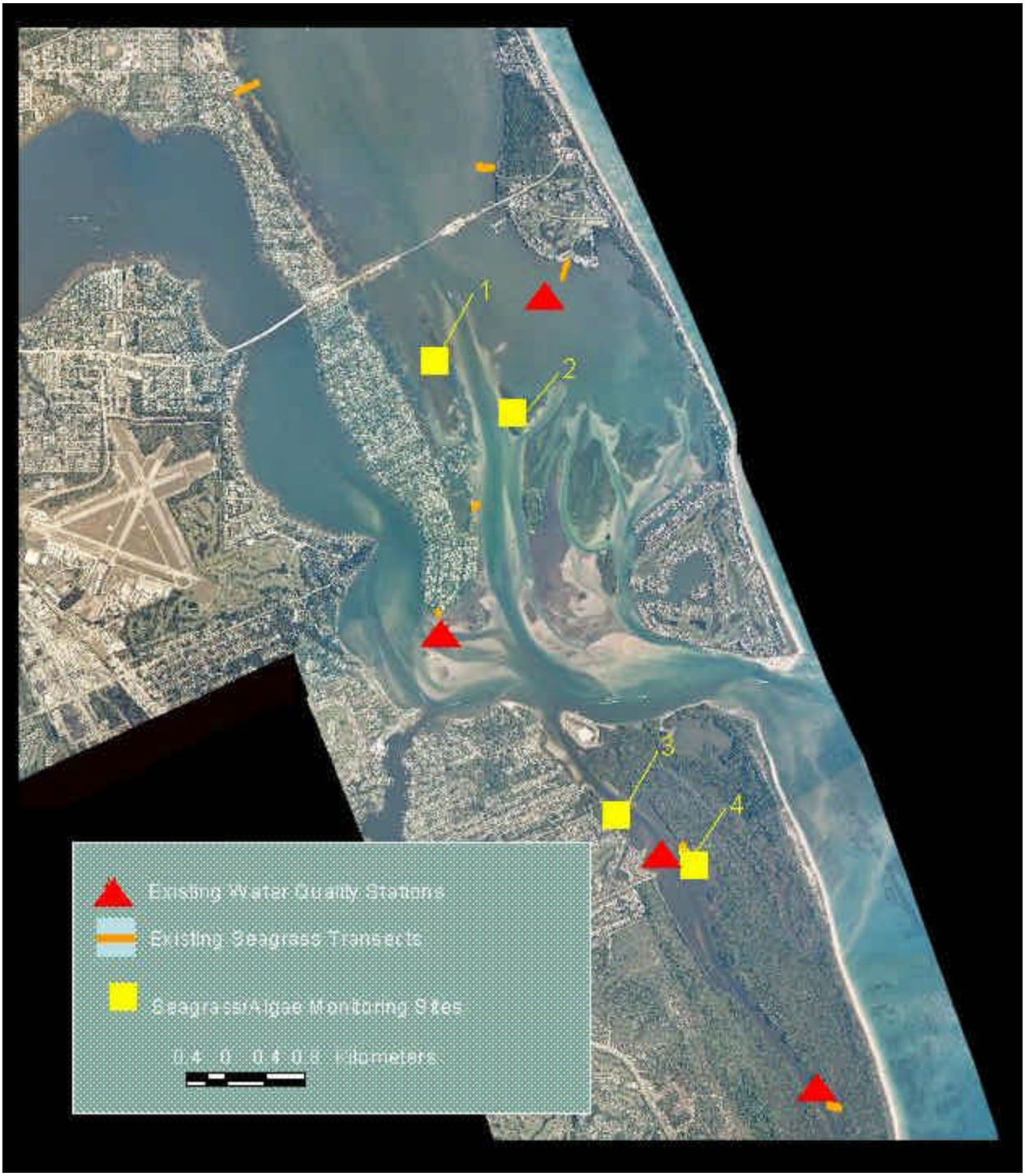


Figure 3-51: SAV Monitoring Locations Near the Mouth of the St. Lucie River

Loxahatchee River Estuary

The Loxahatchee River District and the SFWMD are working cooperatively to assess the seagrass and macro-algae resources in the Loxahatchee River to better understand the impacts of proposed restoration efforts on the estuarine portion of the Loxahatchee River. In the spring of 2003, the Loxahatchee River District, under contract with the SFWMD, began a project to monitor seasonal trends in seagrass and macro-algae in the Central Embayment of the Loxahatchee River to better understand 1) the natural seasonal variability of seagrass and macro-algae in the study area and 2) the response of the seagrass community to freshwater discharge. There are three study sites as shown in Figure 3-48. The monitoring will be conducted once a month and will include shoot counts, canopy height, percent cover, species diversity, species shifts, and species depth distribution. This project is expected to continue for a minimum of three years and will incorporate biomass monitoring for use with a mass-based seagrass model to help determine appropriate freshwater management strategies for restoring and protecting SAV resources in the Loxahatchee River Estuary.

Lake Worth Lagoon

SAV beds in the Lake Worth Lagoon were mapped in 2001, and results indicate that seagrass beds cover at least 1,631 acres or 22 percent of the lagoon. This is considered an underestimate, as the mapping project incorporated only seagrass beds of 0.25 acres or greater in size. PBCERM conducted selected area monitoring at five fixed transect locations in 2000 and four additional fixed transects in 2001 (Figure 3-52). The nine transects are located throughout the lagoon and were monitored for species presence/absence, depth distribution, abundance, and shoot density. PBCERM plans to monitor these transects annually to detect small-scale changes over time as water quality improvements are implemented.

3.3.3.6 Oyster Monitoring Network

Caloosahatchee Estuary

A long-term Caloosahatchee Estuary oyster monitoring program will be conducted using the current Caloosahatchee oyster study (Volety et al. 2001a, 2001b) as a guide to the selection of monitoring stations and monitoring frequency. The program will be initiated three years prior to implementation of Caloosahatchee CERP projects to provide baseline (pre-project) documentation (Volety personal communication 2002) and continue during and after project implementation to document CERP project success.

It is recommended that five oyster monitoring stations be identified for monitoring: three located at previously sampled sites located in Iona Cove and north and south San Carlos Bay (Figure 3-53), one additional location in the lower Caloosahatchee River, and another additional location in San Carlos Bay. This monitoring will include both spat and adults to evaluate recruitment and survivorship success and will follow the monitoring protocol below.

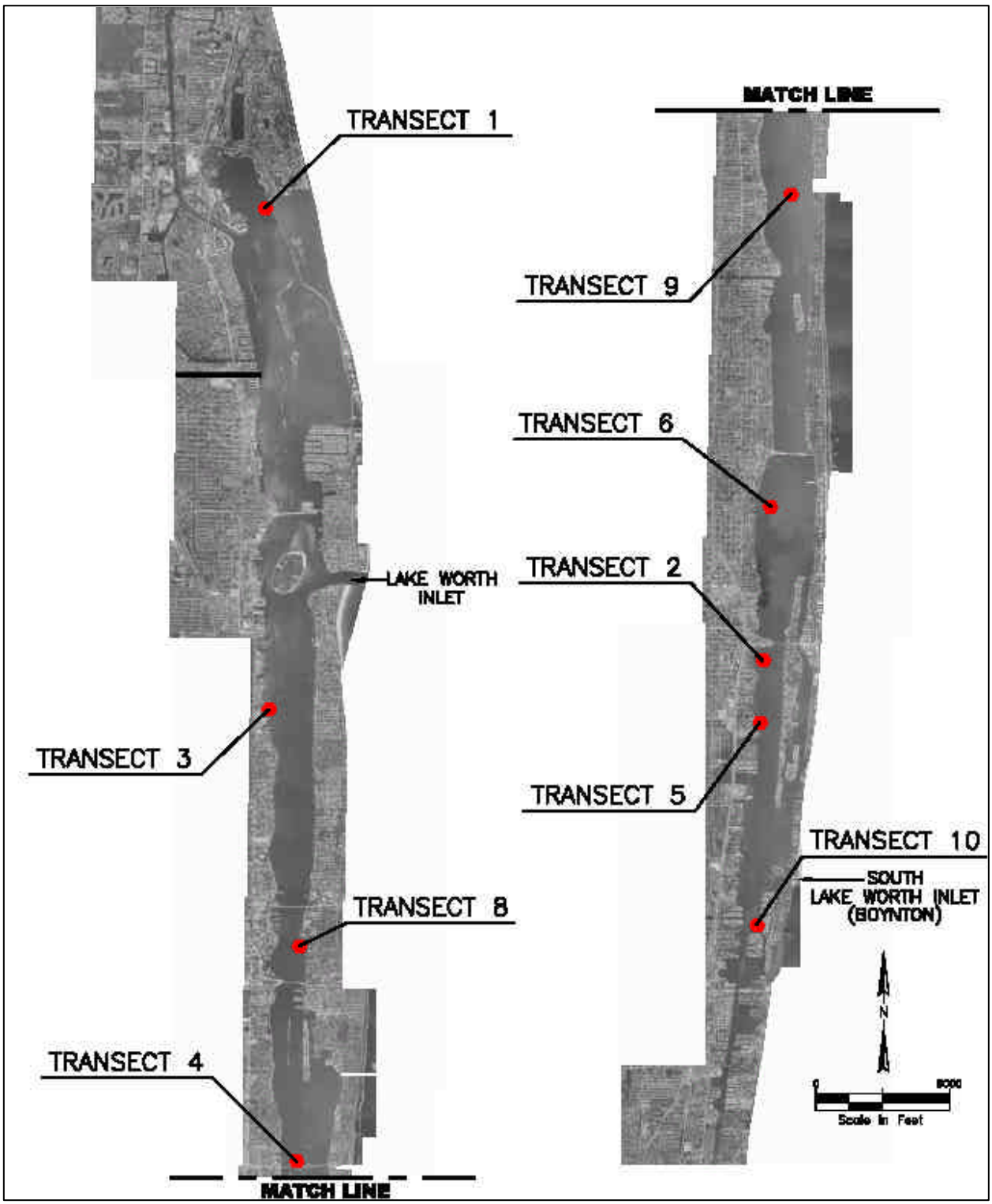


Figure 3-52: SAV Transect Locations for Lake Worth Lagoon

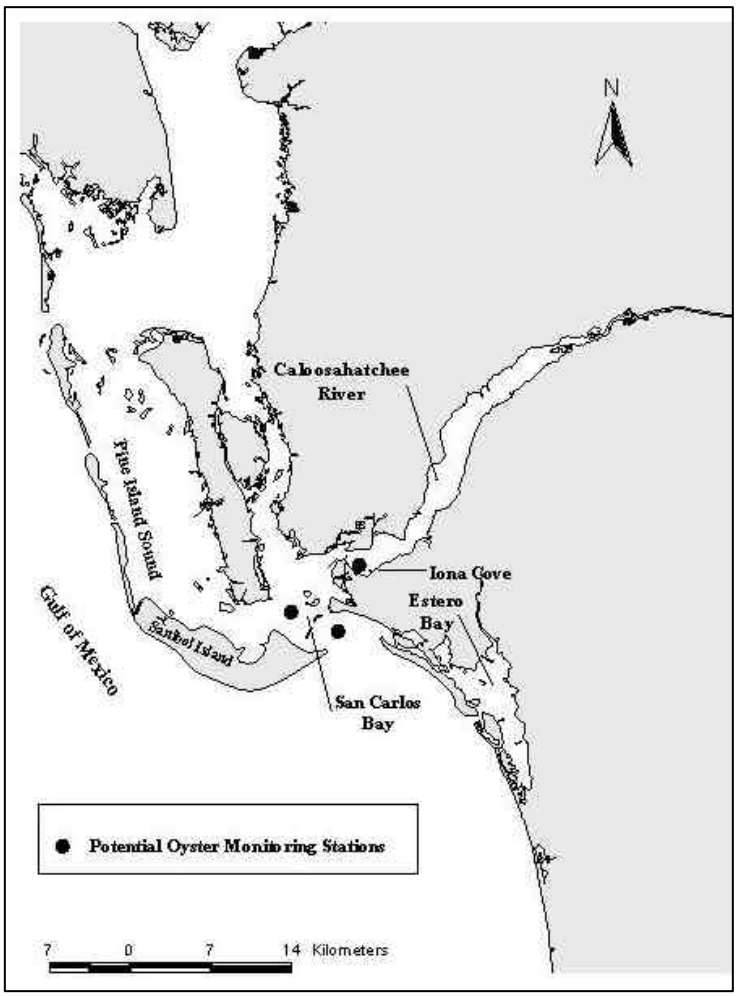


Figure 3-53: Oyster Monitoring Stations in the Caloosahatchee Estuary

Twice a year, in summer and winter, one 100-meter transect will be established parallel to shore at five stations. Each transect will be subdivided into five 20-meter long portions (0-20, 20-40, 40-60, 60-80, and 80-100). On each sampling date, five 1-square meter quadrats will be placed randomly along each transect. A total of five samples will be taken per transect and ten samples per site. For each quadrat, the following measurements will be determined:

- Percent adults, live versus dead – Count and record the number of live adult oysters and the number of dead adult oysters within the quadrat.
- Adult sizes, live versus dead – Measure and record the maximum length of all adult oysters (both dead and alive will be identified) within the quadrat.
- Water depth – Measure from the water surface to the nearest centimeter at the center of each of the quadrats.

- Spat recruitment – Oyster spat recruitment experiments will be conducted at each oyster monitoring station using old adult oyster shells strung together with a weighted galvanized wire. Three shell strings will be deployed at the site each month. A shell string will consist of 12 oyster shells, each 5.7-7.5 centimeters long with a hole drilled in the center and oriented inner surface down when suspended off the bottom. Oyster spat settlement will be monitored monthly (March through October) by counting the number of spat settled on the underside of strung shells.

- Juvenile oyster growth and survival – Four hundred hatchery-raised juvenile oysters (10 - 20 millimeters) will be deployed at all sampling locations in 0.5-millimeter wire-mesh bags. Fifty randomly selected oysters will be measured to the nearest 0.1 millimeter every month from each location for 24 months. Beginning in the third year of monitoring, 250 more juvenile oysters in wire mesh bags will be deployed at each site to examine the effects of high freshwater releases and resulting low salinities on juvenile oysters. Juvenile oysters will continue to be measured monthly.

Concurrent with sampling schedule, this monitoring will also include vertical profiles of dissolved oxygen, salinity, temperature, pH, and conductivity using standard electronic sensors calibrated to manufacturer's specifications.

St. Lucie Estuary

A detailed survey of the eastern oyster, *Crassostrea virginica*, in the St. Lucie River was conducted under contract to the SFWMD in the late summer/early fall of 1997. The survey revealed that oyster shells are present throughout the estuary, but healthy oyster beds are scarce. Densities of the live oysters within the existing beds were typically very low (1 to 40 percent). Of the oyster beds mapped, six were selected for studying oyster recruitment in the St. Lucie Estuary from April 2000 to October 2001 (Figure 3-54). A spat monitoring location was also established in the Indian River Lagoon to monitor recruitment in a higher salinity environment. A final report for this study is in preparation.

The SFWMD has contracted with Florida Atlantic University to conduct mesocosm research to evaluate the salinity tolerances of the St. Lucie Estuary oyster population. Although literature values on oyster salinity tolerances are available, none of the available studies were conducted on oysters from the St. Lucie Estuary. Additionally, the SFWMD is investigating the use of various substrates for increasing oyster habitat in the St. Lucie Estuary.

This plan recommends that the SFWMD continue to move forward with oyster substrate and mesocosm studies and that a St. Lucie Estuary oyster monitoring program be established to help monitor the success of CERP implementation. It is recommended that the CERP monitoring include both spat and adults to evaluate recruitment and survivorship success. Spat recruitment monitoring will be conducted at the seven stations already established by SFWMD (six sites on Figure 3-54 plus one Indian River Lagoon site). Recruitment monitoring will encompass a four-month period at the peak recruitment time (mid-March to mid-July) with spat collectors sampled every two weeks. Adult monitoring is recommended twice a year (winter and summer) at the six estuary sites (Figure 3-54) and will include measurements of size (live and dead) and percent alive.

Loxahatchee River Estuary

During the summer of 2003, the Loxahatchee River District, under contract with the SFWMD, began mapping existing oyster resources in the Loxahatchee River. Based on the findings of that survey, additional oyster monitoring for this region similar to that described for the St. Lucie Estuary may be warranted for inclusion in this monitoring plan.

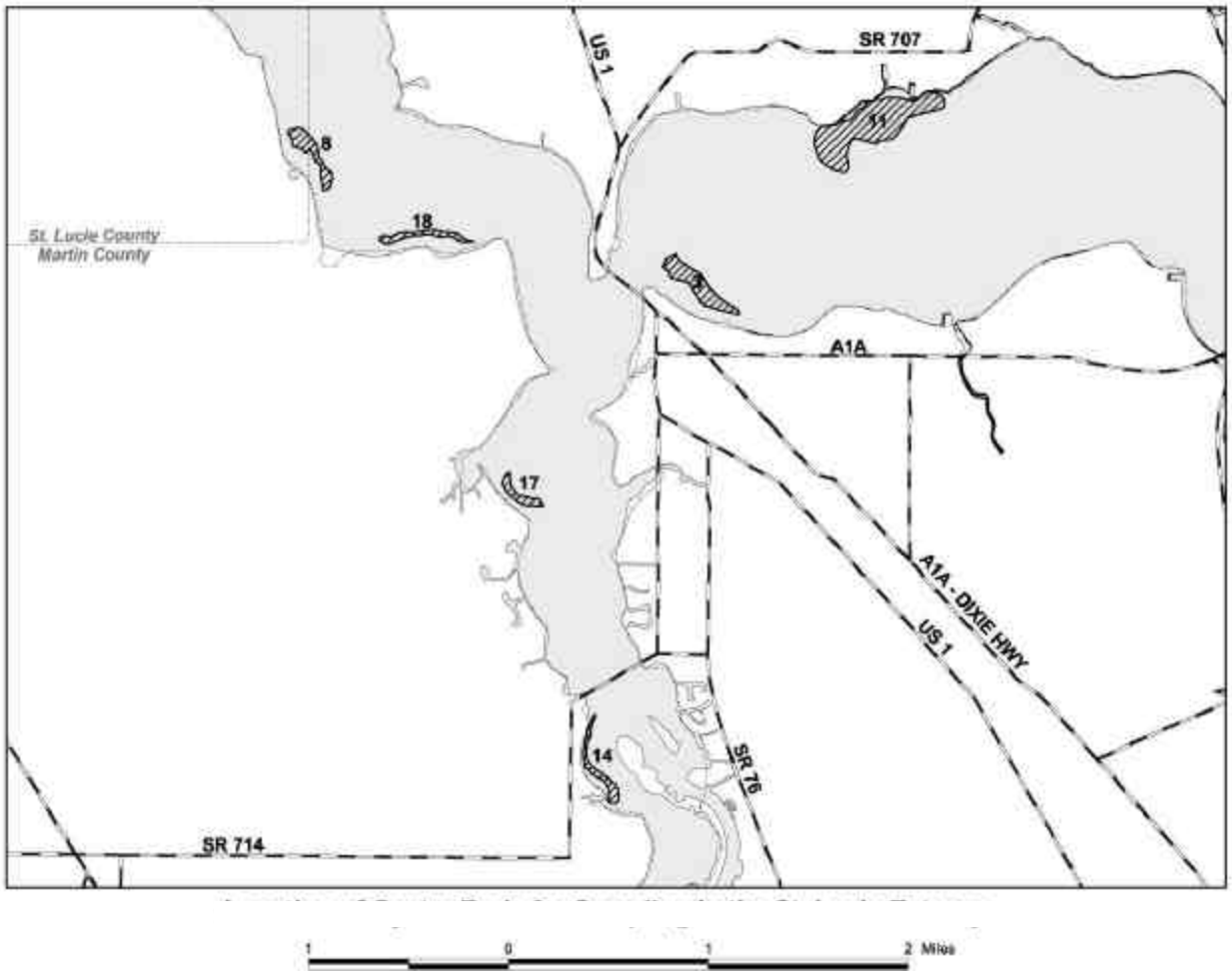


Figure 3-54: Oyster Beds for Oyster Spat and Adult Monitoring within the St. Lucie Estuary

3.3.3.7 Juvenile Fish Community Monitoring Network

Caloosahatchee Estuary (and Lower Charlotte Harbor).

At present, a long-term program to monitor the relative abundance of fisheries resources is underway in Florida's major estuarine, coastal, and reef systems. The program was developed to do the following:

- Address the critical need for effective assessment techniques for an array of species and sizes of fish and selected invertebrates
- Provide timely information for use in management plans
- Monitor trends in the relative abundance of fishes in a variety of estuarine and marine systems throughout Florida; however, the Caloosahatchee Estuary is not presently included in the study area of this project

The Fisheries Independent Monitoring Program administered by Florida Fish and Wildlife Conservation Commission (FWC) is conducting stratified random sampling in the upper portion of Charlotte Harbor to

the upper tip of Pine Island using monthly 70-foot seine hauls, 600-foot seine hauls, purse net sets, and trawl hauls. This project will incorporate an equivalent stratified-random sampling program into lower Charlotte Harbor and the Caloosahatchee Estuary. The study area will be divided into two bay zones (Pine Island Sound and San Carlos Bay/Matlacha Pass) and a riverine zone to include the tidal portions of the Caloosahatchee River. The zones will be divided into 1-nautical mile grids, and appropriate strata for sampling will be assigned for each gear. Gear types and numbers of hauls per month will be assigned in proportion to existing sampling in northern Charlotte Harbor. This project will be initiated at least three years prior to implementation of Caloosahatchee CERP projects and will continue during and after project implementation to document CERP project success.

St. Lucie Estuary and Indian River Lagoon

Seining and roller trawls are common methods of sampling within the SAV beds; however, since SAV communities are currently rare in the St. Lucie Estuary, monitoring will initially be conducted in areas with little or no SAV. The FWC's Fisheries Independent Monitoring Program is currently conducting stratified random sampling in the northern Indian River Lagoon. This monthly sampling using 70-foot seine hauls, 600-foot seine hauls, and trawls collects a wide range of fishes over representative habitats throughout the northern Indian River Lagoon. Beginning in 1998, the sub-adult and adult fishes in the southern Indian River Lagoon and St. Lucie Estuary have been surveyed using 600-foot seine hauls. The inclusion of a juvenile and small fish sampling component in these areas would provide important information in evaluating the effects of CERP projects on fish communities in the St. Lucie Estuary. Sampling sites will be considered for the locations identified as proposed SAV monitoring sites for the St. Lucie Estuary (Figure 3-50). It is recommended that sampling sites be located in *Polygonum* communities in the North Fork in order to provide information on the federal candidate for listing under the Endangered Species Act, the opossum pipefish (*Microphis brachyurus*).

3.3.3.8 Benthic Macroinvertebrate Monitoring

St. Lucie Estuary

Regulatory releases from Lake Okeechobee and basin run-off have been linked to muck accumulation in the St. Lucie Estuary. The implementation of CERP components is expected to significantly decrease the number of harmful regulatory releases. Accumulation and resuspension of muck directly affects the recolonization ability of SAV and oysters and may also be triggering algal blooms within the estuary. "Hotspot" areas have been identified within the St. Lucie Estuary that support very little or no benthic organisms. Benthic organisms are considered to be good indicators of overall ecosystem health. The proposed benthic macroinvertebrate sampling would assist in both establishing a preconstruction baseline and evaluating post-construction project success.

Reports prepared by FDEP staff (the first under the auspices of one of its predecessor agencies, the Florida Department of Environmental Regulation (FDER)) addressing benthic communities along the narrow North Fork of the St. Lucie River represent the only known benthic macroinvertebrate data sets for the northern freshwater riverine system (Rudolph 1990, Graves and Strom 1995). Benthic community structure has been described for downstream estuarine portions by Haunert (1988) and Haunert and Startzman (1980, 1985). The following proposed benthic monitoring plan will build upon historical data, but will be strengthened by using uniform application of established, repeatable sampling methods that will allow comparison of data among stations and anticipated changing conditions due to CERP project implementation. Where and when possible, benthic sampling events will coincide with fish, oyster, and water quality monitoring activities identified in this module.

Triplicate macroinvertebrate sampling will be conducted at thirteen sites (Figure 3-55) quarterly, within seven days plus or minus of a date randomly selected within each quarter (156 discrete samples per year). In order to minimize variability among triplicates, each sample will consist of a re-randomized grab within a sampling zone defined utilizing landscape ecology techniques to identify similar water depth, salinity expectations, and loss on ignition to determine organic content of sediment. The midpoint of each zone is the latitude-longitude coordinates as defined in Table 3-13. The area of each zone shall be uniform throughout the study area and shall not exceed the area equivalent to a 100-meter circle. Samples will be collected utilizing a Van Veen stabilized ponar grab apparatus, and taxa will be identified to the lowest possible level. Samples will be collected outside of maintained channels, not from sandbars or spoil areas, and from sediments overlain by water to a depth of at least 1 meter at low tide. Granulometric and organics sampling will be conducted at every site. One additional core will be extracted and evaluated in the field to characterize redox potential discontinuity (RPD) utilizing International Council for the Exploration of the Sea guidelines.

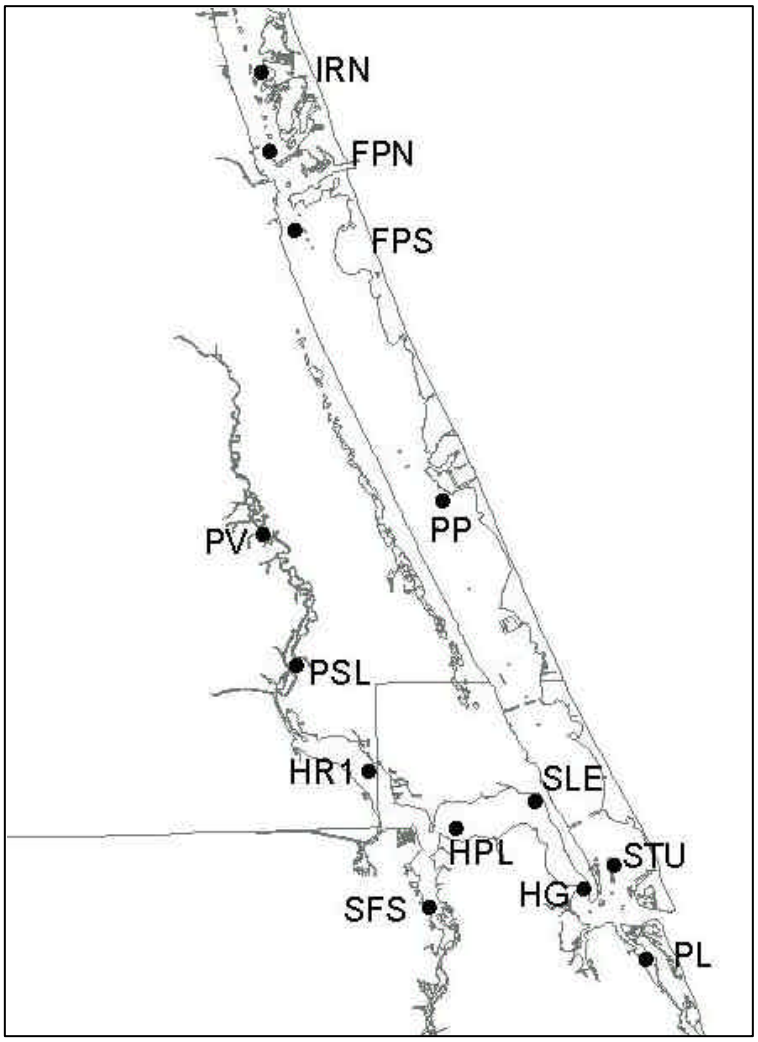


Figure 3-55: St. Lucie Estuary Macroinvertebrate Sample Collection Sites

Table 3-13: Preliminary Site Locations for Macroinvertebrate Sampling Sites in the St. Lucie Estuary

SITE_ID	Description	Latitude	Longitude
PV	Prima Vista Bridge North Folk St. Lucie River	27.3245667	80.3337167
PSL	Port St. Lucie Blvd. North Folk St. Lucie River	27.2715833	80.3202333
HR1	Telemetry Station in North Fork St. Lucie River	27.2280300	80.2891900
SFS	South Fork St. Lucie Estuary near Palm City Bridge	27.1725667	80.2634833
SLE	St. Lucie Estuary	27.2136000	80.2147500
HG	Hells Gate	27.1777700	80.1939200
HPL	Offshore Hospital	27.2042000	80.2501000
PL	Pecks Lake	27.1490000	80.1666000
STU	Stuart Causeway	27.1872000	80.1799000
PP	Power Plant	27.3356000	80.2518000
FPS	Fort Pierce South	27.4461000	80.3154000
FPN	Fort Pierce North	27.4779000	80.3252000
IRN	Indian River North	27.5099000	80.3280000

Loxahatchee River Estuary

The Loxahatchee River District has previously implemented a benthic macroinvertebrate sampling program that incorporates the Loxahatchee River Estuary and portions of the Atlantic Intracoastal Waterway as shown in Figure 3-56 (Dent et al. 1998). The Loxahatchee River District has collected seven years of baseline information as part of this sampling program; however, the program is currently not active within the estuary. The inclusion of this sampling program in the MAP is to allow for the continuation of the Loxahatchee River District sampling protocol, as funding becomes available, to determine changes in composition and distribution of benthic communities over time.

A more comprehensive database will be developed on the benthic community structure throughout the estuarine portions of the Loxahatchee River and attendant reaches of the Intracoastal Waterway using the previous Loxahatchee River District sampling program. Figure 3-56 identifies the nine biological sampling stations employed in the seven-year initial study of benthic macroinvertebrates. Two stations (21 and 25) were placed in the Indian River Lagoon portion of the Intracoastal Waterway, and two stations (31 and 35) were located within the Lake Worth Creek portion of the Intracoastal Waterway south of the Jupiter Inlet. A central embayment station (41), two stations (60 and 62) in the lower northwest fork of the Loxahatchee River, and one station each in the rivers' north prong (54) and the southwest fork (#0) were sampled.

The sampling frequency is designed to provide for two sample runs per year to capture the seasonal differences that exist in South Florida. Samples are taken in February or March of each year to represent dry season or winter conditions, and additional samples are taken in September, October, or November of each year to capture summertime or wet season conditions. The study period includes a number of above normal and below normal rainfall periods that represented moderately wet and moderately dry conditions in the system.

The sample collection procedure for this study uses a square diver core (12.5-centimeters per side) and a sieve bucket with U.S. Standard No. 30 mesh sieve (0.595-millimeter openings). All samples are taken in shallow water, with a depth of approximately one meter at low tide. Four cores are pulled and sieved at each site with the sieved sample from each core placed in a one-liter jar with 900 milliliters of site water

and 100 milliliters of formaldehyde with rose bengal. Samples are then sorted and identified in the laboratory.

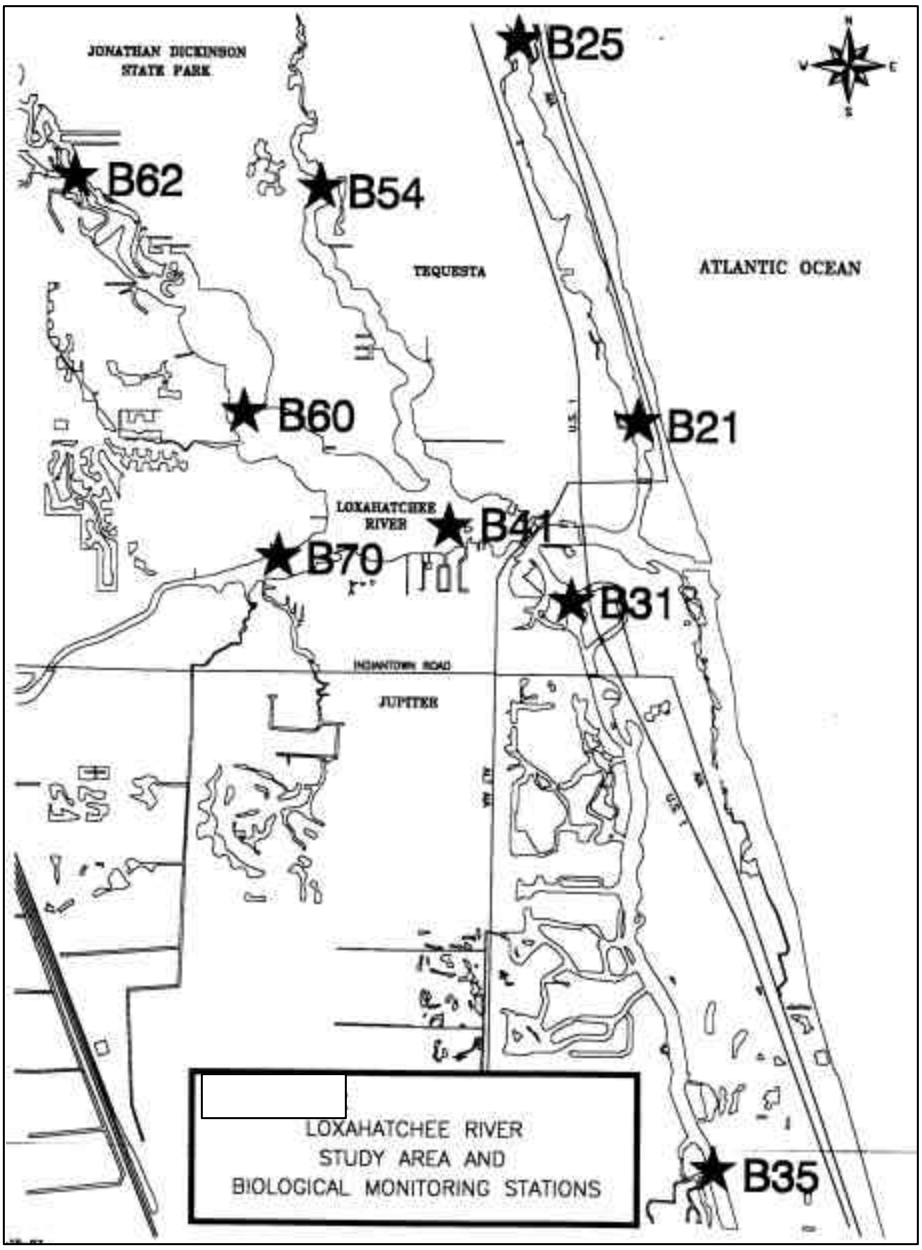


Figure 3-56: Loxahatchee River Estuary Benthic Monitoring Study Sites (Loxahatchee River District)

3.3.4 Key Uncertainties and Research Topics

3.3.4.1 Reconnaissance Study of Caloosahatchee

Justification: The Caloosahatchee River and Estuary (CRE) Collaborative Research Project is one part of the CERP administered by the SFWMD. In 2001, the SFWMD engaged Mote Marine Laboratory, which

in turn engaged the Florida Gulf Coast University, to develop and then implement a collaborative research program addressing the SFWMD's data needs as identified by the Caloosahatchee Estuary Conceptual Ecological Model (Appendix A). The objective of the first year of this study was to design a Final Caloosahatchee River Estuary (CRE) Cooperative Research Plan.

Project Description: The objectives of the collaborative CRE program are to describe present-day conditions of the study area, and to determine and empirically evaluate causal relationships of river flow to the distribution, abundance, and/or condition of selected valued ecosystem components. Specific issues to be evaluated by the CRE Cooperative Research Plan include the following:

- Role of hydrology (discharge) relative to red tide events
- Effects of salinity fluctuations on SAV beds, oysters, and juvenile fish populations and densities
- Ecological significance of SAV beds and oyster bars and the potential to reestablish these communities
- The effect of the presence and intensity of red tide blooms on juvenile fish and manatee health (as assessed through immune function) within the estuary
- Effects of manatee use of SAV on SAV productivity in the Caloosahatchee River and nearby waters
- The effect of loss or reduction of SAV in the estuary on manatee health
- Immunological or other biomarkers that indicate serious exposure and potential compromises of manatee health

Studies began in 2001-2002, on the subjects of red tide, SAV, SAV-dependent fish communities, manatee distribution and abundance, manatee immunology, oyster growth and condition, oyster disease, and oyster-dependent fish communities.

3.3.4.2 Fish Health and Pathology in the St. Lucie Estuary

Justification: Pathological abnormalities generally occur in low numbers in wild fish populations and can serve as a relatively easy indicator of environmental quality (Blazer 2000). Fournie et al. (1996) found that gross pathological abnormalities of all types are most prevalent at sites with high sediment contaminant concentrations. Gross abnormalities in fish in the St. Lucie estuarine system have been reported (Browder 2001, Browder 2002, Browder et al. 2002), suggesting that the prevalence of fish abnormalities would be a suitable quantitative measure of the effect on this system of implementing CERP projects. Planned modifications in the volume, timing, and spatial distribution of freshwater flows are expected to reduce the anthropogenic stress on fish in the St. Lucie system by restoring salinity patterns characteristic of estuaries, reducing contaminant loads, and reducing the input and resuspension of sediments.

The FWC's Florida Marine Research Institute (FMRI) currently (since 1998) conducts fish sampling with seine and trawl in the St. Lucie River system and northern Indian River Lagoon on a monthly basis as part of the state's Marine Fisheries-Independent Monitoring (FIM) Program, which is funded in part by saltwater fishing license fees. Other systems currently sampled through this program include Tampa Bay, Charlotte Harbor, Appalachicola Bay, Cedar Key/Suwannee Estuary, St. John's River and Estuary,

southern Indian River Lagoon, and Florida Bay. Fish observed to have lesions or other types of pathological indicators are submitted to FMRI for further analysis.

An Aquatic Health Program, a 15-year federally-supported program to address sport fish health, is currently managed by the FMRI to study and diagnose the causes of specific diseases in fish. In particular, lesion outbreaks associated with water management activities in the Caloosahatchee and St. Lucie River systems have been intensively monitored over the last five years. A historical review of fish lesion outbreaks since 1979 has determined that there are common environmental and pathogenic factors associated with such events. These data are being used to demonstrate the connection between freshwater releases and the increased incidents of lesions that are produced by a dominant low salinity tolerant fungus (FWC personal communication 2003).

Since 1996, the National Oceanic and Atmospheric Administration (NOAA) Fisheries (with recent funding from FDEP) has sampled fish in the St. Lucie system for the presence of gross abnormalities (17 distinct abnormalities, including lesions of various types and morphological anomalies). Sampling is with hook and line at fixed sites near structures located from the lower North Fork to the nearshore reef. Loxahatchee River and Jupiter Inlet sites recently were added for comparison. Results of weekly sampling are compiled by month and quarter. The FMRI and NOAA projects differ in collecting methods, length of the time series, sampling protocol, sampling locations, sample species composition, and study focus with some overlaps that offer opportunities for comparison.

The research needs/objectives are as follows:

- Establish a baseline for fish health within the St. Lucie Estuary
- Monitor trends in fish health and pathology through documentation of the prevalence of gross abnormalities and the use of a necropsy-based, health assessment index in the St. Lucie Estuary
- Document the spatial and temporal occurrence of epizootic disease
- Better understand relationships between the health of key indicator fish species and environmental quality
- Formulate appropriate fish-health-based performance measures for use in long-term monitoring in South Florida estuaries

Project Description: This project will include the following work activities:

- Identifying a standard methodology for fish sampling and assessment procedures
- Apply the protocols in present use in the St. Lucie system and northern Indian River Lagoon to extend existing monthly time series and explore alternative protocols
- Analyze trends in fish health assessment and prepare a baseline summary report on fish health in the St. Lucie estuarine system

This research proposal assumes that sediment and water quality and hydrological flow monitoring, as well as collection of data relative to seagrass distribution proposed within this monitoring plan for the St. Lucie Estuary, will provide supporting information for improving our understanding of relationships between key indicator fish species and contaminants of concern that occur within the estuarine systems.

3.3.4.3 Bottlenose Dolphin Health Assessment in St. Lucie Estuary

Justification: Redistribution of water flow, in both quantity and timing, is anticipated for several major estuarine systems for the South Florida ecosystem and for smaller tidal creek systems as part of the implementation of the CERP. Salt marsh and sea-grass communities are examples of habitats that will be affected by changes in water flows. Changes in the introduction of toxins to both large estuarine and smaller tidal systems as a result of changes to patterns of freshwater flows may influence the health of and toxin accumulation in resident bottlenose dolphin populations.

Bottlenose dolphins are appropriate indicator animals with which to monitor quality of estuarine habitat in terms of animal health for several reasons. They are long-lived animals that accumulate contaminants in their fatty issues. Small amounts of subcutaneous blubber can be biopsied from living animals for contaminant analysis. Contaminant content can be examined in relation to the health, as reflected in histopathology, blood profiles, and other medical diagnostics. Health assessment projects using methods based on marine mammal veterinary standards have been conducted by NOAA and other entities to determine the status of bottlenose dolphins in a number of estuaries of the southeastern United States. Research has shown that groups of bottlenose dolphins are resident to particular estuaries. Since individual dolphins can be identified (primarily from dorsal fin shape or coloration) through pattern recognition methods, it has been possible to identify resident individuals in both Biscayne Bay and Florida Bay. By following the health of identifiable resident individuals, it is possible to assess the quality of estuarine habitat with respect to contaminants and their effects.

The objective of this research proposal is to monitor the health of resident dolphins in estuarine systems of South Florida. An integrated program of performance measure monitoring needs to be applied to dolphin populations in order to develop health assessment indices, including body burden analysis for toxins. Photo identification techniques are used to identify individual bottlenose dolphins in order to monitor movements and use patterns in conjunction with health assessment measurements. This project is an ongoing NOAA/National Marine Fisheries Service responsibility related to the Marine Mammal Protection Act and requires no RECOVER funding.

Project Description: This project will include the following work activities:

- Photo-ID Program - Conduct resident population studies for abundance and distribution using photographic identification of individuals by distinguishing marks along the dorsal fin.

- Biopsy Program - Blubber samples are collected via projectile dart biopsy system. The blubber sample will be used for lipophilic contaminant analysis. Collateral skin samples can be used for genetic analyses (and subsequent stock identification) and gender determination.

- Health Assessment Survey - Conduct a health assessment profile analysis, which is a combination of veterinary medical diagnostics, zoological body fat condition quantification, and toxicological analysis including physical examination, diagnostic ultrasonography, clinicopathology, urinalysis, microbiology, serologic evaluation, specimen cytologic examination, fecal analysis, milk sampling, and skin/blubber biopsy. Veterinary medical diagnostics can be truncated into a preliminary veterinary health assessment that is based on marine mammal veterinary standards, including physical examination (e.g., vital signs, sex, weight, and body temperature), urinalysis, hematology, serum chemistries, and diagnostic ultrasonography.

3.3.4.4 Manatee Abundance and Distribution Relative to Changes in Freshwater Flows and Seagrass Distribution as a Result of Implementation of CERP Projects

Justification: The range of the Florida manatee (a subspecies of the West Indian manatee) varies seasonally. During summer months, manatees are widely dispersed at the lower reaches of rivers and canals and in estuaries, lagoons, and bays. During the winter, when water temperatures drop below 20 degrees Celsius, manatees typically seek natural and artificial warm waters of South Florida. Important habitat requirements for the Florida manatee include access to submerged, floating, and emergent vegetation (e.g., seagrasses and mangroves), natural freshwater sources, proximity to channels 1-2 meters deep, and access to natural springs or man-made warm water refugia during winter (Hartman 1978).

Changes in manatee populations and distribution related to changes in freshwater flows to coastal areas are anticipated to occur with the implementation of CERP projects. The redistribution of these flows (in both quantity and timing) to estuarine systems is expected to influence manatee behavior in these areas. It is important that a baseline be established relative to manatee habitat and behavioral patterns for important estuarine areas (i.e., St. Lucie Estuary, portions of southwest Florida, the Caloosahatchee Estuary, Florida Bay, and Biscayne Bay).

As part of their research contribution to the CERP, the United States Geological Survey initiated a study on the impacts of hydrological restoration on manatees in the Everglades National Park/Ten Thousand Islands region in June 2000. The major objectives of the study are to determine distribution, movements, and habitat use of manatees associated with coastal waters and rivers and to develop an Across Trophic Level Systems Simulation (ATLSS) model to predict manatee response to changes in hydrology achieved by the Southern Golden Gate Estates project specifically and more broadly by the CERP. Comprehensive field studies in Southwest Florida involving satellite-based tracking and aerial surveys will provide data for the model and document the current distribution and status of the manatee population prior to implementation of restoration activities. Telemetry data from tagged manatees provide a valuable means of documenting the response of manatees to fluctuations in freshwater inflow and changes in distribution, abundance, and type of SAV. Strip-transect methods are proving to be a successful tool for statistically determining manatee population trends in this previously unstudied region. These findings and their integration with the manatee ATLSS model effort address specific CERP objectives:

- Develop relationship between salinity/water quality and manatee use of tidal rivers, creeks, and aquatic refugia for obtaining fresh water for drinking and sheltering from cold

- Develop relationship between hydrology (quantity, quality, and timing) on use by manatees as indicators of status of several communities, including estuaries, bays, creeks, and rivers

- Monitor the status of manatees as an indicator species and a species of special concern

These project objectives can be used to provide supporting information for this research topic and further refine the project description for inclusion of a manatee monitoring component in the MAP.

Manatee distribution is also influenced by interactions with physical structures. The United States Fish and Wildlife Service is currently developing a scope of work with the USACE to investigate the distribution of manatees within the C&SF Project canal system. In addition to addressing causal factors related to entrapment, injury, or mortality of manatees, this effort is also expected to provide information on movements of manatees within inland coastal areas.

Project Description: This project will include the following work activities:

- Radio-tag a representative number of manatees within the South Florida coastal ecosystem and investigate annual movements of these tagged animals through satellite telemetry, focusing on the fall and spring migration patterns. Three to four manatees will be tagged per subregion, which include the St. Lucie Estuary, Biscayne Bay, Florida Bay, Ten Thousand Islands, and Caloosahatchee Estuary. Animals will be visually inspected once a month to validate animal movement and inspect equipment. If it is determined that the tag needs to be replaced and the animals needs to be captured, then a health assessment will be conducted for that animal during the course of tag replacement.

- Investigate the correlations between manatee distribution and abundance to seagrass habitat and freshwater flows within Florida Bay, Biscayne Bay, the St. Lucie estuary, the Caloosahatchee estuary, and Southwest Florida. Develop baseline summary analysis.

This research proposal assumes that hydrological monitoring and collection of data relative to seagrass distribution proposed within other sections of this monitoring plan will provide supporting information for addressing this research topic.

3.3.5 References

Blazer, V.S. 2000. The Necropsy-Based Fish Health Assessment. In: Schmitt, C.J., and G.M. Dethloff (eds). Biomonitoring of Environmental Status and Trends (BEST) Program: Selected Methods for Monitoring Chemical Contaminants and Their Effects in Aquatic Ecosystems. Information and Technology Report USGS/BRD-2000-0005, United States Geological Survey, Biological Resources Division, Columbia, Missouri, pp. 18-32.

Browder, J.A. 2001. July 15, 2002 Progress Report, April 2001-June 2001 Period. To the Florida Department of Environmental Protection from the Southeast Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Miami, Florida.

Browder, J.A., M. Kandrashoff, and W. Kandrashoff. 2002. Abstract. Fish Health Problems in the St. Lucie Estuarine System. Presentation at the Indian River Citrus BMP/St. Lucie River Issue Team Research Forum. 20 Feb. 2002, Ft. Pierce, Florida.

Browder, J.A. 2002. Progress Report, Quarter 7 (Yr-2). To the Florida Department of Environmental Protection from the Southeast Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Miami, Florida.

Chamberlain, R.H., and P.H. Doering. 1998. Preliminary Estimate of Optimum Freshwater Inflow to the Caloosahatchee Estuary: A Resource Based Approach. In: Treat, S.F. (ed.). Proceedings of the Charlotte Harbor Public Conference and Technical Symposium, Charlotte Harbor Estuary Program, Technical Rep. No. 98-02, North Fort Myers, Florida, pp. 111-120.

Dent, R.C., L.R. Bachman, and M.S. Ridler. 1998. Profile of the Benthic Macroinvertebrates in the Loxahatchee River Estuary. Wildpine Ecological Laboratory, Loxahatchee River District; Jupiter, Florida.

FWC Personal communication. 2003. Florida Fish and Wildlife Conservation Commission letter dated June 10, 2003.

Fournie, J.W., J.K. Summers, and S.B. Weisberg. 1996. Prevalence of Gross Pathological Abnormalities in Estuarine Fishes. Trans. Am. Fish. Soc. 125:581-590.

Graves, G.A., D. Strom. 1995. Pesticide Contamination in the Ten Mile Creek, Major Tributary to the Outstanding Florida Waters of the North Fork of the St. Lucie River. Unpublished final report, Florida Department of Environmental Protection, Tallahassee, Florida.

Hartman, D.S. 1978. West Indian Manatee. In: Layne, J.N. (ed). Rare and Endangered Biota of Florida. Volume 1. Mammals. University Presses of Florida, Gainesville, Florida, pp. 27-39.

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

Haunert, D.E., and J.R. Startzman. 1980. Some Seasonal Fisheries Trends and Effects of a 1,000 cfs Fresh Water Discharge on the Fishes and Macroinvertebrates in the St. Lucie Estuary, Florida. Unpublished final report to South Florida Water Management District, West Palm Beach, Florida.

Haunert, D.E., and J.R. Startzman. 1985. Short Term Effects of a Freshwater Discharge on the Biota of the St Lucie Estuary, Florida. Unpublished final report to South Florida Water Management District, West Palm Beach, Florida.

Loftis, J.C. and R.C. Ward. 1980. Sampling Frequency Selection for Regulatory Water Quality Monitoring. Water Resources Bulletin, 16:3, pp. 501-507.

RECOVER. 2003. Quality Assurance Systems Requirements (QASR). RECOVER, c/o South Florida Water Management District, West Palm Beach, Florida, June 23, 2003 draft.

RECOVER. In prep. Performance Measure Documentation Report. RECOVER c/o South Florida Water Management District, West Palm Beach, Florida.

Robertson, D.M. and E.D. Roerish, 1999. Influence of Various Water Quality Sampling Strategies on Load Estimates for Small Streams. Water Resources Research, V.35, n.12, pp. 3747-3759.

Rudolph, Harvey D., 1990, North Fork of the St. Lucie River: Macroinvertebrate Survey in February and August 1986, With a Comparison to Previous Macroinvertebrate Surveys. - A Biological Basin Assessment Survey. Florida Department of Environmental Regulation, Southeast District Branch Office, Port St. Lucie, Florida, (unpublished).

Spooner, J., D.A. Dickey, and J.W. Gilliam. 1990. Determining and Increasing the statistical sensitivity of Nonpoint Source Control Grab Sample Monitoring Programs. Proceedings: Design of Water Quality Information Systems, Information Series No. 61, Colorado Water Resources Research Institute, Fort Collins, Colorado.

Stickley, R.R. 1984. Estuarine Ecology of the Southeastern United States and Gulf of Mexico. Texas A&M University Press; College Station, Texas.

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

Volety, A.K. 2002. Personal communication. Florida Gulf Coast University, Fort Myers, Florida.

Volety, A.K, S.G. Tolley, and J.T. Winstead. 2001a. Effects of Season and Water Quality on Oysters (*Crassostrea virginica*) and Associated Fish Assemblages. 16th Biennial Conference of the Estuarine Research Federation, Book of Abstracts.

Volety, A., K.M. Savarese, and S.G. Tolley. 2001b. Disease Status and Physiological Responses of Oysters as Indicators of Watershed Alteration Effects in Southwest Florida Estuaries. Journal of Shellfish Research 20(1):558.

3.4 LAKE OKEECHOBEE MODULE

3.4.1 Introduction

Lake Okeechobee is a large (1,730 square kilometers) freshwater lake located at the center of the interconnected South Florida aquatic ecosystem. The lake is shallow (average depth <3 meters), originated about 6,000 years ago during oceanic recession, and under natural conditions probably was slightly eutrophic and had vast marshes to the west and south (Havens et al. 1996a). The southern marsh was contiguous with the Florida Everglades, which received water as broad sheet flow from the lake during periods of high rainfall (Gleason 1984). Modern-day Lake Okeechobee differs in size, range of water depths, connections with other parts of the regional ecosystem, and water quality (Steinman et al. 1999, 2001). Two major stressors (excessive phosphorus inputs and unnatural water levels) have significant impacts on the lake's ecological and societal values (Figure 3-57) by a complex set of ecological processes described in the Lake Okeechobee Conceptual Ecological Model (Appendix A, Havens 2001). An additional ecological stressor that is not specifically considered in this document is the introduction and expansion of exotic and nuisance plants, as well as the introduction of some exotic animals. Programs to identify and control exotic species fall primarily under the state's Lake Okeechobee Protection Act (LOPA).

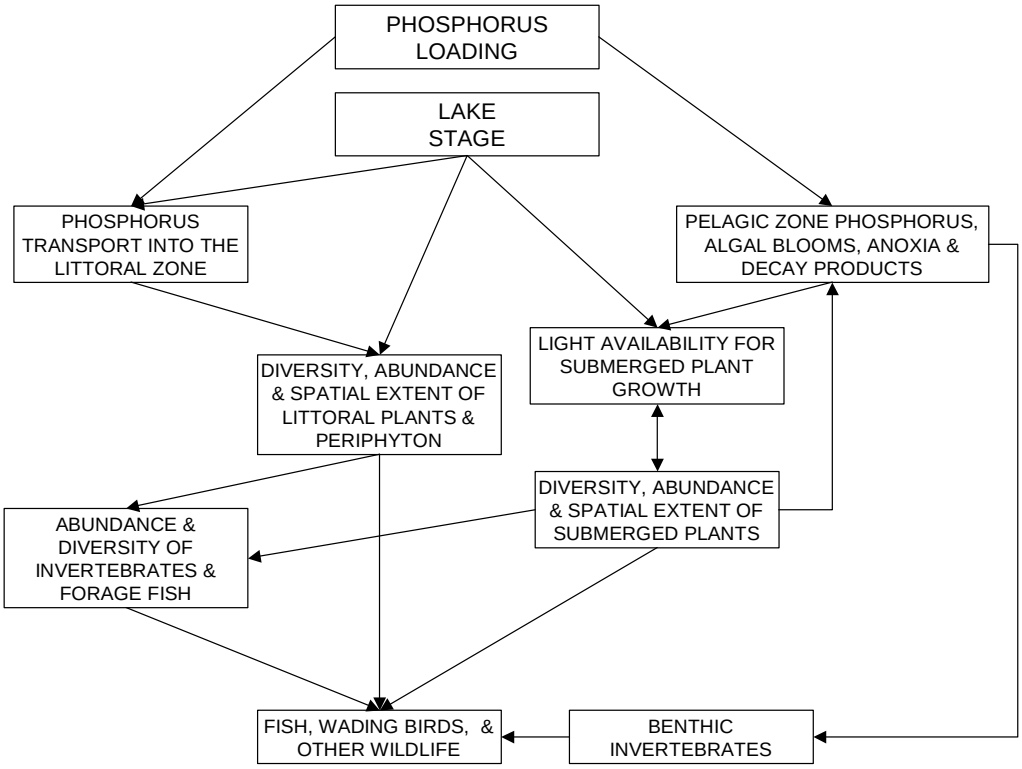


Figure 3-57: Simplified Conceptual Ecological Model to Reflect Expected CERP Influences in Lake Okeechobee

Construction of the Herbert Hoover Dike in the early to mid-1900s reduced the size of the lake's open-water zone by nearly 30 percent. This resulted in a considerable reduction in average water levels and

produced a new littoral zone within the dike that is only a fraction of size of the natural one. Variations in rainfall, evapotranspiration, water supply deliveries from the lake, and operation of the Central and Southern Florida (C&SF) Project (including the regulation schedule, supply-side management, and compliance with any minimum water level criteria) have the potential to affect water levels (stage) in the lake. This becomes stressful to the ecosystem when there is prolonged or extreme high or low lake stage. The impacts of high and low stage are more severe than they would have been when the dike did not encircle the lake. Under natural conditions, water was able to expand and recede over a large low-gradient marsh to the west and south. Today, when stage exceeds 15 feet, water simply stacks up over the much-reduced littoral zone, flooding it to a greater depth. When stage falls below 11 feet, the entire littoral zone is dry, and habitat is not available for wetland biota. Hence, extreme high or low lake levels of any duration or moderate high or low lake levels of prolonged (>12 months) duration can cause significant harm to the ecosystem. In contrast to the harmful effects of extremes, a certain degree of natural variation in lake stage (between approximately 12.5 and 15.5 feet) has been shown to benefit the ecosystem by Smith et al. (1995) and Havens et al. (2003), who investigated responses to late 1990s high water and the 2000-2001 drought. Variation in stage between 12.5 and 15.5 feet is a desired hydrologic result of water storage and detention facilities constructed under the Comprehensive Everglades Restoration Plan (CERP).

The lake also has been impacted in recent decades by excessive inputs of phosphorus from agricultural activities in the watershed (Flaig and Havens 1995, Havens et al. 1996a). These nutrients have exerted the most dramatic impacts on the open-water region, where large algal blooms have occurred (Jones 1987), along with accumulation of soft organic mud bottom sediments (Moore et al. 1998), which cause the lake water to become highly turbid when they are resuspended during windy periods (Maceina and Soballe 1991). Concentrations of total phosphorus in the lake's water column more than doubled in the last 30 years, from 40 to 50 parts per billion (ppb) in the early 1970s to over 100 ppb in 2001 (SFWMD 2002). The primary source of phosphorus pollution is agriculture, with lesser contributions from urban and other sources (Flaig and Havens 1995). As a result of decades of high inputs, the soils in the watershed, the sediments of tributaries, and the lake's bottom sediments now contain much larger quantities of phosphorus than are found in non-impacted systems (Olila and Reddy 1993, Flaig and Reddy 1995). These soils and sediments represent large secondary sources of phosphorus loading to the lake. The deep canals of the C&SF Project also facilitate delivery of phosphorus to the lake, bypassing wetlands that may have attenuated phosphorus concentrations under more natural conditions.

A number of CERP projects are expected to influence the stressors and attributes described in this conceptual ecological model of the lake. Some of these effects will be direct, others indirect (see Appendix B). Projects expected to affect Lake Okeechobee include the following:

- Regional Aquifer Storage and Recovery (ASR) – expected to directly affect lake water level variation and lake water quality

- Lake Okeechobee Watershed Project – expected to directly affect lake water levels and water quality, in particular phosphorus loading rates

- Everglades Agricultural Area (EAA) Reservoir and Treatment Wetlands – expected to directly affect lake water levels and water quality, in particular phosphorus loads

- Lake Istokpoga Regulation Schedule – expected to indirectly affect lake water levels and water quality by altering discharge regime from this lake to its downstream structures that pass water to Lake Okeechobee

- C-44, C-43, Caloosahatchee Storage Reservoirs and/or ASRs – expected to indirectly affect lake water levels by altering the capacity of downstream systems to take water that might presently be held in or delivered back to Lake Okeechobee

- Canal and structure modifications in EAA and Water Conservation Areas – expected to indirectly affect lake water levels by increasing the capacity to convey water to the south

3.4.2 Ecological Premises and CERP Hypotheses as the Basis for Monitoring Components and Supporting Research

Two overarching ecological premises form the basis for most of the CERP restoration goals and strategies for Lake Okeechobee. These relate to the effects of hydrology on 1) water quality (i.e., phosphorus loading and inputs) and 2) lake stages. Monitoring and assessment associated with each of these premises is dependent on the South Florida Hydrology Monitoring Network (Section 3.5).

Figures 3-58 and 3-59 illustrate the linkages of the ecological premises to CERP hypotheses, monitoring components, and key uncertainties and supporting research. Supporting research generally originates from monitoring components, in which case research supports the interpretation of monitoring results. A summary of the monitoring components and supporting research for Lake Okeechobee is listed in Table 3-14 and described in detail in the following sections.

The process used to develop the monitoring plan for Lake Okeechobee, and all of the other modules, is described in Section 2.0, Development of the CERP Monitoring Plan and Adaptive Management Program. The strategy for prioritizing and implementing monitoring components and research topics is discussed in Section 5.0, Implementation Strategy for the CERP Monitoring and Assessment Plan.

3.4.2.1 Water Quality (Figure 3-58)

Ecological Premise: The predrainage Lake Okeechobee was characterized by hydrologic inputs primarily from rainfall and inflow from tributaries draining wetlands, forest, and range lands. This resulted in relatively moderate phosphorus inputs to the lake and moderately eutrophic conditions in the ecosystem. This contrasts sharply with the present condition of high phosphorus inputs from agricultural lands and highly eutrophic lake conditions.

CERP Hypothesis: A decrease in phosphorus inputs to the lake will result in the following changes:

- Reduction in pelagic (open-water) total phosphorus concentrations to 40 ppb

- Increase in pelagic total nitrogen:total phosphorus ratios to >22:1

- Increase in the ratio of diatoms:cyanobacteria to >1.5:1, resulting in a more effective food web to support the lake's fishery

- Decrease noxious cyanobacteria blooms

- Increase in water clarity

- Decrease in the relative abundance of pollution-tolerant benthic macroinvertebrates in the lake sediments

- Increase in the spatial extent and biomass of native submerged vegetation and a decrease in the rate of nuisance and exotic plant species expansion along the edge of the littoral zone
- Increase in fish and wading birds that depend on submerged vegetation for foraging

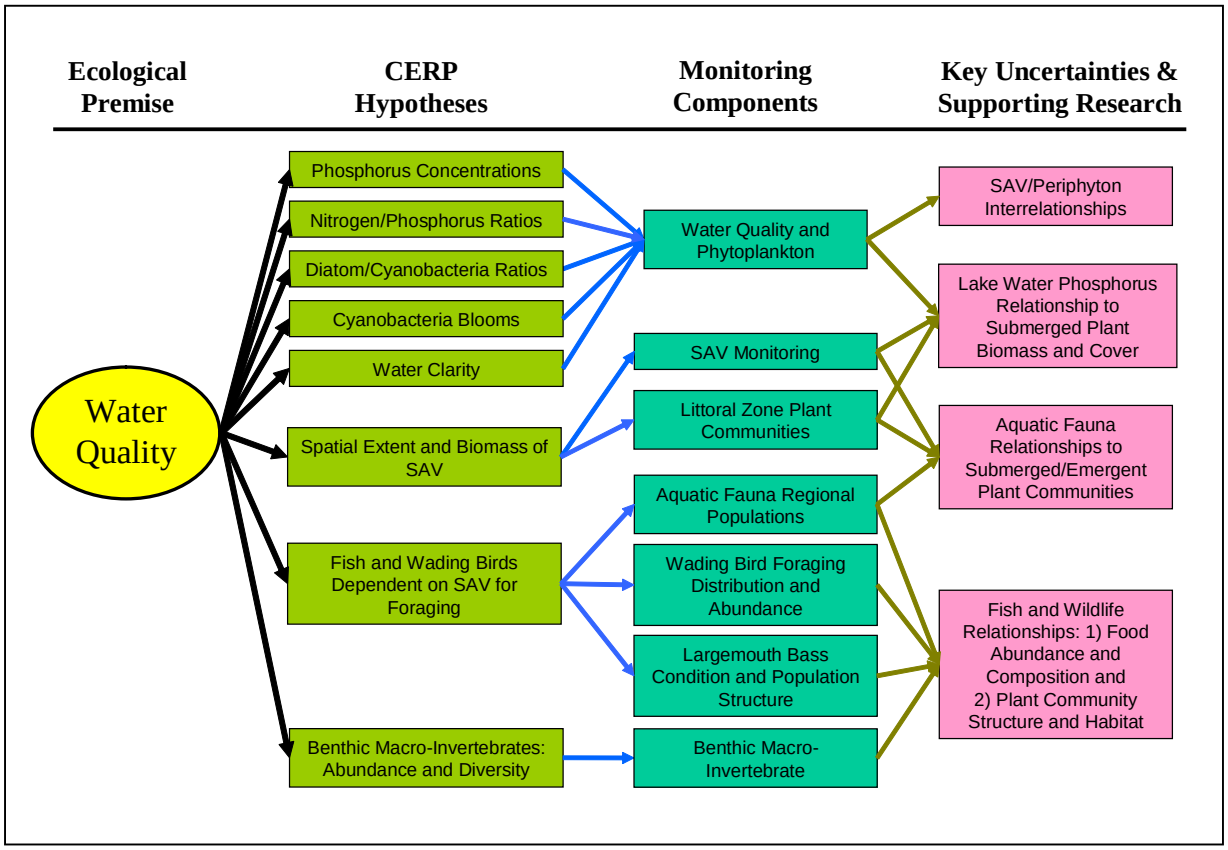


Figure 3-58: Diagram Depicting Relationships between the Ecological Premise, CERP Hypotheses, Monitoring Components, and Supporting Research for Water Quality in Lake Okeechobee

Adaptive Management Question: Will the restoration of more natural inputs of phosphorus have the expected benefits, in terms of the expectations listed above? What further actions may be required in order to accomplish these objectives?

3.4.2.2 Ecological Communities and Effects of Water Stages (Figure 3-59)

Ecological Premise: Sustained lake levels and a reduction of spring recession conditions have resulted in the loss and degradation of predrainage floral and faunal communities in Lake Okeechobee.

CERP Hypotheses: Providing a reduction in the frequency of extreme high water levels (stage >17 feet and stage >15 feet for more than 12 consecutive months) and low water levels (stage <11 feet and stage <12 feet for more than 12 consecutive months) and an increase in the frequency of spring recessions (yearly stage decline from near 15.5 feet in January to near 12.5 feet in June, with no reversal >0.5 feet) will result in the following changes (see Havens 2002 for details):

- Increase in spatial extent of bulrush along the western lakeshore; increased spatial extent of spikerush, beakrush, willow, and other native plants in the littoral zone; and a reduction in the rate of expansion of exotic and nuisance plants
- Increase in spatial extent of vascular submerged plants, in particular eelgrass, peppergrass, and southern naiad
- Shift in taxonomic structure of zooplankton to better support fishery resources
- Increase in diversity, distribution, and abundance of forage fish in the littoral and near-shore zones
- Increase in the use of the littoral zone for wading bird foraging and nesting
- Improvement in the density, age structure, and condition of black crappie, largemouth bass, and bream in the littoral and near-shore zones
- Reduction in the occurrence of harmful shoreline organic berms

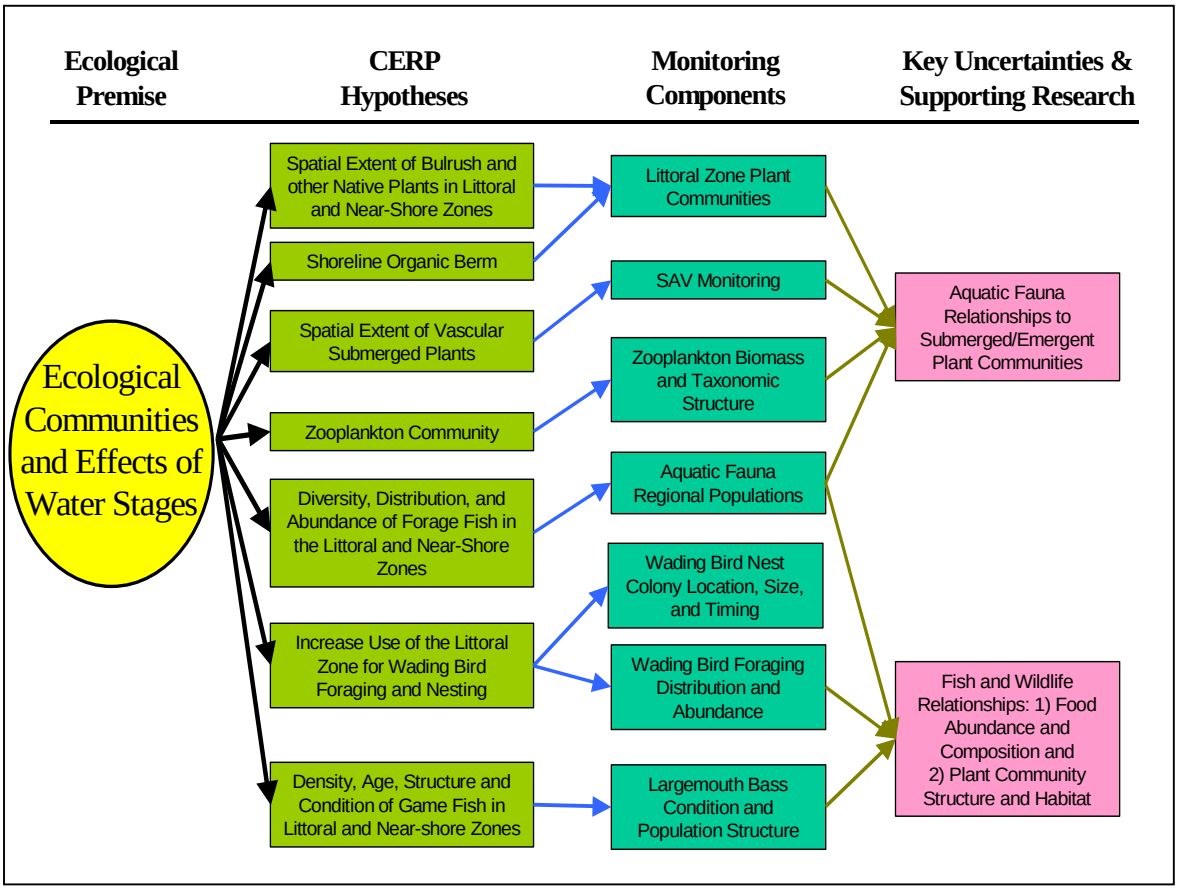


Figure 3-59: Diagram Depicting Relationships between the Ecological Premise, CERP Hypotheses, Monitoring Components, and Supporting Research for Ecological Communities and Effects of Water Stages in Lake Okeechobee

Adaptive Management Question: Will the reduction of extreme high and low lake stages and the increased frequency of spring recessions result in the expected improvements in the ecosystem, as quantified by the above-listed performance measures? What further actions may be required in order to accomplish these objectives?

3.4.2.3 Summary of Monitoring Components and Key Uncertainties and Supporting Research

Table 3-14 summarizes the monitoring components and key uncertainties and supporting research for the Lake Okeechobee Module. The section of this document in which the item is discussed is provided in the second column of Table 3-14 for reference.

The systemwide assessment performance measures are published in a separate document, the Performance Measure Documentation Report (RECOVER In prep). Each Monitoring Assessment Plan (MAP) monitoring component has at least one corresponding performance measure. For reference, the performance measure identification number or numbers are provided in the last column of Table 3-14. Performance measures LO-A1 to LO-A5 correspond to hydrologic monitoring components that are discussed in the South Florida Hydrology Monitoring Network (Section 3.5). A component has not yet been developed for Apple Snail and Snail Kite monitoring, though a performance measure (LO-A9) has been developed. This component will be developed and added to the next update of the Monitoring and Assessment Plan.

Table 3-14: Monitoring Components and Supporting Research for Lake Okeechobee

Monitoring Components	MAP Section	Performance Measure Number
Water Quality and Phytoplankton	3.4.3.1	LO-A14 LO-A15 LO-A16 LO-A17 LO-A18 LO-A19 LO-A20
Littoral Zone Plant Communities	3.4.3.2	LO-A6 LO-A13
Submerged Aquatic Vegetation	3.4.3.3	LO-A7
Zooplankton Biomass and Taxonomic Structure	3.4.3.4	
Benthic Macroinvertebrates	3.4.3.5	LO-A8
Fish Condition and Population Structure	3.4.3.6	LO-A11
Greater Everglades Wetlands Monitoring Components		
Trophic Level - Aquatic Fauna Regional Populations	3.1.3.10	GE-A6
Trophic Level - Wading Bird Foraging Distribution and Abundance	3.1.3.12	LO-A10
Trophic Level - Wading Bird Nesting Colony Location, Size, and Timing	3.1.3.13	LO-A10
American Alligator Distribution, Size, Nesting, and Hole Occupancy	3.1.3.15	LO-A12

Table 3-14 : Monitoring Components and Supporting Research for the Lake Okeechobee (continued)

Key Uncertainties and Supporting Research		
Aquatic Fauna Relationships to Submerged and Emergent Plant Communities	3.4.4.1	
Fish and Wildlife Relationships to Food Abundance and Composition	3.4.4.2	
Fish and Wildlife Relationships to Plant Community Structure and Habitat	3.4.4.3	
Submerged Plant/Periphyton Interrelationships with Light, Nutrients, and Water Depth	3.4.4.4	
Lake Water Phosphorus Relationship to Submerged Plant Biomass and Cover	3.4.4.5	

3.4.3 Monitoring Components

3.4.3.1 Water Quality and Phytoplankton

The objective of water quality monitoring is to determine if CERP projects result in a reduced level of stress on the lake's flora and fauna from high phosphorus loads, high phosphorus concentrations within the ecosystem, and other associated conditions of cultural eutrophication. With regard to inputs of water to the lake, the major focus is on determining phosphorus loads, given the central role of excessive phosphorus in influencing the natural and societal values of the ecosystem. However, because Lake Okeechobee is a Class I surface water body in the State of Florida and provides drinking water to a number of municipalities around the lake, it is critical that the MAP include a suite of select water quality parameters related to Class I standards (Ogburn et al. 1996) in order to assess the cumulative impact of surrounding CERP projects, particularly ASR, on the lake. The issue of Class I standards is addressed in detail in the Lake Okeechobee Conceptual Ecological Model (Appendix A, Havens 2001).

An optimal sampling regime has been proposed by the REstoration COordination and VERification (RECOVER) Water Quality Team to document changes in contaminant loads entering the lower reaches of the Kissimmee River and subsequently the lake, as well as loads transported into the lake from other sub-basins in the watershed that are expected to change as a result of CERP projects. In large part, the proposed monitoring scheme uses the existing legislatively-mandated water quality monitoring network already in place. However, to address the unique impacts to the lake brought about by CERP implementation, some modifications and enhancements (additional parameters and increased sampling frequencies) are required. The stations (Figure 3-60) for monitoring water inputs to the lake and for load calculations associated with major nutrients are located at all major tributaries entering and exiting the system. There also are 17 stations located in the northern watershed of Lake Okeechobee that will be monitored over the next 10 years by the United States Geological Survey (USGS). Data from those stations will provide additional information regarding subregional changes in phosphorus loads to the lake.

Inflow and outflow monitoring (Figure 3-60, Table 3-15, and Table 3-16) will evaluate cumulative water quality trends and conditions anticipated to result from the CERP projects in the lake's watershed. The existing inflow and outflow water quality monitoring network is administered by the South Florida Water Management District (SFWMD) and measures loads to and from the lake and water quality conditions at the lowermost reach of the Kissimmee River. Some structures can switch from being inflows to outflows, depending on water levels in the lake. When water samples are collected, direction of flow is always noted in the data base so that the information can be appropriately used in calculating nutrient mass balances. Flow monitoring is conducted at all major tributary structures where water enters and exits the system (Table 3-16) using either grab samples or a combination of grab samples and autosamplers. Samples are routinely collected on a bi-weekly basis when flow is observed and on a monthly basis when

no flow is observed. At several key inflow/outflow points, samples are collected weekly for nutrients. Other key parameters are sampled monthly or quarterly. Historical data are available from 1973 to present at most locations, although data from the late 1980s onward are considered by SFWMD staff to have the highest degree of reliability due to optimization of quality control at that time. Monitoring details are provided in James et al. (1995a) and the SFWMD's Environmental Monitoring and Assessment Department. Overall, the existing monitoring program is considered adequate to meet the needs of RECOVER, with the exception of increasing the sampling frequency of silicate (SiO_2) and sulfate (SO_4) from quarterly to monthly and adding the collection of select trace metals on a quarterly basis. These enhancements would need to be added as a CERP cost because they are not presently required under the existing monitoring programs.

For in-lake water quality monitoring, a network of stations has previously been optimized by the SFWMD to provide a spatially appropriate sampling of the major ecological zones of the ecosystem (SFWMD 2002). Stations are clustered more densely at the interface region between the littoral and pelagic zones, due to greater heterogeneity in water quality, and are more sparsely clustered at mid-lake, where conditions are relatively homogeneous. The in-lake monitoring (Figure 3-61 and Table 3-17) is designed to provide data necessary to quantify the following performance measures: pelagic total phosphorus; pelagic nitrogen:phosphorus ratio; diatom:cyanobacteria ratio; algal bloom frequency, based on occurrence of chlorophyll *a* concentrations in excess of 40 ppb; water clarity, measured with a Secchi disk; and Class I water quality parameters, as summarized by Ogburn et al. (1996).

In order to more fully address CERP-specific issues, some modification to the current in-lake sampling program has been proposed. The modifications include adding monthly pH measurements at 27 stations, monthly Secchi depth measurements at 13 sites, and quarterly select trace metals sampling at all 38 in-lake stations, as well as increasing the sampling frequency of silicate (SiO_2) and sulfate (SO_4) from quarterly to monthly. Additionally, it is recommended that a sediment pore water survey at 171 sites be continued every 10 years to assess changes in the lake's sediment chemistry and its ability to absorb phosphorus. Comparisons of the 171 sediment pore water samples collected in 1988 and 1998 surveys showed that dissolved phosphorus in pore water doubled, which may indicate that the sediments are losing their ability to absorb phosphorus (Fisher et al. 2001). Because of the tremendous variability in sediments, decade time periods are probably the shortest time period in which a significant change can be determined.

In Figure 3-61, the three major physiographic regions shown in Figure 3-62 (pelagic, near shore, and littoral) are divided into six subregions that have significantly different water quality characteristics. The pelagic, or open water, regions also can display spatial variation in water quality (Philips et al. 1995), but the extent to which this occurs depends strongly on lake stage. That region is not sub-divided here, but this heterogeneity needs to be taken into consideration in data analysis. The stations are sampled monthly from November to April and twice monthly from May to October. Samples are near-surface grabs.

Water quality sampling and flow measurements will follow standard field and laboratory methods described in James et al. (1995b) and the CERP Quality Assurance Systems Requirements (QASR) (RECOVER 2003). Phytoplankton collection and processing will follow standard methods described in Havens et al. (2003).

The water quality monitoring program for Lake Okeechobee and its inflow structures will be periodically reviewed and optimized by the Water Quality Team.

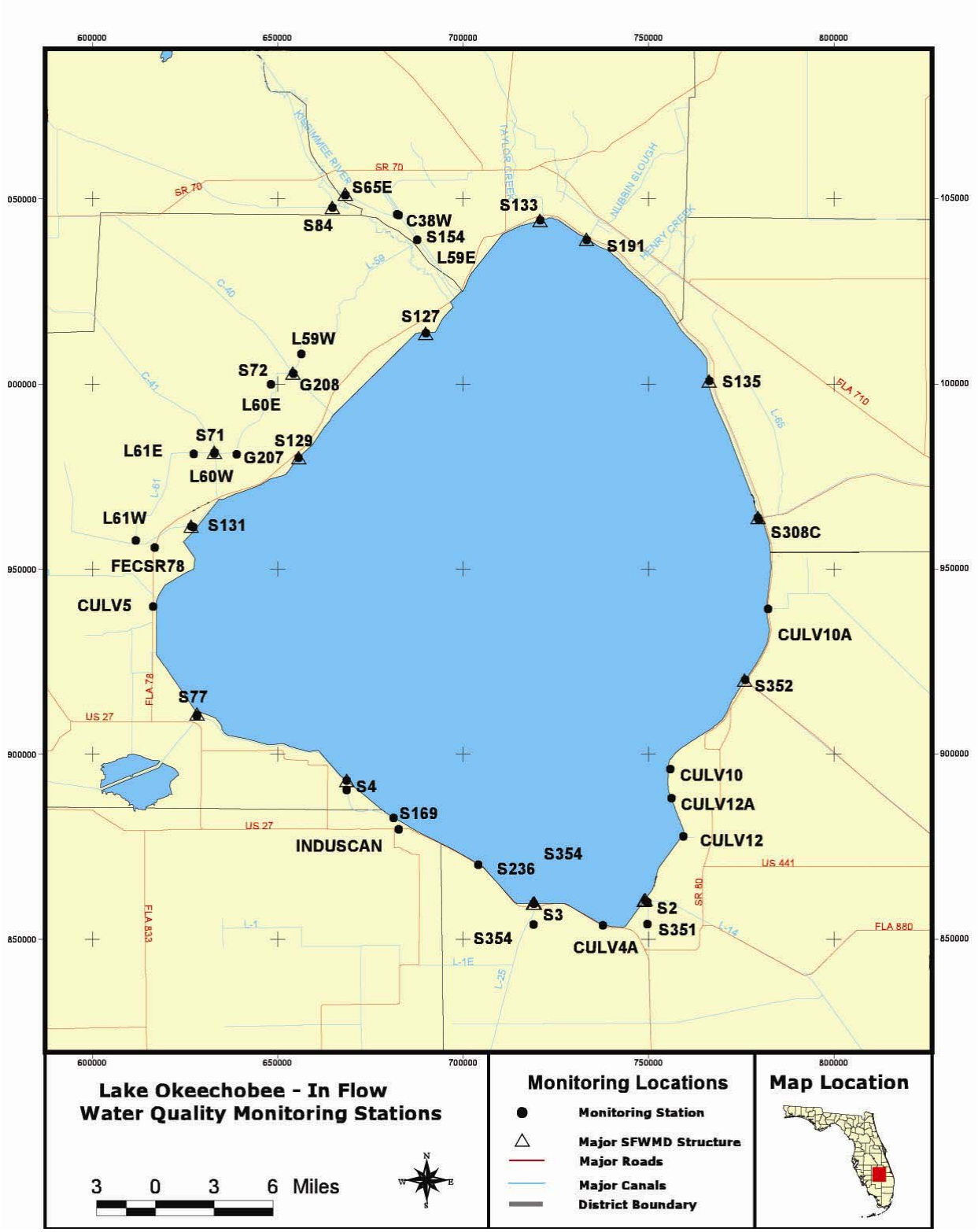


Figure 3-60: **Map of Lake Okeechobee, Showing the Locations of 32 Inflow and Outflow Water Quality and Flow Monitoring Stations. Source: James et al. (1995a) and SFWMD Environmental Monitoring and Assessment Department.**

Table 3-15: Recommended Lake Okeechobee Water Quality Monitoring – (Nutrient Loads and Inflow/Outflow Quality)*

Medium	Group	Parameters	Sites	Frequency	Collection Method
Water	Physical Parameters	DO, pH, conductivity temperature, alkalinity, turbidity, total suspended solids, color	TIN8100, TIN13700, TIN16100, FEBOUT, FEBIN, MBOXSOU, MH32000, MH24000, MH16000, MH12000, OISLAND L001, L002, L003, L004, L005, L006, L007, L008, KBAROUT, KISSRO.03RDPTOUT, POLESOUT, STAKEOUT, TREEOUT, PLN2OUT, PALMOUT, LZ2, LZ25, LZ30, LZ40, LZ42, LZ42N, PELMID, POLE3S, RITAWEST, RITAEAST, CULV10A	Bi-weekly/ monthly/	Water quality probe and grab
Water	Nutrients	TP, TKN, NH_3, NO_2, NO_{2+3}, $Si0_2$, SRP		Bi-weekly/ monthly	Grab and flow –proportional autosampler
Water	Major Ions	Cl, SO_4		Bi-weekly/ monthly	Grab
Water	Other Core Parameters and Trace Metals	Ca, Mg, As, Cd, Cu, Fe, Zn		Quarterly	Grab
Water	Flow	Flow		Continuous	Flow recorders-telemetry, solid state, manual

*See Table 3-17 below for legend

Table 3-16: Lake Okeechobee Inflow and Outflow Monitoring Station Summary. Source: James et al. (1995a) and SFWMD Environmental Monitoring and Assessment Department.

Station Name	Flow Recorder Type	Water Sample Method	Current Water Sample Frequency
Culvert 5	Telemetric and manual	Grab	BWF/M/Q
Culvert 5A	TBI	Grab	BWF/M/Q
S-77	Solid state	Grab	BW/Q
S-4	Telemetric	Grab Grab /autosampler	BWF/M/Q WF (Nutrients)
S-169	Telemetric	Grab	BWF/M/Q
Industrial Canal	TBI (USGS)	Grab	BWF/M/Q
S-236	Manual	Grab	BWF/M/Q

LEGEND:

BW – Samples collected bi-weekly (physical parameters/nutrients)
BWF/M – Samples collected bi-weekly if flow conditions or monthly if non-flow conditions (physical parameters/nutrients/selected major ions)
PE – Pumping events
Q- Samples collected quarterly (selected major ions)
TBI – To be instrumented
WF – Samples collected weekly (flow proportional composite)
WT – Samples collected (weekly time composite)

Table 3-16 (continued): Lake Okeechobee Inflow and Outflow Monitoring Station Summary. Source: James et al. (1995a) and SFWMD Environmental Monitoring and Assessment Department.

Station Name	Flow Recorder Type	Water Sample Method	Current Water Sample Frequency
S-3 S-354	Telemetric Telemetric and solid state	Grab /autosampler Grab /autosampler	BWF/M/Q/PE (nutrients) WF (nutrients)
Culvert 4A	TBI	Grab	BWF/M/Q
S-2 S-351	Telemetric Telemetric and solid state	Grab /autosampler Grab /autosampler	BWF/M/Q/PE (nutrients) WF (nutrients)
Culvert 12	TBI	Grab	BWF/M/Q
Culvert 12A	TBI	Grab	BWF/M/Q
Culvert 10	Telemetric (tailwater only)	Grab	BWF/M/Q
S-352 - Hurricane Gate S-5	Telemetric and solid state	Grab Grab /autosampler	BW/Q WF (nutrients)
Culvert 10A	Telemetric (headwater only)	Grab	BW/Q
S-308C	Solid state (S308)	Grab	BW/Q
S-135	Telemetric	Grab	BWF/M/Q
S-191	Telemetric	Grab Autosampler	BWF/Q WT(nutrients)
S-133	Telemetric	Grab	BWF/M/Q
S-154	Telemetric	Grab Autosampler	BW/Q WT(nutrients)
S-154C	Manual	Grab	BWF/M/Q
S-65E	Telemetric	Grab Autosampler	BW/Q WF (nutrients)
S-84	Telemetric	Grab	BW/Q
S-38W	Telemetric (S38)	Grab	BWF/M/Q
L-59E	TBI	Grab	BWF/M/Q
S-127	Telemetric	Grab	BWF/M
L-59W	Manual (G74)	Grab	BWF/M/Q
S-72	Telemetric	Grab Grab /autosampler	BWF/M/Q WF (nutrients)
L-60E	Manual (G76)	Grab	BWF/M
S-129	Telemetric	Grab	BWF/M/Q
L-60W	Manual	Grab	BWF/M/Q
S-71	Telemetric	Grab Grab /autosampler	BW/Q WF (nutrients)
L-61E	TBI	Grab	BWF/M/Q
S-131	Telemetric	Grab	BWF/M/Q
L-61W	TBI	Grab	BWF/M/Q
FECSR78 (Fisheating Creek)	TBI	Grab	BWF/M/Q

LEGEND:

BW – Samples collected bi-weekly (physical parameters/nutrients)

BWF/M – Samples collected bi-weekly if flow conditions or monthly if non-flow conditions (physical parameters/nutrients/selected major ions)

PE – Pumping events

Q- Samples collected quarterly (selected major ions)

TBI – To be instrumented

WF – Samples collected weekly (flow proportional composite)

WT – Samples collected (weekly time composite)

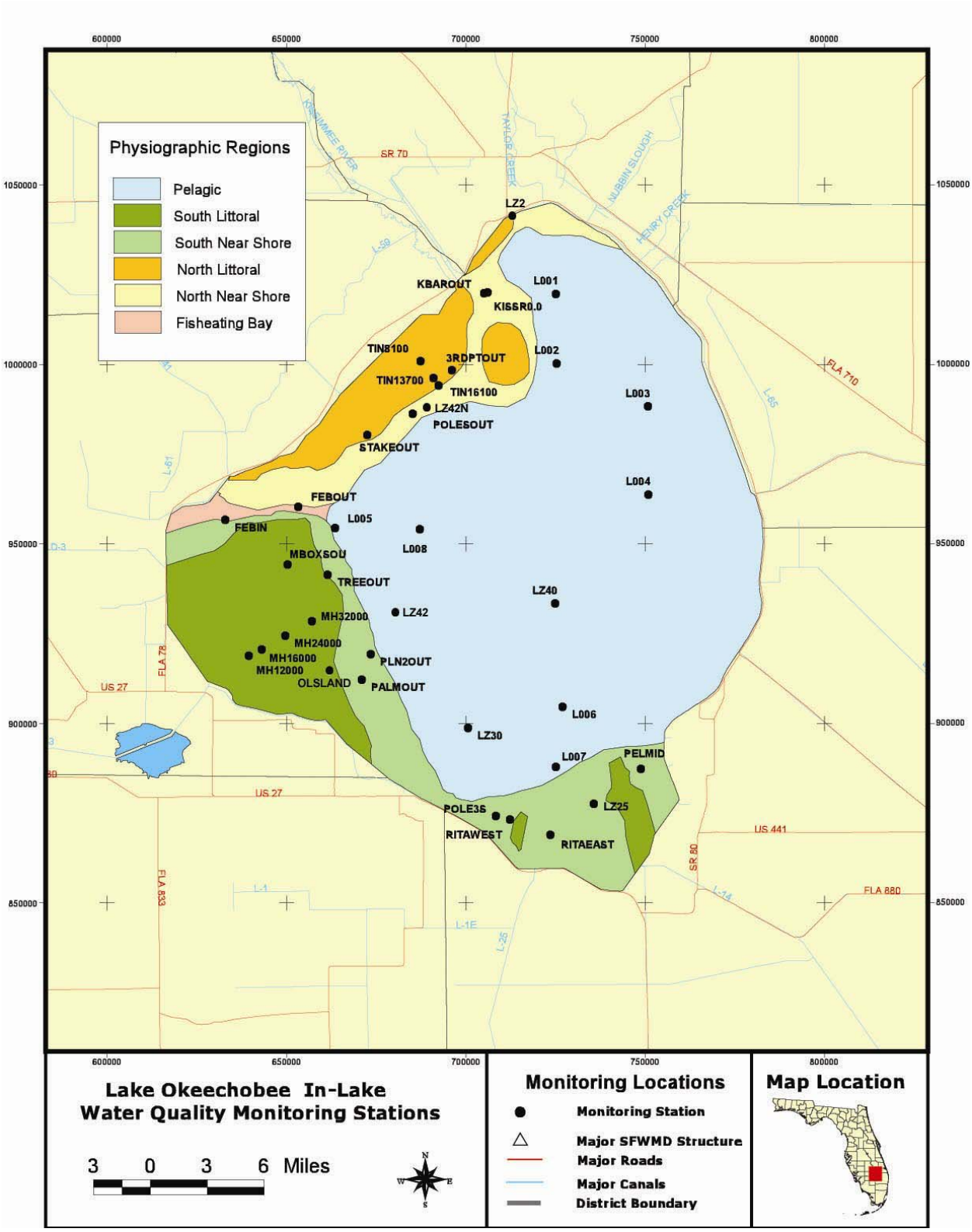


Figure 3-61: Map of Lake Okeechobee, Showing Names and Locations of 33 In-Lake Water Quality Monitoring Stations. Source: SFWMD Environmental Monitoring and Assessment Department

Table 3-17: Lake Okeechobee In-Lake Water Quality Monitoring Parameters*

Medium	Group	Parameters	Sites	Frequency	Collection Method
Water	Physical Parameters	DO, conductivity, pH, temperature, alkalinity, turbidity, solid state, color, Secchi disk depth	TIN8100, TIN13700, TIN16100, FEBOUT, FEBIN, MBOXSOU, MH32000, MH24000, MH16000, MH12000, OISLAND L001, L002, L003, L004, L005, L006, L007, L008, KBAROUT, KISSRO.0 3RDPTOUT, POLESOUT, STAKEOUT, TREEOUT, PLN2OUT, PALMOUT, LZ2, LZ25, LZ30, LZ40, LZ42, LZ42N, PELMID, POLE3S, RITAWEST, RITAEAST, CULV10A	Monthly	Water quality probe and grab
Water	Nutrients	TP, TKN, NH_3, NO_2, NO_{2+3}, $Si0_2$, SRP		Monthly	Grab
Water	Biological	Chlorophylls (corrected for phaeophytin)		Monthly	Grab
Water	Major Ions	SO_4, Cl		Monthly	Grab
Water	Other Core Parameters and Trace Metals	Ca, Mg, Cd, Cu, Fe, Zn		Quarterly	Grab
Water	Biological	Diatom: cyanobacteria ratio	4 pelagic sites	Bi-monthly	Grab
Sediment	Pore-water	Pore-water dissolved SRP and DIN, sediment TP and TN, dry and wet bulk density, ash content, total and dissolved Fe and Mn	171 sites	Every 10 years	Core

LEGEND:

As - arsenic
Ca – calcium
Cd - cadmium
Cl – chloride
Cu – copper
DIN - dissolved inorganic nitrogen
DO – dissolved oxygen
Fe - iron
Mg – magnesium
Mn - manganese NH_3 – ammonia
NO_2 – nitrite
NO_{2+3} – nitrite + nitrate
SiO_2 – silicate
SRP – soluble reactive phosphate
SO_4 - sulfate
TKN – total Kjeldahl nitrogen
TP – total phosphorus
Zn - zinc

3.4.3.2 Littoral Zone Plant Communities

The littoral zone emergent vegetation community found in Lake Okeechobee (Figure 3-62) is a diverse mosaic of native and exotic plants covering an area larger than 400 square kilometers. It provides nesting habitat and food resources for economically important sport fish populations, wading birds, migratory waterfowl, alligator, and the federally-listed endangered Everglades snail kite. The structure of the littoral vegetation community largely determines the extent to which it can provide these habitat values. Littoral vegetation structure is influenced both by hydroperiod and phosphorus loading from the lake's eutrophic pelagic region.

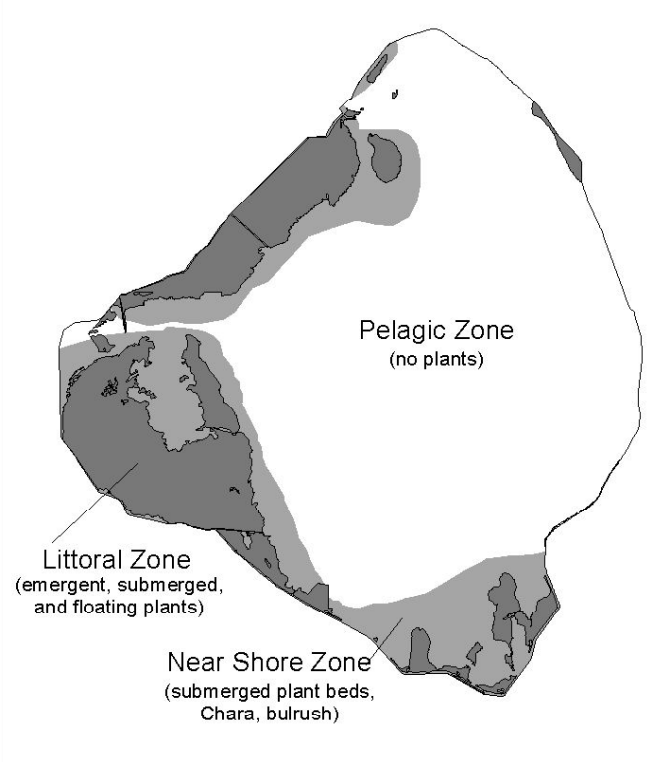


Figure 3-62: Three Major Physiographic Regions of Lake Okeechobee

The spatial distribution of native and exotic plants in the lake's littoral zone is being evaluated in an ongoing program by the SFWMD. Emergent vegetation is photographed using high-resolution infrared aerial photography. Major vegetation classes (34 total) are delineated from the photographs using a stereoscope, and vegetation maps are developed in Arc Info. This process includes extensive ground-truthing. The most recent mapping efforts have resulted in a classification accuracy near 90 percent, which compares favorably with an accuracy of 60 percent that was associated with earlier maps developed from satellite imagery. Mapping will be done every other year to quantify the spatial distribution of torpedograss (*Panicum repens*) because this exotic plant is the focus of an ongoing multi-million dollar per year eradication program. Mapping will be done at the same frequency for bulrush (*Scirpus californicus*), a dynamic community that occurs along the interface between the pelagic and littoral zones. Mapping of the entire littoral vegetation community, a much more cost- and labor-intensive effort, will be carried out at approximately six-year intervals.

There also is an ongoing and rather comprehensive remote sensing project occurring in this area. The goal is to investigate a more efficient, accurate, and cost-effective method that can be developed to frequently evaluate the distribution of plants in Lake Okeechobee's marsh to improve our ability to establish relationships between environmental conditions (e.g., hydrology, water depth, fire, and competition) and plant growth. This project will incorporate the proven remote sensing techniques, especially hyper-spectral remote sensing with the assistance of high-spatial resolution data and radar data, to evaluate the efficacy of our mandated efforts to control exotic plants and protect native plant habitat in Lake Okeechobee more effectively. The monitoring program for emergent plants will be reviewed and revised, if necessary, as this new technology comes on line.

Associated with the lake's littoral zone, a berm of organic material along the western pelagic-littoral interface has been created by deposition of dead submerged and emergent shoreline plants during years when there is sustained high water. Measurement of berm height, width, and length will be conducted at six-year intervals, in concert with the littoral vegetation mapping.

3.4.3.3 Submerged Aquatic Vegetation

Submerged vegetation is a keystone component of the shallow near-shore area that occurs between the littoral zone proper and the deeper water pelagic zone of the lake (see Figure 3-62). Submerged vegetation provides habitat for fish and wading birds and directly affects water quality by stabilizing sediments and providing a substrate for periphyton that actively removes phosphorus from the water column. Therefore, at times and locations where submerged vegetation is very abundant, water is clear, and phytoplankton blooms are rare (Havens et al. 2001, Havens 2003, and see Scheffer 1998 for a general review). Submerged vegetation spatial extent and biomass are expected to increase significantly as a result of major CERP projects.

Submerged aquatic vegetation (SAV) is monitored at two different spatial/temporal scales by the SFWMD. Both methods rely on in-water sampling, as areas with submerged vegetation are generally characterized by water that is highly colored by dissolved organics or suspended solids, which can affect the accuracy of estimates based on remote sensing. In order to obtain quantitative estimates of plant species biomass, sampling is done at sites located along 14 historic transects and one additional transect added in fall 2003 in the lake's northeast region, known as the Henry Creek Marsh (Figure 3-63). On a quarterly basis (and monthly from May to September), triplicate samples are collected at three sites on each transect. Plant sampling is done using a tool constructed of two standard garden rakes bolted together at mid-point to create a tong-like device. The degree of opening is constrained by placing a chain between the two handles so three replicate samplings with the device remove approximately 1 square meter of bottom cover. The harvested material is sorted by species, stripped of epiphyton, and analyzed for dry mass.

A key objective for this sampling is to understand changes in SAV communities in Lake Okeechobee as they relate to changes in water level and transparency. More specifically, this sampling provides data to evaluate the relationship of physical-chemical factors (e.g., nutrient concentrations, light availability) to the spatial and temporal dynamics of SAV biomass and species assemblages within the community. The sampling will incorporate measurements of total depth, Secchi depth, and total suspended solids. Data from the SFWMD water quality monitoring program, which includes stations in the vicinity of all SAV sampling sites, will continue to be used to identify other water quality conditions, including underwater irradiance and temperature profiles, color, chlorophyll *a*, total phosphorus, soluble reactive phosphorus, total nitrogen, dissolved inorganic nitrogen, and volatile suspended solids.

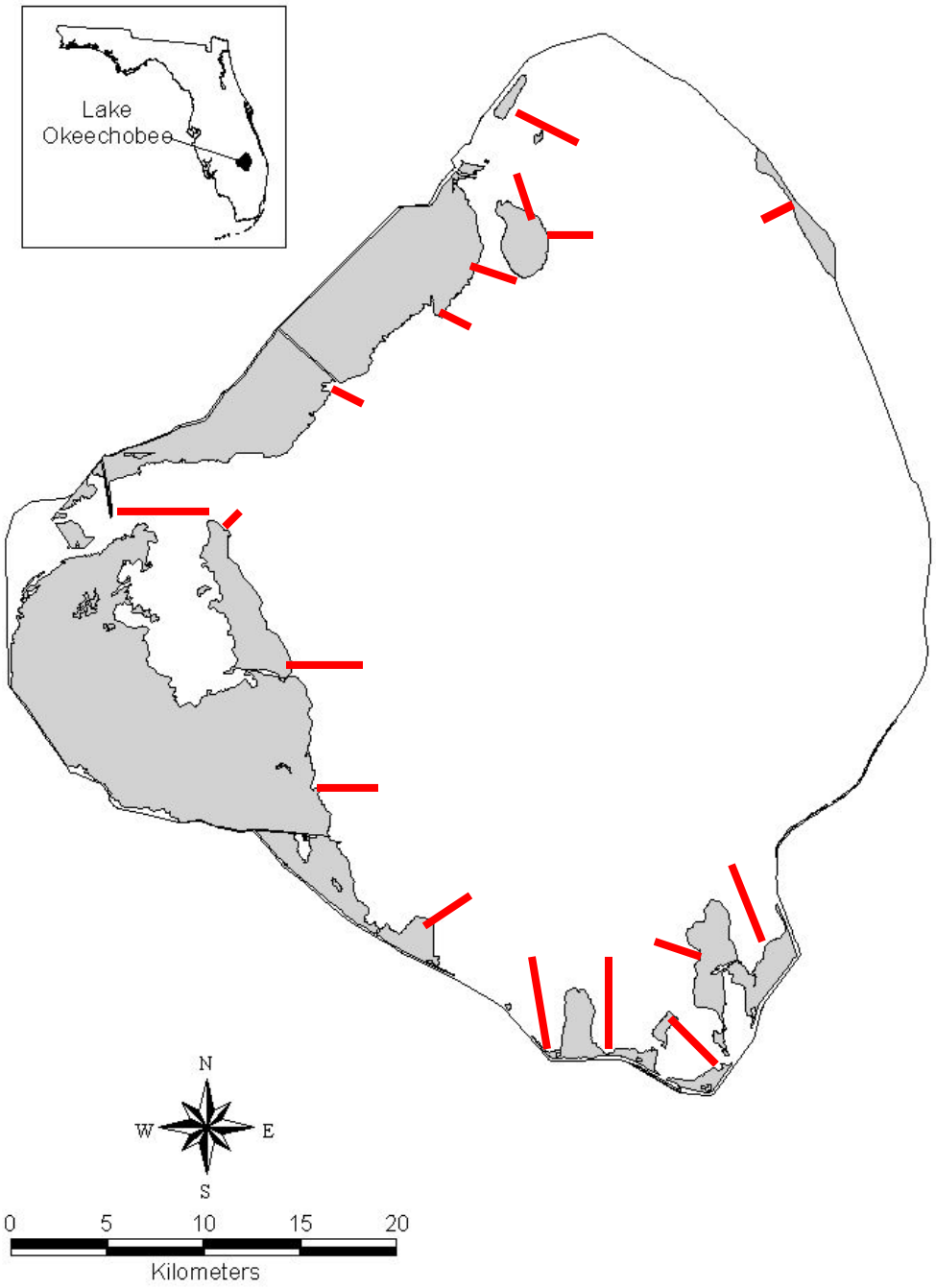


Figure 3-63: Map of Lake Okeechobee, Showing the Location of Transects for Quantitative Evaluation of SAV, Water Depth, Secchi Transparency, and Total Suspended Solids

The spatial extent of each SAV species is determined by an intensive sampling program conducted by the SFWMD each August, at the time of peak SAV biomass (Figure 3-64). Rather than sampling random locations, the entire near-shore zone is sampled at a relatively fine spatial scale. A geographic information system (GIS) coverage of the lake surface is overlaid onto a rectangular grid of 1,000 by 1,000 meter cells in Arc Info. A GIS coverage of the littoral zone is laid onto the map, and littoral cells are clipped from the final coverage, as is the deeper central pelagic region. This results in a near-shore grid of approximately 500 sampling sites. Coordinates for the grid cell center-points are loaded into two Trimble Pathfinder global positioning system (GPS) units (differentially corrected) for use in navigating to the sampling sites. Data collection at each sampling site includes water depth, Secchi disk transparency, sediment type, presence versus absence of vegetation taxa, and a qualitative estimate of SAV biomass (sparse, moderate, dense). Figure 3-64 shows results of the 2002 survey. Maps of this type are produced for each dominant plant species.

Grid cell size = 1 kilometer by 1 kilometer

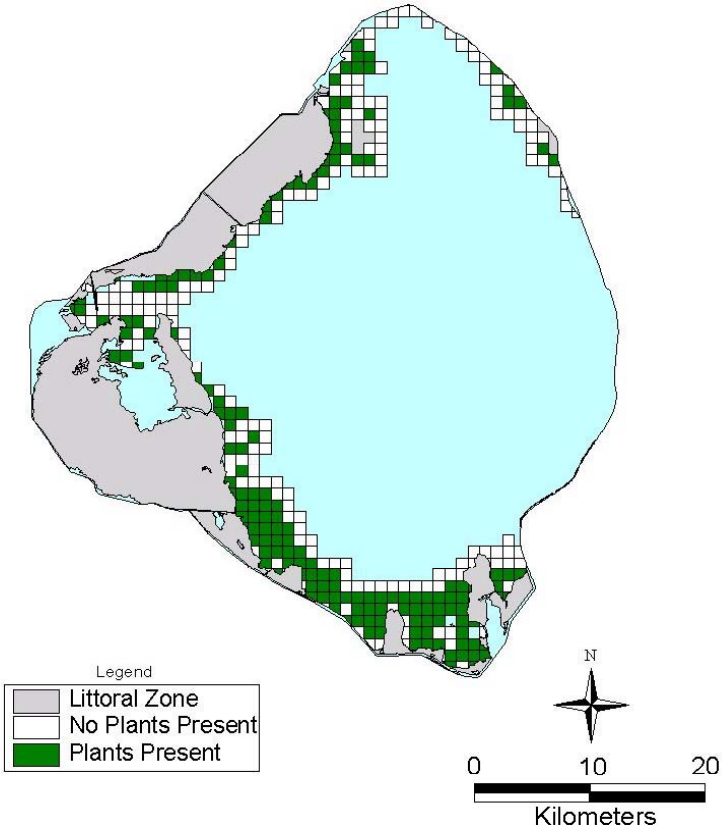


Figure 3-64: Map of Lake Okeechobee, Showing the 1,000 by 1,000 Meter Sampling Grid for 2002 Evaluation of SAV Spatial Extent

Sampling begins near the shoreline and proceeds lakeward along each row of cells until a cell is encountered with no SAV. The boat operator navigates to the sites by GPS, where water depth is measured with a calibrated plastic rod and Secchi depth is measured with a 20-centimeter black and white disk. Plants are placed into a plastic tray and sorted by species, and the information described above is entered into a data logger. Sediment type is determined by inspection of material brought up in the rakes or by observation from the boat where water transparency is good. Sampling with this method is possible up to a maximal depth of approximately 2 meters. Field data are downloaded from the GPS logger into Arc Info, where maps are developed for each of the measured attributes and spatial extents are calculated in hectares. It is assumed that data collected at the center-point of a grid cell represents that of the entire cell. While this may introduce error into the results, it is a necessary assumption given the large spatial scale of sampling.

3.4.3.4 Zooplankton Biomass and Taxonomic Structure

Zooplankton is included as a component of this monitoring plan because of its central position in the lake's pelagic (open-water) food web (e.g., Brooks and Dodson 1965, Lampert et al. 1986, Fernando 1994). Zooplankton provides a critical source of food to young fish, and depending on algal community structure, it has the potential to control the biomass of phytoplankton in the lake's water column, which in turn influences water transparency. Havens et al. (1996b) and Beaver and Havens (1996) provide detailed information on the ecological role of zooplankton in this particular subtropical lake.

Although the overall biomass of zooplankton is expected to remain unchanged with lake restoration efforts, the taxonomic structure is expected to shift toward those species that are considered more desirable food resources for fish populations inhabiting the lake. Zooplankton is sampled on a monthly basis in an ongoing program by the SFWMD at five open-water locations (corresponding to the lake's major ecological zones). The stations (L001, L005, LZ40, POLE3S, and FEBOUT) also are routine SFWMD water quality monitoring locations. A continuous data set for zooplankton exists from August 1994 to present. Macro-zooplankton (cladocerans and copepods) is sampled by triplicate vertical tows of a Wisconsin-type plankton net (30.5-centimeter diameter, 153-millimeter mesh). Samples are preserved in formalin-sucrose solution and later enumerated at 50X magnification to determine species composition and biomass. Macro-zooplankton biomass estimates are derived from species length-weight relationships that were developed from samples collected in the lake during 1998-2001. Micro-zooplankton (rotifers and nauplii) is sampled with a long PVC tube (4-centimeter inner diameter) that collects water in an integrated sample from the lake surface to within 0.25 – 0.50 meters of the sediments. The integrated sample is filtered through a 40-millimeter mesh Student plankton net, preserved in formalin-sucrose solution, and enumerated at 500X magnification with an inverted microscope after 24 hours of holding the samples in sedimentation chambers. Data are obtained as macro-zooplankton. Micro-zooplankton biovolumes are calculated using appropriate geometric formulae and converted to fresh weights and dry weights.

3.4.3.5 Benthic Macroinvertebrates

Benthic macroinvertebrates also play an important role in the lake ecosystem. They provide food resources for fish, contribute to sediment nutrient recycling, and can serve as sensitive indicators of water quality (Jonasson 1969, Brinkhurst 1965, Warren et al. 1995).

Benthic macroinvertebrate communities of the Lake Okeechobee pelagic zone were sampled by the Florida Fish and Wildlife Conservation Commission (FWC) on a quarterly (February, May, August, November) basis in 1987-1988 and then semi-annually (January and July) through 1996. Since 1996, invertebrate communities have been sampled intermittently, with the last collection occurring in June 2000. Sampling was conducted at 18 fixed sites, with six sites each in mud (northern and mid-lake), sand

(western), and peat (southern) habitat zones. Three pseudo-replicate samples were collected at each of the 18 sites during every sampling event, yielding 18 samples per habitat zone and a total of 54 samples. Samples were collected with a petite ponar dredge. Upon collection, samples were placed in buckets, mixed with filtered water, and then sieved to remove excess water. All sampling and rinsing devices were fitted with 300-millimeter Nitex mesh. Samples were placed in labeled containers and preserved in the field with 95 percent ethanol. Physical-chemical measurements obtained at the time of sampling included 0.5-meter incremental profiles of water temperature and dissolved oxygen concentration.

In the littoral zone, sampling was conducted in three study areas from 1987-1990 and along a transect near Indian Prairie canal from 1991-1994. Intermittent sampling was conducted at several locations from 1995-2000. Sampling was stratified by vegetation type. Invertebrate communities inhabiting *Eleocharis* sp., *Hydrilla verticillata*, *Nymphaea* sp., *Panicum repens*, *Pontederia cordata*, *Potamogeton illinoensis*, *Scirpus* sp., *Typha* sp., and *Vallisneria americana* were sampled at various times. Invertebrate communities of submersed and emergent macrophytes were sampled using a modified Hess sampler. Invertebrate communities inhabiting sediments beneath macrophytes were sampled using a corer. Three pseudo-replicate samples were collected from both the macrophyte and bottom habitats at each sampling site during every collection. Upon collection, samples were placed in buckets, mixed with filtered water, and then sieved to remove excess water. All sampling and rinsing devices were fitted with 300-millimeter Nitex mesh. Samples were placed in labeled containers and preserved in the field with 95 percent ethanol. Physical-chemical measurements obtained at the time of sampling included 0.5-meter incremental profiles of water temperature and dissolved oxygen concentration.

In the laboratory, each macroinvertebrate sample was processed separately using stereo-dissecting microscopes with magnification to 40X. Small sample portions were placed in Petri plates and scanned by technicians. Organisms were removed from samples with forceps and preserved in vials. Retained organisms were identified to species level, when possible, by a taxonomist. Damage to specimens and immaturity prevented species level identification of some specimens.

A Lake Okeechobee macroinvertebrate monitoring program as part of this MAP will utilize sites and methods established during the FWC studies, so that data collected as part of the MAP can be compared to the historic data. Ideally, the 18 sampling sites will be sampled on a quarterly basis during months corresponding to FWC collections. Permanent monitoring locations also will be established in both the northwest and western littoral zones of the lake.

3.4.3.6 Fish Condition and Population Structure

An ongoing yearly sampling program by the FWC determines condition and population structure of largemouth bass, which is the lake's most well-known sport fish. In this program, a total of 22 fixed sampling regions have been established around the entire perimeter of the lake. Triplicate samples are taken in each zone during October by 15 minute electrofishing transects. All largemouth bass encountered during the electrofishing operation are weighed, measured, and released at the area of capture. Ancillary data, including water temperature, dissolved oxygen, pH, turbidity, conductivity, and sediment/aquatic plant type, are recorded in the sampling regions.

Given the restricted focus of the ongoing sampling of only one fish species, it is recommended that funds be included in the Lake Okeechobee module of the MAP for a more comprehensive yearly sampling program. This program will include open-water trawls to evaluate year-to-year changes in the condition and relative population density (catch per unit effort) of all major fish species and evaluation of results for all major fish species collected in the shoreline electro-shocking program.

A number of additional biological monitoring components will be measured in Lake Okeechobee under the sampling designs contained within the Greater Everglades Wetlands Module (Section 3.1.3). These include 1) Aquatic Fauna Regional Populations (3.1.3.10); 2) Wading Bird Foraging Distribution and Abundance (3.1.3.12); 3) Wading Bird Nesting Colony Location, Size, and Timing (3.1.3.13); and 4) American Alligator Distribution, Size, Nesting, and Hole Occupancy (3.1.3.15).

3.4.4 Key Uncertainties and Supporting Research

3.4.4.1 Aquatic Fauna Relationships to Submerged and Emergent Plant Communities

Justification: CERP projects, including regional reservoir storage and ASR, are expected to substantially improve the hydroperiod of the western littoral zone in Lake Okeechobee and also affect the inputs of phosphorus and other chemical constituents to the ecosystem. These changes are anticipated to benefit the submerged and emergent plant communities in the littoral zone and consequently the invertebrates and forage fish that support the lake's fish and wildlife (e.g., sport fish, wading birds, snail kites, etc.). At this time, there is not sufficient quantitative information on relationships between invertebrates and forage fish with vegetation type or water depth to make accurate projections of CERP benefits. The ability to make those projections will be critical for optimization of the lake regulation schedule under the CERP.

Project Description: A comprehensive study is needed to address the following key research questions: 1) How will changes in the diversity and abundance of emergent plants in the lake's littoral zone, brought about by reduced phosphorus inputs and an altered hydropattern, affect invertebrates and forage fish? 2) How will changes in the quantity and community composition of epiphyton and benthic algae affect those animal populations? 3) How will invertebrates and forage fish respond to changes in submerged plants and periphyton in the lake's near-shore zone? These questions will be addressed during a 5-year survey, wherein the distribution and abundance of macroinvertebrates and forage fish will be evaluated in major vegetation communities (*Eleocharis*, *Typha*, *Panicum*, *Hydrilla*, *Vallisneria*, *Chara*, and *Potamogeton*) as a function of water depth. The study will include an evaluation of epiphyton and benthic algae associated with the vascular plant communities and will involve quarterly quantitative sampling in three replicate sites for each plant community type. Past experience indicates that a 5-year time frame is necessary to encompass the range of water depths experienced by the ecosystem.

3.4.4.2 Fish and Wildlife Relationships to Food Abundance and Composition

Justification: In addition to affecting the structure of the habitat (vegetation distribution and abundance), CERP projects are expected to affect the structure and function of the food web that supports important biota at higher trophic levels in the lake (e.g., fish, wading birds, raptors, etc.). However, there is limited information on the trophic interactions in the lake food web. The proposed research is designed to fill this information gap.

Project Description: A comprehensive study is needed to address the following research questions: 1) How will changes in the resource base (i.e., macroinvertebrates and forage fish) of littoral food webs affect fish at higher trophic levels? 2) How will those changes affect wading birds, migratory water fowl, alligator, Everglades snail kites, and other wildlife that use that habitat for foraging? 3) How will changes in the resource base of the near-shore and pelagic zones (i.e., macroinvertebrates and zooplankton) affect those animal populations? A two-year study is proposed to evaluate the feeding habits of key biota in the lake, including major fish taxa (at various life stages), wading birds, raptors, and alligators. A combination of traditional gut content analyses and carbon and nitrogen stable isotope tracer methods will be used to accomplish the stated objectives.

3.4.4.3 Fish and Wildlife Relationships to Plant Community Structure and Habitat

Justification: CERP projects are expected to substantially improve both the hydroperiod of the western littoral zone in Lake Okeechobee and the inputs of phosphorus and other chemical constituents to the ecosystem. These changes are anticipated to benefit the submerged and emergent plant communities in the littoral zone and consequently the invertebrates and forage fish that support the lake's fish and wildlife (e.g., sport fish, wading birds, snail kites, etc.). At this time, there is not sufficient quantitative information on relationships between sport fish and other wildlife with vegetation type or water depth to make solid projections of CERP benefits. The ability to make those projections will be critical for optimization of the lake regulation schedule under the CERP.

Project Description: A comprehensive study is needed to address the following research questions: 1) How will changes in the abundance and spatial distribution of plants within the littoral zone affect sport fish, wading birds, migratory waterfowl, the American alligator, the Everglades snail kite, and other wildlife that use that habitat for nesting and foraging? 2) How will changes in the abundance and spatial distribution of near-shore submerged plants affect those animal populations? A multi-year survey is required wherein the distribution and abundance of sport fish and other wildlife will be evaluated in major vegetation communities (*Eleocharis*, *Typha*, *Panicum*, *Hydrilla*, *Vallisneria*, *Chara*, and *Potamogeton*) as a function of water depth. The study will encompass a 5-year period, which past experience indicates is necessary to encompass the full range of water depths experienced by the ecosystem, and will include quarterly quantitative sampling in three replicate sites for each plant community type.

3.4.4.4 Submerged Plant/Periphyton Interrelationships with Light, Nutrients, and Water Depth

Justification: CERP is expected to cause major changes in the hydropattern of Lake Okeechobee. This, in turn, is expected to affect the distribution and abundance of submerged plant communities and their associated periphyton. The submerged vegetation is a keystone component of the lake ecosystem, providing habitat for fish and wildlife and directly affecting water quality by nutrient uptake, sediment stabilization, and a variety of other processes. The ability to quantify and predict how changes in submerged vegetation will affect water quality is critical to CERP and the state's Lake Okeechobee Protection Program.

Project Description: Work has been in progress since 1999 to answer the following research questions: 1) How will a change in the availability of underwater light brought about by reduced algal blooms (reduced phosphorus inputs) and shallower water (altered hydropattern) affect the distribution and abundance of submerged vascular plants and their associated periphyton? 2) How will it affect benthic algae? 3) How will an increase in the spatial extent and biomass of vascular plants, periphyton, and benthic algae affect water clarity, by means of a positive feedback loop whereby these plants stabilize sediments and compete for nutrients with phytoplankton (which in turn increases water column light availability, which stimulates more plants)? This work is being completed in an ongoing program funded by the SFWMD. The results will be available for use in CERP-related modeling and evaluation efforts.

3.4.4.5 Lake Water Phosphorus Relationship to Submerged Plant Biomass and Cover

Justification: With a reduction in damaging high water levels expected to occur under CERP, the submerged plant community in Lake Okeechobee should dramatically increase, in both spatial extent and biomass. Submerged vegetation, and its associated periphyton, is known to be a strong sink for phosphorus due to a variety of mechanisms. The extent to which this occurs in the lake is uncertain, as most research with this subject has been done on deeper temperate lakes. A research program is underway to address this area of uncertainty.

Project Description: An array of experimental and observational work has been in progress since fall 2002 to address this issue. Controlled lake-side mesocosm experiments are being done to evaluate net effects of submerged vegetation on phosphorus concentrations in lake water. Microcosm studies with phosphorus radioisotopes are being done to examine the pathways for phosphorus uptake and processing by plants, periphyton, and sediment. Field studies are being done to construct phosphorus mass balances for submerged plant beds, including dye tracer studies to evaluate degree of interaction between beds and adjacent open water. The information is being used to calibrate and validate a coupled hydrodynamic, water quality, vegetation model that will be available for CERP evaluations in approximately 2004.

This work is being completed with funds provided by the Florida Legislature, in support of the Lake Okeechobee Protection Program. The results will be available for use in CERP modeling and evaluation efforts.

3.4.5 References

Beaver, J.R., and K.E. Havens. 1996. Seasonal and spatial variation in zooplankton community structure and their relation to possible controlling variables in Lake Okeechobee. Freshwater Biology 36: 45-56.

Brinkhurst, R.C. 1965. The biology of the Tubificide with special reference to pollution. In: Biological Problems in Water Pollution. U.S. Department of Health and Welfare, Washington, D.C.

Brooks, J.L., and S.I. Dodson. 1965. Predation, body size, and composition of plankton. Science 150: 28-35.

Fernando, C.H. 1994. Zooplankton, fish, and fisheries in tropical freshwaters. Hydrobiologia 200: 99-118.

Fisher, M.M., K.R. Reddy, and R.T. James. 2001. Long-term changes in the sediment chemistry of a large shallow subtropical lake. Lake and Reservoir Management 17: 217-232.

Flaig, E.G., and K.E. Havens. 1995. Historical trends in the Lake Okeechobee ecosystem I. Land use and nutrient loading. Archiv fur Hydrobiologie Monographische Beitrage 107: 1-24.

Flaig, E.G., and K.R. Reddy. 1995. Fate of phosphorus in the Lake Okeechobee watershed, Florida, USA: overview and recommendations. Ecological Engineering 5: 127-142.

Gleason, P.J. 1984. Environments of South Florida Present and Past II. Miami Geological Society, Coral Gables, Florida.

Havens, K.E. 2001. Lake Okeechobee ecosystem conceptual model. RECOVER c/o South Florida Water Management District, West Palm Beach, Florida.

Havens, K.E. 2002. Development and application of hydrologic restoration goals for a large subtropical lake. Lake and Reservoir Management 18: 285-292.

Havens, K.E. 2003. Submerged aquatic vegetation correlations with depth and light attenuating materials in a shallow subtropical lake. Hydrobiologia, in press.

Havens, K.E., N.G. Aumen, R.T. James and V.H. Smith. 1996a. Rapid ecological changes in a large subtropical lake undergoing cultural eutrophication. Ambio 25: 150-155.

Havens, K.E., T.L. East, and J.R. Beaver. 1996b. Experimental studies of zooplankton-phytoplankton-nutrient interactions in a large subtropical lake (Lake Okeechobee, Florida, USA). Freshwater Biology 36: 579-597.

Havens, K.E., R.T. James, T.L. East and V.H. Smith. 2003. N:P ratios, light limitation, and cyanobacterial dominance in a subtropical lake impacted by non-point source nutrient pollution. Environmental Pollution 122: 379-390.

Havens, K.E., K.R. Jin, A.J. Rodusky, B. Sharfstein, M.A. Brady, T.L. East, N. Iricanin, R.T. James, M.C. Harwell and A.D. Steinman. 2001. Hurricane effects on a shallow lake ecosystem and its response to a controlled manipulation of water level. The Scientific World 1: 44-70.

Havens, K.E., B. Sharfstein, M.A. Brady, T.L. East, M.C. Harwell, R.P. Maki, and A.J. Rodusky. 2003. Recovery of submerged plants from high water stress in a large subtropical lake in Florida, USA. Aquatic Botany, in press.

James, R.T., Jones, B.I., Smith, V.H. 1995a. Historical trends in the Lake Okeechobee ecosystem. II. Nutrient budgets. Archiv fur Hydrobiologie, Supplement 107: 25-47.

James, R.T., Smith, V.H., Jones, B.L. 1995b. Historical trends in the Lake Okeechobee ecosystem. III. Water quality. Archiv fur Hydrobiologie, Supplement 107: 49-69.

Jonasson, P.M. 1969. Bottom fauna and eutrophication. In: Eutrophication: Causes, Consequences, and Correctives. National Academy of Sciences, Washington, D.C.

Jones, B. 1987. Lake Okeechobee eutrophication research and management. Aquatics 9: 21-26.

Lampert, W., W. Fleckner, H. Rai, and B.E. Taylor. 1986. Phytoplankton control by grazing zooplankton: a case study of the spring clear-water phase. Limnology and Oceanography 31: 478-490.

Maceina, M.J. and D.M. Soballe. 1991. Wind-related limnological variation in Lake Okeechobee, Florida. Lake and Reservoir Management 6:93-100.

Moore, P.A., K.R. Reddy and M.M. Fisher. 1998. Phosphorus flux between sediment and overlying water in Lake Okeechobee, Florida: spatial and temporal variations. Journal of Environmental Quality 27: 1428-1439.

Ogburn, R.W., C. Hanlon, S.W. Gong and E. Broughton. 1996. Compliance with water quality criteria in a multiple-use lake, Lake Okeechobee, Florida. Lake and Reservoir Management 12: 371-380.

Olila, O.G. and K.R. Reddy. 1993. Phosphorus sorption characteristics of sediments in shallow eutrophic lakes of Florida. Archiv fur Hydrobiologie 129:45-65.

Phlips, E.J., F.J. Aldridge and P. Hansen. 1995. Patterns of water chemistry, physical and biological parameters in a shallow subtropical lake (Lake Okeechobee, Florida, USA). Archiv fur Hydrobiologie, Advances in Limnology 45: 117-135.

RECOVER. 2003. Quality Assurance Systems Requirements (QASR). RECOVER, c/o South Florida Water Management District, West Palm Beach, Florida, June 23, 2003 draft.

RECOVER. In prep. Performance Measure Documentation Report. RECOVER c/o South Florida Water Management District, West Palm Beach, Florida.

Scheffer, M. 1998. Ecology of Shallow Lakes. Chapman and Hall, London, United Kingdom.

SFWMD. 2002. Surface water improvement and management plan – update for Lake Okeechobee. South Florida Water Management District, West Palm Beach, Florida.

Smith, J.P., J.R. Richardson and M.W. Callopy. 1995. Foraging habitat selection among wading birds (Ciconiiformes) at Lake Okeechobee, Florida, in relation to hydrology and vegetative cover. Archiv fur Hydrobiologie, Advances in Limnology 45: 247-285.

Steinman, A.D., K.E. Havens, N.G. Aumen, R.T. James, K.R. Jin, J. Zhang and B.H. Rosen. 1999. Phosphorus in Lake Okeechobee: sources, sinks, and strategies. In: Reddy, K.R., G.A. O'Conner and C.L. Schelske (Eds.), Phosphorus Biogeochemistry in Subtropical Ecosystems. Lewis Publishers, Boca Raton, Florida.

Steinman, A.D., K.E. Havens, H.J. Carrick and R. Van Zee. 2001. The past, present, and future hydrology and ecology of Lake Okeechobee and its watershed. In: Porter, J. and K. Porter (Eds.), The Everglades, Florida Bay, and Coral Reefs of the Florida Keys: An Ecosystem Sourcebook. CRC Press, Boca Raton, Florida.

Warren, G.L., M.J. Vogel, and D.D. Fox. 1995. Trophic and distributional dynamics of Lake Okeechobee sublittoral benthic invertebrate communities. Archiv fur Hydrobiologie, Advances in Limnology 45: 317-332

3.5 SOUTH FLORIDA HYDROLOGY MONITORING NETWORK MODULE

3.5.1 Introduction

This module addresses the hydrologic monitoring needs of the freshwater system including the natural and human systems dependent on fresh water for their sustenance that will either be affected by the Comprehensive Everglades Restoration Plan (CERP) or affect reaching CERP's restoration goals and objectives (USACE and SFWMD 1999). Hydrology drives the premises and hypotheses contained in the Greater Everglades Wetlands, Southern Estuaries, Northern Estuaries, and Lake Okeechobee Modules and provides the link between the physical changes to be implemented by construction of CERP projects and the water quality and biological attributes in the simplified conceptual ecological models. The simplified conceptual ecological models were derived from the conceptual ecological models (Appendix A) to focus specifically on CERP restoration expectations. Understanding the hydrology of South Florida will enable interpretation of the other modules' monitoring results and either confirm or lead to modification of their hypotheses. Details of how hydrology factors into the ecological premises and CERP hypotheses are included in the four regional modules.

This module also addresses the surface and ground water monitoring needs of the four regional modules, Greater Everglades Wetlands, Southern Estuaries, Northern Estuaries, and Lake Okeechobee, and provides information to evaluate progress towards other water-related needs of the region provided for in the CERP. This last purpose is to monitor CERP's ability to meet its second planning goal (enhance economic value and social well being) and two of its objectives: increase availability of fresh water (agricultural/municipal and industrial) and reduce flood damages (agricultural/urban) (USACE and SFWMD 1999). In addition, this module supports all of the modules by proposing to collect the meteorological data necessary to complete assessment of the system.

Hydrologic monitoring helps to meet the four broad objectives of the Monitoring and Assessment Plan (MAP) by aiding interpretation of chemical and biological performance measures when 1) establishing baseline variability; 2) determining status and trends; 3) detecting unexpected responses of the ecosystem to changes in stressors; and 4) supporting scientific investigations designed to increase ecosystem understanding, establish cause-and-effect, and be able to respond to unanticipated system responses. Without knowing the hydrology of the system as it changes, no greater understanding of the system is possible. Neither would it be possible to identify successes due to CERP implementation.

Hydrology measurements include the stage of surface water; ground water levels in the Biscayne and Floridan aquifers; stages at structures and pump stations that are converted to flow data; and meteorology information collected at weather stations such as rainfall, evapotranspiration, and pan evaporation. The aerial extent of the hydrologic monitoring network is limited to areas directly influenced by the CERP as presented in Figure 1-1 in Section 1. In addition to evaluating the effects of the CERP, the data collected support many other needs of the South Florida Water Management District (SFWMD) and other state and federal agencies. Some of the applications include developing and refining computer simulation models, operating the Central and Southern Florida (C&SF) Project, ascertaining the effects of extreme weather events, and providing data for SFWMD consumptive use permit reviews as well as other permits.

A summary of the projects expected to affect each module or areas within each module is provided in Appendix B. The South Florida Hydrology Monitoring Network Module is not included on this table because all CERP projects are expected to directly influence the hydrological stressors described in the simplified conceptual ecological models.

3.5.2 Ecological Premise and CERP Hypotheses as the Basis for Monitoring Components and Supporting Research

One overarching ecological premise forms the basis for most of the CERP restoration goals and strategies for the South Florida Hydrology Monitoring Network. The premise relates to the increased water storage capacity that will result from CERP implementation.

Figures 3-65 through 3-67 illustrate the linkages of the ecological premise to CERP hypotheses, monitoring components, and key uncertainties and supporting research relating to the natural system, water supply, and flood protection, respectively. Supporting research generally originates from monitoring components, in which case research supports the interpretation of monitoring results. In some cases, supporting research originates directly from a CERP hypothesis, and research will be required to develop an appropriate monitoring component. These linkages are indicated by a red arrow. A summary of the monitoring components and supporting research for South Florida hydrology monitoring is listed in Table 3-18. The list of research topics includes those identified during the development of the current version of the MAP. This list has yet to be prioritized, and it is anticipated that additional research topics of equal or higher priority will be identified in the future.

The process used to develop the monitoring plan for the South Florida Hydrology Network Module, and all of the other modules, is described in Section 2.0, Development of the CERP Monitoring Plan and Adaptive Management Program. The strategy for prioritizing and implementing monitoring components and research topics is discussed in Section 5.0, Implementation Strategy for the CERP Monitoring and Assessment Plan.

3.5.2.1 Water Storage Capacity (Figures 3-65, 3-66, and 3-67)

Ecological Premise: The implementation of the Comprehensive Plan will increase water storage capacity in the regional water management system of South Florida. That increased storage capacity will be sufficient to provide the volume, distribution, and timing of water needed to restore towards Natural System Model (NSM) hydrologic conditions in the Greater Everglades Wetlands and prevent releases of excess water to the natural system, while also providing water for expanding agricultural, industrial, and municipal demands.

CERP Hypotheses: Specific benefits from implementation of the Comprehensive Plan will include the following:

- Restore hydrology in the natural system to conditions similar to the NSM or other restoration targets by distributing the appropriate amount of water to the right place, at the right time, and of the right quality

- Reduce harmful releases of excess water to the natural system such as the Caloosahatchee Estuary, St. Lucie Estuary, Lake Worth Lagoon, and Everglades Protection Area

- Meet a 1-in-10 year level of service for urban and agricultural water supply demands through regional water deliveries and control seepage from the Water Conservation Areas and Everglades National Park (373.0361(2)(a)(1), Florida Statutes (FS))

- Achieve a minimum level for the Biscayne aquifer criterion by preventing saltwater intrusion into the Biscayne aquifer by maintaining the water levels in the primary coastal canals (Section 373.042, FS)

- As the CERP is implemented, maintain flood protection at the levels in existence on December 11, 2000 and in accordance with applicable laws: Section 601(h)(5)(B) Savings Clause, Water Resources Development Act of 2000 (WRDA 2000), and 373.1501(5)(d), FS

Adaptive Management Question: Will implementation of the CERP be able to provide adequate freshwater supplies to meet the natural system hydrologic targets while providing water to meet the water supply needs of agricultural, industrial, and municipal users and maintaining the existing level of flood protection to agricultural and urban land uses? If not, how and to what extent do we alter the physical structure or operations of the system to store an adequate volume of water and distribute it to the natural and human systems when needed, while also maintaining existing levels of flood protection?

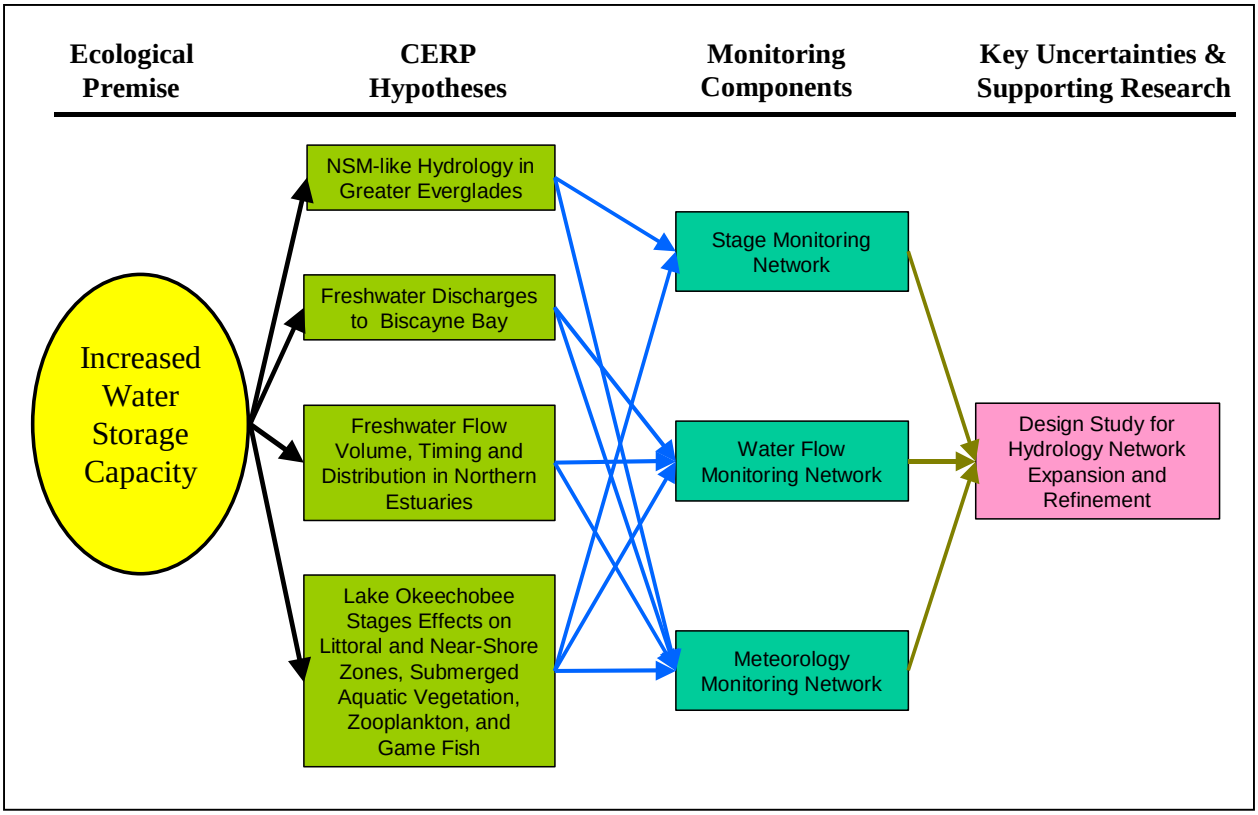


Figure 3-65: Diagram Depicting Relationships between the Ecological Premise, CERP Hypotheses, Monitoring Components, and Supporting Research for Increased Water Storage Capacity as it Relates to the Natural Systems

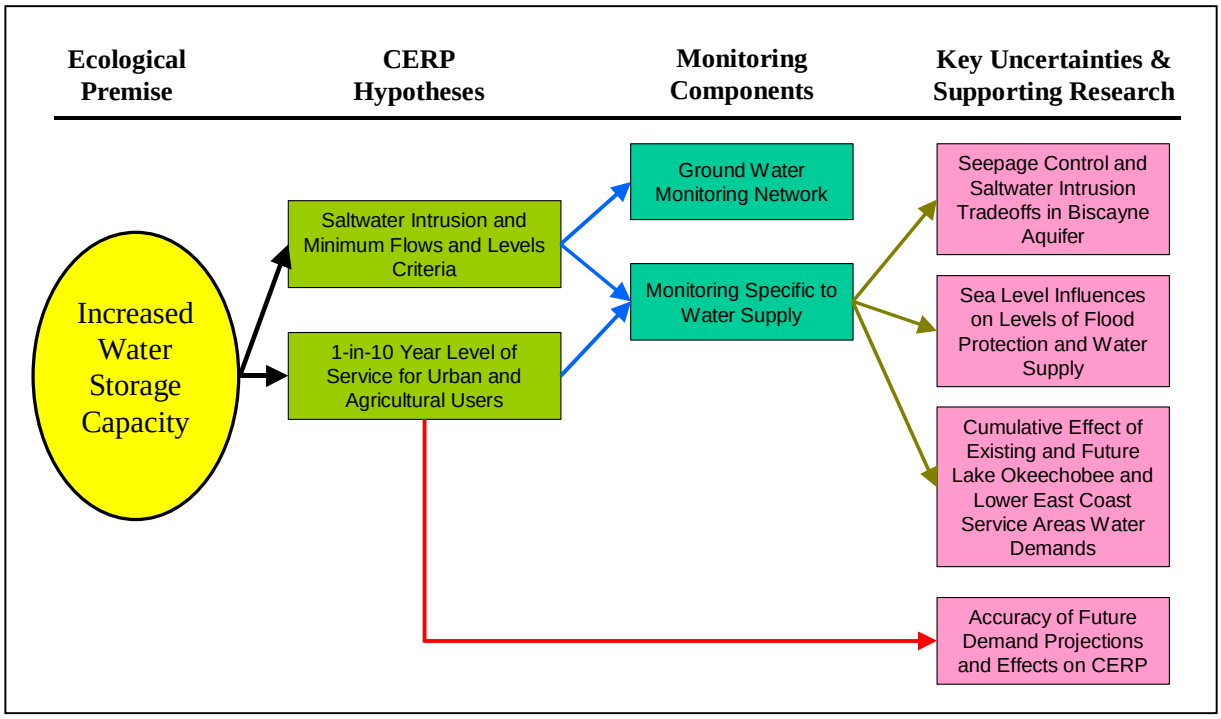


Figure 3-66: Diagram Depicting Relationships between the Ecological Premise, CERP Hypotheses, Monitoring Components, and Supporting Research for Increased Water Storage Capacity as it Relates to Water Supply

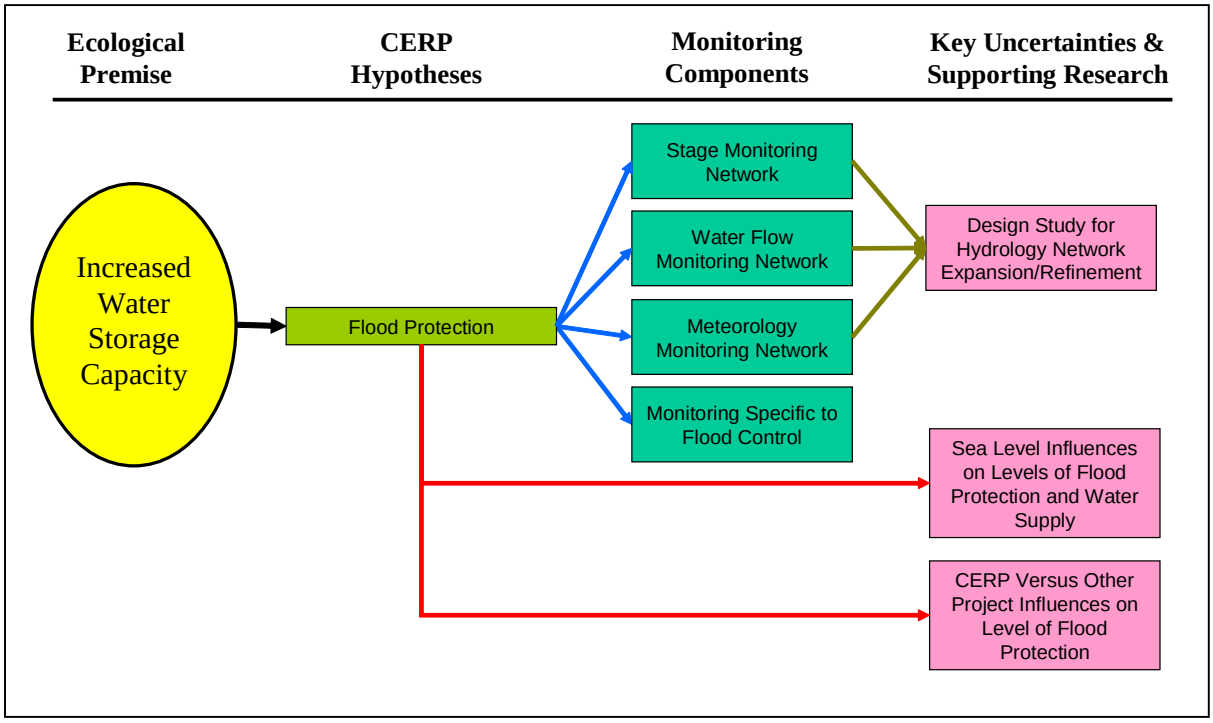


Figure 3-67: Diagram Depicting Relationships between the Ecological Premise, CERP Hypotheses, Monitoring Components, and Supporting Research for Increased Water Storage Capacity as it Relates to Flood Protection

3.5.2.2 Summary of Monitoring Components and Key Uncertainties and Supporting Research

Table 3-18 summarizes the monitoring components and key uncertainties and supporting research for the South Florida Hydrology Monitoring Network Module. The section of this document in which the item is discussed is provided in the second column of Table 3-18 for reference.

The system-wide assessment performance measures contained in the table below are published in a separate document, the Performance Measure Documentation Report (RECOVER In prep). Each MAP monitoring component has at least one corresponding performance measure. For reference, the performance measure identification number or numbers are provided in the last column of Table 3-18.

Table 3-18: Summary List of Monitoring Components and Key Uncertainties and Supporting Research for the South Florida Hydrology Monitoring Network

Monitoring Components	MAP Section	Performance Measure Number
Stage Monitoring Network	3.5.3.1	LO-A1 LO-A2 LO-A3 LO-A4 LO-A5 GE-A1
Ground Water Monitoring Network	3.5.3.2	GE-A1
Water Flow Monitoring Network	3.5.3.3	GE-A1 SE-A1 SE-A2 NE-A1 NE-A2 NE-A3 NE-A4
Meteorology Monitoring Network	3.5.3.4	N/A
Monitoring Specific to Water Supply	3.5.3.5	WS-A1 WS-A2 WS-A4 WS-A5
Monitoring Specific to Flood Protection	3.5.3.6	WS-A3
Key Uncertainties and Supporting Research		
Design Study for Hydrology Network Expansion/Refinement	3.5.4.1	
Sea Level Influences on Levels of Flood Protection and Water Supply	3.5.4.2	
Seepage Control and Saltwater Intrusion Tradeoffs in Biscayne Aquifer	3.5.4.3	
Methodology to Monitor and Evaluate the Success of Pre-CERP Baseline Meeting WRDA 2000 and FS Requirements	3.5.4.4	
Accuracy of Future Demand Projections and Effects on the CERP	3.5.4.5	
Cumulative Effect of Existing and Future Lake Okeechobee and Lower East Coast Water Demands	3.5.4.6	
CERP Versus Other-project Influences on Level of Flood Protection	3.5.4.7	

3.5.3 Monitoring Components

The stage, ground water, water flow, and meteorology monitoring networks are presented in this section. The SFWMD, the United States Geological Survey (USGS), the United States Army Corps of Engineers (USACE), the National Oceanic and Atmospheric Administration (NOAA), Everglades National Park, the Seminole Tribe of Florida and Miccosukee Tribe of Indians of Florida, and county and city governments all provide data that become part of these monitoring networks. The SFWMD manages a large majority of these data in their DBHYDRO database. Periodically the SFWMD updates "active site" maps of these monitoring networks. "Active sites" are defined as SFWMD sites from which data has been added to the database within the previous 12 months, other agency sites that have had data added within the previous 24 months, and new sites added since the previous update. The latest version of the "active site" maps is located at http://www.sfwmd.gov/curre/sitemaps/mapsindex.htm.

3.5.3.1 Stage Monitoring Network

The SFWMD, the USGS, the USACE, and Everglades National Park jointly fund and manage an extensive stage (water level) network within the SFWMD boundaries. As of May 14, 2003, 753 sites were being monitored (Figure 3-68).

The map depicting stage monitoring sites is too detailed to import into this document. It can be accessed on the web at ***http://www.sfwmd.gov/curre/sitemaps/stage.pdf****. If you are viewing this document on a compact disk, click on this link* **hydro maps/Stage.pdf***.*

Figure 3-68: Selected Stage Monitoring Sites

Within the Everglades Protection Area, the following sites are used to determine the daily average stage values:

- Arthur R. Marshall Loxahatchee National Wildlife Refuge: 1-7, 1-8C, and 1-9
- Water Conservation Area 2A: 2A-17B
- Water Conservation Area 3A: 3A-3, 3A-4, and 3A-28
- Everglades National Park: P33, P34, P35, P37, and TSB

Daily hydrographs for selected sites can be found on the SFWMD's Regional Real-Time Data web site at http://www.sfwmd.gov/org/omd/ops/rt/regions.html. In addition, daily stage data from a large number of sites within the SFWMD can be obtained from the USACE's web site at http://www.saj.usace.army.mil/h2o/index.html.

Implementation of the CERP will require periodic modifications to the existing stage monitoring network. REstoration COordination and VERification (RECOVER) anticipates a review of the network to define enhancements, fill in data gaps, and reduce redundancy.

3.5.3.2 Ground Water Monitoring Network

The SFWMD and the USGS jointly manage and fund an extensive ground water monitor well network in South Florida (Figure 3-69). During the 2002 water year (October 1, 2001 to September 30, 2002), the USGS monitored 512 wells in southern Florida to assess regional ground water conditions (Torres personal communication 2003). In southeastern Florida, the principal aquifers monitored are the Biscayne aquifer in Miami-Dade and Broward Counties (230 wells) and the Surficial aquifer system in Palm Beach, St. Lucie, and Martin Counties (52 wells). In southwestern Florida, water levels are measured in the following principal aquifers: water-table aquifer (77 wells), lower Tamiami aquifer (43 wells), sandstone aquifer (42 wells), mid-Hawthorn aquifer (36 wells), lower Hawthorn aquifer (or lower Hawthorn producing zone) (25 wells), and Floridan aquifer system (7 wells). Data from this group of wells is collected by USGS staff and funded cooperatively between the SFWMD and the USGS. These wells are jointly maintained between the two agencies. The second grouping consists of approximately 275 wells, with 245 in the Surficial aquifer and 30 in the Floridan aquifer. This group of wells is currently monitored and maintained by the SFWMD. Daily ground water data from a large number of sites within the SFWMD may be obtained from the SFWMD's Regional Real-time Data web site at http://www.sfwmd.gov/org/omd/ops/rt/regions.html.

*The map depicting stage monitoring sites is too detailed to import into this document. It can be accessed on the web at **http://www.sfwmd.gov/curre/sitemaps/groundwater.pdf**. If you are viewing this document on a compact disk, click on this link hydro maps/Groundwater.pdf.*

Figure 3-69: Selected Ground Water Monitoring Sites

Each of the four regional water supply plans recently published by the SFWMD included recommendations for additional and improved ground water monitoring within their respective regions. The Lower East Coast Regional Water Supply Plan (SFWMD 2000a) recommends augmenting the network to expand the existing saltwater intrusion monitoring in the area. The Upper East Coast Water Supply Plan (SFWMD 1998) recommends developing a comprehensive monitoring program to collect the necessary information to develop the water use, water quality, and water level relationships in the high water use citrus groves in St. Lucie County. Recommendations from the Kissimmee Basin and Lower West Coast Water Supply Plans (SFWMD 2000b and 2000c, respectively) are not included since they are located outside the aerial extent of the MAP.

An evaluation of the monitoring well network was completed in March 2002 by a SFWMD task force (Lukasiewicz et al. 2002), and the resulting report presents specific recommendations for improvements to this well network. The report concluded that, overall, the total number of wells in the network provides adequate spatial resolution; however, the frequency of water level readings is not sufficient to support future ground water computer modeling efforts including those being conducted for CERP regional evaluations. Many recent models developed by the SFWMD (to support regional water supply plan development) run on daily time periods because stages in surface water bodies (i.e., canals) vary on a daily basis. The frequency of ground water level monitoring will need to correspond to the daily time periods of the models to ensure adequate model calibration.

As of 2003, the USGS surface water data-collection network consisted of 40 continuous flow-discharge sites and 34 stage sites, many of which collect water quality data (Torres personal communication 2003). In addition to this surface-water network and as part of USGS special projects in support of Everglades restoration activities along Florida Bay, Barnes Sound, and the southwest coast of Florida, the USGS also

maintains and operates 27 flow, stage, salinity, and temperature stations; 6 continuous stage, salinity, and temperature stations; 2 continuous sheetflow velocity stations; and 1 continuous salinity and temperature station. The SFWMD (Lukasiewicz et al. 2002) has recommended an additional 40 percent of the network be automated. Approximately 30 of these new recorders will be installed on Floridan aquifer wells. The remaining recorders will be installed on existing Surficial and Intermediate aquifer monitor wells.

The SFWMD has provided the following recommendations to improve the USGS and SFWMD network (Lukasiewicz et al. 2002):

- A total of 15 wells can be eliminated from the network due to data redundancies: 7 from the Lower East Coast region, 6 from the Upper East Coast region, and 2 from the Lower West Coast region.

- At least 54 additional new wells need to be drilled and instrumented in the regional network: 37 in the Lower East Coast region, 2 in the Upper East Coast region, and 15 in the Lower West Coast region.

- New instruments recommended include the following: 4 new surface water stage recorders in the Lower East Coast region and 3 new rainfall gauges for the Upper East Coast region.

- A total of 40 wells were identified as requiring repair: 18 in the Lower East Coast, 16 in the Lower West Coast Region, and 6 in the Upper East Coast region. Thirteen of the total 40 wells were repaired by the SFWMD in 2001.

- A total of 82 wells were identified as a high priority to automate with recorders: 49 in the Lower East Coast, 23 in the Lower West Coast Region, and 10 in the Upper East Coast region.

An attempt will be made to coordinate with local governments and utilities that manage local monitoring programs and databases of their own. Much of these data are already received as part of the water use permit process. These data need to be integrated with the data available in DBHYDRO. Integration of data from these sources would be a cost-effective means to increase our coverage both temporally and spatially.

Temporal (semi-annual) water level maps were also recommended for the Lower East Coast and Lower West Coast regions. These maps would be helpful in determining the cone of influence of the major public water supply well fields in the area.

3.5.3.3 Water Flow Monitoring Network

As of May 14, 2003, the SFWMD operated and maintained 318 active flow monitoring sites (Figure 3-70). These sites include pump stations, spillways, culverts, weirs, and open channel measurements. Flow values are derived from instantaneous headwater and tailwater levels, i.e. stage data, measured at every structure and pertinent operating control information such as pump speed or spillway gate opening conditions. Instantaneous flow values are then computed using an in-house computer program called FLOW.

Within SFWMD boundaries, an additional 116 structures of significance are currently operated by other agencies. The SFWMD has agreements with these agencies to obtain their data and load it into DBHYDRO on a regular basis, thereby providing a single source of flow data.

The map depicting stage monitoring sites is too detailed to import into this document. It can be accessed on the web at http://www.sfwmd.gov/curre/sitemaps/flow.pdf. If you are viewing this document on a compact disk, click on this link hydro maps/Flow.pdf.

Figure 3-70: Selected Flow Monitoring Sites

Flow is also obtained at canal sites that are too far from structures to obtain valid data or where it is desired to collect flow-proportional water quality samples for calculating nutrient loads. In these cases, data are obtained from velocity meters installed in canals and stored in an on-site data logger such as a CR-10 for direct transmission or later downloading. A computer program is then used to convert the velocity data into site-specific flow data. The data logger is also programmed with a "trigger" volume that, when reached, sends a signal to an autosampler to collect a water quality sample which is stored in an on-site container. The resulting flow and nutrient concentration data are subjected to quality assurance and quality control (QA/QC) analysis and then used to calculate a load for the time period during which the data were collected. Flow-proportional water quality data are currently being collected by the SFWMD, the USGS, the USACE, and the Miccosukee Tribe of Indians of Florida.

Implementation of the CERP will require periodic modifications to the existing flow monitoring network as structures are removed and new ones are constructed to redirect water conveyance and store water. A review of the monitoring network design will be implemented in order to determine where flow monitoring needs to be modified or enhanced and where data gaps need to be addressed.

Daily flow data from a large number of sites within the SFWMD may be obtained from the SFWMD's Regional Real-time Data web site at http://www.sfwmd.gov/org/omd/rt.html or at the USACE web site at http://www.saj.usace.army.mil/h2o/index.html.

3.5.3.4 Meteorology Monitoring Network

Weather Stations

As of April 30, 2003, there were 40 active weather sites maintained by the SFWMD and two maintained by other agencies (Figure 3-71). The site map provides coded symbols of measured parameters as follows: 24 evaporation sites, 29 wind sites, 29 temperature sites, and 30 solar sites. Daily average data are stored in DBHYDRO after data have been processed and subjected to QA/QC review. Individual data values can be extracted from the District's Data Collection and Validation Process database if needed. Discussion of the rainfall monitoring network is presented below.

The map depicting stage monitoring sites is too detailed to import into this document. It can be accessed on the web at http://www.sfwmd.gov/curre/sitemaps/weather.pdf. If you are viewing this document on a compact disk, click on this link hydro maps\Weather.pdf.

Figure 3-71: Selected Weather Monitoring Sites

Evapotranspiration and Pan Evaporation

The SFWMD maintains a database for daily wetland evapotranspiration at Storm Water Treatment Area 1 West (STA 1W). The daily data are derived from weather station data at the site and application of an evapotranspiration equation.

As of April 30, 2003, the SFWMD's monitoring network contained an additional 23 active pan evaporation stations. District-wide potential evapotranspiration estimation using models and weather data inputs is being expanded by the Environmental Monitoring and Assessment Department and the Electronic Support and Data Acquisition Division to support a number of water supply and water balance needs. Eventually, the network will have 13 new weather stations to estimate potential evapotranspiration. These data will be stored in DBHYDRO (Reardon and Abtew 2002). Modelers running the South Florida Water Management Model (SFWMM) and CERP project teams needing water balance data for planned stormwater treatment areas and reservoirs are potential users of these data. Technical documents related to the subject of evapotranspiration include Abtew (1996), Abtew (2001), Abtew and Obeysekera (1995), and Reardon and Abtew (2002).

Rainfall Monitoring Network

As of April 30, 2003, the SFWMD maintained 293 active rainfall monitoring sites, and other agencies maintained 18 active sites (Figure 3-72). The SFWMD's Operations and Management Division has divided the SFWMD area into the following 15 rainfall regions to facilitate operations:

- Upper Kissimmee
- Lower Kissimmee
- Lake Okeechobee
- East Everglades Agricultural Area
- West Everglades Agricultural Area
- Water Conservation Areas 1 and 2
- Water Conservation Areas 3
- Martin/St. Lucie Counties
- Palm Beach County
- Broward County
- Miami-Dade County
- Lower East Coast
- East Caloosahatchee
- Big Cypress
- Southwest Coast

The map depicting stage monitoring sites is too detailed to import into this document. It can be accessed on the web at http://www.sfwmd.gov/curre/sitemaps/rain.pdf. If you are viewing this document on a compact disk, click on this link hydro maps\Rain.pdf.

Figure 3-72: Selected Rainfall Monitoring Sites

Data from rainfall gages in each region are used to calculate a daily basin-weighted average rainfall sum using the Thiessen Polygon method. Individual rainfall gage values are entered into DBHYDRO.

A plan has been prepared for upgrading and optimizing the current rainfall network over the next three years. The first step will be to upgrade sites that do not have tipping buckets and the ability to send data via telemetry. The second step will be to collect and compare NEXRAD data, i.e., rainfall data measured by radar, with data collected from the upgraded ground-based network. The third step will optimize the ground-based system by relocating selected ground sites from clusters, i.e., areas where there are too many monitoring sites, to areas needing additional sites. The optimization will provide the highest degree of correlation between the NEXRAD and ground-based rainfall data.

In addition to the above mentioned data sources, SFWMD meteorologists issue daily rainfall forecasts for each region and produce a monthly Surface Water Conditions Report that includes a graphical comparison of each region's current monthly rainfall with the region historical average for that month. The daily forecasts and monthly report are also on the Operations Division web site, as is other weather-related data.

Rainfall depth, resulting from a storm event occurring with a given frequency, is an essential variable for design and operation of water control structures, flood control, consumptive use estimation, water supply planning, and water resources management. Rainfall depth is usually evaluated for various durations and frequency of occurrence using point or regional frequency analysis. Recent rainfall frequency analysis reports written for various regions within the District include Ali, et al. (2000), Ali and Abtew (1999), and Pathak 2001.

3.5.3.5 Monitoring Specific to Water Supply

For water supply, a network exists to monitor and report on urban water withdrawals, Lake Okeechobee releases, surface water stages in canals, and ground water stages in the Biscayne and Floridan aquifers. This existing network should be adequate to assess the short-term ability to meet water demands and identify how the demands were met when coupled with information from SFWMD Governing Board declarations of water restrictions. What is lacking are the tools to assess the cumulative and long-term impacts of the current and future urban and agricultural demands on regional water availability, identify trends in water demands, and determine water withdrawal trends compared to demand projections used for planning. In addition, it is essential that the regional system is meeting urban and agricultural demands during drought events and minimizing the effects on the natural system. Therefore, drought event assessments are an important tool to understand the effects of droughts and how the system was operated in response.

3.5.3.6 Monitoring Specific to Flood Protection

The existing network that monitors surface water levels in canals, ground water stages, water releases from structures, and rainfall is adequate to assess real time conditions and provide operating data for the

regional system. The network lacks the ability to aggregate the information and determine a basin's flood protection level of service and provide a comparison to the existing level of flood protection provided by the C&SF Project or other appropriate baselines.

3.5.4 Key Uncertainties and Supporting Research

Many of the supporting research topics needed to answer the key uncertainties related to the South Florida Hydrology Monitoring Network have not been developed. Below is a brief summary of the topics that will be developed for inclusion in the next version of the MAP.

3.5.4.1 Design Study for Hydrology Network Expansion and Refinement

The existing network of surface water, ground water, flow, and meteorology monitoring maintained and operated by the SFWMD, the USGS, and Everglades National Park will be evaluated to determine if additional monitoring locations are necessary to support the other modules. The hydrologic network will provide the necessary information to link changes in the physical components to the changes in chemical and biological components of the system. The monitoring data provided will be sufficient to characterize the hydrologic condition and aid interpretation of the water quality and ecological data collected as part of the other modules. The primary areas of the study are Lake Okeechobee and its tributaries, the remaining Everglades, and the Lower East Coast and Upper East Coast Service Areas. The evaluation of the existing hydrologic and meteorological networks for this study will be divided into four phases:

- Phase 1: Surface water (stages) monitoring network
- Phase 2: Flow (structures and canals) monitoring network
- Phase 3: Meteorology (weather and rainfall) monitoring network
- Phase 4: Open marsh flow velocity estimation monitoring network

The first phase will be initiated as soon as possible to establish a portion of the baseline for hydrologic conditions in the natural system. The ground water monitoring network does not require additional study at the present time. The SFWMD completed an evaluation of the ground water monitoring network in March 2002 (Lukasiewicz et al 2002).

3.5.4.2 Sea Level Influences on Levels of Flood Protection and Water Supply

Flood protection and water supply may be compromised as sea level rises. Operations will need to be altered to mitigate its impacts. A supporting research topic will be developed to determine if the flood protection and water supply system will be adequate or will need to be modified in the future.

3.5.4.3 Seepage Control and Saltwater Intrusion Tradeoffs in Biscayne Aquifer

The C&SF Project drainage system is designed to decrease seepage from the natural system and release excess water to tide. A supporting research topic will be developed to determine the dynamics and cumulative effects of this drainage system on the ability to prevent saltwater intrusion into the Biscayne aquifer and meet other restoration performance measures.

3.5.4.4 Methodology to Monitor and Evaluate the Success of Pre-CERP Baseline in Meeting WRDA 2000 and Florida Statutes Requirements

A pre-CERP baseline is being established through model simulation to meet WRDA and FS requirements. A supporting research topic will be developed to determine how this baseline can be verified through monitoring. The research will determine whether the data will be averaged, weighted over time and space, or handled by some other method.

3.5.4.5 Accuracy of Future Demand Projections and Effects on the CERP

The accuracy of future demand projections and the effects on CERP project design and performance if the actual demands differ from those projected needs to be determined. Future water sources may diversify as lower quality water is sought as a source for urban water demands, perhaps diminishing the demands on fresh water in the system compared to current projections. This topic could be addressed as part of the adaptive management strategy.

3.5.4.6 Cumulative Effect of Existing and Future Lake Okeechobee and Lower East Coast Water Demands

A supporting research topic will be developed to determine the cumulative effect that the existing and future Lake Okeechobee and Lower East Coast Service Areas' demand on regional water deliveries, seepage, and the regional water availability will have on meeting other restoration performance targets. Also, the research will determine if the development of additional regional storage and alternative water supplies will be adequate to meet future demands while meeting natural system performance targets.

3.5.4.7 CERP Versus Other Project Influences on Level of Flood Protection

Other water development projects occurring in the same regional areas and/or timeframe as CERP projects may influence the level of flood protection. A supporting research topic will be developed to determine how other project influences can be differentiated from those of CERP.

3.5.5 References

Abtew, W. 1996. Evapotranspiration Measurements and Modeling for Three Wetland Systems. Journal of American Water Resources Association 32(3):465-473.

Abtew, W. 2001. Evaporation Estimation for Lake Okeechobee in South Florida. Journal of Irrigation and Drainage Engineering, 127(3): 140-147.

Abtew, W., and J. Obeysekera. 1995. Lysimeter Study of Evapotranspiration of Cattails and Comparison of three estimation methods. Transactions of the ASAE 38(1): 121-129.

Ali, A., and W. Abtew. 1999. Regional Rainfall Frequency Analysis for Central and South Florida. Technical Publication WRE 380. South Florida Water Management District, West Palm Beach, Florida.

Ali, A., W. Abtew, S. Van Horn, and N. Khanal. 2000. Temporal and Spatial Characterization of Rainfall over Central and South Florida. Journal of American Water Resources Association 36(4):833-848.

RECOVER. In prep. Performance Measure Documentation Report. RECOVER c/o South Florida Water Management District, West Palm Beach, Florida.

Lukasiewicz, J., C. James, H. Radin, E. Hopkins, D. Butler, T. Bengtsson, and J. Herr. 2002. Ground Water Monitor Well Network Assessment, a District Task Force Report. Technical Memorandum WS-12, South Florida Water Management District, West Palm Beach, Florida.

Pathak, C.S. 2001. Frequency Analysis of Daily Rainfall Maxima for Central and South Florida. Tech. Pub. EMA 390. South Florida Water Management District, West Palm Beach, Florida.

Reardon, A., and W. Abtew. 2002. Evapotranspiration Estimation for South Florida - Documentation for Program ET_SF. Resource Assessment Division, South Florida Water Management District, West Palm Beach, Florida.

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

SFWMD. 2000a. Lower East Coast Regional Water Supply Plan. South Florida Water Management District, West Palm Beach, Florida.

SFWMD. 2000b. Kissimmee Basin Water Supply Plan. South Florida Water Management District, West Palm Beach, Florida.

SFWMD. 2000c. Lower West Coast Water Supply Plan. South Florida Water Management District, West Palm Beach, Florida.

Torres, A.E. Personal communication 2003. United States Geological Survey – Florida Integrated Science Center, Center for Water and Restoration Studies, Tampa, Florida.

USACE and SFWMD. 1999. Central and Southern Florida Project Comprehensive Review Study Final Integrated Feasibility Report and Programmatic Environmental Impact Statement. Jacksonville District, United States Army Corps of Engineers, Jacksonville, Florida, and South Florida Water Management District, West Palm Beach, Florida.

3.6 SOUTH FLORIDA MERCURY BIOACCUMULATION MODULE

3.6.1 Introduction

Mercury is a contaminant of concern in Florida as well as in most states of the United States and in other parts of the world. The concern stems from the fact that mercury is a persistent, bioaccumulative toxicant and, as such, can build up in the food web to levels that are harmful to human and ecosystem health. Widespread elevated concentrations of mercury were first discovered in freshwater fish from the Florida Everglades in 1989; as a result, fish consumption advisories were issued for select species and locations. Elevated concentrations of mercury have subsequently been found in predators like raccoons, alligators, wading birds, and the Florida panther (Fink et al. 1999).

Like other persistent, bioaccumulative toxicants, mercury is a multimedia problem. This is further complicated because as mercury moves through various environmental media, it undergoes a series of chemical and physical transformations (Figure 3-73; Fink et al. 1999, Atkeson and Parks 2001, 2002). For example, inorganic mercury (Hg) reaching the Everglades, largely through atmospheric deposition but also from sedimentary release, is immediately subject to these transformation processes (Atkeson and Parks 2002). End points of these processes can result in its reduction and emission into the atmosphere, sequestration into sediments, or microbially mediated methylation. Methylmercury (MeHg), which is the product of the latter process, is the most toxic and bioaccumulative form of mercury. Because the Comprehensive Everglades Restoration Plan (CERP) is not expected to alter atmospheric loading of mercury, of greatest concern in this context are the factors that govern mercury biogeochemistry as described in Figures 3-74 and 3-75.

Valuable insight into the factors that control mercury biogeochemistry has been gained over the last eight years through the combined work of various agencies working within the South Florida Mercury Science Program (Fink et al. 1999, Fink and Rawlick 2000, Atkeson and Parks 2001, 2002, Gilmour and Krabbenhoft 2001, Stober et al. 2001). This gained insight has been incorporated into the Everglades Mercury Cycling Model (E-MCMII) (Tetra Tech, Inc. 2003). At this writing, this model is undergoing further refinement and could be a valuable tool to predict the effects of hydroperiod restoration as a result of implementation of the CERP on mercury advisory zones.

The system-wide monitoring proposed in this module will provide data that can be used for this model and for the assessment of mercury as a bioaccumulative toxicant. The overall goal of this module is to monitor mercury bioaccumulation to ensure that the CERP does not inadvertently worsen the existing mercury problem in South Florida to the point that risks to humans or wildlife outweigh restoration benefits. However, as the focus of this module is on the system's downstream effects, many of which are distant from project components such as stormwater treatment areas, measurable changes may take years to occur. It is, therefore, important that CERP projects initiate individual monitoring programs in order to detect mercury mobilization more quickly.

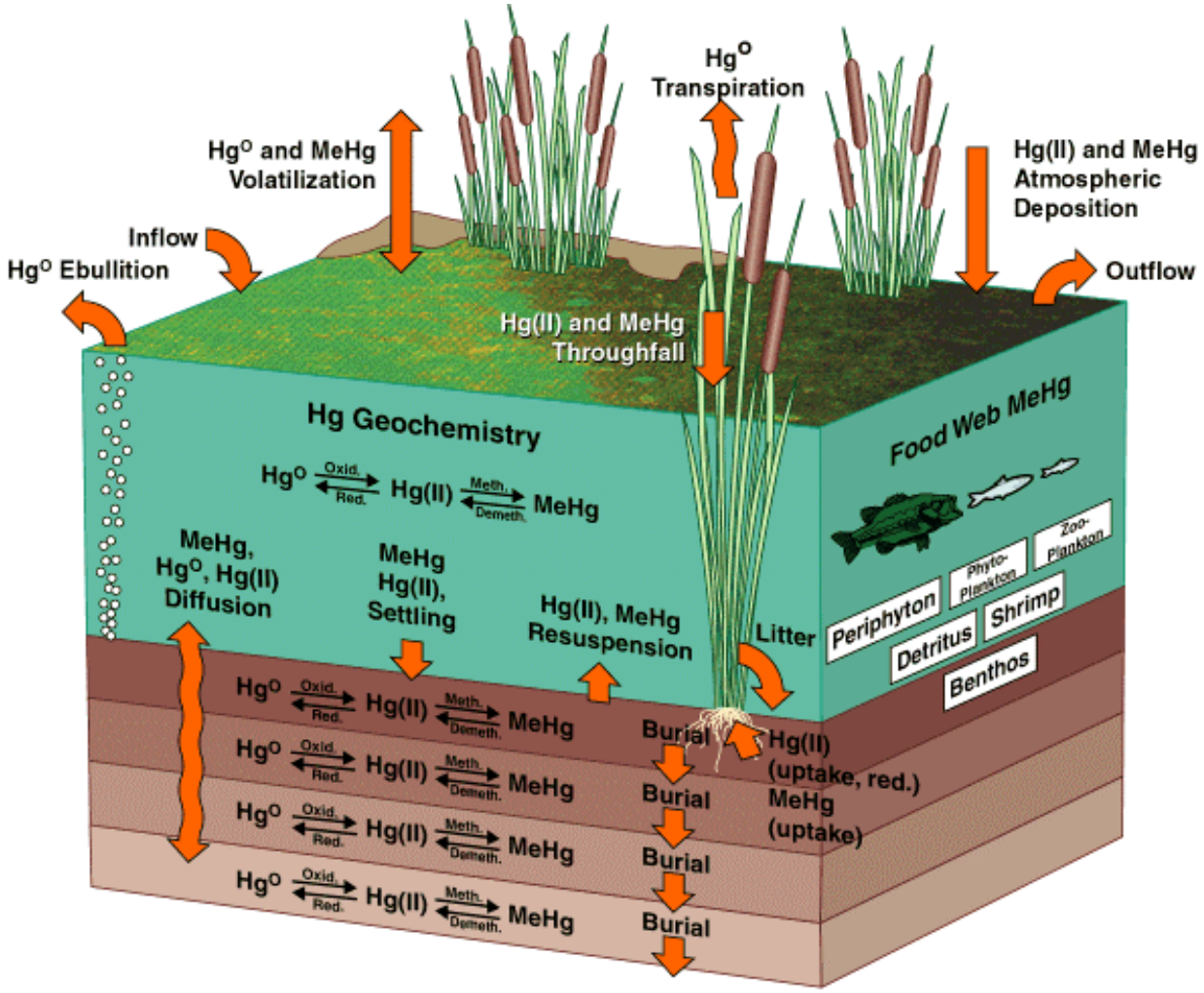


Figure 3-73: Diagrammatic representation of the Everglades Mercury Cycling Model showing multimedia nature of the problem (Source: Tetra Tech, Inc. 2003)

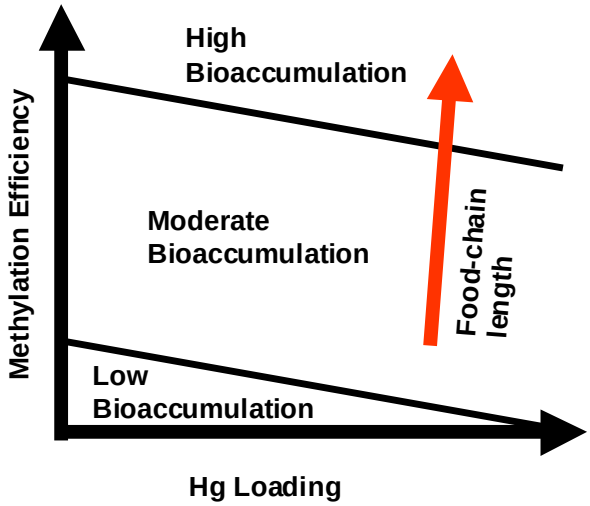


Figure 3-74: **Graphic representation of factors influencing mercury bioaccumulation**

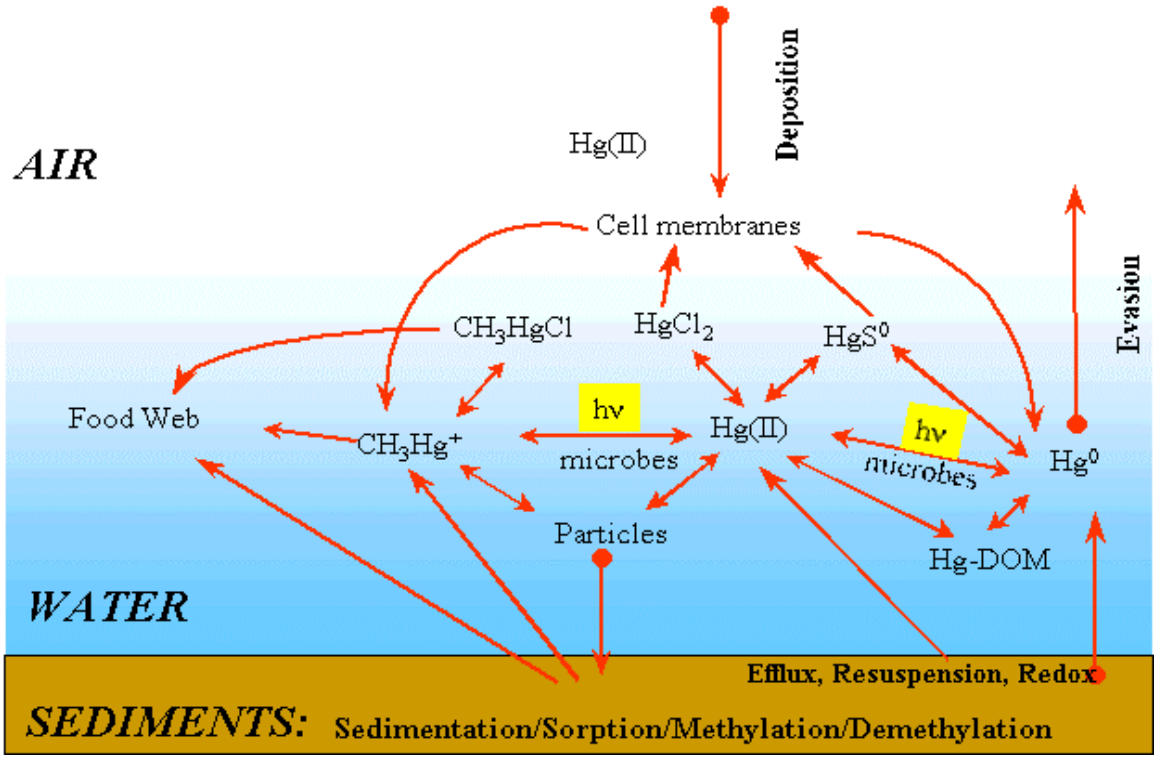


Figure 3-75: **Conceptual model of mercury biogeochemistry and factors affecting methylation efficiency (Source: Krabbenhoft et al. 2000)**

3.6.2 Ecological Premise and CERP Hypotheses as the Basis for Monitoring Components and Supporting Research

Ecological premises describe our current, broad understanding of the causal factors that have led to concerns regarding mercury bioaccumulation with the implementation of water management practices and operation of CERP components. Three general interrelated hypotheses form the basis for most of the CERP restoration goals and strategies for evaluating mercury bioaccumulation. These relate to the mercury biogeochemistry relative to 1) CERP water storage and treatment components, 2) conditions that alter methylation of mercury by sulfate-reducing bacteria, and 3) mercury releases due to changes in soil hydrological conditions. Monitoring and assessment associated with each of these premises is dependent on the South Florida Hydrology Monitoring Network (Section 3.5).

The monitoring components and supporting research are designed to answer adaptive management questions. These will be used to investigate the impact of water management and operations practices on mercury problems in the Greater Everglades ecosystem. Furthermore, they will provide important information to assist in developing potential operational changes that will improve ecosystem response.

Figures 3-76, 3-77, and 3-78 illustrate the linkages of the ecological premises to CERP hypotheses, monitoring components, and key uncertainties and supporting research. In some cases, supporting research originates directly from a CERP hypothesis, and research will be required to develop additional monitoring components to determine the exact cause of any observed increase in mercury bioaccumulation in fishes.

A summary of the monitoring components and supporting research for South Florida Mercury Bioaccumulation Module is listed in Table 3-19. The monitoring components are described in detail in the following sections. The list of research topics includes those identified during the development of the current version of the Monitoring Assessment Plan (MAP), but they have not been fully developed yet. These topics, and possibly others, will be developed in future versions of the MAP.

The process used to develop the monitoring plan for the South Florida Mercury Bioaccumulation Module, and all of the other modules, is described in Section 2.0, Development of the CERP Monitoring Plan and Adaptive Management Program. The strategy for prioritizing and implementing monitoring components and research topics is discussed in Section 5.0, Implementation Strategy for the CERP Monitoring and Assessment Plan.

3.6.2.1 Water Storage Components and Mercury Biogeochemistry (Figure 3-76)

Ecological Premise: Constructed wetlands, especially newly flooded wetlands, can be a significant source of both inorganic and, more importantly, organic mercury.

CERP Hypothesis: Construction and operation of reservoirs, stormwater treatment areas, or reservoir-assisted stormwater treatment areas, as well as spreader canals and other water delivery components, have the potential to result in 1) creation of new areas for mercury methylation, 2) “first flush” of both inorganic and organic mercury from soils, and 3) stimulation of sulfate-reducing bacteria, which methylate inorganic mercury to the more bioaccumulative methylmercury species, through decomposition of flooded terrestrial vegetation and soil carbon. Construction and operation of these CERP components may result in the following:

- The production of a “reservoir effect” within the impoundment, whereby fish biomagnify methylmercury within the project boundary

- An increase in the downstream loading of inorganic and organic mercury and increased biomagnification of methylmercury in fish downstream of the project

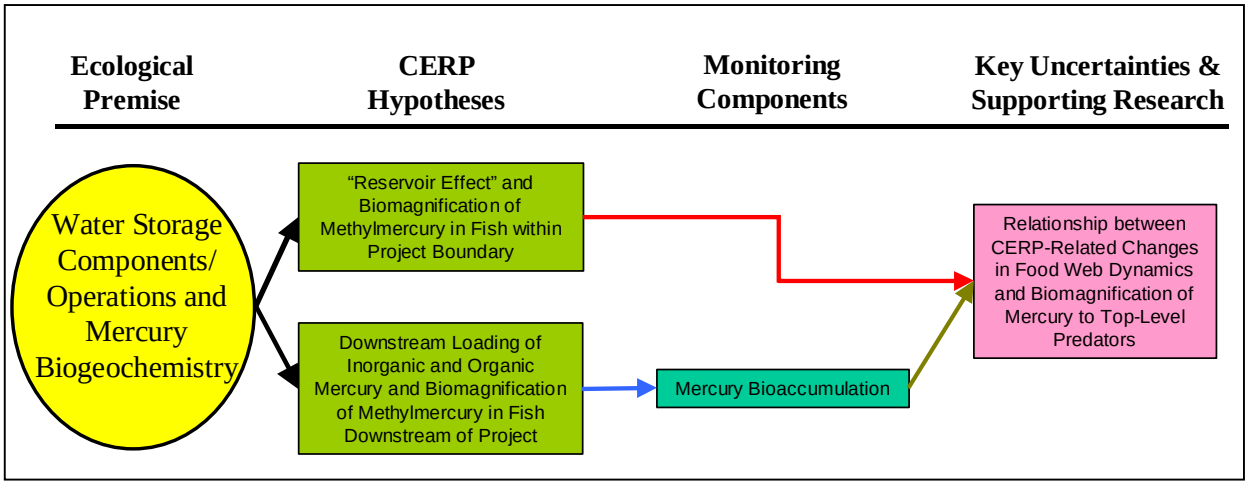


Figure 3-76: Diagram Depicting Relationships between the Ecological Premise, CERP Hypotheses, Monitoring Components, and Supporting Research for Water Storage Components and Mercury Biogeochemistry

Adaptive Management Question: Will the implementation of CERP water storage and treatment components result in system-wide conditions that facilitate the bioavailability of mercury? If so, what further actions are required to minimize or eliminate these conditions?

3.6.2.2 Mercury Methylation and Sulfur Biogeochemistry (Figure 3-77)

Ecological Premise: The efficiency of sulfate-reducing bacteria to methylate inorganic mercury is optimized under specific sulfide-to-sulfate ratios that typically occur when the average surface water concentration of sulfate is greater than 1 milligram per liter (mg/l) and less than 20 mg/l. That is, background concentrations less than 1 mg/l of sulfate will starve the sulfate-reducing bacteria and thus inhibit methlyation, whereas concentrations greater than 20 mg/l (which is not typical or desirable in the Greater Everglades ecosystem) generally result in excess sulfide production by these organisms, which in turn will also inhibit mercury methylation due to a reduction in inorganic mercury bioavailability.

CERP Hypothesis: CERP projects that alter the sulfur cycle within an area (for example, by releasing or redistributing sulfate laden water, via a change in redox conditions with attendant modification of existing sulfur speciation, or by reducing sulfur availability through a decrease in loading and increase in burial) have the potential to increase mercury bioaccumulation through the following:

- Changes in the bioavailability of inorganic mercury utilized by sulfate-reducing bacteria
- Changes in the rate of methylation of mercury through sulfate stimulation

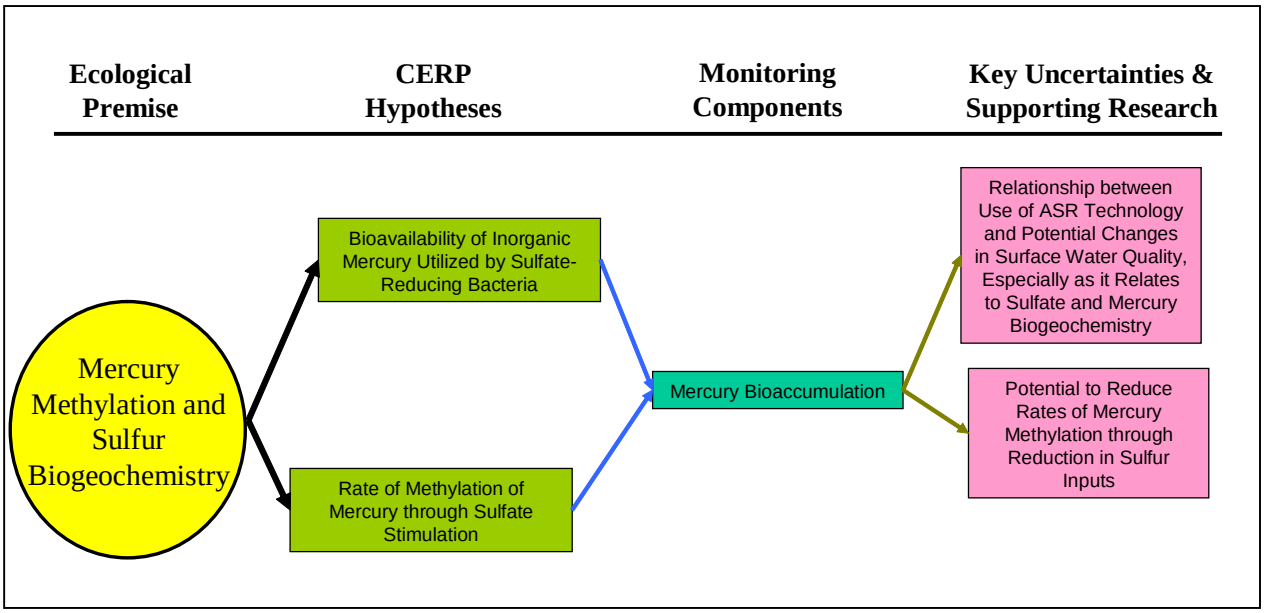


Figure 3-77: Diagram Depicting Relationships between the Ecological Premise, CERP Hypotheses, Monitoring Components, and Supporting Research for Mercury Methylation and Sulfur Biogeochemistry

Adaptive Management Question: Will the implementation of CERP components result in system-wide conditions that produce changes to sulfur biogeochemistry to result in changes in the bioavailability of mercury and rate of methylation? If so, what further actions are required to minimize or eliminate these conditions?

3.6.2.3 Mercury Releases and Soil Hydrological Conditions (Figure 3-78)

Ecological Premise: The drying and rewetting of certain hydric soils can affect mercury biogeochemistry in sediment.

CERP Hypothesis: CERP projects that increase the frequency of drying and rewetting events within wetlands have the potential to change the release of bound mercury from sediments (during dry periods) and alter sulfur speciation within sediments through oxidation (i.e., sulfides are oxidized and, thus, available once more for reduction by sulfate-reducing bacteria). This may result in increases in bioavailable inorganic mercury, sulfate, and, as a result, net methylation.

Adaptive Management Question: Will the implementation of water management practices and operation of CERP components result in system-wide conditions that produce changes to mercury biogeochemistry to result in changes in mercury releases and mercury bioaccumulation rates? If so, what further actions are required to minimize or eliminate these conditions?

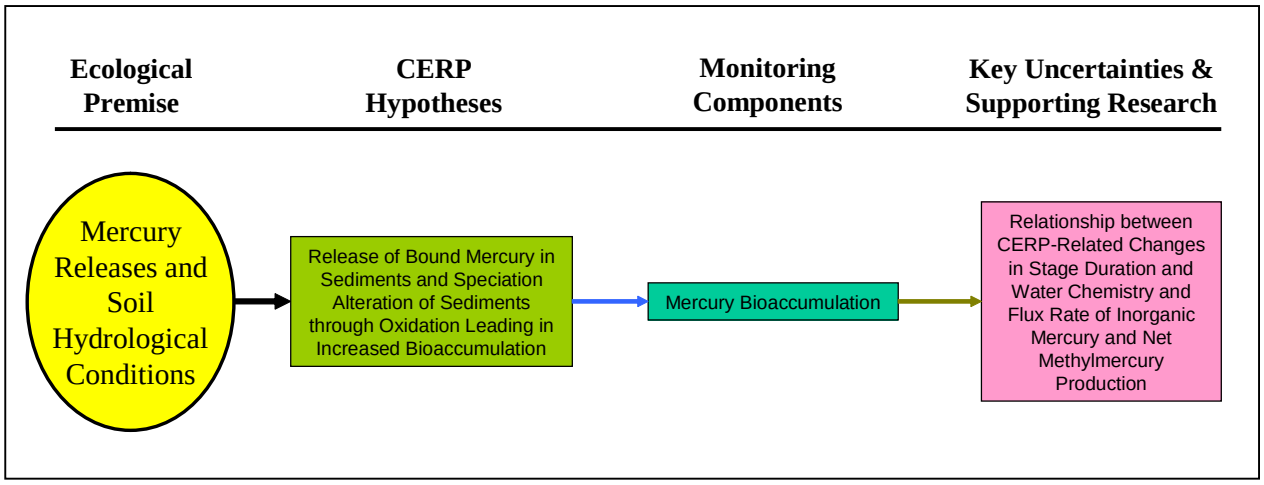


Figure 3-78: Diagram Depicting Relationships between the Ecological Premise, CERP Hypothesis, Monitoring Components, and Supporting Research for Mercury Releases and Soil Hydrological Conditions

3.6.2.4 Summary of Monitoring Components and Key Uncertainties and Supporting Research

Table 3-19 summarizes the monitoring components and key uncertainties and supporting research for the South Florida Mercury Bioaccumulation Module. A system-wide assessment performance measure is being developed for mercury bioaccumulation as part of the development of the Total System Conceptual Ecological Model. This performance measure will be published in either the first edition of the Performance Measure Documentation Report (RECOVER In prep.) to be released by REstoration COordination and VERification (RECOVER) in 2004 or in the next edition of the MAP.

Table 3-19: Monitoring Components and Key Uncertainties and Supporting Research for South Florida Mercury Bioaccumulation

Monitoring Components	MAP Section	Performance Measure Number
Mercury Bioaccumulation	3.6.3.1	TS-A1
Key Uncertainties and Supporting Research		
Relationship between CERP-Related Changes in Stage Duration and Water Chemistry (Including Quantity and Quality of Carbon) and Flux Rate of Inorganic Mercury and Net Methylmercury Production	3.6.4.1	
Relationship between CERP-Related Changes in Food Web Dynamics and Biomagnification of Mercury to Top-Level Predators	3.6.4.2	
Relationship between the Use of Aquifer Storage And Recovery (ASR) Technology and Potential Changes in Surface Water Quality, Especially as it Relates to Sulfate, and Mercury Biogeochemistry	3.6.4.3	
Potential to Reduce Rates of Mercury Methylation through a Reduction in Sulfur Inputs	3.6.4.4	

3.6.3 Monitoring Components

3.6.3.1 Mercury Bioaccumulation

Appropriate fish samples will be collected to evaluate potential mercury bioaccumulation pathways to humans (via analysis of edible fish filet) and wildlife (via analysis of whole fish) using appropriate target species. The selection of target fish species is based on meeting three criteria: 1) fishes known from other studies to bioaccumulate mercury, 2) species that are widely distributed, and 3) species believed to be less mobile than other species, so as to permit inference of localized spatial differences. The following are proposed as indicator species (note: measurements are defined as total length of fish):

<u>Estuarine mercury in fish indicator species</u>

- Crevalle jack (*Caranx hippos*) – filet (12-15 inches)
- Gray snapper (*Lutjanus griseus*) – whole and filet (10-13 inches)

<u>Freshwater mercury in fish indicator species</u>

- Sunfish (*Lepomis* spp. – preferably bluegill, *Lepomis macrochirus*) – whole (4-7 inches)
- Largemouth bass (*Micropterus salmoides*) – filet (11-13 inches, but may include fish outside of this size range)

Sunfish and gray snapper were selected because they are a preferred prey and, thus, should be an excellent indicator of exposure to piscivorous fish and other fish-eating wildlife (e.g., wading birds). Largemouth bass, crevalle jack, and gray snapper were selected as an indicator of potential human exposure. However, other species including other Lepomids (with first priority being given to spotted sunfish, *Lepomis punctatus*, because its trophic status is similar to bluegill), red drum (*Sciaenops ocellatus*), spotted seatrout (*Cynoscion nebulosus,*) and/or other sizes are to be collected if efforts fail to locate targeted fish. Although they are at a different trophic level and integrate exposure over a much shorter time frame (owing to their shorter life spans), mosquitofish *(Gambusia holbrooki*) should be collected because of its widespread occurrence and historical database (i.e., mercury monitoring program for Everglades Forever Act) if efforts fail to locate targeted species.

Virtually all (greater than 85 percent) of the mercury in fish tissues is in the methylated form (Grieb et al. 1990, Bloom 1992, SFWMD unpublished data). Therefore, fish tissue will be analyzed for total mercury, which is a more straightforward and less costly procedure than for methylmercury and can be interpreted as equivalent to an analysis of methylmercury. For gray snapper, samples of both a small portion of the filet as well as the whole fish will be analyzed until a relationship between fillet concentration and whole body concentration can be adequately developed (50-60 specimens); after which, only the filet will be analyzed. Such a relationship has already been established for largemouth bass (Lange et al. 1998, Bevelheimer et al. 1997).

To be consistent with the protocol used by the Florida Fish and Wildlife Conservation Commission (and, hence, their long-term database), mercury concentrations in largemouth bass will be standardized to an expected mean concentration in 3-year-old fish at a given site by regressing mercury against age (for details see Lange et al. 1998 and references therein). To adjust for month of collection, otolith ages will first be converted to decimal age using protocols developed by Lange et al. (1998). Aging of bass may be discontinued in the future, if it is determined that temporal assessments can be made based on bass size (i.e., culling data on bass within the size range of 10-13 inches from the long-term database and

evaluating the significance of location-dependent variability in growth). Because age normalization has not been established as the standard for other targeted species (instead, size is used), age determination is not required at this time; however, otoliths from other species will be reserved for determining age if it is warranted in the future.

Twenty fish of each species identified within the habitat (i.e., estuarine and freshwater) will be collected annually from each region. A maximum of seven fish will be collected from any one location within a region. Locations within regions and sample size (from each location) should be consistent from year-to-year to ensure consistent weighting of this spatially-averaged sample. The regions and locations are as follows:

Estuarine/Coastal Regions

- Indian River (to include the Intracoastal Waterway to the Jupiter Inlet)
- St. Lucie River Estuary
- Loxahatchee Estuary
- Intracoastal sections: Intracoastal Jupiter Inlet to Boynton Inlet (includes Lake Worth), intracoastal Boynton Inlet to Port Everglades Inlet (includes Lakes Wyman and Boca Raton), and intracoastal Port Everglades Inlet to Baker's Haulover Inlet
- Biscayne Bay (includes north Biscayne Bay)
- Card and Barnes Sounds
- Eastern, central, and western Florida Bay
- Whitewater Bay
- Southwestern Everglades National Park/Gulf of Mexico beaches and shorelines (East Cape Sable to Shark River/South end of Ponce De Leon Bay)
- Southwestern Everglades National Park/Gulf of Mexico beaches, river mouths, and shorelines (south end of Ponce De Leon Bay to the north end of First Bay, including the mouths of the Shark River, Ponce De Leon Bay, Harney River, Rodgers River, Broad River, Broad Creek, Lostman's River, unnamed creeks, and First Bay)
- Ten Thousand Islands area from the north end of First Bay to Goodland (includes numerous bays, rivers, and creeks).
- Southwestern coast from Goodland to Punta Rassa (includes Gullivan, Rookery, Estero, and numerous other bays)
- San Carlos Bay

Freshwater Regions

- Caloosahatchee River

- Lake Okeechobee
- Loxahatchee River
- C-44 canal
- Big Cypress National Preserve
- Everglades National Park
- Arthur R. Marshall Loxahatchee National Wildlife Refuge and Water Conservation Areas 2A, 2B, 3A, and 3B
- Kissimmee River
- Model Lands/Southern Glades outside of Everglades National Park
- Grassy Waters Preserve
- Holey Land and Rotenberger Wildlife Management Areas

The resulting data will then be assessed by RECOVER to determine if additional monitoring is needed. Additional monitoring might include additional samples, additional target species (e.g., prey fish such as mosquitofish, sardine), additional media (e.g., sediment, pore water) (based on Figures 3-77 and 3-78), or additional analyses (e.g., sulfur species, isotopic carbon, or nitrogen). All tissue samples will be archived to allow for subsequent pesticide analysis if later deemed advisable.

A considerable level of mercury monitoring already occurs in the freshwater portion of the system under programs mandated by the Everglades Forever Act Permits (EFA-Ch. 373.4592, F.S.; for details see Rumbold and Fink 2002). The MAP identifies this existing legislatively mandated monitoring and identifies gaps that require additional funding to ensure that the program adequately addresses the needs of the CERP. The MAP monitoring program will also actively seek partnerships with other programs to conserve resources. For example, this program will attempt to obtain fishes that are collected under MAP to monitor changes in fish densities during drydowns (wading bird prey density) for mercury analysis. Furthermore, efforts will be made to coordinate this program with other mercury monitoring initiatives or studies underway by the United States Geological Survey, the Florida Marine Research Institute, or the National Oceanic and Atmospheric Administration.

3.6.4 Key Uncertainties and Potential Research Questions (to be developed)

3.6.4.1 Relationship between CERP-Related Changes in Stage Duration and Water Chemistry (Including Quantity and Quality of Carbon) and Flux Rate of Inorganic Mercury and Net Methylmercury Production

3.6.4.2 Relationship between CERP-Related Changes in Food Web Dynamics and Biomagnification of Mercury to Top-Level Predators

3.6.4.3 Relationship between the Use of Aquifer Storage and Recovery (ASR) Technology and Potential Changes in Surface Water Quality, Especially as it Relates to Sulfate, and Mercury Biogeochemistry

3.6.4.4 Potential to Reduce Rates of Mercury Methylation through a Reduction in Sulfur Inputs

3.6.5 References

Atkeson, T., and P. Parks. 2001. The Everglades mercury problem. In: SFWMD, 2001 Everglades Consolidated Report, South Florida Water Management District; West Palm Beach, Florida, Chapter 7.

Atkeson, T., and P. Parks. 2002. Mercury monitoring, research and environmental assessment. In: SFWMD, 2002 Everglades Consolidated Report, South Florida Water Management District; West Palm Beach, Florida, Chapter 2B.

Bevelheimer, M.S., J.J. Beauchamp, B.E. Sample, and G.R. Southworth. 1997. Estimation of Whole-Fish Contamination Concentration from Fish Fillet Data. Prepared by the Risk Assessment Program, Oak Ridge National Laboratory; Oak Ridge, Tennessee.

Bloom, N.S. 1992. On the chemical form of mercury in edible fish and marine invertebrates. Can. J. Fish. Aquat. Sci. 49: 1010-1017.

Fink, L., D.G. Rumbold, and P. Rawlik. 1999. The Everglades mercury problem. In: SFWMD, The Everglades Interim Report, report to the Florida Legislature by the South Florida Water Management District; West Palm Beach, Florida, Chapter 7.

Fink, L., and P. Rawlick. 2000. The Everglades mercury problem. In: SFWMD, 2000 Everglades Consolidated Report, South Florida Water Management District; West Palm Beach, Florida, Chapter 7.

Gilmour, C.C., and D.P. Krabbenhoft. 2001. Status of methylmercury production studies. In: SFWMD, 2001 Everglades Consolidated Report, South Florida Water Management District; West Palm Beach, Florida, Appendix 7-4.

Grieb, T.M., C.T. Driscoll, S.P. Gloss, C.L. Schofield, G.L. Bowie, and D.B. Porcella. 1990. Factors affecting mercury accumulation in fish in the upper Michigan peninsula. Environ. Toxicol. Chem. 9:919-930.

Lange T.R., D.A. Richard, and H.E. Royals. 1998. Trophic Relationships of Mercury Bioaccumulation in Fish from the Florida Everglades. Prepared for the Florida Department of Environmental Protection, Tallahassee, Florida.

Krabbenhoft, D.P., M.L. Olson, J. DeWild, C.C. Gilmour, W.H. Orem, G.R. Aiken, and C. Kendall. 2000. Aquatic cycling of mercury in the Everglades (ACME) Project: Synopsis of Phase I studies and plans for Phase II studies. Poster presentation at the Greater Everglades Ecosystem Restoration Conference – 2000, December 11-15, 2000, Naples, Florida. http://sofia.usgs.gov/geer/2000/posters/merc_cycle/

RECOVER. In prep. RECOVER Performance Measure Documentation Report. RECOVER, c/o South Florida Water Management District, West Palm Beach, Florida.

Rumbold, D.G., and L. Fink. 2002. Annual permit compliance monitoring report for mercury in downstream receiving waters of the Everglades Protection Area. In: SFWMD, 2002 Everglades

Consolidated Report, South Florida Water Management District; West Palm Beach, Florida, Appendix 2B-1.

Stober, Q.J., K. Thornton, R. Jones, J. Richards, C. Ivey, R. Welch, M. Madden, J. Trexler, E. Gaiser, D. Scheidt, and S. Rathbun. 2001. South Florida Ecosystem Assessment: Phase I/II- Everglades Stressors Interaction: Hydropatterns, Eutrophication, Habitat Alteration, and Mercury Contamination. EPA 904-R-01-002, United States Environmental Protection Agency, Atlanta, Georgia.

Tetra Tech, Inc. 2003. Modeling Mercury Cycling and Bioaccumulation in Everglades Marshes with the Everglades Mercury Cycling Model (E-MCM). Prepared for Florida Department of Environmental Protection, Tallahassee, Florida and South Florida Water Management District, West Palm Beach, Florida, Final Report June 2003.

4.0 QUALITY ASSURANCE/QUALITY CONTROL AND DATA VALIDATION, MANAGEMENT, EVALUATION, AND REPORTING

4.1 INTRODUCTION

REstoration COordination and VERification (RECOVER) has determined that environmental data and information developed through the adaptive management process must 1) withstand scientific review and legal scrutiny, 2) be used to develop scientific and technical consensus among agencies, and 3) be fully utilized and integrated into the Comprehensive Everglades Restoration Plan (CERP). Because of this, it is critical that specific data quality objectives (DQOs), standard quality assurance and quality control (QA/QC) procedures, and data quality validation and assessment criteria and procedures be in place prior to initiating any monitoring and research activities. This is necessary to ensure that the resulting data are of the highest quality and usefulness and are checked for proper integrity before being archived into a shared database or reported.

A monitoring and assessment program consists of more than just the collection and laboratory analysis of samples. The QA/QC and data validation along with data management, evaluation, and reporting must also be planned and implemented as integral components of any monitoring and assessment program. Data processing, analysis, and scientific validation of the data through QA/QC procedures are some of the most important responsibilities of all entities participating in this monitoring program. Development of appropriate and consistent QA/QC and data validation and assessment protocols, along with an efficient and well-structured data management system that can be shared by all stakeholders, is key to the successful implementation of the Monitoring and Assessment Plan (MAP). It should be noted that the cost for collecting and analyzing QC samples, conducting the data validation and assessment, and managing data will add from 50 to 100 percent to the total cost for sample collection and laboratory analysis. This section describes how RECOVER will develop and implement these important functions.

4.2 DATA QUALITY OBJECTIVES

The DQOs evolve from the planning and development of sampling designs for data collection activities that are to support decision making and should be defined <u>before</u> any data are collected. Any DQOs resulting from this exercise should explain the purpose of the data collection effort and define the qualitative and quantitative criteria for determining when, where, number, and type of samples or measurements are to be collected for a desired level of confidence and for assessing the quality of the resulting data set for the intended use. In general, DQOs define the acceptance or performance criteria for the quality of the data collected based on ultimate use of data and the required QA/QC practices to support the decision. Each MAP effort will have DQOs established up front.

4.3 QUALITY ASSURANCE/QUALITY CONTROL

One of the most critical components of a monitoring and assessment program to be established and implemented, either at the system-wide or project level, is a QA/QC program that lays out the protocols and procedures for all CERP-related data gathering activities. A well-defined system of QA/QC practices and standard operating procedures (SOPs) is critical for ensuring that the data resulting from the collection and analysis of environmental samples and measurements are of the appropriate type and quality and are scientifically (and legally) sound and defensible.

Details and specificity on QA/QC criteria are essential to ensure that the monitoring data are of the highest quality and usefulness possible. QA review and data validation will be conducted according to

established data DQOs and QA/QC criteria/standards for appropriateness, integrity, compatibility, comparability, and functionality (usefulness) to the MAP.

4.3.1 Need for Standardized Protocols

Currently, each organization that is or will be involved in the CERP monitoring collects data for their own specific purposes. These many organizations utilize their own procedures that have been established and have evolved over the years within their respective agencies. Now, with the onset of the CERP, there is a critical need to establish consistent monitoring procedures and quality assurance protocols. These protocols will establish operating standards for the collection of a variety of data types needed to assess a regional environmental system. When it is time to compile these data to evaluate regional environmental progress, if standards have not been established for a minimum level of quality and completeness to ensure consistency within the program and to allow effective sharing of data, the interpretation of these data from the various entities may be problematic with respect to consistency or comparability.

To address this issue, it was determined that a single comprehensive QA/QC program for both RECOVER and the individual CERP projects must be established up front. This program will establish operating standards for the design, collection, and analyses of a variety of data types recommended in this MAP and for CERP projects. The purpose of the program is to accomplish the following:

- Ensure the consistency and comparability of data using standardized procedures across agencies or organizations
- Provide guidance to those involved in the CERP monitoring activities to establish accuracy and precision criteria for each data type
- Provide for the efficient and effective analysis of data collected by the various organizations in South Florida and provide users of these data with some degree of confidence that the data were collected with similar accuracy and processing standards across agencies
- Provide guidance on accuracy and precision requirements to agencies and organizations involved with establishing new monitoring stations

If common methods are not feasible, calibration exercises and rigorous quality assurance procedures should be conditions of CERP funding.

Standard methods of QA/QC and data validation are well documented and accepted for the majority of hydrologic and water quality sampling and measurement techniques, laboratory analyses, and data processing and analyses. Standard methods may also exist for many of the biological monitoring techniques and remote sensing data collection and processing, but generally these are documented only in the peer-review scientific literature, rather than in commonly-used methods manuals.

4.3.2 CERP Quality Assurance Systems Requirements

Data must be of the right type, quality, and quantity to meet program requirements and DQOs. To attain this goal, CERP must follow federal and state regulations for monitoring operations and sample analysis. In general, all field sampling and data collection performed for the MAP must adhere to the following regulations:

- The collection and quality control protocols and requirements incorporated into the Field Sampling Quality Manual (SFWMD 2002) in compliance with the Florida Department of

Environmental Protection (FDEP) Quality Assurance Rule 62-160, Florida Administrative Code (F.A.C.)

- The FDEP collection and quality control protocols and requirements in DEP-SOP-001/01, incorporated by reference in Rule 62-160.800, F.A.C.

- Any other regulations dictated by the monitoring program requirements such as sampling and analysis plans (SAPs)

Under the sponsorship of RECOVER, a CERP Quality Assurance Systems Requirements (QASR) Manual (RECOVER 2003) is currently being developed to set forth the minimum regulations required for data collection activities. This manual will be the foundation of the CERP QA program and will serve as the basis for the QA program for all monitoring activities conducted during the implementation of the CERP. Several sections of the manual have been released for review. While it is expected that each agency involved in various aspects of the CERP monitoring will perform a certain level of QA/QC checks, the CERP QASR Manual will require further checks throughout the monitoring, analytical, and data evaluation processes to ensure that the quality of the data is consistent and usability is appropriate. The CERP QASR Manual incorporates requirements of the FDEP Rule 62-160, F.A.C., and the current National Environmental Laboratories Accreditation Program (NELAP) guidelines as the minimum requirements for the CERP QA program. The manual will not supplant the state's (i.e., local sponsor's) requirements for approved QA documentation; rather, it will complement the state program. It will be a single point of reference and guidance for all monitoring activities conducted by RECOVER and CERP projects and will ensure data comparability for the assessment of individual project success and regional and system-wide CERP progress.

The draft CERP QASR Manual currently outlines the SOPs and QA/QC guidelines for all CERP water quality monitoring practices; laboratory analysis and methods; and data assessment, validation, and management. Sections describing biological sampling practices, hydrologic and meteorological monitoring and data collection, and remote sensing data acquisition and processing will be forthcoming.

The completed document will lay out the protocols and procedures for all data gathering activities during the implementation of the CERP and will be periodically updated and refined in an effort to strengthen the QA program. The QASR covers the details of the QA/QC program that will be required during the implementation of the MAP, including establishing or defining the DQOs, SOPs for various QA and QC activities, data assessment criteria, and data handling procedures, and describes some of the expected data types and associated elements and standards necessary to produce quality data that are consistent and comparable. Approvals for modifications or alternatives to the procedures described in this document must follow the process outlined in the QASR.

QA activities will entail preparing and updating QA/QC plans; ensuring compliance with current state and federal regulations; conducting field and laboratory audits and preparing feedback reports (ensuring comparable method detection limits [MDLs] are attained); preparing QA/QC reports; investigating quality-related issues and implementing corrective actions; training laboratory and field personnel on QA-related protocol; conducting laboratory proficiency and "round robin" studies; and evaluating field precision and sample contamination based on field QC samples.

QC activities will include assessing sampling or analytical method compliance and comparability; tracking each laboratory's quality performance based on QC results; conducting performance evaluation (blind sample) studies including preparation and distribution to laboratories and tabulating/analyzing results; conducting split sample studies and coordinating and evaluating the results; and analyzing laboratory performance based on performance evaluation results, split sampling results, and analytical run

quality, including "round robin" studies to assess data comparability and consistency among agencies involved in data collection activities.

4.3.3 CERP Quality Assurance Oversight Team

All participants involved in implementing any aspect of environmental monitoring and providing data for the CERP will be required to adhere to the procedures and protocols contained in the CERP QASR (RECOVER 2003). The protocols, controls, and evaluation processes outlined in the QASR must be successfully implemented and monitored in order for the program to be effective. Each entity involved with monitoring must share responsibility for maintaining knowledge of the QA/QC system and for adhering to procedures in the QASR. The ultimate responsibility, however, rests with the Quality Assurance Oversight (QAO) Team that will be an interagency technical group comprised of United States Army Corps of Engineers (USACE), South Florida Water Management District (SFWMD), United States Environmental Protection Agency (USEPA), and FDEP participants. FDEP's role will be to ensure implementation of Chapter 62-160, F.A.C., and provide technical assistance to the QAO Team.

The QAO Team, working and coordinating with RECOVER's Adaptive Assessment and Water Quality Teams, will be charged with implementation and oversight of the CERP QA/QC program and will ensure that monitoring adheres to the QASR. The QAO Team is responsible for dealing with QA issues, establishing a mechanism for distribution of quality system information and changes, and ensuring data meet or exceed the DQOs of the MAP. Some of the team's duties with respect to the MAP will entail the following:

- Developing and implementing data review criteria
- Conducting audits of field and laboratory activities
- Performing QA review of monitoring data
- Implementing a laboratory and field "round robin" program to assess consistency among agencies involved in the data collection activities
- Producing annual QA reports to management
- Developing QA Plans for the MAP and associated quarterly QA reports
- Coordinating a team of governmental and commercial laboratories to ensure adequate training, coordination, and consistency in laboratory and field procedures
- Initiating/conducting systems audits, performance audits, and corrective actions
- Reviewing new and alternative methods and requests for sample modifications
- Conducting data verification, validation, and quality assessment as needed
- Coordinating training for these functions and making sure the guidelines are followed and any deficiencies are corrected

How the elements should be monitored individually and collectively will be determined through consultation with the QAO Team, RECOVER, and the agencies or organization(s) responsible for implementing the various elements of the monitoring plan. Standardized monitoring/data collection

methodologies, sampling schemes, laboratory analytical methods, and QA and reporting procedures for each of the monitoring parameters will be agreed upon and used by all participating investigators in the program for collecting, processing, and managing water quality and hydrologic data. Any changes in methods during the implementation of the plan, once approved, will be documented. The CERP QAO Team will also interact with the CERP Data Management Program to review and comment on all data-related technical specifications; ensure that a proper data QA/QC process will be in place, particularly for data acquisition contracts; and review contract SOWs for environmental monitoring.

A formal inter-agency auditing procedure will be established to ensure that QASR protocols, SOPs, data handling, etc. are adhered to over the lifetime of monitoring activity. An appropriate systematic audit will facilitate long-term comparability and usefulness of the data. It is important to avoid minor changes in protocol that may, at some later time, prove to have irreparably compromised the value of the data. However, mechanisms will be in place to obtain approvals for modifications or alternatives to the standard procedures. The QAO Team must approve any variance in procedures or use of any non-standard methods.

4.3.4 Water Quality Monitoring

Because water quality monitoring and associated QA/QC activities will be conducted by numerous groups and samples will be analyzed by numerous laboratories, those activities must take place according to the guidelines presented in the draft QASR. The draft QASR outlines the requirements for water quality sample and field data collection including pre-field activities, field measurements, field quality assurance, surface water sampling, ground water sampling, sampling of aquatic organisms, sediments/soils and pore water sampling, and post-field activities.

Standard methods will be well documented and accepted for laboratory analyses of environmental samples. All analytical work for the CERP must be performed by laboratories that maintain accreditation under NELAP. Additionally, all methodologies utilized must be accredited under NELAP for the duration of the program, must comply with Rule 62-160, F.A.C., and must be approved for use by the applicable regulatory program, such as the Clean Water Act (33 United States Code [USC] 1251) and Safe Drinking Water Act (42 USC 1316), when available. Guidelines are provided in the QASR for procuring laboratory services with reasonable assurance that all data generated will meet or exceed DQOs for the CERP and that data turnaround and timeframes for qualifying data are adequate.

It is recognized that, in all likelihood, the entities that are (or will be) conducting the monitoring activities for CERP will have an established, approved quality assurance manual according to NELAP (laboratory) or Rule 62-160, F.A.C. (field). Additionally, some of these entities may have (or will be using) laboratories that are certified under the NELAP.

4.3.5 Hydrologic Monitoring

The MAP will utilize the established QA/QC guidelines and standard protocols for hydrologic and meteorological data collection, such as water level, rainfall, structure discharge, etc., that are currently documented in Guidelines for the Collection of Hydrologic and Meteorological Data - Volume 1: Field Applications prepared by the St. Johns River, South Florida, Southwest Florida, and Suwannee River Water Management Districts (SJRWMD et al. 1994). Procedures for calibrating and using the wide variety of instruments that may be deployed to actually measure, record, and transmit these data are included in this document, as well as documentation and review of sensor or measurement devices to ensure that the sensor is capable of achieving the specified accuracy and precision. These guidelines will be incorporated into the CERP QASR Manual.

Standards are developed for the measurement of the following hydrologic parameters and take into account factors such as instrumentation; resolution; precision; accuracy; calibration/recalibration specifications; and field checks, datum, and collection frequency:

- Stage and water levels (headwater, tailwater, ground water, surface water)
- Rainfall - determining rainfall gage type, siting, measurement standards, inspection, and maintenance
- Solar radiation, air temperature, atmospheric pressure, water surface temperature, wind velocity, and relative humidity to compute evaporation and evapotranspiration
- Pan evaporation measurements and energy and mass transfer methods
- Computing evaporation and evapotranspiration values
- Flow or discharge necessary for accurate flood prediction and control and for management of water supply and water quality impact assessment, which must take into consideration velocity, cross-sectional area, and pump discharge
- Flow at control structures such as pump and gate operations

4.3.6 Biological Monitoring

Standard biological monitoring techniques that will be used in the implementation of the MAP will be obtained from either FDEP-established SOPs or peer-reviewed scientific literature for inclusion in the QASR. Nonstandard biological sampling and analysis methodologies will be selected from peer-reviewed published journals or reviewed and approved by the CERP QAO Team. In either case, the implemented sampling technique will be documented and recorded as a permanent component of the QASR to ensure consistency in the use of the methodology throughout the course of the monitoring program.

For biological monitoring, a QA/QC plan will be developed and submitted by each contractor or entity that will be collecting and analyzing the data that design and outline the study and provides published data to validate a method.

4.3.7 Remote Sensing

In order to ensure the consistency and compatibility of remote sensing data and derived products, remote sensing data acquisition, processing, mapping, and associated QA/QC and validation activities will be performed following the guidelines and standard protocols that will be described by the QASR manual that is currently under development.

The QASR manual will outline the requirements for remote sensing data collection and processing including acquisition, geospatial accuracy, processing/interpretation, training, ground-truthing, and validation/verification. The established standard methods and practice protocols that will be in the QASR will be developed for both spaceborne (i.e., satellite) and airborne data of different types of remote sensing technologies, such as panchromatic, multi-spectral, hyperspectral, high-spatial resolution, thermal, radar, LIDAR, etc.

Many standard QA/QC and validation/verification methods and procedures have been developed and widely used by many agencies and organizations for remote sensing data collection and utilization (e.g.,

land use and land cover mapping), especially for those traditional broadband remote sensing data that are commonly referred to as multi-spectral data such as SPOT, Landsat TM, USGS DQO, regular aerial photography, etc. The QASR manual will incorporate these requirements and will modify them to suit the needs and applications for the MAP. Examples of relevant documents include two USACE documents, Manual of Remote Sensing (USACE 2002a) and Photogrammetric Mapping (USACE 2002b), and two Federal Geographic Data Committee documents, Geospatial Positioning Accuracy Standards Part 1: Reporting Methodology (FGDC 1998) and Vegetation Classification Standard (FGDC 1997). For any new remote sensing technologies, such a LIDAR, and new applications that are emerging, evolving, or still under evaluation and experimentation, a custom-developed QA/QC plan will be needed for those special or non-standard needs for the MAP, following the general guidelines of recommended standards and procedures that will be outlined in the QASR manual.

4.4 DATA VALIDATION AND ASSESSMENT

Timely and accurate data assessment is necessary to ensure that both field and analytical activities produce data that meet the MAP's DQOs. Data assessment is conducted in tiers or levels and includes data verification, data validation, and data quality assessment (DQA). As the CERP monitoring efforts proceed, field and laboratory data will be validated and assessed, according to established DQOs and QA/QC criteria/standards, for acceptability, appropriateness, integrity, compatibility, comparability, and functionality (usefulness) to the monitoring and assessment program. Data verification and validation will be conducted using a checklist or other systematic approach. DQA procedures will be defined in the monitoring plans. In all cases, data verification, data validation, and DQA must be documented. Timely data assessments may reduce monitoring program costs because sampling and analytical problems can be corrected for future sampling or data collection events.

Water quality data validation consists of a standardized review process, using certain QC checks and analytical procedures, for judging the analytical quality and overall usability of a set of data. During the process, the "total error" or "total uncertainty" associated with a data set is determined. According to the "total uncertainty," the usability of a data set can be assessed in the context of the previously established DQOs. For hydrologic and meteorological data, a set of validation checks will be performed that includes data recorder name and location; period of record; minimum and maximum values (with any exceedance of valued flagged for investigation); and consistency in use of data units and significant numbers.

A DQA will then be conducted using the validated data set to determine if the quality of the data is satisfactory. This entails conducting a preliminary data review involving calculation of some basic statistical values (summary statistics) and examination of the data using graphical representations to identify patterns and identify relationships with other parameters (i.e., chloride, total dissolved solids and conductivity), confirm or disprove hypotheses, and identify potential problems (i.e., anomalies or outliers). The "structure" of the data can be understood, and appropriate approaches and limitations for using the data can be identified. The results of the review are then used to select an appropriate statistical test that will be used to draw conclusions from the data based on DQOs and verification of the key underlying assumptions of the statistical hypothesis test.

Ongoing/continuous assessment of the data being generated is needed to ensure the quality is good and decisions can be made to filter "unacceptable" data and prevent those data from being entered into the database without appropriate flags. Automated routines to perform "real time" assessment of data sets are currently under development. Only data that meet the established QA/QC criteria and DQOs will be incorporated into the CERP database. *The final decision on whether specific data fail QA/QC criteria and are therefore excluded from the database is made by the QAO Team.* Data will be made available to all users upon conclusion of the data assessment and validation process.

The draft QASR contains criteria for the review, interpretation, and acceptance of water quality data and provides guidelines for the QA/QC of this data. Guidelines are provided for data handling processes and frequency of data assessments; review of analytical runs and data reports from laboratories as well as field data and field note comments; qualifying data based on data qualifiers from Rule 62-160, F.A.C.; and handling data discrepancies and recommendations for and documentation on corrective actions.

To ensure hydrologic and meteorological data accuracy for this monitoring program, the SOPs and guidance outlined in Guidelines for Quality Control and Quality Assurance of Hydrologic and Meteorologic Data – Volume 2: Data Management (SJRWMD et al. 2000) prepared by the Florida water management districts will be used. The document contains detailed, well-documented management practices and general procedures for verification, validation, and correction of hydrologic and meteorological data collected through every means of data collection known by these agencies to be in practice as of 2000.

One of the primary components of an effective data management system is data validation. A set of prescribed procedures will be used to determine the validity of all data received into the data management system. Validation can vary from simple data collection location verification and maximum/minimum range-checking to robust, hard-coded business rule, automated data pre-processing. The difference between the two extremes is available resources. For small volumes of data, a system consisting of manual review of control information and random data value checking might be sufficient. For larger volumes of data, an automated system that performs a set of binary validation procedures based on a set of rigid business rules may be more efficient.

4.5 DATA MANAGEMENT

Another essential component of this system-wide monitoring program is the creation of an efficient and integrated data management system that can be used for storing, retaining, organizing, and accessing data generated by the MAP's proposed monitoring and research activities. This will ensure effortless and efficient retrieval and analysis to facilitate effective interpretation of CERP performance and ecosystem responses, production of periodic assessment reports describing and interpreting the responses, and evaluation of the overall success of the restoration effort.

The types of data that will likely be archived in the resulting environmental data management system include 1) geospatial (e.g., surveys, maps, aerial photography, aerial imagery, and modeling coverages), time series, and operations data with corresponding metadata and 2) technical documents (such as those that describe methods, conceptual ecological models, performance measures, costs, etc.). The data may either be existing and collected from multiple sources (federal, state and local government agencies, tribal governments, universities, and other entities) or generated from both the system-wide and project-level monitoring programs. Also, there is a considerable amount of data that continue to be generated from a number of ongoing monitoring and research programs that will also need to be acquired, organized, validated, formatted, and evaluated following appropriate protocols outlined herein. This information will be used to establish and characterize baseline conditions for the broad array of performance measures, identify monitoring and data gaps, and plan any additional monitoring and investigations to support the performance evaluation of the CERP.

It should be noted that the environmental data management system will be part of a centralized CERP shared data and information network infrastructure that will be managed by the CERP Data Management Program (SFWMD and USACE 2002, 2003). An implementation plan for CERP Environmental Data Management is underway and will be used by the CERP Data Management Program to define and procure the necessary information technology resources and services for the design, development, implementation, operation, and maintenance of a CERP environmental database system and associated

user interface tools. RECOVER will coordinate and provide guidance on a continuous basis with the CERP Data Management Program assisting with these efforts to ensure the system and tools are adequately tested, are successfully implemented, and meet user needs.

4.5.1 System Requirements

The environmental data management system requirements are currently being developed. Preliminary indications are that this system should include a relational-type database that includes geographic information system (GIS) and web-enabling technologies in order to meet the information and management decision needs of RECOVER. One of the highest priorities is to make information from all RECOVER and CERP project environmental programs available through the Internet. This would allow project managers, modelers, scientists, planners, management, other agencies, and the public to access a dynamic, map-driven interface via Web-based applications that are time- and space-relevant. The system should provide capabilities to handle high volume data files; conduct QA/QC, data checking, and validation processes; organize data and information for easy access; track fieldwork, samples, and lab analyses; and facilitate data exchange, interpretation, and reporting. The database, along with data analysis tools (i.e., browser tools and GIS views) will likely be accessible through a user-interface. This Web feature would allow posting of progress updates and communications, on-line document control, querying, and mapping. The system should facilitate electronic access to other information (i.e., modeling, socio-economic, costs, schedules, etc.) that may be necessary to assess CERP performance. The necessary infrastructure and software will be designed to eliminate the potential for security breaches (internally and externally) that could threaten the integrity of the system and the information it contains.

The system that is implemented to manage environmental data for the CERP will depend largely on the continued evolution of the scope of the MAP and on the monitoring requirements of the various CERP projects. Consequently, a flexible database architecture will be necessary to accommodate both uncertainty and change. The environmental database system will be continually maintained, quality assured, updated, and expanded as necessary with additional disk space, memory, and other system enhancements to optimize operational performance; meet the needs of the system-wide, regional, and project-level monitoring; and accommodate continuous acquisition, storage, analysis, and publishing of data.

4.5.2 Data Management Standards

Under the CERP Environmental Data Management effort, a set of standards, processes, procedures, and tools for acquisition, validation, organization, formatting, and archiving of monitoring and research data will be developed to ensure that data can be easily stored, accessed, retrieved, and transferred by all authorized users (SFWMD and USACE 2002, 2003). Common standards provide a natural system of indexing that will make data retrieval as simple as possible. The format in which data and metadata will be submitted must comply with standards set by the CERP Data Management Program so that they are compatible with and can be eventually loaded into the CERP environmental database. All new incoming data generated from the regional and project-level monitoring activities will be subjected to these requirements.

Some of the most common standard practices that will be used as a foundation for CERP environmental data management include the following:

- Having a standard for formatting electronic data files
- Using commonly known and used units of measurement for the types of data that are collected

- Applying scientifically-based, robust quality assurance and data validation procedures
- Using common and standard naming conventions for data collection locations
- Preserving and storing raw data values (to maintain purity of data and have means to reproduce it in raw form in the event the data is processed incorrectly)
- Applying quality control procedures to the database
- Adopting protocols for initiating change to the data content of the database
- Documenting data (metadata) to ensure that a common set of control information (e.g., site registration, global positioning satellite (GPS) coordinates, and horizontal/vertical data) is connected to the collected data

4.6 IMPLEMENTATION OF QA/QC AND DATA VALIDATION REQUIREMENTS

To ensure the QA/QC and data validation and management processes outlined above are implemented and carried out for each monitoring and research component of the MAP, several mechanisms will be put into place. Each component must have a monitoring plan that will lay out the logical order of activities, schedules, and approaches for accomplishing all tasks and objectives. The QASR will include a section specifically dedicated to QA/QC that must be developed in accordance with the requirements set forth in this document and approved by the QAO Team.

The monitoring plan will include a tactical plan on how the work will be accomplished with tasks and timelines established for field sample collection through preparation of assessment reports. The monitoring plan will be constructed to guide the actual execution of tasks, communicate essential aspects of the work to be carried out, and clearly define roles and responsibilities of participants. Detailed field monitoring SOPs and a QA/QC plan, consistent with the QASR requirements, will also be required as part of this work plan which describes steps to be taken to ensure consistency in monitoring effort and ensure linkage with QASR and other agreed upon protocols.

Additionally, specific language will be embedded in all contracts and agreements with entities that have been assigned to carry out the various pieces of monitoring and research for the MAP to ensure that there is compliance with the MAP's QA/QC, data validation, and data management requirements.

4.7 EVALUATION AND REPORTING

In addition to validation and management of the data, another key component that supports RECOVER's ability to interpret system responses in the context of restoration targets is the evaluation and reporting of the data. Data and information generated from the MAP are to be interpreted and assessed, with results reported on a periodic basis. The Adaptive Assessment Team, with assistance from the Water Quality Team, will have the lead role in determining the requirements for the data evaluation process for each of the performance measures and in determining the required formats for reports. A significant amount of time and resources will be required to synthesize, analyze, and publish all the data collected from this effort. The resources required to analyze the large volumes of data generated from this monitoring program and make such data available and understandable to management and other stakeholders as part of the adaptive assessment process are critical elements of a science program and must be explicitly planned and adequately funded.

Data evaluation is an essential prerequisite to the task of interpreting system responses. Through the data evaluation process, data generated by the monitoring and assessment program will provide baseline data and status and trends for each measure in a system-wide context, as well as information on the causal relationships that underlie these trends. The monitoring and assessment results will also be used to revise performance measures and restoration goals where needed (i.e., re-evaluate working hypotheses and the organization of the conceptual ecological models [see Appendix A]).

For this to happen, the data for each monitoring component must be carefully reviewed and analyzed according to protocols and methods that are consistent with the guiding hypotheses and the restoration targets. These data must be amenable (in terms of frequency, replication, etc.) to the types of statistical and other analyses envisioned to be employed for documenting changes in biota, water quality, and hydrology within acceptable limits of certainty. Data evaluation tools and methods will be determined, as will the resources, approaches (i.e., statistical), and time frames needed to compile and analyze large amounts of data and feed those assessments into the adaptive management process. Monitoring data will be presented in specified reporting formats that best illustrate the status and trends, patterns of variability, and probable responses to the effects of the CERP for each of the performance measures.

A detailed technical report will be submitted every three to five years as required under the Programmatic Regulations. The process for assessing the performance of the CERP for this report is described in Section 2.4. RECOVER will work with CERP Public Outreach to convert these technical assessment reports into formats effective for public consumption, selecting a subset of the indicators that are defined in the Performance Measure Documentation Report (RECOVER In prep) and that will be monitored and assessed through the MAP to create an annual CERP report card. Also, using a subset of indicators from the Performance Measure Documentation Report (RECOVER In prep), a CERP Interim Goals Report will be developed, as required under the Programmatic Regulations (DOD 2003).

4.8 REFERENCES

Ogden, J.C., A. McClean, K. Jacobs, P. Sime, T. Barnes, K. Havens, J. Trexler, F. Sklar, H. McSharry, J. Lorenz, D. Rudnick, L. Brandt, M. Duever, S. Newman, and B. Mills. 2003. Appendix 7B2: Draft Baseline CERP Annual Report Card. In: SFWMD, 2003. 2003 Everglades Consolidated Report. South Florida Water Management District, West Palm Beach, Florida.

DOD. 2003. Programmatic Regulations for the Comprehensive Everglades Restoration Plan; Final Rule. Federal Register, Volume 68, Number 218, pp. 64200-64249. Department of Defense, Department of the Army, Corps of Engineers, 33 CFR Part 385, November 12, 2003, Washington, D.C.

FGDC. 1997. Vegetation Classification Standard. Report number FGDC-STD-005, Federal Geographic Data Committee, United States Geological Survey and Department of Interior, Washington, D.C.

FGDC. 1998. Geospatial Positioning Accuracy Standards Part 1: Reporting Methodology. Report number FGDC-STD-007-1998, Federal Geographic Data Committee, United States Geological Survey and Department of Interior, Washington, D.C.

RECOVER. 2003. Draft Comprehensive Everglades Restoration Plan Quality Assurance System Requirements (QASR). RECOVER, c/o South Florida Water Management District, West Palm Beach, Florida.

RECOVER. In prep. RECOVER Performance Measure Documentation Report. RECOVER, c/o South Florida Water Management District, West Palm Beach, Florida.

SFWMD. 2002. Field Sampling Quality Manual. Water Quality Monitoring Division and Water Quality Analysis Division, Environmental Monitoring and Assessment Department, South Florida Water Management District, West Palm Beach, Florida.

SFWMD. 2003. Draft CERP Guidance Memorandum 20.0B - Agency Responsibility and Coordination for Quality Assurance. South Florida Water Management District, West Palm Beach, Florida.

SFWMD and USACE. 2002. Comprehensive Everglades Restoration Plan, Program Management Plan: Data Management. South Florida Water Management District, West Palm Beach, Florida, and United States Army Corps of Engineers, Jacksonville District, Jacksonville, Florida.

SFWMD and USACE. 2003. Draft Comprehensive Everglades Restoration Plan, Program Management Plan: Information Management. South Florida Water Management District, West Palm Beach, Florida, and United States Army Corps of Engineers, Jacksonville District, Jacksonville, Florida, June 2003.

SJRWMD, SFWMD, SWFWMD, and SRWMD. 1994. Guidelines for the Collection of Hydrologic and Meteorologic Data – Volume 1: Field Applications. St. John's Water Management District, Palatka, Florida; South Florida Water Management District, West Palm Beach, Florida; Southwest Florida Water Management District, Fort Myers, Florida; and Suwannee River Water Management District, Live Oak, Florida.

SJRWMD, SFWMD, SWFWMD, SRWMD. 2000. Guidelines for the Collection of Hydrologic and Meteorologic Data – Volume 2: Data Management. St. John's Water Management District, Palatka, Florida; South Florida Water Management District, West Palm Beach, Florida; Southwest Florida Water Management District, Fort Myers, Florida; and Suwannee River Water Management District, Live Oak, Florida.

USACE. 2002. Manual of Remotes Sensing. Remote Sensing GIS Center, United States Army Corps of Engineers Cold Regions Reach Laboratories (CRREL), Hanover, New Hampshire, December 2002 draft.

USACE. 2002. Photogrammetric Mapping. Report number EM 1110-1-1000, Corps of Engineers Directorate of Civil Works, United States Army Corps of Engineers, Washington, D.C.

5.0 IMPLEMENTATION STRATEGY FOR THE CERP MONITORING AND ASSESSMENT PLAN

5.1 INTRODUCTION

Under the REstoration COordination and VERification (RECOVER) Program, the Adaptive Assessment Team has the lead responsibility for developing and updating the Monitoring and Assessment Plan (MAP) design and provides guidance for its implementation. In addition, the Adaptive Assessment Team has the lead responsibility for using the information provided by the monitoring program to assess system responses. The magnitude and complexity of the MAP implementation effort combined with congressionally mandated reporting requirements necessitates that personnel assigned to this task be dedicated and focused on the missions to the greatest extent feasible.

The Comprehensive Everglades Restoration Plan (CERP) monitoring and assessment plan consists of numerous biologic, hydrologic, and water quality components. No single agency can carry out the full suite of monitoring tasks due to logistical challenges, budgetary constraints, and the distribution of interagency expertise. Although lead responsibility for funding and implementing this monitoring program is held by the United States Army Corps of Engineers (USACE) and the South Florida Water Management District (SFWMD), the success of the program will depend on the long-term participation of a number of South Florida agencies, tribal governments, and other stakeholders that are currently conducting monitoring programs in South Florida.

To assist in the development of an implementation strategy for the MAP, RECOVER staff reviewed other large-scale environmental monitoring programs ongoing in the United States to evaluate their success and to document lessons learned that may be applicable to the CERP. Among these was the Chesapeake Bay Monitoring Program (www.chesapeakebay.net/monprgms.htm), which demonstrated a centralized integration of federal, state, and local partners in monitoring program implementation. Key understandings from this program include 1) development and maintenance of a centralized data repository for data management and analysis and 2) development of standardized data collection protocols that are employed by all participating parties.

This chapter begins by outlining a preliminary implementation strategy for a monitoring and assessment program and specific concerns related to MAP implementation. Components of the implementation strategy essential for MAP implementation success are also identified. These components were determined through observations from other large-scale monitoring programs as well as interviews conducted with key personnel participating in RECOVER.

5.2 COMPONENTS OF A MONITORING AND ASSESSMENT IMPLEMENTATION PROGRAM

This section discusses those elements or functions that are necessary for successful MAP implementation including 1) data collection, 2) data management, 3) data analysis, 4) reporting, and 5) quality assurance (Figure 5.1). A description of what these functions generally entail and other important considerations is provided below.

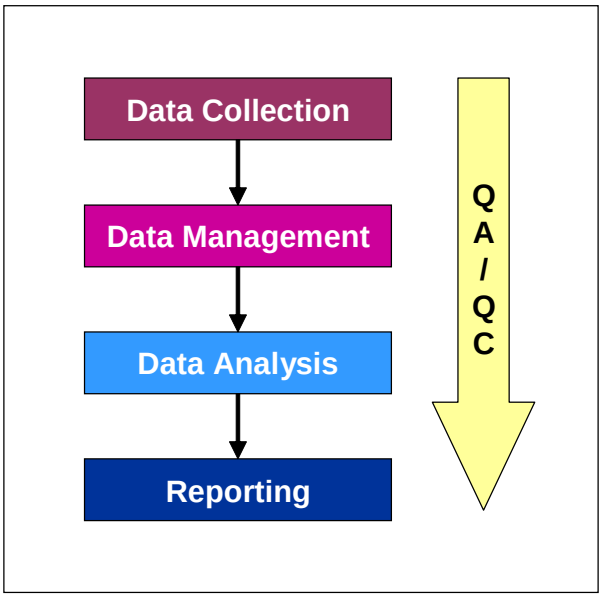


Figure 5-1: Components of Successful Monitoring Plan Implementation

5.2.1 Data Collection

Data collection is the first step in the sequence of activities involved in the implementation of a monitoring program. Data collection involves obtaining field measurements and/or samples of indicators from the ecosystem components being monitored. In some cases, data are obtained instantaneously from a direct field measurement at a particular point in space and time (e.g., in situ measurement of water velocity or dissolved oxygen concentration), whereas in other cases, data generation involves additional analysis of a measurement or sample collected in the field. For example, to measure the chlorophyll *a* concentration at a particular sampling station the collection of a water sample does not generate data until it is subsequently analyzed in a laboratory and the analytical result is recorded. Likewise, the collection of a sediment sample to assess benthic macroinvertebrate diversity does not generate data until the sample is processed by taxonomists. In these latter cases, there is a lag time between the field measurement or sample collection and data generation, and this secondary step is often referred to as data reduction.

Depending upon the accessibility of the ecosystem component involved, data collection can be relatively inexpensive or very costly. Accessing remote areas often requires specialized equipment (e.g., boats, helicopters, all terrain vehicles, etc.) and substantial staff resources. For some indicators, accessibility problems can be overcome by technology including telemetry and remote sensing; however, such technology is often costly to install and maintain and is subject to mechanical breakdowns and software failures.

For most indicators, specialized instrumentation and equipment may be required to obtain a measurement or collect a sample from a particular environment (e.g., benthic samplers, water quality datasondes, etc.). Furthermore, for some indicators, specialized training and expertise may be required. For example, the collection of wading bird tissue samples requires specific knowledge and experience in wading bird biology and pathology. Special permits may also be required to collect specimens from the populations of protected species or samples from highly sensitive habitats.

The various field data collection activities required under the MAP have variable costs and unique requirements. Integrating the responsibilities for these activities under a single entity poses a significant challenge.

5.2.2 Data Management

Data management is the second sequential step in the implementation of a successful monitoring program. Data management involves the transfer and storage of field measurements and sample data obtained from data collection activities. The major function of data management is to provide efficient access to the collected data and related information (e.g., historical trends data, research data, model outputs, data summaries).

The CERP Data Management System is being developed to accommodate management and retrieval of environmental data generated from all CERP activities including MAP implementation. RECOVER will work closely with CERP Data Management to ensure requirements are accurately documented and appropriate systems, interfaces, and data processes are developed. The interoperability of data assembled from multiple sources to support system-wide analysis is a common goal throughout CERP. Creation of a complete and useful inventory of CERP data and their respective metadata will be a key factor in locating appropriate data for the evaluation of project performance.

The amount and complexity of the data that are typically collected under large-scale environmental monitoring programs, and the variety of reports and analyses that are subsequently produced, necessitate a powerful computer-based data management system. To develop the CERP Data Management System, program managers need to define and select the appropriate data management system. They must determine the volume of data; the long-term uses of the data; existing data management capabilities; the number, backgrounds of, and relationships among users of the data; the major types of analyses to be conducted; and quality assurance/quality control and reporting requirements. This information will ensure the selection of a system with the necessary capacity and degree of access

5.2.3 Data Analysis

Data analysis is the third sequential step in monitoring program implementation. Data analysis involves the query and retrieval of data stored or accessible from a centralized data retrieval system, followed by the application of statistical and other analytical techniques to the retrieved data sets. The goals of data analysis are to summarize and simplify the collected data, test for change and differences, generate and examine premises and hypotheses, determine the consequences of observations, and evaluate the uncertainty associated with conclusions drawn from the data. Hypotheses and associated analysis programs should be developed prior to data collection. This development should include both statistical testing and modeling to ensure that the analytical approach is appropriate to the sampling design and the sampling methods.

According to the National Research Council (1990), successful data analysis programs provide the following functions: 1) cut across institutional and media boundaries; 2) partition spatial and temporal variations into their major sources (natural and human induced); 3) are based on an understanding of linkages among physical, chemical, and biological attributes; 4) use standard verified statistical and modeling software and data management systems; 5) state and determine the consequences of assumptions inherent in the sampling design and analysis approach; 6) evaluate the sensitivity of analyses to assumptions; and 7) summarize analysis results using easily understood graphs, maps, and tables.

Forecasting the responses to the implementation of the CERP and assessing trends with reliability presents a significant challenge to RECOVER. Simulation models represent an example of an assessment

tool that can be used to describe environmental complexities as well as forecast the consequences of environmental change. Proposed research for monitoring programs also represents a basic element in the development of predictive models and the interpretation and synthesis of monitoring data and model outputs and can be essential in establishing cause and effect relationships.

5.2.4 Reporting

Reporting is the fourth sequential step in the implementation of a monitoring program, and it represents a critical link to decision makers. The results of monitoring programs, especially regional programs, should be disseminated to a range of scientists, managers, and stakeholders that provide insight and guidance at different technical and managerial levels. Monitoring programs that produce only technical reports summarizing data and scientific findings are not likely to convey to the public or decision makers information essential to effective environmental protection and management. The ability to clearly communicate the results of data analyses to a broad range of audiences through multiple mechanisms will be critical to successful implementation of a monitoring and assessment program.

Many monitoring programs, especially studies addressing resource status and trends, extend over many years. Interim results of these studies should be disseminated regularly, allowing users to determine whether the type and volume of data that they need are being obtained. If the necessary information is not being obtained, mid-course adjustments can then be made to the monitoring program. Such monitoring strategy adjustments are essential to a successful adaptive management strategy. A phased analysis and reporting approach keeps target audiences informed about the value of information being collected, what data remain to be collected, what analyses remain to be completed, and why additional data collection and analyses are needed.

The Programmatic Regulations (DOD 2003) require preparation of a technical report by RECOVER at least every five years that presents an assessment of whether the goals and purposes of the CERP are being achieved, including whether interim goals and interim targets are being achieved or are likely to be achieved.

5.2.5 Quality Assurance

Quality assurance is a critical element of all monitoring programs (USEPA 1984). A quality assurance program is a system of activities undertaken to ensure that the type, amount, and quality of data collected are adequate to meet study objectives. Quality assurance measures must also be applied to data management, data analysis, and reporting activities to ensure monitoring program integrity.

As stated in Section 4 of this document, a CERP Quality Assurance System Requirements (QASR) manual is being developed under the sponsorship of RECOVER. The Quality Assurance Oversight Team will be the responsible party for implementation of the CERP QASR.

5.3 REQUIREMENTS OF MAP IMPLEMENTATION

The previous sections of this chapter provide a discussion of the five basic functions that RECOVER expects to incorporate into monitoring and assessment program implementation: 1) data collection, 2) data management, 3) data analysis, 4) reporting, and 5) quality assurance. Based on examples from other large-scale environmental monitoring programs (National Research Council 1990), as well as interviews conducted with key personnel from the USACE and SFWMD and other agencies potentially involved in MAP implementation, the following requirements have been identified as being essential for successful linkage of these five functions for the monitoring phase of MAP implementation.

- **Standard data and sample collection methods and protocols for all monitoring efforts.** Standard methods and protocols have been developed for most hydrologic and water quality data collection efforts; however, biological data collection methods and protocols are extremely variable. This variability is a function of both the wide range of biological research and monitoring activities proposed in the MAP and the multiple entities likely to be involved in these activities. To increase the comparability of biological data to be collected in the various watersheds and ecosystem components, biological data collection methods and protocols should be standardized to the greatest extent possible so that system-wide changes in response to the CERP can be assessed with a higher level of confidence.

- **A centralized and web-enabled data retrieval system that integrates both hydrologic and water quality data, as well as biological data applicable to the MAP.** It is essential that a complete and useful retrieval system for CERP data be centralized and maintained on a commonly accessible platform. The hardware/software platform for this retrieval system must be flexible, expandable, and upgradeable to keep pace with future technological advancements. Furthermore, to promote data sharing and public involvement, the database should be web-enabled with a user-friendly interface. These requirements are consistent with the CERP Program Management Plan for Data Management (USACE and SFWMD, 2002).

- **Rigorous, task-specific quality assurance procedures and protocols applied uniformly across all MAP implementation functions.** All existing quality assurance and quality control (QA/QC) requirements by individual agencies participating in the CERP and RECOVER must be met. The integrity of the MAP database is critical to the mission of RECOVER, and quality assurance is the process by which data integrity is achieved and maintained. Therefore, rigorous quality assurance procedures and protocols must be developed and applied consistently by all participants across all monitoring elements throughout the duration of the program.

- **Clear lines of communication and efficient coordination between personnel responsible for the five primary functions of MAP implementation.** The personnel involved in the five primary functions of MAP implementation must function as a single integrated management unit to the greatest extent possible to ensure the efficient and timely dissemination of information needed to support the CERP adaptive management strategy and other mandated reporting requirements.

5.4 MAP IMPLEMENTATION ORGANIZATION

Figure 5-2 depicts the management organizational structure currently proposed for implementation of the MAP. This structure provides an approach for RECOVER to implement the five basic functions of a successful monitoring and assessment program. Figure 5-2 shows the hierarchical relationship of this proposed functional management unit to RECOVER, the Adaptive Assessment Team, and the Water Quality Team. The proposed organizational unit also illustrates the linkage to the MAP module subteams.

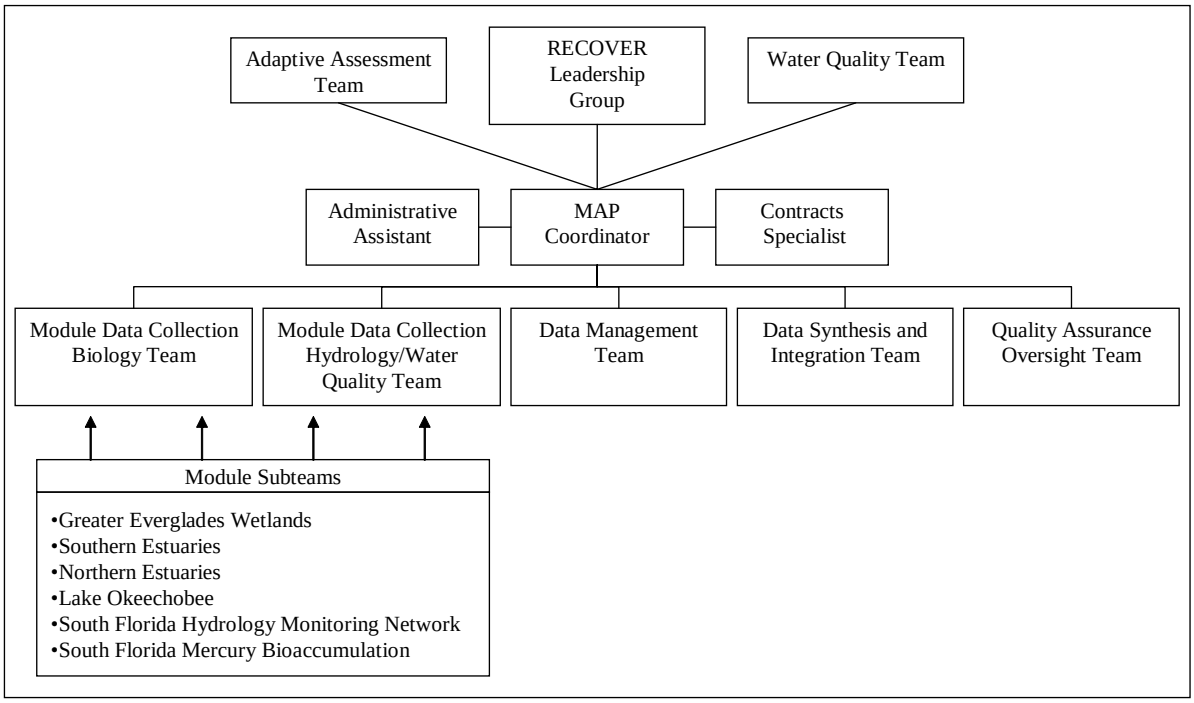


Figure 5-2: Conceptual Organization for the Implementation of the MAP

5.4.1 MAP Coordinator and Supporting Organization

At this time, RECOVER recognizes that an element critical to the success of MAP implementation will be the appointment of a senior level position that is responsible and accountable for the overall coordination and implementation of the MAP. This organizational approach will provide a clear line of authority and accountability for overall MAP coordination and implementation. This approach to MAP implementation is supported by the analysis and evaluation of potential MAP implementation options (EPJV 2003), as well as case studies from other large-scale environmental monitoring programs previously discussed. It is expected that the overall success of the CERP will require an efficient management unit with a responsive organizational structure in place to clearly define baseline conditions and to accurately assess ecosystem changes and CERP responses. Reliance on interagency coordination will likely not produce these results without strong centralized coordination.

The role of the MAP Coordinator is expected to ensure that there is overall consistency and standardization of processes, common systems and technology, and programmatic practices among the regional monitoring program participants. This includes the primary functions of program implementation discussed above. Ideally this position will be filled by someone with the following qualifications: 1) a graduate degree in an applicable field of environmental science; 2) extensive program management and administrative experience; 3) previous experience in the management of large-scale monitoring programs and applicable quality assurance requirements; 4) demonstrated capabilities in biostatistics, technical writing, and communications; 5) knowledge of database technology and applications; and 6) a keen understanding of the South Florida ecosystem. Perhaps most important is the ability to effectively coordinate a diverse group of agencies and contractors to obtain consensus on the development and

application of a system of standard methods, protocols, and quality assurance measures for MAP implementation.

Although the MAP implementation organization, as currently proposed, involves a strong centralization of data management, data analysis, and reporting functions, it is proposed that data collection activities be conducted largely through intra- and inter-agency agreements, as well as contractual arrangements with universities and private sector contractors. The various entities to be involved in the data collection activities in each of the regional modules would be determined on the basis of their particular areas of expertise, missions, traditional functions, and locally available resources.

It is important to note here that the implementation of the MAP is dependent upon data collected from a number of ongoing monitoring programs. Those relevant monitoring networks and programs are currently being identified in support of MAP data collection and meeting agency quality assurance needs.

5.4.2 Module Subteams of the Adaptive Assessment Team

CERP monitoring and research activities identified in the MAP can be divided into two distinct categories: biology and hydrology/water quality. The types of expertise and the methods and protocols required for the collection activities under the MAP coordination and implementation structure are expected to be segregated accordingly to maximize efficiencies. One approach, as shown in Figure 5-2, is for the biological and hydrology/water quality data to be collected under these two respective units, and the subsequent generated data to be integrated into the centralized MAP database, thereby ensuring the appropriate linkages for data analysis purposes. This approach would be complementary with the proposed multi-institutional monitoring and assessment subteams of the Adaptive Assessment Team, as described in Section 2, to coordinate implementation and quality assurance requirements of the monitoring and research projects for each of the modules presented in Section 3:

- Greater Everglades Wetlands
- Southern Estuaries (Florida Bay, Biscayne Bay, and Southwest Florida Coast)
- Northern Estuaries (Caloosahatchee Estuary, St. Lucie Estuary, Indian River Lagoon, Loxahatchee River Estuary, and Lake Worth Lagoon)
- Lake Okeechobee
- South Florida Hydrology Monitoring Network
- South Florida Mercury Bioaccumulation

Under this approach, each module will have its own sampling network designed by the module subteam, with consideration of compatibility and efficiency that can be derived from coordination with the other modules. Module subteams will ensure that implementation of specific monitoring components follows the overall program sequencing developed by the Adaptive Assessment Team and presented below. They will also compare the monitoring data requirements to the data already being collected to identify where existing efforts can be incorporated or modified to meet CERP monitoring and assessment needs.

Based on the MAP and additional supporting monitoring information from the Data Inventory Project, it is proposed that each module subteam will review monitoring statements of work, including estimated costs. Once the statement of work has been reviewed and approved by the Adaptive Assessment Team, the procurement process for the funding agency will be initiated. Submitted work plans are expected to include a strategy and complete descriptions for how the work will be accomplished so efficiency is

maximized, costs are minimized, and task completion is expedited. Each work plan is also expected to present the details on the deliverables and schedules for the various components of the program. Of particular importance will be consistent monitoring protocols and QA/QC guidelines and criteria. The work plan will be expected to guide the actual execution, communicate each essential aspect of the work to be carried out, and clearly define the roles and responsibilities of the participants.

5.4.3 Sequencing of Monitoring Components

The implementation of the currently proposed CERP Monitoring and Assessment Plan is expected to be phased in over a two-year period, with the initial focus on filling data gaps in the existing conditions data. Four goals were initially established to help provide a context for sequencing the monitoring components for fiscal year 2003 and fiscal year 2004, as listed below:

- Establish stations or projects necessary to measure all stressors identified in the simplified conceptual ecological models
- Close the gap of priority biological, hydrological, and water quality monitoring components from existing programs
- Initiate priority baseline research to address uncertainties in system response as determined by Adaptive Assessment Team members
- Initiate priority baseline monitoring components for MAP as determined by Adaptive Assessment Team members

Monitoring components and research topics that met these goals were incorporated into the draft MAP document. In an effort to utilize available funds from the SFWMD that had been authorized for implementation of MAP components in fiscal year 2003, monitoring components and research topics identified in the MAP were evaluated by Adaptive Assessment Team members for consideration as “fast track” items. The following criteria were used to establish “fast track” items for the MAP implementation:

- Provides necessary physical and chemical monitoring data
- Is required as a prerequisite for implementation of other monitoring activities
- Is identified as important scientific research required to support MAP hypotheses
- Provides information for filling gaps in existing biological, hydrological, and water quality data

Based on the results of the evaluation, a proposed list of “fast track” monitoring and research components were identified by the Adaptive Assessment Team as priority components and selected for early implementation under the direction of the SFWMD contracting and budget process. The following list represents the final selection of these “fast track” items:

- Greater Everglades Wetlands - Stratified Random Sampling Design
- Greater Everglades Wetlands - Interior Gradients of Flow and Nutrients - Statistical Design and Optimization of Transects and Sentinel Sites
- Greater Everglades Wetlands - Coastal Gradients of Flow, Salinity, and Nutrients

- Greater Everglades Wetlands - Tidal Creek Survey in Southwest Everglades
- Greater Everglades Wetlands - Support for Expansion of Spatial Soil Mapping
- Greater Everglades Wetlands - Supporting Research - Crayfish Population Dynamics and Hydrological Influences
- Southern Estuaries - Salinity Monitoring Network
- Southern Estuaries - Biological Availability of Organic Nitrogen in Florida Bay Phase I
- Southern Estuaries – Support for Large-scale SAV Remote Sensing
- Regional Hydrology Monitoring Network - Design Study Phase 1
- Regional Hydrology Monitoring Network – Elevation Data Collection for Water Conservation Area 1

RECOVER recognizes that there must be a method for selecting how best to sequence the implementation of the remaining MAP components. Those items that were identified in the initial sequencing of MAP components but were not selected for "fast track" implementation must be implemented in a logical manner. The sequencing of the remaining items must be further refined to ensure components that generate the most meaningful science and information for determining the success of CERP are implemented first in order to make the best use of available funds. For this reason, a method for evaluating each monitoring component and research topic within each module is being developed and applied. These criteria were developed for consideration by each module subteam and may be revised in the future. The list of criteria is provided below. Each monitoring component and research topic will be scored according to responses provided by module team members to the criteria. The monitoring components and research topics will then be grouped according to their total score. Tier 1 represents monitoring components and research topics with high importance and, therefore, high sequencing placement. Tier 2 represents monitoring components and research needs with medium importance, and Tier 3 represents those with lower importance.

5.4.3.1 Criteria for Evaluation of MAP Monitoring Components

The criteria presented below are representative only and may be modified in the future:

- Criterion 1 - Does the monitoring component address a critical issue in the regional conceptual ecological models?
- Criterion 2 - Does the monitoring component have the ability to discriminate between CERP and non-CERP effects?
- Criterion 3 - Is this the most cost-effective manner in which to execute the monitoring component?
- Criterion 4 - Does this monitoring component complement, leverage, or utilize relevant ongoing monitoring programs or initiatives?
- Criterion 5 - Is the monitoring component a keystone element in assessing restoration expectations?

- Criterion 6 - Is the monitoring component an intermediate link toward understanding why other important components have changed?

- Criterion 7 - Is there an adequate long-term record for the monitoring component?

- Criterion 8 - Does the monitoring provide supporting information for interim goal/interim target indicators?

- Criterion 9 - Does monitoring this component provide information that will be important to stakeholders in determining if the goals and objectives of the CERP are being achieved?

- Criterion 10 - Are data provided by this monitoring component necessary within: (1) 0-2 years, (2) 2-4 years, (3) 4-6 years, (4) more than 6 years?

5.4.3.2 Criteria for Evaluation MAP Research Topics

The criteria presented below are representative only and may be modified in the future:

- Criterion 1 – Does this research topic help to increase understanding of ecosystem response to CERP implementation?

- Criterion 2 – Does this research topic address an uncertainty identified in the conceptual ecological models?

- Criterion 3 – Does this research topic complement or improve the adequacy of a component of the monitoring program?

- Criterion 4 – Will the information generated from this research justify the cost?

- Criterion 5 – Does this research topic provide information that will be important to determining if the goals and objectives of the CERP are being achieved?

- Criterion 6 – Does the research topic lead to the identification and development of ecological attributes/indicators?

Implementation of the MAP relies upon continuation of numerous ongoing monitoring programs sponsored by federal, tribal, state, county, and other local agencies. While these ongoing monitoring programs currently meet needs and obligations of sponsoring organizations other than the CERP, they provide information vital to the data inventory of the CERP. Should sponsoring agencies encounter funding limitations, RECOVER will evaluate the need for continuation using the sequencing process described above.

5.4.4 Characterizing Existing Conditions

Prior to determining whether a change in condition or state has occurred, existing conditions will be established for each monitoring component. A key factor in establishing and evaluating existing conditions will be documenting and understanding the natural variability in the monitoring parameters. The extent of natural variability to the extent practical should be established prior to implementation of CERP projects. Additionally, influences from non-CERP anthropogenic stressors on system variability will need to be established.

Ongoing monitoring by other federal, tribal, state, and local agencies have generated data sets for some monitoring components. Existing data sets for monitoring components will be identified, and where those data sets meet minimum requirements for regional coverage, statistical validity, QA/QC, documentation, and accessibility, they will be used to establish existing conditions and analyzed for natural variability. Most existing conditions data sets apply primarily to hydrology and water quality monitoring components. Many biological monitoring components do not have adequate data at this time to establish existing conditions. Monitoring efforts implemented prior to CERP project construction will generate data sets that will provide information to describe existing conditions and estimates of variability for many of the biological monitoring components. This initial monitoring period will also allow an extension of the period used to establish the existing conditions of hydrologic and water quality components and to analyze the interactions of their variability with that of the biological components.

5.4.5 Progress to Date

The initial phase of the MAP development and implementation has focused on the following:

1. ***Formation of a MAP Implementation Strategy Subteam.*** The Adaptive Assessment Team established a subteam responsible for developing an approach to the sequencing of initial activities and to help facilitate the procurement process to ensure activities are initiated as scheduled and planned.

2. ***Designation of Fiscal Year 2003 Fast Track Items.*** As mentioned in Section 5.4.3, several high-priority monitoring components have been selected for early implementation. The Adaptive Assessment Team will expedite scopes of work for these monitoring components in order to begin monitoring activities to fill existing gaps in baseline data.

3. ***Formation of an Integrative Assessment Subteam.*** The Adaptive Assessment Team has established a subteam to begin development of the performance assessment section of the Assessment Guidance Memorandum. Sections of the Assessment Guidance Memorandum will be developed through subteam meetings, and a complete draft of the performance assessment section of the Assessment Guidance Memorandum is expected in January 2004. Performance assessments will examine a combination of historical baseline data, current monitoring data, and the use of modeling tools in a "weight of evidence" approach. The subteam has developed a strategy to scope a pilot modeling exercise used to identify an appropriate combination of modeling tools. The models selected during the pilot modeling exercise will be developed throughout 2004 in order to apply them to the 2005 performance assessment.

4. ***Preparation of a Monitoring and Assessment Plan Implementation Options Analysis Report.*** RECOVER, under a contract administered through the USACE, conducted an options analysis to assess the existing capabilities and resources of the lead agencies, as well as those of potential partner agencies to formulate alternative strategies for MAP coordination and implementation. This analysis focused on data collection, data management, data analysis, and reporting capabilities specifically applicable to the coordination and implementation of the MAP.

5. ***Development of an Environmental Data Management System.*** The CERP Data Management Plan is being revised to incorporate the necessary level of detail to accommodate a CERP Environmental Data Management Strategy and guide implementation efforts. A third-party consultant is developing an Environmental Data Management Implementation Plan to determine additional needs related to the data management plan.

6. ***Development of Quality Assurance System Requirements (QASR) Manual.*** The Adaptive Assessment Team and Water Quality Team established a subteam to develop a quality assurance requirements manual addressing all aspects of environmental monitoring efforts for the CERP. The water quality monitoring section is in its second draft and will be finalized in 2004. The biological monitoring and remote sensing sections are currently being developed with first drafts due in mid-2004. A second draft of the hydrologic monitoring section is due in early 2004. The QASR is a dynamic document that will be periodically updated as new monitoring requirements and techniques are developed.

5.5 REFERENCES

DOD. 2003. Programmatic Regulations for the Comprehensive Everglades Restoration Plan; Final Rule. Federal Register, Volume 68, Number 218, pp. 64200-64249. Department of Defense, Department of the Army, Corps of Engineers, 33 CFR Part 385, November 12, 2003, Washington, D.C.

EPJV. 2003. Monitoring and Assessment Plan (MAP) Implementation Options Analysis. Report by Everglades Partners Joint Venture to the United States Army Corps of Engineers.

National Research Council. 1990. Managing Troubled Waters – The Role of Marine Environmental Monitoring. National Academy Press, Washington, D.C.

Taylor, J.K. 1985. Principles of Quality Assurance of Chemical Measurements. NBSIR 83-3105, National Bureau of Standards, Gaithersburg, Maryland.

USACE and SFWMD. 2002. Central and Southern Florida Project Comprehensive Everglades Restoration Plan – Program Management Plan for Data Management. United States Army Corps of Engineers, Jacksonville District, Jacksonville, Florida, and South Florida Water Management District, West Palm Beach, Florida.

USEPA. 1984. Guidance for Preparation of Combined Work/Quality Assurance Project Plans for Environmental Monitoring. OWRS QA-1, United States Environmental Protection Agency, Washington, D.C.

APPENDIX A: DRAFT CONCEPTUAL ECOLOGICAL MODELS

TABLE OF CONTENTS

Acronyms		**A-v**
A.0	**Introduction**	**A-1**
A.1	**Everglades Ridge and Slough Conceptual Ecological Model**	**A-7**
A.2	**Southern Marl Prairies Conceptual Ecological Model**	**A-29**
A.3	**Everglades Mangrove Estuaries Conceptual Ecological Model**	**A-53**
A.4	**Big Cypress Regional Ecosystem Conceptual Ecological Model**	**A-79**
A.5	**Florida Bay Conceptual Ecological Model**	**A-99**
A.6	**Biscayne Bay Conceptual Ecological Model**	**A-117**
A.7	**Caloosahatchee Estuary Conceptual Ecological Model**	**A-143**
A.8	**St. Lucie Estuary and Indian River Lagoon Conceptual Ecological Model**	**A-171**
A.9	**Lake Okeechobee Conceptual Ecological Model**	**A-193**
A.10	**Loxahatchee Watershed Conceptual Ecological Model**	**A-235**
A.11	**Lake Worth Lagoon Conceptual Ecological Model**	**A-281**

ACRONYMS

C&SF Project	Central and Southern Florida Project
CERP	Comprehensive Everglades Restoration Plan
cfs	cubic feet per second
GIS	geographic information system
NSM	Natural System Model
Restudy	C&SF Project Comprehensive Review Study
PAR	photosynthetically-active radiation
ppb	parts per billion
ppt	parts per thousand
SAV	submerged aquatic vegetation
U.S. 1	United States Highway 1

A.0 INTRODUCTION

A.0.1 Applied Science Strategy

The Comprehensive Everglades Restoration Plan (CERP) team and the Science Coordination Team of the South Florida Ecosystem Restoration Working Group have adopted the "Applied Science Strategy" as a process for linking the sciences and management during the planning and evaluation of the South Florida ecosystem restoration programs (SCT 1997, Ogden et al. 1997, Figure A-1). The creation of a science application strategy was motivated by the need for a broadly accepted process for organizing and converting large amounts of existing scientific and technical information into planning and evaluation tools that would directly support the restoration programs. Some sort of organizing process is clearly required where restoration planning occurs on such large scales, where information from many disciplines is widely scattered in time and place, where focused efforts are needed in order to identify and fill gaps in our information base with "best professional opinion," and where a large degree of consensus regarding the major cause-and-effect relationships is necessary. To be successful, it was felt that this strategy must 1) lay out a scientifically reviewed sequence of steps and tasks for converting research and modeling results into planning objectives, performance measures and evaluation protocols, 2) serve as a strong catalyst for promoting consensus among scientists and managers regarding the nature of the principle resource issues, and the probable routes for resolving these issues, and 3) be a process that can contribute to the objectives and needs of both the scientific and management communities in the regional restoration programs. The Applied Science Strategy is a total systems and multidisciplinary process for determining the most appropriate restoration targets, and the best measures for each of these targets, during and following the implementation of the restoration programs. These tasks are prerequisite to the successful application of "adaptive assessment" during the implementation of the restoration programs.

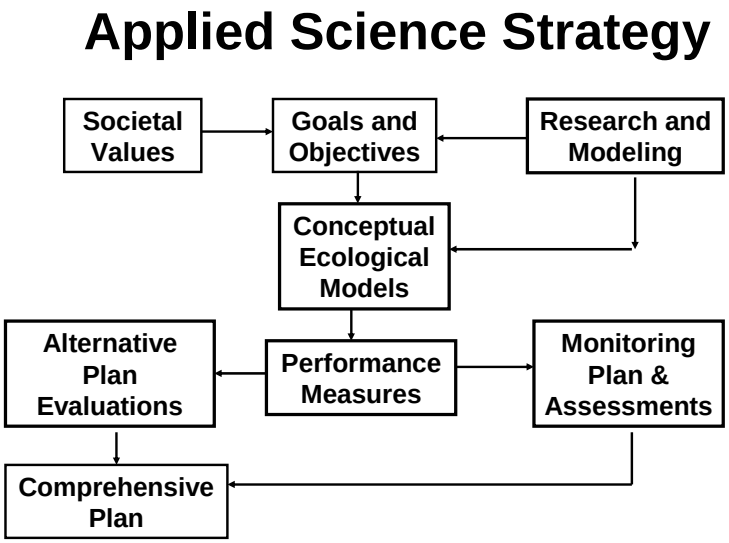


Figure A-1: Applied Science Strategy

A.0.2 Purpose

An essential step in the Applied Science Strategy is the creation of a set of conceptual ecological models of the major wetland physiographic regions in South Florida that will be directly affected by the CERP. The purpose of these models is not to show how ecosystems work, but rather to show how ecosystems are stressed and to identify the sources of this stress, and to be used as a guideline for establishing performance measures for stressors and attributes identified in the process. For this reason, they do not contain feedback loops.

These simple, nonquantitative models are an effective planning tool for developing a consensus regarding a set of causal hypotheses that explain the affects that the major anthropogenic stressors have on the wetland ecosystems. Each model identifies the attributes in the natural systems that are the best indicators of the changes that have occurred as a result of the stressors. Each model also delineates the ecological linkages between the stressors and the attributes and the most appropriate measures for each of the attributes. The development of a consensus regarding the components and linkages in the conceptual ecological models is the first step in the process of reaching agreement on specific hydrological, ecological, and biological measures of restoration success, and for designing a regional, performance-based ecological monitoring program. Conceptual ecological models have been widely used for similar purposes in other regions of North America (e.g., pp. 31-38 in Gentile 1996, also see Rosen et al. 1995).

This report presents eleven draft conceptual ecological models: 1) Everglades Ridge and Slough, 2) Everglades Southern Marl Prairies, 3) Everglades Mangrove Estuaries, 4) Big Cypress Regional Ecosystem, 5) Florida Bay, 6) Biscayne Bay, 7) Caloosahatchee Estuary, 8) St. Lucie Estuary, 9) Lake Okeechobee, 10) Loxahatchee Watershed, and 11) Lake Worth Lagoon (Figure A-2). A Total Systems Model is still being developed. These eleven regional models and the Total System Model provide a basis for developing performance measures for evaluating alternative restoration plans, for designing a performance-based monitoring program, and for adaptive assessment of the South Florida ecosystem restoration programs. The models will be revised as necessary to incorporate new information.

A.0.3 Development

The initial steps in the development of the first nine regional models were to use the informal format of workshops to identify and discuss the causal hypotheses that best explain the major anthropogenically driven alterations in each landscape. From these discussions, the participants created lists of the appropriate stressors, ecological effects, and attributes (indicators) in each landscape. The objective was to identify the physical and biological components and linkages in each landscape that best characterized the changes explained by the hypotheses. Preparers (model leads) for each model used the hypotheses and lists of components to lay out an initial draft of the model, and prepared a supporting narrative document to explain the organization of the model and the supporting science for the hypotheses. The drafts and narratives were reviewed in subsequent workshops, resulting in the models published in the March 2001 draft of the *CERP Monitoring and Assessment Plan* (RECOVER 2001). The drafts conceptual ecological models were also published in the March 2003 draft of the *CERP Monitoring and Assessment Plan* (RECOVER 2003a). The models have been revised by model leads in response to comments received on both draft and, in some cases, were updated to reflect revisions to performance measures made during the development of the Draft Performance Measure Documentation Report (RECOVER 2003b).

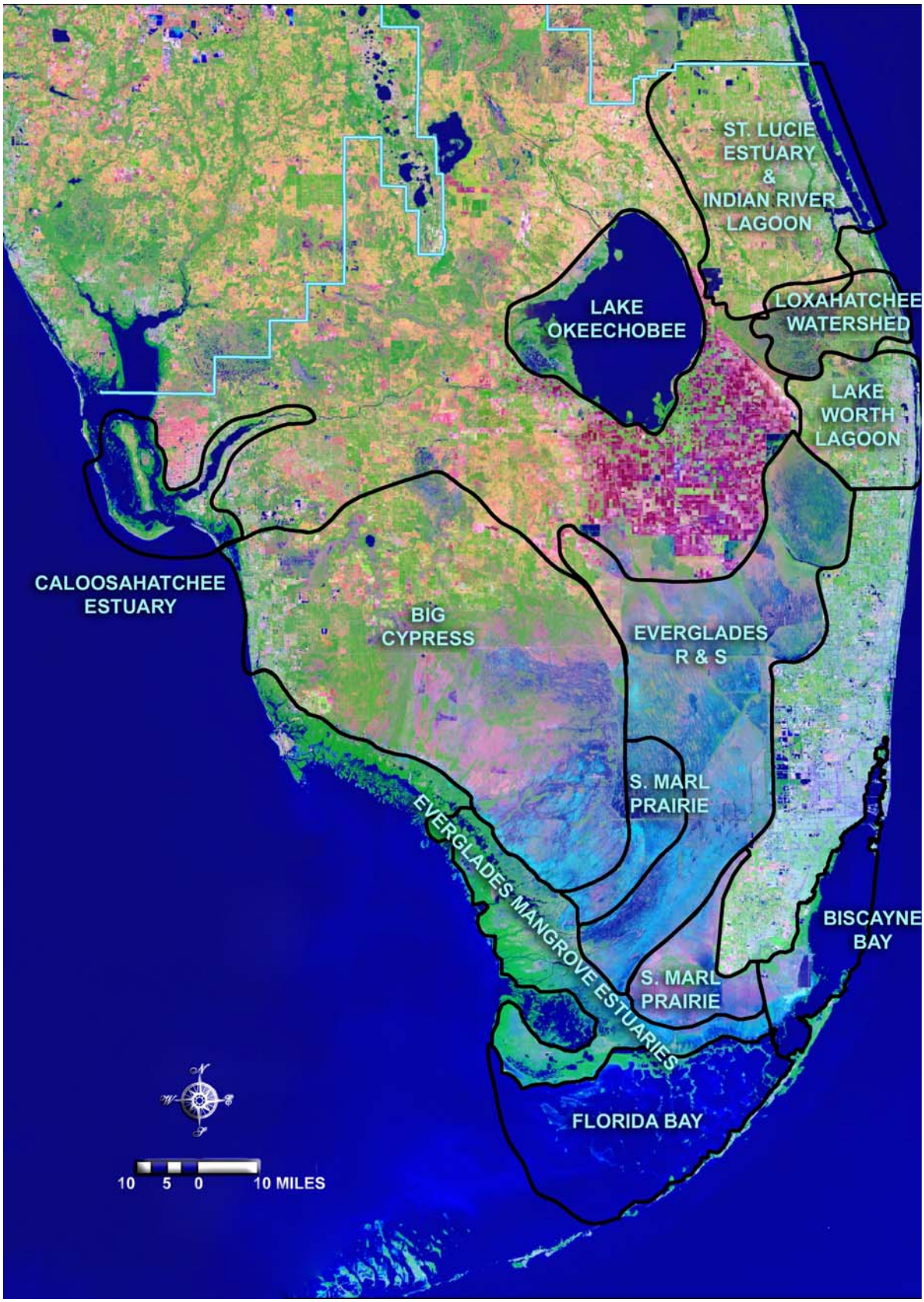


Figure A-2: Boundaries of the Eleven Conceptual Ecological Models

The remaining two conceptual ecological models, Loxahatchee Watershed and Lake Worth Lagoon, were fully developed after the publication of the March 2003 draft of the *CERP Monitoring and Assessment Plan* (RECOVER 2003a) in response to comments on that document. The Restoration Coordination and Verification's (RECOVER's) Adaptive Assessment Team reviewed and commented on these two models during summer 2003.

All of the conceptual ecological models presented within this document are drafts. The final versions will be published in a peer reviewed journal, along with the Total Systems Model, during 2004.

A.0.4 Format

A schematic diagram and a narrative description are provided for each conceptual ecological model. Each model narrative includes 1) a brief introduction to the dynamics and problems of the landscape, 2) descriptions of specific external drivers and ecological stressors, 3) a description of ecological attributes, 4) a discussion of the ecological effects the stressors and external drivers have on the attributes, including descriptions of the major ecological linkages affected by the stressors, and 5) an initial set of recommended performance measures for the attributes.

The schematic diagrams follow a top-to-bottom hierarchy of information that identifies the societal drivers (external sources), the specific stressors on the natural systems, the ecological effects resulting from the stressors, the recommended ecological attributes (indicators), and performance measures for each attribute. The symbols used in the models to indicate each of these model components are presented in Figure A-3.

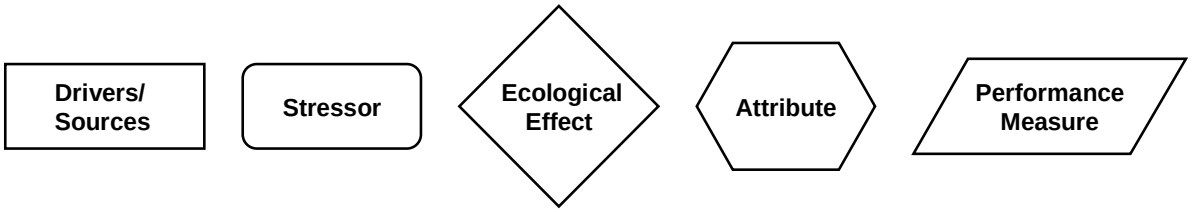


Figure A-3: Symbols Used in the Conceptual Ecological Model Diagrams

The major components of the models are defined as follows:

- **Drivers/Sources:** The major external driving forces that have large-scale influences on natural systems. Drivers can be natural forces (e.g., sea level rise) or anthropogenic (e.g., regional land use programs).

- **Stressors:** The physical or chemical changes that occur within natural systems that are brought about by the drivers, causing significant changes in the biological components, patterns and relationships in natural systems.

- **Ecological Effects:** The biological responses caused by the stressors.

- **Attributes:** A parsimonious subset of all potential biological elements or components of natural systems that are representative of the overall ecological conditions of the system. Attributes typically are populations, species, guilds, communities or processes. Attributes (also known as

indicators or endpoints) are selected to represent the known or hypothesized effects of the stressors (e.g., numbers of nesting wading birds), and the elements of the systems that have important human values (e.g., endangered species, sports fishing).

- **Performance Measures:** The specific feature(s) of each attribute to be monitored to determine how well that attribute is responding to projects designed to correct the adverse effects of the stressors (i.e., to determine the success of the project).

Each stressor is linked to one or more attribute. Measures of responses by the stressors and attributes in each model, and in all models combined, have been edited by a subgroup of the Adaptive Assessment Team and have been incorporated as the minimal set of components in the CERP comprehensive monitoring program for the purpose of determining the success of the restoration programs.

A.0.5 Literature Cited

Gentile, J.H. 1996. South Florida Ecological Sustainability Criteria. Final report from workshop, University Miami, Center for Marine and Environmental Analysis, Rosenstiel School of Marine and Atmospheric Science, Miami, Florida

Ogden, J.C., S.M. Davis, D. Rudnick, and L. Gulick. 1997. Natural Systems Team Report to the Southern Everglades Restoration Alliance. Final draft. South Florida Water Management District, West Palm Beach, Florida

RECOVER. 2001. Monitoring and Assessment Plan. Restoration Coordination and Verification, c/o Jacksonville District, United States Army Corps of Engineers, Jacksonville, Florida, First Draft, March 2001.

RECOVER. 2003a. Monitoring and Assessment Plan. Restoration Coordination and Verification, c/o Jacksonville District, United States Army Corps of Engineers, Jacksonville, Florida, Second Draft, March 2003.

RECOVER. 2003b. Performance Measure Documentation Report. Restoration Coordination and Verification, c/o South Florida Water Management District, West Palm Beach, Florida, May 29, 2003 draft.

Rosen, B.H., P. Adamus and H. Lal. 1995. A conceptual model for the assessment of depressional wetlands in the prairie pothole region. Wetlands Ecology and Management 3:195-208.

SCT. 1997. Integrated Science Plan. Report by the Science Coordination Team to the South Florida Ecosystem Restoration Task Force and Working Group (SFWRTF). Office of the Executive Director, SFERTF, Florida International University, Miami, Florida.

A.1 EVERGLADES RIDGE AND SLOUGH CONCEPTUAL ECOLOGICAL MODEL

A.1.1 Model Lead

John C. Ogden, South Florida Water Management District

A.1.2 Introduction

In its pre-drainage condition, the ridge and slough portion of the Everglades was an expansive, long-hydroperiod, freshwater marsh, characterized by low-velocity "sheet flow", moderate-to-deep organic soils, and alternating sawgrass “ridges” and more open-water “slough” communities (Davis et al. 1994, Gunderson 1994, Gunderson and Loftus 1993, Olmsted and Armentano 1997, Browder and Ogden 1999). The ridge and slough systems were dominated by sawgrass (*Cladium*), water lily, and “wet prairie” species (*Eleocharis* and *Rhynchospora*) communities. A spatially variable mosaic of discreet hardwood hammock, bay head, and willow tree islands occurred throughout, ranging from widely spaced in the central Everglades to more densely distributed in the Loxahatchee basin and Shark River Slough. The ridge and slough system modeled here (Figure A-4) is that portion of the Everglades basin where there are Loxahatchee or Everglades Peat soils (the combined “wet prairie/slough, tree island, sawgrass mosaic” and “sawgrass dominated mosaic” in Davis et al. 1994). The ridge and slough system makes up the deeper central portion of the total Everglades basin. On a much smaller scale, ridge and slough systems occur on both the eastern and western flanks of the Shark Slough in the southern Everglades (e.g., Taylor, East, Middle, Lostman's Sloughs). These sloughs are within the boundaries of the Southern Marl Prairies Conceptual Ecological Model (Section A.2), but are ridge and slough systems, not marl prairie systems. The ridge and slough Everglades was the principal center for primary and secondary production and interannual survival of aquatic organisms in the pre-drainage, freshwater wetlands of southern Florida.

The major, known changes in the ridge and slough systems have been caused by modern land use practices, and by drainage and water management programs in South Florida (Davis and Ogden 1994, Science Subgroup 1993). The stressors resulting from these regional “drivers” include reduced spatial extent, compartmentalization and reduced sheet flow, loss of organic soils, altered water depth, distribution and flow patterns, altered water and soil chemistry, and the introduction of exotic species. It is the effects from these “stressors” that are modeled in the conceptual ecological model for the ridge and slough system.

A.1.3 External Drivers and Ecological Stressors

During the workshops to develop the Everglades Ridge and Slough Conceptual Ecological Model, four major sources of societal influences (drivers) on the Everglades ridge and slough systems were identified: urban and agricultural expansion, influences from industrial and agricultural practices, water management practices, and cultural influences on species composition. These drivers lead to five major ecosystem stressors: reduced spatial extent, degraded water quality, reduced water storage capacity, compartmentalization, and exotic species. The combined effects from these stressors explain much of the ecological changes that have occurred in the ridge and slough system (Figure A-6, Section A.1.9). The four societal drivers, their respective stressors (bold face in text), and the ecological significance of the prestressed condition in the natural system, are discussed below.

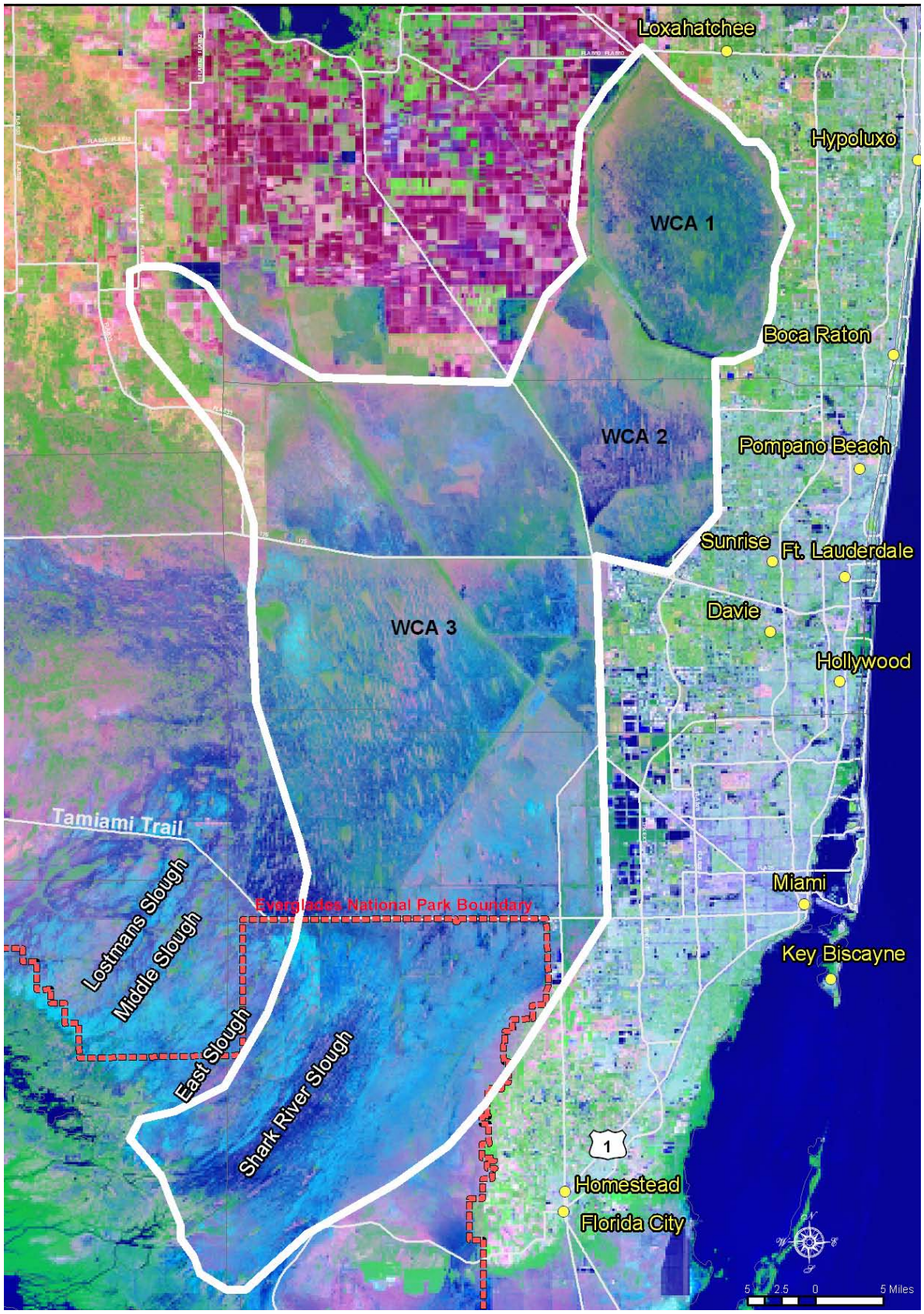


Figure A-4: The Boundary of the Ridge and Slough Conceptual Ecological Model

A.1.3.1 Urban and Agricultural Expansion

Drainage of wetlands and the subsequent conversion of ridge and slough habitat into agricultural and urban uses have **reduced the total spatial extent** of the ridge and slough system in the main Everglades from 490,000 hectare in the pre-drainage system to 365,000 hectare in the current system (Davis et al. 1994). Space was the one physical characteristic of the South Florida wetlands that was necessary for all other physical and ecological components of these systems to be in place. The broad spatial extent of the pre-drainage ridge and slough system was essential for collecting and storing the amount of regional rainfall that was required to maintain the ecological vigor of these systems (Davis and Ogden 1994, Ogden et al. 1999). Large spatial extent provided the foundation for the processes that created and maintained a mosaic of habitats in a low profile terrain (Craighead 1971, DeAngelis and White 1994). Disturbances, such as fire, freezes, tropical storms, and animal related impacts (e.g., an abundance of alligator created ponds and trails), served to increase the complexity of habitats, as well as the range of habitat choices for species of wildlife with either small or large home ranges (Craighead 1968, DeAngelis 1994, Duever et al. 1994, Gunderson and Snyder 1994, Davis and Ogden 1994). Extensive space was necessary for supporting robust numbers of animals requiring extensive feeding and hunting ranges during different seasons and a range of hydrological conditions. For example, the location of feeding and nesting sites for white ibis and other wading birds, snail kites, and other common aquatic birds shifted across large spatial scales, across seasons and years, in response to variability in hydrological patterns (Kushlan 1979, Bennetts et al. 1994, Hoffman et al. 1994, Ogden 1994). The large number of ponds and depressions occurring over an extensive region allowed for comparatively sedentary species such as the alligator to maintain very large regional numbers (Craighead 1968). Greater space enabled the system-wide aquatic production in a nutrient-poor ecosystem necessary to support large numbers of wading birds and alligators (Browder 1976, Mazzotti and Brandt 1994).

A.1.3.2 Influences from Industrial and Agricultural Practices

Another stressor on the Everglades ridge and slough system is **degraded water quality**. Increased loads of phosphorus and mercury, originating as by-products from an array of agricultural and urban industrial practices, were identified as the two alterations in water and soil quality that have been demonstrated or hypothesized, respectively, to have had the greatest ecological significance in the ridge and slough systems (Roelke et al. 1991, Spalding and Forrester 1991, Lange et al. 1994, Browder et al. 1994, Davis 1994, Frederick et al. 1997, Fink and Rawlik 2000).

The pre-drainage ridge and slough Everglades was a shallow, clear-water, low nutrient system (Davis et al. 1987, SFWMD 1992). Aside from fire and infrequent frosts, the unique vegetation of the Everglades evolved in response to both low-nutrient water quality conditions and the seasonal fluctuations of water levels. Gleason and Spackman (1974) described a periphyton community in the northeastern Everglades that may be a remnant of a more widespread community prior to the impacts of elevated phosphorus levels. This is a noncalcareous periphyton (less than 10 percent calcium carbonate) community that is rich in desmids, a type of green algae found most abundantly in low-mineral, oligotrophic waters. Although the dynamics of mercury in the pre-drainage Everglades are poorly known, the level of total mercury in Everglades peat soils was about one-sixth the level found during the 1990s (Fink and Rawlik 2000).

A.1.3.3 Water Management Practices

All five of the major ecological stressors acting on the ridge and slough systems, **reduced spatial extent**, the introduction and spread of **degraded water**, **reduced water storage capacity**, **compartmentalization**, and the introduction and spread of **exotic species**, have had part or all of their origins in water management practices. Major objectives of water management have included water supply and flood control, which have been achieved by means of a complex system of structural and

operational modifications to the natural system. These modifications have 1) contributed to the substantial reduction in spatial extent, 2) provided a network of canals and levees that have accelerated the spread of degraded water and exotic species, 3) greatly reduced the water storage capacity within the remaining natural system, 4) created an unnatural mosaic of impounded and overdrained marshes in the Water Conservation Areas, and 5) substantially disrupted natural patterns of sheet flow direction, location and volume (SFWMD 1992, Science Subgroup 1993, Davis and Ogden 1994, Light and Dineen 1994, Fennema et al. 1994).

The pre-drainage ridge and slough Everglades was a single, hydrologically integrated system, with water depth and distribution (temporally and spatially) largely determined by seasonal and annual rainfall, evaporation, transpiration, natural topography, outflow through natural streams into the ocean, and the system's capacity for surface and ground water storage of water (SFWMD 1992, Fennema et al. 1994). A key feature of the pre-drainage system was its large water storage capacity for extended periods of time, resulting in a system that was much wetter (but not necessarily deeper) than the current system. Water storage was facilitated by the natural damming effects of the east coast ridge and downstream coastal embankments, the large spatial extent of the system, the sponge-like properties of the peat soils, and the slow flow rates through the extensive marshes. As a result, the pre-drainage Everglades sloughs maintained multiyear surface water hydroperiods throughout the deeper, central marshes and along the downstream, marsh-mangrove ecotone, and extensive, shallow water "edges" that varied both spatially and temporally among seasons and years. The depth, distribution, and duration of surface flooding in this environment largely determined the vegetation patterns, as well as the distribution, abundance and seasonal movements and reproductive dynamics of all of the aquatic and many of the terrestrial animals in the Everglades (Kushlan 1989, Davis and Ogden 1994, Holling et al. 1994, Walters and Gunderson 1994).

A.1.3.4 Cultural Influences on Species Composition

The introduction, both intended and unintended, of large numbers of **exotic species** of plants and animals that have been considered desirable from the perspective of a wide range of human values, has resulted in regions of enhanced recreational fishing, localized shifts in fish community structure, loss of tree island habitat, and changes in marsh plant community structure. These changes are due to the interaction of nonnative species with changes in habitat, water quality, and hydrology. Although large areas of the ridge and slough are still considered "pristine," if current trends continue or if vegetation management funds do not increase there may be substantial impacts locally and regionally to the ridge and slough landscape pattern, food web dynamics, and genetic biodiversity. Cultural impacts condidered most likely to require both monitoring and assessment include a) invasions by *Melaleuca*, *Schinus* and lygodium, and b) the distribution of nonnative fishes (Thayer et al. 2000, Loftus 1990, Loftus and Kushlan 1987, Goodyear 2000).

A.1.4 Ecological Attributes

The Everglades ridge and slough model workshops recommended seven biological attributes of the ridge and slough systems that collectively, will provide the best measure of system responses to restoration projects (Figure A-6, Section A.1.9). The model shows how each attribute is linked to one or more stressors. The recommended measures for each attribute should be treated as priority components for a system-wide ecological monitoring program designed to measure the success of the CERP.

A.1.4.1 Peat Soils

The prevailing soils of the ridge and slough systems are Loxahatchee and Everglades peats, which are hydric soils created by depositions of decayed aquatic plants (e.g., *Nymphaea*, *Pontederia*, *Utricularia*,

Sagittaria, and *Cladium*). Peats are indicators of prolonged flooding, characterized by 10 to 12 month annual hydroperiods, and ground water that only uncommonly dropped more than one foot below ground surface (Tropical BioIndustries 1990). Soil accretion rates for peats in the pre-drainage system were estimated at 7.5 centimeters per 100 years.

Losses of peat soils of a few centimeters up to a meter have occurred widely in the ridge and slough Everglades, beginning with the earliest water management practices (Stober et al. 1996, Sklar et al. 2000). Shortened hydroperiods and lowered ground water levels in the ridge and slough system have caused extensive desiccation of soils. The overdrained soils have been lost through oxidation, and increased frequencies and intensities of fires (especially during dry seasons). Loss of soils has substantially altered hydrological gradients, microtopography and flow patterns, increased surface concentrations of phosphorus, and contributed to changes in the structure and distribution of plant communities.

A.1.4.2 Periphyton

The species composition of the microalgal mats in the ridge and slough Everglades is broadly controlled by water depth, duration of surface flooding, and water chemistry (Browder et al. 1994). These algal mats are highly important as a food web base, and for oxygenating the water column. Communities of green algae and diatoms may be especially important to periphyton grazers.

Water management practices and changes in water chemistry including increased levels of total phosphorus have changed the spatial distribution and species composition of the periphyton mats (Browder et al. 1994, Davis 1994). Water management practices have shortened hydroperiods in some areas and increased water depths in other areas. Shortened hydroperiods cause a reduction in the proportion of diatoms and green algae, and an increase in calcareous blue-green algae, thus reducing the food value of periphyton, and affecting the overall productivity of the Everglades. In nutrient enriched areas, species characteristic of low-nutrient waters are replaced by filamentous species.

A.1.4.3 Marsh Plant Communities

The pre-drainage Everglades ridge and slough system was a network of discreet sawgrass (*Cladium*) strands (ridges) and more open water sloughs dominated by water lilies (*Nymphaea*), spikerush (*Eleocharis*), and beakrush (*Rhynchospora*) (Gunderson 1994, Gunderson and Loftus 1993). It has been hypothesized that flow volumes in the pre-drainage ridge and slough system were largely responsible for maintaining the sharply discreet community and elevation differences between the ridges and sloughs (Sklar et al. 2000). The sloughs, deeper than the ridges, were the primary refugia for aquatic animals during dry periods, and were the most important wading bird foraging habitats in the Everglades.

The reduced water storage capacity of the managed Everglades, and the compartmentalization of the northern and central ridge and slough system, have slowed flow rates, have created areas that are either overdrained or are more deeply flooded than was the case in the pre-drainage system, have substantially altered the affects of fire on the marsh communities, and have altered the rates and magnitude of flooding and drying events. As a result, sawgrass has invaded sloughs and wet prairies, beak rush communities have been lost, woody plants have invaded marsh communities, and the extent and species composition of marsh communities has become extensively altered (Kolopinski and Higer 1969, Davis et al. 1994, Sklar et al 2000). Substantial increases in levels of total phosphorus in water and soil have converted both ridge and slough communities into extensive beds of cattails (*Typha*).

A.1.4.4 Tree islands

Discreet hardwood tree and shrub islands are a conspicuous feature of the Everglades ridge and slough system. Depending on elevation, these islands are dominated by swamp hardwoods (e.g., *Acer*, *Salix*, *Persea*, and *Annona*) or upland temperate and tropical species (e.g., *Ficus*, *Celtis*, *Eugenia*, *Mastichodendron*). Gawlik and Rocque (1998) found that tree islands support more species of birds than any other habitat in the central Everglades. Because the maximum elevations of the highest tree islands are only slightly above mean annual maximum water levels, tree islands with their less flood tolerant vegetation are the most sensitive component of the Everglades ridge and slough systems to changes in hydrology (Van der Valk et al. 1998).

Water management practices have substantially impacted Everglades' tree islands (Van der Valk et al. 1998, Sklar et al. 2000). An increase in the frequency and duration of unnatural high water events during wet seasons and an increase in the frequency and intensity of fire during dry seasons has damaged or destroyed many tree islands. The number of tree islands in Water Conservation Area 3 declined from 1,041 to 577 between 1940 and 1995 (Patterson and Finck 1999, Sklar et al. 2000). For this same period, the total spatial extent of tree islands in Water Conservation Area 3 declined by 13,527 acres (61.5 percent).

A.1.4.5 Marsh Fishes, Invertebrates, and Herps

The Everglades ridge and slough systems were the most important centers of secondary production in the freshwater marshes of South Florida. In addition, the deeper, open sloughs were the principal refugia for fishes and aquatic invertebrates during low water periods, and were the places in the Greater Everglades where great numbers of wading birds concentrated to forage during dry seasons (Loftus and Eklund 1994, Hoffman et al. 1989, Kushlan 1986).

The total abundance (numbers and biomass) of fishes, crayfish, grass shrimp, frogs, and turtles in the ridge and slough system has been greatly reduced due to the combined affects of reduced spatial extent of total wetlands, increased frequencies and durations of dryouts in remaining wetlands, altered water recession rates, and possible reductions in secondary production associated with shifts in periphyton composition (Loftus and Eklund 1994, Trexler and Jordan 1999, Browder et al. 1994).

A.1.4.6 Alligators

The American alligator is a keystone species in the Everglades basin. Alligators create trails and ponds that become important wetland corridors and refugia during low water periods. They are top level predators that greatly influence the size classes, distribution, and abundance of marsh animals. Alligators were abundant in the pre-drainage Everglades. Highest numbers and densities in the pre-drainage system apparently were in the broad marl prairies that flanked the southern ridge and slough Everglades, and in the inner, "freshwater" mangrove forest zone downstream from the southern Everglades (Craighead 1968).

In the modern Everglades, alligators are most numerous in the remaining ridge and slough systems (Craighead 1968, Mazzotti and Brandt 1994). It is hypothesized that alligator numbers have been greatly reduced in the marl prairies because of overdrainage and substantially lowered ground water levels (especially during dry seasons). Numbers have been reduced in the lakes and streams of the mainland mangrove forest because of reduced freshwater flow from the Everglades and the resulting higher salinities in these waters. Conversely, alligators may have increased in some portions of the ridge and slough systems (particularly Shark River Slough) where management practices have lowered wet season depths, thereby increasing the extent of suitable, shallowly flooded nesting and foraging habitat.

Improved conditions for nesting have not occurred in all portions of the remaining ridge and slough systems, particularly in Water Conservation Areas 2 and 3 where compartmentalization has caused unnaturally deep water in the southern "conservation" areas and overdrained conditions in the northern areas. Alligators have also suffered in the managed system because of increased frequencies of nest flooding caused by impoundments and regulatory flows, reduced survival of juveniles in canals during low water periods, and poor rates of growth and development due to reduced prey populations in overdrained marshes (Jacobsen and Kushlan 1984, Kushlan and Jacobsen 1990).

A.1.4.7 Wading Birds

The large numbers of wading birds that once nested in the Everglades basin was one of the most defining features of the region. The largest and most persistent wading bird nesting colonies in the pre-drainage Everglades were located at the southern edge of the ridge and slough system along the marsh/mangrove ecotone at the lower end of Shark River Slough, and in the downstream mangrove region (Ogden 1994). It is hypothesized that the unusually large "super colonies" (nesting numbers greater than one standard deviation in excess of the long-term annual mean; Frederick and Ogden in press) that periodically formed in the historical Everglades were a response by wading birds to extreme peaks in prey abundance created in the system by the affects of multiyear wet and dry cycles (Frederick and Ogden 2001).

Wading birds in the current managed system have shown a 75 to 90 percent reduction in the number of nesting birds compared to 1930s numbers (primarily by snowy egrets, tricolored herons, white ibis and wood storks), have relocated colonies away from the estuaries and into the impounded central and northern Everglades, and for white ibis and wood storks, have altered the timing of nesting compared to historical patterns (Ogden 1994). The percentage of wading birds nesting in and adjacent to the southern ridge and slough system in southern Everglades National Park has declined from greater than 90 percent during the 1930s to less than 5 percent for 1996-1999 (Gawlik 1999). The vast majority of wading birds now nest in the Water Conservation Areas.

It is hypothesized that the reduction in number of nesting birds is largely due to a substantial decline in the abundance and availability of the aquatic prey base, caused by water management practices that have overdrained substantial portions of the remaining sloughs, and have altered the location, seasonal timing and magnitude of high water and low water events, relative to traditional colony locations. These hydrological changes have served to alter the location and timing of the centers of prey concentrations in the system. For animals such as wading birds, which operate over large spatial scales, compartmentalization and peripheral drainage have combined to convert a single, expansive wetland system into several, much smaller and hydrologically independent systems. Levees and canals have replaced shallowly flooded marsh edges with more deeply flooded marsh along levee slopes.

A.1.5 Ecological Effects

Critical Linkages between Stressors and Attributes/Working Hypotheses

The ecological effects of the five principle stressors in the Everglades Ridge and Slough Conceptual Ecological Model are based on seven key hypotheses developed during the conceptual ecological model workshops. These hypotheses build on earlier Everglades' hypotheses presented in Davis and Ogden (1994) and Ogden et al. (1999). These seven hypotheses determine the content and organization of the Everglades Ridge and Slough Conceptual Ecological Model. The seven hypotheses are presented here, organized by stressor.

A.1.5.1 Reduced Water Storage Capacity

The ridge and slough Everglades has lost much of its original capacity to store natural volumes of water due to the reduction in the spatial extent of marshes. Two hypotheses have been developed for this effect.

Wet Season

Greater than historical (pre-drainage) water depths occur in the ridge and slough system when the spatial extent of natural wetlands (and of man-made water storage areas) is insufficient to hold and distribute the wet season and/or wet year volumes of water that enter the system either as rain or surface flow. As a result of this reduction in region-wide storage capacity, water becomes "stacked" to unnatural depths in the marshes during wet seasons and wet years. Increased wet season/wet year depths leads to flooding of tree islands, loss of shallow feeding habitat for wading birds, altered and stressed periphyton communities (reduced light penetration), flooding of alligator nests and reduced quality of alligator feeding conditions, and altered species composition and size classes of fishes.

Dry Season

Greater than historical (pre-drainage) frequencies and durations of marsh dryouts occur in the ridge and slough system when the spatial extent of natural wetlands (and of man-made water storage areas) is insufficient to hold the wet season and wet year accumulations of water into the following dry season and dry years, respectively. As a result, water is not available to maintain marsh and ground water levels during dry periods. Increased frequencies and durations of dryout leads to increased rates of loss of organic soils due to increased fire and oxidation, spread of woody vegetation into marshes, reduced survival of fishes, small herps, and aquatic invertebrates, altered periphyton communities (diatoms/greens to blue-greens), reduced alligator nesting effort (dry marshes during courtship period), and expansion of sawgrass into slough communities (i.e., a degradation of the discreet ridge/slough mosaics).

A.1.5.2 Compartmentalization

The ridge and slough Everglades have been converted from a single, hydrologically integrated ecosystem to a collection of hydrologically independent systems (SCT 2003). This change was brought about by the current network of internal levees and canals, and the water management operational criteria that were established for each discreet compartment. Two hypotheses have been developed for this effect.

Effects of Levees

Internal levees have disrupted the directions, timing and rates of sheet flow, and have created mosaics of shallowly and deeply flooded marshes that are unnatural in location, juxtaposition, and in the duration and depths of flooding. Reduced rates of sheet flow have contributed to the leveling of pre-drainage ridge and slough topography and the loss of large amounts of open slough habitats. Ponding, in place of the strong seasonal and multiyear differences in flow rates and volumes that once characterized the interior Everglades, has disrupted the dynamics of cycling and transport of natural nutrients, and has substantially reduced the levels of primary and secondary production in the system. The patchwork of overdrained and overflooded marshes has changed the locations and times when and where aquatic animals operate in the Everglades. Wading bird nesting colonies have moved away from the traditional estuarine locations, and have relocated around the less productive pools that have been created in each impoundment.

Effects of Canals

Internal and peripheral canals have altered the timing of water movement through the Everglades, and have created unnatural deep water corridors and habitats in many formally shallow water marshes. Increased rates of water movement in canals have substantially increased the rates of change in the depth of water in the marshes, and have altered the timing and duration of high water and low water events. These hydrological changes, in turn, have stressed many aspects of animal reproductive cycles (e.g., rapid increases in depth have flooded everything from alligator nests to apple snail egg clusters; rapid reductions in depth lead to longer periods of marsh dryout and reduced survival by aquatic animals). Deep-water corridors have degraded water quality by introducing nutrients and toxins into the interior marshes, and have reduced the amount of water that moves through the marshes as sheet flow. Deep-water corridors and habitats have altered the dynamics and sizes of alligators and fishes, and have opened up much of the Everglades to invasions by exotic fishes.

A.1.5.3 Exotic (Nonnative) Species

Exotic plants have invaded marsh and tree island communities in the ridge and slough Everglades, resulting in substantial shifts in species composition and community structure, and, where exotic plants have formed dense "stands," have reduced habitat diversity (e.g., where *Schinus*, *Melaleuca*, and *Lygodium* have invaded tree islands). The introduction and spread of nonnative fishes into localized habitats of the Everglades marshes may alter the dynamics of marsh fish communities, foraging behavior of wading birds, or genetic biodiversity. The CERP assumes a "precautionary conservation" approach in this regard. That is, nonnative animal introductions are not targets for restoration and are assumed to have negative impacts unless monitoring data can prove otherwise.

A.1.5.4 Reduced Habitat Extent

The spatial extent of the ridge and slough Everglades has been reduced from an estimated 490,000 hectare in the pre-drainage system to 365,000 hectare in the current system (a loss of 25 percent). The large extent and comparatively longer hydroperiods that characterized the original ridge and slough system made it the major center for total secondary production in the freshwater Everglades, and the most important refugia for the survival of aquatic animals during dry seasons and years. The reduced extent of this habitat type has 1) substantially reduced the number of options for where animals with large feeding ranges can find suitable foraging sites (e.g., wading birds and snail kites), 2) lowered the overall amount of aquatic production in a naturally, nutrient-poor environment, where space may have been essential for producing the total biomass of prey necessary to support large numbers of higher vertebrates, and 3) eliminated large areas of long-hydroperiod habitat that kept many fishes and aquatic invertebrates alive during dry periods.

A.1.5.5 Degraded Water and Soil Quality

The pre-drainage ridge and slough system was characterized by clear, clean water; low levels of nutrients; and a periphyton community dominated by species of green algae and diatoms. Slower flow rates, unnatural patterns of ponding and overdrainage, and the addition of excess nutrients and toxins, have greatly altered the water and soil chemistry of the Everglades sloughs. Soil oxidation has resulted in increases in surface concentrations of phosphorus. Excess nutrients have contributed to the conversion of extensive strands and patches of sawgrass into dense cattail "plains," resulting in the loss of plant diversity and a reduction in the extent of useable wildlife habitat (e.g., for foraging wading birds). The increased nutrient loadings also have shifted the dominance of periphyton communities to species of blue-greens, resulting in considerable disruption in aquatic food chains. Toxins such as methylmercury have

killed individual animals, and may be causing behavioral changes that interfere with the reproductive success and long-term rates of survival by many aquatic vertebrates.

A.1.5.6 Critical Ecological Linkages

The seven key hypotheses described above are converted into four critical ecological pathways in the Ridge and Slough Conceptual Ecological Model. These pathways show that the principal, broad-scale ecological responses from the combined affects of the five major ecosystem stressors acting on the ridge and slough systems have been 1) a substantial alteration and degradation in the natural patterns of plant community composition and structure and 2) substantial changes in the distribution, and reductions in abundance, among many of the native animals that are dependant on aquatic habitats and food chains. The relative contribution made by each of the stressors, along the different pathways to these two primary responses is not well known. For example, the presence of physical and biological thresholds, some of which may have been crossed as a result of the affects of the stressors, have yet to be demonstrated for most functions and relationships in the sloughs (an exception might be the 10 parts per billion value for phosphorus). Never-the-less, current understandings of the ridge and slough systems, as expressed by the conceptual ecological model workshop participants, suggest that these four ecological pathways have been most important for explaining how these two broad-scale, ecological responses have been linked to the stressors. These four pathways are as follows:

- The pathway that links the reduction in water storage capacity and the substantial increase in the extent and frequency of overdrained marshes (shortened hydroperiods), with an array of ecological effects characterized by a spread in woody vegetation, reduced numbers of nesting alligators, reduced marsh production, reduced dry season survival by aquatic organisms, and the loss of peat soils.

- The pathway that links compartmentalization, and the adverse affects that levees have on water depth/distribution patterns and sheet flow, with altered patterns of nutrient cycling and reduced marsh production, and relocated animal distribution, production and survival centers.

- The pathway that links the reduction in water storage capacity, compartmentalization and the adverse affects of regulatory releases, with flooded tree islands and flooded alligator nests.

- The duel pathways that link degraded water quality and the effects of canals with increased phosphorus loading, resulting in the spread of cattail monocultures, degraded periphyton communities, and reduced marsh production.

A.1.6 Research Questions

Key uncertainties regarding causal relationships in the Everglades Ridge and Slough Conceptual Ecological Model need to be researched. The recommended research to support this conceptual ecological model is discussed in this section.

Causal Factors Determining the Spatial Coverage, Directionality and Persistence of Sawgrass Ridges, Sloughs, and Tree Islands in the Landscape

How do hydrology and fire interact to sustain the spatial coverage, directionality and coexistence of sawgrass ridges, sloughs, and tree islands that characterized pre-drainage landscapes? What are the respective roles of hydrologic variables and fire as causal factors that sustain discreet, directional slough systems and prevent encroachment by sawgrass? What are the respective roles of hydrologic variables and fire as causal factors that sustain viable tree islands and prevent drowning under high-water

conditions and burn-out under low-water conditions? What are the potential impacts and eradication technologies for *Lygodium* spread on tree islands?

Prevention and Reversal of Cattail Spread under Conditions of Elevated Soil Phosphorus in Nutrient-Enriched and Nonenriched Areas in the Landscape

In nutrient-enriched areas of the ridge and slough landscape, how can current trends of cattail expansion be reversed once phosphorus inputs are reduced? In overdrained, nonenriched areas of the ridge and slough landscape, how can elevated phosphorus concentrations in the subsided peat be sequestered in forms that are unavailable for cattail growth upon the recovery of more natural hydropatterns?

Functional Role of Periphyton Mats in Driving Food Webs

How are populations of marsh fishes and other aquatic fauna related to the spatial cover, primary productivity, and taxonomic composition of periphyton mats?

Functional Importance of Crayfish in Everglades Food Webs

What is the functional importance of the crayfish as an intermediate trophic level and prey base supporting higher consumers, in that the former abundance of white ibis and otter suggests that the Everglades was dominated by a crayfish-based food chain? How are crayfish population density and taxonomic composition related to annual and interannual patterns in hydroperiod and depth, including droughts?

Causal Factors Related to the Formation of Wading Bird Super Colonies

What triggers the formation of super colonies of white ibis and other wading birds after major droughts following multiyear hydroperiods? What are the functional contributions and interrelationships of pulsed nutrient releases, reduction in numbers of predatory fishes, and spikes in abundance of small aquatic prey (particularly crayfish) in supporting super colony formation?

A.1.7 Hydrologic Performance Measures

The four critical pathways (above) suggested by the Everglades Ridge and Slough Conceptual Ecological Model are largely driven by hydrological stressors (**reduced extent of wetlands**, **degraded water quality**, **reduced water storage capacity**, and **compartmentalization**). These pathways suggest that the need for four high priority hydrological restoration targets for meeting the ecological objectives of the CERP.

A.1.7.1 Hydropatterns

The performance measure for hydropatterns includes hydroperiod, water depth and depth-duration patterns, and sheet flow. The targets for each of these aspects of the performance measure are discussed below.

For hydroperiod, the target is the reestablishment of pre-drainage, as depicted by the Natural System Model (NSM), annual and multiyear patterns in the duration of uninterrupted surface flooding in Everglades National Park and the Water Conservation Areas. The frequency, duration, extent and magnitude of marsh dry outs must be reduced. Included in this target is an increase in duration of flooding in the overdrained, northern ends of the Water Conservation Areas without an increase in unnatural

flooding in the southern Water Conservation Areas, and a recovery of the pre-drainage patterns of multiyear hydroperiods in Shark River Slough.

The target for water depth and depth-duration patterns is the recovery of more natural water depth and depth/distribution patterns throughout the ridge and slough systems. This includes the elimination of both overdrainage of the northern portions of the Water Conservation Areas and overflooding of the southern portions of the Water Conservation Areas.

For sheet flow, the target is the recovery of natural patterns in the volume and direction of sheet flow throughout the ridge and slough systems. This includes eliminating or reducing unnatural ponding, and altering patterns of volume and direction of marsh flow.

A.1.8 Ecological Performance Measures

A.1.8.1 Peat Soils

The performance measure for peat soils is accretion rate. The recovery of a peat-accreting system throughout the Everglades ridge and slough should be the short-term restoration target. Included in this target are the recovery of peat accretion in portions of the sloughs where overdrainage has converted soil production from peats to marls (e.g., northeastern Shark River Slough), and the minimization of anthropogenic enrichment of soils. The long-term target is the recovery of pre-drainage soil depth and microtopography contour patterns.

A.1.8.2 Periphyton

The performance measure for periphyton is community composition, distribution and productivity. The restoration target for periphyton is to increase mat cover, biovolume, organic content, and percent noncalcareous algae and diatom composition. Measures of species composition can be used to reflect improvements in water and soil chemistry, and in hydroperiod and depth parameters.

A.1.8.3 Marsh Plant Communities

The performance measures for marsh plant communities are community distribution, proportions, and composition. The long-term restoration targets for marsh plant communities are 1) recover, at a system-wide scale, the expected mosaics and spatial and temporal dynamics of the marsh communities, as should occur with natural patterns of hydrology, fire and soils; 2) decrease the proportion and extent of sawgrass, where sawgrass has invaded slough and wet prairie habitats; and 3) reestablish spatial patterns of ridge and slough communities by restoring pre-drainage flow directionality and volumes. The short-term goal for cattails and exotic plants is to minimize the invasions of these species into ridge and slough communities. The long-term goal for cattails is to eliminate large, monotypic stands.

A.1.8.4 Tree Islands

The performance measures for tree islands are distribution, size and composition. The restoration targets for the ridge and slough tree islands are as follows:

- Prevent any further net loss in the extent and quality of tree islands, using the following criteria: 1) landscape distribution and spatial extent, 2) vegetation community composition, 3) habitat value and ecological function, and 4) geomorphology, including accretion, shape, elevation profile and orientation

- Recover lost tree island habitat where natural elevation rises are preserved, and where natural patterns of succession would be expected, using the above four criteria as measures of recovery

- Recover a more natural mosaic of tree island types across the landscape

A.1.8.5 Marsh Fishes and Invertebrates and Herps

The performance measures for marsh fishes and invertebrates and herps are community composition, size distribution and abundance. The following targets have been established:

- Recover multiyear patterns of fish dynamics, including multiyear increases in marsh fish numbers and biomass, to levels comparable to those measured in Shark River Slough following multiyear, uninterrupted hydroperiods

- Increase densities of the pig frog (Rana grylio) in portions of the ridge and slough system where hydroperiods have been unnaturally reduced to densities comparable to those found in remaining long-hydroperiod marshes

- Increase density of apple snails (Pomacea)

- Increase the size range in biomass and length distributions of marsh fishes

- Increase the relative of abundance of centrarchids and chubsuckers

- Increase the frequency of the species of crayfish typical of long hydroperiod marshes (Procambarus fallax) in relation to the species more characteristic of shorter hydroperiod marshes (P. alleni)

- Maintain the current low frequencies of exotic fishes in the interior ridge and slough system

- Reduce levels of mercury and other toxins in marsh fishes

A.1.8.6 Alligator

The performance measures for alligators are abundance, distribution, nest success, and occupied holes. The targets for alligators in the Everglades ridge and slough system are as follows:

- Shift the highest densities of nests in Everglades National Park from the center to the edges and downstream portions of Shark River Slough

- Establish more uniform density and distribution of alligators, occupied holes, and nests in the Water Conservation Areas

- Improve the overall “health” of alligators in Shark River Slough and the central/southern Water Conservation Areas and establish baselines for contaminant loadings for alligators

- Increase alligator reproduction rates in Shark River Slough and the central and southern Water Conservation Areas, as measured by 1) the frequency of alligator nesting, 2) the frequency of hatching, and 3) the survival of hatchlings

- Decrease the incidence of nest flooding caused by wet season regulatory releases and other water management practices in the Shark River Slough and Water Conservation Areas

- Increase the proportion of juveniles size classes in the total alligator population

A.1.8.7 Wading Birds

The performance measures for wading birds are the abundance, location, and timing of colonies, and the return frequency of super colonies. The targets are 1) increase in total number of wading birds nesting in and adjacent to the ridge and slough Everglades to those proposed by Ogden et al. (1997); 2) substantially increase the proportion of the total birds that nest in the area of the southern Everglades marsh-mangrove ecotone; 3) reestablish historical (1920s-1960s) timing patterns for nesting wading birds, especially for the wood stork and white ibis; and 4) return super colonies to the system at a return frequency of 1 to 2 events per decade. To recover their historical size, super colonies should occur in the headwaters' ecotone at the lower end of Shark River Slough. Super colonies may be the best indicators of the effects of natural hydrologic variability in the system.

The size, timing, and location of wading bird nesting colonies, as well as the occurrence and frequency of "super colonies", should reflect improvements in foraging habitat options under a range of climatological conditions. The quality of foraging habitat depends upon marsh production rates, survival rates of marsh organisms during dry periods, and the location of the major production and survival centers in the slough systems. Protective criteria need to be established for contaminant levels in sediment and water that result in no negative impact to wading birds.

A.1.9 Model

The diagram for the Everglades Ridge and Slough Conceptual Ecological Model is presented in Figure A-5. The key to the symbols used in the diagram is presented in Figure A-6.

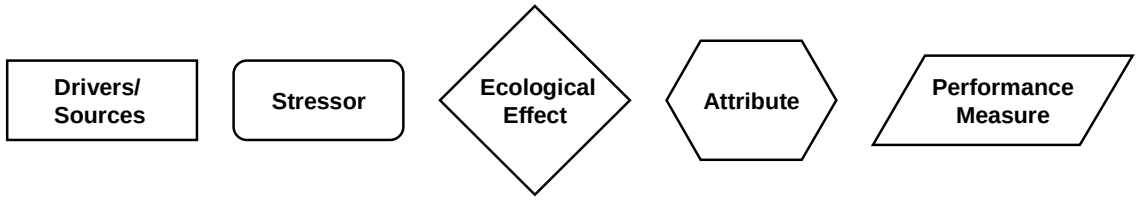


Figure A-5: Key to the Symbols Used in the Following Diagram

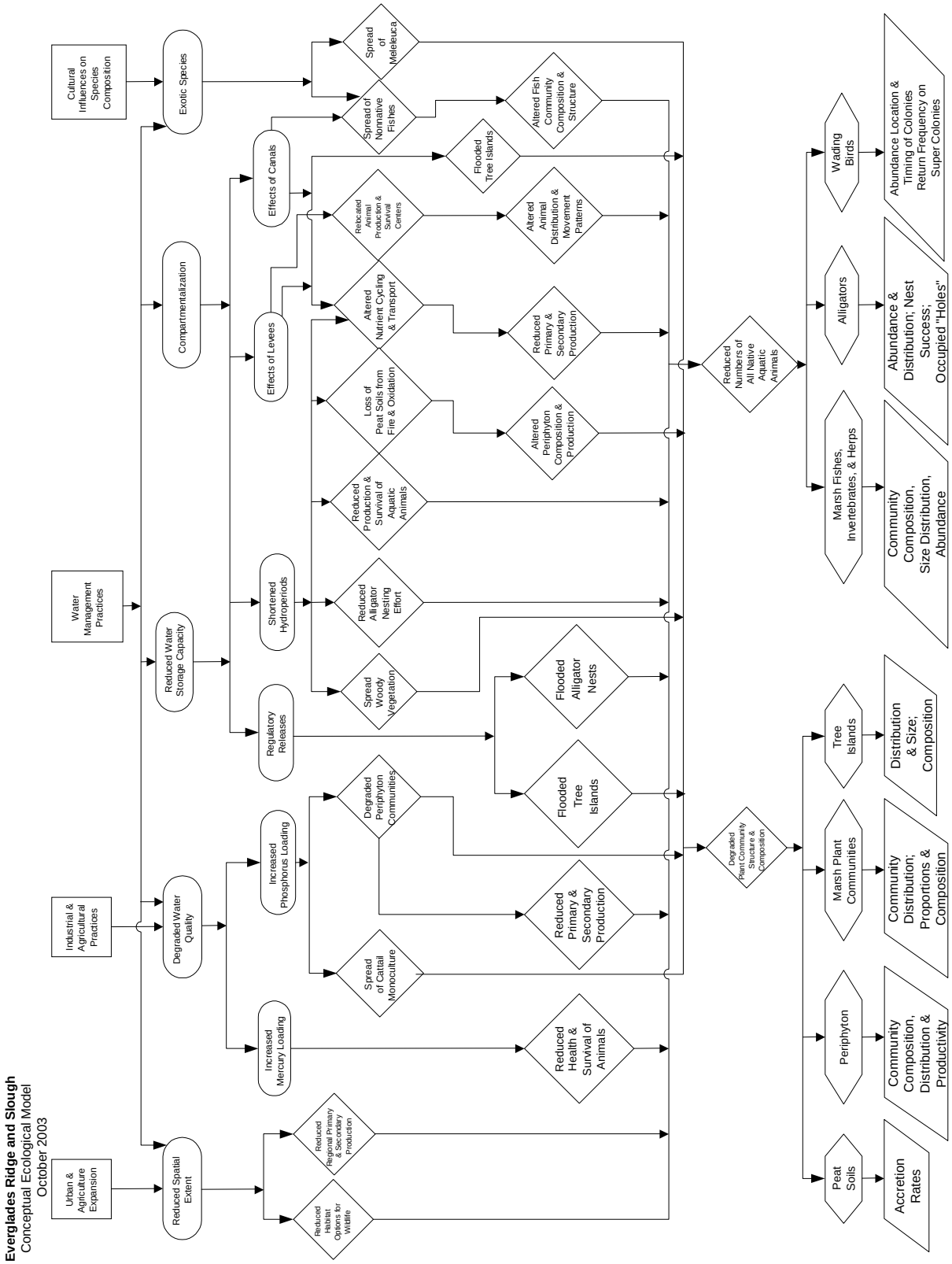


Figure A-6: Everglades Ridge and Slough Conceptual Ecological Model Diagram

A.1.10 Literature Cited

Armentano, T.V. (ed.). 1996. Proceedings of the Conference: Ecological Assessment of the 1994-1995 High Water Conditions in the Southern Everglades. Everglades National Park, Homestead, Florida.

Bancroft, G.T., A.M. Strong, R.J. Sawicki, W. Hoffman, and S.D. Jewell. 1994. Relationships among wading bird foraging patterns, colony locations, and hydrology in the Everglades. In: Davis, S.M., and J.C. Ogden (eds). Everglades, the Ecosystem and its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 615-657

Bennetts, R.E., M.C. Collopy, and J.A. Rodgers, Jr. 1994. The snail kite in the Florida Everglades: a food specialist. In: Davis, S.M., and J.C. Ogden (eds). Everglades, the Ecosystem and its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 507-532.

Bodle, M.J., A.P. Ferriter and D.D. Thayer. 1994. The biology, distribution, and ecological consequences of *Melaleuca quinquenervia* in the Everglades. In: Davis, S.M., and J.C. Ogden (eds), Everglades, the Ecosystem and its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 341-355.

Browder, J.A. 1976. Water, Wetlands, and Wood Storks in Southwest Florida. Ph.D. dissertation, University of Florida, Gainesville, Florida.

Browder, J., and J.C. Ogden. 1999. The natural South Florida system II: pre-drainage ecology. Urban Ecosystems 3: 125-158.

Browder, J.A., P.J. Gleason, and D.R. Swift. 1994. Periphyton in the Everglades: spatial variation, environmental correlates, and ecological implications. In: Davis, S.M., and J.C. Ogden (eds). Everglades, the Ecosystem and its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 379-416.

Courtenay, W.R., Jr. 1994. Nonindigenous fishes in Florida. In: Schmidt, D.C., and T.C. Brown (eds), An Assessment of Invasive Nonindigenous Species in Florida's Public Lands, Technical Report TSS-94-100, Bureau of Aquatic Plant Management, Florida Department of Environmental Protection, Tallahassee, Florida, pp. 57-63.

Craighead, F.C., Sr. 1968. The role of the alligator in shaping plant communities and maintaining wildlife in the southern Everglades. Florida Naturalist 41: 2-7, 69-74, 94.

Craighead, F.C., Sr. 1971. The Trees of South Florida. Volume 1: The Natural Environments and Their Succession. Universityof Miami Press, Coral Gables, Florida.

Davis, S.M. 1994. Phosphorus inputs and vegetation sensitivity in the Everglades. In: Davis, S.M., and J.C. Ogden (eds). Everglades, the Ecosystem and its Restoration, St. Lucie Press, Delray Beach, Florida, pp. 357-378.

Davis, S.M., and J.C. Ogden. 1994. Towards ecosystem restoration. In: Davis, S.M., and J.C. Ogden (eds). Everglades, the Ecosystem and its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 769-796.

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, Florida.

Davis, S.M., L.H. Gunderson, W.A. Park, J. Richardson, and J. Mattson. 1994. Landscape dimension, composition, and function in a changing Everglades ecosystem. In: Davis, S.M., and J.C. Ogden (eds). Everglades, the Ecosystem and its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 419-444.

DeAngelis, D.L. 1994. Synthesis: spatial and temporal characteristics of the environment. In: Davis, S.M., and J.C. Ogden (eds). Everglades, the Ecosystem and its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 307-320.

DeAngelis, D.L., and P.S. White. 1994. Ecosystems as products of spatially and temporally varying driving forces, ecological processes, and landscapes. In: Davis, S.M., and J.C. Ogden (eds). Everglades, the Ecosystem and its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 9-27.

Duever, M.J., J.F. Meeder, L.C. Meeder, and J.M. McCollom. 1994. The climate of South Florida and its role in shaping the Everglades ecosystem. In: Davis, S.M., and J.C. Ogden (eds). Everglades, the Ecosystem and its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 225-248.

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

Fink, L. and P. Rawlik. 2000. The Everglades mercury problem. In: SFWMD. Everglades Consolidated Report, South Florida Water Management District, West Palm Beach, Florida.

Fleming, D.M. 1991. Wildlife Ecology Studies. Volume 1: 1991 Annual Reports. South Florida Research Center, Everglades National Park, Homestead, Florida.

Frederick, P.C., and M.G. Spalding. 1994. Factors affecting reproductive success of wading birds (Ciconiiformes) in the Everglades ecosystem. In: Davis, S.M., and J.C. Ogden (eds). Everglades, the Ecosystem and its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 659-691.

Frederick, P.C., and J.C. Ogden. 2001. Pulsed Breeding of Long-Legged Wading Birds and the Importance of Infrequent Severe Drought Conditions in the Florida Everglades. Wetlands 21:4.

Frederick, P.C., M.G. Spalding, M.S. Sepulveda, G. Williams, S. Bouton, H. Lynch, J. Arrecis, S. Loerzel, and D. Hoffman. 1997. Effects of Environmental Mercury Exposure on Reproduction, Health and Survival of Wading Birds in the Florida Everglades. Department Wildlife Ecology and Conservation, University Florida. Gainesville, Florida.

Gawlik, D.E (ed.). 1999. South Florida Wading Bird Report, Volume 5. South Florida Water Management District, West Palm Beach, Florida.

Gawlik, D.E., and D.A. Rocque. 1998. Avian communities in bayheads, willowheads, and sawgrass marshes of the central Everglades. Wilson Bull. 110: 45-55.

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, Memoir 2, Miami, Florida.

Goodyear, C. 2000. Initial Status Survey of Nonindigenous Animals in South Florida. A report by the South Florida Ecosystem Restoration Working Group, Miami, Florida, May 2000 draft.

Gunderson, L.H. 1994. Vegetation of the Everglades: determinants of community composition. In: Davis, S.M., and J.C. Ogden (eds). Everglades, the Ecosystem and its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 323-340.

Gunderson, L.H., and W.F. Loftus. 1993. The Everglades. In: Martin, W.H., S.G. Boyce, and A.C. Echternacht (eds). Biotic Communities of the Southern United States. John Wiley and Sons, New York, New York, pp. 199-255.

Gunderson, L.H. and J.R. Snyder. 1994. Fire patterns in the southern Everglades. In: Davis, S.M., and J.C. Ogden (eds). Everglades, the Ecosystem and its Restoration. St. Lucie Press, Delray Beach, Florida, pp. Pp. 291-305.

Hoffman, W., G.T. Bancroft, and R.J. Sawicki. 1989. Wading Bird Populations and Distributions in the Water Conservation Areas of the Everglades, 1985-1988. South Florida Water Management District, West Palm Beach, Florida

Hoffman, W., G.T. Bancroft, and R.J. Sawicki. 1994. Foraging habitat of wading birds in the water conservation areas of the Everglades. In: Davis, S.M., and J.C. Ogden (eds). Everglades, the Ecosystem and its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 585-614.

Holling, C.S., L.H. Gunderson, and C.J. Walters. 1994. The structure and dynamics of the Everglades system: guidelines for ecosystem restoration. In: Davis, S.M., and J.C. Ogden (eds). Everglades, the Ecosystem and its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 741-756.

Jacobsen, T., and J.A. Kushlan. 1984. Population Status of the American Alligator *(Alligator mississippiensis)* in Everglades National Park. South Florida Research Center, Everglades National Park, Homestead, Florida.

Kolopinski, M.C., and A.L. Higer. 1969. Some Aspects of the Effects of the Quantity and Quality of Water on Biological Communities in the Everglades National Park. Open File Report 69007, United States Geological Survey, Washington, D.C.

Kushlan, J.A. 1979. Feeding ecology and prey selection in the white ibis. Condor 81: 376-389.

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. 1989. Wetlands and wildlife, the Everglades perspective. In: Sharitz, R.R., and J.W. Gibbons (eds). Freshwater wetlands and wildlife. United States Department Energy Symposium Series No. 61, Oak Ridge, Tennessee, pp. 773-790.

Kushlan, J.A., and T. Jacobsen. 1990. Environmental variability and the reproductive success of Everglades alligators. Journal of Herpetolology 24: 176-184.

Lange, T.R., H.E. Royals, and L.L. Connor. 1994. Mercury accumulation in largemouth bass (*Micropterus salmoides*) in a Florida lake. Arch. Environ. Contam. Toxicol. 27: 466-471.

LaRoche, F.B., and A.P. Ferriter. 1992. The rate of expansion of melaleuca in South Florida. Journal of Aquatic Plant Management 30: 62-65.

Light, S.S., and J.W. Dineen. 1994. Water control in the Everglades: a historical perspective. In: Davis, S.M., and J.C. Ogden (eds). Everglades, the Ecosystem and its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 47-84.

Loftus, W.F. 1986. Distribution and ecology of exotic fishes in Everglades National Park. In: Thomas, L.K., Jr. (ed). 1986 Conference on Science in the National Parks Proceedings, Volume 5: Management of Exotic Species in Natural Communities. George Wright Society, Hancock, Michigan.

Loftus, W.F., and A. Eklund. 1994. Long-term dynamics of an Everglades small-fish assemblage. In: Davis, S.M., and J.C. Ogden (eds). Everglades, the Ecosystem and its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 461-483.

Loftus, W.F., and J.A. Kushlan. 1987. Freshwater fishes of southern Florida. Bulletin Florida State Museum 31 (4): 147-344.

Loftus, W.F., J.D. Chapman, and R. Conrow. 1990. Hydrological effects on Everglades marsh food webs, with relation to marsh restoration efforts. In: Larson, G., and M. Soukup (eds). 1986 Conference on Science in the National Parks Proceedings, Volume 6: Fisheries and Coastal Wetlands Research. George Wright Society, Hancock, Michigan, pp. 1-22.

Loftus, W.F., R.A. Johnson, and G. Anderson. 1992. Ecological impacts of the reduction of groundwater levels in the rocklands. In: Stafford, J.A., and J.J. Simon (eds). Proceedings of the First International Conference of Groundwater Ecology. American Water Resources Association, Bethesda, Maryland, pp. 199-208.

McVoy, C., W. Said, and J. Obeysekera. In preparation. Pre-Drainage Everglades Landscape and Hydrology. South Florida Water Management District, West Palm Beach, Florida.

Mazzotti, F.J., and L.A. Brandt. 1994. Ecology of the American Alligator in a seasonally fluctuating environment. In: Davis, S.M., and J.C. Ogden (eds). Everglades, the Ecosystem and its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 485-505.

Myers, R.L. 1983. Site susceptibility to invasion by the exotic tree *Melaleuca quinquenerva* in South Florida. Journal of Applied Ecology 20: 645-658.

Ogden, J.C. 1994. A comparison of wading bird nesting colony dynamics (1931-1946 and 1974-1989) as an indication of ecosystem conditions in the southern Everglades. In: Davis, S.M., and J.C. Ogden (eds). Everglades, the Ecosystem and its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 533-570.

Ogden, J.C., G.T. Bancroft, and P.C. Frederick. 1997. Ecological success indicators: reestablishment of healthy wading bird populations. In: Science Sub-group (ed). Ecologic and Precursor Success Criteria for South Florida Ecosystem Restoration. Working Group, South Florida Ecosystem Restoration Task Force, Miami, Florida.

Ogden, J.C., J. Browder, J.H. Gentile, L.H. Gunderson, R. Fennema, and J. Wang. 1999. Environmental management scenarios: ecological implications. Urban Ecosystems 3: 159-184.

Olmsted, I., and T.V. Armentano. 1997. Vegetation of Shark Slough, Everglades National Park. Report 97-001, South Florida Natural Resources Center, Everglades National Park. Homestead, Florida.

Patterson, K., and R. Finck. 1999. Tree islands of WCA3. Aerial Photointerpretation and Trend Analysis Project Summary Report. South Florida Water Management District, West Palm Beach, Florida.

Robertson, W.B., Jr., and P.C. Frederick. 1994. The faunal chapters: context, synthesis, and departures. In: Davis, S.M., and J.C. Ogden (eds). Everglades, the Ecosystem and its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 709-737.

Roelke, M.E., D.P. Schultz, C.F. Facemire, and H.E. Royals. 1991. Mercury contamination in Florida panthers. Report of the Florida Panther Technical Subcommittee to the Florida Panther Interagency Committee, Florida Game and Fresh Water Fish Commission, Tallahassee, Florida.

Science Subgroup. 1993. Federal Objectives for the South Florida Restoration. South Florida Management and Coordination Working Group, South Florida Ecosystem Restoration Task Force, Miami, Florida.

SCT. 2003. The Role of Flow in the Everglades Ridge And Slough Landscape. Science Coordination Team, South Florida Ecosystem Restoration Task Force, Miami, Florida.

SFWMD. 1992. Surface Water Improvement and Management Plan for the Everglades: Supporting Information Needs Document. South Florida Water Management District, West Palm Beach, Florida.

Sklar, F., L. Brandt, D. DeAngelis, C. Fitz, D. Gawlik, S. Krupa, C. Madden, F. Mazzotti, C. McVoy, S. Miao, D. Rudnick, K. Rutchney, K. Tarboton, L. Vilchek, and Y. Wu. 2000. Hydrological needs – effects of hydrology on the Everglades. In: SFWMD. Everglades Consolidated Report, South Florida Water Management District, West Palm Beach, Florida, pp. 2-1 to 2-62.

Spalding, M.G., and D.J. Forrester. 1991. Effects of Parasitism and Disease on the Nesting Success of Colonial Wading Birds (Ciconiiformes) in Southern Florida. Nongame Wildlife Program Report NG88-008, Florida Game and Fresh Water Fish Commission, Tallahassee, Florida.

Stober, J., D. Scheidt, R. Jones, K. Thornton, R. Ambrose, and D. France. 1996. South Florida Ecosystem Assessment Monitoring for Adaptive Management: Implications for Ecosystem Restoration. Interim report. EPA 904-R-96-008, Environmental Protection Agency, Athens, Georgia.

Thayer, D., A. Ferriter, M. Bodie, K. Langeland, K. Serbesoff, D. Jones, and B. Doren. 2000. Exotic plants in the Everglades. In: SFWMD. Everglades Consolidated Report, South Florida Water Management District, West Palm Beach, Florida, pp. 14-1 to 14-48.

Trexler, J., and F. Jordan. 1999. Fish and aquatic macroinvertebrate population studies in the Water Conservation Areas. Final Report for South Florida Water Management District contract no. C-E6636, West Palm Beach, Florida

Tropical BioIndustries, Inc. 1990. Hydroperiod Conditions of Key Environmental Indicators of Everglades National Park and Adjacent East Everglades Area as Guide to Selection of an

Optimum Water Plan for Everglades National Park, Florida. Final report for contract from United States Army Corps of Engineers, Jacksonville District, Jacksonville, Florida.

Van der Valk, A., F. Sklar, D. Mason, D. Gawlik, P. Wetzel, S. Newman, C. McVoy, Y. Wu, S. Miao, S. Krupa, and M. Korvela. 1998. Proposed Plan of Work for Tree Island Research. Everglades Systems Research Division, South Florida Water Management District, West Palm Beach, Florida.

Walters, C.J., and L.H. Gunderson. 1994. A screening of water policy alternatives for ecological restoration in the Everglades. In: Davis, S.M., and J.C. Ogden (eds). Everglades, the Ecosystem and its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 757-767.

A.2 SOUTHERN MARL PRAIRIES CONCEPTUAL ECOLOGICAL MODEL

A.2.1 Model Lead

Steven M. Davis, South Florida Water Management District

A.2.2 Introduction

About 190,000 hectares of higher-elevation, freshwater marshes are found on either side of Shark River Slough (Figure A-7). In these systems, water levels typically drop below the ground surface each year (Davis et al. 1994). Consequently peat accretion is inhibited, and substrates consist either of marl produced by periphyton mats, or exposed limestone bedrock (Gleason 1972).

Marl prairies are mosaics of wet prairie, sawgrass, tree island, and tropical hammock communities that support a high diversity of plant species (Olmstead and Loope 1984). A separate landscape, called the rocky glades, occurs at slightly higher elevations than the marl prairies. The rocky glades are characterized by shorter hydroperiods and exposed karst formations of limestone and solution holes. Deposits of marl and organic sediments are limited to the solution holes in the rocky glades. The southern marl prairies to the east of Shark River Slough comprise the watershed for Taylor Slough, a lower-elevation waterway that meanders through the higher-elevation marl prairie south of Long Pine Key, becoming the Taylor River that flows into Little Madeira Bay. Peat deposits and more aquatic plant communities in Taylor Slough indicate prolonged periods of inundation compared to its surrounding marl prairie-rocky glade watershed. The narrow ribbon of slough flowing through more extensive higher-elevation marshes is not amenable to modeling at the 2-by-2 mile grid scale of the regional models used to simulate Comprehensive Everglades Restoration Plan (CERP) scenarios, thus hydrologic performance measures for Taylor Slough require finer-scale models currently under development.

The ephemeral hydrologic characteristics of the southern marl prairies pose stresses to the wetland animal communities regarding survival through the dry season when standing water is usually absent (Loftus and Eklund 1994, Loftus et al. 1990). In that respect, the American alligator represents a keystone species in the southern marl prairies as alligator holes provide important refugia for aquatic fauna during dry periods (Craighead 1968).

A.2.3 External Drivers and Ecological Stressors

The two major sources of societal influences (drivers) on the southern marl prairies are water management practices and agricultural and urban development (Figure A-9, Section A.2.9). The introduction of exotic plants and burning practices exacerbated by compartmentalization also, to a lesser extent, drive the southern marl prairies system. These drivers lead to eight major ecosystem stressors: 1) loss of spatial extent, 2) shortened hydroperiod, 3) increased drought severity, 4) wet season water level reversals, 5) drying pattern reversals, 6) compartmentalization, 7) expansion of exotic plants, and 8) high intensity dry season fires. In Figure A-9, the first four of these stressors are combined under an altered hydropattern stressor. These altered hydropattern stressors and their cooresponding effects and attributes are shown in detail in Figure A-10 (Section A.2.9). The two main societal drivers and their respective stressors are summarized in the next few paragraphs. The stressors are then discussed in more detail in the following subsections (A.2.3.1 through A.2.3.8).

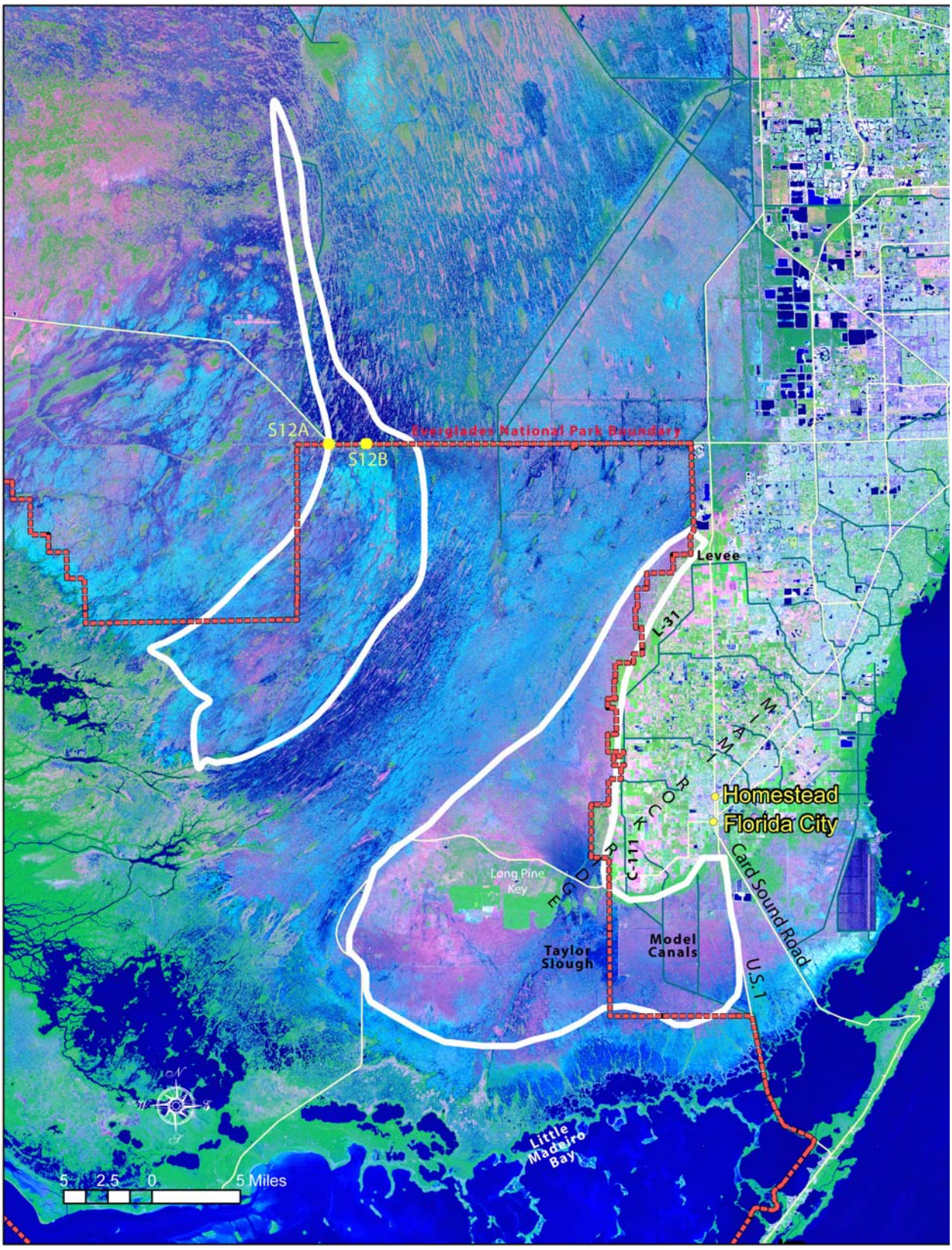


Figure A-7: The Boundary of the Southern Marl Prairies Conceptual Ecological Model

Agricultural and urban development represents a direct loss of spatial extent of the southern marl prairie wetlands through conversion of marshes to farmland and housing (Davis et al. 1994). Development of eastern portions of the southern marl prairies has reduced the spatial extent of these landscapes and has cut off portions of the Taylor Slough watershed. The connectivity of the southern marl prairies to upland habitats has been broken by the development of the eastern portions of these wetlands and of most of the Miami rock ridge. The lost spatial extent and connectivity to uplands on the eastern side of the southern marl prairies cannot be restored on a large scale and must influence expectations for ecosystem restoration.

The water management system that controls flooding in the eastern, developed parts of the southern marl prairies has altered hydropatterns of the remaining wetlands primarily through the lowering of water tables and through the unseasonable regulatory release of water from upstream (Van Lent et al. 1993). A network of canals, levees and roads, particularly the C-111 system, United States Highway 1 (US 1), and Card Sound Road, have compartmentalized the remaining southern marl prairie wetlands. The compartmentalization has geographically altered hydrologic patterns, particularly in the Model Lands area between US 1 and Card Sound Road. The canals and pump stations, in addition to draining wetland areas, are conduits for potential inputs of nutrients, mercury, other toxins, and for the introduction of exotic fishes into the remaining wetland system.

The southern marl prairies to the west of Shark River Slough are geographically isolated from the human population centers of Florida's lower east coast. Consequently, these wetlands have escaped the development, compartmentalization and lowered water table stressors of their eastern counterparts. To the contrary, the western marl prairies are negatively impacted by extended flooding. Water that once flowed eastward into Northeast Shark River Slough is presently diverted to the west through the S-12 A and B discharge gates of Water Conservation Area 3A, resulting in lengthened hydroperiods in the western marl prairies. The extended flooding is exascerbated by drying pattern reversals caused by regulatory water releases through the S-12 A and B structures.

Development provides potential sources of excess nutrients, mercury and other toxins to the natural system via runoff water. Agricultural and urban runoff water from the lower east coast that may be needed for hydropattern restoration of the southern marl prairies may provide elevated inputs of these contaminants. A probable effect of nutrient additions to the southern marl prairies is the loss in the periphyton mat and the dominance of blue-green algae, resulting in a diminished role of periphyton in aquatic food webs and in marl substrate accretion (Browder et al. 1994). Nutrient and contaminant inputs do not appear to currently represent major stressors to the southern marl prairies. However, caution must be taken in utilizing lower east coast runoff for hydropattern restoration because of the potential of nutrients and contaminants as future stressors on these systems.

A.2.3.1 Shortened Hydroperiod

Hydroperiod is the duration of uninterrupted flooding. Shortened hydroperiod is one of the stressors on the southern marl prairies. Under present conditions, most of the southern marl prairies to the east of Shark River Slough remain dry most of an average year, compared to the duration of uninterrupted flooding averaging up to nine months pre-drainage as indicated by the Natural System Model (NSM) (Van Lent et al. 1993, Fennema et al. 1994, VanZee 1999). Shortened hydroperiod directly affects ecosystem food webs through the 1) decrease in the percent composition of diatoms and green algae associated with the periphyton mat, shifting near dominance by the blue greens *Schizothrix* and *Cytonemia* (Browder et al. 1994), 2) reduced secondary production and altered species composition of marsh fishes and other aquatic fauna (Loftus and Eklund 1994, Loftus et al. 1990, Trexler and Loftus 2000, Turner 1999), 3) reduced population density and altered species composition of small herpetofauna, based on abundance in short-hydroperiod habitats in relation to rainfall and water levels on Long Pine

Key (Diffendorfer et al. in preparation; Dalrymple 1987; G. Dalrymple personal communication, Everglades Research Group, Inc.), 4) loss of the potential for wading bird and wood stork foraging during the early dry season (Fleming personal communication in Ogden 1994), and 5) decline in the American alligator population in the landscape where it was once abundant (Craighead 1968, Mazzotti and Brandt 1994). In addition to the already noted alteration of the periphyton mat and filling in of alligator holes, shortened hydroperiod directly affects plant community and habitat structure, by enabling the invasion of nuisance native woody plants (e.g., willow) and exotics (e.g., Brazilian pepper and melaleuca) in a naturally herbaceous landscape (Armentano et al. 1995, Jones and Doren 1997), and by altering the plant species composition of macrophyte vegetation toward more terrestrial plant species (Hofstetter and Hilsenbeck 1980, Hilsenbeck et al. 1979). Shortened hydroperiod indirectly affects plant community and habitat structure by altering the fire regime; hotter and more severe fires exacerbated by the prolonged dry season (Gunderson and Snyder 1994) further alter herbaceous plant species composition and reduce plant community heterogeneity by burning out hardwood hammock tree islands (Loope and Urban 1980). Shortened hydroperiod, in combination with increased drought severity, threatens Cape Sable seaside sparrow reproductive success and survival in the marl prairies to the east of Shark River Slough by increasing the frequency and severity of nest-destroying fires, and by enabling the invasion of woody plants in the absence of fire (Pimm 1995)

A.2.3.2 Increased Drought Severity

Another stressor is increased drought severity. In a system where water levels typically fall below the ground surface each year, remnant pools of standing water in solution holes and alligator holes during the dry season are critical to the survival of aquatic and amphibious fauna such as fish, crayfish, herpetofauna and alligators (Loftus et al. 1992, Mazzotti and Brandt 1994, Diffendorfer et al. in preparation, Dalrymple 1987, Dalrymple personal communication). The function of these dry season refugia is diminished or eliminated when dry conditions are prolonged and minimum water levels during a dry season fall below the bottoms of the solution holes and alligator holes.

A.2.3.3 Wet Season Water Level Reversals

Wet season water reversals is also a stressor. Field observations indicate that when water depth drops to less than 0.2 feet during a period of flooding, aquatic fauna population densities decline, survivors retreat to refugia in solution holes or alligator holes, and population recovery is slowed (Loftus and Eklund 1994; W. Loftus, United States Geological Survey, personal communication).

A.2.3.4 Drying Pattern Reversals and Extended Hydroperiods

Unnaturally high flow volumes from Water Conservation Area 3A through the S-12 A and B outflow gates into the marl prairies to the west of Shark River Slough have created delays and reversals in seasonal drying patterns. The drying pattern reversals and extended hydroperiods detrimentally affect nesting of the endangered Cape Sable seaside sparrow (Pimm 1995). The Cape Sable seaside sparrow depends on predictably dry conditions during its spring nesting period, which corresponds to the late dry season (Pimm 1995).

A.2.3.5 Compartmentalization

The levees that bound and dissect the southern marl prairies on the east side of the Everglades, including the L-31 levee, C-111 system, US 1 and the Card Sound Road, geographically alter hydrologic patterns and break connectivity of wetlands to adjacent uplands resulting in compartmentalization. Canals adjacent to the levees provide corridors of permanently flooded, deep-water habitat that would not otherwise occur in the southern marl prairies. These corridors allow the expansion of exotic and higher trophic level fishes

into areas where they could not survive naturally (Howard et al. 1995). The prevalence of higher trophic fishes in the canals may diminish the value that this habitat might otherwise serve as a dry season refugium for aquatic and amphibious fauna.

A.2.3.6 Loss of Spatial Extent

The conversion of eastern portions of the southern marl prairies to agriculture and residential development has reduced the spatial extent of aquatic habitat and production that negatively impacts fish, crayfish, herpetofauna, alligators, and wood storks and wading birds. The extent of loss in aquatic habitat and production is directly proportional to the spatial extent of the area that has literally been taken out of production as wetland (Davis et al. 1994). Loss of spatial extent may have reduced the range of habitat options that are available at any given time for faunal populations (DeAngelis and White 1994), including nesting by the Cape Sable seaside sparrow (Pimm 1995) and potential foraging by wood storks and wading birds (Fleming, personal communication in Ogden 1994).

A.2.3.7 Expansion of Exotic Plants

Melaleuca, Brazilian pepper and Australian pine are the three most widespread invasive exotic plant species that have spread into native plant communities of the southern marl prairies. The shortened hydroperiod of these systems allows their rapid population expansion after introduction (Olmstead and Loope 1984, Armentano et al. 1995, Jones and Doren 1997).

A.2.3.8 High Intensity Dry Season Fires

Burning practices, particularly from illegally set fires, have shifted the seasonal timing of lightning sparked fires from the May-June early wet season, to the winter-spring dry season (Gunderson and Snyder 1994). Fire severity is exacerbated by shortened hydroperiod and increased drought severity. The road access provided by levees contributes to fire ignition by humans by allowing arsonists access to the marshes and by creating a source of ignition from vehicle sparks (G. Burzycki, Dade County Department of Environmental Resource Management, personal communication). Intense, dry season fires have burned out hardwood hammock tree islands in the southern marl prairies to the east of Shark River Slough. Fire hazard due to overdrainage also poses a threat to Cape Sable seaside sparrow nesting success and survival in the marl prairies to the east of Shark River Slough.

A.2.4 Ecological Attributes

A.2.4.1 Periphyton Mat

The periphyton mat of calcitic algae contributes to aquatic food webs (Browder et al. 1994), habitat structure (Loftus personal communication), and marl sediment accretion (Gleason 1972) in the southern marl prairies. Periphyton species composition is a sensitive indicator of both hydrologic conditions and water quality (Browder et al. 1994). Severely reduced hydroperiod in the southern marl prairies results in a decrease in the diatom and green algal species in the periphyton mat, leaving mostly mat-forming blue-green algae *Schizothrix* and *Cytonemia* (Browder et al. 1994).

A.2.4.2 Marl Substrate

Mat-forming calcitic algae deposit the marl substrate characteristic of the marl prairies (Gleason 1972, Browder et al. 1994), where hydroperiod is too short for the accretion of peat soils. Most of the plant communities described by Olmstead and Loope (1984) and Gunderson (1994) for this region are supported by the marl soils. The dependence of marl deposition on the productivity of the calcitic

periphyton mat implies that the negative impacts of shortened hydroperiod noted above for the periphyton mat would also slow the rate of marl accretion.

A.2.4.3 Vegetation Mosaic and Diversity

A unique feature of the southern marl prairies is the extremely high species richness of the flora. Within the mosaic of low-stature graminoid communities, sawgrass and muhly grass dominate, although more than 100 species of mostly herbaceous plants have been reported (Olmstead and Loope 1984). The higher-elevation tropical hammock and pine forests islands within the prairie landscape support flora of West Indian origin unique to South Florida and the Florida Keys, and contain the highest number of rare and threatened plant species in southern Florida (Gunderson 1994). The plant communities of the southern marl prairies have been impacted by man through development, drainage, exotic invasion and burning practices. Tree island burn-out (Loope and Urban 1980), shifts to more terrestrial plant associations in the graminoid communities (Hofstetter and Hilsenbeck 1980, Hilsenbeck et al. 1979), loss of vegetation heterogeneity associated with the micro-topography of alligator holes (Craighead 1968), and woody plant invasion of the graminoid communities (Armentano et al. 1995) have accompanied shortened hydroperiods and lowered water tables. These effects are exacerbated by the spread of exotic trees (Olmstead and Loope 1984, Armentano et al. 1995, Jones and Doren 1997) and by dry season burning practices (Gunderson and Snyder 1994), particularly from illegally-set fires.

A.2.4.4 Cape Sable Seaside Sparrow

The Cape Sable seaside sparrow is an endangered species endemic to the marl marshes of the southern Everglades. The three major breeding colonies of the sparrow include the western subpopulation in marl marshes to the west of Shark River Slough, the eastern subpopulation to the east of mid-Shark River Slough, and the central subpopulation to the east of southwestern Shark River Slough (Pimm 1995). The sparrow nests during the dry season months, usually April–June, in sites free of standing shrubs or trees. The construction of nests approximately 10 centimeters above the ground at the bases of tussocks of muhly grass and other marsh graminoids makes the sparrow vulnerable both to spring wildfires and unseasonable water depth increases (dry season water level reversals). Successful nesting requires approximately 60 days of nearly dry conditions without fire. Dry season water level reversals have been a particular problem to the nesting success of the western subpopulation, where regulatory water releases through the S-12 A and B outflow gates of Water Conservation Area 3A contribute to the reversals and subsequent nest drowning (Pimm 1995). The eastern subpopulation occupies an overdrained region of marl prairie subject to spring wildfires or to invasion of woody vegetation. The central population is the most stable because of its remote location, although it is vulnerable to naturally-occurring dry season fires.

A.2.4.5 Marshes Fishes, Herpetofauna and Other Aquatic Fauna

The aquatic fauna of freshwater Everglades' marshes include the myriad of small fishes, amphibians, reptiles, crayfish, grass shrimp, snails, amphipods and other invertebrates that play enormously important roles in food webs, nutrient cycles and energy transfers from primary consumers to the highest trophic levels in the ecosystem. Considering their prevalence, little is known about the life histories, population dynamics and ecosystem roles of the aquatic fauna, particularly regarding their ecology in the southern marl prairies.

Population density of small marsh fishes in the Everglades is directly related to the duration of uninterrupted flooding (Trexler and Loftus 2000), and maximum densities are reached only after eight or more years of continual surface water (Loftus and Eklund 1994, Loftus et al. 1990, Turner 1999). The herpetofauna of the short-hydroperiod wetlands reach higher abundance in habitats with longer

hydroperiods and higher water tables (Diffendorfer et al. in preparation, Dalrymple 1987, Dalrymple personal communication). The southern marl prairies, with annual drydowns during most years, represent stressful environments for aquatic fauna. Under pre-drainage conditions, these marshes dried annually for an average of three months; however, under present conditions extensive areas of this landscape are dry for an average of nine months each year (Van Lent et al. 1993, Fennema et al. 1994, VanZee 1999). Survival of aquatic fauna during dry periods in the southern marl prairies depends upon the availability of refugia in solution holes, alligator holes, and under periphyton mats which may retain aquatic or moist environments during absence of surface water (Loftus et al. 1990, Loftus et al. 1992, Dalrymple 1987, Diffendorfer et al. in preparation, Loftus personnal communication, Dalrymple personal communication).

The small marsh fishes provide the major prey base for the wading birds, wood storks and roseate spoonbills that forage and nest in the Everglades (Ogden 1994, Bjork and Powell 1994). Crayfish are particularly important in the diets of white ibis. The marl marshes may provide foraging opportunities for wading birds early in the dry season, when deeper water depths in the lower-elevation sloughs are unsuitable for efficient feeding (Fleming personal communication in Ogden 1994).

Reduced production and altered species composition of fishes and herpetofauna in the southern marl prairies result from 1) the direct impact of shortened hydroperiod (Loftus and Eklund 1994, Trexler and Loftus 2000, Turner 1999, Diffendorfer et al. in preparation, Dalrymple 1987, Dalrymple personnal communication), 2) indirect impacts of shortened hydroperiod via the loss of the periphyton mat and a reduced primary production food base (Browder et al. 1994), 3) reduction in dry season minimum water levels via the diminished dry season refugium function of solution holes, alligator holes and periphyton mats (Loftus et al. 1992, Diffendorfer et al in preparation, Dalrymple 1987, Loftus personal communication, Dalrymple personal communication), 4) reduction in spatial extent of wetland habitat (Davis et al. 1994), and 5) compartmentalization via levees as movement barriers and via canals as corridors for the spread of exotic and higher trophic level fishes (Howard et al. 1995).

A.2.4.6 American Alligator

Prior to drainage, the American alligator was more abundant in the southern marl marshes than in the deeper central marshes of the Everglades (Craighead 1968, Mazzotti and Brandt 1994). By excavating sediments from large solution holes in the limestone bedrock, the alligator created aquatic habitats in which it, and many other groups of aquatic fauna, survived the few months of dry conditions that occurred most years (Craighead 1968). In the excavation of holes and the creation of nest mounds, the alligator created a micro-topography that supported aquatic as well as terrestrial flora and fauna (Craighead 1971, Kushlan 1974). The mounds provided nesting sites not only for the alligator, but also for other marsh reptiles (Deitz and Jackson 1979, Kushlan and Kushlan 1980). In these ways, the alligator was a keystone species in the southern marl prairies because of the aquatic habitats and dry season refugia it created. The high abundance of alligators in the southern marl marshes, in comparison to lower densities in Shark River Slough, was attributed to high water depths in the slough that would have been less suitable for alligators prior to drainage (Ogden 1976, Mazzotti and Brandt 1994). Given the shortened hydroperiods and lowered water tables in the Everglades caused by drainage (Van Lent et al. 1993, Fennema et al. 1994, VanZee 1999) the alligator has mostly abandoned the southern marl prairies, and today the distribution of the alligator in the southern Everglades has shifted to Shark River Slough (Craighead 1968, Mazzotti and Brandt 1994). With the loss of alligators from the southern marl prairies, the habitats and dry season refugia that were provided by its holes and nest mounds have also been lost.

Abandonment by the alligator of the southern marl prairies has resulted from shortened hydroperiod, lowered water table and increased drought severity, as the alligators do not occupy predominantly dry habitat. Cumulative effects leading to the reduced production of aquatic fauna at all trophic levels have probably contributed to the demise of the alligator in the marl prairies, since the alligator depends upon

these organisms for food during various stages of its life history. The reduced population of alligators has in turn allowed depressions that were previously alligator holes to fill in, further diminishing the populations of aquatic fauna upon those approaching which upon which the alligator fed. The restoration of hydroperiods and water tables to near pre-drainage conditions in the southern marl prairies is anticipated to allow the alligator to recolonize this region.

A.2.4.7 Wading Bird and Wood Stork Early Dry Season Foraging

Prior to drainage, the southern marl prairies may have provided shallow-water foraging opportunities for wading birds and wood storks early in the dry season, at a time when water was too deep to allow successful foraging in Shark River Slough (Fleming personal communication in Ogden 1994). The early dry season foraging opportunities may have contributed to the early formation of nesting colonies, and consequent nesting success of the birds. Low fish densities in these seasonally flooded landscapes (Trexler and Loftus 2000) would require considerable concentration to provide an adequate prey base to attract the birds. However, crayfish densities and their linkages to wading bird nesting have yet to be determined in the southern marl prairies. The relationship of the southern marl prairies to wading bird and wood stork nesting remains poorly understood. Because of these uncertainties, wading bird foraging activity is considered to be an indicator of restoration in the southern marl prairies, but not necessarily an indicator of regional wading bird restoration success. Under present conditions, both shortened hydroperiod (Van Lent et al. 1993, Fennema et al. 1994, VanZee 1999) and loss of spatial extent (Davis et al. 1994) have directly reduced the area of feeding habitat and the range of feeding options available to the wading birds and wood storks in the southern marl prairies (Ogden 1994). The value of these landscapes for wading bird and wood stork foraging appears to be very limited today in comparison to pre-drainage conditions (Fleming personal communication in Ogden 1994).

A.2.5 Ecological Effects

Critical Linkages between Stressors and Attributes/Working Hypotheses

As a result of water management-induced stressors, five major causal pathways appear to account for the decline in the ecological attributes of the southern marl prairies. Each pathway, other than that of the Cape Sable seaside sparrow, has been most severely impacted in the southern marl prairies to the east of Shark River Slough. The causal pathways are as follows:

- The periphyton mat has been altered in ways that reduce its contribution to aquatic food chains and marl formation. Diatom and green algal components of the periphyton mat have decreased as a result of severely shortened hydroperiod.

- The American alligator has been mostly eliminated, due to severely shortened hydroperiod and lowered water table, from the landscape where it was once most abundant. Alligator holes in depressions in the limestone bedrock have silted in with organic debris and no longer function as dry season refugia for aquatic fauna. Their loss has decreased the heterogeneity of vegetation habitat and micro-topography.

- The marsh fishes, herpetofauna and probably other aquatic fauna of the southern marl prairies can maintain only a diminished population density and secondary production given the shortened hydroperiod and lowered water table, the altered periphyton mat, the loss of dry season refugia in alligator and solution holes, and the physiological stress due to wet season water level reversals.

- The vegetation community mosaic has lost heterogeneity and changed in species composition due to shortened hydroperiod, lowered water table, and altered fire regime, subsequently there is loss

of alligator holes microtopography, tropical hammock tree island burn-out, woody plant invasion, and the spread of exotic invasive plants.

- The Cape Sable seaside sparrow is limited in reproductive success and population size due to extended flooding and drying pattern reversals from upstream water releases to the west of Shark River Slough. To the east of the Slough, the sparrow is threatened by shortened hydroperiod and lowered water table, resulting either in increased fire frequency and severity, or in woody plant invasion in the absence of fire.

These casual pathways are based on key hypotheses developed during the conceptual ecological model workshops. These hypotheses determine the content and organization of the Southern Marl Prairies Conceptual Ecological Model. The hypotheses are presented here, organized by attribute.

A.2.5.1 Periphyton Mats

Relationship to Hydroperiod

A defining characteristic of marl wetlands is the presence of extensive mats of calcitic algae (Gleason 1972). These mats form during the wet season and require at least four months to fully develop and reach equilibrium between production and respiration. In marl wetlands with shortened hydroperiod due to drainage activities, periphyton mats decrease in spatial cover and primary production. Areas of severely drained marl wetlands to the east of Shark River Slough are devoid of periphyton mats. Reduced hydroperiod also results in a decrease in the diatom and green algal species in the periphyton mat, leaving mostly the mat-forming blue-greens *Schizothrix* and *Cytonemia* (Browder et al. 1994).

Level of certainty – high

Functional Contribution to Food Webs

Periphyton mats are functionally important as a primary production base for aquatic food webs supporting fishes and other aquatic fauna in marl wetlands (Browder et al. 1994). Reduced primary production and decreased representation of diatoms and green algae in periphyton mats contribute to reduced populations of fishes and other aquatic fauna in marl wetlands where hydroperiod has been shortened (Browder et al. 1994). Renewed primary production and food web functions of periphyton mats that will result from the resumption of natural hydroperiods will contribute to increase population densities of fishes and other aquatic fauna.

Level of certainty – low

Functional Contribution to Marl Accretion

Periphyton mats are functionally important in the precipitation of calcite and the accretion of the calcitic sediments that form the marl soils. Rates of marl accretion are directly related to the spatial extent and production of the mats (Gleason 1972). Marl accretion rates will increase as hydroperiods and periphyton mats are restored in presently overdrained marl wetlands.

Regulatory water releases from Water Conservation 3A have lengthened hydroperiod in marl wetlands to the west of Shark River Slough, reducing calcite precipitation and marl production by the periphyton, and shifting the wetlands to peat-forming systems. Reduction of hydroperiods to natural durations will restore calcite-precipitating mats and marl accretion in those wetlands.

Level of certainty – moderate

A.2.5.2 Vegetation Community Mosaic

Relationship to Hydroperiod and Water Table

Natural hydrologic patterns in marl wetlands support gradients of vegetation subtypes are aligned sequentially along hydrologic gradients ranging from 1-2 month hydroperiods (*Schizachrium rhizomatum*-dominated) to 3-5 months (*Muhlenbergia filipes*-dominated) to 6-8 months (*Cladium jamaicense*-dominated). These communities are notable for the high floral species richness, which includes more than 100 herbaceous plant species (Olmstead and Loope 1984). Hydrologic patterns that maintain these community gradients also support higher-elevation tropical hammocks and pine forests that occur as islands within the marl wetlands. These forested communities contain a flora of West Indian origin that is unique in the Florida mainland and that includes the highest number of rare and threatened plant species in southern Florida (Gunderson 1994).

Shortened hydroperiod and lowered water table in overdrained marl wetlands east of Shark River Slough expand the distribution of vegetation subtypes that grow at the upper end of the hydrologic gradient and decrease the distribution of vegetation subtypes that grow at the lower end of the hydrologic gradient (Hofstetter and Hilsenbeck 1980). Lengthened hydroperiod in marl wetlands west of Shark River Slough that receive regulatory water releases from Water Conservation Area 3A have the opposite effect on vegetation distribution. Resumption of natural hydroperiods will restore gradients and distributions of the full range of vegetation subtypes that are representative of marl wetlands (Hofstetter and Hilsenbeck 1980).

Level of certainty – high

Interactions of Hydroperiod and Water Table with Fire

Shortened hydroperiod and lowered water table contribute to the burn-out of islands of tropical hammocks and pine forests in overdrained marl wetlands due to increased intensity of wildfires (Loope and Urban 1980). Wildfire intensity and tree island damage may be augmented by a shift in fire seasonality from naturally-occurring, lightning-ignited fires during the early wet season to burning practices by humans during the dry season. The restoration of natural hydroperiods and water tables, combined with prevention of dry season wildfires, will reduce the incidence of tree island burn-out in marl wetlands (Gunderson and Snyder 1994).

Shortened hydroperiod and lowered water table allow the invasion of woody shrubs and trees into graminoid wetlands of overdrained marl systems (Armentano et al. 1995). Reduction in the frequency of naturally-occurring fires also supports woody plant establishment. Restoration of natural hydroperiods and water tables, in combination with natural fire regimes, will control woody vegetation and deter its expansion in graminoid wetlands.

Level of certainty – high

Relationship to Exotic Plants

The spread of exotic plants into the graminoid wetlands and forested islands of marl systems changes community composition, displaces native species, and contributes to woody invasion. The restoration and maintenance of vegetation mosaics of marl wetlands is contingent to the control and eradication of invasive exotics (Olmstead and Loope 1984, Armentano et al. 1995, Jones and Doren 1997).

Level of certainty – high

A.2.5.3 Cape Sable Seaside Sparrow

Requirements for Sustainability

The sustainability of the Cape Sable seaside sparrow, which is endemic to marl wetlands of the Everglades, requires the maintenance of three stable subpopulations and breeding colonies in the areas where they presently occur: a western subpopulation to the west of Shark River Slough, an eastern subpopulation to the east of mid-Shark River Slough, and a central subpopulation to the east of southwestern Shark River Slough (Pimm 1995).

Cape Sable seaside sparrows usually raise one or two broods in a season, although they may raise a third brood if weather conditions allow (K. Palmer, United States Fish and Wildlife Service, personal communication). Although 45 days of nearly dry conditions without fire would be sufficient for a single nesting event, however, an 80 day period is preferred in order to allow time for subsequent clutches which are considered key to population recovery. The current legal requirement for subpopulation A is a minimum of 50-60 (60 being most desirable) consecutive nesting days, preferably 80 consecutive nesting days, in all years until subpopulation A numbers have increased to at least 1,000 individuals.

The target for subpopulations B-F are as follows (Palmer personal communication):

- 40 consecutive days of water levels below ground for 8 out of 10 years (80 percent of the time) is considered favorable
- 40 consecutive days of water levels below ground for 7 out of 10 years (70 percent of the time) is considered borderline for persistence
- 80 consecutive days of water levels below ground for 8 out of 10 years (80 percent of the time) is considered very favorable
- 80 consecutive days of water levels below ground for 7 out of 10 years (70 percent of the time) is considered favorable

The sustainability of each subpopulation requires successful nesting at least 7 out of 10 years. Sustainability also requires a total population size, based on a five-year running average, ranging from a minimum of 2,000-3,000 birds, to as many as 6,600 birds during particularly good years, with trends in increasing population shared among the three subpopulations.

A habitat maintenance performance measure with a target of 0- to 2-months (0- to 60-days) average discontinuous hydroperiod is not expected to support vegetation favorable to sparrow nesting, a 2- to 4-month (60- to 120-day) average discontinuous hydroperiod is considered favorable and supportive of *Muhlenbergia*-dominated habitat, a 4- to 6-month (120- to 180-day) average discontinuous hydroperiod is considered good for other vegetation favorable to sparrow nesting, and an average discontinuous hydroperiod greater than 6 months (greater than 180 days) is not expected to support vegetation favorable to sparrow nesting.

Level of certainty – moderate

Relationships to Drying Patterns, Fire, and Invasion of Woody Vegetation

The Cape Sable seaside sparrow nests during the dry season months, mostly during April-June, in sites free of standing shrubs or trees. The construction of nests approximately 10 centimeters above the ground

at the bases of tussocks of muhly grass and other marsh graminoids makes the sparrow vulnerable to both spring wildfires and unseasonable water depth increases (dry season water level reversals). Successful nesting requires at least 60 days of nearly dry conditions without fire. Dry season water level reversals have been a particular problem to the nesting success of the western subpopulation, where regulatory water releases through the S-12 A and B outflow gates of Water Conservation Area 3A contribute to reversals and subsequent nest drowning. The eastern subpopulation occupies an overdrained region of marl prairie subject to spring wildfires or the invasion by woody vegetation. The central subpopulation is the most stable because of its remote location, although it is vulnerable to naturally-occurring fires.

The restoration of natural hydroperiods throughout the marl wetlands of the southern Everglades will provide an average of at least 3-4 months of dry conditions during the spring nesting season of the sparrow, fulfilling its water level requirements for successful nesting and multiple clutches most years in all three subpopulations. Hydroperiod restoration in the overdrained marshes of the eastern subpopulation will assist in containing wild fires during the nesting season by increasing soil moisture, and by extending the duration of standing water low-lying areas functioning as fire breaks. Hydroperiod restoration, in combination with natural fire regimes, will prevent the spread of woody vegetation into the nesting grounds of the eastern subpopulation.

Level of certainty – high

A.2.5.4 Aquatic Fauna

Relationship to Spatial Extent

The conversion of portions of the marl wetlands east of Shark River Slough to agricultural and urban land use represents a proportional loss in the populations of fishes and other aquatic fauna that once inhabited that region (Davis et al. 1994). That loss is considered to be irreversible, short of reflooding developed areas and reconnecting them to the remaining natural system.

Level of certainty – high

Relationship to Hydroperiod

The population density, size structure and relative abundance of fishes in marl wetlands are limited by the annual duration of uninterrupted flooding (Trexler and Loftus 2000), which averages approximately 8-9 months per year under natural hydrologic conditions. The annual drying pattern that is typical of marl wetlands limits small fish density to less than 10 fish per square meter, compared to densities approaching 60 fish per square meter in areas of Shark River Slough with multi-year hydroperiods. This difference in densities occurs because fish density is directly related to the period of population recovery between marsh drydowns. The relative abundance of fish species also responds to hydroperiod. Blue-fin killifish, golden topminnow, lake chubsucker, and dollar sunfish are less represented under shorter hydroperiods (Trexler and Loftus 2000). Relative abundance affects size structure, in that the lake chubsucker and dollar sunfish represent larger species in the native fish assemblage of the marl marshes. The reduction of hydroperiod in overdrained marl wetlands limits fish density, size structure and representation of long-hydroperiod species to levels below those expected under natural hydrologic conditions (Trexler and Loftus 2000). Hydroperiod restoration is expected to result in the recovery of fish density, size structure and relative abundance.

Level of certainty- high

Relationship to Dry Season Refugia

Solution holes in exposed bedrock hold standing water during the dry season and supplement alligator holes as drought refugia for fishes and other aquatic fauna in marl wetlands (Loftus et al. 1990, Loftus et al. 1994, Dalrymple 1987, Diffendorfer et al. in prep). The refugia enable these animals to survive the annual dry season and to disperse upon reflooding to repopulate the landscape during the wet season. Lowered water table and shortened hydroperiod in overdrained marl wetlands have increased the frequency and duration of the drying of solution holes and alligator holes, diminishing their drought refugium function and reducing the populations of aquatic fauna that depend on them. Restoration of hydroperiods and water tables toward pre-drainage conditions are expected to renew this refugia function.

Renewal of the dry season refugia functions of alligator holes and solution holes is central to any restoration strategy for overdrained marl wetlands (Loftus et al. 1992, Dalrymple 1987). Their restoration will sustain substantially higher populations of fish and other aquatic fauna by supporting increased survival during dry conditions and increased dispersal and reproduction during the wet season. Success will be realized as increased population density and size structure, and as decreased inter-annual variation in these parameters.

Level of certainty – low

Relationship to Exotic Fishes

The construction of the C-111 and L-31 canal systems through and adjacent to the marl wetlands to the east of Shark River Slough has provided corridors for the spread of exotic fishes into those wetlands (Howard et al. 1995). The most important impact on native fish populations currently appears to result from the occupancy of solution holes by the black acara during the dry season. This South America cichlid appears to prey upon native species in the solution holes, thereby reducing their survival through the dry season, as evidenced by observations of only black acara remaining alive in receding pools of water in the solution holes as the dry season progresses. There is no known deterrent to the persistence and spread of higher trophic level exotic fishes such as the black acara in the marl wetlands where they have become established. The potential for diminished dry season refugium functions of solution holes and possibly alligator holes for native species, as a result of displacement by exotic species, must be considered in restoration strategies and expectations for aquatic fauna in affected marl wetlands.

Level of certainty – low

Relationship to Primary Production

Populations of fishes and other aquatic fauna in marl wetlands are supported by food webs based on the primary production of periphyton mats (Browder et al. 1994). Reduced spatial coverage, reduced primary production, and altered taxonomic composition of periphyton mats support lower population densities of these animals in marl wetlands where hydroperiod has been shortened. Renewed primary production and food web functions of periphyton mats resulting from the resumption of natural hydroperiods will contribute to increase population densities of fishes and other aquatic fauna.

Level of certainty – low

Functional Importance of Macroinvertebrates and Herpetofauna

The constraint that annual drying patterns place on fish populations suggests that macroinvertebrates and herpetofauna may dominate the aquatic fauna as important intermediate trophic levels and prey bases for

higher consumers in marl systems (Fleming personal communication in Ogden 1994). However, little is known about the life histories, population dynamics and ecosystem roles of species such as grass shrimp, crayfish, ranid and hylid frogs, and water snakes. Although they would also be expected to decline in abundance with the overdrainage of marl wetlands, in response to the same factors affecting the fishes, quantitative relationships are mostly lacking. Crayfish and water snakes were noted to be conspicuously abundant in marl wetlands in the early 1900s, apparently at densities much higher than those observed today. Crayfish constitute an important prey item in the diets of many vertebrates that have declined in abundance with the drainage of the Everglades, including pig frogs, otters, alligators, and white and glossy ibis (Momot et al. 1978, Kushlan and Kushlan 1979, Hogger 1988, Hobbs et al. 1989). The lack of information regarding the population dynamics functional roles of macroinvertebrates and herpetofauna in the Everglades, despite the potential importance of these groups, represents an important gap in our information regarding the degradation and restoration of marl systems.

Level of certainty – low

A.2.5.5 American Alligator Populations

Distribution and Abundance

The American alligator was historically abundant and nested in marl wetlands, where it excavated sediments from large solution holes in the limestone bedrock to produce alligator holes. Prior to drainage, alligator populations in the southern Everglades were concentrated in these higher elevation marshes (Craighhead 1968, Mazotti and Brandt 1994). Densities of alligators in the rockland marl marshes north of Long Pine Key exceeded densities in Shark River Slough, where the water was often too deep for nesting. Alligator abundance and reproduction have declined in the marl wetlands where they were previously most abundant. Alligator populations in the southern Everglades are now concentrated in Shark River Slough. As a result, abandoned alligator holes in the marl wetlands have filled in with debris (Craighead 1971, Kushlan 1974).

Alligator population distribution and abundance may be vary geographically due to underlying geology as a limiting factor for nesting habitat in the marl system, in that nesting may be limited to areas where irregularities in the bedrock surface allow for the excavation of alligator holes. For example, establishment of alligator populations and holes due to hydrologic restoration is expected in the rockland marl marshes to the north of Long Pine Key, but it may be less likely in the marl prairies further south.

Level of certainty – high

Relationship to Hydroperiod and Water Table

The decline in alligator abundance and reproduction in marl wetlands is attributed to shortened hydroperiods and lowered water tables (Van Lent et al. 1993, Fennema et al. 1994, Van Zee 1999). Alligators are expected to repopulate presently overdrained areas of marl wetlands, to occupy and excavate most presently filled-in holes, and to resume nesting and successful reproduction over a 5-15 year time frame after restoration of natural hydroperiods and water tables.

Level of certainty – high

Alligator Holes as Dry Season Refugia

The alligator is a keystone species in marl wetlands as alligator holes provide important refugia, allowing aquatic fauna to survive the annual dry season and to radiate out, repopulating the marshes upon

reflooding. The loss of alligators, and the filling-in of alligator holes, has diminished the survival, resilience and population density of populations of aquatic fauna in overdrained marl wetlands (Deitz and Jackson 1979, Kushlan and Kushlan 1980). The restoration of alligator holes is expected to restore their keystone function as drought refugia. As a result, the resilience and density of aquatic fauna populations dependent on the refugium function of the alligator holes should increase.

Level of certainty- low

Alligator Holes as Micro-Topographic Gradients

In the excavation of holes and nest mounds, the alligator also plays a keystone role in creating micro-topographic gradients that support aquatic as well as terrestrial fauna and provide nest sites for other species of marsh reptiles in marl wetlands (Craighead 1971, Kushlan 1974). With the loss of the micro-topographic gradients associated with the holes, aquatic and terrestrial habitats, and dependent flora and fauna have also declined in abundance. The restoration of alligator holes is expected to restore micro-topographic gradients. As a result, the communities and populations of the flora and fauna that depend upon the micro-topography should return to former levels of abundance.

Level of certainty – high

Feedback Loop

A positive feedback loop probably exists from beneficial hydroperiods and water tables to alligator populations, to alligator holes, to aquatic fauna density and distribution, and back to alligator populations. That feedback loop is assumed to have been functional under pre-drainage conditions in marl wetlands where alligators were formerly abundant, although it is clearly not functional in overdrained marshes today. Increasing hydroperiods and water tables toward pre-drainage conditions is expected to renew the positive feedback loop, although the necessary level of hydrologic restoration to accomplish this is uncertain.

Level of certainty – low

A.2.5.6 Wading Birds, Wood Stork and Roseate Spoonbill

Relationship to Hydroperiod and Drying Pattern

It has been proposed that the marl wetlands provide foraging opportunities for wading birds, wood storks and roseate spoonbills during unusually wet years and early in the dry season, when water is too deep to allow successful foraging elsewhere in the southern Everglades (Fleming personal communication in Ogden 1994). The depauperate fish populations resulting from annual drying patterns in the marl wetlands might be considered unlikely to provide enough food resources to influence regional nesting success. However, during specific years when a prolonged wet season is followed by a beneficial drying pattern, the normally low fish density in a relatively unproductive marl system can be concentrated to levels comparable to more productive regions such as Shark River Slough and the Gulf of Mexico estuaries (Trexler and Loftus 2000). Those years have been shown to correspond to the years when roseate spoonbill nested successfully in nearby Florida Bay colonies. Thus, marl wetlands may contribute to regional nesting success under specific hydrological conditions during specific years. Hydroperiod restoration in presently overdrained marl wetlands is expected to increase the frequency of years when prolonged wet seasons and natural drying patterns produce and concentrate fishes to attract larger seasonal aggregations of foraging birds.

Level of certainty – moderate

A.2.6 Research Questions

Key uncertainties regarding ecological response to hydrologic restoration in the marl wetlands pertain to the population dynamics of the marsh fishes and other aquatic fauna in relation to food webs and drought refugia. The overarching question is how hydroperiod restoration of the marl wetlands will influence populations of aquatic fauna representing the food base for higher predators, including wading birds.

Periphyton Productivity Limitation on Aquatic Fauna Populations

Are populations of marsh fishes and other aquatic fauna regulated by food webs generated from primary production of periphyton mats? Will the restoration of periphyton mat spatial cover, primary productivity and taxonomic composition due to hydroperiod restoration yield densities of aquatic fauna above those predicted in response to hydroperiod restoration alone? Develop quantitative relationships and models of periphyton productivity as a factor limiting populations of marsh fishes and other key taxa of aquatic fauna.

Dry Season Refugia Limitation on Aquatic Fauna Populations

Are populations of marsh fishes and other aquatic fauna regulated by the availability of dry season refugia of standing water in alligator holes and solution holes? Although fishes and other aquatic fauna condense in alligator holes and solution holes as marl wetlands dry, do survival rates during the dry season and subsequent wet season dispersal and reproduction sustain population densities above those predicted in relation to hydroperiod alone? Determine survival rates of marsh fishes and other aquatic fauna in alligator and solution holes during dry seasons in relation to the depth and persistence of standing water and the presence of exotic fishes. In relation to duration of flooding, determine rates of dispersal and reproduction of dry season survivors during the wet season. Compare populations of marsh fishes and other aquatic fauna with and without functional dry season refugia in marl wetlands of similar hydroperiod. Develop quantitative relationships and models of dry season refugia as a factor limiting populations of marsh fish and other aquatic fauna in marl wetlands.

Functional Importance of Macroinvertebrates and Herpetofauna

What is the functional importance of crayfish, grass shrimp, ranid and hylid frogs as intermediate trophic levels and prey bases for higher consumers in restored marl wetlands, considering the constraint that annual drying patterns place on marsh fish populations? Are their populations regulated by the same factors regulating marsh fish populations, including hydroperiod, dry season refugia and primary productivity? Are white ibis reproduction and super colony formation related to marl wetland crayfish populations, as influenced by inter-annual hydrologic patterns? Develop quantitative relationships and models of crayfish, grass shrimp and frog populations in relation to hydroperiod, dry season refugia, and primary production in marl wetlands. Develop quantitative relationships and models of the energetic requirements of wading bird nesting colonies, including super colonies, in relation to the density, seasonal concentration and inter-annual variation of populations.

A.2.7 Hydrologic Performance Measures

Recovery of the ecological values of the southern marl prairies is dependent upon the reversal of the cumulative effects of decades of drainage, detrimental fire regimes and exotic plant invasion. Therefore, hydrologic performance measures have been developed for hydroperiod, drought severity and water level reversal.

A.2.7.1 Hydroperiod

The performance measure for hydroperiods is the mean water depth and duration of flooding. The target for flood events is a mean water depth equal to or exceeding 0.2 feet because depths less than 0.2 feet have been observed to impair the establishment of populations of aquatic organisms. The target for duration is the recovery of mean duration of flooding indicated by NSM.

A.2.7.2 Drought Severity

Drought severity exacerbates the effects of shortened duration of flooding and is identified as a hydrologic variable that affects most of the ecological attributes in the conceptual ecological model. Dry events occur when the water level drops either to or below the ground surface. The performance measure for drought severity is the depth water levels drop below the ground surface during a dry event. The target is not to exceed depths below ground indicated by NSM for each dry event.

A.2.7.3 Water Level Reversal

Wet season water level reversal may also be an important hydrologic variable for ecological restoration in the marl prairie/rocky glades. A reversal is distinguished from a dry period in that during a reversal, water depth does not drop to or below the ground surface. The performance measure is the number of reversals. The target is not to exceed the number of reversals indicated by NSM.

A.2.8 Ecological Performance Measures

A.2.8.1 Periphyton Mat

The performance measure for periphyton mats is spatial extent, species composition and primary productivity. The target for periphyton is to increase mat cover, biovolume, organic content, percent noncalcareous algae and diatom composition.

A.2.8.2 Marl Substrate

The performance measure for marl substrate is marl accretion. A target has not been developed.

A.2.8.3 Vegetation Mosaic and Diversity

The performance measure for vegetation mosaic and diversity is emergent macrophyte and tree island community cover and compostion. The target is to increase spatial cover and species composition of gaminoid and tree island communities.

A.2.8.4 Cape Sable Seaside Sparrow

The performance measure for the Cape Sable seaside sparrow is nesting distribution and success and population density. The target for the Cape Sable seaside sparrow is to increase the number of stable subpopulations and the number of individual birds.

A.2.8.5 Marsh Fishes, Herpetofauna and other Aquatic Fauna

The performance measure for marsh fishes, herpetofauna, and other aquatic fauna is density and distribution. A target for marsh fishes and associated fauna in marl prairies is to increase the seasonal production to pre-drainage (NSM) levels as indicated by late wet season population densities in areas

where natural hydroperiods are restored. Another target is to provide high prey-availability patches where wading birds can feed effectively as water levels recede during the dry season.

A.2.8.6 American Alligator

The restoration of pre-drainage (NSM) hydropatterns in the southern marl prairies is anticipated to allow the alligator to recolonize this region. The performance measure for American alligators is spatial distribution and abundance, rate of hole occupancy, frequency of nesting and hatching, and size distribution. The targets are to increase spatial distribution and relative abundance, hole occupancy, nesting success and juvenile size classes.

A.2.8.7 Wading Bird and Wood Stork Foraging Opportunity

The performance measure for wading bird and wood stork foraging opportunity is seasonal abundance, foraging activity, and distribution. The target for wading bird and wood stork foraging opportunity is an increase in flock size and numbers of birds foraging in previously overdrained southern marl prairies.

A.2.9 Model

The diagram for the Southern Marl Prairies Conceptual Ecological Model is presented in Figure A-8. The effects of the altered hydropattern stressors are provided in more detail in Figure A-9. The key to the symbols used in the diagrams is presented in Figure A-10.

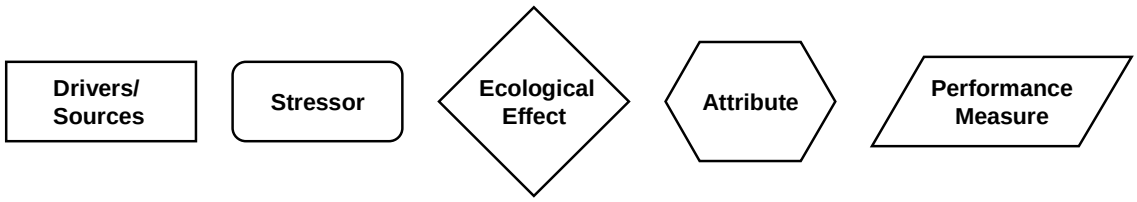


Figure A-8: Key to the Symbols Used in the Following Diagram

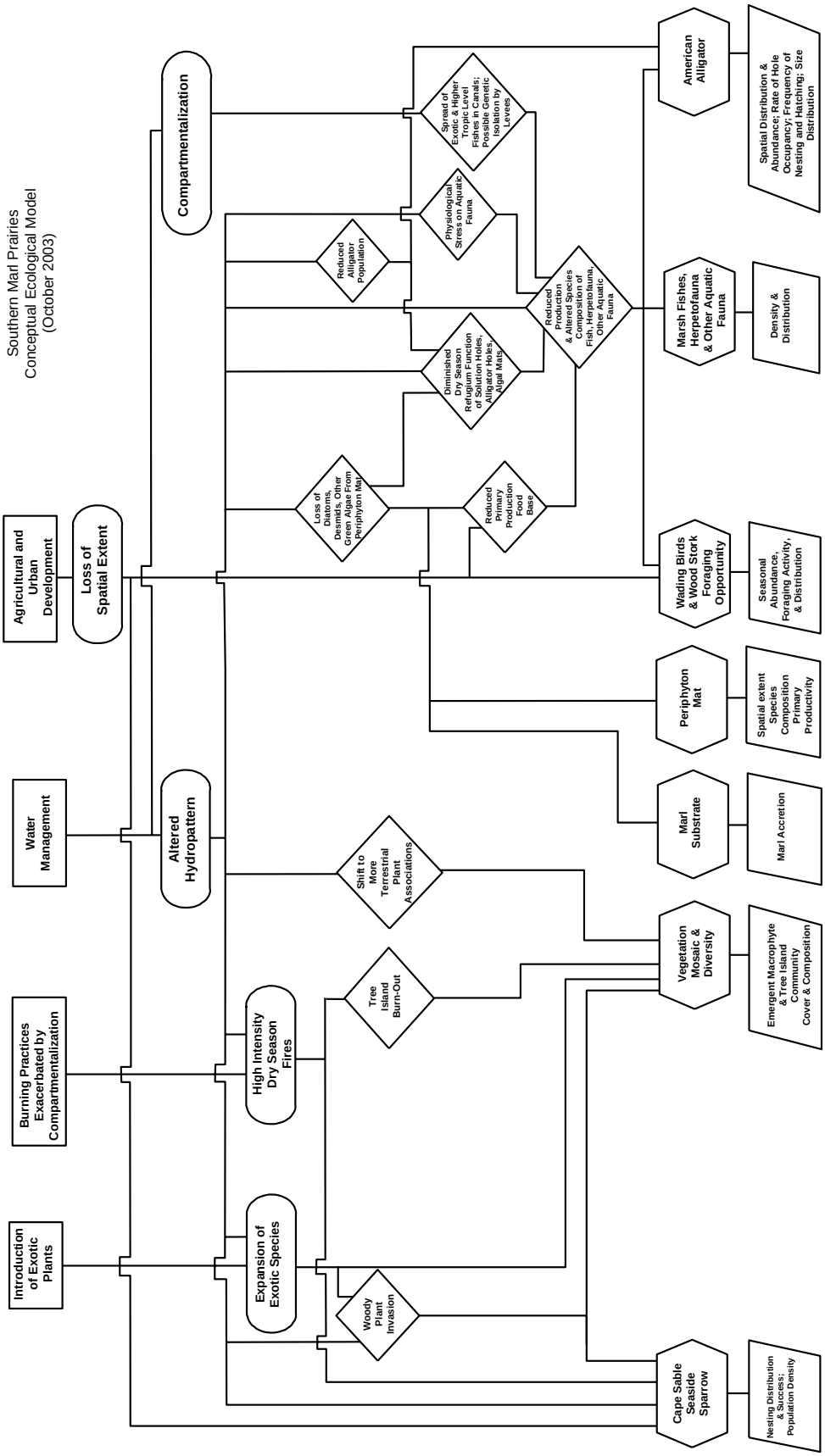


Figure A-9: Diagram of the Southern Marl Prairies Conceptual Ecological Model

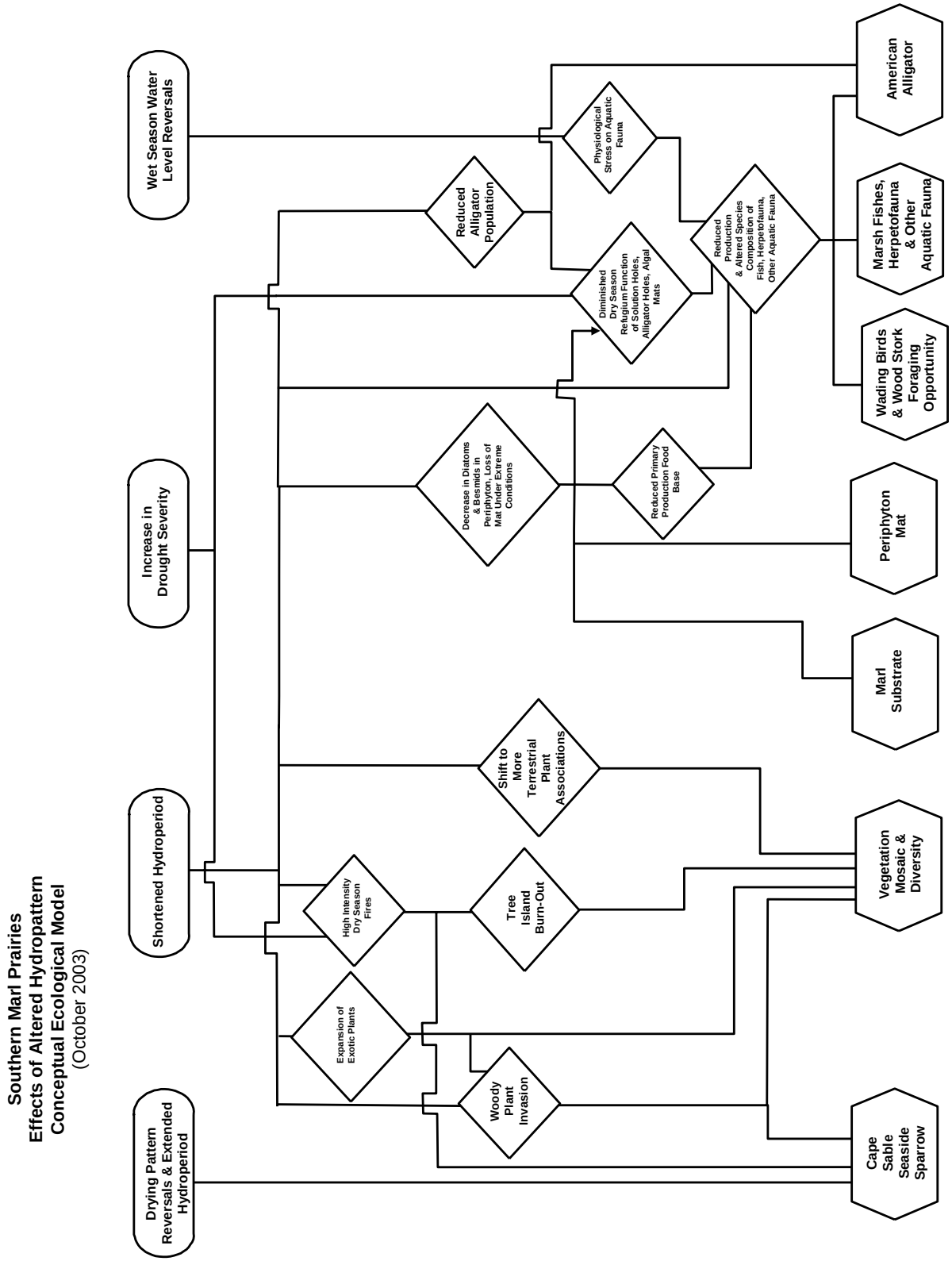


Figure A-10: Diagram of the Effects of Altered Hydropattern in the Southern Marl Prairies

A.2.10 Literature Cited

Armentano, T.V., R.F. Doren, W.J. Platt, and T. Mullins. 1995. Effects of Hurricane Andrew on coastal and interior forests of southern Florida: overview and synthesis. Journal of Coastal Research Special Issue 2: 111-114.

Bjork, R.D., and G.V.N. Powell. 1994. Relations between Hydrologic Conditions and Quality and Quantity of Foraging Habitat for Roseate Spoonbills and Other Wading Birds in the C-111 Basin. National Audubon Society Final Report to South Florida Research Center, Everglades National Park, Homestead, Florida.

Browder, J.A., P.J. Gleason, and D.R. Swift. 1994. Periphyton in the Everglades: Spatial variation, environmental correlates, and ecological implications. In: Davis, S.M., and J.C. Ogden (eds). Everglades, the Ecosystem and its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 379-418.

Busch, D.E., W.F. Loftus, and O.L. Bass, Jr. 1998. Long-term hydrologic effects on marsh plant community structure in the southern Everglades. Wetlands 18: 230-241.

Craighead, F.C. 1968. The role of the alligator in shaping plant communities and maintaining wildlife in the southern Everglades. Florida Naturalist 41: 2-7, 69-74, 94.

Craighead, F.C. 1971. The Trees of South Florida, Volume 1. University of Miami Press, Coral Gables, Florida.

Dalrymple, G.H. 1987. The herpetofauna of Long Pine Key in relation to vegetation and hydrology. In: Szaro, R.C. (ed). Management of Amphibians, Reptiles, and Small Mammals in North America: Proceedings of the Symposium: July 19-21, 1988, Flagstaff, Arizona. General Technical Report RM-166, Rocky Mountain Forest and Range Experiment Station, United States Department of Agriculture Forest Service, Fort Collins, Colorado.

Davis, S.M., L.H. Gunderson, W.A. Park, J.R. Richardson, and J.E. Mattson. 1994. Landscape dimension, composition, and function in a changing Everglades ecosystem. In: Davis, S.M., and J.C. Ogden (eds). Everglades, the Ecosystem and its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 419-444.

DeAngelis, D.L., and P.S. White. 1994. Ecosystems as products of spatially and temporally varying driving forces, ecological processes, and landscapes: A theoretical perspective. In: Davis, S.M., and J.C. Ogden (eds). Everglades, the Ecosystem and its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 9-27.

Deitz, D.C., and D.R. Jackson. 1979. Use of alligator nests by nesting turtles. Journal of Herpetology 13: 510-512.

Diffendorfer, J.E., P.M. Richards, G.H. Dalrymple, and D.L. DeAngelis. In preparation. Using ecosystem and food webs in conservation: an example from the herpetological assemblage.

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

Gleason. 1972. The origin, sedimentation, and stratigraphy of a calcitic mud located in the southern freshwater Everglades. Ph.D. thesis, Pennsylvania State University, University Park, Pennsylvania.

Gunderson, L.H. 1994. Vegetation of the Everglades: Determinants of community composition. . In: Davis, S.M., and J.C. Ogden (eds). Everglades, the Ecosystem and its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 323-340.

Gunderson, L.H., and J.R. Snyder. 1994. Fire patterns in the southern Everglades. In: Davis, S.M., and J.C. Ogden (eds). Everglades, the Ecosystem and its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 291-305.

Hilsenbeck, C.E., R.H. Hofstetter, and T.R. Alexander. 1979. Preliminary Synopsis of Major Plant Communities in the East Everglades Area, Vegetational Maps Supplement. University of Miami Report, University of Miami, Coral Gables, Florida.

Hobbs, H.H., III, J.P. Jass, and J.V. Huner. 1989. A review of global crayfish introductions with particular emphasis on two North American species (*Decapoda, Cambaridae*). Crustaceana 56:299-316

Hofstetter, R.H. and C.E. Hilsenbeck. 1980. Vegetational studies of the east Everglades. Final Report to Dade County Planning Department, East Everglades Resources Planning Project: 109pp.

Hogger, J.B. Ecology, population biology and behaviour. In: Holdich, D.M., and R.S. Lowery (eds). Freshwater Crayfish: Biology, Management and Exploitation. Timber Press, Portland, Oregon, pp. 114-144.

Howard, K.S., W.F. Loftus, and J.C. Trexler. 1995. Seasonal Dynamics of Fishes in Artificial Culvert Pools in the C-111 Basin, Dade County, Florida. Everglades National Park, Homestead, Florida..

Jones, D.B., and R.F. Doren. 1997. Distribution, biology and control of *Schinus terebinthifolius* in southern Florida with special reference to Everglades National Park. In: Brock, J.H., M.Wade, P. Tysek and D. Green (eds). Plant Invasions: Studies From North America and Europe, Backhuys Publishers, Lyden, Netherlands: 81-93.

Kushlan, J.A. 1974. Observations on the role of the American alligator (*Alligator mississippiensis*) in the southern Florida wetlands. Copeia 1974: 993-996.

Kushlan, J.A., and M.S. Kushlan. 1979. Observations on the crayfish in the Everglades, Florida, USA. Crustaceana, Supplement 5: 115-120.

Kushlan, J.A., and M.S. Kushlan. 1980. Everglades alligator nests: Nesting sites for marsh reptiles. Copeia 1980: 930-932.

Loftus, W.F., and A.M. Eklund. 1994. Long-term dynamics of an Everglades fish community. In: Davis, S.M., and J.C. Ogden (eds). Everglades, the Ecosystem and its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 461-483.

Loftus, W. F. and James A. Kushlan. 1987. Freshwater fishes of southern Florida. Bulletin of the Florida State Museum, Biological Sciences 31: 147-344.

Loftus, W.F., J.D. Chapman, and R. Conrow. 1990. Hydrological effects on Everglades marsh food webs, with relation to marsh restoration efforts. In: Larson, G., and M. Soukup (eds). 1986 Conference on Science in the National Parks Proceedings, Volume 6: Fisheries and Coastal Wetlands Research. George Wright Society, Hancock, Michigan, pp. 1-22.

Loftus, W.F., R.A. Johnson, and G.H. Anderson. 1992. Ecological impacts of the reduction of ground water levels in short-hydroperiod marshes of the Everglades. In: Stanford, J.A., and J.J. Simons (eds). Proceedings of the First International Conference on Ground Water Ecology. American Water Resources Association: 199-207.

Loope, L.L., and N.H. Urban. 1980. A survey of fire history and impact in tropical hardwood hammocks in the east Everglades and adjacent portions of Everglades National Park. Report T-592, South Florida Research Center, Everglades National Park, Homestead, Florida.

Mazzotti, F.J., and L.A. Brandt. 1994. Ecology of the American alligator in a seasonally fluctuating environment. In: Davis, S.M., and J.C. Ogden (eds). Everglades, the Ecosystem and its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 485-505.

Momot, W., H. Gowing, and P. Jones. 1978. The dynamics of crayfish and their role in the ecosystem. American Midland Naturalist 99: 10-35.

Ogden, J.C. 1976. Crocodilian ecology in southern Florida. In: Research in the Parks: Transactions of the National Park Centennial Symposium, 1971. National Park Service Symposium Series Number 1, United States Department of the Interior, Washington, D.C.

Ogden, J.C. 1994. A comparison of wading bird nesting colony dynamics (1931-1946 and 1974-1989) as an indication of ecosystem conditions in the southern Everglades. In: Davis, S.M., and J.C. Ogden (eds). Everglades, the Ecosystem and its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 533-570.

Olmstead, I.C., and L.L. Loope. 1984. Plant communities of Everglades National Park. In: Gleason, P.J. (ed). Environments of South Florida: Past and Present II, Miami Geological Society, Coral Gables, Florida.

Pimm, S.L. 1995. Population Ecology of the Cape Sable Seaside Sparrow (*Ammodramus maritima mirabilis*). Annual Report 1995. Department of Ecology and Evolutionary Biology, University of Tennessee, Knoxville, Tennessee..

Trexler, J.C., and W.F. Loftus. 2000. Analysis of relationships of Everglades fish with hydrology using long-term data bases from the Everglades National Park. Report to Everglades National Park, Homestead, Florida.

Trexler, J.C., W.F. Loftus, and O.L. Bass. 1996. Documenting the effects of Hurricane Andrew on Everglades aquatic communities, Part I. In: Trexler, J.C., L. Richardson, and K. Spitze (eds). Effects of Hurricane Andrew on the Structure and Function of Everglades Aquatic Communities. Final Contract Report CA5280-3-9014 to Everglades National Park, Homestead, Florida, pp. 6-136.

Trexler, J.C., W.F. Loftus, F. Jordan, J. Lorenz, J. Chick, and R.M. Kobza. 2001. Empirical assessment of fish introductions in a subtropical wetland: an evaluation of contrasting views. Biological Invasions 2: 265-277.

Turner, A.M., J.C. Trexler, C.F. Jordan, S.J. Slack, P. Geddes, J. Chick, and W.F. Loftus. 1999. Targeting ecological features for conservation: standing crops in the Florida Everglades. Conservation Biology 13-4: 898-911

Van Lent, T.A., R.A. Johnson, and R.J. Fennema. 1993. Water management in Taylor Slough and effects on Florida Bay. Technical Report 93-3, South Florida Natural Resources Center, Everglades National Park, Homestead, Florida.

VanZee, R. 1999. Natural System Model Version 4.5 Documentation Report. Draft report, South Florida Water Management District, West Palm Beach, Florida.

A.3 EVERGLADES MANGROVE ESTUARIES CONCEPTUAL ECOLOGICAL MODEL

A.3.1 Model Lead

Steven M. Davis, South Florida Water Management District, West Palm Beach, Florida

A.3.2 Introduction

A brackish water ecotone of coastal bays and lakes, mangrove and buttonwood forests, salt marshes, tidal creeks, and upland hammocks separates Florida Bay from the freshwater Everglades. The 24-kilometer-wide ecotone adjoins the north shoreline of Florida Bay and the Gulf of Mexico. The model boundary from Turkey Point west to Lostman's River delineates the interface of Biscayne and Florida Bays and the Gulf of Mexico that is affected by freshwater flows from the Everglades (Figure A-11). The Everglades mangrove estuaries are characterized by a salinity gradient and mosaic that vary spatially with topography and that vary seasonally and inter-annually with rainfall and freshwater flow from the Everglades. Because of its location at the lower end of the Everglades drainage basin, the Everglades mangrove estuaries are potentially affected by upstream water management practices that alter the freshwater heads and flows that drive salinity gradients.

A.3.3 External Drivers and Ecological Stressors

The Everglades mangrove estuaries are the product of an interplay of marine and freshwater influences that dominate every aspect of the system as external drivers and ecological stressors (Figure A-13, Section A.3.9). The controlling marine influence is sea level. There is strong evidence that present rates of **sea level rise** in South Florida, which are attributed to global climate change, will massively reconfigure the geomorphology, circulation patterns, salinity patterns, and ecological processes of the during the Twenty-First Century (Wanless et al. 1994). The controlling freshwater influence is flow from the Everglades. The construction and operation of South Florida's water management system during the Twentieth Century has depleted freshwater flow to the estuary and has altered its timing and distribution (VanZee 1999, McIvor et al. 1994). Ecological patterns and processes in the mangrove estuary are closely linked to patterns of hydrology and salinity that have been altered by **reduced freshwater flow**. Declines in many ecological attributes of the estuary correspond to the development of the water management system.

The introduction of **exotic fishes and plants** into South Florida through the aquarium and nursery trades has resulted in the spread of three nuisance species that represent ecosystem stressors in the Everglades mangrove estuaries. The Mayan cichlid presently dominates the fish community in the mangrove wetlands east of Taylor Slough (Trexler et al. 2001), and the exotic plants *Schinus* and *Colubrina* have invaded mangrove forests. Although less pervasive than sea level and freshwater flow, potential impacts from the spread of exotics merit a better understanding of their ecological roles and potentials for control in the Everglades mangrove estuaries.

A.3.4 Ecological Attributes

This section provides a general overview of the ecological attributes that have been selected as indicators of ecological health in the Everglades mangrove estuaries, and the rationale for their selection. Detailed descriptions of the attributes, and of our current understanding of the relationships of attributes to stressors, are provided in the following section on linkage hypotheses.

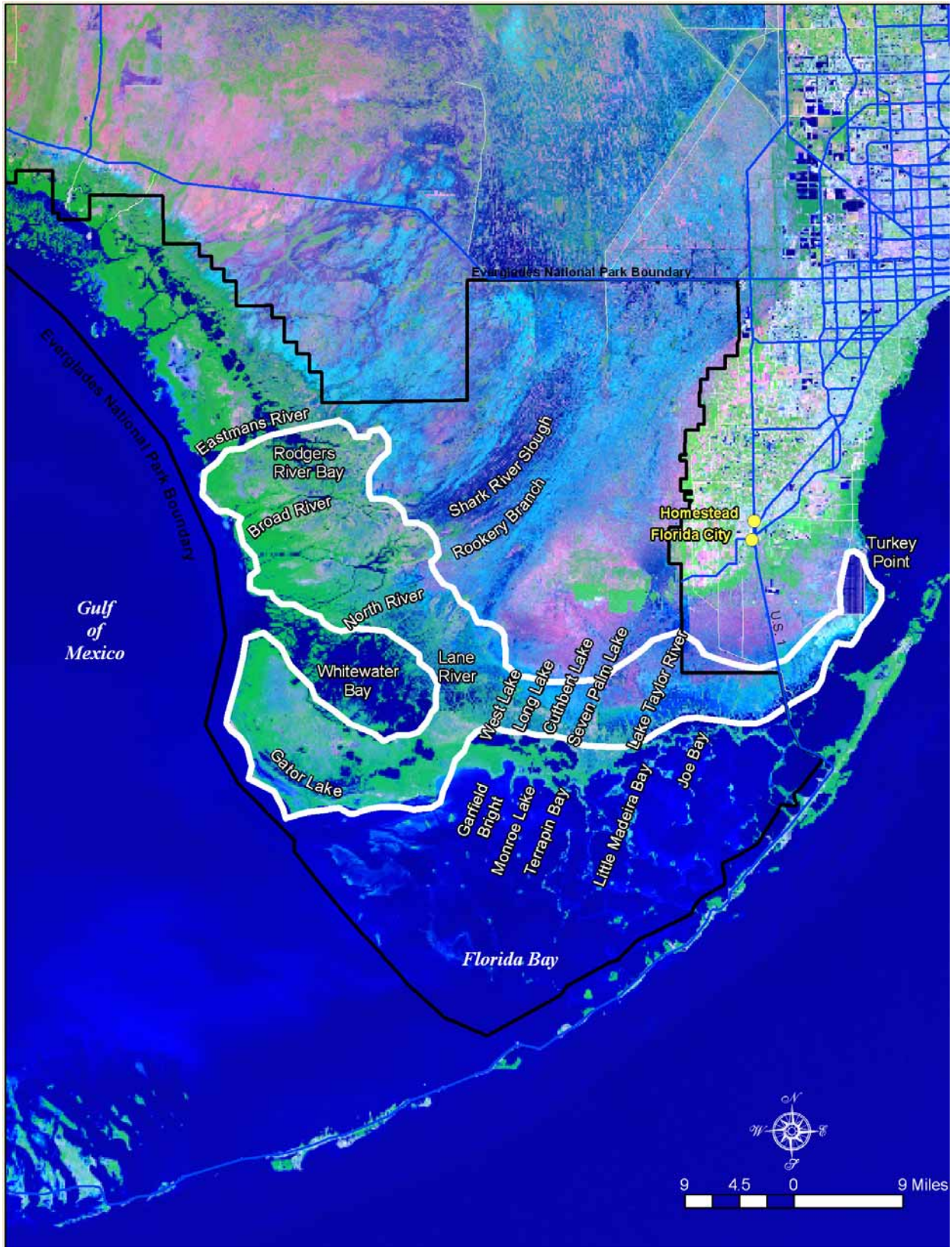


Figure A-11: The Boundary of the Everglades Mangrove Estuaries Conceptual Ecological Model

A.3.4.1 Estuarine Geomorphology

The shoreline and landscape mosaic of the Everglades mangrove estuaries is likely to be massively reconfigured during the Twenty-First Century due to the interaction of sea level rise and hurricanes (Wanless et al. 1994). The dynamics of the coastal storm berm that separates the estuarine zone from Florida Bay, and the accretion of peat in Gulf of Mexico mangrove forests, are key factors determining the rate and extent of that reconfiguration. As a result of shoreline transgression, the Everglades mangrove estuaries are expected to move inland into the lower Everglades. Thus a functional estuary and its ecological attributes, as influenced by the resumption of natural freshwater flow volume and duration, must be viewed as spatially dynamic with a long-term trend toward inland movement. Regardless of rising sea level, a salinity gradient supportive of ecologically functional Everglades mangrove estuaries will be required to maintain the integrity of the South Florida ecosystem. The spatially dynamic aspects of the Everglades mangrove estuaries, resulting from sea level rise and geomorphic processes, influence all the ecological attributes and restoration expectations for the estuary.

A.3.4.2 Mangrove Forests and Associated Plant Communities: Structure and Function

Mangrove forests (*Rhizophora*, *Avicennia*, *Laguncularia*, and *Conocarpus*) dominate the primary productivity and soil accretion within the Everglades mangrove estuaries (Childers et al. 1999). That productivity appears to reflect the nutrient status of the estuarine interface, which is related to the mixing of water from the Everglades with that from the Gulf of Mexico and Florida Bay. Childers et al. (1999) observed a clear productivity peak in the oligohaline zone of Shark River Slough. The peak is found in soil and water nutrient concentrations, in biomass and productivity of marsh plants, mangroves and phytoplankton, and in secondary consumer biomass. The peak appears to result from low-phosphorus, high-nitrogen fresh water meeting higher-phosphorus, lower-nitrogen marine water (Rudnick et al. 1999). The productivity peak that was found in the interface of the Shark River Slough basin with the Gulf of Mexico was not found in the interface of the Taylor Slough/Panhandle basin with Florida Bay (Childers et al. 1999). This appears to occur in part because northeast Florida Bay scavenges available phosphorus from coastal waters before it reaches the oligohaline zone of the Taylor Slough/Panhandle basin (Fourqurean et al. 1993). The mangrove estuary provides a sink for nitrogen from Everglades water before it enters Florida Bay (Chen and Twilley 1999; D. Rudnick, South Florida Water Management District unpublished data), which may represent an important support function regarding the nutrient status of the bay.

The mosaic of mangrove forests and associated plant communities, documented by Welsh et al. (1995), defines the habitats of the Everglades mangrove estuaries. The spatial distribution of those habitats, in combination with the salinity gradient that overlays them, determines the suitability of this region to sustain its faunal attributes (Browder and Moore 1981).

Embedded within the mangrove forests are tidal creeks and adjacent salt marshes, upland tropical hardwood hammocks, halophytic prairies, and coastal lakes. The coastal lakes such as Seven Palm Lake, Cuthbert Lake, Long Lake, West Lake, Lake Monroe and the Taylor River ponds support seasonal beds of submerged aquatic vegetation (SAV) under oligohaline to mesohaline conditions. At the seaward interface of the mangrove estuaries, coastal basins adjoin Florida Bay and the Gulf of Mexico. These basins, including Joe Bay, Little Madeira Bay, Terrapin Bay, Garfield Bight, and Whitewater Bay, also support SAV characteristic of their salinity regimes. At the landward interface of the mangrove estuaries with marl wetlands, a “white zone” band of sparse, relatively unproductive, mixed mangrove and graminoid vegetation is considered an indicator of the balance between freshwater flow and sea level rise (Ross et al. 2002). Working hypotheses relate the distribution and persistence of each of these plant communities to one or more of the stressors that have been identified for the Everglades mangrove estuaries.

The SAV of coastal lakes and basins provide an important food resource for seasonal waterfowl aggregations. Reduction in these beds of SAV, due to shifts toward more marine conditions, appear to have contributed to the decline in numbers of coot, scaup, widgeon and pintail that once were seasonally abundant in the coastal lakes and basins.

A.3.4.3 Estuarine Fish Communities and Fisheries

The oligohaline wetlands of the mangrove estuary support a resident community of small fishes that is functionally important as an intermediate trophic level supporting wading birds and other higher consumers (Lorenz 2000). The production and seasonal concentration of the wetland fishes appear to vary with salinity, hydrology and nutrient status in the estuary (Trexler and Loftus 2000, Lorenz 2000), all of which are controlled by freshwater flow and sea level.

Shoreline habitats and coastal basins of the mangrove estuary provide nursery grounds for sport and commercial fisheries including spotted seatrout, common snook and pink shrimp. Spotted seatrout complete their complete life cycle within Florida Bay and coastal Gulf waters, and thereby represent a good sport fish indicator of changing estuarine conditions. Post larval spotted seatrout utilize the coastal basins of the mangrove estuary as nursery grounds from Terrapin Bay west.

Mangrove estuaries in Everglades National Park, along with Florida Bay, are nursery grounds for pink shrimp, an ecologically and economically important species in South Florida. Pink shrimp are harvested commercially on the Tortugas grounds, and the pink shrimp fishery is one of South Florida's most valuable fisheries in terms of ex-vessel value. Pink shrimp are also a food source for many recreationally and commercially important estuarine and marine species such as mangrove snapper and spotted seatrout (Higher Trophic Levels Working Group 1998). Pink shrimp spawning occurs in the Dry Tortugas area, and eggs and larvae are carried inshore by currents and tides (Jones et al. 1970, Hughes 1969). Browder (1985) and Sheridan (1996) have found positive relationships between indices of freshwater inflow to the coast and Tortugas pink shrimp landings. The suitability of coastal and shoreline habitats as nursery grounds for spotted seatrout and pink shrimp appears to be largely dependant upon salinity patterns (Browder and Moore 1981) that are driven by freshwater flow and sea level.

A.3.4.4 Wood Stork and Roseate Spoonbill

The large nesting colonies of wood storks and great egrets in the Everglades during the early 1900s were concentrated in the Everglades mangrove estuaries (Ogden 1994). The East River, Lane River, Rookery Branch, Broad River, and Rodgers River Bay colonies, in the headwaters of the tidal rivers entering the Gulf of Mexico, supported approximately 90 percent of the total nesting population of these and other wading bird species during the period of 1931-1946. Additional colonies along the southern mainland of Florida Bay included Gator Lake, Mud Lake, Mud Hole (located east of Gator Lake), Cuthbert Lake and Madeira Rookery. The collapse of all of these coastal nesting colonies during the second half of the century is attributed largely to a decline in the production and density the food base for the nesting birds (Ogden 1994), which consists of the resident mangrove fishes and particularly the topminnows and sunfish that grow to a size that wood storks can capture (Ogden et al. 1978).

A decline in roseate spoonbill nesting in northeast Florida Bay and a shift of nesting distribution from eastern to western Florida Bay (Powell et al. 1989) are also attributed to the reduction in populations of resident mangrove fishes upon which they feed (Bjork and Powell 1994). Small fishes have been reported to be the primary part of the diet of roseate spoonbills in Florida Bay (Allen 1942, Powell and Bjork 1990).

The collapse of coastal colonies of wood stork and great egret, and of northeast Florida Bay colonies of roseate spoonbill, corresponded to the construction of the Central and South Florida (C&SF) Project and the resulting reduction of freshwater flow to the estuarine interface compared to Natural Systems Model (NSM) simulations (VanZee 1999).

A.3.4.5 Estuarine Crocodilian Populations

The American alligator was historically abundant (and nested) in freshwater mangrove areas of the Everglades according to Craighead (1968). Today, reduced freshwater flow into estuaries apparently has resulted in succession of former freshwater mangrove areas to saltwater systems, changing the pattern of occupancy by alligators. Salinity is a major factor limiting the distribution and abundance of alligators in estuarine habitats (Dunson and Mazzotti 1989, Mazzotti and Dunson 1989). Alligators appear to be good indicators of restoring freshwater flows to estuarine systems and the subsequent reestablishment of an extensive freshwater/brackish water zone.

The American crocodile dwells in the ponds and creeks of the mangrove estuaries of Florida Bay (Ogden 1976, Mazzotti 1983). American crocodiles are tolerant of a wide salinity range as adults because of their ability to osmoregulate (Mazzotti 1989). Juvenile crocodiles lack this ability, however, (Mazzotti 1989) and their growth and survival decline at salinities exceeding 20 parts per thousand (ppt) (Mazzotti et al. 1988, Mazzotti and Dunson 1984, Moler 1991). Juvenile crocodiles tend to seek freshwater pockets such as black mangrove stands when those choices are available.

A.3.5 Ecological Effects

Critical Linkages between Stressors and Attributes/Working Hypotheses

Ecological changes resulting from the restoration of freshwater flow to the mangrove estuaries will be strongly influenced by three interrelated causal relationships. All involve estuarine productivity and subsequent effects on sediment accretion and food webs. Key hypotheses were developed based on these causal pathways during the conceptual ecological model workshops. These hypotheses determine the content and organization of the Everglades Mangrove Estuaries Conceptual Ecological Model. The hypotheses are presented here, organized by attribute.

A.3.6 Estuarine Geomorphology

Relationship to Sea Level and Sediment Accretion

Shoreline transgression of the Everglades mangrove estuaries will occur due to the present rate of sea level rise, which is conservatively estimated to be two feet over the next century (Wanless et al. 1994). The coastal storm berm of inorganic sediments that separates the estuarine zone from Florida Bay will accrete at a rate insufficient to keep up with sea level rise. The embankment will be breached by hurricanes during the next century, increasing the exchange of water, sediment, organic matter and nutrients between the bay and estuary, and allowing the influx of marine conditions into presently oligohaline-mesohaline areas of the estuary. The mangrove forests of the Shark River and other Gulf of Mexico estuaries to the west of Florida Bay will similarly be overtaken by rates of sea level rise that will exceed rates of organic soil accretion. Hurricanes will erode and blow-out portions the mangrove forests during the next century, creating new water courses, open-water lakes and basins, halophytic prairies and exchanges of water, sediment, organic matter and nutrients with the gulf. As a result of shoreline transgression, the Everglades mangrove estuaries are expected to move inland into the lower Everglades over the next century. Thus a functional estuary and its attributes, as influenced by the resumption of natural freshwater flow volume and duration, must be viewed as spatially dynamic with a long-term trend toward inland movement.

Shoreline transgression in the gulf mangroves may be partially offset by the productivity, peat accretion, and resulting increase in soil surface elevation of the mangrove forests, as affected by the mixing of water and nutrients from the Gulf of Mexico and the Everglades. Coastal wetlands accumulate sediment by accretion, with the result that they increase in elevation over time relative to stable features of the coast. Negative feedback between the process of accretion and the wetland's elevation, measured relative to local sea level, regulates wetland elevation so that it tracks long-term changes in sea level (Nyman et al. 1993). Measured accretion rates for wetlands along the Gulf of Mexico and Atlantic coasts of the United States generally equal or exceed the local long-term rise in relative sea level. Based on the assumption that accretion is controlled by the in situ production of organic matter, Bricker-Urso et al. (1989) estimate the maximum sustainable rate of accretion to be about 16 millimeters per year.

An alternative hypothesis (T. Armentano, Everglades National Park, personal communication) is that there is no demonstrable reason to conclude that sea level rise will simply trigger a landward shift of the present mangrove forest inland. Much of the present mangrove forest (other than peripheral populations) has occupied its present sites for centuries or millennia during a period of relatively stable sea levels. These sites are characterized by deep peat deposits and a specific range of nutrient conditions determined to a great extent by the locations of the forest relative to the Gulf of Mexico, Florida Bay and the freshwater sloughs. The environment of future mangrove forests may differ from present conditions. Clearly at least, soil conditions in sites that may experience future mangrove colonization differ markedly from present mangrove forest sites. In addition, with an accelerated sea level rise, there may not be sufficient time for mangrove forests to develop a deep peat substrate in new sites. Instead, the new forests may be structurally less developed, and less productive, resembling the stunted forests of some Florida Bay islands or the interior dwarf mangrove forest. It is also possible, however, that the "expansion forests" will be more diverse, supporting species excluded from the closed canopies of well-developed forests.

Sea level rise and shoreline transgression in South Florida are well documented, as summarized by H.R. Wanless (University of Miami, personal communication). Over the past 75 years, the mangrove margin of South Florida has undergone dramatic changes in response to a combination of a 0.7 foot rise in relative sea level in South Florida; four category 4-5 hurricane events; and reduction in water level and sheet flow from the interior freshwater marshes (the Everglades). The current condition is one of dramatic evolution of the coastal mangrove fringe. There has been a significant advance of the mangrove community into the freshwater wetlands in response to both sea level rise and reduced freshwater flow. Mangrove estuaries have retreated as much as 159 meters in response to hurricane events.

D.L. Childers (Florida International University personal communication) notes that although the mangrove ecotone is likely to be spatially dynamic over the time frame of Everglades' restoration, the future evolution of the coastal wetland margin involves many uncertainties. Predictions of the rate of sea level rise over the next 50 years are quite variable. It is difficult to predict how the balance of increased freshwater flow and variable predictions of sea level rise will control transgression. Long-term changes in regional climate will affect both storm frequency/intensity and inter-annual precipitation patterns. The dynamics of soil elevation change in these wetlands are not well documented. Models do not exist to reliably simulate the various combinations of sea level rise, freshwater flow, regional climate change, and soil elevation dynamics.

A sediment accretion model (Callaway et al. 1996) integrates information on sedimentation and substrate diagenetic processes and predicts substrate accretion under conditions of altered hydrology, water quality, and supply of mineral sediments. Despite trends and estimates of wetland soil accretion relative to sea level, the fact remains that shoreline transgression in relation to sea level rise is ongoing in South Florida. The lack of predictive capability regarding trends in the productivity and peat accretion of gulf mangrove forests, and the clearly suppressed productivity and peat accretion of the Florida Bay and Biscayne Bay

mangrove fringes, yield a relatively high level of uncertainty that the mangrove forests of South Florida will accrete peat at a rate equal to the present rate of sea level rise.

Level of certainty - low

A.3.7 Mangrove Forests and Associated Plant Communities

Relationship of Mangrove Productivity to Nutrient Mixing and Freshwater Flow

Production and organic soil accretion in the oligohaline zone of mangrove forests of the Shark River and other gulf estuaries reflect enhanced levels of general estuarine productivity (Childers et al. 1999), as influenced by nutrient mixing between inflowing fresh water from the Everglades and tidally fluctuating salt water from the Gulf of Mexico (Rudnick et al. 1999). Production of the dwarf mangrove forests adjacent to Florida Bay reflects suppressed levels of general estuarine productivity, as influenced by limited nutrient mixing between relatively small Everglades inflows and dampened tidal fluctuations of low-phosphorus bay water. The lower production of Florida Bay mangrove forests appears to occur in part because northeast Florida Bay scavenges available phosphorus from coastal waters before it reaches the oligohaline zone of the Taylor Slough/Panhandle basin (Fourqurean et al. 1993). Productivity and organic sediment accretion in the mangrove estuary create a sink for dissolved organic nitrogen inputs from Everglades' flows (Chen and Twilley 1999, Rudnick unpublished data). This may provide a support function for Florida Bay by maintaining nitrogen limitation of productivity in the bay.

Productivity in the mangrove forests and associated plant communities is depressed by diminished nutrient mixing resulting from reduced freshwater flow volume and duration. Productivity in the mangrove forests and associated plant communities also is depressed by more frequent and extended periods of hypersalinity resulting from reduced freshwater flow volume and duration. Resumption of natural volumes and durations of freshwater flow are expected to increase productivity due to increased nutrient mixing and decreased incidence of hypersalinity.

A productivity peak in gulf estuaries is supported by evidence from many attributes (Childers et al. 1999). The relationship of the productivity peak to the balance between freshwater flow and nutrient content of gulf waters is likely but has yet to be demonstrated. It is not possible to predict how the balance between freshwater flow and nutrient content of Gulf of Mexico waters will change over the next 50 years, particularly when this requires parallel predictions of coastal eutrophication phenomena in this region of the gulf. Furthermore, no reliable models exist to aid in these difficult predictions. Nonetheless, we can hypothesize reliably well that increased freshwater flow alone should increase both the magnitude and spatial extent of the oligohaline productivity peak in the gulf mangrove ecotone.

The strong retention of phosphorus in the mangrove zone is already known, but the fate of nitrogen, which may strongly affect Florida Bay, is not known (D. Rudnick, South Florida Water Management District, personal communication). Evidence points toward potentially high denitrification rates which will help Florida Bay. Modeling by the Long-Term Ecological Research (LTER) Project based at Florida International University should provide a more accurate prediction of mangrove zone nutrient dynamics as a function of water levels and flows. The LTER project is funded by the National Science Foundation. It is investigating how variability in regional climate, freshwater inputs, disturbance, and perturbations affect the coastal Everglades ecosystem. The long-term research program will focus on testing the following central idea and hypotheses:

Regional processes mediated by water flow control population and ecosystem level dynamics at any location within the coastal Everglades landscape. This phenomenon is best exemplified in the dynamics

of an estuarine oligohaline zone where fresh water draining phosphorus-limited Everglades' marshes mixes with water from the more nitrogen-limited coastal ocean.

Three hypotheses have been developed for this relationship:

- **Hypothesis 1:** In nutrient-poor coastal systems, long-term changes in the quantity or quality of organic matter inputs will exert strong and direct controls on estuarine productivity, because inorganic nutrients are at such low levels.

- **Hypothesis 2:** Interannual and long-term changes in freshwater flow control the magnitude of nutrients and organic matter inputs to the estuarine zone, while ecological processes in the freshwater marsh and coastal ocean control the quality and characteristics of those inputs.

- **Hypothesis 3:** Long-term changes in freshwater flow (primarily manifest through management and Everglades restoration) will interact with long-term changes in the climatic and disturbance (sea level rise, hurricanes, fires) regimes to modify ecological pattern and process across coastal landscapes.

Level of certainty - low

Relationship of Halophytic Prairie Expansion to Hurricane Impacts and Sea Level Rise

The area of halophytic prairie within the mangrove zone will expand in coming decades in association with hurricane impacts exacerbated by sea level rise (Armentano personal communication). Since the Labor Day hurricane of 1935, and more clearly, since Hurricane Donna in 1960, halophytic prairies have been a conspicuous feature of the mangrove zone. Evidence suggests that this community represents a long-term (on the order of decades, perhaps a century or more) landscape element that becomes established where tropical storms alter coastal sediments in such a way that mangrove and buttonwood forests are killed. Furthermore, in many areas, once the halophytic prairie (dominants include *Batis maritima*, *Salicornia* spp., and *Blutaperon vermicularis*) becomes established it appears capable of retarding recruitment of tree species, thus creating a long-term, low productivity nonpeat forming shrub-herb community within the forested mangrove zone.

The replacement of mangrove and buttonwood forests by halophytic prairie following severe hurricanes has been documented by Craighead (1971), Craighead and Gilbert, (1962), and Armentano et al. (1995). Uncertainty remains regarding the specific soil and seedling layer conditions in halophytic prairies, the factors limiting mangrove and buttonwood recruitment in these sites, and the specific forces that convert mangrove forest to halophytic prairie within the differing mangrove forest types of South Florida.

Level of certainty - moderate

Relationship of Tropical Forest Communities to Sea Level Rise

Sea level rise and consequent shifts in saline environments, mangrove environments and storm berms will differentially reduce or eliminate tropical forest communities and species that are intolerant of saline conditions, lowering overall (beta) diversity of the mangrove zone (Armentano personal communication). Embedded within the saline-adapted mangrove forest zone are unique tropical forest communities with limited tolerance of salt water and saline soils. Included are midden forests, thatch palm hammocks, mixed coastal hammocks and buttonwood hammocks. These communities, which contribute to the local and landscape species diversity within the mangrove zone (including providing substrate for epiphytes) are able to persist because of the presence of elevated substrates like storm berms and human-originated

deposits. As coastal areas become increasingly marine, they will be exposed to salt stress and increasing competition from salt-adapted species. The extent to which the nonsalt adapted communities will be able to move inland in a dominantly freshwater wetland environment is unknown but may be limited by site availability and competition from freshwater wetland and bay swamp species. Thus these communities may become increasingly rare in the coming decades.

The distribution of nonsalt tolerant tropical forest communities on elevation rises within the mangrove zone has been described by Craighead (1971), Craighead and Gilbert (1962), Armentano et al. (2000), and Jones and Armentano (1999). Key uncertainties include the extent to which changing coastal conditions will reduce growth and aerial extent of these nonmangrove forest communities, and whether these species are capable of shifting to more interior sites.

Level of certainty - moderate

Relationship of Coastal Lake Submerged Aquatic Vegetation to Salinity and Freshwater Flow

Submerged aquatic vegetation (SAV) in the coastal lakes and basins of the mangrove estuary reflects seasonal salinity variations from oligohaline to mesohaline conditions. Prolonged periods of elevated salinity in the coastal lakes and basins, resulting from diminished freshwater flow volume and duration, have reduced the seasonal duration and cover of these species along shorelines and in tributaries. Beds of SAV are expected to persist in larger beds, longer into the dry season, and lower in the estuarine system when oligohaline to mesohaline conditions are restored upon the resumption of natural freshwater flow volume and duration.

Reduction in beds of SAV has contributed to the decline in numbers coot, scaup, widgeon and pintail that were once seasonally abundant in the coastal lakes and basins (Kushlan et al. 1982). Extended persistence and cover of SAV resulting from prolonged periods of oligohaline to mesohaline conditions will encourage the return of winter populations of waterfowl to the coastal lakes and basins.

The species richness and total and species-specific percent cover of the SAV found in the individual lakes, ponds and bays that make up this aquatic network vary both seasonally and inter-annually in fairly predictable patterns that are related to salinity (Morrison and Bean 1997, Montaque et al. 1998, Richards and Fourqurean 1999). Salinity ranges for the suite of 10-12 species are well documented, including *Utricularia* and *Najas* under oligohaline salinities with an upper limit of approximately 5-8 ppt, *Chara* under mesohaline salinities of approximately 15-20 ppt, and *Ruppia* under mesohaline salinities of 10-25 ppt.

The waterfowl species that once aggregated in large numbers in the coastal lakes and basins of the mangrove zone are dependent on SAV as their primary food resource. Their local decline corresponds to the decline in that food resource, despite the overall resurgence of populations in other parts of North America. Recent high-rainfall years have witnessed an increase in coot numbers on the West Lake to approximately 2,000 during winter 1996-1997 (O.L. Bass, Jr., Everglades National Park, personal communication), but not to the population size of approximately 50,000 that overwintered there until the 1960s (Kushlan et al. 1982).

Level of certainty - high

Relationship of Tidal Creek Loss to Freshwater Flow and Sea Level Rise

The dendritic pattern of tidal creeks and adjacent salt marshes within the mangrove forests is being lost, due to mangrove encroachment and siltation resulting from reduced freshwater flow volume and duration

in combination with sea level rise. The siltation and mangrove encroachment of tidal creeks (Craighead 1971, Meeder et al. 1996) has progressed to the extent that open water courses that were described earlier this century are no longer recognizable (G. Simmons, gladesman, personal communication). The causal factors, including the relative contributions of reduced freshwater flow and sea level rise, remain unclear.

Level of certainty - low

Relationship of Plant Community Structure to Invasion by Exotics

The spread of the exotic plants *Schinus* and *Colubrina* is changing community structure of mangrove forests and associated plant communities. *Schinus* and *Colubrina* have become established in some mangrove forests and tropical forest communities of the Everglades mangrove estuaries (Armentano et al. 1995). Prevention of their continued spread requires an intensive program of manual removal and herbicide application.

Level of certainty - high

Changes in the "White Zone" in Relation to Sea Level Rise and Freshwater Flow

The position of the "white zone", a band of relatively unproductive coastal wetland that appears white on color infrared or black-and-white aerial photos, is considered an indicator of the balance between fresh water supplied from upstream sources and rising sea level. If sea level continues to rise at its current rate or faster, the leading edge of the white zone will continue to move toward the interior, except along tidal creeks or major drainages. These changes will be least evident in areas in which freshwater input is augmented and greatest in areas cut off from freshwater flow. In settings where further interiorward movement is prevented by canals, roads or other barriers, the white zone will be entirely supplanted by closed-canopy mangrove scrub communities similar to those currently bounding it on the coastal side.

Although production and composition in the white zone are certainly affected by some of the same environmental factors, it is primarily its low cover and reflective substrate that defines it. Plant species composition within the white zone has changed over time, and currently varies considerably throughout South Florida. In the future, the long-term trend from a mangrove-graminoid mixture to a monodominant mangrove community is expected to continue, more rapidly in water-deprived basins than those experiencing surface water sheet flow. In general, the nature of the future white zone will be subject to many local factors, in ways our current understanding does not permit us to predict. For instance, inasmuch as the South Florida white zone is associated with phosphorus-deficient marl or limestone substrates, the soil materials encountered in its movement away from the coast are likely to affect it at population, community and ecosystem levels.

Egler (1952) described the white zone as a band of low, open vegetation separating the mangrove swamps adjacent to the southeast Saline Everglades coast (Taylor Slough to Turkey Point) from the sawgrass marshes of the interior. Its composition included a mixture of sawgrass, spikerush and red mangrove. He considered the inner edge to mark the farthest extent of storm tides. Ross et al. (2000) documented changes in the extent and plant species composition of the white zone since Egler's work. They found interiorward movement throughout the region over circa 50-year time period, ranging from less than 1 to about 4 kilometer. Movement was maximum in areas entirely cut off from upstream freshwater sources (wetlands east of US 1), minimum in wetlands whose water supply was supplemented by canal sources (wetlands west of US 1 and directly south of the C-111 Canal), and intermediate in more remote portions of Everglades National Park (wetlands north of Joe Bay and southwest of the C-111 Canal). These patterns strongly suggest that freshwater input may partially mitigate for a phenomenon driven primarily by sea level rise. Working along a hydrologically isolated coastal transect south of Turkey Point, Meeder

et al. (1996) documented an inland movement of the interior boundary of the white zone of 1,900 meters during the period 1940-1994. This distance equated to a vertical shift of 13 centimeters, during a period in which sea level rose by about 11 centimeters.

The white zone is not necessarily fixed or invariant in species composition over time. Egler (1952) described its composition as a mixture of sawgrass, spikerush and red mangrove. Ross et al. (2000) integrated their own vegetation data with field results presented by Egler (1952), and concluded that the compositional gradient in southeast saline Everglades marshes had shifted considerably further inland between the two surveys than had the position of the white zone. In a subsequent study at Turkey Point, Ross et al. (2002) found several diatom taxa, but no plants or mollusks that were restricted to the white zone.

The South Florida white zone is a local manifestation of a more widespread coastal phenomenon, in which a zone of relatively unproductive or low-stature vegetation occupies a position near the interface of marine with fresh water or terrestrial ecosystems (e.g., Carter 1988, Montague and Wiegert 1990). To our knowledge, there has been little or no research on the origin of this biogeographic pattern. Ross et al. (2002) hypothesized that the following four factors were involved locally: 1) wide seasonal fluctuations in salinity and moisture content, 2) absence of freshwater input from upstream sources, 3) heavy marl soils that may contribute to phosphorus limitation, and 4) sporadic occurrence of natural disturbances. However, a better functional understanding of white zone dynamics will require more extensive transect surveys, as well as manipulative experiments in which one or more of the above factors are controlled.

Level of certainty - moderate

A.3.7.1 Estuarine Fish Communities and Fisheries

Relationship of Resident Mangrove Fish Populations to Estuarine Salinity, Nutrient Status and Hydrology

Populations of small marsh fishes in the mangrove zone (sheepshead minnows, sailfin mollies, topminnows, rainwater killifish and sunfish) reflect 1) estuarine salinity, 2) estuarine nutrient status and productivity, and 3) estuarine hydroperiod and drying patterns. These stressors and their effects on populations of small wetlands fish are discussed in the following paragraphs.

The resident fish assemblage decreases in density and size distribution when salinity exceeds 5-8 ppt (Lorenz 1997, 1999, 2000). This relationship has been demonstrated for the Florida Bay mangrove wetlands, but not for the Gulf of Mexico estuaries. Furthermore, salinity is inversely auto-correlated with hydroperiod in the Florida Bay mangrove wetlands, and the relative contribution of each of these variables is not known.

Densities of small fishes in Shark River Slough are approximately 50 percent higher at Rookery Branch, near the interface with the Gulf of Mexico, in comparison to more upstream sites (Trexler and Loftus 2000). Higher fish densities at Rookery Branch correspond to the enhanced nutrient status and productivity peak in that area (Childers et al. 1999). In contrast, lower fish densities at the estuarine interface of Taylor Slough relative to sites upstream (Lorenz 1999, 2000, Trexler and Loftus 2000) correspond to low nutrient status and productivity there. The hypothetical relationship of fish density to enhanced productivity in gulf estuaries is based on a limited number of fish samples collected from one site (Rookery Branch).

Seasonal drying patterns following extended periods of flooding can condense the oligohaline marsh fishes in the Florida Bay estuarine interface to densities comparable to those in the gulf estuaries. Populations of small marsh fishes in the mangrove zone are expected to increase in density, size

distribution and seasonal concentration upon the resumption of natural freshwater flow volume and duration to the estuary, due to the combined effects of extended periods of oligohaline salinity, enhanced estuarine nutrient status and productivity, enhanced hydroperiod and drying patterns, and tidal creek restoration. Receding water levels following an extended annual hydroperiod can concentrate small fishes in Craighead Basin, at the estuarine interface of Taylor Slough, to densities comparable to the estuarine interface of Shark River Slough (Lorenz 2000).

Relationships of fish populations to hydrology in gulf estuaries are unknown. Populations of small marsh fishes in gulf estuaries may respond to hydroperiod and water recession patterns very differently than Everglades marsh fish communities because of more complex topography created by a dendritic pattern of tidal creeks. The tidal creeks may further influence the resident mangrove fish community as corridors for the immigration of juveniles of more marine species.

Level of certainty - low

Relationship of Resident Mangrove Fish Community to Exotic Fishes

The resident mangrove community of small marsh fishes is presently dominated by the exotic Mayan cichlid between Highway Creek and the Taylor River, and expansion of the cichlid into other parts of the estuary is likely. Trexler et al. (in review) has reported that the Mayan cichlid is the dominant species in the mangrove estuary of Florida Bay from Taylor River east to Highway Creek.

Level of certainty - high

Relationship of Spotted Seatrout and Common Snook Populations to Salinity

Juvenile density and sport catch of spotted seatrout in the coastal basins of the mangrove estuary reflect the suitability of estuarine habitat and nursery grounds as influenced by salinity and water levels. Juvenile density is expected to increase in the coastal basins from Terrapin Bay west due to the resumption of natural volumes and timing of freshwater flow to the estuary, in response to the reduction of the frequency and duration of hypersalinity events in the basins, in combination with the prolongation of oligohaline conditions in the tidal tributaries. Sport catch per unit effort is anticipated to follow a similar trend, indicating beneficial estuarine conditions for the survival of juveniles to adults.

Post larval spotted sea trout utilize the coastal basins of the Florida Bay mangrove estuary as nursery grounds from Terrapin Bay west to Whitewater Bay. Densities of post-larvae in those basins are highest at an intermediate salinity range of 20-30 ppt, and densities drop when salinity exceeds that of seawater (35 ppt) (Thayer et al. 1998, Schmidt 1993). It is unknown if growth and survival of spotted seatrout will predict the adult abundance and distribution based on sport catch per unit effort in relation to environmental conditions.

Level of certainty - moderate

Relationship of Pink Shrimp Juvenile Density and Adult Catch Per Unit Effort to Salinity and Freshwater Flow

Juvenile density of pink shrimp in Whitewater Bay reflects the suitability of estuarine nursery grounds as influenced by salinity. Optimal salinity conditions for survival appear to be somewhat below that of seawater (35 ppt). Pink shrimp juvenile density is expected to increase in Whitewater Bay in response to the restoration of estuarine salinity ranges and the reduction of the frequency and duration of hyper-salinity events. Beneficial conditions in Whitewater Bay will augment the annual pink shrimp recruitment

from the Florida Bay and gulf estuaries to contribute to increased annual catch per unit effort in the Tortugas fishing grounds.

Pink Shrimp spawning occurs in the Dry Tortugas area, and eggs and larvae are carried inshore by currents and tides (Jones et al. 1970, Hughes 1969). Browder (1985), Sheridan (1996) and Browder et al. (1999) have found positive relationships between indices of freshwater inflow to the coast and Tortugas pink shrimp landings. Sheridan's annually updated statistical model based on various freshwater inflow indices has successfully predicted annual pink shrimp landings in most of the past decade (P. Sheridan, National Marine Fisheries, unpublished data; Sheridan 1996). The salinity gradient associated with coastal runoff may provide navigational directions to immigrating young pink shrimp (Hughes 1969). Survival rates of juvenile pink shrimp are sensitive to salinity and decrease markedly under extreme hypersaline conditions (Browder et al. 1999). Optimal salinities for survival are not fully determined, but probably are somewhat below that of seawater (35 ppt). Tabb et al. (1962), Rice (1997), and others have documented that the mangrove estuaries in the Whitewater Bay system of Everglades National Park are pink shrimp nursery grounds. However, two areas of uncertainty remain. It is not possible to trace the origins of Tortugas landings to specific nursery grounds and environmental conditions, including the mangrove estuary coastal basins, Florida Bay and Gulf of Mexico estuaries. There is a lack of sufficient information to quantitatively link juvenile pink shrimp abundance and salinity in the estuary to upland water management practices.

Level of certainty - moderate

A.3.7.2 Wood Stork and Roseate Spoonbill Nesting Colonies

Relationship of Nesting Colony Locations to Resident Mangrove Fish Populations

Nesting colonies of wood stork and great egret in South Florida were concentrated in the tributary headwaters and southern mainland of the Everglades mangrove estuaries during much of the Twentieth Century. Those colonies have completely collapsed beginning in the 1960s. Nesting colonies of roseate spoonbill have shifted in distribution westward from northeast Florida Bay to the Gulf of Mexico during the same time period.

The collapse of the wood stork and great egret colonies, and the abandonment of northeast Florida Bay nesting islands by spoonbills, are attributed to a decline in the production and availability their food base, which is the resident community of small marsh fishes in the Everglades mangrove estuaries. The topminnows and sunfish that grow to a size that wood storks can capture are considered to be particularly important (Ogden et al. 1978). Because of their close linkage to the resident mangrove fish community, the nesting colonies reflect conditions of estuarine salinity, hydrology, nutrient status and productivity that affect the density, size distribution, and seasonal concentration of the fishes.

The resumption of natural freshwater flow volume and duration to the estuary is expected reestablish nesting colonies of wood stork and great egret in the tributary headwaters and southern mainland, and to renew spoonbill nesting in northeast Florida Bay, in response to increased production and availability of the resident mangrove fishes. Contributing factors include increased frequency and duration of oligohaline salinity conditions, restored hydroperiods and related drying patterns, and enhanced estuarine nutrient status and productivity.

There is a high degree of certainty that the large nesting colonies of wood storks and great egrets in the Everglades during the early 1900s were concentrated in the Everglades mangrove estuaries (Ogden 1994). The East River, Lane River, Rookery Branch, Broad River, and Rodgers River Bay colonies, in the headwaters of the tidal rivers entering the Gulf of Mexico, supported approximately 90 percent of the

total nesting population of these and other wading bird species during the period of 1931-1946. Additional colonies along the southern mainland of Florida Bay included Gator Lake, Mud Lake, Mud Hole (located east of Gator Lake), Cuthbert Lake and Madeira Rookery. There is also a high degree of certainty that roseate spoonbill nesting in northeast Florida Bay has decreased and has shifted in distribution from eastern to western Florida Bay (Powell et al. 1989).

There is a low degree of certainty regarding the causes of the collapse of all of the coastal nesting colonies of wood storks and great egrets and the likelihood of their reestablishment upon the resumption of natural freshwater flows. The hypothesis that colony abandonment is related to population decline in the resident mangrove fishes due to altered hydrology (Ogden 1994) depends on the validity of the hypotheses relating estuarine geomorphology to sea level, estuarine productivity to nutrient mixing and freshwater flow, and resident mangrove fish populations to estuarine salinity, nutrient status and hydrology. Levels of certainty in all three of these hypotheses have been characterized as low.

Bjork and Powell (1994) provide evidence that the decline of spoonbill nesting in northeast Florida Bay is related to the reduction in populations of resident mangrove fishes upon which they feed, due to increased salinity resulting from reduced freshwater flow. Small fishes have been reported to be the primary part of the diet of roseate spoonbills in Florida Bay (Allen 1942, Powell and Bjork 1990). The relatively sparse populations of marsh fishes along the estuarine interface of northeast Florida Bay today require very specific drying patterns to make them available in densities adequate to support spoonbill nesting. Lorenz (2000) reported a water depth threshold of 12 centimeters, averaged over the 21-day post-hatching period of roseate spoonbills that is necessary to concentrate the fish prey base in Taylor Slough coastal sites. Water level recession to 12-centimeters depth during that period can concentrate the normally low fish density in that region to 85 fish per square mile in the remaining pockets of water. The 12-centimeter depth threshold fits well with success or failure of spoonbill nesting in northeast Florida Bay colonies.

Level of certainty - low

A.3.7.3 Estuarine Crocodilian Populations

The loss of alligators from the mangrove estuary is attributed to increased salinity in the tidal tributaries resulting from diminished freshwater flow volume and duration. According to Craighead (1968) alligators were historically abundant (and nested) in freshwater mangrove areas of the Everglades. Today nesting is limited, and few juveniles are observed. Reduced freshwater flow into estuaries apparently has resulted in succession of former freshwater mangrove areas to saltwater systems, changing the pattern of occupancy by alligators. Salinity is a major factor limiting the distribution and abundance of alligators in estuarine habitats (Dunson and Mazzotti 1989, Mazzotti and Dunson 1989). Alligators lose the capacity to utilize estuarine habitats for feeding, growth and reproduction when salinity exceeds oligohaline levels (Joanen 1969). When alligators occur in salt water it is usually to feed, and there is always a freshwater refugium in close proximity (Jacobsen 1983, Tamarack 1988). In a natural experiment in North Carolina, alligators that were exposed to diversion of freshwater flows due to construction of a power plant relocated to the diversion canal to maintain access to fresh water. Small alligators are especially vulnerable to exposure to salt water. In laboratory experiments, small alligators ceased feeding and exhibited signs of stress when exposed to salinities greater than 10 ppt (Lauren 1985). Alligators do feed and gain mass at 4 ppt (Mazzotti and Dunson 1984). For these reasons alligators are good indicators of restoring freshwater flows to estuarine systems and the subsequent reestablishment of an extensive freshwater/brackish water zone. The alligator is expected to repopulate and resume nesting in the freshwater reaches of tidal rivers upon the restoration of freshwater flow volume and duration to the Everglades mangrove estuaries.

The American crocodile dwells in the ponds and creeks of the mangrove estuaries of Florida Bay (Ogden 1976, Mazzotti 1983). American crocodiles are tolerant of a wide salinity range as adults because of their

ability to osmoregulate (Mazzotti 1989). Juvenile crocodiles lack this ability, however, (Mazzotti 1989) and their growth and survival decline at salinities exceeding 20 ppt (Mazzotti et al. 1988, Mazzotti and Dunson 1984, Moler 1991). Juvenile crocodiles tend to seek freshwater pockets such as black mangrove stands when those choices are available. Diminished freshwater flow volume and duration has increased salinity in the shoreline and tidal creek habitats of juvenile crocodiles, thereby reducing their growth and survival in the mangrove estuary. Resumption of natural freshwater flow volume and duration to the mangrove estuaries will reestablish a salinity gradient with levels less than 20 ppt in shoreline and tidal creek habitats that will increase the growth and survival of juvenile crocodiles.

Level of certainty - high

A.3.8 Research Questions

The three interrelated causal relationships, estuarine productivity and subsequent effects on sediment accretion and food webs, of the Everglades mangrove estuaries have a low level of certainty. Supporting research is required to increase the level of certainity of these relationships.

Estuarine Productivity

How will estuarine productivity change in relationship to the restoration of freshwater flow, to sea level rise, and to the associated variables of nutrient mixing and salinity? How do the mangrove forests of Florida Bay and the Gulf of Mexico differ in this respect? Develop quantitative relationships and predictive models of estuarine productivity in relation to freshwater flow, sea level, salinity and nutrient mixing.

Estuarine Sediment Accretion

How will estuarine productivity affect the accretion of mangrove peat, and will predicted rates of peat accretion equal or exceed the predicted local, long-term rise in sea level? How will predicted rates of organic and inorganic sediment accretion, in combination with sea level rise, influence shoreline transgression and an inland shift in marine and estuarine environments? Develop quantitative relationships and predictive models of peat accretion resulting from productivity in gulf mangrove forests, as affected by sea level rise, freshwater flow and regional climate change. Similarly, develop quantitative relationships and predictive models of accretion of the coastal storm berm of Florida Bay as affected by sea level rise, freshwater flow and regional climate change.

Estuarine Food Webs

How will estuarine productivity interact with salinity and hydrology to affect populations of resident mangrove fishes, in food webs supporting nesting colonies of wood stork and roseate spoonbill? Develop quantitative relationships and predictive models of resident mangrove fish population density and size structure in relation to estuarine productivity, salinity and hydrology. Develop quantitative relationships and predictive models of the energetic requirements of wood stork and roseate spoonbill nesting colonies in relation to the population density, size structure and seasonal concentration of resident mangrove fishes.

A.3.9 Hydrologic Performance Measures

Ecological restoration of the Everglades mangrove estuaries requires a reduction in the frequency of high salinity events that have been identified as detrimental for each coastal basin through the conceptual ecological model process. Another restoration measure is to increase the frequency of low salinity events

that have been identified as beneficial for each coastal basin. The high and low salinity levels represent the best professional judgement of those scientists working in the mangrove estuary, based on the existing information on the biological requirements and distributions of the estuarine organisms that are described above, available salinity data, and field observation.

Table A-1 displays the lower and upper salinity levels identified for coastal basins. It is desirable to decrease the frequency that salinity exceeds upper levels, and to increase the frequency that salinity drops below lower levels.

Table A-1: Salinity Values

Basin	Lower Level	Upper Level
Joe Bay	5 ppt	15 ppt
Little Madeira Bay	15 ppt	25 ppt
Terrapin Bay	25 ppt	35 ppt
Garfield Bight	25 ppt	35 ppt
North River Mouth	5 ppt	15 ppt

The strategy for ecological restoration of the Everglades mangrove estuaries is to maintain freshwater heads and flows in the Everglades at the upstream end of the salinity gradient in order to achieve desirable salinity regimes in the Florida Bay coastal basins at the downstream end of the salinity gradient. Regression analyses demonstrated inverse relationships of salinity in the coastal basins to water level upstream in the Everglades (Davis 1997). The regressions indicated that stages of 7.3 and 6.3 feet mean sea level at the P33 gage in mid-Shark River Slough produce the lower and upper salinity levels for Joe Bay, Little Madeira Bay, Terrapin Bay, Garfield Bight and North River Mouth. Four performance measures for the ecological restoration of the Florida Bay mangrove estuaries are derived from the simulated stages at the P33 gage and salinity levels in the coastal basins: frequency of stages of 6.3 feet or greater and 7.3 feet or greater at P33; and Natural Systems Model (NSM) high and low salinity levels.

The frequency of stages of 6.3 feet or greater at P33 is applied as a performance measure for the Florida Bay coastal basins. The performance measure is the number of months during the 31-year period of record when stages at P33 rose to, or above, 6.3 feet. The target is the number of months that NSM provided stages of 6.3 feet or above. A reduced frequency of high salinity events is given a high priority in the ecological restoration of the coastal basins.

The frequency of stages of 7.3 feet or greater at P33 is applied as a performance measure to the Florida Bay coastal basins. The performance measure is the number of months during the 31-year period of record when stages at P33 rose to, or above, 7.3 feet. The target is the number of months that NSM provided stages of 7.3 feet or above. An increased frequency of low salinity events is given a lower priority than a reduced frequency of high events.

The transition from the late dry season to the early wet season during March through June is a critical period to estuarine organisms in the Florida Bay coastal basins regarding the frequency and duration of high salinity events. Salinity is estimated based on relationships between mean monthly salinity in the coastal basins and water stage at the P33 gage in mid-Shark River Slough. The cumulative salinity difference (ppt) from the high salinity levels that have been identified for Florida Bay coastal basins is summed during the dry/wet season transition months of March-June. Differences are summed over five coastal basins (Joe Bay, Little Madeira Bay, Terrapin Bay, Garfield Bight and North River Mouth) and

over the 31-year period of record. Differences above the specified high salinity levels are given a positive value, and differences below the high salinity levels are given a negative value. The target is to reduce the cumulative salinity difference to a value that does not exceed the cumulative difference produced by NSM.

During the August-October transition from the late wet season to the early dry season, it is important to achieve low salinity levels in the Florida Bay coastal basins to provide the seasonal environment for low-salinity estuarine organisms and to postpone the onset of high salinity events further into the dry season. Salinity is estimated based on relationships between mean monthly salinity in the coastal basins and water stage at the P33 gage in mid-Shark River Slough. The cumulative salinity difference (ppt) from the low salinity levels that have been identified for the Florida Bay coastal basins is summed during the wet/dry season transition months of August-October. Differences are summed over the five coastal basins and over the 31-year period of record. Differences above the specified low salinity levels are given a positive value, and differences below the low salinity levels are given a negative value. The target is to reduce the cumulative salinity difference to a value that does not exceed the cumulative difference produced by NSM.

Ecological attributes and indicators of restoration success in the Florida Bay mangrove estuaries that are linked to the above hydrology/salinity performance measures in the conceptual ecological model include 1) increased production of low-salinity mangrove fishes, 2) reestablishment of coastal nesting colonies of wood storks/great egrets and eastern Florida Bay colonies of roseate spoonbill, 3) earlier timing of coastal colony formation by wood storks/great egrets and of Florida Bay colony formation by roseate spoonbills, 4) increased growth and survival of juvenile American crocodiles, 5) return of American alligators to the tidal rivers, 6) increased cover of low-to-moderate salinity aquatic macrophyte communities in coastal lakes and basins, 7) return of seasonal waterfowl aggregations to coastal lakes and basins, 8) enhanced nursery ground value for spotted seatrout and pink shrimp in coastal basins, and 9) persistence and resilience of the mangrove, salt marsh and tidal creek vegetation mosaic.

A.3.10 Ecological Performance Measures

Table A-2 lists the ecological performance measures associated with the Everglades Mangrove Estuaries Conceptual Ecological Model.

Table A-2: Ecological Performance Measures for the Everglades Mangrove Estuaries Conceptual Ecological Model

Estuarine Geomorphology
Sea Level Rise
Shoreline Transgression
Coastal Storm Berm Accretion/Erosion
Mangrove Soil Accretion
Salinity Gradient/Mosaic
Mangrove Forests and Associated Plant Communities Mangrove Forest Functional Roles Mangrove Primary Productivity Mangrove Soil Accretion Nitrogen Accretion in Mangrove Soils Nutrient Flux Into and Out of Mangrove Estuary Plant Community Distribution and Taxonomic Composition Mangrove Forests Tidal Creeks and Adjacent Salt Marshes Coastal Lake and Basin SAV/Waterfowl White Zone Halophytic Prairie Tropical Forest Communities
Estuarine Fish Communities and Fisheries Resident Mangrove Fish Community Population Density Taxonomic Composition Size Structure Seasonal Concentration Spotted Seatrout Juvenile Density Sport Catch Catch Per Unit Effort Pink Shrimp Juvenile Density Commercial Catch, Tortugas Landings Catch Per Unit Effort
Wood Stork and Roseate Spoonbill Wood Stork/Great Egret Nesting Colonies: Southern Mainland and Tributary Headwaters Colony Distribution Timing of Colony Formation Number of Nesting Pairs Nesting Success Roseate Spoonbill Nesting Colonies: Florida Bay and Gulf of Mexico Colony Distribution Number of Nesting Pairs
Estuarine Crocodilian Populations American Alligator Distribution and Density Size Class Relative Abundance Nest Distribution and Density Body Condition Index American Crocodile: Juvenile Growth and Survival

A.3.11 Model

The diagram for the Everglades Mangrove Estuaries Conceptual Ecological Model is presented in Figure A-13. The key to the symbols used in the diagram is presented in Figure A-2.

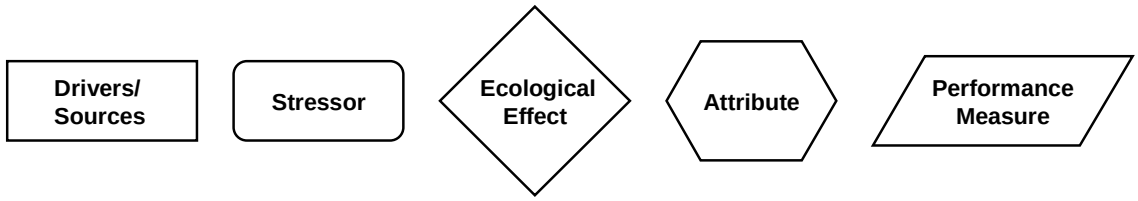


Figure A-12: Key to the Symbols Used in the Following Diagram

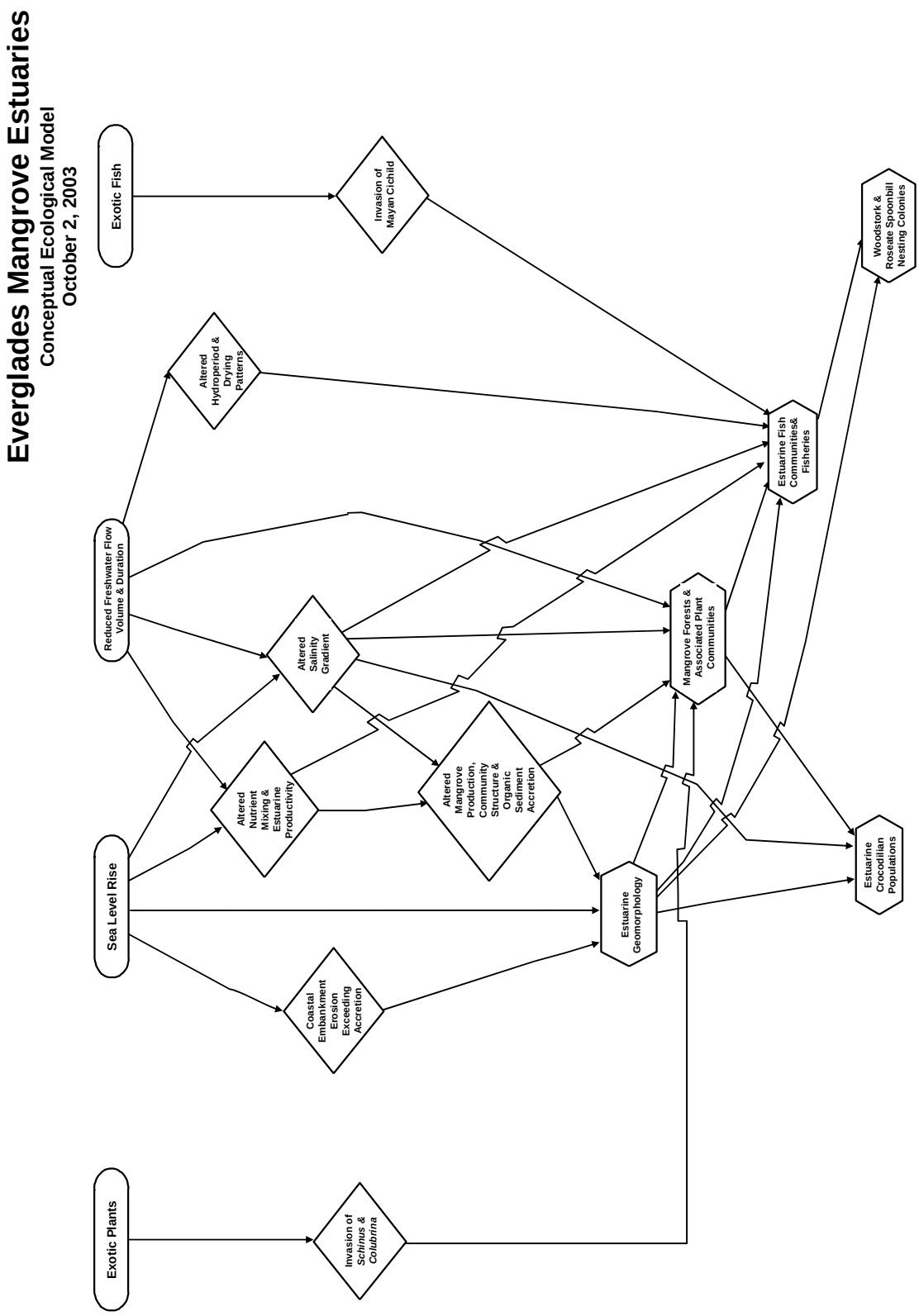


Figure A-13: Everglades Mangrove Estuaries Conceptual Ecological Model Diagram

A.3.12 Literature Cited

Allen, R.P. 1942. The Roseate Spoonbill. Dover Publications, New York.

Armentano, T.V., R.F. Doren, W.J. Platt, and T. Mullins. 1995. Effects of Hurricane Andrew on coastal and interior forests of southern Florida: Overview and synthesis. Journal of Coastal Research Special Issue 2: 111-114.

Bjork, R.D., and G.V.N. Powell. 1994. Relations between Hydrologic Conditions and Quality and Quantity of Foraging Habitat for Roseate Spoonbills and Other Wading Bird in the C-111 Basin. National Audubon Society Final Report to South Florida Research Center, Everglades National Park, Homestead, Florida.

Bricker-Urso. S. S.W. Nixon, J.K. Cochran, D.J. Hirshberg, and C. Hunt. 1989. Accretion rates and sediment accumulation in Rhode Island salt marshes. Estuaries 12:300-317.

Browder, J.A. 1985. Relationship between pink shrimp production on the Tortugas grounds and water flow patterns in the Florida Everglades. Bulletin of Marine Science 37: 830-856.

Browder, J.A., V.R. Restrepo, J.K. Rice, M.B. Robblee, and Z. Zein-Eldin. 1999. Environmental influences on potential recruitment of pink shrimp, *penaeus duorarum*, from Florida Bay nursery grounds. Estuaries 22:484-499.

Browder, J.A., and D. Moore. 1981. A new approach to determining the quantitative relationship between fishery production and the flow of fresh water to estuaries. In: Cross, R., and D. Williams (eds). Proceedings of the National Symposium on Freshwater Inflow to Estuaries, Volume 1. FWS/OBS-81/04, Office of Biological Services, United States Fish and Wildlife Service, Washington, D.C., pp. 403-430.

Callaway, J.C., Nyman, J.A., and DeLaune, R.D. 1996. Sediment accretion in coastal wetlands: A review and a simulation model of processes. Current Topics in Wetland Biogeochemistry 2:2-23.

Carter, R.W.G. 1988. Coastal Environments. Academic, London.

Chen, R., and R.R. Twilley. 1999. Patterns of mangrove forest structure and soil nutrient dynamics along the Shark River Estuary, Florida. Estuaries 22: 955-970.

Childers, D.L, J.N. Boyer, J.W. Fourqurean, R. Jaffe, R.D. Jones, and J. Trexler. 1999. Coastal Oligotrophic Ecosystems Research – the Coastal Everglades. Regional Controls of Population and Ecosystem Dynamics in an Oligotrophic Wetland-Dominated Coastal Landscape. A research proposal to the Long-Term Ecological Research (LTER) in Land/Ocean Margin Ecosystems, National Science Foundation, Washington, D.C.

Craighead, F.C. 1968. The role of the alligator in shaping plant communities and maintaining wildlife in the southern Everglades. Florida Naturalist 41:2-7, 69-74, 94.

Craighead, F.C. 1971. The Trees of South Florida. University of Miami Press, Miami, Florida.

Craighead, F.C., Sr., and V.C. Gilbert. 1962. The effects of Hurricane Donna on the vegetation of southern Florida: The Quarterly Journal of the Florida Academy of Sciences 25:1-28.

Davis, S.M. 1997. Salinity in coastal basins estimated from upstream water stages. In: Central and Southern Florida Project Comprehensive review Study, Comprehensive Plan Evaluation, Evaluation of Alternative Plans, About the P.M.s.

Dunson, W.A., and F.J. Mazzotti. 1989. Salinity as a limiting factor in the distribution of reptiles in Florida Bay: A theory for the estuarine origin of marine snakes and turtles. Bulletin of Marine Sciences 44: 229-244.

Egler, F.E. 1952. Southeast saline Everglades vegetation, Florida, and its management. Vegetation 3: 213-265.

Fourqurean, J.W., R.D. Jones, and J.C. Zieman. 1993. Processes influencing water column nutrient characteristics and phosphorus limitation of phytoplankton biomass in Florida Bay, Florida, USA: Inferences from spatial distributions. Estuarine, Coastal and Shelf Science 36: 295-314.

Higher Trophic Level Working Group. 1998. Draft Report of Higher Trophic Level Working Group of Florida Bay Program Management Committee. South Florida Ecosystem Restoration Task Force, Miami, Florida.

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

Jacobsen, T. 1983. Crocodilians and islands: Status of the American alligator and the American crocodile in the lower Florida Keys. Florida Field Naturalist 11: 1-24.

Joanen, T. 1969. Nesting ecology of the alligators in Louisiana. Proceedings of the Annual Conference Southeast Association of Game Fish Comm. 23:141-151.

Jones, A.C., D.E. Di itriou, J.J. Ewald, and J.H. Tweedy. 1970. Distribution of early developmental stages of pink shrimp, *Penaeus duorarum*, in Florida waters. Bulletin of Marine Science 20: 634-661.

Kushlan, J.D., O.L. Bass Jr., and L.C. McEwan. 1982. Wintering waterfowl in Everglades National Park. Report T-670, South Florida Research Center, Everglades National Park, Homestead, Florida.

Lauren, D.J. 1985. The effect of chronic saline exposure on the electrolyte balance, nitrogen metabolism, and corticosterone titer in the American alligator, *Alligator mississippiensis.* Comp. Biochem. Physiol. 81A:217-223.

Lorenz, J.J. 1997. The effects of hydrology on resident fishes of the Everglades mangrove zone. National Audubon Society Final Report to South Florida Research Center, Everglades National Park, Homestead, Florida.

Lorenz, J.J. 1999. The response of fishes to physical-chemical changes in the mangroves of northeast Florida Bay. Estuaries 22: 500-517.

Lorenz, J.J. 2000. The impact of water management on roseate spoonbills and their piscine prey in the coastal wetlands of Florida Bay. PhD dissertation, University of Miami, Coral Gables, Florida.

Mazzotti, F.J. 1983. The ecology of *Crocodylus acutus* in Florida. Ph.D. dissertation, Pennsylvania State University, University Park, Pennsylvania.

Mazzotti, F.J. 1989 Factors affecting nesting success of the American crocodile, *Crocodylus acutus*, in Florida Bay. Bulletin of Marine Sciences 44:220-228.

Mazzotti, F.J., and W.A. Dunson. 1984. Adaptations of *Crocodylus acutus* and *Alligator* for life in saline water. Comp. Biochem. Physiol. 79A: 641-646.

Mazzotti, F.J., and W.A. Dunson. 1989. Osmoregulation in crocodilians. American Zool. 29: 903-920.

Mazzotti, F.J., A. Dunbar-Cooper, and J.A. Kushlan. 1988. Desiccation and cryptic nest flooding as probable causes of embryonic mortality in the American crocodile, *Crocodylus acutus*, in Everglades National Park, Florida. Florida Scientist 52: 65-72.

McIvor, C.C., J.A. Ley, and R.D. Bjork. 1994. Changes in freshwater inflow from the Everglades to Florida Bay including effects on biota and biotic processes. In: Davis, S.M., and J.C. Ogden (eds). Everglades, the Ecosystem and its Restoration. St. Lucie Press, Delray Beach, Florida, pp.117-146.

Meeder, J.F., M.S. Ross, G. Telesnicki, P.L. Ruiz, and J.P. Sah. 1996. Vegetation Analysis in the C-111/Taylor Slough Basin. Document 1: The Southeast Saline Everglades Revisited: a Half-Century of Coastal Vegetation Change. Document 2: Marine Transgression in the Southeast Saline Everglades, Florida: Rates, Causes and Plant Sediment Responses. Final Report for Contract C-4244, Southeast Environmental Research Program, Florida International University, Miami, Florida.

Moler, P.E. 1991. American Crocodile Population Dynamics. Florida Game and Freshwater Fish Commission, Tallahassee, Florida.

Montague, C.L., and Wiegert, R.G. 1990. Salt marshes. In: Myers, R.L. and J.J. Ewel (eds). Ecosystems of Florida. University of Central Florida Press, Orlando, Florida.

Morrison, D., and D.L. Bean. 1997. Benthic Macrophyte and Invertebrate Distribution and Seasonality in the Everglades-Florida Bay Ecotone. National Audubon Society Final Report to South Florida Research Center, Everglades National Park, Homestead, Florida.

Nyman. J.A., DeLaune, R.D., Roberts, H.H. & Patrick Jr., W.H., 1993. Relationship between vegetation and soil formation in a rapidly submerging coastal marsh. Marine Ecology Progress Series 96: 269-279.

Ogden, J.C. 1976. Crocodilian ecology in southern Florida. In: National Park Service. Research in the Parks: Transactions of the National Park Centennial Symposium, 1971. National Park Service Symposium Series No. 1. United States Department of the Interior, Washington, D.C.

Ogden, J.C. 1994. A comparison of wading bird nesting colony dynamics (1931-1946 and 1974-1989) as an indication of ecosystem conditions in the southern Everglades. In: Davis, S.M., and J.C. Ogden (eds). Everglades: The Ecosystem and Its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 533-570.

Ogden, J.C., J.A. Kushlan, and J.A. Tilmont. 1978. The Food Habits and Nesting Success of Wood Storks in the Everglades National Park in 1974. Natural Resources Report 16, United States National Park Service, Washington, D.C.

Powell, G.V.N., and R.D. Bjork. 1990. Relationships between Hydrologic Conditions and Quality and Quantity of Foraging Habitat for Roseate Spoonbills and Other Wading Birds in the C-111 Basin. National Audubon Society Second Annual Report to South Florida Research Center, Everglades National Park, Homestead, Florida.

Powell, G.V.N., R.D. Bjork, J.C. Ogden, R.T. Paul, A.H. Powell, and W.B. Robertson, Jr. 1989. Population trends of some South Florida wading birds. Wilson Bulletin 101: 436-457.

Rice, J.K. 1997. An analysis of environmental factors influencing juvenile pink shrimp (*Penaeus duorarum*) abundance in southwest Florida. Masters Thesis. University of Miami, Coral Gables, Florida.

Ross, M.S., J.F. Meeder, J.P. Sah, P.L. Ruiz, and G.J. Telesnicki. 2000. The southeast saline Everglades revisited: 50 years of coastal vegetation change. Journal of Vegetation Science 11: 101-112.

Ross, M.S., E.E. Gaiser, J.F. Meeder, and M.T. Lewin. 2002. Multi-taxon analysis of the "White Zone." A common ecotonal feature of the South Florida coastal wetlands. In: Porter, J.W., and K.G. Porter (eds). The Everglades, Florida Bay, and Coral Reefs of the Florida Keys: An Ecosystem Sourcebook. CRC Press, Boca Raton, Florida, pp. 205-238.

Rudnick, D.T., Z. Chen, D.L. Childers, J.N. Boyer, and T.D. Fontaine. 1999. Phosphorus and nitrogen inputs in Florida Bay: The importance of the Everglades watershed. Estuaries 22: 398-416.

Schmidt, T.W. 1993. Community characteristics of dominant forage fishes and decapods in the Whitewater Bay-Shark River Estuary, Everglades National Park. Technical Report NPS/SEREVER/NRTR-93/12, Everglades National Park, Homestead, Florida.

Sheridan, P.F. 1996. Forecasting the fishery for pink shrimp, *Penaeus duorarum*, on the Tortugas grounds, Florida. Fishery Bulletin 94: 743-755.

Tabb, D.C., D.L. Dubrow, and A.E. Jones. 1962. Studies on the biology of the pink shrimp *Penaeus duorarum* Burkenroad, in Everglades National Park, Florida. Technical Series 37: 1-30, Florida State Board of Conservation, University of Miami, Miami Laboratory, Miami, Florida.

Tamarack, J.L. 1988. Georgia's coastal island alligators, variations and habitat and prey availability. In: Proceedings of the Eighth Working Meeting of the Crocodile Specialist Group, IUCN - Gland, Switzerland, pp. 105-118.

Thayer, G.W., A.B. Powell, and D.E. Hess. 1998. Response of larval, juvenile and small adult fishes to changes in environmental conditions in Florida Bay: A decadal comparison. In: Proceedings of the 1998 Florida Bay Science Conference, May 12-14, 1998. Florida Bay and Adjacent Marine Science Program, c/o Everglades National Park, Homestead, Florida.

Trexler, J.C., and W.F. Loftus. 2000. Analysis of relationships of Everglades fish with hydrology using long-term data bases from the Everglades National Park. Report to Everglades National Park, Homestead, Florida.

Trexler, J.C., W.F. Loftus, F. Jordan, J. Lorenz, J. Chick, and R.M. Kobza. 2001. Empirical assessment of fish introductions in a subtropical wetland: an evaluation of contrasting views. Biological Invasions 2: 265-277.

VanZee, R. 1999. Natural System Model Version 4.5 Documentation Report. South Florida Water Management District, West Palm Beach, Florida.

Wanless, H.R., R.W. Parkinson, and L.P. Tedesco. 1994. Sea level control on stability of Everglades wetlands. In: Davis, S.M., and J.C. Ogden (eds). Everglades: The Ecosystem and Its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 199-223.

Welsh, R., M. Remillard, and R.F. Doren. 1995. GIS data base development for South Florida's national parks and preserves. Photogrammetric Engineering and Remote Sensing 61(1): 1371-1381.

A.4 BIG CYPRESS REGIONAL ECOSYSTEM CONCEPTUAL ECOLOGICAL MODEL

A.4.1 Model Lead

Michael J. Duever, South Florida Water Management District

A.4.2 Introduction

The Big Cypress region covered by this conceptual ecological model includes the freshwater portions of the area extending from the southern edge of the Caloosahatchee River watershed boundary in Lee, Hendry, and northern Collier Counties, and west of the Everglades, as delimited approximately by L-2, L-3 and L-28 in the north and a diagonal line running from Forty-Mile Bend on Tamiami Trail southwest to the coast (Figure A-14). In this region historic water flows were primarily south to the Gulf of Mexico, with minor flows in small creeks that pass through the west coast ridge to the gulf and somewhat more significant flows east into the Everglades in the northeast corner of the area (Klein et al. 1970). We define the water table throughout the Big Cypress as being at the top of the surficial aquifer, which would be above ground over much of the area during the wet season and below ground over most of these same areas during the dry season.

Big Cypress region has three distinct subregions based on the kind and degree of development present in each (Lehman 1976). The least disturbed area, because the hydrology is largely rainfall-driven, is located within the Big Cypress National Preserve in the southeastern portion of the region (Duever et al. 1986). The preserve, along with a portion of the adjacent Seminole Indian Reservation to the north, is the Big Cypress subregion that was included in the Central and Southern Florida (C&SF) Project Review Study (Restudy) alternatives analyses (USACE and SFWMD 1999), although only the eastern portion of this area was affected by components included in the various restoration alternatives. The most developed portion of the area, including both urban and agricultural development, is located on and just east of the coastal ridge from Naples north to Fort Myers. The rest of the area is a mixture of agricultural lands, suburban and rural communities, and small-to-large natural areas that have been altered to varying degrees by upstream and/or adjacent development. Despite the very different degrees of development in the three subregions, the kinds of stressors and their effects on ecosystem attributes are similar throughout the Big Cypress region and they differ only in the severity of their impacts.

The Big Cypress region is comparable to the freshwater Everglades in terms of natural community diversity, although the Big Cypress communities are primarily forested and tend to form more of a mosaic as opposed to vast expanses of a number of primarily herbaceous community types. The most extensive natural communities in the Big Cypress are distributed throughout the region along very gentle topographic gradients from short-hydroperiod pinelands on the uplands through marshes to long-hydroperiod cypress forests on lower elevations (Craighead 1971, Davis 1943, Duever 1984, Klein et al. 1970). Small open-water ponds are found in scattered deeper depressions, and small islands of hardwood forest or “hammocks” occur on elevated sites among or along the edges of deeper herbaceous and forested wetlands. While the Big Cypress is dominated by temperate species, there is a tropical component that is most prevalent in forested upland and swamp communities (Duever et al. 1986). This component is most abundant and diverse close to the Gulf of Mexico coast, but occurs further inland in association with larger and deeper wetlands, where it is protected from cold winter weather by the temperate forest canopy and/or the moderating effects of standing water. Under natural conditions, the range of annual fluctuation in water levels above and below ground and the duration of inundation are the primary factors influencing the distribution of these communities, although frequent fires exert a secondary influence by controlling the kinds and structure of their dominant plant species (Craighead 1971, Duever 1984, Harper 1927, Klein et al. 1970). Cypress and marsh communities tend to be more

common towards the south as elevations approach sea level, while pinelands are more common on the higher and deeper-sand substrates to the north and on the west coast ridge along the Gulf of Mexico.

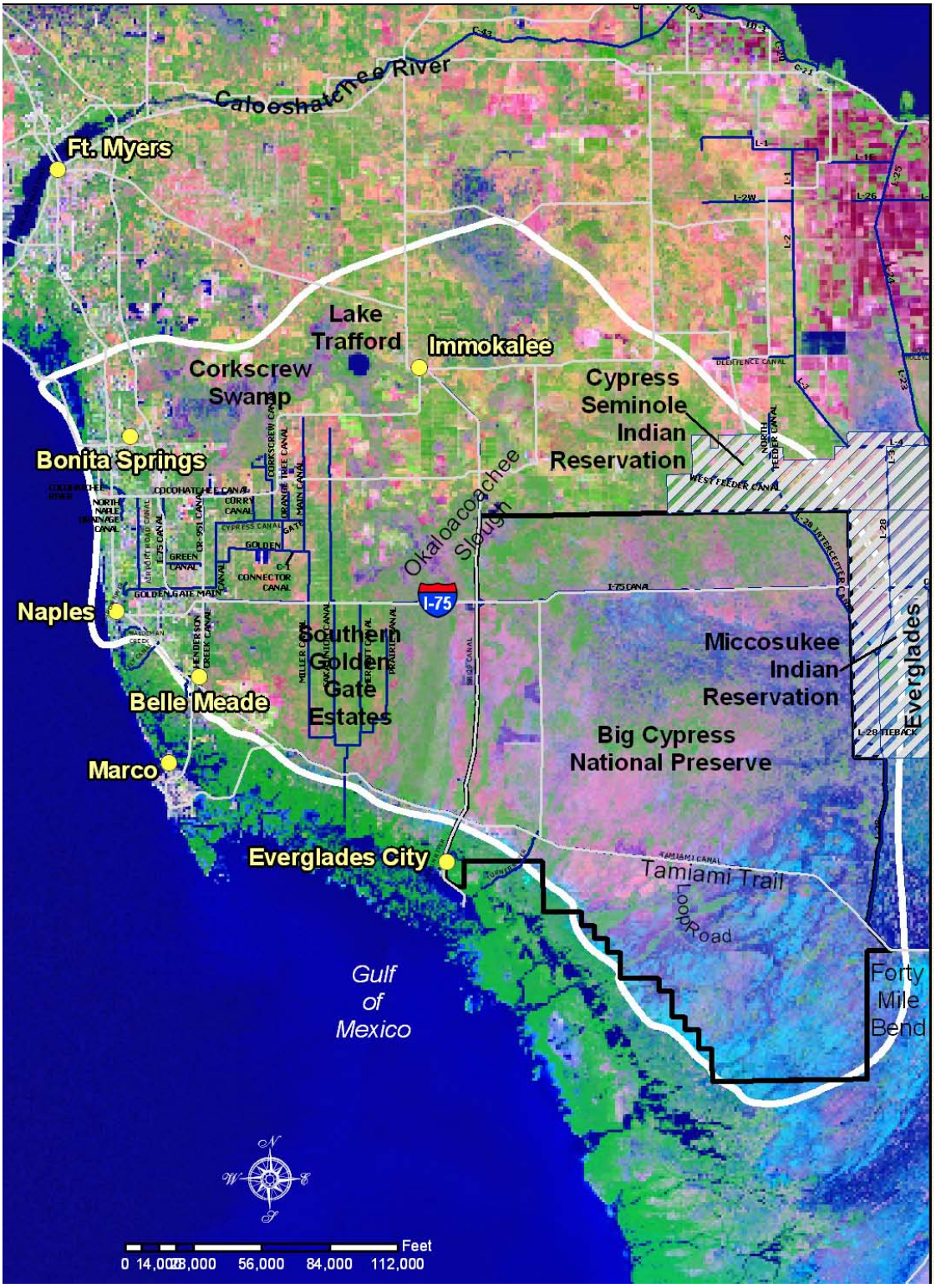


Figure A-14: The Boundary of the Big Cypress Regional Ecosystem Conceptual Ecological Model

A.4.3 External Drivers and Ecological Stressors

The ultimate source of all ecological stressors in the Big Cypress ecosystem is development for agricultural and residential use. The area's seasonally high water table required the construction of an extensive system of small ditches connected to larger and larger canals to assure that water levels remain below ground throughout the year, in order to make the land suitable for crops and housing (Lehman 1976). The drainage systems produce **lowered water tables and shortened hydroperiods** for considerable distances in otherwise unaltered lands around and downstream of them (Carter et al. 1973, Klein et al. 1970, Swayze and McPherson 1977). These drier conditions can facilitate major shifts in the composition of affected wetland plant communities to a composition more similar to that found in more upslope communities. These shifts can include colonization by native woody species, such as slash pine, cabbage palms, and a variety of hardwoods, such as red maple (*Acer rubrum*) and laurel oak (*Quercus laurifolia*), or by exotic species, such as melaleuca (*Melaleuca quinquenervia*). Changes in community composition would be further accelerated by the more frequent and severe fires that typically occur under these drier conditions (Robertson 1953, Wade et al. 1980). In addition, the water in canals draining these lands normally has a different chemistry than that found in natural Big Cypress waters. This is of particular concern in terms of undesirably **higher concentrations of nutrients and dissolved minerals** (Duever et al. 1986), which can encourage the spread and potential dominance of sites by invasive native and exotic vegetation. The human response to South Florida's dry season produces an additional hydrologic stress on natural systems in the Big Cypress in terms of **lowered water tables and shortened hydroperiods**. When weather conditions are dry for extended periods, water use for crops, lawns, etc. goes up substantially resulting in lower than normal water levels in and for considerable distances around the wells that provide this water (Lehman 1976, Rochow 1985). Excessive drawdowns associated with canals and wellfields can produce very significant impacts on native amphibian, fish, and crayfish populations that depend on the presence of at least some inundated wetlands or moist wetland substrate for their survival through the dry season. These drawdowns can also eliminate the standing water that normally helps to protect tropical vegetation from winter freezes (Duever et al. 1978).

Changes in land use associated with agricultural and residential development not only cause **habitat loss** on the affected lands, but **fragmentation of the habitat mosaic**. Habitat loss directly impacts the availability of resources required by organisms that utilize these areas. However, the distribution of these habitats across the landscape is even more important because few organisms utilize only one habitat type, particularly in a landscape that can fluctuate seasonally from mostly inundated to completely dry and that may be affected by widespread and sometimes severe fires. Thus, when wetland connections to adjacent uplands are severed, innumerable biologically important flows are interrupted and ecosystem diversity and viability are severely compromised (Forman and Godron 1986, Harris 1984). Fragmentation and habitat loss also affects populations by reducing the spatial extent of their resource base to the point where it is no longer able to support viable populations. Exposure of wildlife to hazards associated with development, such as roads, increases dramatically as habitats become smaller and are more and more fragmented, and the resulting extensive edges also facilitate the movement of exotic plants and animals into the native landscape.

As development increases in an area, the **seasonality and frequency of fire** in natural communities becomes increasingly unnatural (Wade et al. 1980). Natural fires were normally most common during the summer wet season as a result of the high frequency of lightning (Duever 1984). However, they were most widespread at the beginning of the wet season, when the region was at its driest and lightning storms were just beginning to occur. Early in this century, cattlemen greatly increased the frequency of winter fires to provide more forage for their cattle during the nongrowing season (Ackerman 1976, Alvarez no date, Kennard 1915). More recently, fire has been suppressed over much of the more developed portions of the area, which has caused unusually severe fires when they finally occur, as they always do eventually

(Hofstetter 1984). The lack of fire has allowed succession to proceed in many areas, so that herbaceous communities are being invaded by dense shrub thickets and pine and cypress forests are being invaded by shrubs and hardwoods (Hofstetter 1984).

Exotic plants and animals produce drastic alterations in the composition and structure of natural communities, although many of these changes are poorly documented, such as the impacts resulting from the **spread of feral hogs and exotic fish** (Crowder 1974, Dineen 1984, Duever et al. 1986, Layne 1984). Some that are well documented include the **spread of melaleuca and other exotic plants** (Duever et al. 1986, Myers 1975). Some species, such as melaleuca and feral hogs, can readily utilize undisturbed natural communities. However, development has facilitated the invasion of exotics by creating an abundance of disturbed sites that normally would have been recolonized by native species, but these species are now being outcompeted by more rapidly invading exotics (Elton 1958, Odum 1971). In addition, farms and residential areas create new habitats that are more suitable to new species, which then invade adjacent natural areas and impact native populations either directly by predation or indirectly through competition for resources.

The **increasing amounts of pesticides, mercury and other contaminants** that are being used over much of South Florida pose a variety of types of threats to fauna at all trophic levels in all South Florida ecosystems, including the Big Cypress Region. They accumulate in both aquatic and terrestrial food chains.

A.4.4 Ecological Attributes

A.4.4.1 Vegetation Community Gradients and Habitat Mosaic

The vegetatation community gradients and habitat mosiac attribute is affected by all of the stressors except mercury and other contaminants, which tend to be more obviously impacting on animal populations than on plant communities. Hydrologic and fire regimes control the character and distribution of the major types of Big Cypress plant communities (Craighead 1971, Davis 1943). The most frequent and widespread hydrologic alterations typically result in reduced depth and duration of inundation, which tends to shift affected wetland plant communities towards shallower wetland types, or with sufficient drainage to upland types (Alexander and Crook 1973, Duever 1984). Fires are more frequent and severe in these drier environments, in some areas resulting in dense stands of fire-tolerant cabbage palms and fast-growing woody exotics, such as melaleuca (Gunderson and Loope 1982, Tabb et al. 1976). Drainage can also impact tropical components of the communities by eliminating the moderating effect of standing water on cold winter temperatures (Duever et al. 1978). Less frequent alterations involve increasing depths and/or duration of inundation, which can convert uplands to wetlands and wetlands to aquatic habitats. In some situations, such as retention areas associated with on-site canal drainage systems, altered hydrology can produce unnatural permanently disturbed habitats that are at times too deeply flooded to support upland vegetation, but for too short a period to produce wetland communities. However, where sites have been previously drained, incorporation into detention areas with subsequently increased flooding, can result in improved conditions for some wetlands (J.C. Volin, Florida Atlantic University, and W.A. Dunson, Seminole Tribe of Florida, personal communication).

Natural communities in South Florida are adapted to surface waters with a chemical composition that contains low concentrations of dissolved minerals and nutrients. Changes in surface water quality typically involve increased nutrient and mineral concentrations coming from ditch and canal outflows into natural wetlands (Drew and Schomer 1984). These increased concentrations can produce dramatic shifts from diverse herbaceous communities to communities dominated by a few invasive exotic and native species, such as primrose willow and cattail respectively, which are adapted to high nutrient and dissolved mineral concentrations.

Dormant season fires and reduced fire frequencies can result in successional shifts from herbaceous to shrubby communities and from open pinelands, herbaceous wetlands, and cypress forests to shrub and hardwood dominated forests (Alexander and Crook 1971, Duever 1984). As fuels build up in these sites, the inevitable severe wildfire will eventually occur (Hofstetter 1984), and the sites will most likely be converted to early successional communities dominated by weedy herbaceous, vine and shrub species, a large proportion of which are much less abundant, if even present, in natural communities.

Land use changes reduce the area of affected communities and often eliminate the transitions from one to another, particularly along upland to aquatic hydrologic gradients. Since wetlands have more legal protection and are more difficult to develop than uplands, habitat loss is greatest in historical uplands, although this may not be obvious because new upland habitat is being created by the drainage occurring throughout much of the area. Upland development is also resulting in wetlands becoming more and more isolated from each other as well as from other natural parts of the system, which is in turn affecting their faunal populations and fire regimes. Roads represent a particularly insidious form of habitat fragmentation. They often begin as dirt tracks through the countryside, which gradually attract more use and are thus improved to accommodate the increased use, which in turn attracts residential or commercial development. Initially, the dirt tracts are only threats in terms of mortality of individual organisms. However, as development occurs along the road, adjacent habitats are destroyed, and the surrounding landscape is increasingly fragmented.

All of the ecosystem alterations associated with development are facilitating the increasingly rapid spread of nuisance and exotic species throughout the Big Cypress region landscape (Drew and Schomer 1984, Duever et al. 1986). In many areas, exotic woody vegetation such as melaleuca, Brazilian pepper, or downy rosemyrtle completely dominates what were previously herbaceous communities or open pinelands. Cattails and primrose willow have replaced marsh communities that once supported diverse herbaceous species assemblages. Feral hogs annually “plow” thousands of acres, with unknown impacts on what they are foraging on, but quite visible soil disturbance effects that further exacerbate the spread of exotic plants (Duever et al. 1986, Layne 1984).

Measurements of changes in the vegetation mosaic in terms of community cover, density, composition, structure and distribution would provide a basis for assessing gains and losses in the spatial distribution as well as the health of these communities in the Big Cypress region. The types of measures used to make these evaluations would depend upon the plant community involved, but would primarily be associated with restoring and/or maintaining natural hydrologic (quantity and quality) and fire regimes, and controlling at least the more aggressive exotic and nuisance plant species. The measures would be designed to evaluate dominant structural and compositional characteristics described below for each of the major community types (Duever 1984). In addition, the current official federal and Florida State lists that indicate the wetland status of each plant species could be used to document changes in the wetland status of sites following restoration.

Hardwood hammocks exist in the long-term absence of fire, which is in turn dependent upon an undisturbed hydrologic regime. The occurrence of very severe droughts would allow fires to enter some examples of this community type, but droughts of this severity would not likely occur more often than once in about 500 years, and probably even less frequently at the majority of sites. A hammock community unaffected by recent fire would be expected to have a tall, closed canopy with a variably open-to-dense shrub and ground cover. The presence of viable populations of tree snails (*Liguus fasciatus*) and tropical plant species in appropriate settings, such as near the Gulf of Mexico coast and in association with major wetlands would indicate the presence of a hydrology adequate to protect these organisms from freezes. Even undisturbed hammocks are susceptible to invasion by a variety of exotic plant species, such as old world climbing fern (*Lygodium microphyllum*) and Java plum (*Syzygium cumini*).

Pine flatwoods are savanna communities with an open canopy of slash pine (*Pinus elliotti* var. *densa*) and a diverse ground cover of grasses, sedges, and broad-leaved forbs. Shrubs, particularly palmetto, *Serenoa repens*, are typically maintained by a natural fire regime as a scattered and low growing component of this community. A fire frequency of approximately once every three to five years maintains this community structure by controlling colonization by shrubs and hardwoods, while allowing adequate survival of young pines. There is a moisture gradient over which pine flatwoods exist. Wetter sites have a diverse herbaceous ground cover, while drier sites have a more extensive cover of palmetto and mixed shrubs. These two types tend to co-exist as a mosaic, with the wetter type becoming more dominant within the mosaic as one moves down slope and the drier type becoming more dominant as one moves upslope. Even undisturbed pine flatwoods are susceptible to invasion by a variety of exotic plant species, such as melaleuca and downy rose myrtle (*Rhodomyrtus tomentosa*).

Herbaceous wetlands are dominated by grasses and sedges, along with a variety of broad-leaved forbs. The dominant species are often arranged in a pattern of concentric rings or zones of vegetation oriented perpendicular to the hydrologic gradient. The driest sites are short hydroperiod wet prairies that typically occur on a mineral substrate. Wet prairies support a diverse plant community that can vary in structure from open to dense, and is generally dominated by short vegetation less than about 4 feet tall. This structure allows substantial amounts of sunlight to reach the water surface, which facilitates development of productive submerged algal communities. The wettest sites are long hydroperiod marshes that typically occur on a deep organic substrate. They have a lower diversity than wet prairies, and a relatively tall, dense structure that allows little sunlight to reach the water surface. Drainage can convert the drier sites to upland communities, and the wetter sites to something more similar to the drier sites. Loss of organic soils can be particularly damaging, because of their rapid disappearance following drainage and their very slow rate of recovery even when the hydrologic regime is restored. In the absence of a fire frequency of about every three to ten years, shrubs and trees gradually colonize these wetlands, and can eventually convert them to forested sites. As with all South Florida communities, herbaceous wetlands are low-nutrient systems. Significant increases in nutrients can drastically alter their composition. The best documented example of this alteration is the conversion of sawgrass marshes to cattail marshes in areas where there have been substantial inputs of phosphorus (Davis 1994). However, as with the upland communities, even undisturbed herbaceous wetlands are susceptible to invasion by a variety of exotic plant species, such as melaleuca on drier sites and West Indian marsh grass (*Hymenachne amplexicaulis*) on wetter sites.

Forested wetlands occupy sites that are typically wetter than those occupied by herbaceous communities. As a result, they burn less frequently, and woody vegetation is able to colonize and dominate these sites. As with the other major community types, the character of forested wetlands changes substantially along a moisture gradient that, in concert with organic soil depths, controls the frequency and severity of fires. Virtually mono-specific stands of young, densely-spaced cypress, *Taxodium distichum*, growing on a mineral soil dominate the canopy of sites at the drier end of this gradient, where severe fires probably occur every 15 to 50 years. A diverse grass and sedge ground cover with few shrubs is usually found on these sites. At the wet end of the gradient are forests still dominated by a dense cypress canopy, but here they are large and more widely spaced and are growing on a deep organic soil. There is typically a well-developed subcanopy of hardwoods, and a variably dense cover of shrubs and herbaceous vegetation, with scattered ponds that may have an open water surface or a cover of floating plants. Fire still occurs in these latter sites, but because of their very wet setting, severe fires are not likely at a frequency greater than about once every 1,000 years. However, the more varied topography of these sites, which contributes to their high diversity, partially results from patchy and variable consumption of the underlying peat during these rare fire events. Diversity associated with topographic variation is also increased when a large cypress dies, and the fallen log and stump are colonized by vegetation that could not become established on the forest floor because of the depth and duration of inundation in this community. Drainage of these sites can result in the conversion of the shallower forested wetlands to herbaceous wetlands or upland communities through a more frequent and severe fire regime, and conversion of the

deeper wetland plant communities to something more similar to the shallower forested wetlands. There are again the same problems associated with rapid organic soil loss following drainage, and its very slow recovery following reestablishment of the hydrologic regime. Hydrologic restoration of drained sites would be evidenced by the redevelopment of a closed cypress canopy through expansion of existing canopies and seedling establishment, and the presence of stressed and dying species less tolerant of extended inundation than cypress, such as slash pine, laurel oak, and grape vines (*Vitis* sp.) that invaded the site following drainage. Reestablishment of an appropriate fire regime would still allow fire to regularly enter the shorter hydroperiod cypress forests so that hardwoods would not be present on these sites. The longer hydroperiod mixed cypress forests would not experience fires for periods on the order of centuries, and hardwoods, such as dahoon holly (*Ilex cassine*), sweet bay (*Magnolia virginiana*), and red maple, would be a major subcanopy component of these diverse systems. As for the hardwood hammocks, the presence of tropical plant species in appropriate settings, such as near the Gulf of Mexico coast and in association with major wetlands would indicate the presence of a hydrology adequate to protect these organisms from freezes.

The above discussion is not meant to be exhaustive, but provides examples of the kinds of community characteristics and site changes that would be useful to monitor, particularly in areas that are established as major restoration sites or are set aside for preservation. Rates of change in these communities in response to increased or decreased levels of stressors will vary from three to twenty or more years depending on community type and the management required to accomplish restoration. Early successional communities, such as the herbaceous wetlands and pine flatwoods, tend to respond more rapidly to changes than do later successional communities, such as the hammocks and forested wetlands. Management actions that directly affect vegetation, such as herbiciding or prescribed fire, will produce more rapid responses than will management actions that indirectly affect it, such as changes in hydrology or a reduction in fire frequency.

A.4.4.2 Organic Soils

Organic soils accumulate in depressions that are inundated for much of the year, particularly during the summer months when litter decomposition rates are high. Extended inundation in the nonturbulent waters found in wetlands limits the amount of oxygen reaching the ground surface and decomposing litter assimilates what little does get there. The resulting anaerobic conditions allow the accumulation of organic soils up to a point where the ground surface is exposed to air for less than approximately eight months during an average year. These organic soils create a unique environment that supports unique plant communities, and allows for greater species diversity and structural development then most other wetland communities in South Florida.

Organic soils accumulate very slowly, on the order of about 1 to 2 feet per 1,000 years, but they can be lost much more rapidly. Similar depths can oxidize in less than a decade due to increased exposure to air associated with a lowered water table following drainage. They can be lost even more rapidly, in a matter of days, when consumed by fires following drainage. Response to hydrologic restoration would be very slow, probably taking centuries, but it would limit further organic soil loss and provide a setting for the long-term recovery of the site.

A.4.4.3 Red-Cockaded Woodpecker

Logging of old growth pines, which occurred in the Big Cypress region through the 1950s, has removed many of the prime red-cockaded woodpecker nesting trees throughout its range (Ligon 1971, Patterson and Robertson 1981). In addition, conversion to agriculture and housing is eliminating their habitat. The current altered fire regime is resulting in colonization by native and exotic woody vegetation of the remaining pinelands, which is eliminating the open character of these pinelands that is needed to support

this species (Patterson and Robertson 1981, Jackson 1971). Successful reproduction in this species is one possible measure of pineland condition, since it is dependent upon mature, open pinelands. Suitable habitat should be extensive enough so that it would burn regularly, while having a hydrology that would prevent excessively severe fires. Sites should not support nuisance exotics that would tend to grow up and both eliminate the site's open character and produce fuel loads that would result in excessively severe fires. Response to restoration that increases the suitability of habitat would likely be expected within five to ten years, where reestablishing the open character of a pineland is involved, but could be thirty or more years, where young pine stands need to reach large enough sizes to provide suitable nest sites.

A.4.4.4 Native Fish, Crayfish, and Amphibians

Native fish, crayfish and amphibian species are affected primarily by altered hydrology and land use changes, both of which have resulted in habitat loss and fragmentation over large areas of the Big Cypress region. Of particular concern is the loss of dry season refugia, which have been replaced by deep canals and excavations with quite different physical and biological characteristics. Abundance of marsh fishes has been correlated with duration of flooding in the Everglades (Loftus and Eklund 1994), suggesting a decline in fish populations in remaining Big Cypress wetlands where water tables have been lowered and hydroperiods shortened. Habitat fragmentation is particularly damaging to these species, which in more natural settings take advantage of the wet season expansion of surface waters into the surrounding uplands by increasing their numbers and biomass, which then becomes available to wading birds and other predators during the surface water's subsequent retreat during the dry season (Carlson and Duever 1979, Kolopinski and Higer 1969, Kushlan et al. 1975). A poorly known influence on them are exotic fish and amphibian species that have invaded the area, which are both preying on native species and competing with them for resources (Dineen 1984, Duever et al. 1986). Documenting the abundance, distribution, and diversity of these taxa will provide useful measures of how the stressors affecting them are being minimized in protected areas and are being ameliorated in areas being restored. Since these populations show a dramatic annual cycle in their numbers and biomass, responses to increasing or decreasing levels of stressors should be detectable within three to five years.

A.4.4.5 Wood Stork

The Big Cypress region supported the two largest nesting colonies of wood storks in North America between 1900 and 1965 (J.C. Ogden, South Florida Water Management District, personal communication). During that period, 6,000-10,000 pairs nested annually in the Corkscrew colony, the Sadie Cypress colony of Okaloacoochee Slough, and smaller subsidiary colonies. Since 1965, wood stork nesting in Big Cypress has declined and has ranged from less than 500 to 1,500 pairs since 1990 (Ogden personal communication). The subsidiary colonies have been largely lost. Accompanying the decline in numbers of nesting pairs has been a reduction in nesting success in the remaining colonies. The decline in success is attributed to a change in the timing of the initiation of nesting from November to February (Kushlan et al. 1975, Ogden et al. 1987, Ogden 1994). Delay in nesting until February puts nesting out of synchrony with seasonal rainfall patterns. With the onset of the wet season, rising water levels decrease food availability before the young storks fledge, causing nestling mortality due to starvation. The reduction in numbers of nesting pairs and nesting success is attributed to the loss of early dry season foraging habitat of the higher elevation wetlands of the Big Cypress region that have been drained and developed. Recovery of fish production in the higher elevation wetlands by raising water tables in preserved areas in the western and northern portions of the Big Cypress basin is expected to halt the decline in wood stork nesting in the region. A trend of increasing numbers of nesting pairs, nesting success and reestablishment of subsidiary colonies should be evident over a decade-long time scale after water table recovery.

A.4.4.6 Florida Panther

The endangered Florida panther (*Puma concolor coryi*) is the only representative of the species *P. concolor* surviving in the eastern United States. Over the past 100 years, bounty hunting, land clearing, urbanization, and increased human activity throughout the landscape have contributed to the rangewide decline of the panther and have resulted in a population threatened with extinction. The panther's current distribution occupies approximately 890,000 hectares, which is greatly reduced from the subspecies' historical range. The current verified population (2002) totals 80 panthers, which represents the number of adult and subadult panthers documented during field investigations (McBride 2002). The only known reproducing Florida panther population is located in the Big Cypress/Everglades physiographic region of South Florida. Seventeen years of monitoring indicate a stable but saturated panther population in the northern portion of its current range, which encompasses public lands north of Interstate 75 and adjacent private lands (D.K. Jansen, Florida Fish and Wildlife Conservation Commission, personal communication). Habitat vacancies in southern Big Cypress National Preserve and Everglades National Park have not been filled due to the difficulty of population increase when there are few individuals, at times only a single sex, and infrequent ingress of new individuals. The initial results of genetic restoration have been promising, with an increasing population, signs of increased genetic health, current recolonization of areas in Big Cypress National Preserve and Everglades National Park recently unoccupied, and increased dispersal (McBride 2000, 2001, 2002, Maehr et al. 2002).

The habitat of the Florida panther is an extensive landscape comprised of a mixture of natural, semi-natural, and agricultural land uses. Within this landscape, panthers maintain functional home ranges, have access to mates, find suitable denning sites, rear young, and disperse upon reaching adulthood. The maintenance and enhancement of appropriate cover types, existing agricultural land uses, and landscape configurations is necessary to conserve the existing panther population in South Florida. Panther require dry areas for daytime resting but readily travel through inundated habitats (Jansen 1987). Deer, a preferred prey species, benefit from a hydroperiod that promotes nutritious wetland vegetation (Loveless 1959), and prescribed fire improves the nutritional quality of food used by panther prey species.

Stressors for the panther include loss and fragmentation of habitat due to urbanization and agricultural development, genetic erosion, mortality associated with road hazards, and mercury toxicosis. The sources of methylmercury, reported as the cause of death of at least one panther and known to compromise normal biological functions, have yet to be confirmed and remedied (Roelke et al. 1991). Habitat protection, including land acquisition, land management (e.g., exotic control and prescribed fire), and restoration of natural hydroperiods with clean water would benefit the panther by providing suitable land for population expansion, as well as an uncontaminated and abundant prey base (Jansen personal communication).

A.4.4.7 Aquatic Fauna

Potential inputs of pesticides, mercury and other contaminants in agricultural and urban runoff water, which may be needed for hydropattern restoration in the Big Cypress, could result in reduced health, behavioral and physical abnormalities, and loss of reproductive vigor unless measures are taken to restrict loads of these toxins in waters flowing into natural areas. Measures of aquatic faunal health that reflect responses to the mercury and pesticide inputs include body burdens of mercury and other toxins in representative top predators, especially long-lived predators/scavengers such as fish and alligators.

A.4.5 Ecological Effects

Critical Linkages between Stressors and Attributes/Working Hypotheses

The ecological effects of the seven principle stressors in the Big Cypress Regional Ecosystem Conceptual Ecological Model are based on 14 key hypotheses developed during the conceptual model workshops. These hypotheses determine the content and organization of the Big Cypress Regional Ecosystem Conceptual Ecological Model. The 14 hypotheses are presented here, organized by attribute.

A.4.5.1 Vegetation Community Gradients and Habitat Mosaic

Relationship of Vegetation to Reduced Hydrologic Regime

The occurrence and distribution of all native and some exotic plant communities in the Big Cypress region are a function of hydrology. A reduction in hydroperiod and depth results in dominance by more terrestrial communities, while an increase in hydroperiod and depth results in dominance by plant communities more tolerant of extended inundation. Severe reduction or alteration of hydrologic regimes result in further changes in vegetation due to invasion of exotic plants, increased fire severity, woody plant colonization, and reduction in populations of native tropical plant species due to freezes.

Level of certainty – High

Relationship of Vegetation to Habitat Loss and Fragmentation

Loss of plant community spatial coverage is proportional to the loss of Big Cypress habitats to drainage and development. In addition, disturbance related to compartmentalization facilitate exotic vegetation invasion, since invading species typically are more prolific, disseminate their propagules more widely, and grow more rapidly than most native species.

Level of certainty – High

Relationship of Vegetation to Exotic Plant Invasion

A number of the more aggressive exotic plant species can completely alter the species composition and structure of plant communities, as well as the ecological processes operating on a site. Spread of exotic plants is related to fire and disturbance, as noted in other hypotheses.

Level of certainty – High

Relationship of Vegetation to Exotic Hog Impacts

Hog impacts result from their rooting of soils over extensive areas. Their effects are thought to operate primarily at the plant species composition level, in terms of reducing populations of species upon which they forage, and favoring others that are benefited by soil disturbance.

Level of certainty – Moderate

Relationship of Vegetation to Fire

The occurrence and distribution of all native and some exotic plant communities in Big Cypress are a function of fire. Certain exotic plant species are very fire adapted, and their structural and chemical characteristics can greatly increase fire frequency and severity as they come to dominate a site. Increased

fire frequency results from reduced hydrologic regime. Increased fire severity also results from reduced hydrologic regime, in combination with less frequent fire, which in turn results in fuel build-up. Less frequent fire also results in woody plant colonization.

Level of certainty – High

Relationship of Vegetation to Nutrient Inputs

Nutrient inputs affect species composition, primarily in wetland plant communities, by favoring populations of aggressive native and exotic species, which reduces other native species populations through competition.

Level of certainty – High for phosphorus and
Low for other water quality parameters

A.4.5.2 Wetland Aquatic Fauna

Relationship of Aquatic Fauna Populations to Habitat Loss

The conversion of portions of the Big Cypress region to agricultural and urban land use represents a proportional loss in the populations of fishes and other aquatic fauna that once inhabited that region. That loss is considered to be irreversible, short of reflooding developed areas and reconnecting them to the remaining natural system.

Level of certainty – High

Relationship of Marsh Fish Populations to Hydroperiod

The density, size structure and taxonomic composition of fish populations in Big Cypress wetlands are limited by the annual duration of uninterrupted flooding. This is because fish density is directly related to the period of population recovery between marsh dry downs. The relative abundance of fish species also responds to hydroperiod. Centrarchids and other larger fish species are less represented under shorter hydroperiods, which affects size structure of marsh fish populations. The reduction of hydroperiod in overdrained Big Cypress wetlands limits fish density, size structure and representation of long-hydroperiod species to levels below those expected under natural hydrologic conditions. Hydroperiod restoration is expected to result in the recovery of fish density, size structure and relative abundance. Hypothetical relationships of fish populations to hydroperiod are based on those developed in the Everglades, and comparatively little information is available for Big Cypress, which differs considerably from the Everglades in topography and hydrology.

Level of certainty- low

Relationship of Marsh Fish Populations to Exotic Fishes

Canals and areas close to canals support exotic fish species, which can dominate the fish populations in those areas. So far, the distribution of high densities of exotic fishes appears to be limited to canals and wetlands hydrologically-connected to these canals.

Level of certainty – Moderate

Macroinvertebrate and Herpetofauna Populations: Controlling Variables and Functional Importance

Hypotheses that have been proposed for population responses of marsh fishes to hydroperiod and exotics are assumed to also apply to mollusks, crayfish and amphibians. However, little is known about the life histories, population dynamics and ecosystem roles of species such as apple snails, grass shrimp, crayfish, and frogs in the Big Cypress region. Although they would also be expected to decline in abundance with the overdrainage of Big Cypress wetlands, in response to the same factors affecting the fishes, quantitative relationships are mostly lacking. Crayfish constitute an important prey item in the diets of many vertebrates inhabiting the Big Cypress region, including pig frogs, otters, alligators and white and glossy ibis. The lack of information regarding the population dynamics functional roles of macroinvertebrates and herpetofauna in the Big Cypress region, despite the potential importance of these groups, represents an important gap in our information regarding the degradation and restoration of wetland systems.

Level of certainty – Low

Relationship of the Health of Aquatic Fauna to of Environmental Contaminants

Environmental contaminants, such as pesticides and heavy metals, can be concentrated in organisms through food webs. These bioaccumulated toxins can have significant effects on the health of populations of aquatic fauna, and ultimately on their survival of at lest some species. Contaminants can also significantly affect aquatic fauna without being bioaccumulated, particularly for those species with gills or permeable surfaces exposed to water.

Level of certainty – High

A.4.5.3 Wood Stork

Relationship of Wood Stork Nesting to Density, Size Structure and Seasonal Concentration of Marsh Fish Populations

The density and seasonal concentration of fishes above approximately 10 centimeters in length is the primary factor limiting the wood stork's ability to reproduce in their traditional large nesting colonies in the Big Cypress region. The conversion and drainage of wetlands, including larger wetlands as well as shallow depressions in hydric pinewoods, has resulted in a reduction in the distribution, density and seasonal concentration of marsh fish populations, which is the primary cause of nesting failure and colony abandonment by wood storks in the Big Cypress region.

Level of certainty – Moderate

A.4.5.4 Florida Panther

Relationship of Florida Panther Population to Habitat Loss and Fragmentation

Level of certainty – High

Relationship of Florida Panther Health to Bioaccumulation of Environmental Contaminants

Level of certainty – Moderate

A.4.6 Research Questions

Key uncertainties regarding causal relationships in the Big Cypress Regional Ecosystem Conceptual Ecological Model need to be researched. The recommended research to support this conceptual ecological model is discussed in this section.

Relationship of Wetland Aquatic Fauna Populations to Hydroperiod and Water Depth

How do hydroperiod and water depth affect the density, biomass, and taxonomic composition of fish, crayfish, grass shrimp, and frog populations, as intermediate trophic levels in food webs of Big Cypress wetlands? What are the hydroperiod and depth requirements to produce wetland fishes greater than 10 centimeters in length as a forage base for wood storks? Develop quantitative relationships and models of fish, crayfish, grass shrimp, apple snail, and frog populations in relation to hydroperiod and depth in the major wetland habitats of the Big Cypress region.

Plant Community Alterations Associated with Inflows of Drainage Water with High Mineral Content

How are the composition and structure of native plant communities altered when water with a higher than normal mineral content for surface waters enters wetland systems from canals, aquifer storage and recovery, and in-ground reservoirs?

Feral Hog Impacts on Plant Communities

How does hog rooting affect the composition of native plant communities, particularly in enhancing the spread of exotic or invasive species?

A.4.7 Hydrologic Performance Measures

Successful protection of undisturbed areas and restoration of disturbed areas require the establishment of hydrologic targets that define the desired characteristics of a site's hydrologic regime, and then the development of hydrologic performance measures to evaluate the current status of the site relative to the targets. During the Restudy, for those portions of the Big Cypress that were included in the South Florida Water Management Model (SFWMM), hydrologic targets were based on conditions predicted by the Natural System Model (NSM). A number of performance measures were used to evaluate the hydrologic condition of indicator regions to assess how they were affected by proposed restoration alternatives that resulted in modified versions of the SFWMM (USACE and SFWMD 1999). Plans are underway to create a South Florida regional hydrologic model that will include lands that the South Florida Water Management District is responsible for in southwest Florida. A NSM will also be created for the southwest Florida area by modifying the new South Florida regional hydrologic model, just as the original NSM was created by modifying the existing SFWMM.

Since the completion of the Restudy, the indicator regions and hydrologic performance measures have been modified to incorporate lessons learned during the Restudy and to take advantage of newly available information. There are currently five indicator regions within the eastern portion of the Big Cypress, in the area where the SFWMM alternative analyses have predicted changes in hydrology as a result of Comprehensive Everglades Restoration Plan (CERP) activities. The indicator regions are distributed from just south of the Seminole Indian Reservation into the Everglades south of the Loop Road.

New performance measures have been proposed to evaluate regional effects predicted during the detailed design of individual CERP components and to provide targets for field monitoring following

implementation of the components. Those associated with hydrologic conditions in the indicator regions include the following:

- Average inundation duration with the target being NSM conditions
- Duration of water level deviation from NSM with four targets, which are a function of a threshold above or below NSM water levels that is defined by whether NSM water levels are above or below ground
- Number of dry events during the 31-year period of the model runs with the target being NSM conditions
- Seasonal amplitude and interannual variability in water levels with the target being NSM conditions.

In addition, there was a performance measure for monthly, wet-dry seasonal, and annual overland flow volumes across two transects in the eastern portion of the Big Cypress. Again, NSM conditions are the targets.

Until the SFWMM and NSM models are available, it will be impossible to accurately utilize the new performance measures for all but the easternmost portion of the Big Cypress region. Information on the hydrologic regimes of the major Big Cypress freshwater plant community types are described in Duever (1984), and these could be used as interim hydrologic targets for the major freshwater communities. These are based on the fact that all aspects of a plant community's hydrologic regime are significant in determining its taxonomic and structural characteristics, as well as its distribution across the Big Cypress landscape. The annual duration of inundation, or hydroperiod, is the most important aspect of the hydrologic regime (Duever 1984), largely because of South Florida's minimal topographic relief and its distinct wet and dry seasons. Short hydroperiods eliminate wetland species that are intolerant of the more frequent and severe fires on sites that are dry most of the year, while long hydroperiods eliminate upland species intolerant of extended inundation in low areas (Duever et al. 1978). Maximum and minimum water levels are also important. Wet season water depths can eliminate emergent species that cannot tolerate extended periods of being submerged. The extent of dry season water level declines can influence the frequency and severity of fires entering wetlands, particularly those with organic soils, which maintain a relatively moist substrate and microclimate as long as they are in contact with the water table (Coultas and Duever 1984). During the wet season, water naturally moved as sheet flow across the Big Cypress (Klein et al. 1970). The fact that the water is moving is important, particularly in terms of the resulting water column mixing, which produces a very different water quality than is found in ponded water.

It is important to be aware that the above performance measures are based on long-term averages, and there is a great deal of natural year-to-year variability in these values. In addition, the same types of communities vary substantially from one place to another, because of differences in their setting and site history. Even though extreme environmental events can have major affects in shaping natural communities, they don't normally produce shifts from one community type to another because the overall ecosystem has evolved in the context of these events. These concepts will be important to take into consideration when evaluating the field monitoring data during the course of the restoration.

A.4.8 Ecological Performance Measures

Ecological performance measures were developed based primarily on attributes identified in the Big Cypress Regional Ecosystem Conceptual Ecological Model. However, a number of the attributes

identified in the model have not been included in the current set of performance measures and others have been modified or added to provide greater consistency among the greater Everglades regional conceptual ecological models.

Some attributes were not included because we could not see a clear relationship to CERP restoration actions. Examples are *red-cockaded woodpecker nesting success* or *panther habitat*. In addition, some such as panther numbers were not included because we felt it would be difficult to document change in response to CERP actions. In some cases, a Big Cypress performance measure was generalized to provide for greater consistency with similar performance measures in other greater Everglades regional conceptual ecological models. Examples include wood storks being combined under *wading bird nesting*, and native fish, crayfish, and amphibians being combined under *wetland aquatic fauna*. *Alligator abundance, distribution, and size classes*, *alligator condition*, and *wetland soil accretion* were three performance measures that were added to provide for consistency with the other greater Everglades regional conceptual ecological models. Five performance measures were developed to provide a basis for monitoring Big Cypress plant communities. These included *composition and structure of major plant communities*, *plant community mosaic*, *plant community gradients*, *wetland restoration*, and *forested wetland hydrology indicators*.

Water quality performance measures are being developed only for those portions of the Big Cypress that will be affected by CERP restoration actions. These include sites along the eastern portion of the Big Cypress adjacent to the Everglades and the Big Cypress Critical Projects, such South Golden Gate Estates hydrologic restoration, Lake Trafford demucking, southern Corkscrew Regional Ecosystem watershed (CREW) restoration, Tamiami Trail canal plugs and bridges, and Belle Meade and Henderson Creek restoration. *Phosphorus loads and concentrations* are the water quality performance measures that have the strongest scientific basis and the most widespread and long-term database in South Florida. They have been proposed for monitoring throughout the area. Other performance measures proposed for widespread monitoring throughout the greater Everglades include *organics (pesticides) and trace metals (mercury)*. However, there is only a very limited database on their occurrence in the South Florida environment, and even less information on their effects on the ecosystem, particularly as it relates to CERP restoration actions. A few other performance measures have been proposed for individual Critical Projects in the Big Cypress region. One is *hardness* in South Golden Gate Estates, where most of the nonprecipitation water inputs will be from canal flows. The other is *dissolved oxygen* in Lake Trafford where a large accumulation of muck sediments will be removed.

A.4.9 Model

The diagram for the Big Cypress Regional Ecosystem Conceptual Ecological Model is presented in **Figure A-16**. The key to the symbols used in the diagram is presented in **Figure A-15**.

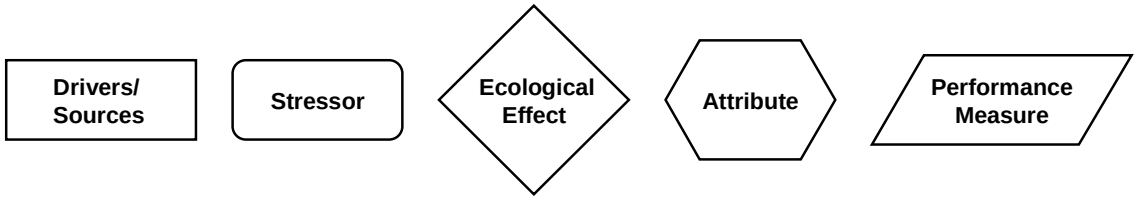


Figure A-15: Key to the Symbols Used in the Following Diagram

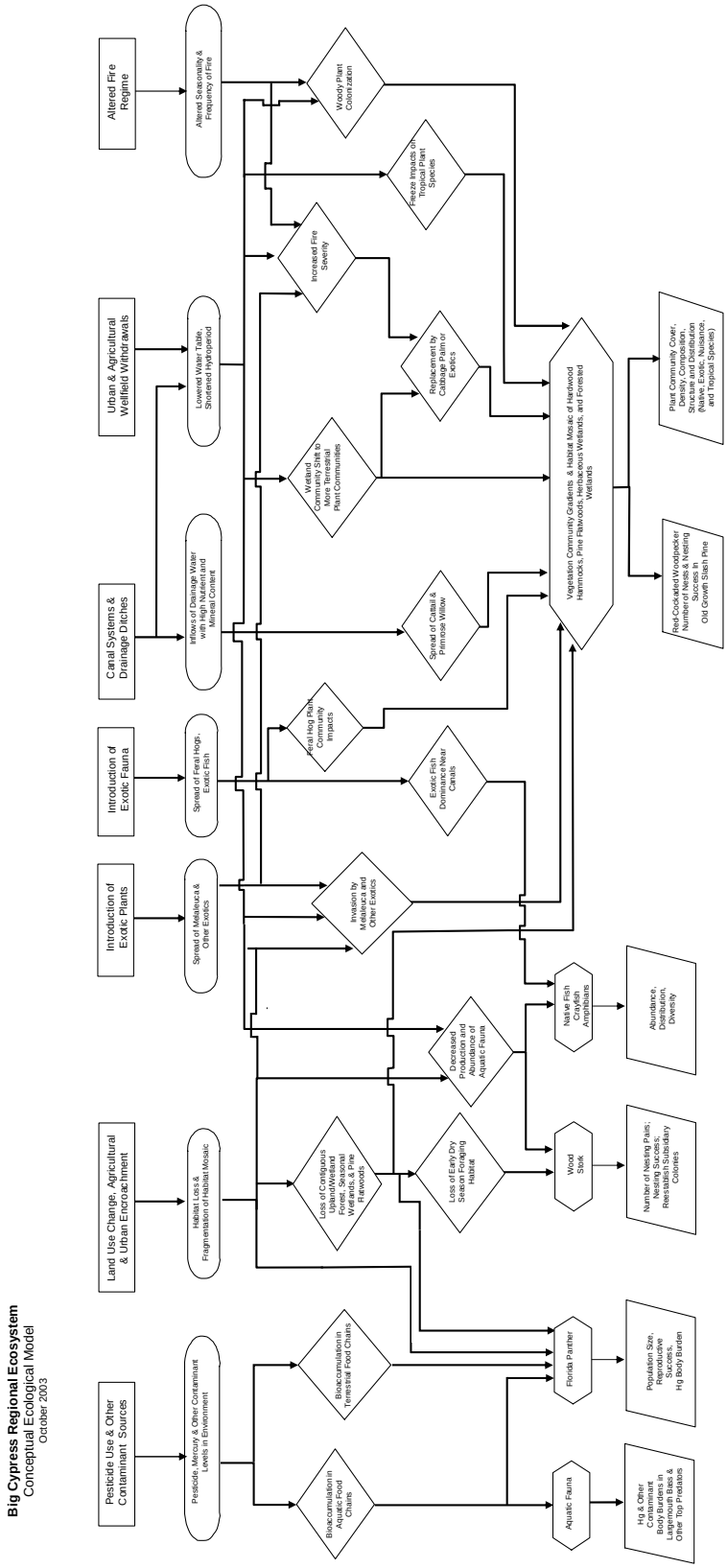


Figure A-16: Big Cypress Regional Ecosystem Conceptual Ecological Model Diagram

A.4.10 Literature Cited

Ackerman, J.A., Jr. 1976. Florida cowman, a history of Florida cattle raising. Florida Cattleman's Association, Kissimmee.

Alexander, T.R., and A.G. Crook. 1973. Recent and long term vegetation changes and patterns in South Florida. Appendix G, Part I. South Florida Ecological Study. University of Miami, Coral Gables, Florida.

Alvarez, K.C. no date. A Brief History of Florida Cattle Ranching (1521-1900). Unpublished report.

Carlson, J.E., and M. J. Duever. 1979. Seasonal fish population fluctuations in South Florida swamp. Proceedings of Annual Conference of Southeastern Association of Fish and Wildlife Agencies 31: 603-611.

Carter, M. R., L.A. Burns, T.R. Cavinder, K.R. Dugger, P.L. Fore, D.B. Hicks, H.L. Revells, and T.W. Schmidt. 1973. Ecosystem analysis of the Big Cypress Swamp and estuaries. EPA 904/9-74-002, United States Environmental Protection Agency, Athens, Georgia.

Coultas, C.L., and M.J. Duever. 1984. Soils of cypress swamps. In: Odum, H.T., and K.C. Ewel (eds). Cypress Swamps. University of Florida Press, Gainesville, Florida, pp. 51-59.

Craighead, F.C., Sr. 1971. The Trees of South Florida. Volume 1. The Natural Environments and Their Succession. University of Miami Press, Miami, Florida.

Crowder, J.P. 1974. The Exotic Vertebrates of South Florida. Ecological Report DI-SFEP-74-30, Bureau of Sport Fisheries and Wildlife, United States Department of the Interior, Washington, D.C.

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

Davis, S.M. 1994. Phosphorus Inputs and Vegetation Sensitivity in the Everglades. In: Davis, S.M., and J. C. Ogden (eds). Everglades: The Ecosystem and its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 357- 378.

Dineen, J.W. 1984. The fishes of the Everglades. In: Gleason, P.J. (ed). Environments of South Florida: Past and Present II. Miami Geological Society, Miami, Florida, pp. 258-268.

Drew, R.D., and N.S. Schomer. 1984. An Ecological Characterization of the Caloosahatchee River/Big Cypress Watershed. FWS/OBS-82/58, Minerals Management Service and Fish and Wildlife Service, United States Department of the Interior.

Duever, M.J., J.E. Carlson, L.A. Riopelle, and L.C. Duever. 1978. Ecosystem analyses at Corkscrew Swamp. In: Odum, H.T., and K.C. Ewel (eds). Cypress Wetlands for Water Management, Recycling, and Conservation. Fourth Annual Report to National Science Foundation and Rockefeller Foundation. Center for Wetlands, University of Florida, Gainesville, Florida, pp. 534-570.

Duever, M.J. 1984. Environmental factors controlling plant communities of the Big Cypress Swamp. In: Gleason, P.J. (ed). Environments of South Florida: Past and Present II. Miami Geological Society, Miami, Florida, pp. 127-137.

Duever, M.J., J.E. Carlson, J.F. Meeder, L.C. Duever, L.H. Gunderson, L.A. Riopelle, T.R. Alexander, R.L. Myers, and D.P. Spangler. 1986. The Big Cypress National Preserve. National Audubon Society Research Report No. 8, New York.

Elton, C.S. 1958. The Ecology of Invasions by Animals and Plants. John Wiley, New York.

Forman, R.T.T., and M. Godron. 1986. Landscape Ecology. John Wiley and Sons, New York.

Gunderson, L.H., and L.L. Loope. 1982. A survey and inventory of the plant communities in the Raccoon Point area, Big Cypress National Preserve. Report T-665, South Florida Research Center, National Park Service, Everglades National Park, Homestead, Florida.

Harper, R.M. 1927. Natural resources of southern Florida. Eighteenth Annual Report of Florida Geological Survey, Tallahassee, Florida, pp. 25-206.

Harris, L.D. 1984. The Fragmented Forest: Island Biogeography Theory and the Preservation of Biotic Diversity. University of Chicago Press, Chicago, Illinois.

Hofstetter, R.H. 1984. The effect of fire on the pineland and sawgrass communities of southern Florida. In: Gleason, P.J. (ed). Environments of South Florida: Past and Present II. Miami Geological Society, Miami, Florida, pp. 465-476.

Jackson, J.A. 1971. The evolution, taxonomy, distribution, past populations and current status of the red-cockaded woodpecker. In: R.L. Thompson (ed). Proceedings of a Symposium on the Red-cockaded Woodpecker, Okefenokee National Wildlife Refuge, Folkston, Georgia, pp. 4-29.

Jansen, D.K. 1987. Big Cypress Use Study. Florida Game and Freshwater Fish Commission, Tallahassee, Florida.

Kennard, F.H. 1915. The Okaloacoochee Slough. Auk 32: 154-166.

Klein, H., W.J. Schneider, B.F. McPherson, and T.J. Buchanan. 1970. Some Hydrologic and Biologic Aspects of the Big Cypress Swamp Drainage Area. Open File Report 70003, United States Geological Survey, Washington, D.C.

Kolopinski, M.C. and A. L. Higer. 1969. Some aspects of the effects of the quantity and quality of water on biological communities in the Everglades National Park. Open File Report 69007, United States Geological Survey, Washington, D.C.

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. Open File Report 75-434, Geological Survey, United States Department of the Interior, Washington, D.C.

Layne, J.N. 1984. The land mammals of South Florida. In: Gleason, P.J. (ed). Environments of South Florida: Past and Present II. Miami Geological Society, Miami, Florida, pp. 269-296.

Lehman, M.E. 1976. Collier County: Growth Pressure in a Wetlands Wilderness. Florida Bureau of Comprehensive Planning, Tallahassee, Florida.

Ligon, J.D. 1971. Some factors influencing numbers of the red-cockaded woodpecker. In: Thompson, R.L. (ed). Proceedings of a Symposium on the Red-Cockaded Woodpecker, Okefenokee National Wildlife Refuge, Folkston, Georgia, pp. 30-43.

Loftus, W.F., and A. Eklund. 1994. Long-term dynamics of an Everglades small-fish assemblage. In: Davis, S.M., and J. C. Ogden (eds). Everglades: The Ecosystem and its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 461-483.

Logan, T., A.C. Eller, Jr., R. Morrell, D. Ruffner, and J. Sewell. 1993. Florida Panther Habitat Preservation Plan: South Florida Population. Florida Panther Interagency Committee, c/o United States Fish and Wildlife Service, University of Florida, Gainesville, Florida.

Loveless, C.M. 1959. The Everglades deer herd, life history and management. Technical Bulletin 6, Florida Game and Freshwater Fish Commission, Tallahassee, Florida.

Maehr, D.S., E.D. Land, D.B. Shindle, O.L. Bass, and T.S. Hoctor. 2002. Florida panther dispersal and conservation. Biological Conservation 106:187-197.

McBride, R.T. 2000. Current Panther Distribution and Habitat Use: a Review of field Notes, Fall 1999-Winter 2000. Report to Florida Panther Subteam of MERIT, United States Fish and Wildlife Service, South Florida Ecosystem Office, Vero Beach, Florida.

McBride, R.T. 2001. Current Panther Distribution, Population Trends, and Habitat Use: Report of Field Work: Fall 2000-Winter 2001. Report to Florida Panther Subteam of MERIT, United States Fish and Wildlife Service, South Florida Ecosystem Office, Vero Beach, Florida.

McBride, R.T. 2002. Current Panther Distribution and Conservation Implications - Highlights of Field Work: Fall 2001-Winter 2002. Report to Florida Panther SubTeam of MERIT, United States Fish and Wildlife Service, South Florida Ecosystem Office, Vero Beach, Florida.

Myers, R.L. 1975. The Relationship of Site Conditions to the Invading Capability of Melaleuca Quinquenervia in Southwest Florida. Master's Thesis, University of Florida, Gainesville.

Odum, H.T. 1971. Environment, Power, and Society. John Wiley, New York.

Ogden, J.C., D.A. McCrimmon, Jr., G.T. Bancroft, and B.W. Patty. 1987. Breeding populations of the wood stork in the southeastern United States. The Condor 89: 752-759.

Ogden, J. C. 1994. A comparison of wading bird nesting colony dynamics (1931-1946 and 1974-1989) as an indication of ecosystem conditions in the southern Everglades. In: Davis, S.M., and J. C. Ogden (eds). Everglades: The Ecosystem and its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 533-570.

Patterson, G.A., and W.B. Robertson, Jr. 1981. Distribution and Habitat of the Red-Cockaded Woodpecker in the Big Cypress National Preserve. South Florida Research Center, National Park Service, Homestead, Florida.

Robertson, W.B., Jr. 1953. A Survey of the Effects of Fire in Everglades National Park. Unpublished Report. United States Department of the Interior, National Park Service, Homestead, Florida.

Rochow, T.F. 1985. Hydrologic and vegetational changes resulting from underground pumping at the Cypress Creek well field, Pasco County, Florida. Florida Scientist 48: 65-80.

Roelke, M.E., D.P. Schultz, C.F. Facemire, S.F. Sundlof, and H.E. Royls. 1991. Mercury contamination in Florida panthers. A Report of the Florida Panther Technical Subcommittee to the Florida Panther Interagency Committee, Florida Game and Fresh Water Fish Commission, Tallahassee, Florida.

Swayze, L.J., and B.F. McPherson. 1977. The effect of the Faka Union canal system on water levels in the Fakahatchee Strand, Collier County, Florida. Water Resources Investigation Report 77-61, United States Geological Survey, Washington, D.C.

Tabb, D.C., E.J. Heald, T.R. Alexander, M.A. Roessler, and G.L. Beardsley. 1976. An ecological and hydrological assessment of the Golden Gate Estates drainage basin, with recommendations for future land use and water management strategies. Tropical Bioindustries Development Company. Miami, Florida.

USACE and SFWMD. 1999. Central and Southern Florida Project Comprehensive Review Study, Final Integrated Feasibility Report and Programmatic Environmental Impact Statement. United States Army Corps of Engineers, Jacksonville District, Jacksonville, Florida, and South Florida Water Management District, West Palm Beach, Florida.

Wade, D., J. Ewel, R. Hofstetter. 1980. Fire in South Florida Ecosystems. Forest Service General Technical Report SE-17, United States Department of Agriculture, Washington, D.C.

A.5 FLORIDA BAY CONCEPTUAL ECOLOGICAL MODEL

A.5.1 Model Lead

David Rudnick, South Florida Water Management District

A.5.2 Introduction

A simple conceptual ecological model of the Florida Bay ecosystem (Figure A-17) is presented here. This model is consistent with our effort to assess the current understanding of South Florida's ecosystems, identify the most important human effects on these ecosystems, identify restoration goals and success criteria, and identify the minimum measurements required to determine whether these criteria are being met. The structure of the model is largely based on the expert opinions of scientists who have focused their attention on Florida Bay during the past several years. During this time, detailed reviews of our understanding of the Florida Bay have been presented (Boesch et al. 1993, Boesch et al. 1995, Boesch et al. 1997, Fourqurean and Robblee 1999). Detailed plans that identify quantitative information needs for environmental management decision making, as well as strategies to provide this information have also been presented (Armentano et al. 1994, Armentano et al. 1997). While the conceptual ecological model presented here is largely consistent with the body of knowledge described in the reviews and plans noted above, some details or omissions of this model may not be consistent will the opinions of some contributors to the interagency Florida Bay Research Program.

A.5.2.1 Florida Bay Primer

Florida Bay is a triangularly shaped estuary, with an area of about 850 square miles that lies between the southern tip of the Florida mainland and the Florida Keys. About 80 percent of this estuary is within the boundaries of Everglades National Park. A defining feature of the bay is its shallow depth, with a mean depth of about 1 meter (Schomer and Drew 1982). This shallowness allows light to penetrate through the water to the sediment surface in almost all areas of the bay and results in the potential for the bay to sustain seagrass beds as a dominant habitat and source of productivity. The shallowness of the bay also affects the circulation and salinity regime of the bay; with a complex network of shallow mud banks, water exchange among the bay's basins and between these basins and the Gulf of Mexico is restricted (Smith 1994, Wang et al. 1994). With a long residence time and shallow depth, the salinity of Florida Bay water can rapidly rise during drought periods. Salinity levels as high as twice that of seawater have been measured (McIvor et al. 1994). Another defining feature of the bay is that the sediments are primarily composed of carbonate mud, which can scavenge inorganic phosphorus from bay waters (DeKanel and Morse 1978).

Until the 1980s, Florida Bay was perceived by the public and environmental managers as being a healthy estuary, with clear water, lush seagrass beds, and productive fish and shrimp populations. By the mid-1980s, however, catches of pink shrimp had declined dramatically (Browder et al. 1999) and in 1987, the mass mortality of turtle grass (*Thalassia*) beds began (Robblee et al. 1991). By 1992, the ecosystem appeared to shift from a clear water system, dominated by primary production on the sediment (benthic production) to a turbid water system, dominated by algae blooms in the water column and resuspended sediment. The conceptual ecological model focuses on these changes in seagrasses and water quality as the central issues to be considered by environmental managers.

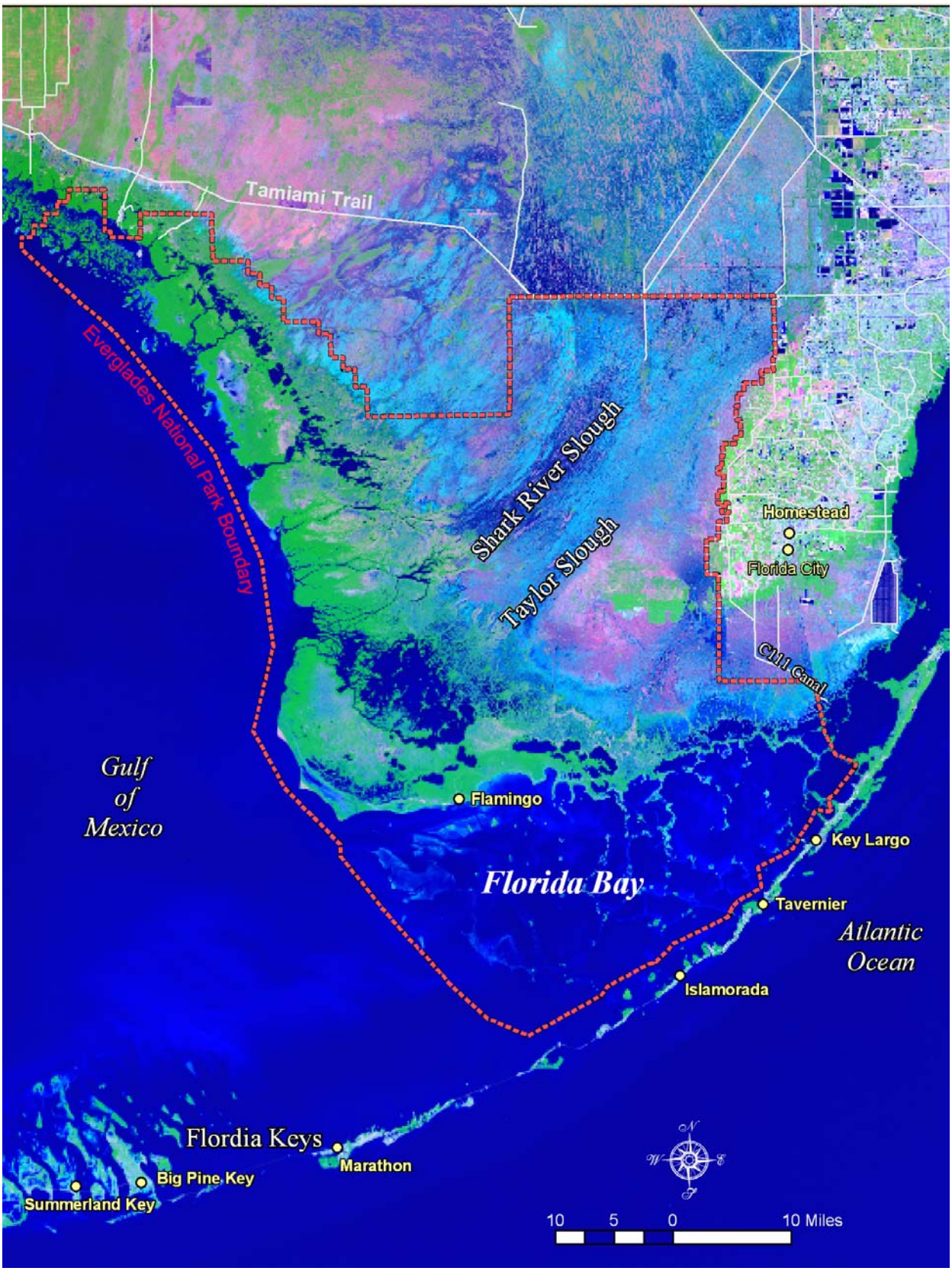


Figure A-17: The Boundary of the Florida Bay Conceptual Ecological Model

A.5.2.2 Reality Check

The simple model presented below does not address the spatial complexity of Florida Bay. Florida Bay is, indeed, not so much a singular estuary, but a complex array of basins, banks, and islands that differ across a set of regions. The mosaic of seagrass habitat and mangrove habitat, as well as water quality and ecosystem processes vary distinctly with this spatial variation. Nevertheless, only a single, generic model is described and this model is intended to summarize the main characteristics and trends of the bay. While the structure of this model is appropriate for most areas of the bay, the relative importance of the model's components differ considerably among the bay's subregions. Any application of this model (for example, recommendations for a specific set of monitoring parameters and guidelines) must take the spatial variability of the bay into account.

A.5.3 External Drivers and Ecological Stressors

It has often been assumed that a direct cause of Florida Bay's ecological changes is a long-term increase in the bay's salinity that resulted from the diversion of fresh water away from Florida Bay via South Florida Water Management District canals. However, recent research has indicated that the bay's changes are not attributable to a single cause; while decreased freshwater inflow and resultant increased salinity have been part of the problem, it appears that other human activities, as well as natural forces, have also contributed to the problem (Armentano et al. 1997, Boesch et al. 1993, Boesch et al. 1995, Boesch et al. 1997, Fourqurean and Robblee 1999). This conceptual ecological model thus includes both natural and human derived sources of stress (Figure A-19, Section A.5.9). The discussion of external drivers and ecological stressors below is organized by stressor with the drivers in bold.

A.5.3.1 Altered Salinity Regime

The salinity regime of an estuary is a primary determinant of the species composition of communities, as well as strongly influencing functions of these communities (Sklar and Browder 1998). Salinity is a direct stress on biota; all estuarine biota have adapted to a given salinity range and a given degree of salinity variability. For a given organism, changing salinity beyond this range or too quickly within this range can result in poor health or death. Thus long-term changes in salinity *level* or *variability* are detrimental to some species, but favorable for other species.

Florida Bay's salinity regime varies greatly over time and space. This variation ranges from coastal areas that can be nearly fresh during the wet season, to large areas of the central bay that can have salinity levels near 70 parts per thousand (ppt) during prolonged droughts, to nearly stable marine conditions (about 35 ppt) on the western boundary of the bay. The main forces that determine salinity regime in the bay are the inflow of fresh water from the Everglades, rainfall over the bay, evaporation from the bay, and exchange with seawater from the Gulf of Mexico and the Atlantic Ocean. Both freshwater inflow and seawater exchange have changed drastically in the past hundred years, resulting in an alteration of the bay's salinity regime.

Freshwater inflow to Florida Bay decreased in volume and changed in timing and distribution during this century because of **water management**. Hydrologic alteration began in the late 1800s, but accelerated with the construction of drainage canals by 1920, the Tamiami Trail by 1930, and the Central and South Florida (C&SF) Project and South Dade Conveyance System from the early 1950s through 1980 (Light and Dineen 1994). With the diversion of fresh water to the Atlantic coast and Gulf of Mexico coast, the bay's mean salinity inevitably increased. The extent of this increase and how the variability of salinity changed is not known, but is the subject of current research.

Results from this research indicate that another important development that altered the salinity regime of Florida Bay was construction of the **Flagler Railway** across the Florida Keys from 1905 to 1912 (Swart et al. 1996, Swart et al. 1999). It appears that in the last century, prior to railway construction and water management, Florida Bay had a lower mean salinity and more frequent periods of low (10 ppt - 20 ppt) salinity than during this century. The extent and frequency of high salinity events does not appear to have changed between centuries. The bay's salinity regime changed abruptly around 1910 because passes between the keys were filled to support the railway. Thus, water exchange between Florida Bay and the Atlantic Ocean was decreased and water circulation throughout the bay was probably altered.

Two important natural controls of salinity, **sea level rise** and the frequency of **major hurricanes** must also be considered. Florida Bay is a very young estuary, the product of sea level rising over the shallow slope of the Everglades during the past 4,000 years. With rising sea level, the bay not only became larger but also became deeper. With greater depth, exchange of water between the sea and the bay probably increased, resulting in a more stable salinity regime with salinity levels increasingly similar to the sea. However, a factor that has counteracted the rising sea is the accumulation of sediment, which makes the bay more shallow. Most sediment that accumulates in Florida Bay is carbonate that is precipitated from water by organisms that live in the bay. The extent to which these sediments accumulate is a function of the biology of these organisms (including skeletal carbonate production), the chemistry of the water, and the physical energy available to transport some of these sediments from the bay. **Major hurricanes** are thought to be important high energy events that can flush the bay of these sediments. However, since 1965, no major hurricane has directly affected Florida Bay. Florida Bay's ecological changes during the past decade may thus be indirectly influenced by changing circulation patterns and resultant changing salinity regimes because of changing water depth in the bay.

A.5.3.2 Nitrogen and Phosphorus Inputs

The productivity and food web structure of all ecosystems is strongly influenced by patterns of nutrient cycling and the import and export of these nutrients. Throughout the world, estuarine ecosystems have undergone dramatic ecological changes because they have been enriched by nutrients derived from human activity. These changes have often been catastrophic, with the loss of seagrasses and the occurrence of algal blooms and lethal low oxygen or anoxic events. The input of nitrogen and phosphorus to estuaries is thus a potentially important stressor of estuaries.

The importance of nitrogen and phosphorus as stressors in Florida Bay is unclear. In general, the bay is rich in nitrogen and poor in phosphorus, especially towards the eastern region of the bay (Boyer et al. 1997). There is little evidence that nutrient inputs to the bay have increased during this century, but with expanding **agriculture and residential development** in South Florida through this century, and particularly development of the Florida Keys, nutrient enrichment almost certainly has occurred (Lapointe and Clark 1992, Orem et al. 1999). Anthropogenic nutrients that enter Florida Bay are derived not only from such local sources (fertilizer and wastes from agriculture and residential areas), but also from remote sources. It is likely that remote contributions to the Gulf of Mexico, such as from the phosphate fertilizer industry of the Tampa-Port Charlotte area and residential development from Tampa to Naples, are the most important external sources of nutrients (Rudnick et al. 1999). This enrichment from external sources, however, may be less important to the bay's ecology than its own internal sources and cycling. It is, nevertheless, a reasonable hypothesis that a chronic increase in nutrient inputs has occurred in Florida Bay in this century and this increase has contributed to ecological changes. Ongoing research will provide information to test this hypothesis. Development of a water quality model will also help us understand the effects of past nutrient inputs and predict the effects of future management scenarios.

In this conceptual ecological model, **water management** is listed as a source of stress because the canal system can transport nutrients through the wetlands toward the bay, decreasing nutrient retention by the

wetlands and possibly increasing nutrient inputs to the bay. Nutrient inputs from the Everglades and the Gulf of Mexico are affected not only by changes of fresh water flowing from Taylor Slough and Shark River Slough, but also by changes in bay circulation. Nutrient retention within the Bay is certainly sensitive to these changes in circulation, which have been caused by **Flagler Railway** construction and the balance of **sea level rise** and sedimentation or sediment removal by **major hurricanes**. The influence of hurricanes may be particularly important, as nutrients (particularly phosphorus) accumulate in the bay's carbonate sediment and the absence of major hurricanes may have resulted in an accumulation of nutrients during the past few decades.

A.5.3.3 Pesticides and Mercury

With the widespread **agriculture and residential development** of South Florida, the application and release of pesticides and other toxic materials has increased. Mercury is of particular concern because of high concentrations of methylmercury in upper trophic level species. However, it is unclear whether anthropogenic mercury inputs to the Everglades or Florida Bay have increased or whether, perhaps more importantly, mercury cycling and methylation rates have changed. Pesticides and mercury are of concern because they can affect human health after the consumption of fish or other biota with high concentrations of these toxins, and because other species may be adversely affected by these compounds. To date, there is no evidence the main ecological changes in Florida Bay are in any way linked to inputs of toxic compounds. **Water management** affects the distribution of these toxic materials and potentially their transport to Florida Bay. Controlling water levels in wetlands may also influence the decomposition of pesticides and mercury methylation rates because both of these processes are sensitive to the presence of oxygen in soils, which is affected by water levels.

A.5.3.4 Fishing Pressure

For any species that is the target of **recreational or commercial fisherman**, fishing pressure directly affects population dynamics and community structure. Within Everglades National Park, commercial fishing has been prohibited since 1985, but populations that live outside of Everglades National Park boundaries for at least part of their life cycle, which includes most of Florida Bay's sportfish species, are nevertheless affected by fisheries (Tilmant 1989).

A.5.4 Ecological Attributes

A set of Florida Bay's attributes that are either indicators of the health of the ecosystem or intrinsically important to society are given in this conceptual ecological model. These attributes in most cases are biological components of the ecosystem, including seagrass, mollusks, shrimp, fish and birds, but also an aggregated attribute (water quality condition) that includes phytoplankton blooms and aspects of the bay's chemical and physical condition. While the list of biological components is broad, it is clear from the links to stressors that are presented that these attributes are not equally weighted within the model; the central attribute of this conceptual ecological model of Florida Bay is the seagrass community. Details of each attribute and linkage are given below.

A.5.4.1 Seagrass Community

The keystone of the Florida Bay ecosystem is its seagrasses (Zieman et al. 1989, Fourqurean and Robblee 1999). These plants are not only a highly productive foundation of the food web, but are also the main habitat of higher trophic levels and a controller of the bay's water quality. Understanding how seagrasses affect water quality is essential for understanding the current status and fate of the bay.

Seagrasses affect water quality by three mechanisms: nutrient uptake and storage, binding of sediments by their roots, and trapping of particles within their leaf canopy. With the growth of lush seagrass beds, these mechanisms drive the bay towards a condition of clear water, with low nutrients for algae growth in the water and low concentrations of suspended sediment in the water. During the 1970s through the mid-1980s, lush *Thalassia* beds grew throughout central and western Florida Bay and the water was reported to be crystal clear. We hypothesize that with the onset of a *Thalassia* mass-mortality event in 1987 (Robblee et al. 1991), these mechanisms reversed, initiating a cycle that causes continued seagrass habitat loss and propagates persistent turbid water with algal blooms (Stumpf et al. 1999).

The cause of the 1987 mass-mortality event is not known, but thought to be related to earlier changes in two stressors, the salinity regime and nutrient availability. These changes caused *Thalassia* beds to grow to an unsustainable density by the mid-1980s. It is also likely that a decrease in shoal grass and widgeon grass (*Halodule and Ruppia*) occurred with the *Thalassia* increase. *Thalassia* "overgrowth" may have occurred because the species thrived when the salinity regime of the bay was stabilized, with few periods of low salinity. Nutrient enrichment also may have played a role, with a chronic accumulation of nutrients caused by increased inputs over decades or decreased outputs because of the absence of major hurricanes or closure of keys' passes. The factors that conspired to initiate the mass-mortality event in 1987 are also unknown, but thought to be related to the high respiratory demands of the dense grass beds and accumulated organic matter. During the summer of 1987, with high temperatures, sulfide levels may have risen to lethal concentrations. Low concentrations of dissolved oxygen in hypersaline bottom water may have been a critical component of this die-off scenario.

Regardless of the cause of the mass-mortality event, once this event was initiated, the ecology of Florida Bay changed. The cycle causing continued seagrass habitat loss, which characterizes the present Florida Bay, is illustrated in the model. Continued seagrass mortality results in increased sediment suspension (Prager and Halley 1999) and increased nutrient release from the sediments (increased nitrogen and phosphorus), stimulating the growth of phytoplankton (algae) in the water column. The presence of both phytoplankton and suspended sediment result in decreased light penetration to the seagrass bed. In this cycle, it is this decreased light that stresses the seagrasses and sustains the feedback loop. Light penetration is thus an essential aspect of the water quality condition attribute discussed in the next section.

The dynamics of this feedback loop are probably not independent of the salinity regime. A disease of seagrass, caused by a slime mold infection, seems to be more common at salinities near or greater than seawater (greater than or equal to 35 ppt) than at low (15 to 20 ppt) salinities (Landsberg et al. 1996). This may have played a role in either the initial seagrass mass mortality event, but more likely has served to continue seagrass mortality since that event. The incidence of this disease may be directly affected by water management actions.

If the state of the seagrass community is to be used as a criterion to decide the success of environmental restoration efforts, environmental managers must specify the desirability of alternative states. The consensus among scientists is that the Florida Bay of the 1970s and early 1980s, with lush *Thalassia* and clear water, was probably a temporary and atypical condition. From an ecological perspective, restoration should probably strive for a more diverse seagrass community, less dominated by *Thalassia* than during that period. Such diversity of seagrass habitat is generally expected to benefit upper trophic level species.

A.5.4.2 Water Quality Condition

Water quality condition reflects not only obvious characteristics, such as salinity, but also the light field, algal blooms in the water column, and the availability of nutrients in the ecosystem. All of these characteristics are closely related to the condition of seagrasses and the food web structure and dynamics of the bay. While these characteristics have been monitored and researched since the early 1990s, earlier

information is scarce for salinity and even less available for other characteristics. Thus, at the present time, we do not know whether nutrient inputs to the bay have actually increased in recent decades or whether periods with sustained algal blooms and high turbidity occurred in the past.

Salinity has frequently been suggested as a primary restoration target. However, establishing salinity success criteria, such as those used in the C&SF Comprehensive Review Study's (Restudy's) evaluation of the effects of hydrological alternatives on coastal salinity (USACE and SFWMD 1999), depends on the development of a model of the "natural" salinity distribution of Florida Bay in time and space. This requires a both a water budget for the bay (monitoring rainfall, evaporation, and freshwater flow, ground water flow, water level, and salinity) and a hydrodynamic model, which is now under development. With modeled salinity variability for a wide variety of target sites in the bay, the fit of observed salinity fields to modeled fields could serve as the basis of deciding levels of success.

The magnitude of nutrient inputs to the bay and their relationship to freshwater inputs is under investigation. Success criteria based on water column nutrient concentrations are probably less meaningful than criteria based on nutrient loading. Results show that phosphorus loads to the bay do not greatly increase with increased freshwater inputs (Rudnick et al. 1999), but Florida Bay is probably very sensitive to any increase in phosphorus availability. Unlike phosphorus, nitrogen loads probably do increase with more freshwater flow and algal blooms in western and central Florida Bay appear to be stimulated by increased nitrogen (Tomas 1996). The potential thus exists for hydrological restoration to increase nitrogen loading and stimulate phytoplankton blooms (Brand 2000). Because most of the nitrogen that is exported from the Everglades to the bay is in the form of organic compounds (Rudnick et al. 1999), the fate of these compounds within the bay is a critical unknown; if these compounds are easily decomposed and their nitrogen is available to algae, then increased freshwater flow could stimulate algal growth. However, internal losses (denitrification) of this nitrogen may compensate for any increased nitrogen supply.

Finally, as emphasized earlier, the penetration of light through Florida Bay waters is a key to the health of seagrasses. An important success criterion should be light penetration, which is largely a function of turbidity from algae and suspended sediment. Light penetration should be sufficient to support a viable seagrass habitat. Such light-based criteria have been used successfully in other estuaries.

A.5.4.3 Mollusks and Other Benthic Grazers

Consumption of phytoplankton cells by mollusks and other benthic filter feeders and suspension feeders may have a significant impact on the distribution, magnitude, and duration of algal blooms. The long-term abundance and biomass of these grazers may increase such that blooms decrease. However, some grazers may be negatively affected by the blue-green algae (*Synechococcus* sp., the dominant species in central Florida Bay's algal blooms [Phlips and Badylak 1996]) and loss of seagrass habitat loss. Benthic grazers' abundance, biomass, and distribution should be monitored because of their functional link with phytoplankton blooms and also because their shells provide information on historical community structure. The composition and activity of the mollusk community is a function of salinity, seagrass and other habitat availability, and food supply. Studies of long-term changes in the composition of this community (by analyzing shells in the sediment) have indeed found changes that reflect the large-scale changes of the bay's salinity regime. Furthermore, because mollusks can be important as grazers of phytoplankton, the trophic status of the bay is reflected by mollusk community composition. It is also important to monitor other major invertebrate groups that could control phytoplankton blooms, such as sponges and tunicates. With increased phytoplankton blooms, benthic filter feeders and other grazers may increase such that they decrease these blooms.

A.5.4.4 Pink Shrimp

Pink shrimp are intrinsically important to society as an economic asset. They are also ecologically important, serving as a major component of the diet of game fish and wading birds; pink shrimp are an indicator of the bay's productivity. Florida Bay and nearby coastal areas are a primary nursery ground for pink shrimp. This nursery supports the shrimp fishery of the Tortugas grounds (Ehrhardt and Legault 1999). Hydrological and ecological changes in the Everglades and Florida Bay may have impacted this fishery, which experienced a decline in annual harvest from about 10 million pounds per year in the 1960s and 1970s to only about 2 million pounds per year in the late 1980s (Ehrhardt and Legault 1999). This decline may have been associated with seagrass habitat loss or high salinity (50 to 70 ppt) during the 1989-1990 drought; experiments have shown that pink shrimp mortality rates increase with salinities above 40 ppt (Browder et al. 1999). Shrimp harvest statistics indicate that shrimp productivity increases with increasing freshwater flow from the Everglades (Browder et al. 1999).

A.5.4.5 Fish Populations

The health of Florida Bay's fish populations is of great importance to the public; sport fishing is a major economic asset to the region. Recruitment, growth and survivorship of these fish populations are affected by many factors, including salinity conditions, habitat quality and availability, food web dynamics and fishing. Changes in mangrove and seagrass habitats are likely to influence the structure and function of the fish community. However, seagrass mass mortality appears to have had a greater influence on fish community structure than on the absolute abundance of fish; no dramatic baywide decreases in fish abundance have been observed along with seagrass mass mortality (Thayer et al. 1999). Rather, a shift in the species composition of this upper trophic level has occurred as a result of the cycle of seagrass habitat loss and sustained algal blooms. While some fish species have declined, fish that eat algae in the water, such as the bay anchovy, are thriving. Thus the stressors, such as altered salinity, not only affect upper trophic level animals directly, but also affect them indirectly through food web changes.

Another important stressor that needs to be considered with regard to fish populations is the impact of pesticides and mercury. As concentrations of mercury and some pesticides greatly increase in upper trophic level animals, such as sport fish, (via the process of bioaccumulation), and people eat such fish, a human health issue potentially exists. Pesticides and mercury can also have ecological impacts by physiologically stressing organisms (particularly reproductive functions). The extent of any existing problem with these toxic compounds in Florida Bay is being investigated, but they currently do not appear to significantly impact human health or ecological health in the bay. The possible impact of future restoration efforts on these issues, however, must still be considered.

Among the many fish species that could be used as indicators of the health of the ecosystem's upper trophic level, there is consensus among scientists that spotted sea trout is a key species. This is the only major sport fish species that spends its entire life-span in the bay. Population changes and toxic residues in this species thus reflect the specific problems of the bay and should also reflect the restoration actions that we take. For northeastern Florida Bay, the abundance of snook, red drum, crevalle jack, and mullet should also be considered.

A.5.4.6 Fish-Eating Birds

Florida Bay and its mangrove coastline are important feeding and breeding grounds for water fowl and wading birds. Conceptual ecological models for other regions of the Everglades, particularly the Everglades Mangrove Estuaries Conceptual Ecological Model, present more detailed descriptions of the use of bird populations as ecological indicators and consider a wide variety of birds. For the Florida Bay Conceptual Ecological Model, we consider only fish-eating birds, such as osprey, brown pelicans and

cormorants. These birds are important predators of fish in the bay and are potentially impacted by any stressors that affect their prey base, including salinity changes, nutrient inputs, toxic compounds, and fishing pressure. As with other top predators, these bird species are the most vulnerable members of the ecosystem with regard to pesticide and mercury effects.

A.5.5 Ecological Effects

Critical Linkages Between Stressors and Attributes/Working Hypotheses

Described below are major hypotheses regarding the structure and function of Florida Bay. The level of certainty associated with each hypothesis was estimated. More detailed descriptions and reviews of many of the ideas presented below, as well as this narrative as a whole, can be found on the web page of the Florida Bay and Adjacent Marine Systems Science Program (www.aoml.noaa.gov/flbay/; see "Science Program" and then "Important Documents").

A.5.5.1 Estuarine Geomorphology and Water Circulation

Relationship of Mud Bank Dynamics and Accretion to Sea Level Rise

The mud banks and associated seagrass beds of Florida Bay will accrete sediments at rates comparable to predicted rates of sea level rise, which are estimated to be roughly two feet during the next 100 years. Persistence of the mud banks will sustain patterns of banks and basins, and related circulation patterns much as they are today, even with the occurrence of future major hurricanes.

Level of certainty - moderate

Relationship of the Exchange and Circulation of Gulf and Atlantic Water

Predicted rates of sea level rise during the next century will increase the exchange and circulation of Gulf of Mexico and Atlantic water in Florida Bay, shifting the bay from an estuarine to a more marine system. Construction of the Flagler Railway and Keys Highway decreased water exchange between the bay and Atlantic, increasing water residence time in the Bay and changing circulation and salinity patterns.

Level of certainty – moderate

A.5.5.2 Hydrologic Restoration and Water Quality Condition

Linkage of Everglades Hydrology to Freshwater Inflow, Circulation and Water Quality in Florida Bay

Water quality and circulation of coastal systems are linked to inland, freshwater wetlands through a combination of diffuse overland flow, creek and river flow, and ground water seepage. The salinity regime of Florida Bay, as well as many other aspects of the Florida Bay ecosystem (water residence time, stratification, nutrient loading, etc.) depend upon the quantity, timing, and distribution of freshwater inputs to the bay. Planning and implementation of ecosystem restoration requires the capability to link, through a predictive model, changes in hydrology of Everglades wetlands and consequent changes in Florida Bay and adjacent coastal ecosystems. These linkages have yet to be modeled and this is perhaps the highest priority need for Florida Bay restoration.

Level of certainty- low

Relationship of Phytoplankton Blooms to Nutrient Sources, Seagrass Die-off, Sediment Resuspension and Circulation Pattern

The spatial extent, duration, density and prevalence of *Synechococcus* in phytoplankton blooms in central Florida Bay are controlled by the combined and inter-related effects of external nitrogen loading, internal phosphorus cycling, seagrass die-off, sediment resuspension and water residence time. Seagrass die-off results in increased phytoplankton growth because of increased sedimentary nutrient mobilization, reduction in competition for water column nutrients, and decreased grazing pressure because of the loss of habitat for benthic filter feeders. Sediment resuspension due to seagrass die-off supplies additional water column nutrients via both porewater advection and desorption of surface-bound nutrients from resuspended particles, which is salinity dependent. The latter process may be an important phosphorus source for phytoplankton.

Level of certainty – low

Relationship of Phytoplankton Blooms to Dissolved Organic Nutrients

Dissolved organic nutrients are available to phytoplankton and support phytoplankton blooms in Florida Bay. Increased inputs of dissolved organic nitrogen from the restoration of natural water inflows from the Everglades will thus increase the prevalence of phytoplankton blooms in Florida Bay.

Level of certainty – low

Relationship of Salinity to Nutrient Cycling and Availability

Reduced incidence of hypersalinity will yield greater phosphorus retention within the bay sediments. With this greater retention, the extent of phosphorus limitation in the bay will increase and algal growth will decrease.

Level of certainty- moderate

Functional Importance of Florida Bay as Source and Sink for Nitrogen

A net loss of nitrogen occurs in Florida Bay because of rapid denitrification. Both nitrogen fixation and denitrification occur within bay sediments and seagrass beds and the rates of these processes are likely to greatly exceed the rate of nitrogen input from the Everglades watershed. The impact of any change of nitrogen loading to the bay that is associated with hydrologic restoration will depend upon the relative magnitude of these rates. Internal nitrogen cycling rates (and the balance of nitrogen fixation and denitrification) will also change with restoration, because of changing salinity and seagrass community structure. Internal nitrogen cycling rates (and the balance of nitrogen fixation and denitrification) will also change with restoration, because of changing salinity and seagrass community structure.

Level of certainty - low

A.5.5.3 Seagrass Community

Relationship of Seagrass Community to Light Penetration, Nutrient Availability, Salinity Sulfide Toxicity, Epiphyte Load, and Disease

The spatial coverage, biomass, production and taxonomic composition of seagrass beds in Florida Bay are controlled by the combined and inter-related effects of light penetration, epiphyte load, nutrient

availability, salinity, sulfide toxicity, and disease. Decreased salinity caused by increasing freshwater flow will have a direct effect on seagrass communities through physiological mechanisms, resulting in greater spatial heterogeneity of seagrass beds, a decrease in the dominance of *Thalassia testudinum*, and an increase in coverage by other seagrass species. Decreased salinity will also decrease the importance of slime mold infection of *Thalassia*. Light availability will depend upon phytoplankton growth and sediment resuspension, which depend both on nutrient availability, grazing, and seagrass bed binding of sediments.

Level of certainty - moderate

A.5.5.4 Estuarine Fish Communities and Fisheries

Seagrass Habitat and Salinity as Determinants of Fish Community Structure

Seagrass habitat loss and sustained algal blooms have resulted in a community shift from demersal to pelagic fish species, including increased abundance of fish that eat algae in the water, such as the bay anchovy. Decreased freshwater flow has resulted in a community shift from euryhaline to marine fish species.

Level of certainty - moderate

Relationship of Spotted Seatrout Populations to Salinity

Juvenile density and sport catch of spotted seatrout in Florida Bay reflect the suitability of estuarine habitat and nursery grounds as influenced by salinity. Density of post-larvae is highest at an intermediate salinity range of 20-40 ppt (Alsuth and Gilmore 1994). Juvenile density is expected to increase due to the resumption of natural volumes and timing of freshwater flow into the bay, in response to a reduction in the frequency and duration of hyper-salinity events. Adult abundance and distribution based on sport catch per unit effort should reflect juvenile growth and survival, although that relationship is not presently known.

Level of certainty - moderate

Relationship of Pink Shrimp Juvenile Density and Adult Catch Per Unit Effort to Salinity and Freshwater Flow

Juvenile density of pink shrimp in Florida Bay reflects the suitability of estuarine nursery grounds as influenced by salinity. Optimal salinity conditions for survival appear to be somewhat below that of seawater (35 ppt). Pink shrimp juvenile density is expected to increase in Florida Bay in response to the restoration of estuarine salinity ranges and the reduction of the frequency and duration of hypersalinity events. Beneficial conditions in Florida Bay will contribute to an increase in annual catch per unit effort in the Tortugas fishing grounds.

Level of certainty – moderate

A.5.6 Research Questions

Although Florida Bay is one of the most intensively studied ecosystems in South Florida, three key areas of uncertainty hamper our ability to predict ecological responses to the restoration of freshwater flows to Florida Bay. They pertain to 1) the hydrologic linkage between the Everglades and the bay, including the relationship of changing upland hydrologic conditions to freshwater flow to the bay and water circulation

and salinity within the bay; 2) the fate and ecological consequences of increased nutrient inputs that may accompany restored in flows to the bay; and 3) the relationship of phytoplankton blooms to nutrient sources, seagrass die-off, sediment resuspension and circulation pattern.

Linkage of Everglades Hydrology to Freshwater Inflow

How does Everglades' hydrology relate to the inflow and circulation of fresh water in Florida Bay? Develop a validated, predictive model to link changes in Everglades' hydrology to consequent changes in the freshwater inflow and circulation of surface and ground water in the bay. Develop validated hydrodynamic and water quality models of the bay that can accurately predict water residence times and salinity in the bay.

Fate and Ecological Consequences of Increased Nutrient Inputs That May Accompany Restored Freshwater Inflows to the Bay

What is the functional importance of Florida Bay as a source and sink of nitrogen? Is there a net loss of nitrogen in Florida Bay via denitrification? Measure quantitative relationships of nitrogen inputs from the Everglades and dentrification and nitrogen fixation rates within the bay, their relationships to salinity patterns, and model how they will change with restoration of natural freshwater inflows and salinity patterns. Will increased inputs of dissolved organic nitrogen from the restoration of natural water inflows of the Everglades result in an increase in the prevalence of phytoplankton blooms in Florida Bay? Determine the extent to which dissolved organic nutrients in different sources of water, particularly Everglades' runoff, are mineralized. Determine the availability of dissolved organic nutrients directly to phytoplankton in different water sources.

Relationship of Phytoplankton Blooms to Nutrient Sources, Seagrass Die-off, Sediment Resuspension and Circulation Pattern

Phytoplankton blooms may be strongly influenced by factors other than nitrogen availability. Rates of phosphorus supply and grazing (particularly benthic grazing) need to be measured, and relationships with seagrass cover and sediment resuspension determined. These dynamics need to be included in a water quality model.

A.5.7 Hydrologic Performance Measures

A.5.7.1 Salinity Pattern

Salinity patterns will be altered as a result of the modification of the volume, timing and distribution of freshwater inflow. The desired alterations include less abrupt and less extreme decreases in salinity in northeastern Florida Bay; a reduction in the frequency, extremity and extent of hypersaline conditions in the central and western bay; an increase in the frequency and extent of low salinity conditions in the central bay; and an increase the frequency and extent of salinities less than that of seawater in the western bay, extending westward along the Gulf of Mexico coastal shelf to Lostman's River.

A.5.8 Ecological Performance Measures

A list of fundamental measures associated with each of the model's ecosystem attributes is given in Table A-3. This list should be considered minimal; interpretation of many of these measures requires a set of associated measures. The list includes not only "structural" variables (e.g., pink shrimp abundance), but also dynamic, process variables (e.g., nutrient fluxes). Note that this list does not reflect the temporal or spatial time scale at which measurements are necessary, but temporal patterns, such as seasonality and

interannual variability, and spatial patterns are a central aspect of ecological dynamics. Also note that the power to predict the fate of any ecosystem requires more than monitoring; research and modeling are also essential, with these three interdependent approaches providing the scientific basis for environmental management.

Table A-3: Ecological Performance Measures for the Florida Bay Conceptual Ecological Model Listed by Attribute

Water Quality Condition	
Salinity	Phytoplankton
Dissolved Oxygen	Nutrient Concentrations
Freshwater Inflow	Nutrient Fluxes
Water Budget	Sediment Nutrients and Toxics
Light Extinction and Turbidity	
Seagrass Community	
Spatial Heterogen	Coverage
Biomass	Pure Water Sulfide
Productivity	Disease Frequency
Mollusks and Filter Feeders	
Grazing Rates on Phytoplankton	Mollusk Abundance and Diversity
Zooplankton and Benthic Grazer Biomass	
Pink Shrimp	
Abundance	Mortality
Productivity	
Fish Community	
Diversity	Mortality
Abundance	Toxic Residues
Productivity	
Fisheating Birds	
Abundance	Mortality
Reproduction	Toxic Residues

A.5.9 Model

The diagram for the Florida Bay Conceptual Ecological Model is presented in Figure A-19. The key to the symbols used in the diagram is presented in Figure A-18.

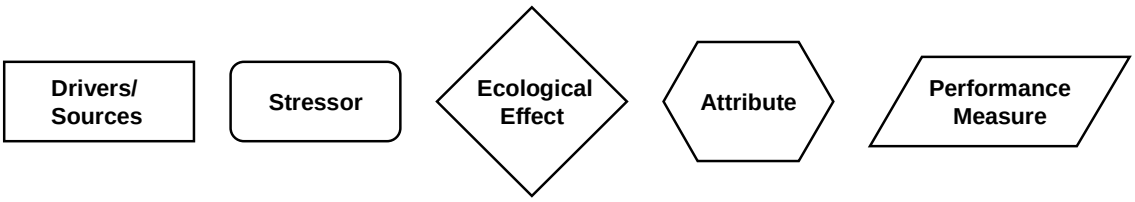


Figure A-18: Key to the Symbols Used in the Following Diagram

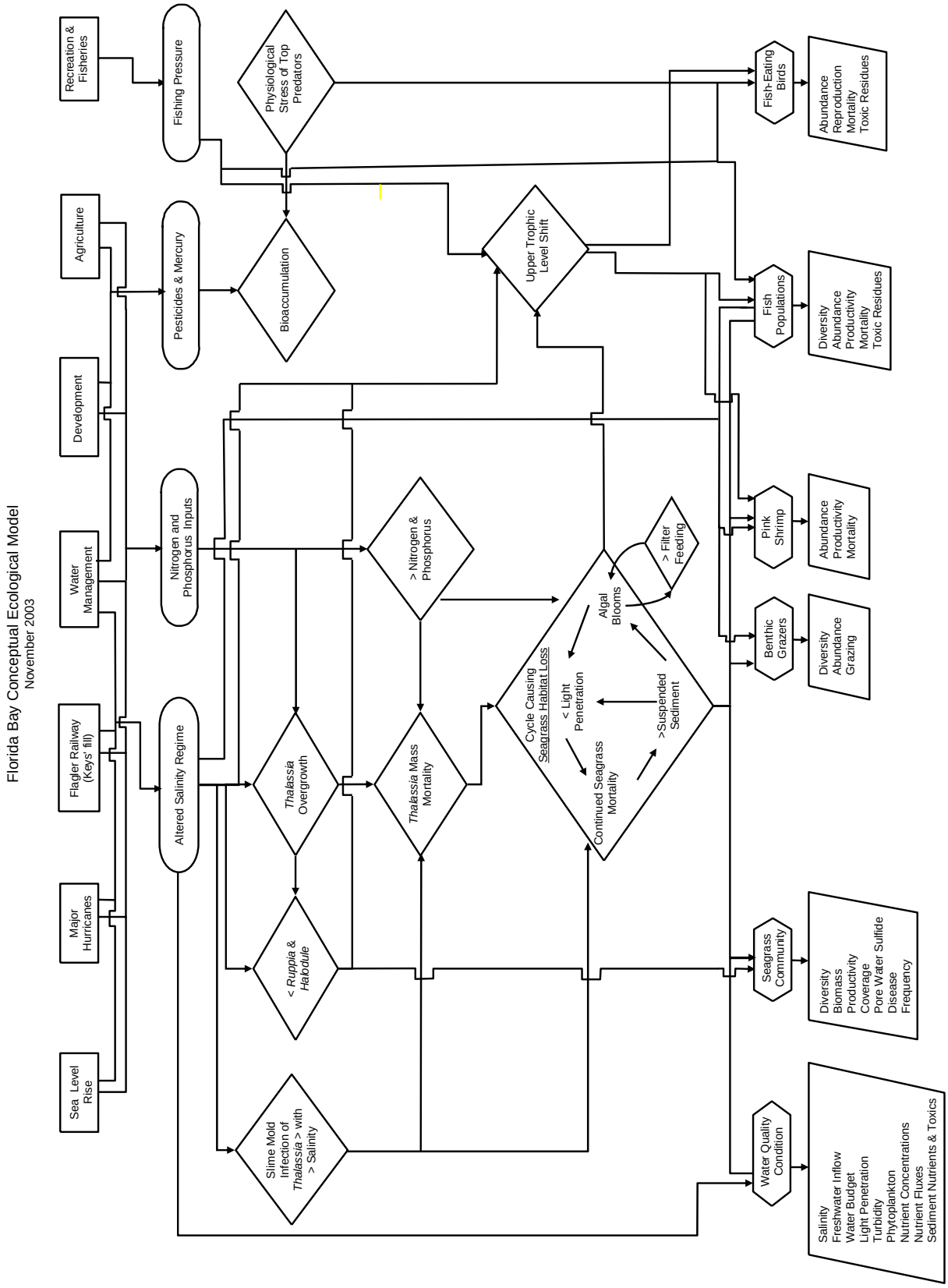


Figure A-19: Florida Bay Conceptual Ecological Model Diagram

A.5.10 Literature Cited

Alsuth, S., and R.G. Gilmore. 1994. Salinity and temperature tolerance limits for larval spotted seatrout, *Cynoscion nebulosusC.* (Pisces: Sciaenidae). International Journal for the Exploration of the Sea. Council Meeting Papers, ICES-CM-1994/L:17.

Armentano, T., M. Robblee, P. Ortner, N. Thompson, D. Rudnick, and J. Hunt. 1994. Science Plan for Florida Bay.

Armentano, T., R. Brock, J. Hunt, W. Kruzynski, D. Rudnick, S. Traxler, N. Thompson, P. Ortner, K. Cairnes, M. Robblee, and R. Halley. 1997. Strategic Plan for the Interagency Florida Bay Science Program. Florida Bay Program Management Committee, c/o Everglades National Park, Homestead, Florida.

Boesch, D., N. Armstrong, C. D'Elia, N. Maynard, H. Paerl, and S. Williams. 1993. Deterioration of the Florida Bay Ecosystem: An Evaluation of the Scientific Evidence. Report to the Interagency Working Group on Florida Bay, c/o Everglades National Park, Homestead, Florida.

Boesch, D., N. Armstrong, J. Cloern, L. Deegan, R. Perkins, and S. Williams. 1995. Report of the Florida Bay Science Review Panel on Florida Bay Science Conference: Report by Principal Investigators, October 17-18, 1995, Gainesville Florida. Florida Bay and Adjacent Waters Research Program, c/o Everglades National Park, Homestead, Florida.

Boesch, D., N. Armstrong, J. Cloern, L. Deegan, S. McCutcheon, R. Perkins, and S. Williams. 1997. Annual Report of the Florida Bay Science Oversight Panel: Perspectives from the 1996 Florida Bay Science Conference and Review of the Strategic Plan. Report to the Program Management Committee, Interagency Florida Bay Science Program, c/o Everglades National Park, Homestead, Florida.

Bortone, S.A. 2002. Biology of the spotted seatrout. CRC Press, Boca Raton, Florida.

Boyer, J.N., J.W. Fourqurean, and R.D. Jones. 1997. Spatial characterization of water quality in Florida Bay and Whitewater Bay by multivariate analysis: zones of similar influence (ZSI). Estuaries 20:743-758.

Brand, L.E. 2000. An evaluation of the scientific basis for "restoring" Florida Bay by increasing freshwater runoff from the Everglades. Report for Reef Relief, Key West, Florida.

Browder, J.A., V.R. Restrepo, J.K. Rice, M.B. Robblee, and Z. Zein-Eldin. 1999. Environmental influences on potential recruitment of pink shrimp, *penaeus duorarum*, from Florida Bay nursery grounds. Estuaries 22:484-499.

DeKanel, J., and J.W. Morse. 1978. The chemistry of orthophosphate uptake from seawater on to calcite and aragonite. Geochem. Cosmochem. Acta. 42:1335-1340.

Ehrhardt, N.M., and C.M. Legault. 1999. Pink shrimp, *Farfantepenaeus duorarum*, recruitment variability as an indicator of Florida Bay dynamics. Estuaries 22:471-83.

Fourqurean, J.W. and M.B. Robblee. 1999. Florida Bay: a history of recent ecological changes. Estuaries 99:345-357.

Landsberg, J.H., B.A. Blakesley, A. Baker, G. McRae, M. Durako, J. Hall, R. Reese, and J. Styer. 1996. Examining the correlation between the prescence of the slime mold, *Labyrinthula* sp. and the loss of *Thalassia testudinum* in Florida Bay. In: Proceedings of the 1996 Florida Bay Science Conference, Key Largo, Florida. Florida Bay and Adjacent Waters Research Program, c/o Everglades National Park, Homestead, Florida.

Lapointe, B.E., and M.W. Clark. 1992. Nutrient inputs from the watershed and coastal eutrophication in the Florida Keys. Estuaries 15:465-476.

Light, S.S., and J.W. Dineen. 1994. Water control in the Everglades: a historical perspective. In: Davis, S.M., and J.C. Ogden (eds.). Everglades: The Ecosystem and Its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 47-84.

McIvor, C.C., J.A. Ley, and R.D. Bjork. 1994. Changes in freshwater inflow from the Everglades to Florida Bay including effects on biota and biotic processes: a review. In: Davis, S.M., and J.C. Ogden (eds.). Everglades: The Ecosystem and Its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 117-146.

Orem, W.H, C.W. Holmes, C. Kendall, H.E. Lerch, A.L. Bates, S.R. Silva, A. Boylan, M. Corum, M. Marot, and C. Hedgman. 1999. Geochemistry of Florida Bay sediments: nutrient history at five sites in eastern and central Florida Bay. J. Coastal Res. 15:1055-1071.

Phlips, E.J., and S. Badylak. 1996. Spatial variability in phytoplankton standing crop and composition in a shallow inner-shelf lagoon, Florida Bay, Florida, USA. Bull. Mar. Sci. 58:203-216.

Prager, E.J., and R.B. Halley. 1999. The influence of seagrass on shell layers and Florida Bay mudbanks. J. Coastal Res. 15: 1151-1162.

Robblee, M.B., T.R. Barber, P.R. Carlson, Jr., M.J. Durako, J.W. Fourqurean, L.K. Muehlstein, D. Porter, L.A. Yarbro, R.T. Zieman, and J.C. Zieman. 1991. Mass mortality of the tropical seagrass *Thalassia testudinum* in Florida Bay (USA). Mar. Ecol. Prog. Ser. 71:297-299.

Rudnick, D.T., Z. Chen, D. Childers, J. Boyer, and T. Fontaine. 1999. Phosphorus and nitrogen inputs to Florida Bay: the importance of the Everglades watershed. Estuaries 22:398-416.

Schomer, N.S., and R.D. Drew. 1982. An ecological characterization of the lower Everglades, Florida Bay, and the Florida Keys. WS/OBS-82/58.1, United States Fish and Wildlife Service, Office of Biological Services, Washington, D.C.

Sklar, F.H., and J.A. Browder. 1998. Coastal environmental impacts brought about by alterations of freshwater flow in the Gulf of Mexico. Environ. Management 22:547-562.

Smith, N.P. 1994. Long-term gulf-to-Atlantic transport through tidal channels in the Florida Keys. Bull. Mar. Sci. 54:602-609.

Stumpf, R.P., M.L. Frayer, M.J. Durako, and J.C. Brock. 1999. Variations in water clarity and bottom albedo in Florida Bay from 1985 to 1997. Estuaries 22:431-444.

Swart, P.K., G.F. Healy, R.E. Dodge, P. Kramer, J.H. Hudson, R.B. Halley, and M.B. Robblee. 1996. The stable oxygen and carbon isotopic record from a coral growing in Florida Bay: a 160 year record of climatic and anthropogenic influence. Palaeo, Palaeo, Palaeo 123:219-237.

Swart, P.K., G.F. Healy, L. Greer, M. Lutz, A. Saied, D. Anderegg, R.E. Dodge, and D. Rudnick. 1999. The use of proxy chemical records in coral skeletons to ascertain past environmental conditions in Florida Bay. Estuaries 22:384-397.

Tilmant, J.T. 1989. A history and an overview of recent trends in the fisheries of Florida Bay. Bull. Mar. Sci. 44:3-33.

Thayer, G.W., A.B. Powell, and D.E. Hoss. 1999. Composition of larval, juvenile, and small adult fishes relative to changes in environmental conditions in Florida Bay. Estuaries 22:518-533.

Tomas, C.R. 1996. The role of nutrients in initiating and supporting Florida Bay microalgal blooms and primary production. In: Proceedings of the 1996 Florida Bay Science Conference, Key Largo, Florida, Florida Bay and Adjacent Waters Research Program, c/o Everglades National Park, Homestead, Florida.

USACE and SFWMD. 1999. Central and Southern Florida Project Comprehensive Review Study, Final Integrated Feasibility Report and Programmatic Environmental Impact Statement. United States Army Corps of Engineers, Jacksonville District, Jacksonville, Florida, and South Florida Water Management District, West Palm Beach, Florida.

Wang, J.D., J. van de Kreeke, N. Krishnan, and D. Smith. 1994. Wind and tide response in Florida Bay. Bull. Mar. Sci. 54: 579-601.

Zieman, J.C., J.W. Fourqurean, and R.L. Iverson. 1989. Distribution, abundance and productivity of seagrasses and macroalgae in Florida Bay. Bull. Mar. Sci. 44: 292-311.

A.6 BISCAYNE BAY CONCEPTUAL ECOLOGICAL MODEL

A.6.1 Model Leads

Joan Browder, National Oceanic and Atmospheric Administration
Richard Alleman, South Florida Water Management District
Peter Ortner, National Oceanic and Atmospheric Administration
Susan Markley, Miami-Dade County Department of Environmental Resource Management

Parts of this narrative were extracted from the Biscayne Bay Issue Report, authored by Sarah Bellmund, Joan Browder, and Susan Alspach

A.6.2 Introduction

Biscayne Bay (Figure A-20) is a naturally clear-water bay with a tropically enriched flora and fauna. The bay was historically bordered in places by a thin band of mangroves and, otherwise, with herbaceous wetlands. It was connected to the Greater Everglades ecosystem hydrologically through tributaries, sloughs, and ground water flow. Because of the bay's shallow depths and clear waters, its productivity is largely benthic-based. Water clarity is maintained by healthy benthic communities, which filter particulates, absorb available nutrients, and stabilize sediments. Benthic communities in the central and southern bay consist of several species of seagrasses, a mix of soft and hard corals and attached macro-algae, and coral-algal bank fringe that alternate for dominance in different areas. In portions of the northern bay, where the bottom and shoreline has been disturbed by past dredging, filling and bulkheading, the cover of seagrass and other submerged aquatic vegetation (SAV) has been lost, and water column nutrients and turbidity levels are relatively higher. Where the natural depth of the bay is retained, some high-quality seagrass beds exist.

Biscayne Bay's water quality has improved substantially in the past 30 years because of the elimination of the direct discharge of sewage into the bay (McNulty 1970). Water quality generally meets or exceeds federal, state and local standards for recreational uses and propagation of fish and wildlife. In recognition of its exceptional values, the State of Florida has designated the bay and its natural tributaries as Outstanding Florida Waters, and as such they receive the highest level of protection from degradation. Most of the bay is part of a state aquatic preserve. The preserve includes Biscayne National Park, which covers roughly 75 percent of the bay area. The bay has been significantly affected by past development, water management and sewage disposal practices (Alleman et al. 1995). Changes in physical and ecological water quality characteristics can be attributed at least partly to loss of wetland and seagrass communities. Also, the bay still receives dissolved nutrients, trace metals, organic chemicals and suspended sediments via stormwater runoff, sewage overflows, canal discharge and discharges from industrial facilities or vessels. Canal water typically has lower dissolved oxygen and clarity and higher concentrations of contaminants than receiving waters of the bay, and so represents a source of degradation.

Water management actions related to drainage and water supply for the development of urban and agricultural areas have substantially changed freshwater inflow to Biscayne Bay. Historically, Biscayne Bay provided both estuarine and marine habitat and associated fauna, but the bay's estuarine habitat, which is dependent on freshwater inflow, has been greatly reduced. Estuarine habitat has been eliminated or seriously degraded by changes that were made in the quantity, timing and distribution of freshwater inflow by the construction and operation of the Central and Southern Florida (C&SF) Project. A consequence is that the bay has lost valuable estuarine fishery species such as red drum that once were sufficiently abundant to support a fishery (Smith 1896).

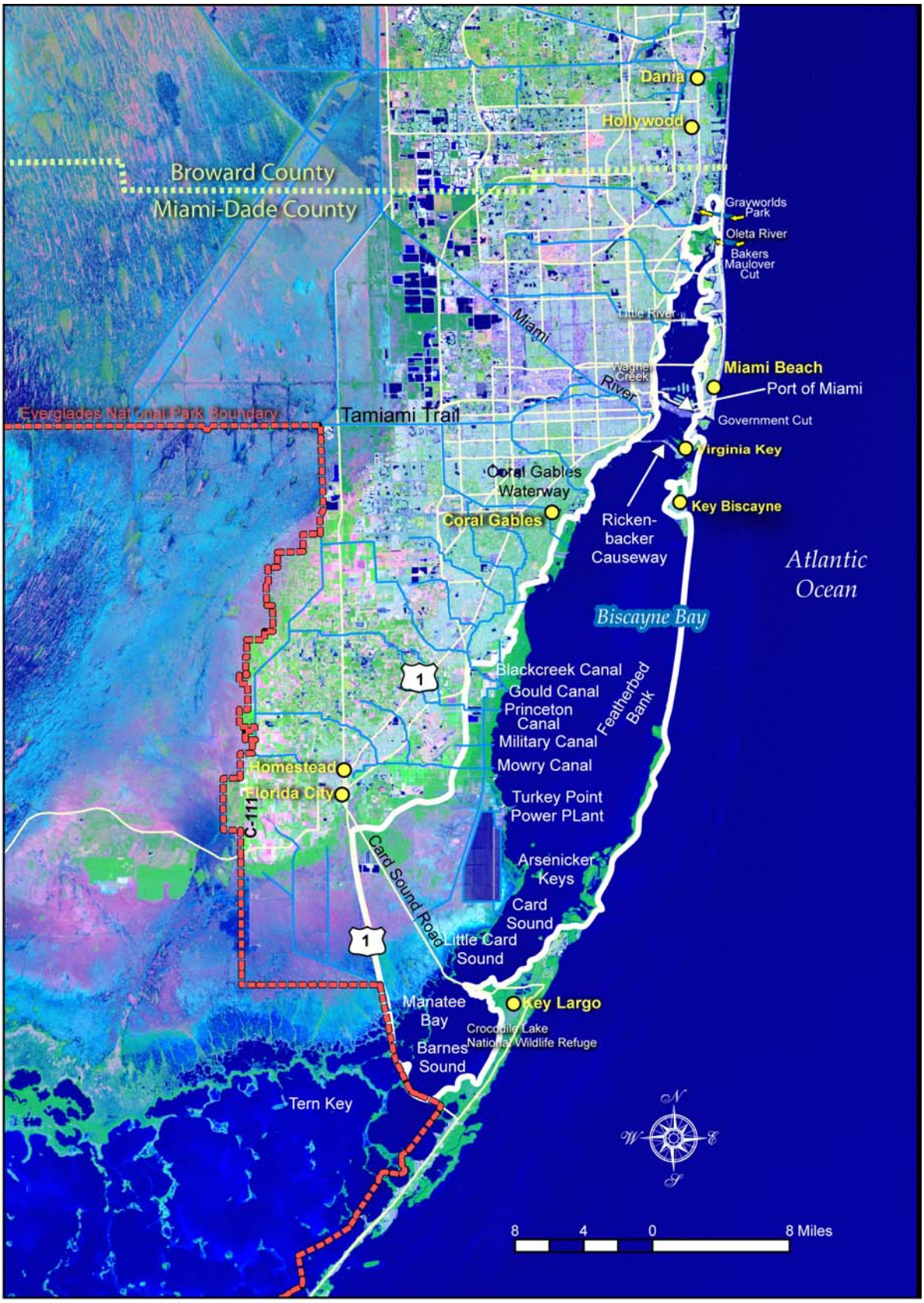


Figure A-20: The Boundary of the Biscayne Bay Conceptual Ecological Model

In the past, freshwater and brackish marsh habitats bordered the bay's western shoreline and barrier islands, but over the last century, western shorelines of the bay and eastern barrier islands, including Miami Beach and Key Biscayne, have undergone extensive loss of marsh and mangroves (Harlem 1979). The western bay was heavily impacted by the construction of 19 water management canals constructed to prevent intermittent coastal flooding that drained wetlands and facilitate urban expansion and agriculture.

Construction of the major canals through the Everglades and channelization of natural tributaries and transverse glades that carried fresh water to Biscayne Bay lowered the regional and coastal water table (Parker et al. 1955), decreased ground water flow to the bay, and reduced the number of sites where surface water entered the bay. This eliminated the natural salinity gradient through coastal wetlands and tidal creeks into the bay that had provided critical estuarine habitat for bay species requiring low-to-moderate salinity waters. In addition, delivery of fresh water into the bay as a pulsed, point-source discharge degraded estuarine habitat near canal mouths by creating biologically damaging zones of bottom scouring and rapid salinity fluctuations. Departures from natural salinity patterns are ecologically damaging because salinity affects physiological processes that control the growth, survival, reproduction and general wellbeing of both plants and animals. The general lowering of the water table on the east-coast ridge and diversion of both surface and ground water into canals has degraded not only estuarine habitat of the bay but also adjacent coastal wetland communities, including herbaceous freshwater and coastal wetlands that relate functionally to estuarine habitat. Even coastal tropical hammocks have been affected by the lowered water table.

A conceptual ecological model in the risk assessment framework has been developed for Biscayne Bay (Figure A-22, Section A.6.9). The model depicts the general pathways by which driving forces (in rectangles), particularly those related to modern human culture, affect "attributes" of the ecosystem (in hexagons) that are intrinsically important to ecosystem function or are generally viewed by humans as valuable and important to maintain. Drivers are manifested as stressors (ovals) that exert their impact on the ecosystem in various ways, or "effects" (diamonds). "Performance measures" (trapezoids) provide the parameters about the attributes that can be measured to determine the direction (positive or negative) and intensity of effects.

In the Biscayne Bay Conceptual Ecological Model, the two principal drivers are **watershed development** and **water management**. They exert their effects through five principal stressors, as arranged left to right in the model diagram (Figure A-22, Section A.6.9): **toxicant and pathogen inputs**, **altered solids and nutrient inputs**, **altered circulation**, **altered freshwater inflow**, and **operations** of physical structure, particularly water control structures, vessels and dredges. Paramount of these stressors is **altered freshwater flow**, which includes volume, timing and spatial distribution and will be directly affected by the Comprehensive Everglades Restoration Plan (CERP). In the model, principal effects of these stressors have been grouped into four categories: **water and sediment contaminants**; **nutrients, solids and water transparency**; **freshwater flow and salinity**; and **physical impacts**. The two drivers are interrelated and the principal stressors are related to both drivers and to each other, but are more strongly related to one driver or the other, as shown. The "effects" categories fit reasonably well under only one or two stressors as shown, but many attributes are associated with more than one effects category and stressor; therefore, relationships between attributes and stressors are even more complex than indicated in the model. Attributes in this model include not only living ecosystem components but also vital environmental characteristics such as salinity and water and sediment quality. A preliminary set of performance measures is proposed for each attribute.

A.6.3 External Drivers and Ecological Stressors

The two principal drivers identified are **watershed development** and **water management**. Watershed development is the main driver behind water management, shoreline and bottom alteration, and vessel traffic. Watershed development was a primary driving force behind the implementation of a highly controlled water management system, and much of the dredging and shoreline alteration that has occurred has been a direct result of development.

Biscayne Bay's watersheds span most of Miami-Dade County, parts of Broward and Monroe Counties, and the interior Everglades to Lake Okeechobee. These areas, except for the central Everglades, have experienced exponential expansion of the modern human population in the past century. The expansion was made possible by a system of canals, levees and water control structures initially constructed to drain the Everglades but ultimately used to lower the water table and prevent flooding on the east coast ridge and wetlands immediately adjacent to the ridge, including parts of the Everglades and much of the coastal wetlands. Population growth is continuing to exert pressures of all types on Biscayne Bay.

Water levels are controlled in Miami-Dade County by the regional canals of the C&SF Project including the South Dade Conveyance System, smaller local drainage canals, and stormwater infrastructure projects. The present water management canal network extends to the southernmost reaches of the county. Currently 19 canals discharge fresh water into Biscayne Bay. These canals maintain flood control in 17 eastern Miami-Dade County surface water management basins (Cooper and Lane 1987) as well as regulate water levels in the Water Conservation Areas of the Everglades, by releasing water to Biscayne Bay. Canal levels are maintained to control ground water elevation on the coastal ridge as well as in historic wetlands that have been drained and developed. The canals are operated in a way that controls ground water stage within about 1 to 2 feet to reduce the risk of flooding (Cooper and Lane 1987). Ground water stage, which influences the amount of water entering the bay as ground water, was about 6 to 8 feet higher prior to the initiation of water management (Parker et al. 1955).

The primary stressors associated with watershed development and water management have been identified as **toxicant and pathogen inputs**, **altered solids and nutrient inputs**, **altered circulation**, **altered freshwater inflow**, and **operations**. These stressors can best be described in terms of the four distinct environments of Biscayne Bay - north, central, south and extreme south bays - that have been subjected to these stressors to varying degrees.

The north bay, which extends from the Miami-Dade County/Broward County line south to the Rickenbacker Causeway, makes up a relatively small portion of the original bay and is now further constricted in size by many small artificial islands and causeways. It accounts for only 10 percent of the bay's surface water area (DERM 1985). The north bay was once bordered on both sides by mangrove wetlands and salt marsh, however, the only remaining mangrove wetlands today are on the western side of the extreme northern bay and on Virginia Key. These areas, although somewhat disturbed, are still important wildlife areas. Much of the northern bay's shoreline is bulk headed. The Port of Miami and many marinas are located in this part of the bay. The flows of several tributaries, including the Oleta River, Arch Creek, Little River, and the Miami River, which all are now canalized and run through heavily urbanized/industrialized areas, empty into the north bay. This part of the bay also receives the flow of other canals. Under natural conditions, and even today, this part of the bay receives more fresh water relative to its volume than any other part of the bay. Prior to human alterations, north Biscayne Bay was a fresh to brackish water system (Harlem 1979). The salinity regime, circulation, and ecological characteristics of north Biscayne Bay were irrevocably changed by physical alterations that occurred in the first part of the Twentieth Century (Harlem 1979, Buchanan and Klein 1976). These include the opening of Baker's Haulover Cut to the Atlantic in 1925; the widening and deepening of Government Cut; extensive dredging and filling; bulkhead construction; and channelization of overland and ground

water flow into canals. Dredging and filling activities altered circulation patterns and contributed to increased turbidity by changing the profile of the bay bottom and replacing the vegetated, sloped shoreline that absorbed wave energy with vertical bulkheads that reflected it, stirring up bottom sediments (Dade County 1981, Alleman et al. 1995). Both salinity patterns and water clarity were affected by such changes, and in turn affected submerged vegetation composition and distribution patterns.

Central Biscayne Bay, which extends from the Rickenbacker Causeway south to Featherbed Bank, and south Biscayne Bay, from Featherbed Bank to Card Sound, form the largest portion of the bay, 45 and 30 percent of the bay's surface water area, respectively. They were historically less brackish than north Biscayne Bay, although the region still contained areas receiving extensive overland and ground water inflow. Dole (1914) reported that, seasonally, large quantities of fresh water moved into the bay through springs in porous rocks and sediments as well as through streams along the western shore of the bay. Surface water moved into central and south bay through broad natural flow channels that are frequently referred to as transverse glades (Davis 1943, Buchanan and Klein 1976). The western shoreline of Biscayne Bay south of the Rickenbacker Causeway received sufficient fresh water to maintain extensive freshwater swamps and marshes and a narrow fringe of mangroves (Harlem 1979, Reark 1974, Thorhaug et al. 1976). These coastal freshwater marshes were drained and farmed during the first half of the Twentieth Century (Reark 1974), until overdrainage, salt intrusion, hurricane storm surges, and new opportunities to farm in the rocky uplands resulted in wholesale abandonment of coastal farmland (USEPA 1994).

Central and south Biscayne Bay did not experience as much physical alteration of bay bottom and shoreline as the northern bay. Alterations to central and south Biscayne Bay resulted from regional drainage activities that essentially eliminated inflow from subterranean springs by the 1940s (Reark 1974) and channelized remaining overland and ground water flow into canals. The most significant impact from alteration was the regional increase in salinity that has resulted in the slow conversion of productive estuarine habitat on the western side of the bay into a more marine and occasionally hypersaline environment (Alleman et al. 1995).

The extreme southern bay, defined here as Card Sound, Little Card Sound, Barnes Sound, and Manatee Bay (15 percent of surface area), has more physically intact shoreline and coastal wetland habitat than the rest of the bay. On the other hand, this part of the bay probably has experienced the greatest alteration in freshwater flow and salinity patterns, and its wetlands are seriously degraded. Regional and local drainage activities and roads such as U.S. Highway 1 have effectively interrupted freshwater inflow to this part of the bay except through the C-111 canal, which discharges flood waters into Manatee Bay through managed control structures. The C-111 canal is part of the South Miami-Dade Conveyance System that drains much of southwestern Miami-Dade County. Faunal records in sedimentary cores indicate an overall increase in salinity in Manatee Bay over the past 150 years, probably associated with sea level rise; a change from mesohaline (5-18 parts per thousand [ppt]) to euhaline (30-35 ppt) conditions in the early 1900s, possibly associated with the original drainage of the Everglades and construction of the Flagler Railway; and recent extreme fluctuations between low-salinity and hypersaline conditions, probably associated with completion of the South Dade Conveyance System in about 1980 (Ishman et al. 1998). The Miami-Dade County Department of Environmental Resources Management (DERM) (unpublished in Ishman et al. 1998) reports salinities as high as 45 ppt and as low as 14 ppt in recent years in Manatee Bay. Water exchange in this part of the bay is restricted by both natural barriers and barriers created by Card Sound Road and U.S. Highway 1 (U.S. 1).

Both commercial and recreational fishing occurs in Biscayne Bay. Commercial fishing activity has decreased over the years, at least partially due to state regulations restricting gear. Two commercial fisheries based on pink shrimp operate in Biscayne Bay. One employs roller-frame trawls, and the second uses wing nets. Presently, pink shrimp are caught in Biscayne Bay both for bait and for human

consumption. A trap fishery for blue crab also operates in Biscayne Bay. A sponge fishery still exists in the southernmost part of the bay (outside of Biscayne National Park). State regulations limit trawling gear to the roller-frame trawl (instead of the otter trawl) to prevent damage to seagrass, but Ault et al. (1997) tested the use of the roller-frame trawl in hard bottom areas of the bay and found damage to hard bottom flora and fauna. Spotted seatrout, snook and tarpon currently are being caught by recreational fishermen in seagrass areas in north Biscayne Bay (E. Carney, shallowwater angler, personal communication).

A.6.4 Ecological Attributes

The environmental indicators of ecological health that have been identified as exceptionally important with respect to Biscayne Bay are temporal and spatial **salinity** patterns and **water and sediment quality**. Biological indicators of ecological health that have been selected include **seagrass habitat**; **mangrove functionality**; **herbaceous wetland habitat**; **benthic communities**; **pink shrimp, blue crabs, stone crabs, oysters and lobsters**; **estuarine fish communities**; **fish and bottlenosed dolphin health**; **crocodiles**; **manatees**; and **wading birds**. The ecological indicators were selected based on one or more of the following characteristics: 1) recognized sensitivity to the conditions the CERP is expected to change, 2) relative importance in the bay ecosystem, and 3) importance to bay restoration because of their linkages.

A.6.4.1 Salinity

Salinity affects physiological processes that control the growth, survival, and reproduction of both plants and animals (e.g., Kinne 1971). Aquatic plants and animals have salinity optima and limits beyond which they do not thrive. Data and historic accounts document a significantly greater and more diffuse freshwater flow to the bay (via surface sheet flow, ground water and freshwater ‘springs’ within the bay). These conditions generated a diverse salinity regime, with a general gradient from the western shoreline to the eastern portions of the bay. The natural pattern of salinity distribution and fluctuation were major determinants of habitat development, the composition of biological communities within these habitats, and their overall productivity. Therefore, restoration of more natural salinity patterns is a necessary prerequisite to restoration of the bay’s natural estuarine diversity and productivity.

A.6.4.2 Water and Sediment Quality

Open waters of Biscayne Bay are generally characterized by high dissolved oxygen concentration, low nutrient and chlorophyll concentrations and high clarity. Sewage-related bacteria, trace metals and other toxicants are typically not detectable in Biscayne Bay waters. However, water quality in a number of the canals that discharge to the bay is poor in comparison to the open waters of the bay. As is the case with other South Florida natural systems, Biscayne Bay water quality is at risk of nutrient enrichment due to impacts by urban stormwater runoff, industrial discharges and sewage contamination emanating from the canals. Water quality can also be affected by ground water inputs. In some areas, ground water contains elevated levels of ammonia nitrogen, from landfill leachate, and nitrate-nitrogen, from agriculture (DERM 1987, Alleman 1990, Markley et al. 1990, DERM 1993, Alleman et al. 1995, Lietz 1999, Meeder and Boyer 2001). Submarine ground water discharge into shallow near-shore waters is a source of elevated nutrients (Meeder et al. 1997); nutrient concentrations in shallow ground water (beneath the near-shore bay between Mowry Canal and Military Canal) are higher than in bay or canal waters or deep ground water. The structure and operation of the South Florida water management system, as well as land uses and urban and agricultural practices, affect ground water nutrient loads to Biscayne Bay. Sea level rise could potentially affect ground water loads.

The community composition, distribution and health of macro-benthic, infaunal and demersal organisms can be affected by the presence of toxic substances in the sediments. Potentially toxic pollutants, such as

metals and organic chemicals, that usually have low water solubility, tend to bind to particulate material and accumulate in sediments (Seal et al. 1994, Long et al. 2000). Most contaminants in Biscayne Bay occur in highest concentrations in conveyance canals, rivers, streams and marinas, with lowest concentrations down the central north-south axis of the bay (Corcoran et al. 1983, Alleman et al. 1995). Trace metals and organic contaminants, such as some pesticides and polychlorinated biphenyls (PCBs) are found in higher concentrations in the Miami River and Wagner Creek than any other area in the State of Florida (Schmale 1991, DERM 1993, Seal et al. 1994). Other canals that have exhibited high levels of sediment toxicity include Little River, Black Creek Canal, and Military Canal (USEPA 1999, DERM unpublished data). More recent studies (Long et al. 2000, 2002) showed that contaminant levels in Biscayne Bay sediments are slightly below the national average, whereas toxicity levels are slightly above. The study supported earlier findings that contamination and toxicity were most severe in several conveyance canals and a few natural tributaries, and that sediments from the open basins were less toxic than those from the adjoining canals and tributaries. In the more open waters of the bay, chemical concentrations and toxicity were generally higher north of Rickenbacker Causeway than south of it. However, a section of southern Biscayne Bay showed remarkably high toxicity that could not be attributed to any of the substances analyzed. While the causes of toxicity were not determined in the study, evidence suggests that mixtures of some metals and synthetic organic chemicals are the likely contributors to toxicity observed in the lower Miami River. An amphipod survival test showed a high degree of correspondence with a gradient in chemical contamination in the river and adjoining reaches of the bay. Because contaminants are conveyed to the bay through the canal system, changes in the distribution or sources of fresh water may affect the amount and pattern of water and sediment quality, which in turn affect habitat quality, water column and benthic productivity, and diversity.

A.6.4.3 Seagrass Habitat

Large areas of the bay bottom support seagrass communities because of the relatively low nutrients and high water clarity in Biscayne Bay. Seagrass has been documented to cover up to 64 percent of the bay bottom (DERM 1985). These areas function as vital habitat to support critical life stages for a variety of ecologically, economically and recreationally important species. At least seven species of seagrasses commonly occur in Biscayne Bay: *Thalassia testudinum* (turtle grass), *Halodule wrightii* (shoal grass), *Syringodium filiforme* (manatee grass), three species of *Halophila*, including *H. johnsonii*, which is a federally-listed protected species, and *Ruppia maritima*. Distribution of seagrass species is generally related to water clarity, quality and salinity levels and stability. In north Biscayne Bay, where salinities are commonly lower due to many freshwater tributary and canal flows, salinity fluctuation is greater, and water clarity is generally lower, *S. filiforme* and *H. wrightii* are common. Significant mixed *Thalassia/Syringodium* beds also exist in the north bay. *Thalassia* is most prominent in central and south Biscayne Bay where salinities are higher and more consistent and nutrient levels are lower.

In the western near-shore area of south Biscayne Bay, the distribution of seagrass species and other benthic flora and fauna are influenced by submarine ground water seepage (Kohout and Kolipinski 1967, Meeder et al. 1999). Presence or absence of *Thalassia* defines distinct zones where ground water influence is substantial (absent) or insignificant (present). In their study area, Meeder et al. (1999) found the maximum ground water seepage about 200 meters from shore along a transect from 25 to 300 meters from shore. The amount of ground water seepage and its influence have been affected by the general lowering of the water table (Parker et al. 1955) associated with the South Florida water management system. Sea level rise could also affect ground water seepage to Biscayne Bay

South Biscayne Bay receives episodic (irregularly pulsed) freshwater inflows through South Florida Water Management District canals (particularly the Goulds, Princeton, Mowry and C-111 canals), which cause abrupt salinity changes in near-shore waters. J. Meeder (Florida International University, personal communication) has observed a seasonal decline and loss of seagrass leafy biomass in association with

early wet season discharges from the Mowry Canal. Extremely high, pulsed flows are released from the C-111 canal into Manatee Bay intermittently. Flows to Manatee Bay from the C-111 canal alternate between extremely high and zero, and water circulation in Manatee Bay and adjacent Barnes Sound is very restricted, resulting in abrupt high amplitude salinity changes. Seagrass composition in these areas has been documented to vary between *Ruppia*, *Thalassia* and *Halodule*, or mixtures of *Halodule* and *Ruppia* or *Halodule* and *Thalassia*, depending on salinity regime.

A.6.4.4 Mangrove Functionality and Herbaceous Wetlands

The presence of a system of coastal wetlands integrated by the inflow of fresh water from upstream and, to varying degrees, by tidal exchange, is essential to the restoration of a fully functional Biscayne Bay ecosystem. These highly productive habitats provide nursery, foraging and refuge areas for many fish and invertebrate species. In addition, these coastal wetlands help maintain water and habitat quality by filtering sediments and nutrients from inflowing waters. Biscayne Bay's remaining mangroves and associated herbaceous wetlands, including near-shore freshwater wetlands, have lost much of their ecological function because channelization has diverted fresh water away from coastal feeder streams and creeks. Restoration of both brackish and freshwater wetlands and coastal creeks on the western shore of Biscayne Bay is important to the success of restoration and, therefore, is defined as an indicator of success. In the southern part of the western bay, water management and watershed development activities to date have led to an encroachment of scrub mangroves on former freshwater wetland. Freshwater wetlands are a vital component of the coastal wetland system and their loss is undesirable, even when replaced by mangroves.

A.6.4.5 Benthic Communities

Benthic organisms provide essential ecological and biological functions in the bay and can influence the quality of the environment. These communities can filter/trap particulates, serve as refuge, and provide a food source for fish and macroinvertebrates. Benthic communities can serve as important indicators of environmental quality that respond to changes in freshwater inflow or water quality via change in cover, density, or community composition. Certain changes in fixed benthic communities (i.e., density, distribution and composition of mollusks) are readily discernable and may be relatable to specific directions and magnitudes of change. The benthic community is the basis for development of high quality habitat that will support diverse fish and motile invertebrate populations. Degradation or loss of benthic communities will diminish the ability of the bay to maintain the mosaic of conditions that support high habitat diversity and productivity.

A.6.4.6 Pink Shrimp, Blue Crabs, Stone Crabs, Oysters and Lobsters

Pink shrimp and blue crabs are estuarine species that, in their juvenile stages, live in areas influenced by inflows of fresh water. These species would be expected to benefit from an expansion in estuarine habitat in the western bay. Pink shrimp's ecological characteristics and economic value and the background of knowledge about this species in South Florida make it an appropriate biological indicator of change in freshwater inflow quantity, timing and distribution. Furthermore a commercial pink shrimp bait fishery has operated in Biscayne Bay for many years, and a commercial fishery harvesting pink shrimp from the bay for human consumption has started recently. The distribution of juvenile pink shrimp in Biscayne Bay has been measured and modeled (Campos and Berkley 1986, Ault et al. 1999a, 1999b).

A.6.4.7 Estuarine Fish Communities

Several estuarine fish species known to have occurred in Biscayne Bay in the past (Smith 1896, Udey et al. 2002) contributed to the bay's commercial and recreational fisheries but appear to be scarce or absent in the bay today. As a consequence, the fishing opportunity in the bay is diminished, and fishing in the bay has lost some of its attraction. The estuarine fish community could make an important contribution to the fishing experience in the bay if its abundance and diversity were restored. An increase in the area of the bay's estuarine habitat would be expected to lead to greater abundance and diversity of estuarine fishes, including those desired by anglers.

Freshwater fish communities that extend into oligohaline (0-5 ppt salinity) environments can reach high densities under spatially and seasonally favorable conditions and provide abundant prey to pisciverous estuarine fish as well as to wading birds. An increase in the distribution and abundance of fish in the fresh to brackish water wetlands adjacent to Biscayne Bay would be an indication of restored functionality of the coastal wetland-estuarine near-shore habitat that is important to the bay's diversity and productivity.

A number of reef fish species are found in Biscayne Bay. These include snappers (especially gray snapper), grunts, sparids and the great barracuda (Serafy et al. 2003).

A.6.4.8 Fish and Bottlenosed Dolphin Health

The health of fish communities and the health of a resident bottlenosed dolphin group are valuable attributes of the Biscayne Bay ecosystem. Several externally visible abnormalities occur in a number of Biscayne Bay fish (Browder et al. 1993) and are more prevalent in fish sampled from human-impacted sites (Gassman et al. 1994). This is consistent with Fournie et al. (1996) for Gulf of Mexico estuaries and Sanders et al. (1999) for Ohio rivers. The prevalence of abnormal fish is being used as part of a biological integrity index in a growing number of state and national monitoring programs (Simon 1999).

A group of bottlenosed dolphins is found in Biscayne Bay that consists of permanent residents and near-shore migrants. National Oceanic and Atmospheric Administration (NOAA) Fisheries conducts a photo identification program in the Biscayne Bay that can potentially distinguish residents from migrants. Through the Southeast Fisheries Science Center, the NOAA Fisheries Miami Laboratory has been conducting health assessments of other bottlenosed dolphin in the southeast to attain baseline information on marine mammal contaminant levels, associated diseases and incidence, and impacts of human-related pollution on marine mammal populations. The program conducts real-time and retrospective evaluation for the accumulation of toxicants in various tissues of bottlenose dolphins and other marine mammal species in relation to their health, as reflected in histopathology, blood profiles and other medical diagnostics (Hansen and Wells 1996, Sweeney 1992, Worthy 1992, Reif et al. in prep). Biopsies of small amounts of subcutaneous blubber can be taken from living animals for contaminant analysis during low-level monitoring activities. Health assessment profiles of dolphin populations for comparison to regularly monitored and assessed "reference" populations can be developed in this manner. The bottlenose dolphin and other marine mammals are protected species under the Federal Marine Mammals Protection Act of 1972. Opportunistic biopsy sampling of the Biscayne Bay resident dolphin population was begun in February 2000 as a pilot study by the NOAA Fisheries Miami Laboratory.

A.6.4.9 Crocodile

The American crocodile is an endangered species with nesting grounds at the Florida Power and Light Turkey Point Power Plant and Crocodile Lake National Wildlife Refuge, and nursery grounds in the ponds, creeks and canals of Biscayne Bay's western mangrove zone south of the Coral Gables Waterway. Recent studies indicate an increase in the number of nests occurring in cooling canal area of the Turkey

Point Power Plant since the early 1980s, while nest numbers at the Crocodile Lake National Wildlife Refuge have remained relatively stable (Mazzotti et al. 2002). Nesting success in the Turkey Point Power Plant may be responsible for an increase in the number of crocodile sightings occurring north of the plant, and may indicate an expansion of the animal's range. Crocodiles have been sighted as far north as Key Biscayne and the Miami River (M. Cherkiss, University of Florida, personal communication). Although nest numbers have remained relatively stable at the Crocodile Lake National Wildlife Refuge, the population in this area may be increasing, based on an increase in the number of crocodile sightings throughout the Florida Keys and an increase in the number of road kills occurring along U.S. 1 and Card Sound Road over the past several years (S. Klett, Crocodile Lake National Wildlife Refuge, personal communication).

A habitat suitability model for crocodiles has been developed based on salinity levels (Mazzotti and Brandt 1995). This model shows that salinities between 0-20 ppt provide the most suitable habitat, 20-40 ppt provides intermediate suitability, and 40 ppt is least suitable. Applying the model to Biscayne Bay indicates that restoring freshwater flow to more natural conditions would benefit crocodiles, especially along the western shore in the central and southern regions. Restoration efforts would include redirecting flow from conveyance canals through coastal mangrove wetlands, and maintaining flow into the beginning of the dry season.

A.6.4.10 Manatee

Manatees occur throughout Biscayne Bay on a year-round basis, but are most consistently observed in tributaries and near-shore seagrass beds, that are used as foraging areas. The bay provides important feeding areas for manatees in southeast Florida, particularly the northern area of the bay (north of Rickenbacker Causeway). The northern region of the bay is also a major thoroughfare for manatees moving between the winter aggregation sites from Port Everglades to Coral Gables and Little River. Radio telemetry studies documented a high use of the seagrass beds by tagged manatees in the northern bay area during the night (C. Beck, United States Geological Survey, personal communication). Manatees moved out of the canals to feed in the bay at dark, perhaps when boat traffic was reduced. Due to these nocturnal habits, aerial surveys in this region may underestimate the manatee's use of Biscayne Bay. Manatees depend upon canals as a source of fresh water, for cold-weather refuge, and for resting. Changes in timing and volume of freshwater delivery could affect manatee distribution and use of canal habitat and could modify foraging/resting/breeding habitat.

Manatees are an endangered species in serious jeopardy because of abnormally high death rates associated with human activities. Biscayne Bay is a local population center for manatees, and their high mortality in water control structures as well from injuries caused by vessels is a major concern. Manatees utilizing Biscayne Bay fall within the "Atlantic Region" of population studies conducted on the animals. This region includes all manatees occurring in the lower St. Johns River, the east coast, and the Florida Keys, which are almost one half of the entire population. Adult survival rates for manatees in the Atlantic Region are only 90.7 percent, lower than any other region (Langtimm et al. 1998). This value is very close to the 90 percent level that is the cutoff for sustaining population growth. More recent data indicate the population meets reproduction criterion, but it is unclear whether it meets survival and population growth criteria (USFWS 2001). Between 1989-1999 manatee deaths in the Atlantic Region averaged 107 per year (range = 70-135), with human-related causes accounting for 34 percent of the total deaths and 57 percent of the adult mortality. Watercraft-related deaths are increasing moderately.

A.6.4.11 Wading Birds

Wading birds are being used as biological indicators throughout the region because of their close association with hydropattern. The islands, tidal flats and coastal wetlands of Biscayne Bay provide

valuable habitat for wading birds. Frequently used nesting sites occur at Greynold's Park near the northern bay, in the Arsenicker Keys in the southern bay off Turkey Point, and on small islands off Key Biscayne and Virginia Key. Tidal flats and coastal wetlands of the bay provide important feeding habitat for wading birds that nest nearby. For example, roseate spoonbills that nest in the Tern Keys of northeastern Florida Bay feed in mangrove creeks and herbaceous wetlands of southern Biscayne Bay (Card and Barnes Sound areas), as well as those of Florida Bay. Wood storks that nest in the southern Everglades also feed in wetlands of southern Biscayne Bay.

A.6.5 Ecological Effects

Critical Linkages between Stressors and Attributes/Working Hypotheses

The ecological effects of the five principle stressors in the Biscayne Bay Conceptual Ecological Model are based on 16 key hypotheses developed during the conceptual model workshops. These hypotheses determine the content and organization of the Biscayne Bay Conceptual Ecological Model. The 16 hypotheses are presented here, organized by attribute.

A.6.5.1 Freshwater Inflow and Salinity

Relationship between Freshwater Inflows and Salinity Patterns in Biscayne Bay

Altered freshwater inflows have caused changes in the salinity patterns of the bay. Distribution of freshwater inflow in time and space has a major effect on the pattern of salinity distribution and salinity stability. Routing freshwater flow to the bay through canals and away from coastal creeks and wetlands has resulted in a loss of estuarine habitat. The salinity gradient resulting from large point source discharges is very different from that resulting from the more diffuse flow from tidal creeks and ground water seepage along the coast. Flow distributed along the coast results in a positive salinity gradient from interior wetlands into the bay. Canal discharges (i.e., point sources) short-circuit coastal wetlands and do not create positive gradients from interior wetlands outward. Although it is generally recognized that a relationship between freshwater inflow and salinity exists in Biscayne Bay, this relationship has not been well quantified in the critical western near-shore zone and associated wetlands, where the greatest effect of a change in freshwater inflow is experienced.

Level of certainty - low

Relationship between Actual Freshwater Inflow to Biscayne Bay and Water Management

Changes in upstream water management practices change freshwater flows to Biscayne Bay. Both flow rate and the distribution of freshwater inputs to Biscayne Bay have been altered by the construction and operation of the present water management system (Buchanan and Klein 1976). Modeling results with the South Florida Water Management Model (SFWMM) indicate that CERP's proposed changes to water management features and practices in Biscayne Bay's watershed will affect freshwater delivery patterns to the bay. The system of canals and water control structures provides a means to highly manipulate most of the runoff. Relationships between rainfall in the watershed, freshwater delivery patterns, and potential changes to the water management system are, however, unclear. Estimated daily discharge rates through coastal canal structures bear little relationship to daily rainfall. Furthermore, the current method of estimating discharge rates at the structures can introduce significant error (Swain et al. 1997). Fundamental information to relate rainfall to runoff and the influence of water management is needed.

Level of certainty – low

A.6.5.2 Water Quality

Relationship of Water Quality in Biscayne to Water Quality in Discharge from Ground Water, Stormwater and Canals

A primary controlling factor of the water quality in Biscayne Bay is the quality of water discharged into the bay. In general, water clarity in Biscayne Bay is high and inorganic nutrient concentrations are naturally low. Biscayne Bay is therefore vulnerable to nutrient loading, especially from phosphorus. Water nutrient concentrations, turbidity, photosynthetically-active radiation (PAR), bacteria, plankton taxa, size and composition of plankton, as well as phytoplankton biomass, as reflected in chlorophyll and other pigments, are influenced by altered inputs of solids and nutrients received via canal discharge, stormwater runoff and ground water. Episodic and chronic sewage contamination and resultant bacterial and nutrient inputs are problematic in some tributaries. Contamination of ground water by leachate from landfills has been documented to impact water of Biscayne Bay (Alleman 1990, Alleman et al. 1995). Canals in south Miami-Dade County exhibit high levels of inorganic nitrogen. CERP's proposed changes in freshwater delivery, particularly in south Miami-Dade County, may affect nutrient concentrations. In particular, proposals to reroute canals through coastal wetlands may reduce nutrients reaching Biscayne Bay, and wastewater reuse may increase nutrient loading. Water quality targets that would protect open waters of south Biscayne Bay from degradation have been proposed for inorganic nitrogen and phosphorus.

Level of certainty - high

Relationship of water quality in Biscayne Bay to water management

Water quality in Biscayne Bay will change as a result of changes in water management practices.

Level of certainty - low

A.6.5.3 Seagrass and Other Benthic Communities

Relationship of Seagrass Abundance and Distribution to Water Management Practices

Seagrass and benthic communities require a consistent salinity regime and substrate that is not physically disturbed. The abundance, distribution and composition of seagrasses will be determined, in part, by modifications of sources, quantity and distribution of freshwater inputs and associated modified turbidity and available nutrient inputs. Changes in the composition and aerial coverage of seagrasses can affect the habitat quantity and quality of breeding, refuge and feeding areas available for dependant invertebrate and vertebrate species. Modifications of flow from a 'point source' to more 'diffuse' delivery will aid in mitigating or remediating elevated sediment and nutrient levels in the water being delivered to the bay.

Level of certainty – moderate

A.6.5.4 Mangrove Functionality and Herbaceous Wetlands

Relationship of Freshwater Inflow and the Boundary between Mngrove and Herbaceous Wetlands

Diversion or reduction of freshwater inflow has caused a loss of tidal creeks and diminished mangrove function. The alteration of freshwater inflow has caused a shift in the boundary between the mangrove and herbaceous wetland, an inland migration of the boundary of the white zone, and a loss of herbaceous wetland. Recent studies in the wetlands of Barnes and Card Sounds indicate that the boundary of the

white zone has moved inland by an average of 1.5 kilometers since 1940, and the zone is expanding (Ross et al. 2000). The most significant changes to the white zone boundary and width occur in areas cut off from freshwater sources by canals or roads (especially east of U.S. 1). Another study suggests that the low productivity of the white zone may be primarily the result of wide seasonal fluctuations in soil salinity and moisture content and the absence of freshwater input from upstream sources (Ross et al. 2002). Restoration of tidal creeks may be required to restore full mangrove functionality.

Level of certainty - moderate

Relationship of Sea Level Rise and the Boundary between Mangrove and Herbaceous Wetlands

Sea level rise has an influence on the shift in the boundary between the mangrove and herbaceous wetland, the shift in the boundary of the white zone, and the loss of herbaceous wetland.

Level of certainty – low

A.6.5.5 Benthic Communities

Relationship of Inflows and Bottom Habitat

Benthic communities are directly impacted by the volume and intensity of flow and flow variation into the bay. Point source discharges of fresh water into the bay via conveyance canals result in large, but ephemeral, salinity fluctuations that deleteriously affect benthic plants and animals (Montague and Ley 1993, Irlandi et al. 1997). Decline of leafy biomass in near-shore seagrass beds has been observed in near-shore western south Biscayne Bay between Mowry Canal and Military Canal following the early summer increase in freshwater discharges from Mowry Canal (Meeder personal communication). The bay bottom in the vicinity of canals often is devoid of benthic organisms. Sudden and prolonged salinity reduction associated with pulse release of large volumes of fresh water have been documented to destroy established benthic sessile communities in Manatee Bay in the extreme south of Biscayne Bay (DERM unpublished data). Recovery is dependent upon the duration of salinity stability between events.

Level of certainty – high

A.6.5.6 Pink Shrimp

Relationship of Juvenile Pink Shrimp to Shrimp Harvests

High densities of juvenile pink shrimp enable high catch rates in fisheries. A close link between juvenile densities and catch rates in bay shrimp fisheries would be expected because the nursery grounds and the fishing grounds overlap or are in close proximity. Catch per unit of effort in bay shrimp fisheries may reflect abundance of pink shrimp in the bay, but a relationship has not yet been determined. Fishing effort may affect juvenile density on fishing grounds, but trawls cannot operate in waters less than 1-meter deep, where the main nursery grounds in Biscayne Bay appear to be located (Diaz 2001). The relationship of pink shrimp juveniles in Biscayne Bay to offshore spawning or fishing grounds also is unknown. The nearest known spawning and fishing grounds are in the Dry Tortugas, and no connection between these grounds and shrimp recruited from Biscayne Bay nursery grounds has been made.

Level of certainty - low

Relationship of Water Management to Suitable Pink Shrimp Habitat

Changes in water management in relation to the CERP will expand the area of optimal habitat and salinity for juvenile pink shrimp. Salinity, which affects many physiological processes, is a major environmental factor influencing estuarine species. Each species has an associated optimum salinity range. Although a species may be found outside of this range, survival, growth and reproduction may not be great. Optimum salinity must occur in conjunction with suitable habitat in order to provide full advantage to the species.

Level of certainty – low

A.6.5.7 Estuarine Fish Community

Relationship of Habitat Loss and Estuarine Fish Communities

The abundance and biomass of estuarine fishes has been reduced and species diversity has changed due to a loss of estuarine habitat along the western shoreline of Biscayne Bay (Serafy et al. 2001). Much of this habitat loss stems from changes in freshwater inflow that have disturbed the natural correspondence of favorable salinity with favorable bottom and shoreline habitat for estuarine species (Browder and Moore 1981). These species need a persistent positive salinity gradient extending from coastal wetlands, tidal creeks and shallow near-shore waters into the bay. Flow from canals rather than through coastal wetlands prevents development of a positive gradient from interior wetlands into the bay. The unnaturally high salinity fluctuations caused by canal discharges further reduce the suitable habitat for estuarine fish communities (Serafy et al. 1997). Presently, Biscayne Bay alternates between receiving very little fresh water for long periods of time and receiving large freshwater pulses. Neither condition provides habitat for estuarine species. Many species that can withstand gradual changes in salinity are vulnerable to the abrupt lowering of salinity caused by large freshwater pulses. Little detailed information about fish and macroinvertebrates in near-shore Biscayne Bay is available for use in restoring estuarine habitat.

Level of certainty – low

A.6.5.8 Fish and Bottlenosed Dolphin Health

Contaminants are present in Biscayne Bay sediments at various locations, including the Miami River mouth, and may affect faunal health and development in the bay. Fish and bottlenosed dolphin were selected to help monitor potential adverse effects of contaminants because a relatively high prevalence of morphological abnormalities has been found in fish from some locations in Biscayne Bay, and bottlenosed dolphin are a long-lived species in whom contaminants are known to accumulate, based on studies in other estuaries.

Relationship of Fish Abnormalities to Human Influences

The relationship between exposure to anthropogenic inputs and fish morphological abnormalities observed in Biscayne Bay fishes needs evaluation in view of the higher prevalence of fish with abnormalities in areas of the bay directly exposed to human inputs. Recently, the most common abnormalities in Biscayne Bay fish are scale disorientation and deformed or missing dorsal fin spines, which are found in a number of species (Browder et al. 1993). Limited data from selected locations showed a significant correlation between combined abnormalities and aliphatic hydrocarbons in sediments and between abnormalities in blue-striped grunt and sediment copper, but no other significant correlations with sediment contaminants were found (Gassman et al. 1994). Other human-related influences that affect physical and chemical properties of bay water and habitat may affect fish health and development.

Level of certainty - low

Relationship of Bottlenosed Dolphin Toxicant Body Burden to Toxicants in the Sediments.

The body burden of toxicants in the Biscayne Bay resident bottlenosed dolphin population may reflect their toxicant exposure. Body burdens could be correlated with various health assessment indices that relate the status of population health. A program is gradually evolving, through NOAA and collaborators, that characterizes toxicant body burdens and blood profiles of dolphin populations resident to various estuaries of the southeastern United States. Information from Biscayne Bay dolphin populations can be compared to national information for perspective.

Level of certainty - low

A.6.5.9 Manatees

Relationship of Manatee Mortality and Water Control Structures

Water control flood gates are the leading cause of determinable manatee moralities in Biscayne Bay (Mayo and Markley 1995, FWC 1999, USFWS 1999). This area leads the state in flood-gate and other human-related causes of manatee mortality. Manatees are attracted to canals as a source of fresh water and cold-weather refuge. Over the last two decades, water control structure operations have been modified, and some gates have been retrofitted with pressure-sensitive devices that allow the gates to open if they close on an object. Although this has resulted in some improvement, mortalities have continued. Modification of gates or their operation may affect manatee mortality. Additionally, cold winters increase the number of manatees coming to Biscayne Bay, which increases their vulnerability to human related impacts (e.g., control structures and boats) during that time of year.

Level of certainty - high

Relationship of Manatee Distribution to the Timing, Location, and Volume of Freshwater Inflow

Changes in the timing, location and volume of freshwater inflow could affect manatee distribution within the bay and the use of canal habitat.

Level of certainty - moderate

A.6.5.10 Wading Birds

Relationship of Wading Bird Nesting Activity, Nesting Success and Foraging Activity to Water Management Structures and Their Management

Lorenz (2001) showed that nesting success of roseate spoonbills at the Tern Key colony has been detrimentally affected by water management structures and operations in Florida Bay. Feeding opportunities for roseate spoonbills and other wading birds also have been diminished by the reduction in freshwater flow to Biscayne Bay wetlands resulting from road construction and diversion of water into canals. Modification of the structure and operation of the water management system in relation to Biscayne Bay wetlands could affect nesting success at the Tern Key site. Improvements in water management might also affect the activity and nesting success of colonies of wading birds that nest on islands in Biscayne Bay.

Level of certainty - moderate

A.6.6 Research Questions

Relationship of Fish Abnormalities to Human Influences

What is the functional relationship of toxicant concentrations and fish exposure to the types of abnormalities observed?

Relationship of Bottlenosed Dolphin (Tursiops truncatus) Toxicant Body Burden to Toxicants in the Sediments

What is the actual exposure to toxicants of the dolphins in Biscayne Bay?

Relationship of Water Quality in Biscayne Bay to Water Management

What is the quantitative link between water management and flow at the boundary of the bay ecosystem?

Relationship between turbidity and Nutrient Concentrations and the Reestablishment of Seagrasses along the Western Shoreline of Biscayne Bay

Why are the seagrasses absent from this area and are the changes in water management going to change this?

Relationship between Actual Freshwater Inflow to Biscayne Bay and Water Management

Is there a direct relationship between the inflow of fresh water to Biscayne Bay and water management practices in the watershed?

Relationship of Habitat Loss and Estuarine Fish Communities

What is the appropriate salinity gradient to maintain from interior coastal wetlands through the near-shore zone in order to optimize the diversity and abundance of estuarine fish species and salt-tolerant freshwater fish in Biscayne Bay and its coastal wetlands?

Relationship of Water Management to Suitable Pink Shrimp Habitat

How is juvenile pink shrimp abundance affected by changes in the quantity, timing and distribution of freshwater inflow?

Relationship of Juvenile Pink Shrimp to Adult Catch and Relationship of Fishery Catch Per Unit Effort to Freshwater Inflow

Is there a direct quantitative relationship between juvenile pink shrimp abundance and adult catch per unit effort of adult pink shrimp in local bay fisheries? Is the catch per unit of effort in these fisheries affected by freshwater inflow? Does local fishing effort affect shrimp density?

Relationship of Freshwater Flow to Estuarine Habitat

How is estuarine habitat affected by the quantity, timing and distribution of freshwater inflow?

Relationship of the Boundary between Mangrove and Herbaceous Wetlands and Freshwater Inflow Changes and Sea Level Rise

What are the effects of freshwater inflow change and sea level rise on the white zone?

Relationship of Wading Bird Nesting Activity, Nesting Success, and Foraging Activity to Water Management Structures and Their Management

Will wading bird nesting activity, nesting success and foraging activity be improved by the reestablishment of hydropatterns in Biscayne Bay's coastal wetlands?

A.6.7 Hydrologic Performance Measures

A.6.7.1 Temporal and Spatial Salinity Patterns

One performance measure for salinity is the mesohaline and oligohaline patterns. The target is to provide mesohaline salinity patterns in the near-shore environment of the bay and lower salinity in the mouths of tidal creeks.

Surface water discharges to Biscayne Bay is another hydrologic performance measure because the alteration of surface water discharges is the primary mechanism for changing salinity patterns within Biscayne Bay. The target is to increase inflows to southern Biscayne Bay via the tidal creeks and herbaceous marshes of the South Dade Wetlands.

A.6.8 Ecological Performance Measures

A.6.8.1 Water Quality

Water quality performance measures for Biscayne Bay include nutrients, algal bloom frequency and water clarity (PAR). Historical background levels of surface water nutrient (total phosphorus and total nitrogen) concentrations and loads must be maintained or reduced. Frequency of algal bloom occurrences must not increase in the northern bay and should be zero for the open waters of central and southern bay. Existing water clarity must be maintained in clear regions of Biscayne Bay presently supporting healthy seagrass communities and improved in those estuarine regions where reduced water clarity is limiting growth of seagrasses.

A.6.8.2 Sediment Quality

Restoration efforts and changes in water management practices may affect the conveyance of contaminants in sediments; therefore, toxicant concentrations are also a performance measure. The target is not to increase the geographic extent and concentration of sediment toxicity and water column toxicants/pathogens in Biscayne Bay and the coastal wetlands as a result of these alterations.

A.6.8.3 Seagrass Habitat

The performance measure for seagrass is cover and composition. The target is to reestablish seagrass beds, consisting primarily of *Halodule*, in near-shore areas of the bay that are presently devoid of seagrass.

A.6.8.4 Mangrove Functionality

The performance measure for mangrove functionality is the percent of creeks restored and the percent of shoreline with submerged roots and epiphytes. Targets have not been developed.

A.6.8.5 Herbaceous Wetlands

The performance measure for herbaceous wetlands is coverage, boundary shift and white zone shift. Targets have not been developed.

A.6.8.6 Benthic Communities

The performance measure for benthic communities is the percent of shoal, shoreline length populated, density, coverage of brittle forms and diversity by height. Targets have not been developed.

A.6.8.7 Pink Shrimp, Blue Crabs, Stone Crabs, Oysters and Lobsters

The performance measure for pink shrimp, blue crabs, stone crabs, oysters and lobsters is density, abundance and catch rate. The targets are 1) increase the abundance of juvenile shrimp and 2) increase the abundance and diversity of fish and macroinvertebrates associated with seagrass beds.

A.6.8.8 Estuarine Fish Communities

The performance measure for the estuarine fish communities is abundance, density and species composition. The target is to increase the diversity and density of fish assemblages in the mangrove shorelines of the bay.

A.6.8.9 Fish and Bottlenosed Dolphin Health

The performance measure for fish is fish abnormality prevalence. The performance measure for bottlenose dolphin health is dolphin blood profiles and body burden. Targets have not been developed.

A.6.8.10 Crocodiles

The performance measure for the crocodiles is juvenile growth rate, survival and abundance. The target is for the population to show an increase in yearly survival and an increase in growth rates for animals aged zero to three years.

A.6.8.11 Manatees

The performance measure for manatees is mortality rate, distribution and abundance. The target is to maintain or enhance habitat values in canals as reflected by continued use of canals by manatees.

A.6.8.12 Wading Birds

The performance measure for wading birds is the number feeding. Targets have not been developed.

A.6.9 Model

The diagram for the Biscayne Bay Conceptual Ecological Model is presented in Figure A-22. The key to the symbols used in the diagram is presented in Figure A-21.

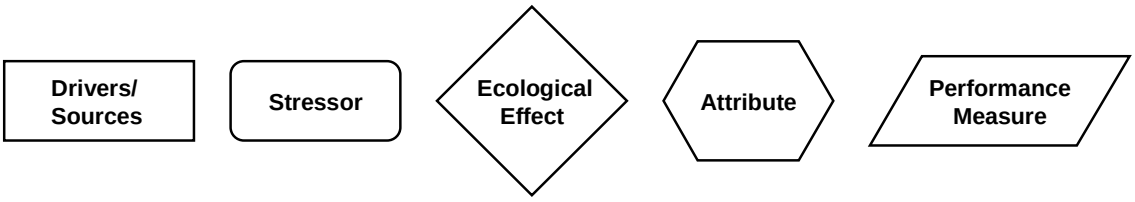


Figure A-21: Key to the Symbols Used in the Following Diagram

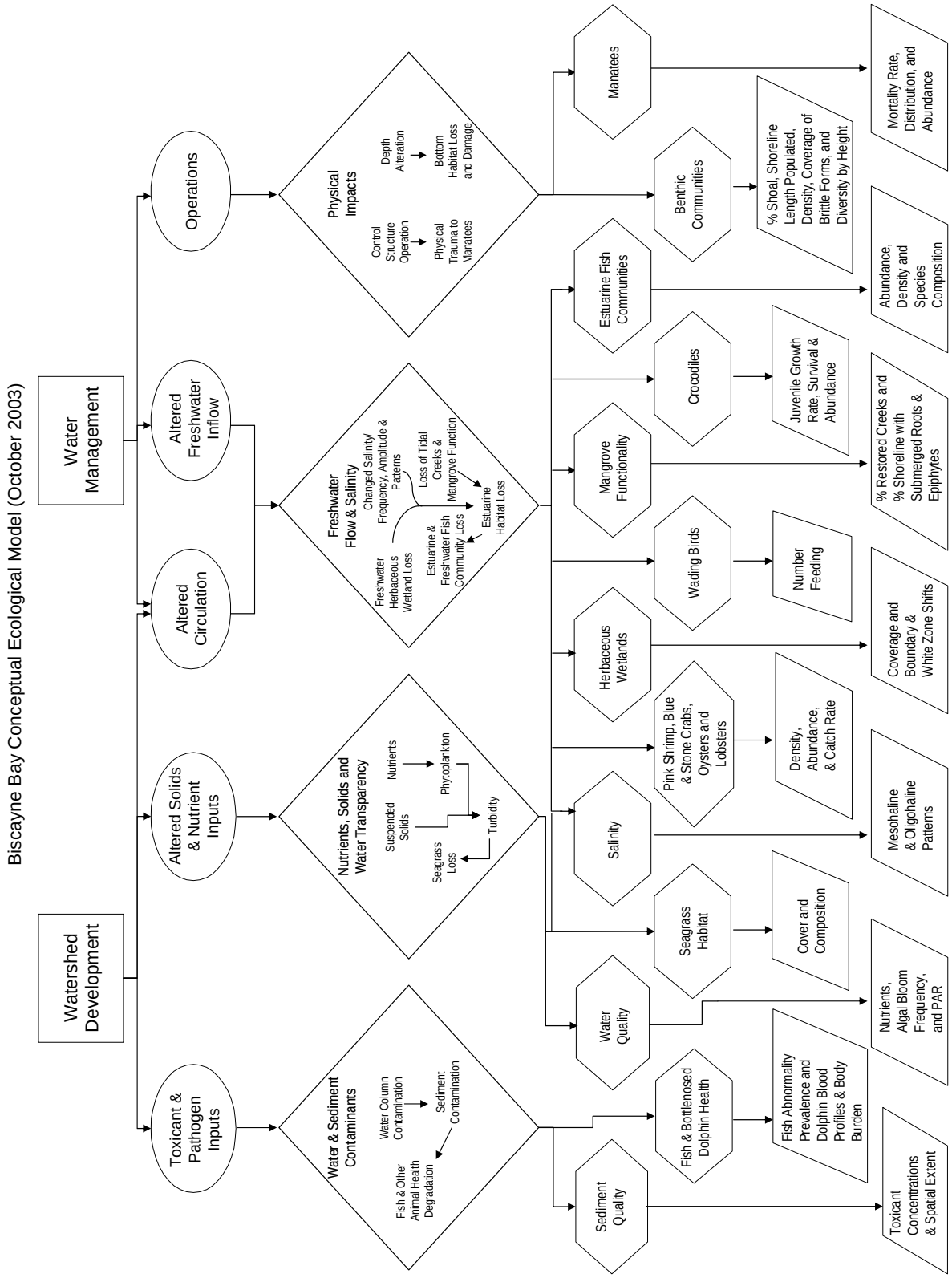


Figure A-22: Biscayne Bay Conceptual Ecological Model Diagram

A.6.10 Literature Cited

Alleman, R.A. 1990. Surface Water Quality in the Vicinity of Black Point, Dade County, Florida. Technical Report 90-14, Miami Dade Department of Environmental Management, Miami, Florida.

Alleman, R.W., S.A. Bellmund, D.W. Black, S.E. Formati, C.A. Gove, and L.K. Gulick. 1995. An Update of the Surface Water Improvement and Management Plan for Biscayne Bay, Technical Supporting Document and Appendices. South Florida Water Management District, West Palm Beach, Florida.

Ault, J.S., G.A. Diaz, S.G. Smith, J. Luo, and J.E. Serafy. 1999a. An efficient sampling survey design to estimate pink shrimp population abundance in Biscayne Bay, Florida. North American Journal of Fisheries Management 19:696-712.

Ault, J.S., J. Luo, S.G. Smith, J.E. Serafy, G. Diaz, and R. Humston. 1999b. A spatial multistock production model. Canadian Journal of Fisheries and Aquatic Sciences 56(S1):4-25.

Ault, J., J. Serafy, D. DiResta, and J. Dandelski. 1997. Impacts of Commercial Fishing on Key Habitats within Biscayne National Park. Annual report on Cooperative Agreement No. CA-5250-6-9016 to Biscayne National Park from Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, Florida.

Brook, I.M. 1982. The effect of freshwater canal discharge on the stability of two seagrass benthic communities in Biscayne National Park, Florida. Oceanol. Acta 5-4: 63-72.

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

Browder, J.A., D.B. McClellan, D.E. Harper, M.G. Kandrashoff, and W. Kandrashoff. 1993. A major developmental defect observed in several Biscayne Bay, Florida, fish species. Environ. Biol. Fish. 37:181-188.

Buchanan, T.J., and H. Klein. 1976. Effects of water management of freshwater discharges to Biscayne Bay. In: Biscayne Bay: Past/Present/Future. Thorhaug, A., and A. Volker (eds). Sea Grant Special Publication No. 5, University of Miami, Coral Gables, Florida, pp. 113-132.

Campos, W.L., and S.A. Berkeley. 1986. Impact of the Commercial Fishery on the Population of Bait Shrimp (*Penaeus* spp.) in Biscayne Bay. Final Report to the Dade County Department of Environmental Resources Management.

Chinn Fatt J., and J.D. Wang. 1987. Canal discharge impacts on Biscayne Bay salinities. Research/Resources Management Report SER-89, Southeast Region, National Park Service, Atlanta, Georgia.

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

Corcoran, E.F., M.S. Brown, F.R. Baddour, S.A. Chasens, and A.D. Frey. 1983. Biscayne Bay Hydrocarbon Study. Final Report to Florida Department of Natural Resources, St. Petersburg, Florida, from University of Miami, Florida.

Davis. J.H. 1943. The Natural Features of Southern Florida, Especially the Vegetation and the Everglades. Bulletin No. 25, Florida Geological Survey, Tallahassee, Florida.

DERM. 1985. Biscayne Bay Today, a Summary Report on Its Physical and Biological Characteristics. Miami-Dade County Department of Environmental Resources Management, Miami, Florida.

DERM. 1993. Miami River Water Quality Plan. A Report to the Miami River Water Quality Commission. DERM Technical Report 93-3, Miami-Dade County Department of Environmental Resources Management, Miami, Florida.

Diaz, G.A. 2001. Population Dynamics and Assessment of Pink Shrimp (*Farfantepenaeus duorarum*) in Subtropical Nursery Grounds. Ph.D. Dissertation, University of Miami, Coral Gables, Florida.

Dole, R.B. 1914. Some chemical characteristics of seawater at Tortugas and around Biscayne Bay, Florida. Papers from Tortugas Laboratory, Carnegie Institute, Washington, D.C. 5(182):69-78.

FWC. 1999. Save the Manatee Trust Fund Fiscal Year 1998-1999 Annual Report. Florida Fish and Wildlife Conservation Commission, Tallahassee, Florida.

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

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

Hansen, L.J., and R.S. Wells. 1996. Bottlenose Dolphin Death Assessment: Field Report on Sampling near Beaufort, North Carolina, during 1995. Technical Memorandum NMFS-SEFSC-382, Center for Coastal Fisheries and Habitat Research, National Oceanic and Atmospheric Administration, Beaufort, North Carolina.

Harlem, P.W. 1979. Aerial Photographic Interpretation of the Historical Changes in Northern Biscayne Bay, Florida, 1925-1976. Sea Grant Technical Bulletin No. 40, University of Miami, Coral Gables, Florida.

Irlandi, E., S. Macia, and J.E. Serafy. 1997. Salinity reduction from freshwater canal discharge: effects on mortality and feeding of an urchin (*Lytechinus variegates*) and gastropod (*Astracea tecta*). Bulletin of Marine Sciences 61:869-879.

Ishman, S.E., T.M. Cronin, G.L. Brewster-Wingard, D.A. Willard, and D.J. Verardo. 1998. Record of ecosystem change, Manatee Bay, Barnes Sound, Florida. Journal of Coastal Research Special Issue 26:125-138.

Kinne, O. 1971. Invertebrates. In Barnes, H. (ed). Marine Ecology, Volume 1, Part 2. Wiley Interscience, New York, pp 821-995.

Kohout, F.A. and M.C. Kolipinski. 1967. Biological zonation related to groundwater discharge along the shore of Biscayne Bay, Miami, Florida: pp. 488-499 in: Estuaries: American Association for the advancement of Science Publication No. 83.

Langtimm, C.A., T.J. O'Shea, R. Pradel, and C.A. Beck. 1998. Estimates of annual survival probabilities for adult Florida manatees (*Trichemus manatus latirostris*). Ecology 79(3):981-997.

Lee, T.N. 1975. Circulation and exchange processes in southeast Florida's coastal lagoons. Technical Report TR75-3, Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, Florida.

Lietz, A.C. 1999. Methodology for Estimating Nutrient Loads Discharged from the East Coast Canals to Biscayne Bay, Miami-Dade County, Florida. Water Resources Investigations Report 99-4094, United States Geological Survey, Tallahassee, Florida.

Long, E.R., G.M. Sloane, G.I. Scott, B. Thompson, R.S. Carr, J. Biedenbach, T.L. Wade, B.J. Presley, K.J. Scott, C. Mueller, G. Breken-Fols, B. Albrecht, J.W. Anderson, and G.T. Chandler. 2000. Magnitude and Extent of Chemical Contamination and Toxicity in Sediments of Biscayne Bay and Vicinity. Technical Memorandum NOS NCCOS CCMA 141, Center for Coastal Monitoring and Assessment, National Centers for Coastal Ocean Science, National Ocean Service, National Oceanic and Atmospheric Administration, Silver Spring, Maryland.

Long, E.R., M.J. Hameedi, G.M. Sloane, and L.B. Read. 2002. Chemical contamination, toxicity, and benthic community indices in sediments of the lower Miami River and adjoining portions of Biscayne Bay, Florida. Estuaries 25(4A):622-637.

Lorenz, J.J. 2001. The effects of water management on roseate spoonbills and their piscine prey I. Responses to a multiyear high rainfall period: Implications for the restoration of Taylor Slough. In: Programs and Abstracts of the 2001 Florida Bay Science Conference, 23-26 April, 2001, Key Largo, Florida. Florida Bay and Adjacent Waters Research Program, c/o Everglades National Park, Homestead, Florida, p.188

Lorenz, J.J. 2001. The effects of water management on roseate spoonbills and their piscine prey II: Water depth and hydroperiod effects on prey availability and spoonbill nesting success. In: Programs and Abstracts of the 2001 Florida Bay Science Conference, 23-26 April, 2001, Key Largo, Florida. Florida Bay and Adjacent Waters Research Program, c/o Everglades National Park, Homestead, Florida, p.190.

Markley, S.M., D.K. Valdes, and R. Menge. 1990. Sanitary Sewer Contamination of the Miami River. DERM Technical Report 90-9, Miami-Dade County Department of Environmental Resource Management, Miami, Florida.

Mayo, K.E., and S.M. Markley. 1995. Dade County Manatee Protection Plan. DERM Technical Report 95-5, Miami-Dade County Department of Environmental Resource Management, Miami, Florida.

Mazzotti, F.J., and L.A. Brandt. 1995. A Biological Assessment of the Effects of the C-111 Project on the American Crocodile in Northeastern Florida Bay, Everglades National Park. Final Report. Department of Wildlife Ecology and Conservation, University of Florida, Gainesville, Florida.

Mazzotti, F.J., M.S. Cherkiss, G.S. Cook, and E. McKercher. 2002. Status and Conservation of the American Crocodile in Florida: Recovering an Endangered Species While Restoring an

Endangered Ecosystem. Draft Final Report to the National Park Service, Everglades National Park, Homestead, Florida.

McNulty, J.K. 1970. Effects of Abatement of Domestic Sewage Pollution on the Benthos, Volumes of Zooplankton, and the Fouling Organisms of Biscayne Bay. University of Miami Press, Coral Gables, Florida.

Meeder, J.F., J. Alvalord, M. Byrn, M.S. Ross, and A. Renshaw. 1997. Distribution of Benthic Nearshore Communities and Their Relationship to Ground Water Nutrient Loading. Final Report to Biscayne National Park from the Southeast Environmental Research Program, Florida International University, Miami, Florida.

Meeder, J., and J.N. Boyer. 2001. Total Ammonia Concentration in Soil, Sediments, Surface Water, and Ground Water along the Western Shoreline of Biscayne Bay with the Focus on Black Point and a Reference Mangrove Site. Final Report to the National Park Service in response to Project Statement BISC-N-011.000 under National Park Service/Florida International University Cooperative Agreement No. CA5280-8-9038. Southeast Environmental Research Center, Florida International University, Miami, Florida.

Meeder, J.F., P.W. Harlem, M.S. Ross, E. Gaiser, and R. Jaffe. 2000. Southern Biscayne Bay Watershed Historic Creek Characterization (Tasks 1, 2, and 3). Annual report to the South Florida Water Management District. Southeast Environmental Research Center, Florida International University, Miami, Florida.

Montague, C.L., and J.A. Ley. 1993. A possible effect of salinity fluctuations on abundance of benthic vegetation and associated fauna in northeastern Florida Bay. Estuaries 16:707-717.

Parker, G.G., G.E. Ferguson, and S.K. Love. 1955. Water Resources of Southern Florida with Special Reference to the Geology and Groundwater of the Miami Area. Water Supply Paper 1255. United States Geological Survey, United States Government Printing Office, Washington, D.C.

Reark, J.B. 1974. A history of the colonization of mangroves on a tract of land on Biscayne Bay, Florida. In: Walsh, G., S. Snedaker, and H. Teas (eds). Proceedings of the International Symposium on Biology and Management of Mangroves, October 8-11, 1974, Volume II, University of Florida, Gainesville, Florida, pp. 776-804.

Reif, J.S., L.J. Hansen, S. Galloway, G. Mitchum, and T.J. Schmitt. 1995. The Relationship between Chlorinated Hydrocarbon Contaminants and Selected Health Parameters in Bottlenose Dolphins (*Tursiops truncatus*) from Matagorda Bay, Texas, 1992. Draft contract report to Southest Fisheries Science Center, National Marine Service Fisheries, Miami, Florida, dated January 21, 1995.

Ross, M.S., J.F. Meeder, J.P. Sah, P.L. Ruiz, and G.J. Telesnicki. 2000. The southeast saline everglades revisited: a half-century of coastal vegetation change. J. Vegetation Sci. 11:101-112.

Ross, M.S., E.E. Gaiser, J.F. Meeder, and M.T. Lewin. 2002. Multi-taxon analysis of the “white zone.” A common ecotonal feature of the South Florida coastal wetlands. In: Porter, J.W., and K.G. Porter (eds). The Everglades, Florida Bay, and Coral Reefs of the Florida Keys: An Ecosystem Sourcebook. CRC Press, Boca Raton, Florida, pp. 205-238.

Sanders, T.P., R.J. Miltner, C.O. Yoder, and E.T. Rankin. 1999. The use of external deformities, erosion, lesions, and tumors (DELT anomalies) in fish assemblages for characterizing aquatic resources: a case study of seven Ohio streams. In: Simon, T.P. Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities. CRC Press, New York, pp. 225-246.

Schmale, M.C. 1991. Effects of Historical Contaminants on Biota in Biscayne Bay, Florida 1991-93. Report prepared by Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, Florida, for South Florida Water Management District, West Palm Beach, Florida.

Seal, T.L., F.D. Calder, G.M. Sloane, S.J. Schropp, and H.L. Windom. 1994. Florida Coastal Sediment Contaminants Atlas. Florida Department of Environmental Protection, Tallahassee, Florida.

Serafy, J.E., C.H. Faunce, and J.J. Lorenz. 2003. Mangrove shoreline fishes of Biscayne Bay, Florida. Bulletin of Marine Science 72(1):161–180.

Serafy, J.E., K.C. Lindeman, T.E. Hopkins, and J.S. Ault. 1997. Effects of freshwater canal discharge on fish assemblages in a subtropical bay: field and laboratory observations. Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, Florida, Marine Ecology Progress Series 160:161-172.

Serafy, J.E., J.S. Ault, P. Ortner, and R. Curry. 2001. Coupling Biscayne Bay's natural resources and fisheries to environmental quality and freshwater inflow management., In: Biscayne Bay Partnership Initiative. Science Team Final Reports. Miami, Florida, pp. 163-174.

Simon, T.P. 1999. Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities. CRC Press, Washington, D.C.

Skinner, R.H., and W. Kandrashoff. 1988. Abnormalities and diseases observed in commercial fish catches from Biscayne Bay, Florida. In: Browder, J. (ed). Aquatic Organisms as Indicators of Environmental Pollution. AWRA Monograph Series #12, Water Resources Bulletin 24: 961-966.

Smith, H.M. 1896. Notes on Biscayne Bay, Florida, with references to its adaptability as the site of a marine hatching and experimental station. In: Report to the U.S. Commissioner of Fish and Fisheries for 1896, Government Printing Office, Washington, D.C., pp. 169-186.

Swain, E.D., A. Kapadia, S. Kone, E. Demisse, D. Mtundu, and G.M. Tillis. 1997. Determining discharge-coefficient ratings for coastal structures in Dade County, Florida. Water Resources Investigations Report 97-4079, United States Geological Survey, Tallahassee, Florida.

Sweeney, J. 1992. Report Summary of the Bottlenosed Dolphin Health Assessment Project, Matagorda Bay, Texas. Report to the National Marine Fisheries Service.

Thorhaug, A., M.A. Roessler, and D.C. Tabb. 1976. Man's impact on the biology of Biscayne Bay. In: Thorhaug, A. (ed). Biscayne Bay: Past, Present, and Future. Sea Grant Special Report No. 5, University of Miami, Coral Gables, Florida, pp. 301-312.

Udey, L., A. Cantillo, W. Kandrashoff, and J. Browder. 2002. Results of a fish health survey of north Biscayne Bay: June 1976-June 1977. Technical Memorandum NOS N CCOS CCMA, National Oceanic and Atmospheric Administration, Silver Spring, Maryland, and Technical Report 2002-02, Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, Florida.

USEPA. 1994. Technical Summary Document for the Advance Identification of Possible Future Disposal Sites and Areas Generally Unsuitable for Disposal of Dredged or Fill Material in Wetlands Adjacent to Southwest Biscayne Bay, Dade County, Florida. EPA 904/R-94/007, Region IV, United States Environmental Protection Agency, Atlanta, Georgia, and Technical Document 94-2, Miami-Dade Department of Environmental Resources Management, Miami, Florida.

USEPA. 1999. Region 4 Military Canal Special Study Homestead Air Force Base, Florida. SESD Project No. 98-0062, Final Report, United States Environmental Protection Agency, Atlanta Georgia.

USFWS. 1998. Draft Coordination Act Report on the Central and Southern Florida Project Comprehensive Review Study, United States Fish and Wildlife Service, Vero Beach, Florida.

USFWS. 2001. Florida Manatee Recovery Plan (*Trichechus manatus latirostris*), Third Revision. United States Fish and Wildlife Service, Atlanta, Georgia.

Wang, J.D., E. Daddio, and M.D. Horwitz. 1978. Canal Discharges into South Biscayne Bay. Report to the Miami-Dade County Department of Environmental Resources Management, Miami, Florida, by Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, Florida.

Worthy, G.A.J. 1992. Body Condition of Free-Ranging Bottlenose Dolphins, (*Tursiops truncatus*) in the Vicinity of Port O'Connor, Texas-July 1992. Contract report to National Marine Fisheries Service, Southeast Fisheries Science Center, Miami Laboratory, Miami, Florida

A.7 CALOOSAHATCHEE ESTUARY CONCEPTUAL ECOLOGICAL MODEL

A.7.1 Model Lead

Tomma Barnes, South Florida Water Management District

A.7.2 Introduction

The Caloosahatchee Estuary is located on the lower west coast of Florida. The Caloosahatchee River was originally a shallow, meandering river with headwaters in the proximity of Lake Hicpochee and tidal influence almost to La Belle. To accommodate navigation, flood control and land reclamation needs, the freshwater portion of the river was reconfigured into a canal known as C-43. Many canals were constructed along the banks of the river in support of the many agricultural communities associated with the river. In addition, three lock-and-dam structures (S-77, S-78, and S-79) were added to control flow and stage height.

Today, the Caloosahatchee River extends 105 kilometers from Lake Okeechobee to San Carlos Bay. The freshwater portion ranges from 50 to 130 meters in width and 6 to 9 meters in depth. Many of the original bends remain as oxbows along both sides of the canal. The width of the estuarine portion is irregular, from 160 meters in the upper portion to 2,500 meters downstream at San Carlos Bay (Scarlatos 1988). The narrow section extends from Franklin Lock and Dam (S-79) to Beautiful Island. This area has an average depth of 6 meters, and the area downstream of Beautiful Island has an average depth of 1.5 meters (Scarlatos 1988). The pattern and period of flow of the Caloosahatchee River is highly variable based on demand (Drew and Schomer 1984).

The tidal Caloosahatchee basin includes portions of Lee and Charlotte Counties. The estuary between Franklin Lock and Shell Point is 42 kilometers long and is bordered by Fort Myers on the southern shore and Cape Coral on the northern shore. Water discharges from the Caloosahatchee pass Shell Point and enter the Gulf of Mexico at San Carlos Bay. Because of the long and narrow configuration of the estuary, changes in wind, tide, runoff or precipitation can have effects on estuarine features such as flow, water depth, salinity and turbidity. Therefore, due to the dynamic nature of the estuary, characterization of the system is difficult.

Major changes in the hydrology of the Caloosahatchee watershed are the result of significant modifications in land and canal development, as well as water management policy. Adverse ecological impacts in the estuary have occurred as a result of hydrological changes in the timing, distribution, quality and volume of fresh water released into the estuary from the watershed and Lake Okeechobee (SFWMD 1999). Despite these impacts, the Caloosahatchee Estuary continues to be an important environmental and economic resource. Understanding how this system responds to stressors will provide a basis for well-informed management decisions.

The model boundary for the Caloosahatchee Estuary Conceptual Ecological Model extends east to the S-79 structure (Figure A-23). This is the final downstream structure and marks the beginning of the Caloosahatchee Estuary. Also known as the W.P. Franklin Lock and Dam, this structure maintains specified water levels upstream, regulates freshwater discharge into the estuary, and acts as an impediment to saltwater intrusion to the river. From there, the model extends southwest through Estero Bay and into the Gulf of Mexico through Big Carlos Pass and includes a freshwater plume that extends approximately 3 miles offshore. The area of Bokeelia, at the northern end of Pine Island serves as the northern boundary. The model's western boundary extends 3 miles offshore of Sanibel and Captiva Islands, making a turn through Captiva Pass.

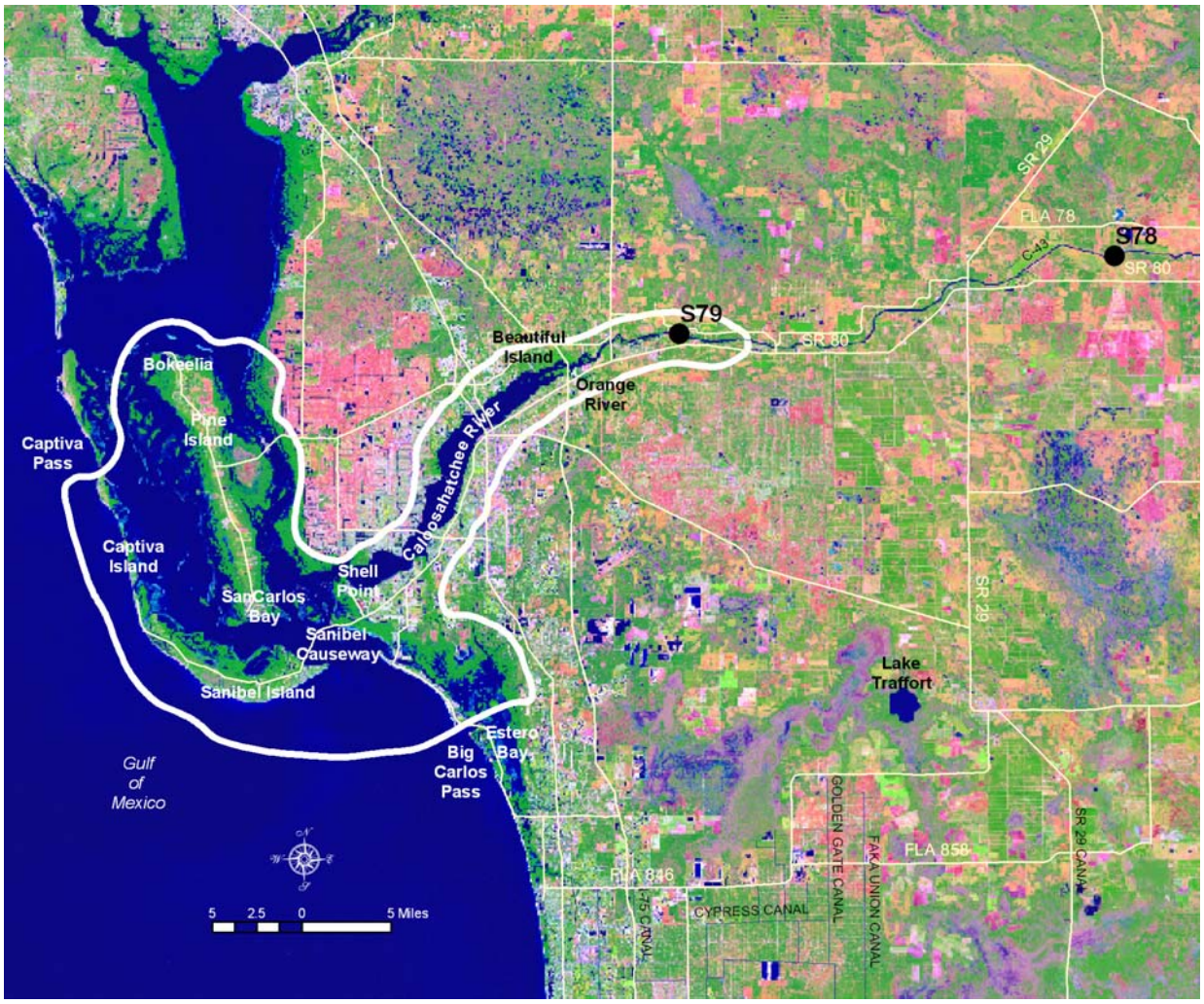


Figure A-23: Boundary of the Caloosahatchee Estuary Conceptual Ecological Model

A.7.3 External Drivers and Ecological Stressors

A.7.3.1 Sources

Sea Level Rise

Sea level rise is an important nonsocietal driver (Figure A-25, Section A.7.9) (Wanless et al. 1994) that is causing the inland movement of marine conditions into the Everglades mangrove estuaries (Meeder et al. 1996, Tampa Bay Regional Planning Council 1993). Sea level has been rising along Florida's west coast and is projected to rise at an accelerated rate because of global warming (Tampa Bay Regional Planning Council 1993). The inland movement of marine conditions due to sea level rise is happening independent from other societal-driven stressors.

Societal-Driven

Societal-driven sources of ecological stressors in the Caloosahatchee Estuary include **water management**, **land use and development**, and **navigation** (Figure A-25, Section A.7.9). Water

management practices have resulted in drastic modifications to the system in order to convey more watershed runoff and include regulatory releases from Lake Okeechobee. These changes have caused large fluctuations in the volume, timing and frequency of freshwater inflow to the estuary and have had an overwhelming impact on the ecology of the estuarine system through the alteration of salinity zonation. Changes in land use associated with an increase in development and agriculture have led to loss and fragmentation of coastal and shoreline habitat, and changes in water use and an increase in water demands. Decreased water quality, resulting from an increased input of nutrients and dissolved organics into the system, has also been an effect of this urban and agriculture pressure. The need for navigation from the east coast through Lake Okeechobee to the west coast has resulted in the dredging and the channelization of the original Caloosahatchee River to the current C-43 canal.

A.7.3.2 Stressors

Altered Hydrology

Altered hydrology is one of the predominate stressors of the system and takes the form of excessive water withdrawals (demand) and over drainage. This causes changes in the timing and quality of the watershed runoff to the estuary, which now includes regulatory releases from Lake Okeechobee. These alterations result from providing flood protection and water supply to a growing agriculture and urban population. The altered hydrology is facilitated by the physical changes made in the watershed, which include the development of a complex network of secondary canals, enlargement of C-43 to convey more water, and the addition of three water control structures on C-43, which connect the canal to Lake Okeechobee. Accompanying these hydrologic changes is a decrease in water quality, marked by increases in turbidity and nutrient loading, changes in water residence time in the estuary, and alteration in the natural salinity regime.

Altered Estuarine Salinity

Altered estuarine salinity has resulted from man-made hydrological modifications that have dramatically altered the natural quantity, quality, timing and distribution of flows to the estuary, often without proper regard to the biological integrity of the estuary (Haunert et al. 2000). During the wet season, rainfall runoff that was historically retained within the undeveloped watershed now reaches the river in greater volume and less time (USACE 1957). Additionally, the construction of S-79 has confined the estuary by restricting freshwater/low salinity waters from the upper reaches of the estuary during the dry season. Alterations in the delivery of freshwater at S-79 cause salinity to vary widely in time and space (USACE 1957). Rapid and unnatural fluctuations in salinity have contributed to major impacts on submerged plant abundance and distribution, including a loss of the natural gradient of grass species between downtown Fort Myers and the mouth of the river.

The estuarine environment is sensitive to freshwater releases and disruption of the volume, distribution, circulation and temporal patterns of freshwater discharges could place severe stress on the entire ecosystem. Myers and Ewel (1990) found “such salinity patterns affect productivity, population distribution, community composition, predator-prey interactions and food web structure in the inshore marine habitat. In many ways, salinity is a master ecological variable that controls important aspects of community structure and food web organization in coastal systems.”

Physical Alterations to the Estuary

Physical alterations to the estuary have also impacted the presence and abundance of species historically found within the system. These alterations include conversion of wetlands, dredging of channels and spoil disposal, changes in shoreline, snagging of navigation hazards, and decrease in spatial extent of the

estuary through construction of barriers (such as S-79) (Harris et al. 1983). The addition of the Intracoastal Waterway and the Sanibel Causeway altered water flow and habitat (Harris, et al. 1983). Changes in the physical dimension of the estuary, which resulted from the addition of S-79, reduced (or eliminated) the upstream oligohaline portion of the estuary, especially during the dry season (Chamberlain and Doering 1998a). This salinity zone is an important nursery area, feeding area and refugia for juvenile stages of desirable sport and commercial fishes. Construction and operation of the water control structures may interfere with migrations patterns of many estuarine species, by acting as a barrier between the freshwater and saline water habitats and have historically resulted in deaths of manatees attempting to pass through these structures.

Input and Elevated Levels of Nutrients, Toxins and Dissolved Organics

Nutrients and dissolved organics enter the system as a result of anthropogenic activities in the watershed. The greatest loadings come from agricultural runoff facilitated by water management practices, urban runoff, and point source discharges to the estuary from sewage treatment plants (Post, Buckley, Schuh, and Jernigan and W. Dexter Bender and Associates, Inc 1999, Drew and Schomer 1984). In addition, atmospheric deposition contributes to nitrogen loading (Squires et al. 1998). These constituents lead to increased phytoplankton production and interact with altered salinity patterns, increased water color, and sediment loading to reduce light penetration. This can lead to declines in submerged plant abundance. Increases in areas of low dissolved oxygen and shifts in species composition of benthic invertebrates to more pollution tolerant organisms are linked to increased nutrient levels (Barbour et al. 1996).

Toxins which include pesticides, fungicides, herbicides, coliforms from sewage treatment plants, oils, greases, mercury, and other heavy metals such as copper and zinc can be introduced into the system from urban development, agricultural practices and boating. Direct toxic effects have been documented in other South Florida systems on zooplankton and fish. Indirect effects can occur through the process of bioaccumulation or biomagnification through the food web, increasing the toxic load to top predators (Day et al. 1989). Studies in the Caloosahatchee River and Estuary have been unable to detect serious contamination of sediments with toxins (La Rose and McPherson 1983, Fernandez. et al. 1999). It is recommended that monitoring be continued.

Boating and Fishing Pressure

Boating pressure is a stressor to the estuary through direct impacts such as seagrass scarring, sediment resuspension, wake erosion, and construction of boating channels. In addition, boat collisions are the leading cause of human-related manatee mortality (W. Dexter Bender and Associates 1995). Fishing pressure from sport and commercial fisheries has impacted standing stocks of many species (Post, Buckley, Schuh, and Jernigan and W. Dexter Bender and Associates, Inc. 1999) and in turn impacted those species that depend on fish as their primary food source. Recent resource trends for local fisheries show some increase as a result of changes in the management process (Muller et al. 1996, McMichael 1997).

A.7.4 Ecological Attributes

Six attributes have been identified in the Caloosahatchee Estuary as the biological or ecological indicators of environmental stress. These attributes are discussed below.

A.7.4.1 Submerged Aquatic Vegetation Distribution, Community Structure and Function

Submerged aquatic vegetation (SAV), for the purpose of this conceptual ecological model, includes only the vascular underwater plants that live throughout the estuary and in near-coast waters. SAV play several

roles in maintaining an estuary's health. They provide habitat and nursery grounds for many fish and invertebrate communities and are especially important in benthic based primary productivity. SAV and the organisms that live on them are important food sources in the estuarine system. Manatees, waterfowl and wading birds rely heavily on seagrass systems as forage areas. SAV help maintain water clarity by trapping fine sediments and they improve water quality by taking up large quantities of nutrients that would otherwise accelerate the eutrophication of the estuarine system.

Tape grass (*Vallisneria americana)* is the dominant SAV in the upper Caloosahatchee Estuary and occurs in well-defined beds in shallow water. *Vallisneria americana* is thought to be an important habitat for a variety of freshwater and estuarine invertebrate and vertebrate species, including some commercially and recreationally important fishes (Bortone and Turpin 1999). Additionally, it can serve as a food source for the Florida manatee (*Trichechus manatus*). Shoal grass (*Halodule wrightii)*, turtle grass *(Thalassia testudinum)*, and manatee grass *(Syringodium filiforme)* are the most common higher salinity grasses in the Caloosahatchee Estuary. *Argopectin* sp., the bay scallop, prefers shoal and turtle grass beds. Increasing scallop populations to resemble historic distributions is currently a goal of the Charlotte Harbor Estuarine Program (CHNEP 1999).

All species of SAV have a preferred and tolerable salinity range. They respond unfavorably when salinity alterations exceed these ranges. Degraded water quality and physical alterations, such as the Sanibel Causeway and the Intracoastal Waterway have also shown negative impacts to the seagrasses. The result has been a regional decrease of seagrass coverage (Chamberlain and Doering 1998a). This decline negatively impacts the fish and invertebrate communities. It also causes destabilization of sediments and a shift in primary productivity from benthic macrophytes to phytoplankton, both of which provide negative biofeedback to further affect seagrass beds.

A.7.4.2 Oyster Bar Abundance, Community Structure, and Function

Oysters are sensitive to salinity and siltation. They require salinity levels above 4-5 parts per thousand (ppt) (Loosanoff 1932) with an optimal salinity range between 14 and 28 ppt (Chanley 1958, Galtsoff 1964) varying with geographical region. Higher salinity levels increase negative effects from saltwater predators such as oyster drills (Hofstetter 1977, White and Wilson 1996) and the protozoan parasite *Perkinsus marinus* (Dermo) (Volety 1995), the primary oyster pathogen in the Gulf of Mexico (Soniat 1996). Dermo is estimated to have killed 80 percent of the oysters in a bed under optimal salinity and temperature within Chesapeake Bay (Andrews 1988). Presently, increased oligohaline conditions have limited distribution of oysters in the Caloosahatchee Estuary.

Oyster bars provide several important functions, including habitat and food for other species. Wells (1961) lists 303 species that depend on oyster bars either directly or indirectly. Individual oysters filter 4 to 34 liters of water per hour, removing phytoplankton, particulate organic carbon, sediments, pollutants and microorganisms from the water column (A. Volety, Florida Gulf Coast University, personal communication). This process results in greater light penetration, promoting the growth of SAV immediately downstream of the oyster bars.

The epidemiology of Dermo disease coupled with physiological responses of oysters in relations to environmental and anthropogenic stress will yield critical information on conditions necessary for healthy oyster reefs. Salinity and water quality conditions that yield enhanced distribution of healthy oyster reefs can be used as hydrological targets for restoring and maintaining suitable salinity and water quality in the Caloosahatchee Estuary.

A.7.4.3 Sand/Muck Benthic Community Structure and Function

Open bottoms in the Caloosahatchee Estuary are composed of mixtures of sand, mud, shell and bedrock. Macroinvertebrates, including mollusks, inhabit the sand/muck open bottom of the estuary, and are dominant elements of both the estuarine and tidal river Caloosahatchee ecosystems.

The number, diversity, dispersion and condition of macroinvertebrates have been studied for decades, forming a large and robust body of information on adaptations of numerous phyla to the physical and chemical conditions unique to estuaries. Numerous studies have demonstrated that spatial and temporal trends in macroinvertebrate attributes vary in consistent form with variations in river flow, current speed, salinity, dissolved oxygen and foodstuffs such as particulate organic carbon, phytoplankton, macrophytes and prey. In recent years, a variety of studies have been published that indicate the extent to which macroinvertebrate attributes can be related specifically to independent variables such as freshwater inflow and salinity alterations.

Rangia cuneata, a member of the clam family Mactridae, and *Polymesoda carolineata*, in the family Corbiculidae, are commonly found associated with mud and sandy bottoms in the Caloosahatchee Estuary. Both of these mollusks require lower salinities and can be used as indicators of estuarine condition. Furthermore, because mollusks leave behind their shells upon death, it is possible to look at the death assemblage to construct historical salinity regimes. Shell characteristics such as size, shape and ornamentation vary according to salinity and can be used to construct historical salinity regimes. The death assemblage, which is sampled along with live community, can be utilized as an indicator of conditions prior to recent alterations to the system and provide a useful target when compared with current conditions.

A.7.4.4 Estuarine Fish Community Structure and Function

At least 70 percent of Florida's recreationally sought fishes depend on estuaries for at least part of their life histories (Harris et al. 1983, Estevez 1998, Lindall 1973). Within the estuary, seagrass communities provide critical refugia for juvenile fish such as redfish, grouper, snook and spotted seatrout. The decline in juvenile abundance and distribution of these and other species, along with the overall decline in species richness may be related to a decline in this seagrass habitat and/or a result of alterations in the salinity regime and the timing of the freshwater discharges.

Commercial and recreational fishing pressure has also increased along the west coast of Florida. With this increase, there has been a decline in reported landings (Post, Buckley, Schuh, and Jernigan and W. Dexter Bender and Associates, Inc 1999). In Lee County, clear evidence for this decrease can be seen with the spotted seatrout where there has been a decline on catch per unit effort from 1986 to 1995 (Bortone and Wilzbach 1997).

The blue crab fishery is the largest, year-round fishery in the upper and middle portion of the Caloosahatchee River. This commercial fishery is intensely fished virtually every day of the year by several hundred crab traps and will be able to provide fishery landings data that can be correlated to other estuarine components to provide evidence of the overall productivity of the system. Blue crabs also move freely about the system and are good monitors of localized changes in conditions relative to temperature, salinity and other water quality parameters.

A.7.4.5 Manatee Population Abundance, Distribution and Health

Manatees are a very visible and publicly appreciated feature of the Caloosahatchee Estuary. They have been listed by the state and federal government as an endangered species and are protected throughout

their range. In the Caloosahatchee Estuary, the largest concentration of manatees is found in the upper tidal reaches of the estuary, near the Orange River and the warm water outflow of the Florida Power and Light power generating plant (USFWS 1995).

The Florida manatee is an opportunistic herbivore, feeding on a wide variety of plants. SAV, especially *Vallisneria americana*, can be an important food resource for manatees in the Caloosahatchee Estuary. Other critical requirements for the manatee are warm water in winter months and access to fresh water. They prefer waters with salinities less than 25 ppt, but can move freely between fresh and salt water (USFWS 1999)

Lee County leads the west coast of Florida in the total number of manatee deaths. Some of these deaths can be attributed to cold stress, watercraft, entanglement with crab lines, gill nets and monofilament fishing line. Lee County also leads all other west coast counties in the number of deaths in the categories of dependent calves, natural causes and undetermined.

An unusual number of manatee deaths were documented in 1996 (U.S. Marine Mammal Commission 1996). The beginning and ending of this event coincided with an inshore bloom of *Karenia brevis*, known as red tide, in southwest Florida (Baden 1996). Research found that the critical circumstances contributing to the high manatee mortality appeared to be related to the concentration and geographic distribution of the red tide outbreaks, in relation to salinity, as well as the persistence of the bloom in relation to the distribution of the manatees and their length of exposure to the red tide (Landsberg and Steidinger 1998). Eighty-one of 149 manatee deaths associated with this bloom of red tide occurred in Lee County, primarily in the Caloosahatchee Estuary (K. Dryden, United States Fish and Wildlife Service, personal communication)

A.7.4.6 Shoreline Mangrove Habitat

In 1982 approximately 674,260 acres of mangrove forests occurred in Florida (Lewis et al. 1985). Approximately 2,995 acres of mangroves are found in the Lower Caloosahatchee River subbasin (Post, Buckley, Schuh, and Jernigan and W. Dexter Bender and Associates, Inc 1999). In the Caloosahatchee Estuary, mangroves support fish and macroinvertebrate communities by providing protected nursery areas for fishes, crustaceans and shellfish, and food for a multitude of important commercial and recreational marine species such as snook, snapper, tarpon, jack, sheepshead, red drum, oyster and shrimp (Harris et al. 1983, Lindall 1973). Mangrove roots act to trap sediments and prevent shoreline erosion and provide attachment surfaces for various marine organisms. Additionally, mangrove forests provide habitat for a highly diverse population of birds (Odum et al. 1982).

Mangrove shoreline habitats have decreased in spatial extent and in function. Large areas of mangroves have been lost or fragmented through dredge-and-fill activities (National Safety Council 1998, Estevez 1998). In addition, mangroves are sensitive to alterations in upland drainage. In some areas, drainage for agricultural and urban development has reduced overland flows of fresh water to the mangroves. This results in an increased amount of concentrated runoff, which in turn changes the salinity balance, reduces the flushing of detritus, and washes nutrients directly into the estuary without the benefit of filtration by the mangrove system (Estevez 1998)

A.7.5 Ecological Effects

Critical Linkages between Stressors and Attributes/Working Hypotheses

The ecological effects of the five principle stressors in the Caloosahatchee Estuary Conceptual Ecological Model are based on 18 key hypotheses developed during the conceptual model workshops. These

hypotheses determine the content and organization of the Caloosahatchee Estuary Conceptual Ecological Model. The 18 hypotheses are presented here, organized by attribute.

A.7.5.1 Sumberged Aquatic Vegetation and Plankton

Relationship of Altered Salinity and Submerged Aquatic Vegetation

Altered estuarine salinity resulting from hydrologic alterations resulting from water management practices has had a negative effect on SAV and have resulted in large decreases the spatial extent of SAV in the Caloosahatchee River and Estuary.

Different species of SAV have different desirable salinity ranges. When salinity falls outside of these ranges the SAV is negatively impacted and may result in a reduction in densities and distribution (Chamberlain and Doering 1998b). Increases or decreases in salinity may give one species a competitive advantage over another (Livingston 1987). Tabb et al (1962) stated, "Most of the effects of man-made changes on plant and animal populations in Florida estuaries are a result of alterations in salinity and turbidity."

Level of certainty - moderate

Relationship of Submerged Aquatic Vegetation and Salinity to Mollusk Populations and Fish Recruitment

Negative changes in SAV community structure and function along with changes in the natural salinity regime has resulted in substantial losses of mollusk populations and a decrease in larval and adult fish recruitment into the estuary. Fish densities are typically greater in grass bed habitat within South Florida's estuaries and coastal lagoons than in adjacent habitats (Reid 1954, Tabb et al. 1962, Roessler 1965, Yokel 1975, Weinstein et al. 1977). The grass beds provide protection from predation for animals living in it. The dense seagrass blades and rhizomes associated with the grasses provide cover for invertebrates and small fishes while also interfering with the feeding efficiency of their potential predators (Zieman 1982, Heck et al. 1997). Reduction in size and health of SAV beds effects the location, abundance and speciation of fisheries in the estuary.

Level of certainty - low

Relationship of Submerged Aquatic Vegetation to Nutrients.

The increase of nutrients into the estuary from land use has had negative impacts on SAV through increased epiphytic growth on SAV and decreased light penetration which restricts the depth at which SAV and growth. Reduction in penetration of light into the water column is often blamed for the disappearance and diminishing of previously healthy seagrass meadows. Because seagrasses are rooted plants attached to the bottom, reduced light reduces photosynthesis, growth and reproduction. This condition is cited as a major source of seagrass decline in Florida estuarine systems. (Durako 1988).

Increased nutrients, such as nitrogen and phosphorous, can lead to light deprivation by stimulating the growth of phytoplankton. These blooms cloud the water and severely diminish sunlight penetration (Livingston 1987). This turbidity can increase to such a level that seagrasses persist only in patches (Zieman 1982). Nutrients can also trigger a thick growth of epiphytes which can also block the sunlight before it can reach the surface of the seagrass (Murray et al. 1999). In fact, nutrient input has such an effect that relatively minor changes in water quality can lead to sharp reductions in the productivity of seagrasses which can lead to broad habitat changes (Livingston 1984).

Level of certainty - moderate

Relationship of Plankton to Nutrients

Changes in plankton composition occur when we see an increase in nutrients or an alteration in the natural hydrology of the system. Water quality is also a major determinate of the health and condition of estuarine systems. Changes in water quality are often the linkage between the stressor and the ecosystem value. The amount of nutrients entering the Caloosahatchee River and Estuary has important effects on the water quality of the system. Organisms use these nutrients, but excessive amounts may have negative impacts (Neilson and Cronin 1981). Algal blooms and epiphyte growth may cause decreased water clarity and block sunlight for aquatic plants (Day 1989). As algae die, organic decomposition depletes the oxygen in the water (LaRose and McPherson 1983, Drew and Schomer 1984, Day 1989). Low levels of dissolved oxygen can have negative effects on fish and other aquatic organisms (Heyl 1998). Eutrophication may also result in an increase in red tide blooms.

The Florida Department of Environmental Protection has set water quality standards for the state (F.S. 62-40.430). Although these are often moving targets, they should be met for the Caloosahatchee in order to ensure a healthy system. In addition, the Charlotte Harbor National Estuary Program has defined a specific list of water quality parameters that should be used to meet specific program goals (CHNEP 1999).

Level of certainty - moderate

Relationship of Current and Historical Submerged Aquatic Vegetation Coverage to Potential Distribution

The SAV in the Caloosahatchee Estuary will increase as estuarine conditions improve. The extent of this increase depends on available area with suitable salinity, substrate, water clarity and temperature.

Seagrasses require light for photosynthesis. A number of factors can influence water clarity and light penetration. These include color and suspended solids. The different species of SAV have distinct requirements for light. Numerous research indicates that *Thallassia testudium, Halodule wrightii,* and *Syringodium filiforme* require levels of at least 10-15 percent of surface irradiance, while *Halophila decipiens, Halophila englemannii, Halophila johnsonii,* and *Ruppia maritima* appear to have somewhat lower requirements, perhaps as low as 2-3 percent of surface irradiance (URS Greiner Woodward Clyde 1999).

Most seagrasses appear to tolerate a wide range of substrate conditions. Virtually all seagrasses seem to grow on sandy or silty muds and on sands with some mud contents (Reid 1954, Voss and Voss 1955, Phillips 1960) and require a sufficient depth of sediment for proper development. Substrates also contain nutrients, especially nitrogen and phosphorous, available for SAV growth (Duarte 1991). The microbially mediated chemical processes in marine sediments provide a major source of these nutrients (Capone and Taylor 1980).

Each species of SAV has their own temperature and salinity tolerance ranges and their tolerance to salinity variation is similar to their temperature tolerances. *Halodule wrightii* is the most broadly euryhaline, *Thallassia testudium* is intermediate, and *Syringodium filiforme* and *Halophila* have the narrowest tolerance ranges (McMillian 1979, Zieman 1982). *Vallisneria americana* is generally a freshwater grass but can tolerate salinities of near 10 ppt. Therefore, *Vallisneria* is also an important component of the oligohaline estuarine SAV community (Twilley and Barko 1990, Adair et al. 1994, Kraemer et al. 1999).

Level of certainty - low

A.7.5.2 Oysters

Relationship of Oysters to Other Estuarine Species

Oyster bars also provide habitat and food for numerous estuarine species including gastropod mollusks, polychaete worms, decapod crustaceans, various boring sponges, fish and birds, including the endangered oyster catcher. The American oyster (*Crassostrea virginica*) is the dominant species in the oyster reef community. There may be over 40 species of macro-fauna living in oyster beds (Bahr and Lanier 1981) with the total number of species exceeding 300 (Wells 1961).

Oysters, clams and scallops are natural components of southern estuaries and were documented to be abundant in the system (Estevez 1998, Leverone 2000). Although currently less abundant (Chamberlain and Doering 1998a, Sackett 1888), they continue to be an important resource commercially and recreationally. This reduction in oyster coverage was largely due to shell mining, altered freshwater inflow, and changes in hydrodynamics. This decrease has resulted into a decrease in the oyster reef community of the estuary.

Level of certainty - high

Relationship of Oysters to Sediment Loads

The oyster population in the Caloosahatchee and surrounding estuary has decreased due to increased sediment loads resulting from man induced alterations in the natural hydrology. Adult oysters have effective morphological adaptations for feeding in much higher levels of suspended solids than are usually encountered under normal conditions (Nelson 1922, Kennedy 1996). Oysters from relatively turbid estuaries appear to be capable of feeding at total solids concentrations as high as 0.4 grams per liter but significantly reduce their pumping rates at as low as 0.1 grams per liter (Nelson 1923, Loosanoff and Tommers 1948). Suspended solids may clog gills and interfere with filtering and respiration of the oysters (Cake 1983). Increased sediment loads to the estuary as a result of discharges from Lake Okeechobee can have detrimental effects on oysters and other filter feeding bivalves.

Level of certainty - moderate

Relationship of Salinity to Oysters

Alterations of flows have lead to dry season increases in salinity in the estuarine portion of the river. This increase in salinity increases negative physiological effects on oysters and from saltwater predators in the area.

Salinity is important in determining the distribution of coastal and estuarine bivalves. Adult oysters in the Gulf of Mexico normally occur at salinities between 10 and 30 ppt but they tolerate a salinity range of 2 to 40 ppt (Gunter and Geyer 1955). Short pulses of freshwater inflow can greatly benefit oyster populations by killing predators, such as the southern oyster drill and the welk, which cannot tolerate low salinity water (Owen 1953, Marshall 1954), while excessive freshwater inflows may kill entire populations of oysters (Gunter 1953, Schlesselman 1955, MacKenzie 1977).

Changes in salinity can also affect the structural and functional properties of these bivalves through changes in 1) total osmotic concentration, 2) relative proportions of solutes, 3) coefficients of absorption and saturation of dissolved gases, and 4) density and viscosity (Kinne 1964). These bivalve physiological processes translate to functional processes in ecosystems (Dame 1996).

and saturation of dissolved gases, and 4) density and viscosity (Kinne 1964). These bivalve physiological processes translate to functional processes in ecosystems (Dame 1996).

Protozoa are probably the most common cause of epizootic outbreaks that result in mass moralities on oysters. One of the most important is Dermo, caused by a member of the phylum Apicomplexa, *Perkinsus marinus*. It is characterized by emaciation of the digestive gland of the oyster. Dermo has limits imposed by salinity and temperature (Dame 1996) and is more intense in areas of higher salinities (Burreson and Ragone 1996, Calvo et al. 1996).

Level of certainty – moderate

A.7.5.3 Fisheries

Relationship of Submerged Aquatic Vegetation to Juvenile Fish Abundance

A decline in the amount of seagrass habitat/coverage has occurred in the Caloosahatchee drainage. The consequences of this decline is a reduction in potential habitat for a number of seagrass dependent species, and especially the juvenile life stages of most estuarine dependent species (Virnstein 1987, Stoner 1984, Zieman 1982). Specifically, larval gag (*Mycteroperca microlepis*) use sea grass beds a settlement substrate after having hatched offshore on natural hard bottom structures. The larvae settle in the higher salinity areas of San Carlos Bay and Pine Island Sound in the spring of each year. After attaining a size of about 60 - 80 millimeters total length they migrate offshore to take up residence on offshore reefs (Jory and Iverson 1989). Juvenile spotted seatrout (*Cynoscion nebulosus*) use grass beds for protection from predation while adults feed on many of the seagrass associated species such as shrimp and smaller fishes (Pearson 1929, Miles 1950, Perret et al. 1980). Concomitant with reduction in habitat for specific life histories of selected species the reduction in grass beds also has led to an overall reduction in species diversity within the system (S. Bortone, Sanibel Captiva Conservation Foundation Marine Lab, personal communication).

Level of certainty - moderate

Relationship of Salinity and Freshwater Discharge to Juvenile Fish

Alterations in the natural salinity regime and timing of freshwater discharges have resulted in a decline in juvenile fish abundance, distribution and species richness. Alterations in the salinity regime places undo stress on the sensitive life history stages of many estuarine species (Emery 1957, Odum 1970, Lindall 1973, Perry and McIlwain 1986, Chamberlain and Doering 1998b). While estuarine species are generally well adapted to cope with varying salinity conditions and cycles they are not so robust as to accommodate large shifts the timing cycle of salinity regimes. A simple case in point is the egg stage of spotted seatrout. Trout eggs are neutrally buoyant at about 20-22 ppt (Pattillo et al. 1997). They spawn during the warmer months of the year (Lassuy 1983). If large and protracted reductions in salinity were to occur during the summer months, it could lead to the reduction or elimination of an entire year-class of spotted seatrout.

Level of certainty – moderate

Relationship of Fish to Red Tide

An increase in occurrence of red tide in southwest Florida has contributed to increased mortality in estuarine fishes. Red tide was first identified during a catastrophic mortality event of marine fishes and other animals that took place between November 1946 and August 1947 (Gunter et al. 1948). Since then, investigations of literature have shown 450 years of documented, what is thought to have been, red tide

off of Florida's west coast. Regardless, due to scarcity of this data, it is undetermined if there has been an actual increase in occurrence or severity of red tide in Florida waters.

Red tides typically occur in late summer and early fall months but have occurred in every month of the year. They begin about 10-40 miles off shore and are transported inshore by currents and winds. These red tide blooms have been associated with invertebrate, fish, bird and marine mammal mortalities (Gunter et al. 1948, Landsberg and Steidinger 1998, Bossart et al. 1998).

Level of certainty - moderate

Relationship of Blue Crab Fishery to Temperature, Salinity, and Other Water Quality Parameter

Because changes in temperature, salinity and other water quality parameters have had a negative impact on the local blue crab fishery, complete fishery information on this species can be used to measure the production status of the estuary. Due to its environmental requirements, the ubiquitous blue crab and its fishery can serve as important monitors for the health and condition of the estuarine system. Factors affecting distribution and survival include substratum, food availability, available shelter, water temperature and salinity (Perry and McIlwain 1986, Chamberlain and Doering 1998b).

The blue crab fishery data base has a long history in the area and can be easily monitored for catch and effort. Concomitantly, the availability of environmental data from the system allows determination of the association of the fishery status relative to environmental conditions. Thus continued, but more intense, long-term monitoring of the blue crab fishery, when coupled with currently recorded environmental parameters such as temperature, salinity, nutrient conditions and geographic information system (GIS) mapped land-water features will permit direct determination of the association that blue crab production (as measured by the catch per unit effort statistic) has with environmental water quality in the system (Bortone personal communication).

Level of certainty - low

Relationship of Fishing Pressure to Fish Landings

Increased fishing pressure has resulted in a decrease in the number of landings of both commercial and recreationally sought fish. Increased fishing pressure in Southwest Florida has presumably led to increases in landings and also a decrease in the catch per unit effort of the system. Unfortunately, the data on landings and effort may not be comprehensive enough historically to make such a claim but they do lead to suspicions. An alternative measure is to simultaneously examine life history features of the community of organisms that should respond should the above be true. For example, growth rates for some predators (that no longer have as many competitors for food resources) should increase. Likewise age at first reproduction might be lower as the species respond to having larger, more mature individuals removed from the population. Using historical (but imprecise) data, and coupling that with more recent and more accurate fishery and life history data will help authenticate this statement.

Level of certainty - moderate

A.7.5.4 Manatees

Relationship of Manatee Populations and Submerged Aquatic Vegetation

Manatees depend on SAV for food and habitat in the Caloosahatchee Estuary. Seagrass beds and mangroves provide important areas for manatee foraging, calving, resting and mating. Preferred manatee habitat in South Florida is characterized by the availability of SAV (Smith 1993).

Manatees are opportunistic herbivores and feed on a variety of submergent, emergent and floating vegetation with seagrasses comprising the largest component of their diet in South Florida (Hartman 1979, Zieman 1982, Smith 1993). Manatees usually forage in shallow grass beds that are adjacent to deeper channels (Hartman 1979, Powell and Rathbun 1984). Some manatees have been observed to return to the same seagrass beds year after year and may show preference for certain areas (USFWS 1999).

Level of certainty - high

Relationship of Manatee Populations to Habitat Loss and Boating Pressure

Manatee use of the Caloosahatchee River is affected by the increase in boating pressure and the decrease in the river's water quality. Manatees and their habitats are continually threatened by human activity such as habitat loss for residential and commercial purposes, increased turbidity levels from upland urbanization activities, pollution from discharge and stormwater runoff, aquatic recreational and commercial activities, and alterations of natural hydrology.

The greatest present threat to manatees in southwest Florida is the high rate of morality caused by watercraft collisions. Boat channels are often used by manatees to travel from one region to another (Curran 1989, Sirenia 1993). Manatees do not always move out of the way of boats using these channels, which make them vulnerable to collisions. Also, watercrafts using shallow coastal areas for fishing and siteseeing increase the likelihood of a manatee injury or death if the boat passes over them.

The number of registered boaters in the state of Florida has increased from approximately 100,000 in 1960 to greater than 700,000 in 1997 (Marine Mammal Commission 1992, Write et al. 1995). Ninety-seven percent of these were registered for recreational use. Ackerman et al. (1995) found that the number of manatees killed in collisions with watercrafts each year correlated with the total number of pleasure and commercial watercrafts registered in Florida.

The second most significant threat to manatees is the loss and degradation of habitat, due primarily to direct damage by aquatic recreational and commercial boating activities, coastal construction, and pollution from sewage discharge and storm water runoff (Marine Mammal Commission 1992, Smith 1993). The seagrass beds that manatees rely on for foraging incur direct damage from boat propellers (Zieman 1982, Dawes et al. 1997). Propeller dredging of bottom habitat by boats, propeller wash and wave wake disturbance cause boat induced turbidity. Sediments around seagrasses become unconsolidated and suspended. This delays recolonization of the grasses for two to five years or longer, depending on the species type.

Level of certainty - high

Relationship of Manatees to Red Tide

Red tide has historically been responsible for an increase in manatee mortality. Marine mammal mortality associated with red tide is poorly known. Some instances of bottlenose dolphin moralities have been

blamed on the toxin because of their coincidence with red tide blooms (Gunter et al. 1948, Geraci 1989). Also, a link has been suggested between the death of seven manatees in 1963 and a red tide near Fort Myers (Layne 1965, Bossart et al 1998).

More recently, during a 1996 die off of manatees, a large number of manatees aggregated in warm waters near the Fort Myers power plant. Final reports conclude that brevetoxins from a bloom of red tide (dinoflagellates) were responsible for the death of those manatees. Toxins were found in the manatee carcasses in the liver, kidney and lung tissues, and also in stomach contents (USFWS 1999). Manatee deaths are often attributed to red tide. However, in 1996 their increased vulnerability was due to their dispersal from this warm water refuge where red tide was present.

Level of certainty - low

A.7.5.5 Shoreline Mangroves

Relationship of Mangrove System Function and Shoreline Fragmentation

The ecological functionality of the mangrove system, which includes their filtering, stabilizing, habitat, and protective roles, has been decreased through fragmentation of the mangrove shoreline as a result of shoreline development and dredge and fill activities.

Mangroves carry out a number of ecological functions, including land formation (Warming 1925, Davis 1940), sediment stabilization, primary productivity, filtration of land runoff, and serve as habitats and nurseries (Dawes 1998, MacNae 1968, Odum et al. 1982). In South Florida, mangroves have been destroyed by dredge-fill operations to create real estate, and port and industrial facilities. Mangrove destruction results in a chain of reactions that affect estuarine and off shore production. In Tampa Bay, 44 percent of the mangrove and salt marsh land has been lost due to construction and resultant turbidity from runoff and pollution (Lewis and Estevez 1988). This loss has been linked to declines in fin fish and commercial shrimping in the region (Dawes 1998).

Specifically, urbanization/shoreline development has resulted in an extensive loss of mangrove habitat along the Caloosahatchee Estuary. These native shorelines perform important functions, which include absorbing floodwaters, recharging floodwaters, assimilating waste and excess nutrients, and provide food and cover for a multitude of fish and wildlife. These functions help to maintain water quality, recycle nutrients and control erosion (Harris et al. 1983).

Level of certainty - high

Relationship of Mangrove System Productivity and Upland Flows

Productivity in the shoreline mangrove systems is depressed as a result of diminished upland flows of fresh water to the mangroves. Low salinity mangrove forests have been recognized as critical nursery habitat for species such as blue crab, snook, tarpon and ladyfish (Odum et al. 1982, Gilmore et al. 1983, Lewis et al. 1985). Much of this habitat has been lost or highly modified. In many areas, freshwater upland flows to these mangrove systems have been decreased or depleted due to a rerouting of the water through canals. Changes in freshwater discharge have also altered the structure of mangrove forests. The reduction and modification of this habitat type may represent a limiting factor in total population sizes of some estuarine-dependent species (Lewis 1990).

Level of certainty - moderate

A.7.5.6 Research Questions

Relationship of Manatee Mortality to Red Tide

Will changes in salinity, nutrient load, and water residence time due to the restoration of the recommended estuarine salinity envelope reduce the occurrence of red tide in inland waters at times coincident to when manatees move between inland waters and estuarine waters?

Relationship of Blue Crab Fishery to Temperature, Salinity and Other Water Quality Parameters

How does catch per unit effort of the blue crab fishery respond to the combined effects of temperature, salinity and other water quality parameters in the Caloosahatchee estuary? Can blue crab catch per unit effort be used as an indicator of estuarine health in the estuary?

Relationship of Mollusk Populations and Fish Recruitment to Submerged Aquatic Vegetation and Salinity

Will changing the salinity regime to a more natural condition and increasing the coverage of SAV in the Caloosahatchee Estuary provide a more suitable environment for estuarine mollusks and fishes? Will this lead to an increase in population density and community diversity?

Relationship of Current and Historical Submerged Aquatic Vegetation Coverage to Potential Distribution

What areas in the estuary potentially provide optimal conditions for seagrass reestablishment? Will we see this reestablishment with changing conditions?

A.7.6 Hydrologic Performance Measures

Salinity envelope maintenance of appropriate freshwater inflows is essential for a healthy estuarine system. Freshwater inflow ranges and timing must promote and maintain the health of important taxa found in the Caloosahatchee Estuary. Estuarine biota, such as SAV, fish, oysters and clams, are well adapted to and depend upon natural seasonal changes in salinity. Preliminary analysis suggests that a minimum inflow of 300 cubic feet per second (cfs) during the dry season will promote the growth of the upstream submerged plant, *Vallisneria americana* (tape grass). Inflows greater than about 2,500-3,000 cfs may be detrimental to other biota anytime of the year; therefore, a distribution of inflows that has the greatest frequency range from 300 to less than 1,500 cfs, with a peak of 300-800 cfs, should be generally beneficial to the biota of the Caloosahatchee Estuary (Chamberlain and Doering 1998a and b).

The temporary storage and concurrent decrease in velocity of floodwaters within upstream wetlands aid in controlling the timing, duration and quantity of freshwater inflows to the estuary (SFWMD 2000). Upstream wetlands and their associated ground water systems serve as freshwater reservoirs for the maintenance of base flow discharges into the estuaries, providing favorable salinities for estuarine biota. During the wet season, upstream wetlands provide pulses of organic detritus, which are exported downstream to the brackish water zone. These materials are an important link in the estuarine food chain (SFWMD 2000).

Many freshwater wetland systems in the planning area provide base flows to the estuary. Wetlands as far inland as the Okaloacoochee Slough in Hendry County (see Figure A-14 in A.4 Big Cypress Regional Ecosystem Conceptual Ecological Model) contribute to base flows entering the estuarine system (SFWMD 2000, SFWMD 1999). Maintenance of these base flows is crucial to propagation of many fish species, such as redfish, snapper and spotted seatrout, which contribute to the extensive commercial and recreational fishing industries (SFWMD 2000, Lindall 1973).

A.7.6.1 Ecological Performance Measures

A.7.6.2 Submerged Aquatic Vegetation Distribution, Community Structure and Function

The performance measures for SAV community structure and function are distribution, density/abundance, and community composition. Seagrass beds must be reestablished in the Caloosahatchee Estuary to increase biodiversity within the system and enhance habitat value for fish, caridean shrimp, wading birds, and manatees. The coverage of seagrasses must increase in areas that are indicated to be suitable habitat. To achieve these targets, flows needed to achieve the proper salinity range for SAV must be maintained (see A.7.7 Hydrologic Performance Measures).

A.7.6.3 Oyster Bar Abundance, Community Structure and Function

The performance measures for oyster bar community structure and function are oyster growth, disease, mortality, recruitment and aerial coverage. The targets are to increase the abundance and health of oysters, restore oyster beds in suitable habitat, and maintain habitat function of oyster beds for fish, crabs and birds. To achieve these targets, flows needed to achieve the proper salinity range for oysters must be maintained (see A.7.7 Hydrologic Performance Measures).

A.7.6.4 Sand/Mud Benthic Community Structure and Function

The performance measures for sand/mud community structure and function are *Rangia cuneata* and *Polymesoda carolineata* abundance, distribution and condition. The target is to obtain targeted normal distribution, population size, and condition across optimal salinity ranges for these freshwater species of clam.

A.7.6.5 Shoreline Mangrove Habitat

The performance measures for shoreline mangrove habitat are shoreline mangrove percent cover and mangrove tree crab abundance. The targets are to restore and maintain shoreline mangrove habitat and to increase or maintain functionality of the mangrove system. To achieve these targets, further loss of mangrove habitat must be eliminated and mangrove habitat must be restored when possible. The mangrove tree crab will be used an indicator species to measure increase or loss of functionality in the mangrove system.

A.7.6.6 Estuarine Fish Community Structure and Function

The performance measure for estuarine fish community structure and function are juvenile fish abundance, diversity and community structure. The target is to restore assemblages with abundance, taxonomic composition, diversity and representation of life stages characteristic of targeted salinity regimes for each estuary.

A.7.6.7 Manatee Population Abundance, Distribution and Health

The performance measure for manatee population abundance, distribution and health is manatee distribution and abundance. Restoration and preservation of the manatee population in the Caloosahatchee Estuary will be achieved by maintaining and enhancing current habitat and foraging areas for manatees in the Caloosahatchee Estuary and in canals to promote species recovery, especially near the Florida Power and Light warm water refugia. This can be measured in two ways: through the enhancement of SAV in the upper and middle sectons of the Calooshatchee River and by maintaining habitat values in canals.

A.7.6.8 Water and Sediment Quality

The water and sediment quality performance measures for the Caloosahatchee Estuary are total phosphorous, total nitrogen, chlorophyll *a*, photosynthetically-active radiation (PAR), secchi depth, trace metals, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and pesticides. The target is to reduce total phosphorus and total nitrogen concentrations, reduce concentrations of toxicants, such as heavy metals and pesticides, and pathogens, reduce algal bloom frequency, and increase water clarity.

A.7.7 Model

The diagram for the Caloosahatchee Estuary Conceptual Ecological Model is presented in Figure A-25. The key to the symbols used in the diagram is presented in Figure A-24.

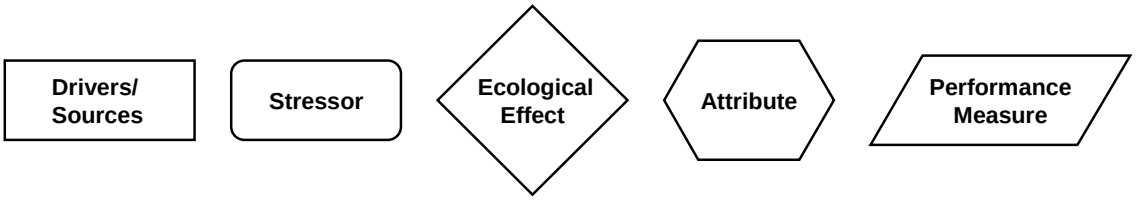


Figure A-24: Key to the Symbols Used in the Following Diagram

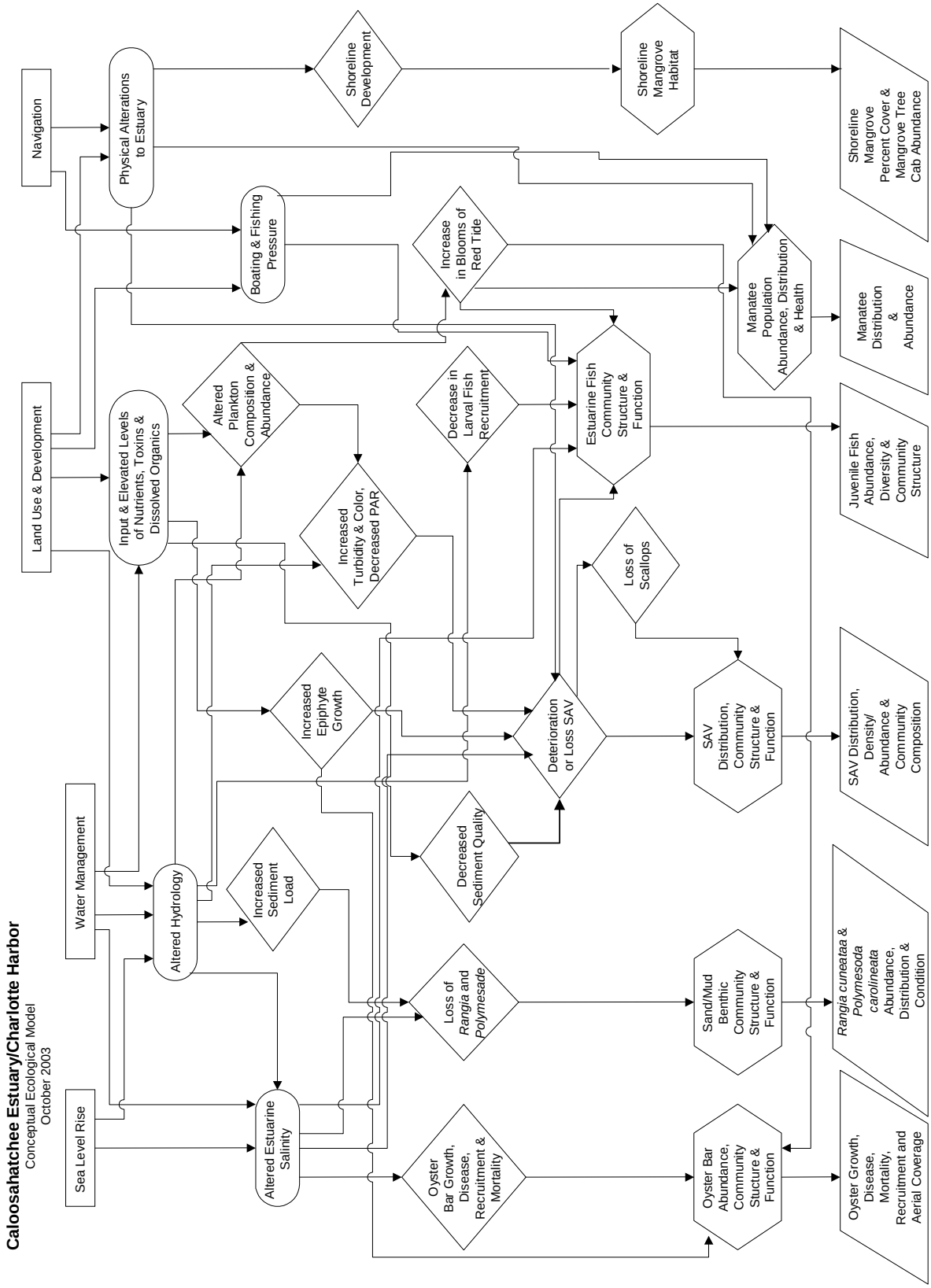


Figure A-25: Caloosahatchee Estuary Conceptual Ecological Model Diagram

A.7.8 Literature Cited

Ackerman, B.B., S.D. Wright, R.K. Bonde, C.A. Beck, and D.J. Banowetz. 1995. Analysis of watercraft-related mortality in manatees in Florida, 1979-1991. In: O'Shea, T.J., B.B. Ackerman, and H.F. Percival (eds). Population Biology of the Florida Manatee: Information and Technology Report I. United StatesDepartment of the Interior, National Biological Service, Washington, D.C., pp. 259-268.

Adair, S.E., J.L. Moore, and C.P. Onuf. 1994. Distribution and status of submerged vegetation in estuaries of the upper Texas coast. Wetlands 14(2):110-121.

Andrews, J. D. 1988. Epizootiology of the disease caused by the oyster pathogen *Perkinsus marinus* and its effects on the oyster industry. Amer. Fish. Soc. Sp. Publ. 18:47-63.

Baden, B.D. 1996. Analysis of Biotoxins (Red Tide) in Manatee Tissues. Report No. MR148, Marine and Freshwater Biomedical Sciences Center, National Institute of Environmental Health Sciences, Rosenstiel School of Marine and Atmospheric Sciences, University of Miami, Miami, Florida, pp. 1-12.

Bahr, L.M., and W.P. Lanier. 1981. The Ecology of Intertidal Oyster Reefs of the South Atlantic Coast: A Community Profile. FWS/OBS-81/15, United States Fish and Wildlife Service, , Washington, D.C.

Barbour, M.T., J. Gerritsen, and J.S. White. 1996. The Development of the Stream Condition Index for Florida. Florida Department of Environmental Protection, Tallahassee, Florida.

Bortone, S.A., and R.K. Turpin. 1999. Tape grass life history metrics associated with environmental variables in a controlled estuary. In: Bortone, S.A. (ed). Seagrasses: Monitoring, Ecology, Physiology, and Management. CRC Press, Boca Raton, Florida, pp. 65-79.

Bortone, S.A., and M.A. Wilzbach. 1997. Status and Trends of the Commercial and Recreational Landings of Spotted Seatrout (*Cynoscion nebulosus*): South Florida. Technical Publication No. 2, Florida Center for Environmental Studies, Palm Beach Gardens, Florida.

Bossart, G.D., D.G. Baden, R.Y. Ewing, B. Roberts, and S.D. Wright. 1998. Brevitoxicosis in manatees (*Trichechus manatus latirostris*) from the 1996 epizootic: gross, histologic and immunohistochemical features. Toxicol. Pathol. 26: 276-282.

Burreson, E.M., and L.M. Ragone Calvo. 1996. Epizootiology of *Perkinsus marinus* disease of oysters in Chesapeake Bay, with emphasis on data since 1985. J. Shellfish Res. 15(1): 17-34.

Cake, E.W., Jr. 1983. Habitat Suitability Models: Gulf of Mexico American Oysters. FWS/OBS-82/10.57, United States Fish Wildlife Service, , Washington, D.C.

Calvo, G.W.., R.J. Fagan, K.N. Greenhawk, G.F. Smith, and S.J. Jorday. 1996. Spatial distribution and intensity of *Perkinsus marinus* infections in oyster recovery areas in Maryland. J. Shellfish Res. 15(2): 381-389.

Capone, D.G., and B.F. Taylor. 1980. Microbial nitrogen cycling in a seagrass community. In: Kennedy, V.S. (ed). Estuarine Perspectives. Acedemic Press, New York, pp. 153-162.

Chamberlain, R.H., and P.H. Doering. 1998a. Freshwater inflow to the Caloosahatchee Estuary and the resource-based method for evaluation. In: Treat, S.F. (ed). Proceedings of the Charoltte Harbor Public Conference and Technical Symposium. Technical Report No. 98-02, Charlotte Harbor Estuary Program, North Fort Myers, Florida, pp. 88-91.

Chamberlain, R.H., and P.H. Doering. 1998b. Preliminary estimate of optimum freshwater inflow to the Caloosahatchee Estuary: A resource based approach. In: Treat, S.F. (ed). Proceedings of the Charoltte Harbor Public Conference and Technical Symposium. Technical Report No. 98-02, Charlotte Harbor Estuary Program, North Fort Myers, Florida, pp. 111-120.

Chanley, P.E. 1958. Survival of some juvenile bivalves in water of low salinity factor. Ecol. Monogr. 31: 239-266.

CHNEP. 1999. Committing to Our Future, Volume 1: A Draft Comprehensive Conservation and Management Plan for the Greater Charlotte Harbor Watershed. Charlotte Harbor National Estuary Program, North Fort Myers, Florida.

Coastal Coordinating Council. 1974. Florida Coastal Zone Management Atlas. Coastal Coordinating Council, State of Florida, Tallahassee, Florida.

Curran, A.P. 1989. Analysis of the Effect of Boat Traffic on Manatee (*Trichechus manatus*) Densities in Four Selected Study Areas in Brevard County, Florida. Master's thesis, Florida Institute of Technology, Melbourne, Florida.

Dame, R.F. 1996. Ecology of Marine Bivalves: an Ecosystem Approach. CRC Press, Boca Raton, Florida.

Davis, J.H. 1940. The Ecology and Geologic Role of Mangroves in Florida. Publication No. 517, Carnegie Institute, Washington, D.C.

Dawes, C.J., J. Andorfer, C. Rose, C. Uranowski, and N. Ehringer. 1997. Regrowth of the seagrass *Thalassia testudinum* into propeller scars. Aquatic Botany 59: 139-155.

Dawes, C.J. 1998. Marine Botany. Second Edition. John Wiley & Sons, Inc, New York.

Day, J.W., C.A.S. Hall, W.M. Kemp, and A. Yanez-Arancibia. 1989. Estuarine Ecology. John Wiley & Sons, Inc, New York.

Drew, R.D., and N.S. Schomer 1984. An Ecological Characterization of the Caloosahatchee River/Big Cypress Watershed. FWS/OBS-82/58.2, United States Fish and Wildlife Service, , Washington, D.C.

Duarte, C.M. 1991. Seagrass depth limits. Aquatic Botany. 40: 263-377.

Durako, M.J. 1988. The seagrass bed: a community under assault. Florida Naturalist Fall 1988, pp. 6-8.

Emery, K.O., and R.E. Stevenson. 1957. Estuaries and lagoons: 1. Physical and chemical characteristics. In: Hedgpeth, J.W. (ed). Treatise on Marine Ecology and Paleoecology, Volume 1. Geol. Soc. Am. Mem. 67, pp. 673-639

Estevez, E. 1998. The Story of the Greater Charlotte Harbor Watershed. Charlotte Harbor National Estuary Program, Fort Myers, Florida.

Fernandez, M., M. Marot, and C. Holmes. 1999. Reconnaissance of Chemical and Physical Characteristics of Selected Bottom Sediments of the Caloosahatchee River and Estuary, Tributaries, and Contiguous Bays, Lee County, Florida July 20-30 1998. Open-File Report 99-226, United States Geological Survey, Tallahassee, Florida.

Galtsoff, P.S. 1964. The American oyster *Crassostrea virginica* Gmelin. Fish. Bull. 64: 1-480.

Garrot, R.A., B.A. Ackerman, J.R. Cary, D.M. Heisey, J.E. Reynolds III, P.M. Rose, and J.R. Wilcox. 1994. Trends in counts of Florida manatees at winter aggregation sites. Journal of Wildlife Management 58 (4): 642-654.

Geraci, J.R. 1989. Clinical Investigation of the 1987-88 Mass Mortality of Bottlenose Dolphins along the U.S. Central and South Atlantic Coast. United States Marine Mammal Commission, Washington, D.C.

Gilmore, R.G., C.J. Donohoe, and D.W. Cooke. 1983. Observations on the distribution and biology of east-central Florida populations of the common snook, *Centrpoomus undecimalis* (Bloch). Florida Scientist 46: 313-336.

Gunter, G. 1953. The relationship of the Bonnet Carre spillway to oyster beds in Mississippi Sound and the Louisiana marsh, with a report on the 1950 opening. Publ. Inst. Mar. Sci. Univ. Tex 3(1): 17-71.

Gunter, G., and R.A. Geyer. 1955. Studies of fouling organisms in the notheastern Gulf of Mexico. Publ. Inst. Mar. Sci. Univ. Tex. 4(1): 39-67.

Gunter, G., and G.E. Hall. 1965. A biological Investigation of the Caloosahatchee estuary of Florida. Gulf Research Reports 2: 1-71.

Gunter, G., R,H, Williams, C.C. Davis, and F.G.W. Smith. 1948. Ecol. Monofr. 18: 309-324.

Hartman, D.S. 1979. Ecology and behavior of the manatee (*Trichechus manatus*) in Florida. Special Publication: American Society of Mammologists Special Report No. 5: 1-153.

Harris, B.A., K.D. Haddad, K.A. Steidinger, and J.A. Huff. 1983. Assessment of Fisheries Habitat: Charlotte Harbor and Lake Worth, Florida. Florida Department of Natural Resources, Bureau of Marine Research, St. Petersburg, Florida.

Haunert, D., B. Chamberlain, P. Doering, and K. Konyha. 2000. Technical Criteria to Guide an Adaptive Management Strategy for Minimum Flows to the Caloosahatchee Estuary, Florida. South Florida Water Management District, West Palm Beach, Florida, draft.

Heck, K.L., Jr., D.A. Nadeau, and R. Thomas. 1997. The nursery role of seagrass beds. Gulf of Mexico Science 15:50-54.

Heyl, M.G. 1998. Hypoxia in upper Charlotte Harbor. In: Treat, S.F. (ed). Proceedings of the Charoltte Harbor Public Conference and Technical Symposium. Technical Report No. 98-02, Charlotte Harbor Estuary Program, North Fort Myers, Florida, pp. 219-227.

Hofstetter, R.P. 1977. Trends in the Population Levels of the American Oyster, *Crassostrea virginica* Gmelin on Public Reefs in Galveston Bay, Texas. Technical Series 24, Texas Parks and Wildlife Department, Austin, Texas.

Jory, D.E., and E.S. Iverson. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (South Florida)--black, red, and Nassau groupers. Biological Report 82(11.110), United States Fish and Wildlife Service, Washington, D.C.

Kennedy, V.S. 1996. Biology of larvae and spat. In: Kennedy, V.S., R.I.E. Newell and A.F. Eble (eds), The Eastern Oyster *Crassostrea virginica*, Maryland Sea Grant College Publication, College Park, Maryland, pp. 371 – 421.

Kinne, O. 1964. The effects of temperature and salinity on marine and brackish-water animals II. Salinity and temperature/salinity combinations. Oceanogr. Mar. Biol. Annu. Rev. 2, 281-339.

Kraemer, G.P., R.H. Chamberlain, P.H. Doering, A.D. Steinman, and M.D. Hanisak. 1999. Physiological responses of transplants of freshwater angiosperm *Vallisneria americana* along a salinity gradient in the Caloosahatchee Estuary (Southwestern Florida). Estuaries 22(1): 138-148.

Landsberg, J.H., and K.A. Steidinger. 1998. A historical review of *Gymnodinium breve* red tides implicated in mass mortalities of the manatee (*Trichechus manatus latirostris*) in Florida, USA. In: Reguera, B., J. Blanco, M.L. Fernandez, and T. Wyatts (eds). Proceedings of the Eight International Conference on Harmful Algae, Vigo, Spain. Xunta de Galicia and Intergovernmental Oceanographic Commission of UNESCO, pp. 97-100.

Lassuy, D.R. 1983. Species Profiles: Life Histories and Environmental Requirements (Gulf of Mexico)--Spotted Seatrout. FWS/OBS-82/11.4, Division of Biological Services, United States Fish and Wildlife Service, Washington, D.C.

Layne, J.N. 1965. Observations on marine mammals in Florida waters. Bulletin of the Florida State Museum 9: 131-181.

La Rose, H.R., and B.F. McPherson. 1983. Chemical and Hydrologic Assessment of the Caloosahatchee River Basin, Lake Okeechobee to Franklin Lock, Florida. Water-Resources Investigations Report 83-4126, United States Geological Survey Tallahassee, Florida.

Leverone, Jay R. 2000. Use of Shell Remains to Determine Historical Bay Scallop Population Distributions in the San Carlos/Tarpon Bay-Pine Island Sound. Mote Marine Laboratory Technical Report No. 667, Sarasota, Florida.

Lewis, R.R. 1990. Creation and restoration of coastal plain wetlands in Florida. In: Kusler, J.A., and M.E. Kentula (eds). Wetland Creation and Restoration: The Status of the Science. Island Press, Washington, D.C., pp. 73-101.

Lewis, R.R., III, R.G. Gilmore, Jr., D.W. Crewz, and W.E. Odum. 1985. Mangrove habitat and fisheries resources of Florida. In: Seaman, W., Jr. (ed). Florida Aquatic Habitat and Fishery Resources. Florida Chapter, American Fisheries Society, Kissimmee, Florida, pp.281-336.

Lewis III, R.R., and E.D. Estevez. 1988. The Ecology of Tampa Bay, Florida: An Estuarine Profile, Biological Report 85, United States Fish and Wildlife Service, Washington, D.C.

Lindall, W.N. Jr. 1973. Alterations of Estuaries of South Florida: A Threat to Its Fish Resources. Marine Fisheries Review 35-10: 1-8.

Livingston, R.J. 1987. Historic trends of human impacts on seagrass meadows of Florida. In: Durako, M.J., R.C. Phillips, and R.R. Lewis, III (eds). Proceedings of the Symposium on Subtropical-Tropical Seagrasses of the Southeastern United States. Publications No. 42, Florida Marine Research Institute, St. Petersburg, Florida, pp. 139-152.

Livingston, R.J. 1984. The relationships of physical factors and biological response in coastal seagrass meadows. Estuaries 7(4A): 377-390.

Loosanoff, V.L. 1932. Observations on propagation of oysters in James and Corrotoman Rivers and the seaside of Virginia. Virginia Comm. Fish., Newport News, Virginia, pp 1-45.

Loosanoff, V.L., and F.D. Tommers. 1948. Effect of suspended silt and other substances on rate of feeding of oysters. Science 107: 69-70.

Marine Mammal Commission. 1992. Annual Report to Congress, 1991. Marine Mammal Commission, Washington, D.C.

MacKenzie, C.L. Jr. 1977. Development of an aquacultural program for rehabilitation of damaged oyster reefs in Mississippi. U.S. Natl. Mar. Fish. Serv. Mar. Fish Rev. 39(8): 1-3.

MacNae, N. 1968. A general account of the fauna and flora of mangrove swamps and forests in the Indo-West Pacific region. Adv. Mar. Biol. 6: 73-270.

McMichael, R. 1997. Fisheries-Independent Monitoring Programs 1996 Annual Data Summary Report. I-viii, Florida Marine Research Institute, St. Petersburg, Florida.

McMillian, C. 1979. Differentiation in response to chilling temperatures among populations of three marine spermatophytes: *Thalassia testudium, Syringodium filiforme,* and *Halodule wrightii.* Am. J. Bot. 66(7): 810-819.

Meeder, J.F., M.S. Ross, G. Telesnicki, P.L. Ruiz, and J.P. Sah. 1996. Vegetation Analysis in the C-111/Taylor Slough Basin, Document 1: The Southeast Saline Everglades Revisited: A Half-Century of Coastal Vegetation Change, and Document 2: Marine Transgression in Southeast Saline Everglades, Florida: Rates, Causes, and Plant Sediment Responses. Final report for Contract C-4244, Southeast Environmental Research Program, Florida International University, Miami, Florida.

Miles, D.W. 1950. The life histories of the seatrout *Cynoscion nebulosus* and the redfish, *Sciaenops ocellatus*. Tex. Game, Fish and Oyster Comm., Mar. Lab. Annu. Rep. 1949-1950 (Mimeo).

Muller, R.G., M.D. Murphy, and M.P. Armstrong. 1996. Florida's Inshore and Nearshore Species: Status and Trends Report. Department of Environmental Protection, Florida Marine Research Institute, St. Petersburg, Florida.

Murray, L M., Kemp, and D. Gurber. 1999. Compararive studies of seagrass and epiphyte communities in Florida Bay and two other South Florida estuaries in relation to freshwater inputs. Abstract. In: 1999 Florida Bay and Adjacent Marine Systems Science Conference Program and Abstracts.

Florida Bay Program Management Committee, c/o Everglades National Park, Homestead, Florida.

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

National Safety Council. 1998. Coastal Challenges: A Guide to Coastal and Marine Issues. National Safety Council's Environmental Health Center, Washington, D.C.

Neilson, B., and L. Cronin. 1981. Estuaries and Nutrients. Humana, Clifton, New Jersey.

Nelson, T.C. 1922. Report of the Biologist. In: Ann. Rep. N. J. Agric. Exp. Sta., New Brunswick, New Jersey, pp 321-343

Odum, W.E. 1970. Insidious alteration of the estuarine environment. Trans. Am. Fish. Soc. 99: 836-847.

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, United States Fish and Wildlife Service, Washington, D.C.

Owen, H.M. The relationship of high temperature and low rainfall to oyster production in Louisiana. Bull. Mar. Sci. Gulf Caribb #(1): 34-43.

Pattillo, M.E., T.E. Czapla, D.M. Nelson, and M.E. Monaco. 1997. Distribution and Abundance of Fishes and Invertebrates in Gulf of Mexico Estuaries, Volume II: Species Life History Summaries. Estuarine Living Marine Resources Report No. 11, Strategic Environmental Assessments Division, National Ocean Service, National Oceanic and Atmospheric Administration, Silver Springs, Maryland.

Pearson, J.C. 1929. Natural history and conservation of the redfish and other commercial sciaenids on the Texas Coast. Bull. U.S. Bur. Fish. 4: 129-214.

Perret, W.S., J.E. Weaver, R.O. Williams, P.L. Johansen, T.D. McIlwain, R.C. Raulerson, and W.M. Tatum. 1980. Fishery profiles of red drum and spotted seatrout. Report No. 6, Gulf States Marine Fisheries Commission, Ocean Springs, Mississippi.

Perry, H.M., and T.D. McIlwain. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Gulf of Mexico)--blue crab. Biology Report 82 (11.55), United States Fish and Wildlife Service, Washington, D.C.

Phillips, R.C. 1960. Observations on the Ecology and Distribution of Florida Seagrasses. Professional Papers Series No. 2, Florida State Board of Conservation Marine Laboratory, St. Petersberg, Florida.

Post, Buckley, Schuh, and Jernigan, and W. Dexter Bender and Associates, Inc. 1999. Synthesis of Technical Information Volume 1: A Characterization of Water Quality, Hydrologic Alterations, and Fish and Wildlife Habitat in the Greater Charlotte Harbor Watershed. Charlotte Harbor National Estuary Program, Fort Myers, Florida.

Powell, J.A., and G.B. Rathbun 1984. Distribution and abundance of manatees along the northern coast of the Gulf of Mexico. Northeast Gulf Science 7(1): 1-28.

Roessler, M.A. 1965. An analysis of the variability of fish populations taken by otter trwl in Biscayne Bay, Florida. Trans. Am. Fish. Soc. 94: 311-318.

Reid, G.K. Jr. 1954. An ecological study of the Gulf of Mexico fishes in the vicinity of Cedar Key, Florida. Bulletin of Marine Science of the Gulf and Caribbean. 4(1): 1-94.

Reid, J.P., G.B. Rathbun, and J.R. Wilcox. 1991. Distribution patterns of individually identifiable West Indian manatees (*Trichechus manatus*) in Florida. Marine Mammal Science 7(2): 180-190.

Sackett, J.W. 1888. Survey of Caloosahatchee River, Florida. Report to the Captain of the United States Engineering Office, St. Augustine, Florida.

Scarlatos, P.D. 1988. Caloosahatchee estuary hydrodynamics. Technical Publication 88-7, South Florida Water Management District, West Palm Beach, Florida.

Schlesselman, G.W. 1955. The gulf coast oyster industry of the United States. Geograph. Rev. 45(4): 531-541.

Sirenia. 1993. 1993 Annual Report on the Radio Telemetry of Manatees in Puerto Rico. Sirenia Project, National Biological Service, Gainesville, Florida.

Smith, K.N. 1993. Manatee Habitat and Human-Related Threats to Seagrass in Florida: A review. Department of Environmental Protection, Division of Marine Resources, Tallahassee, Florida.

Soniat, T.M. 1996. Epizootiology of *Perkinsus marinus* disease of eastern oysters in the Gulf of Mexico, Journal of Shellfish Research 15: 35-43.

SFWMD. 2000. Caloosahatchee Water Management Plan. South Florida Water Management District, West Palm Beach, Florida

SFWMD. 1999. Draft District Water Management Plan. South Florida Water Management District, West Palm Beach, Florida.

Squires, A.P., H. Zarbock, and S. Janicki. 1989. Loadings of Total Nitrogen, Total Phosphorus, and Total Suspended Solids to Charlotte Harbor. In: Treat, S.F. (ed). Proceedings of the Charoltte Harbor Public Conference and Technical Symposium. Technical Report No. 98-02, Charlotte Harbor Estuary Program, North Fort Myers, Florida, pp. 187-200.

Stoker, Y.E. 1992. Salinity Distribution and Variation with Freshwater Inflow and Tide, and Potential Changes in Salinity Due to Altered Freshwater Inflow in the Charlotte Harbor Estuarine System, Florida. United States Geological Survey, Tallahassee, Florida.

Stoner, A.W. 1984. Distribution of fishes in seagrass meadows: Role of macrophyte biomass and species composition. United States Dept Comm. Fish. Bull. 81: 837-846.

Tabb, D.C., D.L. Dubrow, and R.B. Manning. 1962. The ecology of Northern Florida Bay and adjacent estuaries. Fla. State Board Conserv. Tech. Ser. 39: 1-81.

Tampa Bay Regional Planning Council. 1993. Implications and Management of a Sea Level Rise in the Sarasota Bay Region. Tampa, Florida.

Twilly, R.F., and J.W. Barko. 1990. The growth of submerged macrophytes under experimental salinity and light conditions. Estuaries 13: 311-321.

URS Greiner Woodward Clyde. 1999. Distribution of Oysters and Submerged Aquatic Vegetation in the St. Lucie Estuary. Prepared under contract no. C-7779 for South Florida Water Management District, West Palm Beach, Florida.

USACE. 1957. General Design Memorandum, Caloosahatchee River and Control Structures (Canal 43 Lock and Spillway Structures 77, 78, and 79) Part IV: Central and Southern Florida Project. Serial No.36, Jacksonville District, United States Army Corp of Engineers, Jacksonville, Florida.

USFWS. 1999. South Florida Multi-Species Recovery Plan. United States Fish and Wildlife Service, Atlanta, Georgia.

USFWS. 1995. Florida Manatee Recovery Plan Second Revision. United States Fish and Wildlife Service, Atlanta, Georgia.

U.S. Marine Mammal Commission. U.S. Marine Mammal Commission Annual Report to Congress. 1996. United States Marine Mammal Commission, Bethesda, Maryland, pp 6-18.

Virstnstein, R.W. 1987. Seagrass-associated invertebrate communities of the southeastern U.S.A.: A review. In: Durako, M.J., R.C. Phillips, and R.R. Lewis (eds), Proceedings of the Symposium in Subtropical-Tropical Seagrasses of the Southeastern U.S., Publication 42, Bureau Marine Research, Florida Department of Natural Resources, St.Petersburg, Florida, pp. 89-116.

Volety, A. K. 1995. A study of the histozoic oyster parasite, Perkinsus marinus: I. Disease processes in American oysters, II. Biochemistry of *P. marinus*. PhD Dissertation, Virginia Institute of Marine Science, College of William and Mary, Williamsburg, Virginia.

Voss, G.L., and N.A. Voss. 1955. An ecological study of Soldier Key, Biscayne Bay, Florida. Bulletin of Marine Science of the Gulf and Caribbean. 5(3): 203-229.

W. Dexter Bander and Associates, Inc. 1995. Lee County Manatee Protection Plan Draft. Lee County, Florida.

Wanless, H.R., R.W. Parkinson, and L.P. Tedesco. 1994. Sea level control on stability of Everglades wetlands. In: Davis, S.M., and J.C. Ogden (eds). Everglades: The Ecosystem and Its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 199-223.

Warming, E. 1925. Oecology of Plants. Oxford University Press, Oxford, United Kingdom.

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

Weinstein, M.P., C.M. Courtney, and J.C. Kinch. 1977. The Marco Island estuary: a summary of physiochemical and biological parameters. Fla. Sci. 40(2): 98-124.

White, M.E., and E.A. Wilson. 1996. Predators, pests, and competitors. In: Kennedy, V.S., R.I.E. Newell, and A.F. Able (eds). The Eastern Oyster, *Crassostrea virginica*. UM-SG-TS-96-01, Maryland Sea Grant College Publication, pp. 559-79.

Wright, S.D., B.B. Ackerman, R.K. Bonde, C.A. Beck, and D.J. Banowetz. 1995. Analysis of watercraft-related mortality in manatees in Florida, 1979-1991. In: O'Shea, T.J., B.B. Ackerman, and H.F. Percival (eds). Population Biology of the Florida Manatee: Information and Technology Report I. United States Department of the Interior, National Biological Service, Washington, D.C., pp 259-268.

Yokel, B.J. 1975. Rookery Bay Land Use Studies: Environmental Planning Strategies for Development of a Mangrove Shoreline, No. 5. Estuarine Biology. Conservation Foundation, Washington, D.C.

Zieman, J.C. 1982. The ecology of the seagrasses of South Florida: a Community Profile. FWS/OBS-82/25, United States Fish and Wildlife Service, Office of Biological Services, Washington, D.C.

A.8 ST. LUCIE ESTUARY AND INDIAN RIVER LAGOON CONCEPTUAL ECOLOGICAL MODEL

A.8.1 Model Lead

Patti Sime, South Florida Water Management District

A.8.2 Introduction

The St. Lucie Estuary is a major component of the southern portion of the Indian River Lagoon. It is located on the southeast coast of Florida and discharges into the Atlantic Ocean through the St. Lucie Inlet. The Indian River Lagoon receives discharges from many subbasins including Taylor Creek, the C-25 canal, Moores Creek, the Virginia Avenue Canal to the north of the St. Lucie Estuary, and areas located north of Fort Pierce (Woodward-Clyde 1994).

The model boundary for the St. Lucie Estuary and southern Indian River Lagoon Conceptual Ecological Model extends south from the Jupiter Inlet, north to the St. Lucie County line, located north of the Fort Pierce Inlet. The Fort Pierce Inlet provides an additional connection between the Indian River Lagoon and the Atlantic Ocean. There are no major tributaries to the Indian River Lagoon from the St. Lucie Inlet south to the Jupiter Inlet. The model boundary extends eastward in the Atlantic Ocean out to the three-mile limit to include the near-shore reef tract. The western boundary includes the open-channel headwaters of the North and South Fork of the St. Lucie Estuary, up to the coastal canal structures (C-23, C-24, C-25, and C-44) (Figure A-26).

Due to extensive urban and agricultural drainage projects in the watershed of the St. Lucie Estuary, the historic drainage basin area has been greatly expanded to almost 775 square miles (Haunert et al. 1994). Major canals in the watershed include the C-23 and C-24, part of the Central and South Florida Flood Control Project. In addition, the St. Lucie Canal (C-44), which provides both navigation and the release of floodwaters from Lake Okeechobee, links the St. Lucie Estuary to Lake Okeechobee. Drainage basin expansion has also occurred, to a lesser extent, in other watersheds of the Indian River Lagoon. Canal 25, located north of the St. Lucie Estuary, has increased drainage into the Ft. Pierce Inlet section of the Indian River Lagoon.

The major effects of anthropogenic changes in both the St. Lucie Estuary and Indian River Lagoon watersheds are significant alterations in the timing (excess wet season flows, insufficient dry season flows), distribution, quality, and volume of freshwater entering the estuary, lagoon, and the ocean (Haunert et al. 1994). Despite these impacts, the St. Lucie Estuary and the Indian River Lagoon represent important aquatic habitats, with significant environmental and economic values. Understanding how these systems respond to stressors will provide a basis for well-informed management decisions relative to restoration activities.

Figure A-26: The Boundary of the St. Lucie Estuary and Indian River Lagoon Conceptual Ecological Model

A.8.3 External Drivers and Ecological Stressors

Sources of ecological stressors in the St. Lucie Estuary and the Indian River Lagoon originate from **agricultural and urban land use and development** and the ensuing construction and operation of **water management** systems, both in the local watersheds of the estuary and lagoon and in the larger drainage basin of Lake Okeechobee (Figure A-29, Section A.8.9). **Sea level rise** is also a factor that affects the ecology of these systems and should be considered during restoration efforts. These following drivers have been identified as the major stressors to the St. Lucie Estuary and Indian River Lagoon:

- **Altered freshwater flow volume and timing**, which result from Lake Okeechobee regulatory releases, basin flood releases, and basin water withdrawals. This includes 1) regulatory releases from Lake Okeechobee, 2) discretionary releases from Lake Okeechobee to the St. Lucie Estuary, 3) basin flood releases during wet periods that result from the combination of the enlargement of the local drainage basins and the drainage of agricultural and urban land uses within the basins, and 4) basin water withdrawals during dry periods that result from agricultural and urban water demands within the basins.

- **Altered estuary salinity** as a result of altered freshwater flows.

- **Input of nutrients and dissolved organic matter** that originate from agricultural and urban land use practices, compounded by regulatory and flood releases.

- **Input of contaminants** that result from pesticide and herbicide use in the drainage basins, via the canal system and overland flow discharging into the estuaries.

- Recreational stressors such as increases in **boating pressure** and **recreational/commercial fisheries**

- **Physical alterations** to the estuaries and adjacent tributaries resulting from the construction and maintenance of inlets, as well as the development of the shoreline and adjacent wetlands

A.8.4 Ecological Attributes

A.8.4.1 Salinity

Estuarine environments are sensitive to freshwater inputs. Modifications to natural patterns of volume, distribution, circulation or timing of freshwater discharges can cause severe stress upon the entire ecosystem (Haunert et al. 1994). Salinity patterns affect productivity, population distribution, community composition, predator-prey relationships and food web structure in the inshore marine habitat. In coastal ecosystems, salinity is a key ecological variable that controls important aspects of community structure and food web organization (Myers and Ewel 1990).

In 1975, the South Florida Water Management District began baseline investigations to determine seasonal presence of biota and to document the short-term reactions of estuarine organisms under various salinity conditions during controlled regulatory releases and watershed runoff events (Haunert and Startzman 1980, 1985; Haunert 1987). In 1987, researchers at the South Florida Water Management District began to develop the application of a resource-based management strategy similar to the “valued ecosystem component” approach developed by the United States Environmental Protection Agency (USEPA 1987) as part of its National Estuary Program. Through this strategy, management objectives can be defined by providing a suitable salinity and water quality environment for key species. Utilizing the application of the resource-based management strategy or valued ecosystem component approach, a

favorable range of inflow and related salinity was established for juvenile marine fish and shellfish, oysters and submerged aquatic vegetation (SAV). This favorable range of flows is referred to as the "salinity envelope." A series of curves for salinity regimes in the St. Lucie Estuary was developed by providing a salinity model with constant inflows until a steady salinity gradient was obtained. Using these salinity curves, preferred salinity envelopes for oysters and SAV can been illustrated. This provides a method to predict where healthy populations of valued ecosystem attributes (i.e., valued ecosystem components) would exist if the favorable range of flows and salinity is not violated beyond the frequency that is attributed to natural variation of flows from the watershed. A geographic information system (GIS) was utilized to define specific locations within the designated valued ecosystem component distributions. Factors in addition to salinity that were considered for oysters and SAV included appropriate depth and type of sediment. A salinity envelope of 350 to 2,000 cubic feet per second (cfs) was established for the St. Lucie Estuary based on previous research on fish and shellfish, as well as predicted monthly mean salinity from various inflows at designated areas.

Due to significant improvements in the current understanding of St. Lucie Estuary watershed flows, estuary salinity, and the need to go beyond establishing a favorable range of favorable flows, a reassessment of the flow distribution for the St. Lucie Estuary is required to establish a target flow distribution. St. Lucie Estuary watershed flow distribution targets should ensure the protection of the salinity-sensitive biota in the estuary. It is assumed that species diversity in the St. Lucie Estuary requires the hydrology to have characteristics of a natural system and that the monthly flow distribution is a critical hydrologic characteristic. Particularly, the frequency of low monthly flows and high monthly flows should be similar to that of a natural system. Table A-4 summarizes the flow distribution by range of the three "natural distributions" analyzed and used for comparison to the "current condition" as represented by the modeled watershed runoff based on 1995 land use conditions. NSM is the Natural Systems Model developed for the St. Lucie Estuary watershed, HSPF is the Hydrologic Simulation Program Fortran estimation of predevelopment conditions in the St. Lucie Estuary watershed and Peace River represents the natural watershed conditions in the Peace River Florida watershed. (Haunert and Konyha 2001).

Table A-4: List of Natural Flow-Frequency Distributions and the 1995 Base Flow-Frequency Distributions, Based on 1965-1995 Climate

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

A.8.4.2 Submerged Aquatic Vegetation Distribution, Abundance and Health

The submerged seagrasses and freshwater macrophytes provide habitat and nursery grounds for many fish and invertebrate communities (Gilmore 1977, 1988; Gilmore et al. 1981, 1983; Stoner 1983), and provide food sources for key trophic level species as well as commercially important organisms (Dawes et al. 1995, Virnstein and Cairns 1986). SAV communities also have an important role in benthic-based primary productivity and sediment stabilization (Stoner 1983, Virnstein et al. 1983, Gilmore 1987, Woodward-Clyde 1998). Seagrass meadows have been described as the marine analog of tropical rain forests because of their structural complexity, biodiversity and productivity (Simenstad 1994). In the Indian River Lagoon, seagrass habitats provide the ecological basis for a fishery industry worth about a billion dollars a year (Virnstein and Morris 1996).

All species of SAV respond negatively to rapidly changing salinity. Decreased light penetration that results from silt, turbidity, color and phytoplankton blooms further stresses these plant communities. The result has been a decline in the spatial coverage of beds of SAV in the estuary and lagoon (Woodward-Clyde 1998). The loss of seagrasses negatively impacts fish and invertebrate communities, destabilizes sediments and promotes a shift in primary productivity from benthic macrophytes to phytoplankton. The latter two factors can provide negative feedback to further diminish seagrass beds (Woodward-Clyde 1998).

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

In a seagrass change analysis of the Southern Indian River Lagoon, the 47-mile portion of the lagoon was divided into five segments (Robbins and Conrad 2001) (Figure A-27). A preliminary target of the Surface Water Improvement and Management (SWIM) seagrass program is to restore and maintain seagrasses to a depth of 5.6 feet lagoonwide (Virnstein and Morris 1996). Between 1992 and 1999, the maximum southern Indian River Lagoon seagrass area (9,864 acres) occurred in 1996 representing approximately 50 percent of the target acreage. The lowest acreage mapped during this period occurred in 1999 when seagrass covered approximately 39 percent (7,808 acres) of the target area. Total seagrass acreage per mapping year is presented in Table A-5 for the entire southern Indian River Lagoon region. However, trends observed for the southern Indian River Lagoon as a whole do not necessarily reflect seagrass "health" and trends for individual segments. Accordingly, results for each segment are also presented in the tables and discussed in more detail in Robbins and Conrad (2001). The St. Lucie Estuary GIS Application Model developed by Woodward-Clyde for the South Florida Water Management District in 1998 identifies major areas of the estuary that would be suitable for seagrass establishment.

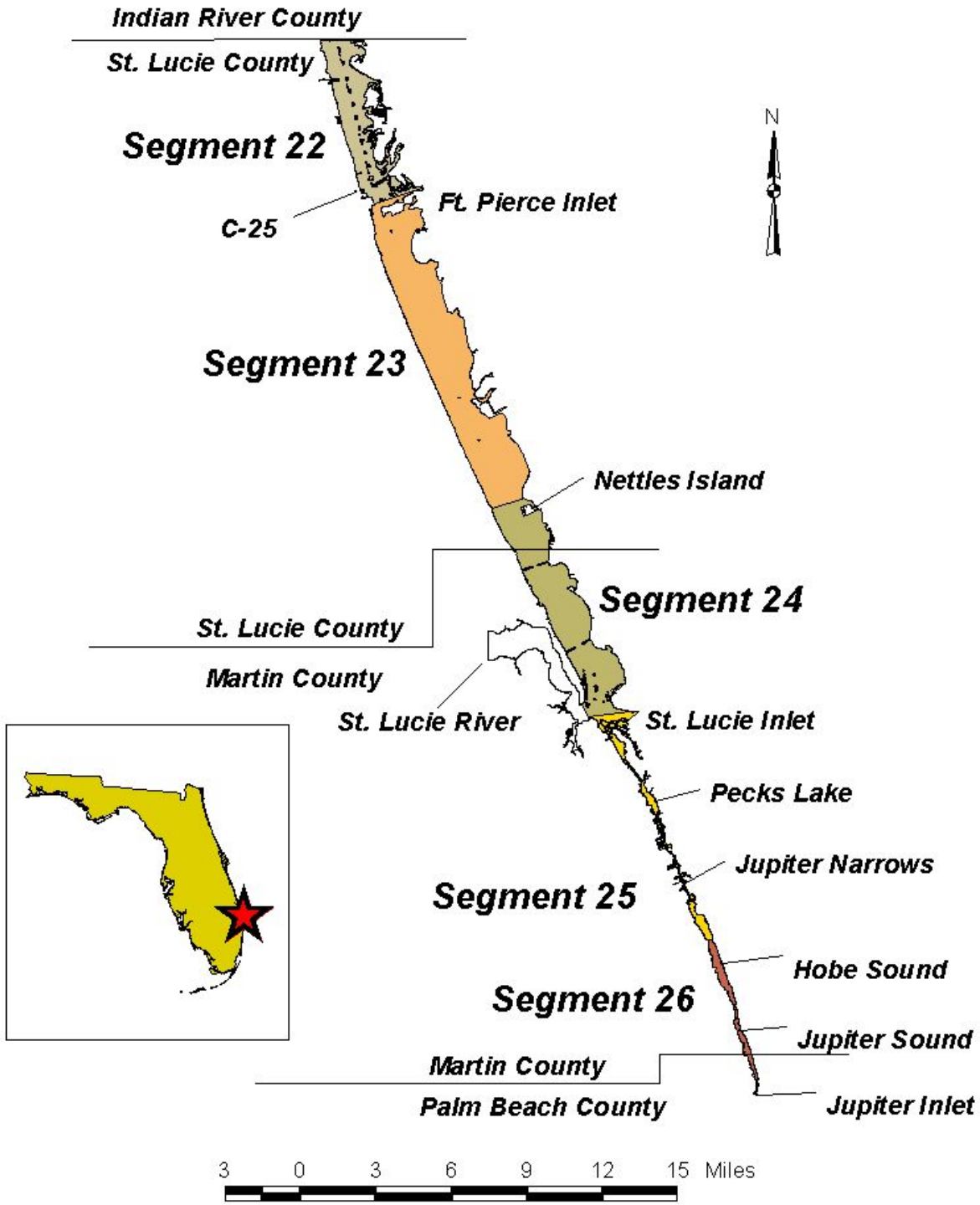


Figure A-27: Segments in the Seagrass Change Analysis of the Southern Indian River Lagoon

Table A-5: Southern Indian River Lagoon Seagrass (1986 – 1999) and Seagrass Target Acreage

Lagoon Segment Number	Total Seagrass Acreage Per Mapping Year						Target Acreage
	1986	1989	1992	1994	1996	1999	
26	-	-	365	341	303	320	324
25	-	-	413	281	136	134	870
24	1,806	1,279	1,513	1,571	1,589	1,520	5,469
23	3,916	4,815	4,273	5,007	5,187	2,856	8,833
22	2,471	2,435	2,310	2,307	2,649	2,978	4,303
Total	8,193	8,529	8,874	9,507	9,864	7,808	19,799

A.8.4.3 Oyster Communities

Oysters (*Crassostrea virginica*) and other bivalves, such as mussels, found in the St. Lucie Estuary and Indian River Lagoon are sensitive to salinity and siltation. Estuaries represent depositional features, dominated by soft sediments with little surface structure or roughness. Under natural conditions, oyster reefs can be very large and provide extensive attachment area for oyster spat and numerous associated species such as mussels, tunicates, bryozoans and barnacles (Woodward-Clyde 1998). Several studies (Pearse and Wharton 1938, Wells 1961, Bahr and Lanier 1981) have found from 40 to over 300 faunal species in oyster beds, including other mollusks, crustaceans, annelids, numerteans, flatworms, sponges, coelenterates and protozoa. As summarized in Woodward-Clyde (1998), oysters exhibit varied preferred salinity ranges and mortality thresholds. The exact thresholds vary depending on age, condition, temperature and other factors. Generally, adult oysters require salinity levels above 3 parts per thousand (ppt), with optimal growth and survival at 12-20 ppt. Oyster communities are adversely affected by diseases, predators and algal blooms at seawater salinity conditions. “Dermo” disease, caused by the endoparasite *Perkinsus marinus*, is limited to salinities greater than 9 ppt and has been implicated as a cause of 50 percent of adult oyster mortality in Florida (Quick and Mackin 1971, Mackin 1962).

Oysters have been documented in the past as abundant in the estuary and lagoon. Presently, their distribution is limited to approximately 200 acres from the estimated historic coverage of 1,400 acres. A restoration target of approximately 900 acres of healthy oyster beds has been established based on reestablishing a salinity distribution in the areas that provide a potentially suitable bottom habitat as indicated by the St. Lucie Estuary GIS Application Model (Woodward-Clyde 1998).

A.8.4.4 Estuarine Fish Communities/Sport and Commercial Fisheries

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

Submerged aquatic vegetation communities provide nursery ground habitat for juvenile stages for reef and recreationally important fishes in the St. Lucie Estuary and Indian River Lagoon (Lewis 1984, Virnstein et al.. 1983). This community includes mutton snapper (*Lutjanus analis*), yellowtail snapper (*Ocyurus chrysurus*), lane snapper (*Lutjanus synagris*), yellowtail parrot fish (*Sparisoma rubripinne*), gag grouper (*Mycteroperca microlepis*), pinfish (*Lagodon rhomboids*), tarpon (*Megalops atlanticus*), common

snook (*Centropomus undecimalus*), crevalle jack (*Cranx hippos*), spotted sea trout (*Cynoscion nebulosus*), and redfish (*Sciaenops ocellatus*). The distribution of these juvenile fishes indicates a stenohaline and stenothermic condition in seagrass beds. Seagrass loss and alterations to the salinity gradient diminish the suitable habitat used as nursery grounds for juvenile reef fishes (R.G. Gilmore, Coastal and Ocean Science, Inc., personal correspondence 2000).

Ichthyoplankton recruitment into the St. Lucie Estuary and Indian River Lagoon is diminished due to freshwater flushing resulting from regulatory discharges during key times of the year (Gaines and Bertness 1992). Estuarine fish species that are negatively affected include spotted seatrout, common snook, opossum pipefish (*Microphis brachyurus lineatus*), and lower trophic level fishes. Settlement rates of juvenile snook at specific sites can provide a measure of ichthyoplankton recruitment (Gilmore personal correspondence 2000). The spotted seatrout is an estuarine-dependant species that is specifically associated with seagrass beds in the estuary and lagoon. Post-larval and juvenile densities in seagrass beds, particularly shoalgrass, reflect seasonal salinity and hydrology changes and seagrass bed recovery, (Gilmore personal correspondence 2000).

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

Large freshwater releases from the St. Lucie Canal in the winter of 1998 produced significant incidences of fish disease and mortality, promoted toxic dinoflagellate blooms, and reduced the overall biodiversity of estuarine and freshwater fish communities within the Indian River Lagoon for several months post release (Gilmore personal data and observations May 1998). Diseased and abnormal fish have also been documented within the St. Lucie Estuary. In 1979, 1980, and in March 1998, within several weeks of sudden releases of large volumes of water (greater than 8,000 cfs) into the St. Lucie Estuary, an increased prevalence (greater than 6 percent) of fish with ulcerative mycosis, which is caused primarily by a fungus, was recorded (Florida Fish and Wildlife Conservation Commission/Florida Marine Research Institute unpublished data). Since March 1998, the Florida Marine Research Institute has noted a low level of prevalence of fish with ulcerative mycosis in monthly surveys and principally in silver mullet, striped mullet, and sheepshead. The incidence of ulcerative mycosis is consistently correlated with low salinity habitats (Landsberg et al. 2000, Kane et al. 2000) and is known elsewhere in the United States to be attributed to the fungus *Aphanomyces invadens* (Blazer et al. 1999). The range of fish health problems in the St. Lucie and Indian River systems are likely to be attributed to low salinity inputs and associated pathogens, contaminants and potentially harmful algal bloom species. The frequency of abnormalities of all types appears to have increased in recent years (Browder et al. 1997, Fournie et al. 1996, Gabriel 1999, Gassman et al. 1994). A study is currently underway to determine if there are links between these abnormalities and the toxins being transported with the freshwater discharges.

Although harvesting of fish and shellfish by the human population of the region has been shown to extend at least 8,000 years ago to the Ais and Timucuan Indians, the first commercial fisheries did not develop until the 1890s. Woodward-Clyde (1994) documented a shift in finfish species composition with a higher proportion of lower priced species taken more recently. The increased harvest of species such as menhaden and mullet may also have an effect on the overall ecology and productivity of the lagoon. One

species, the spotted seatrout, has shown a steady and significant decline in landing (over 50 percent) from 1962 to 1988. Because this species is almost entirely dependent upon the lagoon throughout its life cycle, this decline may be indicative of conditions within the lagoon. Recreational fishing continues to expand as well within the St. Lucie Estuary and Indian River Lagoon with the growth of both full-time residents and tourists. The number of fishing trips by residents alone increased from 806,067 in 1970 to 1,811,815 in 1990 and is estimated to be 2,890,448 by 2010 (Woodward-Clyde 1994).

A.8.4.5 Estuarine Benthic Communities

Benthic macroinvertebrate communities in the St. Lucie Estuary and Indian River Lagoon are sensitive to bottom type, water quality and salinity fluctuations. A decline in diversity of benthic organisms and the spread of pollution-tolerant macroinvertebrates, such as the polychaete worm, *Glycinde solitaria*, is often one indicator of deteriorated water quality in the estuary and lagoon (J. Beal, Florida Department of Environmental Protection, personal communication). Furthermore, the fluctuation between periods of high and low discharge causes alternating shifts between estuarine and freshwater species (Haunert and Startzman 1985). Their results indicated an overall reduction of 44 percent of the benthic macroinvertebrates. The greatest change in benthic species composition occurred in the newly created oligohaline zone (0.5 to 5 ppt). Some species of macroinvertebrates (freshwater midges) showed significant increases and there was an introduction of six freshwater species under these conditions. At least four estuarine species were recorded as lost from the oligohaline zone. Changes in biodiversity and speciation in the benthic communities as a result of restoration actions have been studied in the Indian River Lagoon by Virnstein (1990). This study noted that, at a meter spatial scale, seagrass beds in the Indian River Lagoon may contain three times the density of macro-benthic invertebrates found in unvegetated sediments only a few meters away. At a centimeter spatial scale, two core samples located adjacent to one another in an apparently homogeneous habitat, were found to exhibit differences in density of macro-benthic invertebrates by a factor of two or three (Virnstein 1990).

A.8.4.6 Shoreline Habitat

Mangrove wetlands and the emergent bank vegetation of tributaries of the St. Lucie Estuary and Indian River Lagoon support fish and macroinvertebrate communities and prevent siltation due to bank erosion. These shoreline habitats have decreased in spatial extent and in function through habitat loss and the loss of connectivity of presently isolated floodplain and shoreline plant communities. A significant portion of the floodplain in the North Fork of the St. Lucie River is completely or partially isolated from river's main branch because of dredging conducted during the 1920-1940s. As a result of these dredging activities, certain natural communities including floodplain swamp, floodplain forest, hydric hammock and oxbows (blackwater river and stream) are no longer fully connected to the existing main branch, resulting in a loss of natural filtration of water-borne nutrients originating in the watershed. Pilot projects are underway to reconnect mangrove and freshwater wetlands to the main channels of the North and South Forks.

A.8.4.7 Near-Shore Reef

A near-shore reef forms bands of unique marine habitat two to three miles offshore of the Atlantic Coast between the St. Lucie and Ft. Pierce Inlets. This near-shore reef, built by Sabellarid polychaetes, represents the northern extent of nonreef building corals. The reef provides foraging habitat for juvenile representatives of the federally-endangered green sea turtles. The near-shore reef is adversely affected by high level discharges and the resulting silt and salinity plumes that are found primarily to the south of the St. Lucie and Ft. Pierce Inlets (Gilmore personal correspondence 2000). Approximately 66 percent of the seagrass fishes in the lagoon are catadramous species that spawn on the continental shelf (Gilmore 1988). Continental shelf fish biodiversity is influenced by various reef structures and is also susceptible to

sedimentation. Major live coral reefs, *Oculina varicosa,* are only abundant on the shelf edges between 60 and 100 meters. These complex rock, Sabellarid and coral structures provide important habitat that supports a diverse benthic fish community on the continental shelf whose associated faunas increase the lagoon fish biodiversity adjacent to ocean inlets such as the St. Lucie Inlet (Gilmore 1995).

A.8.5 Ecological Effects

Critical Linkages between Stressors and Attributes/Working Hypotheses

Several major causal pathways appear to account for the decline in the ecological attributes of the St. Lucie Estuary and Indian River Lagoon. These casual pathways are based on key hypotheses developed during the conceptual ecological model workshops. These hypotheses determine the content and organization of the St. Lucie Estuary and Indian River Lagoon Conceptual Ecological Model. A discussion of the causal pathways is provided below, followed by the key hypotheses, which are organized by attribute.

The most significant ecological impact to the St. Lucie Estuary and Indian River Lagoon is the alteration of estuarine salinity zones. Salinity is one of the principal factors influencing the distribution and abundance of organisms inhabiting estuaries (Kennish 1990). Changes in the distribution, timing and rapidity of change of salinity include low saline events, due to basin and Lake Okeechobee regulatory water releases, and hypersaline events, due to excessive basin water withdrawals and drought conditions.

Accompanying the regulatory water releases is the transport of massive volumes of organic and inorganic sediments, which contribute to deposits of muck in the estuaries (Shrader 1984, Gunter and Hall 1963, Pitt 1972). The large accumulations of muck covering the bottom of the estuary dramatically decrease the quality and quantity of habitat for benthic macroinvertebrates, oysters and finfish. High volume releases create an oceanic plume of colored water and suspended solids extending to the near-shore reef in the Atlantic Ocean. Together, altered salinity and siltation can have negative impacts to important components of the estuarine and near-shore reef ecosystems, including SAV, phytoplankton, fish and macroinvertebrate communities, fish-eating birds, and reef-building polychaetes (Haunert 1988). The recurring high-flow conditions in the St. Lucie Estuary have significantly reduced the numbers of oysters and the frequency at which these high flows occur have impeded recovery of this community (Cake 1983). Damage to the near-shore reef habitat, especially to chicken-liver sponge communities, can result in secondary effects on juvenile green sea turtles that feed on the sponges (J.A. Browder, National Oceanic and Atmospheric Administration, personal correspondence 2000). Changes in temporal and spatial patterns of salinity envelopes can be significant stressors to fish and shellfish populations. Lowered salinities can result in atypical freshwater conditions that are conducive to the persistence of fish pathogens, such as fungi, that have been found in lesioned fish within the St. Lucie Estuary (J. Landsberg, Florida Marine Research Institute, personal correspondence 2000).

The above conditions are exacerbated by the loss and fragmentation of shoreline habitat and by the input of toxins, nutrients and dissolved organics (Haunert et al. 1994). The loss and fragmentation of habitat due to human development results in the direct loss of mangrove wetlands and emergent bank vegetation upon which fish and macroinvertebrate communities depend. Increased inputs of nutrients and dissolved organics degrade water quality altering the phytoplankton composition and abundance, which contributes to the accumulation of muck. The accumulation in muck in turn covers estuarine hard bottom habitat, and contributes to changes in phytoplankton and SAV communities. Increased levels of toxicants, from agricultural run-off, urban development and the boating industry including metals, pesticides and their residues, can cause adverse impacts to aquatic food chains leading to fish-eating birds. A decrease in the numbers, diversity and health of fisheries may also have secondary effects on the health and mortality of the resident dolphin population in the Indian River Lagoon (Browder personal correspondence 2000).

A.8.5.1 Submerged Aquatic Vegetation Abundance, Distribution and Health

Relationship of Submerged Aquatic Vegetation to Altered Estuarine Salinity Envelope

Changes in normal salinity ranges can adversely affect SAV. Different species of SAV have different desirable salinity ranges. When the salinity falls outside these optimal ranges, adverse impacts to the size, density and species compositions of seagrass beds can occur

Level of certainty - moderate

Relationship of Submerged Aquatic Vegetation to Input of Nutrients and Dissolved Organic Matter

The input of increased levels of nutrients and dissolved organic matter effect SAV abundance and health by increasing the phytoplankton levels and water color, which can affect the amount of light penetration in the water column and its availability to SAV communities.

Level of certainty - low

Relationship of Submerged Aquatic Vegetation to Increased Epiphyte Growth

Increased epiphyte growth can be caused by both increases in available nutrients that accelerate their growth and/or a decrease in grazers that help keep the epiphytes on the SAV at a normal level by feeding on them. This increase in epiphytes can shade the blade of the SAV, thus decreasing the amount of light that can be absorbed by the plant and used for photosynthesis.

Level of certainty - low

Relationship of Submerged Aquatic Vegetation to Accumulation of Muck and Ooze

Submerged aquatic vegetation communities require suitable substrate for successful recruitment and establishment. Large deposits of muck and ooze that have displaced normal sandy substrate in the estuary and portions of the Indian River Lagoon have contributed to the decrease in extent of SAV beds.

Level of certainty - moderate

Relationship of Submerged Aquatic Vegetation to Boating Pressure

The increase in the numbers of boats in the lagoon has contributed to the decrease in extent of SAV beds. Shallow areas, which normally contain the healthiest and most abundant beds, are most likely to be impacted when boats run aground, or boat props come in close proximity to the grass beds.

Level of certainty - high

Relationship of Physical Alterations in the Estuary to Submerged Aquatic Vegetation Distribution, Abundance and Health

The physical alterations in the estuary that have an adverse impact on SAV include the destruction of natural shoreline and replacement with hardened shoreline such as bulkhead and seawalls. As the shallow sloping shorelines are eliminated, the area available with the appropriate depth for SAV recruitment and growth will decline.

Level of certainty - high

A.8.5.2 Oyster Communities

Relationship of Oysters to Extreme Alterations of the Estuarine Salinity Envelope

Extremely large rainfall events or sudden large volume releases from Lake Okeechobee cause large volumes of fresh water over a short period of time to enter the estuary causing a sudden drop in salinity. This sudden drop can lead to significant mortality in the oyster population.

Level of certainty - high

Relationship of Oysters to Lower Level Releases of Fresh Water that Result in Less Than Ideal Salinity Conditions in the Estuary

Less extreme, but still undesirable fluctuations in salinity, stresses the oyster population and may (depending on the timing and severity of the salinity change) affect the reproductive success during that given time frame. The health of the oysters is compromised during these episodes, making the oyster more susceptible to predators and disease.

Level of certainty - low

Relationship of Oysters to Muck and Ooze Accumulation

Oyster recruitment is negatively effected by the accumulation of muck and ooze in the estuary. Muck and ooze are unsuitable substrates for spat settlement. Areas that once contained sand and/or shell have been covered by these very soft, unconsolidated sediments. Freshwater flows into the estuary and lagoon carries sediments with high organic content. Alteration of freshwater flow can also result in an increase in the transport of floating aquatics into the estuary, which then degrade and contribute to the rate of organic and muck accumulation. Increased volume of fresh water from the watershed also increases nutrient loads, which have contributed to higher than normal levels of algae in the system. As the algae dies off and settles to the bottom, it also accelerates the muck and ooze formation process.

Level of certainty - moderate

A.8.5.3 Estuarine Fish Communities

Relationship of Estuarine Fish Communities to Reduced Coverage and Health of Submerged Aquatic Vegetation

SAV provide nursery grounds for many fish and invertebrate communities. A reduction in size and health of SAV beds effects the location, abundance and speciation of fisheries in the estuary.

Level of certainty - moderate

Relationship of Estuarine Fish Communities to Increased Levels of Toxins

Toxins which are introduced to the estuary with the freshwater inputs can bioaccumulate in the fish causing increased levels (above what is thought to be normal “background” levels) of fish abnormalities. Certain species of fish appear to be more susceptible than others to the effects of toxins.

Level of certainty - low

Relationship of Estuarine Fish Communities to Loss of Mangrove Habitat

Mangroves supply both a structural refuge for juvenile fish and are an important component in the detrital food chain for the estuary. Destruction of the mangrove shorelines, which once lined large areas of the lagoon and estuary, has negatively impacted the fisheries in the estuary and lagoon. In large areas of the estuary, all natural shoreline has been lost to development.

Level of certainty - high

Relationship of Estuarine Fish Communities to Loss and Fragmentation of Freshwater Floodplain Forest

The loss and fragmentation of freshwater floodplain forest in the North and South Forks of the estuary has decreased the quality of the habitat in the oligohaline zone. Areas of shoreline that have been converted from natural forest, shrub or emergent vegetation due to development, no longer provide habitat for nursery ground for juvenile fisheries. These oligohaline zones are very important because the low salinity zone provides refuge to the juvenile fish from the larger predatory fish that prefer higher salinities.

Level of certainty - moderate

A.8.5.4 Estuarine Benthic Communities

Relationship of Macroinvertebrate Community Shift to Altered Salinity Envelope

Sudden and severe shifts in salinity can result in changes in the diversity and species composition of benthic invertebrates in the estuary and lagoon. The increase in nutrients and toxins carried into the estuary with the freshwater can also cause a shift to more pollutant tolerant species. Toxins can also bioaccumulate causing a decline in the health of the communities and adversely impact aquatic food webs.

Level of certainty - low

A.8.5.5 Shoreline Habitat

Relationship of Loss of Mangroves and Loss of Freshwater Floodplain Forest to Physical Alterations to the Estuary

Physical alterations to the estuary caused by increased population in the coastal zone has lead to the conversion of natural shoreline, both mangrove and freshwater floodplain, to seawalls, bulkheads and other types of hardened shoreline. This loss of habitat impacts many other important components of the estuary including fisheries, crabs, benthic invertebrates and birds.

Level of certainty - high

A.8.5.6 Near-Shore Reef

Relationship of Near-Shore Reef to Altered Freshwater Flows

Oceanic plumes of fresh water and the associated sediments are damaging to near-shore reefs. During periods of extreme discharge events, large volumes of fresh water are pushed through the St. Lucie Estuary and Indian River Lagoon onto the near-shore reefs. This highly colored fresh water carries with it sediments that affect the health and abundance of the near-shore reef community.

Level of certainty - low

A.8.5.7 Estuarine Geomorphology

Relationship of the Exchange of Atlantic Ocean Water with the Indian River Lagoon and St. Lucie Estuary to Sea Level Rise

Predicted rates of sea level rise during the next century (up to two feet) will increase the exchange and circulation of Atlantic Ocean water with that in the Indian River Lagoon and the St. Lucie Estuary. The effect of this would be a more saline condition overall and a shift in the location and salinity ranges in the estuary. This shift could effect the location and health of most of the flora and fauna in the estuary including SAV, oysters, benthic communities and shoreline vegetation.

Level of certainty - low

A.8.6 Research Questions

Ecological changes resulting from the restoration of freshwater flows to the St. Lucie Estuary and Indian River Lagoon will be influenced by interrelated causal relationships with low levels of certainty. All of these uncertainties involve the freshwater flow into the estuary and lagoon. Several of these relationships are based purely on the volume, timing and distribution of the fresh water itself, while others include the elevated levels of nutrients and toxins that are associated with flows originating from the developed watershed.

Relationship of Submerged Aquatic Vegetation to Input of Nutrients and Dissolved Organic Matter

What effect does increased levels of nutrients and dissolved organics have on light attenuation and its subsequent effect on the distribution, health and abundance of SAV in the St. Lucie Estuary and Indian River Lagoon?

Relationship of Macroinvertebrate Community Shift to Altered Salinity Envelope

What effect do undesirable salinity shifts have on the diversity and community species composition of macroinvertebrates in the St. Lucie Estuary and Indian River Lagoon?

Relationship of Submerged Aquatic Vegetation to Increased Epiphyte Growth

What is the relationship of the amount of epiphyte coverage found on SAV with the location, abundance and diversity different species in the St. Lucie Estuary and Indian River Lagoon?

Relationship of Oysters to Lower Level Releases of Fresh Water That Result in Less Than Ideal Salinity Conditions in the St. Lucie Estuary

What is the functional relationship between lower volume and longer timeframe releases on the health and long-term survivability and reproduction of the oyster community in the St. Lucie Estuary?

Relationship of Estuarine Fish Communities to Salinity Fluctuations

How do changes in salinity influences the prevalence of fish with lesions? What is the functional relationship between salinity regimes, fish lesions, and the proliferation of certain fish pathogens and potentially harmful algal bloom species?

Relationship of Estuarine Fish Communities to Increased Levels of Toxins

What is the functional relationship between toxins and abnormalities and/or lesions found on fish in the St. Lucie Estuary and Indian River Lagoon?

Relationship of Near-Shore Reef to Altered Freshwater Flows

What effect do large volume releases from either Lake Okeechobee or the St. Lucie Estuary watershed have on the near-shore reefs and their associated faunal communities?

Relationship of the Exchange of Atlantic Ocean Water with the Indian River Lagoon and St. Lucie Estuary to Sea Level Rise

What is the relationship of sea level rise to the estuary "salinity envelope"?

A.8.7 Hydrologic Performance Measures

A.8.7.1 Salinity Envelope

The performance measure for the salinity envelope in the St. Lucie Estuary and Indian River Lagoon is the occurrences of high and low flows. The targets are as follows:

High Flows

- Decrease the numbers of occurrences of flows between 2,000 cfs and 3,000 cfs to less than 4.6 percent of the time
- Decrease the number of occurrences of flows greater than 3,000 cfs to less than 2.7 percent of the time

Low Flows

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

A.8.8 Ecological Performance Measures

A.8.8.1 Submerged Aquatic Vegetation

The performance measures for submerged aquatic vegetation are as follows:

- Increase coverage of *Halodule, Ruppia and Vallisneria* in the St. Lucie Estuary to include all areas (approximately 920 acres) that are indicated to be suitable habitat based on the St. Lucie Estuary GIS Application Model.
- Increase coverage of beds of *Halodule*, *Ruppia*, *Syringodium*, *Thalassia*, and the three *Halophila* species, including *H. johnsonii*, in the Indian River Lagoon at depths down to 5.6 feet (Virnstein and Morris 1996).

A.8.8.2 Oysters

The performance measure for oysters in the St. Lucie Estuary is to increase abundance and health of oysters. The St. Lucie Estuary GIS Application Model will be used to indicate areas most likely to

support the reestablishment of oysters. The target is to reestablish approximately 900 acres of healthy oyster populations.

A.8.8.3 Estuarine Fish Communities

The performance measures for estuarine fish communities are as follows:

Species Richness/Diversity

- Increase species richness at benchmark locations, such as Bessey Cove (Gilmore personal communication) to levels equaling or exceeding those in the historic 1970s database. In other representative sample sites, increase species richness above present baseline conditions

Fish Health and Pathology

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

Juvenile Reef and Recreationally Important Fish

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

Lower Trophic Level Fishes

- Increase abundance of mullet, menhaden and anchovy to historic 1970s database based on catch per unit effort

Spotted Sea Trout

- Increase post-larval and juvenile densities in representative seagrass beds, particularly shoalgrass, from present baseline conditions

Snook

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

Redfish

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

Opossum Pipefish

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

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

A.8.8.4 Estuarine Benthic Communities

The performance measure for estuarine benthic communities is to increase species richness, abundance and diversity of benthic species to that typically found in a healthy estuarine community.

A.8.8.5 Shoreline Habitat

The performance measures for shoreline habitat are as follows:

- Increase spatial extent of mangrove and emergent shoreline plant communities through replanting.
- Reconnect approximately 100,000 linear feet of isolated river floodplain and remove and control exotics on the reconnected floodplain.

A.8.8.6 Near-Shore Reef

The performance measures for shoreline habitat are as follows:

- Reduce siltation rates to natural levels on reefs off the St. Lucie and Fort Pierce Inlets by reducing the silt carried by freshwater plumes that result from high discharge events from both the St. Lucie Estuary watershed and Lake Okeechobee.
- Reduce salinity fluctuations on reefs off the St. Lucie and Ft. Pierce inlets by eliminating the freshwater plumes reaching the reefs that result from high discharge events from both the St. Lucie Estuary watershed and Lake Okeechobee. Ecological indicators and targets include the restoration of coral, fish and macro-invertebrate community structure and biodiversity of reefs to that documented in 1970's baseline data.

A.8.9 Model

The diagram for the St. Lucie Estuary and South Indian River Lagoon Conceptual Ecological Model is presented in Figure A-29. The key to the symbols used in the diagram is presented in Figure A-28.

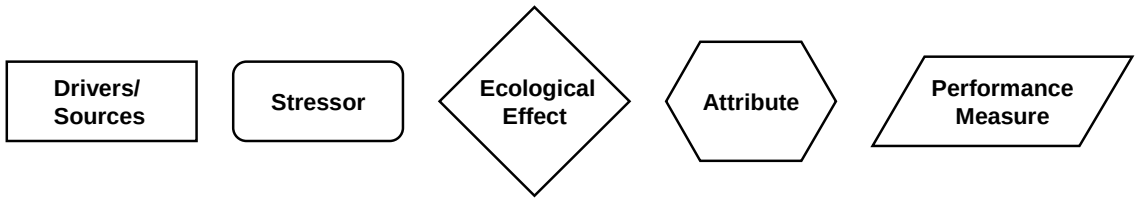


Figure A-28: Key to the Symbols Used in the Following Diagram

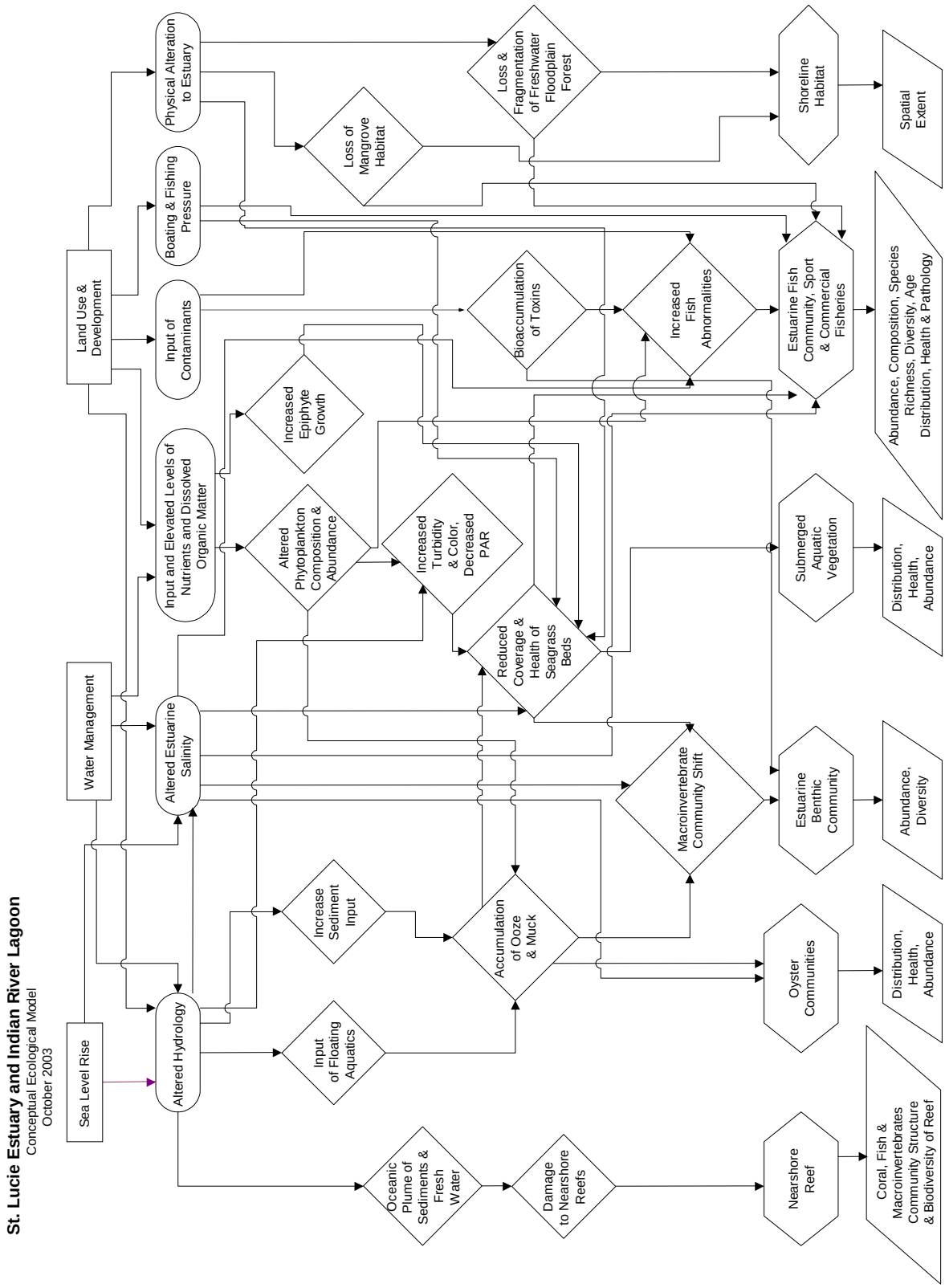


Figure A-29: St. Lucie Estuary and Indian River Lagoon Conceptual Ecological Model Diagram

A.8.10 Literature Cited

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

Blazer, V.S., W.K. Vogelbein, C.L. Densmore, E.B. May, J.H. Lilley, and D.E. Zwerner. 1999. Aphanomyces as a cause of ulcerative skin lesions of menhaden from Chesapeake Bay tributaries. J. Aquatic Animal Health 11: 340-349.

Browder, J.A., N.P. Gassman, M.C. Schmale, and C. Sindermann. 1997. Restoration success criteria based on prevalence of abnormalities in fish. In: Science Subgroup. Ecological and Precursor Success Criteria for South Florida Ecosystem Restoration. Science Sub-group Report to the Working Group of the South Florida Ecosystem Restoration Task Force, Miami, Florida.

Browder, J.A. and D. Moore. 1981. A new approach to determining the quantitative relationship between fishery production and the flow of freshwater to estuaries In: Cross, R., and D.L. Williams (eds). Proceedings of the National Symposium on Fresh Water Inflow to Estuaries, September 1980, San Antonio, Texas, Volume 1. FWS/OBS-81/04, United States Fish and Wildlife Service, Washington, D.C., pp. 403-430.

Cake, E.W., Jr. 1983. Habitat suitability Index Models: Gulf of Mexico American Oyster. FWS/OBS-82/10.57, Office of Biological Services, United States Fish and Wildlife Service, United States Department of the Interior, Washington, D.C.

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

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

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

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

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

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

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

Gilmore, R.G. 1987. Fish, macrocrustacean, and avian, population dynamics and cohabitation in tidally influenced impounded subtropical wetlands. In: Whitman, W.R., and W.H. Meredith (eds).

Proceedings of a Symposium in Waterfowl and Wetland Management in the Coastal Zone of the Atlantic Flyway. Delaware Department of Natural Resources and Environmental Control, Dover, Delaware.

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

Gilmore, R.G., C.J. Donahoe, D.W. Cooke, and D.J. Herema. 1981. Fishes of the Indian River lagoon and adjacent waters, Florida. Technical Report 41, Harbor Branch Foundation, Fort Pierce, Florida.

Gilmore, R.G. 1988. Subtropical seagrass fish communities, population dynamics, species guilds and microhabitat associations in the Indian River Lagoon. Ph.D. Dissertation, Department of Biological Sciences, Florida Technical University; Melbourne, Florida.

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

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

Gunter G., and G.E. Hall. 1963. Biological investigations of the St. Lucie Estuary (Florida) in Connection with Lake Okeechobee Discharges through the St. Lucie Canal. Gulf Research Reports 1(5), Gulf States Marine Fisheries Commission, Ocean Springs, Mississippi.

Haunert, D.E. 1988. Sediment Characteristics and Toxic Substances in the St. Lucie Estuary, Florida. Technical Publication DRE-259, South Florida Water Management District, West Palm Beach, Florida.

Haunert, D.E., and K. Konyha. 2001 Establishing St. Lucie Estuary Watershed Inflow Targets to Enhance Mesohaline Biota. Unpublished, South Florida Water Management District, West Palm Beach, Florida.

Haunert, D.E., and R.J. Startzman. 1980. Some Seasonal Fisheries Trends and Effects of a 1000 cfs Freshwater Discharge on the Fishes and Macroinvertebrates in the St. Lucie Estuary, Florida. Technical Publication DRE-109, South Florida Water Management District, West Palm Beach, Florida.

Haunert, D.E., and R.J. Startzman. 1985. Some Short-Term Effects of a Freshwater Discharge on Biota of the St. Lucie Estuary, Florida. Technical Publication DRE-213, South Florida Water Management District, West Palm Beach, Florida.

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

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

Kane, A.S., M.J. Dykstra, E.J. Noga, R. Reimschussel, A. Baya, C. Driscoll, H.W. Paerl, and J. Landsberg. 2000. Etiologies, observations and reporting of estuarine finfish lesions. Marine Environmental Research 50: 473-477.

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

Landsberg, J.H., E. Sosa, S. Cook, A. Forstchen, N. Perry, B. Winner, J. Whittington, K.A. Steidinger, and J.W. Bernstein. 2000. Fish lesions and Pfiesteria in Florida. Presented at the American Fisheries Society Fish Health Section Meeting, Pensacola, Florida.

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

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

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

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

Pitt, W.A., Jr. 1972. Sediment loads in canals 18, 23, 24 in southeastern Florida. Open File Report 72013, United States Geological Survey, Tallahassee, Florida.

Quick, J.A., Jr., and J.G. Mackin. 1971. Oyster parasitism by *Labyrinthomyxa marina* in Florida. Marine Research Laboratory Professional Paper Series no. 13., Florida Department of Natural Resources, Tallahassee, Florida.

Robbins, R., and C. Conrad. 2001. Southern Indian River Lagoon Seagrass Change Analysis (1986-1999). South Florida Water Management District, West Palm Beach, Florida.

Shrader, D.C. 1984. Holocene sedimentation in a low energy microtidal estuary, St. Lucie River, Florida. Masters thesis, University of Florida, Gainesville, Florida.

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

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

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

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

Virnstein, R.W., and K.D. Cairns. 1986. Seagrass Maps of the Indian River Lagoon. Report submitted by Seagrass Ecosystems Analysts, Inc., to the St. Johns River Water Management District, Palatka, Florida.

Virnstein, R.W., and L.J. Morris. 1996. Seagrass preservation and restoration: a diagnostic plan for the Indian River Lagoon. Technical Memorandum 14, St. Johns River Water Management District, Palatka, Florida.

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

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

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

Woodward-Clyde. 1994. Uses of the Indian River Lagoon. Prepared for the Indian River Lagoon National Estuary Program, Melbourne, Florida.

A.9 LAKE OKEECHOBEE CONCEPTUAL ECOLOGICAL MODEL

A.9.1 Model Lead

Karl E. Havens, South Florida Water Management District

A.9.2 Introduction

Lake Okeechobee is a large (1,730 square kilometers) freshwater lake located at the center of the interconnected South Florida aquatic ecosystem. The lake is shallow (average depth less than 3 meters), originated about 6,000 years ago during oceanic recession, and under natural conditions probably was a slightly eutrophic and had vast marshes to the west and south. The southern marsh was contiguous with the Florida Everglades, which received water as a broad sheet flow from the lake during periods of high rainfall (Gleason 1984).

Modern-day Lake Okeechobee differs in size, range of water depths, and connections with other parts of the regional ecosystem (Figure A-30) (Steinman et al. 2002a). Construction of the Herbert Hoover Dike in the early to mid-1900s reduced the size of the lake's open-water zone by nearly 30 percent, resulted in a considerable reduction in average water levels, and produced a new littoral zone within the dike that is only a fraction of size of the natural one. The lake also has been impacted in recent decades by excessive inputs of nutrients from agricultural activities in the watershed (Flaig and Havens 1995, Havens et al. 1996a). These nutrients have exerted the most dramatic impacts on the open-water region, where large algal blooms have occurred, along with accumulation of soft organic mud bottom sediments, which cause the lake water to become highly turbid when they are resuspended during windy periods (Maceina and Soballe 1991). The littoral zone has been invaded by 15 species of exotic plants, most notably *Melaleuca quinquenervia* and *Panicum repens* (torpedograss), which have expanded over large areas, displacing native plants. Despite these human impacts, and a consensus that the lake’s overall health has been greatly degraded by human actions, Lake Okeechobee continues to be a vital aquatic resource of South Florida, with irreplaceable natural and societal values. It is anticipated that the Comprehensive Everglades Restoration Plan (CERP), along with other local and regional restoration efforts, will improve hydrologic conditions in the lake (Figure A-30), and that this will lead to improvements in the ecological attributes of the system.

An ecosystem conceptual ecological model was developed for Lake Okeechobee restoration planning purposes diagram (Figure A-32, Section A.9.9). This model indicates, via a simple box-and-arrow, how various cultural stressors affect attributes of the ecosystem that are of value to nature and society. The model is comprised of a top-to-bottom hierarchy of sources, stressors, ecosystem effects, attributes and performance measures. For each performance measure there is a quantitative target (a desired endpoint of CERP and other local/regional restoration efforts) and a suite of monitoring parameters (RECOVER 2003a). The model for Lake Okeechobee is complex because the lake is comprised of three distinct components that have dramatically different structure and function: a littoral marsh, a near-shore region, and an open water (pelagic) region. Stressors in one zone may have indirect effects that cross the boundary into another. The Lake Okeechobee conceptual ecological model was developed in the context of this heterogeneity. The model also reflects the lake's present spatial extent, rather than the larger historical boundaries.

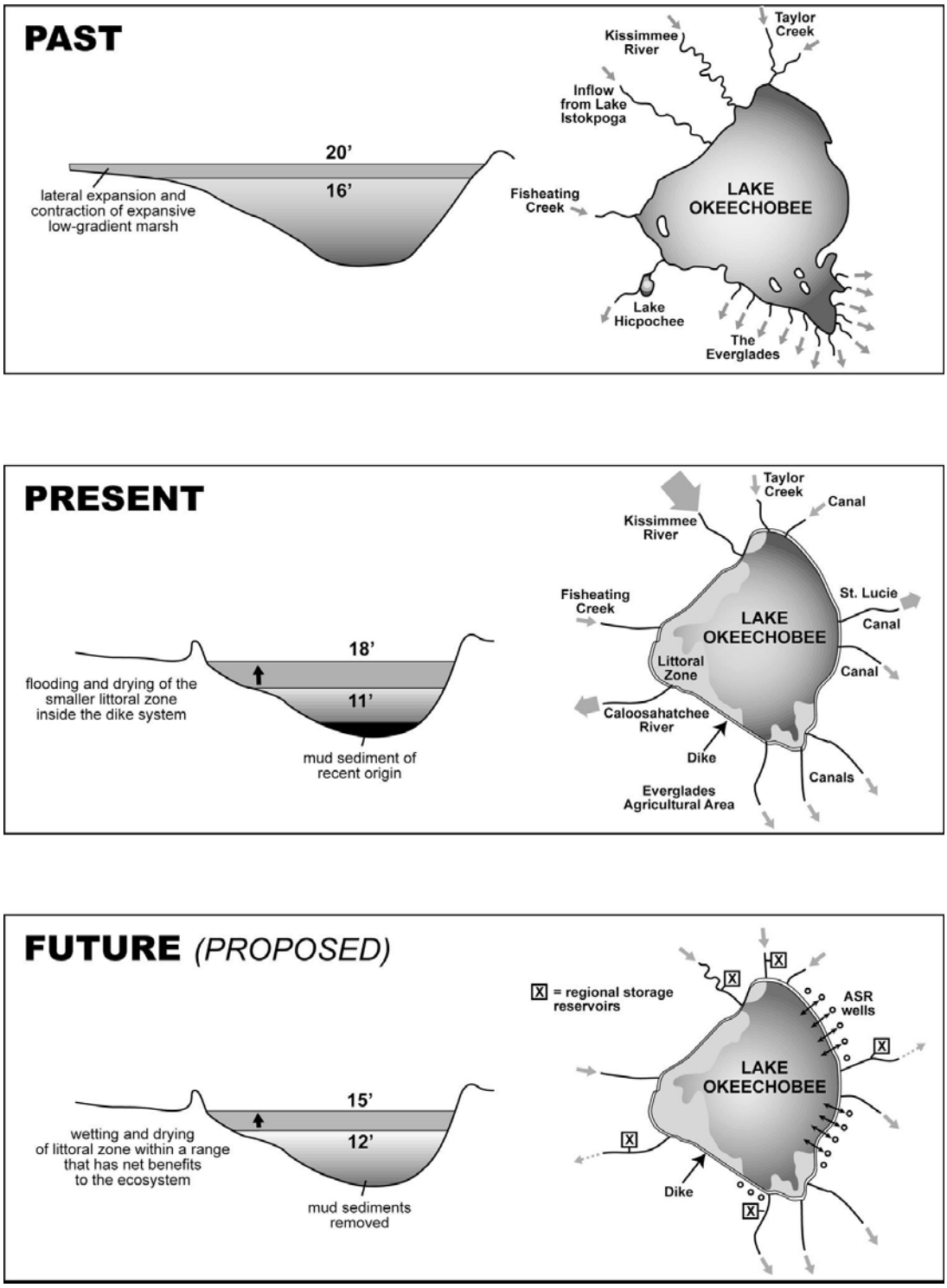


Figure A-30: Map of Lake Okeechobee and part of its surrounding watershed, showing conditions prior to construction of the Central and Southern Florida (C&SF) Project (PAST), today's conditions (PRESENT), and conditions anticipated after completion of the CERP (FUTURE). The figures show the spatial extent of the lake's open water region, the magnitude of various inflows and outflows, and ranges of water levels under each condition.

A.9.3 External Driver and Ecological Stressors

Seven in-lake stressors that have strong impacts on the lake's natural and societal values originate from five distinct external sources (Figure A-32, Section A.9.9). Elevated concentrations of nitrogen and Class I/III chemical contaminants, including chloride, certain pesticides, and total dissolved solids, are by-products of agriculture or other human activities in the watershed. These contaminants may have detrimental effects in the ecosystem, but in general, are focused in particular locations (e.g., near input sources). A much greater concern, from the standpoint of ecosystem effects is the elevated level of phosphorus. High concentrations of this nutrient, which are largely responsible for the rapid eutrophication of the lake in the last two decades, are a result of excessive inputs from the watershed. The primary source of phosphorus pollution is agriculture, with lesser contributions from urban and other sources (Flaig and Havens 1995). As a result of decades of high inputs, the soils in the watershed, the sediments of tributaries, and the lake's bottom sediments now contain large quantities of phosphorus (Olila and Reddy 1993, Flaig and Reddy 1995, Fisher et al. 2001). These soils and sediments represent large secondary sources of phosphorus loading to the lake. The deep canals of the C&SF Project facilitate delivery of phosphorus and other chemical stressors to the lake.

The pelagic region of Lake Okeechobee experiences elevated concentrations of resuspended sediments, whose source is a region of soft organic mud that covers about 50 percent of the central lake bottom. When wind mixes the shallow water column, the upper few centimeters of mud are resuspended. The spatial extent, depth and phosphorus content of this mud have increased rapidly in the last 100 years, coincident with agricultural development and increased nutrient inputs from the watershed (Brezonik and Engstrom 1999). The Herbert Hoover Dike may facilitate sediment accumulation by preventing natural flushing that once may have occurred during high water events.

Variations in rainfall, evapotranspiration, water supply deliveries from the lake and operation of the C&SF Project (including the regulation schedule, supply-side management, and compliance with any minimum water level criteria) have the potential to affect water levels (stage) in the lake. This becomes stressful to the ecosystem when there is prolonged or extreme high or low lake stage. The impacts of high and low stage are more severe than they would have been when the dike did not encircle the lake. Under natural conditions, water was able to expand and recede over a large low-gradient marsh to the west and south. Today, when lake stage exceeds 15 feet National Geodetic Vertical Datum (NGVD), water simply stacks up over the smaller (yet still over 400 square kilometer) littoral zone, flooding it to a greater depth. When lake stage falls below 11 feet, the entire littoral zone is dry, and lateral expansion is constrained to the east due to a relatively steep drop off in the lakes bottom contours. Hence, extreme high or low lake levels of any duration, or moderate high or low lake levels of prolonged (greater than 12 months) duration, can cause significant harm to the ecosystem, as described below in greater detail. In contrast to the harmful effects of extremes, a certain degree of natural variation in lake stage, between 12 and 15 feet NGVD, has been shown to benefit the ecosystem (Smith et al. 1995, Smith 1997) and is a desired hydrologic result of the CERP.

In recent decades, Lake Okeechobee has experienced a rapid expansion of exotic and nuisance plants and the introduction and expansion of certain exotic animals. The plants have been the greatest concern to date. There now are 15 species of exotic plants in the lake's littoral zone. Species that have caused the most substantial harm are melaleuca and torpedograss (*Panicum repens*), which were purposely introduced to the region for dike stabilization and cattle forage, respectively. Other exotic plants that have stressed the lake's values include *Hydrilla* sp., water hyacinth (*Eichhornia crassipes*), and water lettuce (*Pistia stratiotes*). Exotic animals in the lake now include fish (*Tilapia aurea),* mollusks (*Corbicula fluminea*), and microinvertebrates (*Daphnia lumholtzii*). Each of these species exerts different impacts on the ecosystem, as discussed below. Many of these species have been accidentally introduced to the lake, and this situation is likely to continue, as new species are introduced to the United States and

subsequently spread by boats and other mechanisms into Florida waters. Certain species known to have dramatic ecological impacts and the ability to tolerate conditions in the lake (e.g., the zebra mussel) should be monitored for presence/absence on a regular basis.

A.9.4 Ecological Attributes

The Conceptual Model working group identified four major attributes associated with the Lake Okeechobee ecosystem (Figure A-32, Section A.9.9). The attributes encompass the overall ecological health of the lake, and they also reflect the quality of several societal uses of the resource, including fishing, drinking water quality, hunting, wildlife observation and recreational boating. Two nonecological attributes that are strongly linked with the lake, water supply and flood control, are not included as attributes in the conceptual ecological model. Those cultural attributes are reflected in models of the Lake Okeechobee Service Area and the Lower East Coast; both have their own set of performance measures, some of which reflect water supply from the lake and flood protection. In the Lake Okeechobee ecosystem conceptual ecological model, they represent sources of high and low lake stage (ecological stressors) and are indicated as such.

The first attribute is lake water quality, which directly affects the quality of the habitat for vegetation, fish and other wildlife. Poor water quality in the last two decades can be linked with reduced overall health of the biotic components of the ecosystem (Havens et al. 1996a Havens and Schelske 2001). Water quality in the lake also affects drinking water quality, and it can affect the health of downstream ecosystems (the St. Lucie and Caloosahatchee Estuaries and the Florida Everglades) that receive water from the lake. The second attribute is the lake's fish and aquatic fauna. Lake Okeechobee supports a commercial and recreational fishery that has an estimated economic value in excess of $480 million U.S. dollars (Furse and Fox 1994). The fishery also supports a diverse community of birds and other animals. The third attribute of the lake is a diverse native vegetation mosaic. It provides nesting and foraging habitat for fish and other animals, areas of beauty for recreation, and the ability to mitigate poor water quality. This vegetation mosaic has been seriously degraded due to expansion of exotic plants in the littoral region and nearly a complete loss of submerged plant beds in the near-shore region during periods of prolonged high water. The fourth attribute is the lake's diverse community of birds and animals that includes snail kites, wading birds and water fowl. The littoral zone of Lake Okeechobee provides one of the largest habitats in South Florida for the federally-endangered snail kite (Bennetts and Kitchens 1997), and it supports large resident and migratory populations of wading birds (Smith et al. 1995). A variety of migratory water fowl reside in the lake during the winter, and the alligator population is one of the largest in the state of Florida.

A.9.5 Ecological Effects

Critical Linkages between Stressors and Attributes/Working Hypotheses

The pathways linking cultural stressors to ecological attributes are complex (Figure A-32, Section A.9.9).), and have a solid foundation in research and modeling conducted by scientists at the South Florida Water Management District, the Florida Fish and Wildlife Conservation Commission, and Florida public universities. As we learn more about how the ecosystem functions, it is possible that additional pathways could be added to the model, or adjustments made to existing pathways. It should be noted, for example, that in its present form, the model does not include frogs, snakes, rats, mice and other small animals known to occur in the lake's littoral zone. This does not necessarily mean that they have an insignificant role in the ecosystem. In fact, during some routine gut analysis of largemouth bass in the late 1990s, frogs were found quite frequently, indicating that they may be an important food source for this sport fish. The animals listed above also may be important diet items for young alligators. The model is a flexible planning tool that, at any given time, reflects the current state of scientific knowledge about Lake

Okeechobee. Ecosystem effects are described here in the context of sets of working hypotheses regarding how each identified attribute in the model is thought to be affected by the major ecosystem stressors.

A.9.5.1 Lake Water Quality

Water quality in Lake Okeechobee has been dramatically affected by nutrients associated with human activities in its watershed. Total phosphorus concentrations measured in the lake today (greater than 110 parts per billion [ppb]) are more than double those measured in the early 1970s, when the South Florida Water Management District first began to collect water quality data on a regular basis (James et al. 1995a, Havens et al. 2003). The high concentrations reflect a long history of excessive phosphorus inputs to the system (James et al. 1995b) and today, an internal load of phosphorus from the lake sediments approximately equals that of the external load in magnitude (Olila and Reddy 1993). Turbidity of the lake water also is high, especially in the central pelagic region, due to resuspension of sediment material from the lake bottom (Maceina and Soballe 1991, Hanlon et al. 1998). During times when lake stage is high (greater than 15 feet) there appears to be substantial transport of turbid, phosphorus-laden water from mid-lake to the south and west shoreline areas (Maceina 1993, Havens 1997), where another water quality problem occurs - the development of dense blooms of noxious cyanobacteria (blue-green algae). When these algae occur in high densities they can cause taste, odor and trihalomethane problems for the five municipalities that draw water from the lake for drinking. When the blooms peak and then collapse, aquatic animal life is threatened because of reduced dissolved oxygen concentrations and decay products from the algae (Jones 1987, Paerl 1988).

In addition to phosphorus and its related water quality problems, Lake Okeechobee is considered impaired by the United States Environmental Protection Agency based on its standards for un-ionized ammonia, chlorides, coliform bacteria and iron. Iron and chloride may largely originate from natural sources in the ground water and soils, and as such, may be removed from the listing by the United States Environmental Protection Agency, as was recently done for dissolved oxygen. From an ecosystem perspective, the major concerns are related to the excessive phosphorus levels and their direct and indirect effects. The following hypotheses describe the major factors considered to affect phosphorus dynamics in the lake.

High rates of External Phosphorus Loading from Tributaries and Internal Phosphorus Loading from Contaminated Lake Sediments are Responsible for the High Concentrations of Phosphorus that Occur in the Water Column of Lake Okeechobee

The lake has experienced high rates of phosphorus loading from its watershed for many decades (SFWMD 2002). At present the loading is in excess of 500 metric tons per year, far greater than the 140 metric tons per year mandated by the Florida Department of Environmental Protection (FDEP 2000) Total Maximum Daily Load (TMDL) Rule for total phosphorus. The TMDL represents the loading rate that is necessary to protect the ecosystem from imbalance, and it corresponds to an in-lake total phosphorus concentration goal of 40 ppb (Havens and Walker 2002). When phosphorus enters the lake, a large fraction is stored in the lake sediments (James et al. 1995b). Due to the long history of high inputs, those sediments now contain over 30,000 metric tons of phosphorus in their upper 10 centimeters alone (Olila and Reddy 1993, Fisher et al. 2001). This phosphorus can be mobilized into the overlying water column by various processes, including diffusion (Moore et al. 1998), wind resuspension (Hanlon 1999), and bioturbation (Van Rees et al. 1996). This internal loading makes the lake ecosystem resilient to changes in its phosphorus concentration when external inputs vary, a situation that is common in shallow eutrophic lakes (Sas 1989, Moss et al. 1996). From a management standpoint, this means that lake responses to load reductions based on the implementation of elements in the CERP and the Lake Okeechobee Protection Plan are likely to occur with time lag of 30 to 50 years, based on model runs using the South Florida Water Management District's Lake Okeechobee Water Quality Model (James et al. 1997). Eventually,

however, phosphorus-rich surface sediments are expected to be covered by new sediment material with reduced phosphorus content. When this occurs, rates of internal loading should begin to decline.

Prediction - Watershed-scale treatment facilities (including large reservoirs and stormwater treatment areas) constructed under the CERP and the Lake Okeechobee Protection Plan, along with enhanced phosphorus source control, will result in reduced rates of phosphorus loading to the lake. Given a sufficient period of time (perhaps decades or more), internal loading rates also will decline. The net result should be a decline in lake water phosphorus concentrations, but the timing of this response is uncertain.

Level of certainty - high

High Lake Stage Results in Conditions that Exacerbate the Problem of Phosphorus Pollution in the Lake's Water Column

While it is clear that there is a link between stage and total phosphorus (Canfield and Hoyer 1988, Havens 1997), the underlying mechanisms may be complex, ranging from large-scale changes in the physics of water circulation to alterations in the interaction between biological communities. One of the first effects to be suggested (Maceina 1993) was that at high stage there is greater horizontal transport of phosphorus from the mid-lake region, where concentrations are highest due to the resuspension of underlying mud sediment, into more phosphorus-deficient near-shore areas. The evidence for this hypothesis was largely observational, but it has been supported with results from the South Florida Water Management District's Lake Okeechobee Hydrodynamic Model. The underlying mechanism is related to underwater currents and the morphology of the lake basin. When wind moves across the lake surface it creates large circulation gyres (Jin et al. 2000) whose spatial extent is affected by water depth. When lake stage is low (less than 13 feet), an elevated ridge of limestone along the south and west perimeter of the lake hinders mixing of water between the mid-lake and shoreline regions. This is thought to reduce phosphorus and sediment transport to the shoreline region and be responsible, in part, for the low phosphorus concentrations and high transparency that occur there when stage is low (Maceina 1993, Havens 1997).

Another factor that may become important at low lake stage is uptake of phosphorus by submerged macrophytes. During years when stage is low, the lake can support a large spatial extent of submerged macrophytes (Hopson and Zimba 1993, Havens et al. 2002). For example, in 1989, after stage declined to below 11 feet, remote sensing indicated that submerged plants covered 12,400 hectares of the lake bottom (Richardson and Harris 1995). In summer 2000, after a managed lake recession operation and a decline in stage to below 12 feet, the total extent of submerged plants determined from an intensive field survey was 17,700 hectares. This large spatial extent of plants persisted in summer 2001 and 2002 (Havens 2003), but declined in 2003 with increased lake stages in a predictable manner.

Submerged macrophytes have the capability to reduce water column phosphorus concentrations by a number of processes. These include 1) stabilization of lake sediments by their roots; 2) a reduction of water flow velocity and shearing stress on sediments due to wave attenuation (Vermaat et al. 2000); 3) trapping of sediment material; and 4) direct uptake of phosphorus by roots in the sediments or from the water by epiphytic algae (Carrigan and Kalff 1982, Burkholder et al. 1990). Phosphorus also may be lost in dense beds of plants if photosynthesis elevates pH to a level where calcium carbonate precipitates from the water, because the simultaneous precipitation of phosphate can be quite high under those conditions (Murphy et al. 1983). In Florida lakes, up to 96 percent of the combined water column and macrophyte phosphorus can occur in the tissues of macrophytes (Canfield et al. 1983).

Benthic micro-algae and *Chara*, a macro-alga, also can become abundant under low stage conditions in Lake Okeechobee (Steinman et al. 1997a, 1997b, 2002b), and these algae can directly compete for water column phosphorus with phytoplankton (Havens et al. 1996c, Hwang et al. 1998). When lake stage is

high, the growth of macrophytes and attached algae is suppressed due to light limitation caused by the deeper water and the high turbidity that accompanies greater materials transport from the mid-lake region. Hence lake stage can affect water column phosphorus concentrations by determining the relative mass of that nutrient that occurs in attached macrophytes and algae (high when lake stage is low) or phytoplankton (high when lake stage is high).

Prediction - When alternative water storage locations (aquifer storage and recovery wells and regional storage reservoirs) are brought on line under the CERP, it is predicted that there will be a reduced number of high lake stage events in Lake Okeechobee. This should directly benefit water quality in the lake, by providing conditions where there is both reduced horizontal transport of phosphorus into the shoreline area and increased growth of macrophytes and attached algae that can remove phosphorus from the water.

Level of certainty - high

Biological and Chemical Changes that Occurred in the Lake Due to Cultural Eutrophication Have Contributed to a "Positive Feedback" That Helps Maintain High Phosphorus Concentrations Due to a Lack of Ecosystem Assimilative Capacity

A phosphorus mass-balance for the lake indicates that every year, approximately 400 metric tons of that element is stored in lake sediments (James et al. 1995b). Hence, the lake is described as a "net sink" for phosphorus. However, since the early 1970s, this internal storage of phosphorus has been declining (Havens and James 1997, Havens and Schelske 2001), suggesting that the lake's assimilative capacity is being used up. That might occur, for example, if the binding sites (calcium and iron minerals) on sediment particles became saturated with phosphorus. There is some evidence that this is occurring. Fisher et al. (2001) compared the concentrations of sediment pore-water phosphorus in samples collected from the lake in 1988 versus 1998, and found that they had more than doubled. Pore-water phosphorus is unbound phosphorus that essentially is a surplus or nonassimilated fraction. At this point, we assume that this increase in pore-water phosphorus reflects a reduction in binding sites, and hence a reduction in assimilative capacity. However, more research is needed to verify that the increase in pore-water phosphorus is not attributable to other factors, such as increased rates of phosphorus diagenesis.

If external phosphorus loading rates remain high, a further loss of sediment assimilative capacity might occur. On the other hand, this trend might be reversed after a period of substantially reduced loads.

Along with these chemical processes, there have been a number of biological changes in the lake that could reduce the system's capacity to assimilate phosphorus (Havens and Schelske 2001). In the lake's water column, diatoms have been replaced by cyanobacteria as the dominant phytoplankton (Cichra et al. 1995, Havens et al. 2003), and this could decrease the rate of phosphorus transport to sediments because cyanobacteria settle much slower than diatoms (Reynolds 1984). Among the benthic macroinvertebrates, oligochaetes have replaced chironomids and other insect larvae as the dominant taxa (Warren et al. 1995), largely because they are able to tolerate the anoxic conditions that occur in the lake's enriched sediments (Warren et al. 1995). This macroinvertebrate trend may have resulted in a reduced net loss of phosphorus from the lake water because oligochaetes pump large quantities of soluble phosphorus from the sediments into the overlying water when they feed (Van Rees et al. 1996). Likewise, the lake's fish community contains a relatively large proportion of taxa that feed in the benthos, providing another pathway for upward phosphorus transport. There is a potential for reversal of these biological changes if phosphorus loads to the lake are substantially reduced.

Prediction - If projects implemented under the CERP and the Lake Okeechobee Protection Act result in substantially reduced loads of phosphorus to the lake and reduce the water column phosphorus concentrations, there might be a reversal of physio-chemical and biological trends that have recently led

to a low phosphorus assimilative capacity. If this occurs, lake assimilative capacity could increase, and might proceed more rapidly than presently anticipated.

Level of certainty - high

Blooms of Noxious Cyanobacteria and Their Associated Effects on Water Quality Are a Direct Consequence of High Phosphorus Concentrations

The relationship between cyanobacteria blooms and phosphorus enrichment has been well established in the literature (Horne 1979, Paerl 1988). In lakes with prolonged high rates of external loading, phosphorus often reaches concentrations where it is in surplus relative to algal demands. When this occurs, some other nutrient element (most often nitrogen) becomes "secondarily limiting" (Schelske 1984) to algal growth. Havens (1995) documented a trend in the water quality of Lake Okeechobee indicative of a transition towards secondary nitrogen limitation after the early 1980s, and Aldridge et al. (1995) and Phlips et al. (1997) documented that nitrogen now is the primary limiting factor for phytoplankton growth in the lake. Havens et al. (2003) recently confirmed that conditions strongly favor dominance by blue-green algae, and that such algae almost always dominate the lake's phytoplankton. In contrast, Brezonik et al. (1979) documented that there once were areas of phosphorus limitation in this lake. Nitrogen limitation favors dominance by bloom-forming cyanobacteria that can 1) remain buoyant in the water column, and 2) obtain nitrogen from the atmosphere by the process of nitrogen fixation (Horne 1977). Taxa that have this capacity include *Anabaena*, *Microcystis*, and *Aphanizomenon*; these taxa predominate in Lake Okeechobee when it experiences severe algal blooms.

Prediction - If projects carried out under the CERP and the Lake Okeechobee Protection Plan result in reduced in-lake phosphorus concentrations, levels of surplus phosphorus may be reduced to the extent that phosphorus again becomes the nutrient most often limiting to phytoplankton growth. That condition would favor dominance of diatoms and other algae over cyanobacteria, resulting in a reduction in the frequency of algal blooms.

Level of certainty - high

A.9.5.2 Fish and Aquatic Fauna

Lake Okeechobee supports a nationally recognized sport fishery for largemouth bass (*Micropterus salmoides*) and black crappie (*Pomoxis nigromacultus*), as well as a commercial fishery for various catfish and bream (*Lepomis* spp.). According to Fox et al. (1993) these fisheries generate nearly $30 million per year for the local economies and they have an asset value that is in excess of $100 million (Bell 1987). Another estimate (Furse and Fox 1994) places the value of the fishery at more than $300 million, and considers only the recreational fish species.

In addition to the sport and commercial species, Lake Okeechobee supports a diverse community of fish, including (in total) 41 species (Bull et al. 1995, Havens et al. 1996b). These fish provide a food resource for wading birds, alligators and other animals that use the lake as a foraging habitat. Fish use both the littoral and pelagic regions of the lake and some of the top predators (including largemouth bass and Florida gar, *Lepisosteus platyrhincus*) display a migration between the two habitats (Fry et al. 1999). Gut analysis and stable isotope data indicate that the fish depend on a wide range of food resources, including benthic macroinvertebrates and zooplankton (Havens et al. 1996b, Fry et al. 1999). These in turn are dependent on a continual input of energy in the form of plant, periphyton and phytoplankton primary productivity, and allochthonous inputs of carbon that can fuel bacterial growth. Fish also depend on the lake's aquatic plant communities to provide them with spawning habitat, to serve as a refuge from the environment and predators, and to support the complex food web described above (Fox et al. 1993).

As a result of human impacts on the lake, there have been dramatic changes in both the resource base that supports the fishery and the aquatic plant communities that provide fish habitat. These changes include eutrophication-related shifts in macroinvertebrate and plant community structure, and large-scale loss of certain plant community components due to stresses associated with high water. In fall 1999, scientists at the Florida Fish and Wildlife Conservation Commission reported declines both in the population size and early age classes of important sport fish, a result that likely was related to loss of habitat after several years of high water and loss of vegetative habitat. Other components of the lake's wildlife community (e.g., wading birds and migratory water fowl) also may be affected by eutrophication and high-water related changes in the food web and habitat structure.

The hypotheses presented here are closely linked with those provided under the sections of this document dealing with native vegetation mosaic and snail kites, wading birds, and alligators. This reflects the tight linkage between these components of the lake's food web. The focus of this section is on fish and invertebrate animals. Hypotheses generally are related to particular regions of the lake (i.e., littoral, near-shore and pelagic), although it is recognized that certain species migrate between these habitats.

The Species Composition, Abundance, and Biomass of Benthic Macroinvertebrate Communities in the Lake's Pelagic Region are Primarily Affected by the High Rates of Loading of Nutrients and Organic Carbon to That Region

As a result of sustained high rates of nutrient loading and high rates of phytoplankton production, there has been a high rate of organic loading to the lake sediments, high rates of bacterial metabolism, and hypoxic or anoxic conditions in the near-surface sediments. These conditions collectively favor the dominance of pollution-tolerant macroinvertebrates such as certain oligochaetes. Warren et al. (1995) documented that between the early 1970s and early 1990s, the relative abundance of oligochaetes increased in the pelagic sediments from 30 to 80 percent of the total community. This high relative abundance persisted during the last decade (G. Warren, Florida Fish and Wildlife Conservation Commision, personal communication), and species known to be pollution-tolerant (e.g., *Limnodrilus hoffmeisteri*) continued to be abundant. At the same time, species that previously occurred in the lake and still occur in nearby unpolluted lakes (various ephemeropterans and trichopterans), have become rare or absent in Lake Okeechobee. These trends are nearly identical to those observed in Lake Erie when it underwent rapid eutrophication between 1930 and 1960 (Carr and Hiltunen 1965).

The predominance of oligochaetes is a concern for two reasons. First, as mentioned above, they can contribute substantially to the internal loading of phosphorus. Second, they do not have an adult stage that emerges from the water (as occurs for ephemeropterans, trichopterans and other aquatic insects), and therefore do not provide a food resource for animals that feed on such emergent forms. This includes migratory waterfowl and a variety of fish.

Prediction - If projects implemented under the CERP and the Lake Okeechobee Protection Plan result in a substantial reduction in phosphorus loading to the lake, at some time in the future the surface lake sediments may be less enriched with nutrients and organic matter. If this occurs the sediments will be a more favorable habitat for a diverse benthic macroinvertebrate community, and the dominance of oligochaetes should decline. The timing and extent of this recovery are uncertain.

Level of certainty - high

The Biomass of Zooplankton in the Lake's Open Water Region is Controlled by Resource Supply, While Taxonomic Composition is Determined Primarily by Predation and Temperature Tolerance

The zooplankton of Lake Okeechobee is comprised of 61 native and one exotic species (Havens et al. 1996b, Havens and East 1997), and includes rotifers, copepods and sparse amounts of cladocerans. The total biomass correlates significantly with nutrient and chlorophyll concentrations (Crisman et al. 1995, Beaver and Havens 1996), suggesting resource limitation. This conclusion is supported by results of experimental nutrient-addition studies (Havens et al. 1996c). Havens and East (1997) also documented that the dominance of large cyanobacteria in the lake's phytoplankton community may contribute to resource limitation because the algae cannot be directly grazed by many of the lake's zooplankton. As a result, the major pathway for energy transfer to zooplankton involves multiple steps (phytoplankton → excreted organic carbon → bacteria → protozoa → zooplankton) and low ecological transfer efficiency (Havens et al. 2000). One reason this may occur is that the abundance of large cladoceran zooplankton, which can directly graze large algae at high rates, is very low in Florida lakes (Crisman and Beaver 1990).

Two factors may explain the absence of large cladocerans: 1) high rates of grazing by fish eliminates the largest most visible zooplankton taxa (large cladocerans); and 2) high water temperatures preclude the occurrence of cladocerans during all but the coolest months of the year. Both hypotheses are supported by experimental research on other lakes, as well as by work on Lake Okeechobee. Crisman and Beaver (1990) documented that in fish-free enclosures in the near-shore region of the lake, cladoceran biomass increased dramatically, and Beaver and Havens (1996) noted that the very high biomass of threadfin shad (*Dorosoma petenense*), a voracious zooplanktivore, should preclude occurrence of any large cladocerans. East et al. (1999) found that abundance of the native *Daphnia ambigua* is reduced dramatically during summer, when water temperatures are high, but *D. lumholtzi*, a tropical exotic, increases during that period. The exotic species also has large spines that may provide a greater defense against fish predation during summer months. Total zooplankton biomass generally is lower during mid-summer then in spring and fall in Lake Okeechobee and other Florida lakes.

Predictions - If projects implemented in the CERP and the Lake Okeechobee Protection Plan result in reduced nutrient inputs to the lake and declines in phytoplankton and bacterial biomass, the total biomass of zooplankton might be expected to decline. However, this decline might be ameliorated by improvements in food quality (a shift from inedible cyanobacteria to edible diatoms). The efficiency of the plankton food web is expected to increase, and should be reflected by increased ratios of zooplankton to phytoplankton biomass and productivity. Effects of the CERP on the taxonomic structure of zooplankton are uncertain because factors controlling this attribute may not be influenced by the project.

Level of certainty - Intermediate

Macroinvertebrates in the Near-Shore Region of the Lake are Strongly Dependent on the Habitat Values Provided by Submersed and Emergent Macrophytes

Under favorable conditions, near-shore macrophyte habitat, including *Hydrilla verticillata*, *Potamogeton illinoinsis* (peppergrass), *Scirpus* sp. (bulrush) and *Vallisneria americana* (eelgrass) support a high biomass of macroinvertebrates (Warren and Vogel 1991). Many of these macroinvertebrates, including the grass shrimp *Palaemonetes paludosus*, the amphipod *Hyalella azteca*, and larvae of the midge genera *Dicrotendipes*, *Glyptotendipes*, and *Rheotanytarsus*, are integral to the diets of largemouth bass, black crappie, redear sunfish (*Lepomis microlophus)*, and bluegill sunfish (*L. macrochirus*).

Coincident with a decline in macrophytes in the late 1990s, much of the habitat for macroinvertebrates was lost. In a June 2000 survey, Warren and Hohlt (Florida Fish and Wildlife Conservation Commission unpublished data) recorded extremely low densities of invertebrates in habitats (bulrush and mud

sediments) that formerly (1987-1991) supported high numbers. Scientists and members of the public who frequent the lake also noticed a near absence of winged adult midges emerging from the lake during summer 2000. As noted above, these kinds of changes have potential negative consequences for birds and fish that depend on immature and adult invertebrates as a food resource. The extent to which these communities recovered as a result of lower water levels and increased macrophyte biomass in 2000-2003 remains to be seen, because there has not been an ongoing monitoring of macroinvertebrates in the lake.

Prediction - If projects implemented in the CERP result in a reduced frequency of prolonged and/or extreme high lake stage events, the near-shore bulrush community is likely to recover some of its previously greater spatial extent and density. When this occurs there should be a concomitant increase in the abundance of macroinvertebrates dependent upon submersed and emergent macrophyte habitats.

Level of certainty - high

Macroinvertebrate Community Structure in the Littoral Zone is Affected by Variation in Hydroperiod, Distribution of Plant Communities, and Dissolved Oxygen Concentrations

Warren and Hohlt (1994) and Warren and Vogel (Florida Fish and Wildlife Conservation Commission unpublished data) examined littoral macroinvertebrate community structure on *Eleocharis* sp. (spikerush), *Panicum repens* (torpedograss), *Pontaderia sp.*, bulrush, and *Typha* sp. (cattail). Because of their growth habits, the torpedograss, *Pontaderia* and cattail habitats were characterized by low dissolved oxygen concentrations and poor quality macroinvertebrate communities. Spikerush habitat had a more vertical growth form and lower production of thatch material, and was characterized by higher dissolved oxygen concentrations and a higher quality macroinvertebrate community.

Based on surveys conducted by the Florida Fish and Wildlife Conservation Commission, we also know that the littoral zone includes at least 174 macroinvertebrate taxa (Havens et al. 1996b), representing a wide range of functional and taxonomic groups. Analysis of fish gut contents and stable isotope studies reveal that macroinvertebrates represent important diet components for small forage fish and sport fish in the interior littoral zone (Havens et al. 2003). Macroinvertebrates were found to account for greater than 40 percent of the volumetric gut contents of redear sunfish, bluegill sunfish, largemouth bass and bowfin (*Amia calva*) at a sampling site in Moonshine Bay, located in the west-central littoral zone.

One of the most visible members of littoral macroinvertebrate community, from a resource management perspective, is the Florida apple snail (*Pomacea paludosa*). This species is a principal food item for the federally-endangered Everglades snail kite (*Rostramus sociabilis)* (Bennetts and Kitchens 1997), and it also is consumed by certain wading birds, migratory water fowl, turtles and small alligators. As such, it is an important component of the littoral food web. Research dealing with apple snails in South Florida (Turner 1996, Darby et al. 1997) indicates that 1) the most favorable habitat for these animals includes a mosaic of sparsely and densely vegetated habitats; 2) animals survive only for 12 to 18 months, and lay their eggs on emergent vegetation during a 4 to 12 week period between March and July; and 3) juvenile snails can survive drying for 2 to 3 months. Dry-downs are not necessarily harmful to the snail populations, as long as they do not coincide with the peak period of egg production or last for many months, so that a large percentage of the existing population is killed. Since snails are slow-moving animals, repopulation of large areas following prolonged dry downs may require multiple years of favorable conditions.

Another factor that can significantly impact apple snails is reversal of lake stage during the egg laying period. Snails lay their eggs several centimeters above the water surface on the emergent stems of spike rush, bulrush, cattail and other plants (Darby et al. 1997). If lake stage rises during this period and eggs

become flooded, they experience high mortality due to physiological effects on developing snail embryos and from loss of adhesion to stems (Turner 1994).

Research dealing with apple snail growth responses to varying food types indicates that the nutrient content of grazed material also could affect the populations. Sharfstein and Steinman (2001) maintained young apple snails in laboratory cultures, and provided the animals with either the epiphyton associated with spike rush stems, epiphyton of bladderwort or metaphyton collected from near the sediment surface. These are three distinct and typical components of the periphyton community in the lake's central littoral zone (Havens et al. 1997). Snails feeding on bladderwort epiphyton grew significantly more than snails feeding on the other food types, perhaps because the bladderwort epiphyton had a higher nitrogen and chlorophyll content. Changes in plant community structure that shift the periphyton towards a dominance by less nutritious forms could potentially result in reduced apple snail growth. The extent to which human factors might be expected to bring about such a change is unclear.

Prediction - Three major predictions emerge from what is presently known about the littoral macroinvertebrate community. First, it is predicted that apple snails and other beneficial invertebrates will benefit from lake stage operations that minimize the frequency of prolonged spring draw-downs that dry out their habitat (i.e., prolonged lake stages below 12 feet). Second, it is predicted that snails and other invertebrates will benefit from operations that minimize the occurrence of stage reversals during the March-July period of maximal egg laying. Third, it is predicted that snails and other invertebrates will benefit from lake stage operations and other management actions (e.g., exotics control) that maintain a diverse mosaic of native littoral vegetation types, including spike rush, bladderwort, bulrush, sawgrass and other emergent species.

Level of certainty - Intermediate

The Abundance and Taxonomic Composition of Fish in the Lake's Pelagic Zone is Affected by Nutrient Inputs to the System, Which Determine the Biomass of Phytoplankton in the Water Column and Macroinvertebrates in the Benthos

Bull et al. (1995) studied the distribution of fish in open-water habitats of the lake during the late 1980s and early 1990s, sampling fish at 25 sites with a large trawl net. They found that the deeper central and north regions of the lake supported distinct fish assemblages, which differed from those found in the near-shore and littoral habitats. The central assemblage was dominated by threadfin shad (*Dorosoma petenense*) and black crappie (*Pomoxis nigromaculatus*) in summer, and by black crappie and white catfish (*Ameirus catus*) in winter. The abundance of shad was significantly correlated with phytoplankton chlorophyll *a* concentrations. This reflects a feeding preference for phytoplankton and zooplankton (Baker and Schmitz 1971). White catfish abundance was strongly correlated with water depth, indicating the fact that these species tend to forage in the cooler deep water areas of the lake, where they may prey on benthic macroinvertebrates, detritus and smaller fish (Havens unpublished gut content data). Bull et al. (1995) documented that the north pelagic region is strongly dominated by threadfin shad and black crappie. It supports the highest densities of these species both in summer and winter, probably due to high food availability. Phlips et al. (1995) documented that the north region, in closest proximity to high nutrient inputs from agricultural tributaries, displays high phytoplankton biomass. The phytoplankton provides a direct source of food for shad, and also a source of organic matter loading to support a high biomass of benthic macroinvertebrates. Black crappie prey heavily on *Chironomus crassicaudatus*, a chironomid that occurs at extremely high densities (up to 21,000 per square meter) in the nutrient-rich mud sediments that occur in the northern region (Warren et al. 1995).

Prediction - Substantial reductions in nutrient loading to the lake, brought about by projects in the CERP or the Lake Okeechobee Protection Plan, might lead to declines in the abundance of certain fish taxa (e.g.,

threadfin shad, black crappie). These fish presently occur at high densities due to an abundance of food resources (phytoplankton and certain chironomids) linked to high rates of nutrient inputs. On the other hand, other changes in the lake that benefit certain fish might counteract these declines. Crappie recruitment was reduced in the late 1990s (M. Allen, University of Florida, personal communication) and this was linked to high lake stage. Productivity seems to have increased in 2003, after a period of lower water levels. Hence a rehabilitated lake, with a reduced frequency of prolonged high lake stage and reduced nutrient loads, might actually support a healthier population of that sport fish than is the case for the existing lake system.

Level of certainty - Intermediate

Fish in the Near-Shore Region Depend Heavily on the Occurrence of a Healthy Community of Submersed and Emergent Plants

Fisheries research conducted on other lakes has shown that vascular aquatic plants provide multiple benefits to fish communities. These include 1) substrate and cover for spawning (Loftus and Kushlan 1987); 2) habitat for foraging (Janacek 1988); and 3) protective habitat for larval and young adult stages of fish (Barnett and Schneider 1974, Conrow et al. 1990). In Lake Okeechobee, Furse and Fox (1994) documented that bulrush, eelgrass, peppergrass and *Hydrilla* provide habitat for a variety of sport and forage fish (40 species total) in the near-shore area.

Furse and Fox (1994) noted that eelgrass, peppergrass and spikerush provide habitat in the lake for juvenile sport fish and small forage fish, and that bulrush, hydrilla and pondweed account for most of the lake's recreational fishery value. Bulrush recreational value was four times higher than that estimated for any other component of the vegetation community in the near-shore area. Given these multiple functions, and the large-scale loss of both submerged aquatic vegetation (SAV), spikerush and bulrush that occurred in the late 1990s (details below), it was not surprising that in the October 1999 fisheries survey, scientists noted significant declines in population densities and young age classes of economically important sport fish (Florida Fish and Wildlife Conservation Commission unpublished data). After water levels were low in 2000-2002 and vegetation strongly rebounded, the fish recovered, with an age distribution indicating a healthy population for both largemouth bass and black crappie in 2002.

Prediction - If the modified hydrologic regime under the CERP results in conditions that are more favorable for growth of SAV and bulrush in the near-shore zone of the lake, there will be substantial benefits to the lake's fish community.

Level of certainty - high

Fish that Spend All or Part of Their Life Cycle in the Littoral Zone of Lake Okeechobee are Affected by Factors That Significantly Alter the Structure of the Habitat, its Resource Base, and its Water Quantity and Quality

In general, a lake's vegetated littoral zone provides important habitat for fish, in particular for small forage fish taxa and the juvenile stages of larger species, which use the littoral zone as a refuge from predators and as a foraging area (Werner et al. 1983, Rozas and Odum 1988). In the case of Lake Okeechobee, surveys by Chick and McIvor (1994) documented a high biomass and diversity of fish in the littoral zone, with distinct fish assemblages occurring in different plant communities (eelgrass, peppergrass and hydrilla). This is similar to the findings of Furse and Fox (1994) except that in this case, the focal point of the study was the interior and northern littoral regions, rather than the near-shore area. Fry et al. (1999) also documented, using stable isotope data, that a variety of fish may begin life in the lake's littoral zone and then migrate out into deeper water as they grow in size and "move up" in the food chain.

Chick and McIvor (1994) concluded that the littoral zone should be viewed as a complex landscape, comprised of distinct habitats that provide varying resource, refuge and other features for the fisheries. This finding is important, but it seriously complicates our ability to understand the full suite of factors affecting fish while they are in the littoral zone. The landscape contains more than 30 distinct vegetation types, including emergent, submerged and floating-leaf plants with dramatically different densities and growth forms. One thing that seems clear, however, is that certain rapidly expanding exotic and nuisance plants create conditions that generally are not favorable for fish. Species of particular concern are torpedograss and cattail. Greater detail regarding the expansion of these plants and conditions favoring their dominance is provided below under the Native Vegetation Mosaic section. In brief, both species have spread over tens of thousands of acres in the lake's littoral zone, displacing native plant communities that provide good habitat for fish and wildlife.

One of the displaced plants, spikerush, provides particularly good habitat for fish (Chick and McIvor 1994). It includes enough open water to allow large fish to effectively forage, but also provides cover associated with the emergent plant stems and associated whorls of bladderwort (*Utricularia* spp.) that are common in this habitat. The spikerush community also supports a high diversity of macroinvertebrates and attached periphyton that provide a food resource for the fish. In contrast, both torpedograss and cattail display a very dense growth form, with little open water for animals to move through and, as a result of the poor light conditions, little or no periphyton. Water quality inside dense stands of torpedograss also is not suitable for aquatic animals. Nighttime dissolved oxygen concentrations typically are near zero and mid-day values are as low as 0.5 milligrams per liter (South Florida Water Management District unpublished data).

The spread of torpedograss, as discussed below, may largely be a function of the occurrence of low lake stage, since expansion is favored when there is little or no standing water over the sediment surface. Expansion of cattail may be a function of phosphorus inputs from the pelagic zone and periods of long hydroperiod (Newman et al. 1996). The conditions that promote cattail expansion also may be responsible for the increased density of water lily (*Nymphaea* spp.) that has been observed in the interior littoral zone in the last several years. In areas where the density of this plant is high, there has been a deep accumulation of dead leaf material and coarse organic detritus, sometimes leaving only 5 to 10 centimeters of open water column. This habitat is not considered to be suitable for fish foraging or reproduction (Florida Fish and Wildlife Conservation Commission staff personal communications). Recent years of long hydroperiod also have allowed a deep accumulation of periphyton and detritus in spikerush areas, such that sandy substrate (good fish nesting habitat) is less available.

Predictions - If projects implemented in CERP result in a reduced occurrence of prolonged high or low stage, the conditions that have favored expansion of cattail, water lily and torpedograss should be reduced in their occurrence. This situation, along with active measures (controlled fires and/or herbicide application) to kill torpedograss and cattail, should provide benefits to the lake's fish and wading bird communities.

Level of certainty - Intermediate

A.9.5.3 Other Aquatic Fauna

The information available at this time is insufficient to formulate hypotheses or predictions regarding other aquatic animals in the lake. The lake's littoral zone is used by society as a resource for hunting frogs and collecting snakes and turtles for commercial sales, but the distribution and abundance of these animals is unknown. The only study to consider herptofauna in the lake (USACE 1999) included sampling only at a few selected locations, but indicated that there are at least 15 common species. These included snakes, frogs and turtles. The number of animals collected was reduced to near zero during a

period when lake stage became very high, but it was impossible to determine if this was a causal effect or an artifact of low sampling efficiency (the traps were designed for sampling in shallower water).

A.9.5.4 Native Vegetation Mosaic

The littoral zone of Lake Okeechobee, in its current form, is a relatively recent system. Much of it was formed after construction of the Herbert Hoover Dike in the mid-1900s and control of the lake at a lower average surface elevation than under presettlement conditions. The lake's natural littoral zone probably was much larger and occurred to the west and south of its present location (Havens et al. 1996a, Steinman et al. 2002a). The existing littoral zone supported a diverse array of native plants when it first was mapped in the early 1970s (Pesnell and Brown 1976). The community included large areas of spikerush, sawgrass (*Cladium jamaicensis*), willow (*Salix caroliniana*) and beakrush (*Rhynchospora tracyi*). At the south end of the lake there were remnant stands of pond apple (*Annona glabra*) and along the western shore there was a nearly continuous band of dense bulrush immediately lake-ward of a zone dominated by spike rush and submerged plants. Although there is no quantitative record, various anecdotal reports from the early 1970s indicate that the submerged plant beds were both widespread and dense, including species such as eelgrass and peppergrass, which are favorable habitats for fish (Furse and Fox 1994).

Today the vegetation mosaic of the littoral zone is dramatically different (Richardson and Harris 1995). Upland areas that previously were dominated by beakrush and mixed grass assemblages now have been infested by the invasive exotic torpedograss. Certain areas have become dominated by the exotic tree melaleuca (*Melaleuca quinquenervia*), although much of that species has been killed by herbicide (SFWMD 2002). The spatial extent of willow has declined and there has been a large expansion of cattail. Pristine spikerush sloughs in the interior littoral zone now are surrounded by cattail (an invasive nuisance species) and torpedograss and contain a higher density of water lily (*Nymphaea* spp.) than in the 1970s. The long-shore bulrush stands now are sparse (less than 50 percent of the former coverage) relative to their historic amounts, and the shoreline spike rush community no longer exists. Submerged vegetation was largely eliminated from the near-shore pelagic region in the late 1990s, but as indicated above, a marked recovery occurred during a period of low water levels in 2000 to 2002.

Three main factors have interactively affected the native vegetation mosaic in Lake Okeechobee. These factors are altered hydroperiod, excessive phosphorus loading, and the introduction and expansion of exotic plants. The following general hypotheses describe how these factors are thought to affect the vegetation mosaic attribute, and are organized by geographic region (littoral zone, near-shore bulrush zone and near-shore submerged vegetation zone).

In the Littoral Zone, the Distribution of Native and Exotic Plants Primarily is Determined by Hydroperiod

Short hydroperiod regions support native species including spikerush, beakrush, willow and cordgrass (*Spartina bakeri*), and exotic species including torpedograss, melaleuca and Brazilian pepper (*Schinus terebinthifolius*). Long hydroperiod regions support spikerush, cattail, sawgrass, bladderwort and water lily. Periods of extremely short or long hydroperiod (low and high lake stage events) that have occurred since the early 1970s are considered largely responsible for changes in the relative distribution of these plants.

Two periods of very low lake stage, in 1980-1981 and 1989-1990, may be responsible for much of the expansion that has occurred in exotic plant populations. Controlled experiments with melaleuca (Lockhart 1995) and torpedograss (Smith et al. 2003) have shown that these species cannot successfully invade native plant habitat that is inundated with water. Melaleuca seeds cannot effectively germinate under water, and torpedograss fragments (the plant’s main mode of colonization) cannot establish roots when

water depths exceed 50 centimeters. However, once plants are established (e.g., during a period when water depth is low), they can tolerate relatively deep and prolonged flooding. Field observations indicate that much of the expansion of melaleuca and torpedograss in the littoral zone occurred following droughts in 1981 and 1980, when lake stage fell below 11 feet, creating favorable habitat for colonization by seeds and fragments over nearly the entire littoral landscape.

When lake stage is low there also is an increased probability of fire occurring in the littoral zone, either due to natural causes (e.g., lightening strikes) or in controlled burn programs. Fires have documented benefits to the littoral vegetation mosaic. Fires burn away accumulated thatch in dense stands of emergent macrophytes, opening up the habitat to wildlife, and they also burn away much of the above-ground biomass of torpedograss monocultures, which allows for more effective control of this exotic with herbicide (Hanlon and Langeland 2000). Fires also allow buried seeds to germinate from the exposed sediments, providing the potential for species to recolonize the habitat (Williges and Harris 1995).

Several years of high lake stage in the late 1990s are considered responsible for changes that occurred in the dominance of native plant species in the interior littoral zone. From 1994 to 2000, lake stage exceeded 17 feet on four occasions and never fell substantially below 13 feet. These conditions may have favored development of dense stands of water lily in a west-central littoral region called "Moonshine Bay" where there previously was only spike rush and bladderwort. The dense lily communities may have degraded this habitat for fish and wildlife use due to a thick accumulation of dead leaf material and coarse organic detritus, which occupied up to 80 percent of the water column depth at some sites (South Florida Water Management District staff personal observation). These conditions were changed when the 2000-2001 drought dried the littoral zone, allowing the organic material to oxidize and/or burn in widespread fires.

Prediction - Because the lake stage regime expected under the CERP more closely mimics that which occurred in the early 1970s, it is expected to favor the type of littoral vegetation mosaic that occurred at that time. However, the new stage regime is likely to include periods of low lake stage, which will have both positive effects (drying and oxidation of accumulated organic debris) and negative impacts (increased spread of exotics). An aggressive program to control the spread of torpedograss is under development, and along with the ongoing melaleuca eradication program, may be a critical long-term measure to complement the modified hydroperiod that is established by the CERP.

Level of certainty - high

Excessive Inputs of Phosphorus from the Lake's Pelagic Zone Have Promoted the Spread of Cattail in Certain Littoral Areas and May Have Contributed to the Expansion of Water Lily

The pelagic zone of Lake Okeechobee has total phosphorus concentrations that average over 110 ppb (James et al. 1995a), while concentrations in the interior littoral zone are typically between 10 and 15 ppb (Havens et al. 1997, Hwang et al. 1998). At high lake stage, currents transport phosphorus-rich water from mid-lake towards the pelagic-littoral interface (Maceina 1993, Havens 1997) and into the littoral zone proper. This phenomenon recently has been documented by the South Florida Water Management District’s lake hydrodynamic model and by evaluation of water quality data during recent years when lake stage has been high. Studies of periphyton communities in the littoral zone indicate that there have been nutrient impacts similar to those observed in the Everglades (McCormick et al. 1996).

Aerial photographs and early maps (Pesnell and Brown 1976) of the littoral zone indicate that in the 1970s there was little or no cattail in the area of Moonshine Bay. In general, the area was characterized by a near-monoculture of spikerush. Today there is dense cattail along the edges of all boat trails leading from open water into Moonshine Bay from the north and west. There also is a dense "wall" of cattail along nearly the entire eastern edge of the littoral zone, where the plant community is in direct contact

with pelagic water (Richardson and Harris 1995). Stimulation of cattail growth by phosphorus enrichment and high water levels in Lake Okeechobee is consistent with results from experimental research carried out in the Everglades (Newman et al. 1996).

Prediction - Under the CERP, it is anticipated that the duration and return frequency of high water events will be reduced, and phosphorus inputs to the lake also should decline as a result of components of the CERP and the Lake Okeechobee Protection Program. Taken together these actions are expected to result in less phosphorus transport into the littoral zone, and a reduced rate of cattail expansion.

Level of certainty - Intermediate

Prolonged Periods of Deep Water, Combined with Damage from Wind-Driven Waves, Have Dramatically Reduced the Spatial Extent and Biomass of Near-Shore Bulrush Stands and Submerged Aquatic Vegetation

Recent estimates indicate that by the late 1990s, the spatial extent of bulrush was reduced by more than 50 percent from its recorded maximum in the early 1970s (Florida Fish and Wildlife Conservation Commission unpublished data). Two factors may interactively have contributed to this decline. First, long periods of deep standing water may have resulted in conditions where only a small percentage of the plant's photosynthetic tissues were above water (Hanlon 2003). Under those circumstances, bulrush has been documented to draw on its underground rhizomes as an energy reserve, until eventually the plants have insufficient energy for net growth and survival (van der Valk 1994).

In a similar manner, high water had resulted in a dramatic decline in the spatial extent of SAV by 1999, following several years of high lake stage. High water levels have two related effects on underwater irradiance, and in turn, on the rate of growth and survival of submerged plants. First, when lake stage is high, light reaches the bottom only in a limited area close to the lake shore, where depths are shallow. This limits the lakeward extent of submerged plant habitat (Havens 2003). Second, under high stage conditions, there is increased transport of sediment-laden water from the mid-lake area (where these sediments are resuspended by wind) to the near-shore area that supports submerged plants (Maceina 1993, Havens 1997). When combined with a deeper water column, the increased turbidity results in little or no light reaching the lake bottom. Research has shown that submerged plant biomass in Lake Okeechobee is negatively correlated with water depth (Hopson and Zimba 1993) and that the highest submerged plant biomass occurs when stage is very low (Phlips et al. 1993). Controlled experiments have confirmed a cause-effect relationship between underwater irradiance and growth rates of submerged plants from the lake (Grimshaw et al. 2002).

Once submerged plants are lost, a positive feedback maintains the turbid condition. Without plants to stabilize sediments, there is increased sediment resuspension and no competition with phytoplankton for nutrients. Resuspended sediments and algal blooms result in higher turbidity, which prevents plant recovery. This cycle is very difficult to break once it is established (Scheffer 1989). Only dramatic actions, such as the considerable lowering of stage that occurred in 2000-2001 (Havens et al. 2001), allow plants to recolonize the site. Once this occurs, however, the plants can establish a different feedback loop that maintains clear water (the plants support sediments and they also remove nutrients from the water so that algal blooms do not occur).

Prediction - The goals of the CERP include both a lowering of average water levels in the lake and a reduced frequency of extreme high water levels (when damaging wave effects occur). Under those conditions, the distribution and abundance of bulrush and submerged plants are expected to increase.

Level of certainty - high

High Water Levels Have Eroded the Eastern Lakeward Edge of the Littoral Zone and Resulted in the Accumulation of a Dense Organic "Berm" of Dead Plant Material and Lake Sediment at the Pelagic-Littoral Interface

According to biologists who have worked on the lake since the 1960s, organic berms are a common feature of the impounded system. The berm that formed in the late 1990s, however, was considered to be the most large-scale and permanent one ever to have occurred. In some areas it was over one-meter tall, greater than 10-meters wide, and it established a community of woody vegetation including small primrose willow trees. Scientists at the Florida Fish and Wildlife Conservation Commission expressed concern that this organic berm is ecologically harmful because 1) it may prevent normal water exchange between the littoral zone and marsh, in particular, it may block the egress of water from the marsh after periods of heavy rainfall over that area; 2) it may block normal migration routes for fish; and 3) it may act as a "break-wall" that does not gradually attenuate waves in the manner that an edge of vegetation would, and this causes erosion of sediments and any submerged plants that might develop at its lakeward edge. Some large areas of berm were scraped up and deposited in spoil islands along the western lake shore in 2001 in a cooperative project of the Florida Fish and Wildlife Conservation Commission, the United States Army Corps of Engineers, and the South Florida Water Management District.

District staff have documented that the lake-ward edge of the littoral zone and the berm are highly dynamic, forming and eroding in much the same manner that a sandy beach is eroded and redeposited elsewhere by strong surf. In the case of the lake, however, the erosion is of the littoral plant community itself. Hanlon (2003) documented by comparison of historic geographic information system (GIS) vegetation maps that the lakeward edge of the northwest littoral zone was eroded by up to 300 meters between 1996 and 1999. During a period of particularly high lake levels (near 18 feet) in fall-winter 1998, staff documented recession of the littoral edge of up to 10 meters in just 90 days. Output from the South Florida Water Mangament District's lake hydrodynamic model (Jin et al. 2000) indicates that under high stage conditions, and in the absence of dense bulrush stands to attenuate wave energy, there are strong long-shore currents that could scour sediments and submerged plants, and erode the lakeshore along much of the western edge.

Prediction - Under the lower lake stage schedule of the CERP, it is predicted that littoral shoreline erosion and berm formation should be substantially reduced. It may be necessary, however, to carry out a project to remove the organic material that has accumulated during high water periods that occurred prior to CERP implementation.

Level of certainty - high

A.9.5.5 Snail Kites

The littoral zone of Lake Okeechobee is designated as one of the critical habitats (Federal Register 42 [155]:40685-40688) for the Everglades snail kite, a federally-endangered species. Snail kites use the littoral zone as a habitat for nesting and foraging; other habitats for this bird include Everglades National Park, the Water Conservation Areas, the Big Cypress basin, and lakes and wetlands located to the north and east of Lake Okeechobee. Kites are known to migrate extensively across the South Florida landscape (Bennetts and Kitchens 1997), and as such, cannot be effectively managed in a site-specific context.

The availability of multiple wetland habitats is considered to be critical for kites and is the foundation of the "meta-habitat hypothesis" proposed by Bennetts and Kitchens (1997). In this hypothesis, the risk to the regional population is minimized by the ability of kites to move to different habitats within the regional network as the quality of localized habitats fluctuates. For this to be effective, it is important that conditions in the habitats not be degraded to the extent that they are no longer functional during times

when snail kites require their use. For example, when a regional drought occurs, the littoral zone of Lake Okeechobee may represent the only large wetland system with suitable foraging and nesting conditions. Hence the lake should not be degraded to the extent that it loses its apple snail populations or suitable foraging (e.g., spike rush slough areas) and nesting (e.g., willow) habitat.

Snail Kite Foraging Habitat in the Littoral Zone Is Degraded When Dense Cattail or Torpedograss Replaces Relatively Open Spikerush Habitat

Bennetts and Kitchens (1997) noted that the quality of habitat for kites is adversely influenced both by certain changes in water quality and the expansion of exotic plants. In each case, the key factor is replacement of relatively open foraging habitat with habitat dominated by dense vegetation. They note that in the Everglades, nutrient enrichment favors dominance of cattail, and that this could impact kites, which require relatively open water areas for foraging because they must detect their prey visually (Sykes 1987, Bennetts et al. 1988). Likewise, dense stands of torpedograss cannot support animal prey due to low dissolved oxygen, and do not permit effective foraging by visual predators since the vegetation typically hides the water column. The same probably holds true where spikerush develops dense growth of floating-leaf plants such as water lily.

Level of certainty - Intermediate

Snail Kite Foraging Habitat in the Littoral Zone Is Degraded When the Abundance of Apple Snails is Substantially Reduced

Apple snails are the major food item of the snail kite. Therefore, if environmental conditions (e.g., a prolonged dry down coincident with the season of egg laying or a lake stage reversal after eggs are laid) result in a major "crash" of apple snails, the habitat will be unfavorable for kites until the food resource recovers.

Level of certainty - high

Snail Kite Nesting Habitat in the Littoral Zone is Degraded When the Spatial Extent of Sawgrass and Willow is Reduced.

According to Bennetts and Kitchens (1997), snail kites nest primarily in willow and other woody vegetation types. Hence the spatial extent of these plant types will directly affect whether or not the littoral zone represents viable habitat for kite nesting. Two factors contributing to loss of this habitat in Lake Okeechobee include prolonged periods of deep water and the expansion of torpedograss.

Level of certainty - Intermediate

The Lake Okeechobee Littoral Zone is Essential Habitat for the Florida Population of Snail Kites during Periods of Extensive Drought

This hypothesis follows directly from the meta-habitat hypothesis of Bennetts and Kitchens (1997) and their findings regarding use of the lake by kites during years when other regional habitats are dry due to drought conditions.

Level of certainty - high

A.9.5.6 Wading Birds

Lake Okeechobee has long been recognized as an important nesting location for wading birds. Anecdotal records from National Audubon Society game wardens during the 1940s documented large concentrations of nesting birds at the lake (David 1994). More quantitative surveys during the period 1957-1978, showed that there were typically about 4,700 nests per year, with peaks in nesting effort in 1972 and 1974. During those years, there were approximately 10,000 wading bird nests on the lake, mostly of White Ibis at the King's Bar colony, near the mouth of the Kissimmee River. It was considered to be one of the largest and most important wading bird colonies in central Florida. After an increase in the lake regulation schedule in 1978, wading bird nesting effort declined and stabilized at about 2,000 nests (David 1994), at least up until 1992, when it was last surveyed (Smith and Collopy 1995).

The primary hypotheses to explain the general decline in nesting effort after 1978, as well as individual years of low nesting effort, is that increased lake water levels decreased the quality or quantity of habitat. The following hypotheses describe in more detail how water levels affect wading bird nesting on the lake.

Seasonal Lake Stage Recessions Benefit Wading Bird Populations

In the Everglades, fish populations are 2-4 times higher in marshes that are inundated than in areas that dry out regularly (Loftus and Eklund 1994). However, as water levels fall during the dry season, small depressions in the marsh surface act as places where fish become concentrated. Fish concentrations increase by a factor of 20 to 150 in the Everglades and Big Cypress National Preserve (Carter et al. 1973, Loftus and Eklund 1994, Howard et al. 1995). These patches of concentrated prey are typically shallow with no vegetation. Thus, individual fish become more vulnerable to capture and wading bird feeding success is increased (Kushlan 1976). Although these high-density food patches may be scattered in the landscape, wading birds have adaptations such as white plumage and social foraging that allow them to minimize their search time (Kushlan 1981, Erwin 1983). Thus, at the landscape scale, wading birds are able to exploit small patches of highly available prey and large foraging aggregations indicate good feeding conditions. Species such as wood storks, white ibises, and snowy egrets appear to be more dependent, than are other wading bird species, on good feeding conditions to have years of high reproductive output (Gawlik 2001). Hydrologic patterns that produce the maximum number of these patches with high prey availability (i.e., high lake stages at the end of the wet season and low lake stages at the end of the dry season) tend to produce good wading bird nesting effort (Smith and Collopy 1995).

Prediction – Because the lake stage regime expected under the CERP more closely mimics that which occurred in the early 1970s, the frequency at which the marsh dries should increase and favor increased reproduction for snowy egrets and white ibises.

Level of certainty - high

Large Stands of Willow Are Beneficial to Wading Bird Nesting

In Everglades and Lake Okeechobee, most wading bird colonies occur in willow trees (Zaffke 1984, Frederick and Spalding 1994). Willow is thought to be the preferred nesting substrate because it can tolerate longer hydroperiods than most tree species and therefore is usually in deeper water than other species. Wading birds seem to prefer to nest in deep water because it increases the likelihood that their nests will remain surrounded by water throughout the nesting season. Such conditions reduce the probability of their nests being predated by raccoons (Frederick and Spalding 1994). Despite the tolerance for long hydroperiods, even willow can not withstand prolonged periods of deep water. It Lake Okeechobee, high water has had negative impacts on willow stands in certain lower elevation regions of

the littoral zone. Therefore, it is possible that the preferred nesting sites for wading birds could be a factor limiting population sizes.

Prediction - The goals of the CERP include both a lowering of average water levels in the lake and a reduced frequency of extreme high water levels. If this water management regime stops the loss of willow or increases the amount of willow, then nesting habitat quality for wading birds will be remain stable or increase.

Level of certainty - high

A.9.5.7 Waterfowl

Lake Okeechobee hosts more than 100,000 migratory waterfowl in many years (ongoing mid-winter surveys of the Florida Fish and Wildlife Conservation Commission), although the numbers vary greatly between years (Chamberlain 1960, Bellrose 1976). Migratory behavior may allow these birds to exploit seasonally rich and variable habitats in the regional landscape.

Most numerous in the mid-winter surveys are lesser scaup (*Aythya affinis*), which inhabit the pelagic zone of the lake and whose numbers range from 50,000 to 300,000. Scaup dive for their food in water up to several meters deep (Bellrose 1976) and their diet on Lake Okeechobee is unknown. The second most abundant species has been the ring-necked duck (*Aythya collaris*), Florida's most harvested duck. Close to half of all ring-necked ducks wintering in the Atlantic Flyway formerly used Lake Okeechobee (Bellrose 1976), but the spread of *Hydrilla*, a highly preferred food, apparently has spread ringnecks around Florida (Johnson and Montalbano 1984, Jeske 1985, Esler 1990). Ring-necked duck numbers on Lake Okeechobee fell from an average of 5,807 from 1991-1995, to an average of 489 from 1996-2000. This 92 percent decline was apparently due to the loss of submerged plants on the lake during this period of high water, combined with the availability of alternate habitat locations.

Fisheating Bay is surveyed independently of the rest of the lake for waterfowl, and ring-necked duck numbers in that location declined from a 5-year average of 5,190 in 1991-1995 to 2,798 in 1996-2000 (data were missing in 1999), a 46 percent change. During the same period, American coots (*Fulica americana*) declined by 77 percent on the larger part of the lake, from a 5-year average of 15,303 between 1991-1995, to an average of 3,508 from 1996-2000. In Fisheating Bay, coots increased from 13,805 in 1991-1995 to 19,546 in 1996-2000, although lakewide there still is an overall downward trend (21 percent). Like ring-necked ducks, coots feed on submerged vegetation (Bellrose1976, Montalbano et al. 1979, Esler 1990) and their declining numbers are likely correlated with declining acres of those plants in the lake. The higher numbers of birds in Fisheating Bay may be due to the few surviving areas of H*ydrilla* and other submerged plants (e.g., *Vallisineria*) that remained in the lake during the late 1990s.

Dabbling ducks prefer marshy areas and are more difficult to accurately survey than the diving ducks discussed above. An average of 338 dabbling ducks was detected on the lake between 1991-2000 (mid-winter inventory by the Florida Fish and Wildlife Conservation Commission). Considering that there are a potential 90,000 acres of habitat for these birds, this number is extremely low and reflects impaired habitat conditions. For comparison, Johnson and Montalbano (1984) detected an average of 11,886 dabbling ducks just in Fisheating Bay during a study in 1981-1982. High water levels impede dabbling ducks from using the lake because they rarely dive to feed and prefer water less than 1-feet deep (White and James 1978, Johnson and Montalbano 1984, Gray 1993). Chronic high water levels, or more specifically, lack of a spring dry down, prevent the growth of moist soil vegetation that is important in producing seeds that many ducks prefer (Goodwin 1979, Fredrickson and Taylor 1982).

Numbers of Ring-Necked Ducks and Coots Decline When Submerged Vegetation Is Lost Due to High Water Levels

Waterfowl numbers in any location in a given year are related to size of the fall flight, weather and habitat conditions north of Florida, and habitat conditions in the Florida peninsula. Lake Okeechobee is large enough that waterfowl will find it and if suitable habitat is available, they will use it in some numbers, related to quality of the habitat. Quality habitat in this case is submerged vegetation.

Level of certainty - Intermediate

Numbers of Dabbling Ducks (Genus Anas and Aix) Are Strongly Correlated with Areas of Water Less Than 6 Inches Deep, and Presence of a Spring Recession

Dabbling ducks are expected to respond positively to quality habitat (Goodwin 1979). A spring recession produces somewhat predictable vegetation responses (Richardson et al. 1995) and shallow water for foraging.

Level of certainty - Intermediate

A.9.6 Research Questions

A.9.6.1 Water Quality

Internal versu External Loads

Despite a considerable amount of research dealing with sediment-water phosphorus dynamics and internal loading in Lake Okeechobee, there is uncertainty regarding the timing of lake response to external load reductions. Particularly important factors that could influence the response include 1) the rate of phosphorus deposition by particle sedimentation; 2) the depth of the "active sediment layer" that interacts with the overlying water column; 3) the rate of burial of sediment material into deep storage where it no longer plays a role in the lake's phosphorus cycle; and 4) removal by mineral formation. In the recent Lake Okeechobee total maximum daily load (TMDL) process, there were differing viewpoints among experts regarding these factors, indicating an area of research need.

Lake Stage versus Phosphorus

Although there is good evidence that lake stage affects water column total phosphorus concentrations in both the pelagic and littoral regions of Lake Okeechobee, some of the key mechanisms still have not been quantified to the extent that they can be incorporated into predictive models. Effects of stage on water currents and horizontal materials transport now can be effectively modeled using the lake hydrodynamic model, as can transport of nutrients into the littoral zone. Effects of plants and attached algae on water column phosphorus concentrations, however, presently cannot be predicted, despite the fact that they may be of considerable importance under moderate and low stage conditions. Efforts are underway to quantify how submerged plant communities respond to changes in underwater irradiance. This information, along with results of studies to quantify effects of plants on nutrients and turbidity, is needed for development of a model of near-shore water quality and plant distribution. Similar information needs to be collected and incorporated into the models for periphyton and benthic algae, since these components of the community have the potential to attain a high biomass.

Phosphorus Assimilative Capacity

Although results from other shallow lakes indicate that biological recovery from cultural eutrophication in Lake Okeechobee might result in a greater lake assimilative capacity (Havens and Schelske 2001), the magnitude of these effects is uncertain. In order to periodically reevaluate (and perhaps modify) the lake phosphorus loading target, there is a need to quantify some of the key relationships and incorporate them into predictive models. This will require an evaluation of phosphorus sources and sinks associated with algal settling, cyanobacteria vertical migration, and perhaps oligochaete bioturbation. Long-term assessment of the magnitude of these processes needs to accompany model development and validation. There also is a need to determine whether recent increases in sediment dissolved phosphorus reflects a loss of assimilative capacity or increased diagenesis.

Phosphorus and Algal Blooms

The relationship between excess phosphorus concentrations and algal bloom development is well established in the general limnological literature and in the literature dealing with Lake Okeechobee. That blooms will decline if in-lake phosphorus concentrations are substantially reduced is quite certain. One area of uncertainty that does exist, however, is the extent to which algal blooms in themselves might make the lake resilient to recovery. The taxa of cyanobacteria that occur in Lake Okeechobee are known to occur in a "dormant" state at the sediment surface, and during formation of blooms they may be responsible for a large transport of phosphorus upward from the sediments to the water column (Barbiero and Welch 1992, Havens et al. 1998). Quantifying the magnitude of this process would increase the certainty of predictions of lake recovery from excessive phosphorus loading.

In regard to the effects of blooms, we also lack information regarding quantitative linkages between bloom occurrence/magnitude and important societal values, such as drinking water quality (taste, odor, trihalomethanes), recreational use of the water resource, and fishing. Since the lake is highly visible as a public natural resource and is the headwaters for the Everglades, we believe that it is important to quantify these relationships so that performance measures can be developed for these potential benefits of the project.

A.9.6.2 Fish and Aquatic Fauna

Macroinvertebrates and Zooplankton

Based on responses of other eutrophic lakes, it can be predicted with a relatively high degree of certainty that if the pelagic sediments develop a less enriched character due to reduced phosphorus inputs, the abundance of pollution-tolerant oligochaetes will decline and other less tolerant species will return. The timing and magnitude of recovery is uncertain, but can be determined with long-term monitoring. Likewise there is a relatively high certainty that restoration of near-shore bulrush and submerged vegetation communities will result in an increased abundance of the macroinvertebrate taxa that use that habitat.

The uncertainty regarding responses of littoral macroinvertebrates to the CERP is greater, reflecting a general lack of information about how invertebrate communities are distributed across that landscape. There has been a considerable amount of research in South Florida dealing with apple snails, and therefore there is a greater certainty regarding the responses of those particular animals.

Factors affecting zooplankton biomass and composition are relatively well studied (e.g., Havens et al. 1996c), and long-term monitoring should suffice to document that timing and magnitude of any major changes in that community. It will be particularly important to keep track of abundances of cladocerans

(including the exotic *Daphnia lumholtzii*) since these animals are the most effective grazers of phytoplankton and the optimal food resources of zooplanktivorous fish.

Open-Water and Littoral Fish Communities

The diet habits of fish in the pelagic region have been documented in some preliminary studies, and the factors potentially controlling their distribution and abundance were quantified in a comprehensive survey study with multivariate statistics (Bull et al. 1995). There is some uncertainty regarding responses of these fish to the CERP, since the work to date has not included any cause-effect experiments. The timing and magnitude of pelagic fish responses to the CERP cannot be determined unless a comprehensive long-term monitoring program is established. At this time, there is no systematic monitoring of pelagic fish in this lake.

There also is some uncertainty regarding how the CERP will influence near-shore fish. It seems clear that their habitat structure (submerged and emergent vegetation) will be enhanced if the CERP results in a reduced frequency of damaging high water levels. Benefits to the fish community are not as predictable, however, because they will depend on both changes in habitat and resource availability. The timing and magnitude of near-shore fish responses to the CERP cannot be determined unless a more comprehensive long-term monitoring program is established. At this time, the only systematic monitoring is a Florida Fish and Wildlife Conservation Commission survey of largemouth bass and black crappie, conducted once a year by electro-shocking.

There is a high level of uncertainty regarding littoral fish responses to the CERP because only a few of the region's major plant community types have been sampled for these animals. To accurately predict how the CERP will affect the lake's fishery, which depends heavily on the littoral zone, better information is needed regarding use of particular native and exotic plant assemblages. Furthermore, only preliminary diet studies have been conducted in the littoral zone (only in Moonshine Bay), and a more in depth study of feeding habits is needed to predict how littoral fish will respond to changes that the CERP might cause at lower trophic levels. Likewise, the distribution, abundance and responses of those lower trophic level organisms to changes in water level and nutrient inputs need to be determined.

Other Animals

Another area of uncertainty regarding the lake ecosystem is in regard to reptiles, amphibians and other aquatic animals that utilize the littoral zone as foraging and/or nesting habitat. Only limited survey studies have been performed. These need to be supplemented with more detailed studies of the relationship between vegetation, hydroperiod and aquatic animal occurrence, as well as studies to determine the role of the animals in the littoral food web. Preliminary data indicate that some of these animals (e.g., certain frogs) may be food resources for economically important species such as the largemouth bass.

A.9.6.3 Native Vegetation Mosaic

Littoral Zone and Hydroperiod

The uncertainty associated with the relationship between emergent littoral vegetation and hydroperiod is low, because the linkage has been established from intensive GIS mapping and multivariate modeling (Richardson et al. 1995), and because controlled experiments have established how variations in water level affect the establishment and growth of key plant taxa (Smith et al. 2003). So far, the focus of experiments has been on torpeodgrass, melaleuca and spikerush. Studies are needed for other dominant littoral plant taxa. For example, the link between water lily expansion and long hydroperiod is circumstantial, since this species is known to respond both to hydroperiod and increased phosphorus

inputs (McCormick et al. 1999). Because dense water lily degrades spikerush habitat, this is an area of uncertainty that merits further consideration.

Littoral Zone and Phosphorus

Uncertainty is associated with the relationship between the littoral zone and phosphorus, but we can draw some inferences from research conducted in the nearby Florida Everglades, and from some short-term controlled mesocosm experiments to evaluate periphyton responses in Lake Okeechobee (Havens et al. 1997). Nutrient effects on primary producers (plants and periphyton) are most firmly established; relatively little is known about how nutrients affect higher trophic levels in the littoral food web. It may be particularly important to quantify experimentally how increased or decreased nutrient-induced changes in plants and periphyton affect the productivity of certain key animal species such as apple snails (prey for snail kites) or small forage fish (prey for sport fish taxa and wading birds).

Bulrush and Submerged Vegetation and High Water

It is clear that prolonged or extreme high water has damaging effects on bulrush and submerged vegetation of the lake's plant community. However, the causal mechanisms are only generally understood. Given the critical role that these plants play in terms of water quality and fish/wildlife habitat, research is needed to identify the "lake stage window" (yearly range of water levels) that is required to support a healthy community. There also is a need to determine conditions necessary to allow recovery of the community when unfavorable conditions do occur (e.g., two successive years of high rainfall and high stage). South Florida Water Management District staff also intends to modify the existing lake water quality model so that it can predict, with a fine spatial scale, the extent of submerged vegetation that might occur under different lake stage management scenarios. That tool will be useful to the Restoration Coordination and Verification (RECOVER) process, because it will allow plan evaluations by the Regional Evaluation Team to include not only hydrologic and water chemistry predictions, but also predictions regarding responses of one of the lake's key biological communities.

Shoreline Erosion and Berm Formation

Erosion of the western shoreline has been linked with high lake stage and wind-driven waves, and long-term monitoring will continue in order to keep track of any further shoreline degradation. The ecological impacts of the organic berm have not been documented, but this may not be a particularly high research priority if plans call for its removal.

A.9.6.4 Snail Kites, Wading Birds and Waterfowl

Prey Availability and Water Level Recession

The uncertainty associated with the general relationship between prey availability and water level recession is fairly low. One of the first studies of wading birds in South Florida (Kahl 1964) reported this general relationship and a subsequent study (Kushlan 1976) substantiated it. The main area of uncertainty is in how different species will respond and why the level of response is still quite variable among years.

Nesting Substrate as a Population Constraint

The uncertainty associated with nesting substrate as a population constraint is high. It is not clear whether the lack of willow as a nesting substrate is limiting the population size of any species of wading birds on the lake. More importantly, there is no information on the consequences of birds using less preferred

nesting substrate. It is assumed that the use of less preferred nest sites will reduce nesting success, but if that assumption is invalid then there will be little effect on the overall population size.

A.9.7 Hydrological Performance Measures

A key feature of the Lake Okeechobee Conceptual Ecological Model is the high degree of interconnectedness; any given stressor may impact ecological attributes directly, or impact those same attributes indirectly, by exacerbating the effects of other stressors. Two stressors that display particularly strong effects (direct and indirect) on the attributes are high and low water levels. Taken together, they have the potential to affect the rate of lake eutrophication, the spatial extent and overall health of submerged and emergent plant communities, fisheries, birds, other wildlife and the quality of water taken from the lake from human uses.

Water inputs and lake levels also are the variables most directly impacted by proposed components of the CERP. Therefore, a suite of hydrologic performance measures was developed based on our understanding of the ecosystem and used by the C&SF Project Comprehensive Review Study (Restudy) Alternative Evaluation Team (USACE and SFWMD 1999) to evaluate potential impacts of various planning alternatives on lake ecosystem health. These performance measures have been peer-reviewed and published in the open scientific literature (Havens 2002). The Regional Evaluation Team of CERP uses these same performance measures for the lake during the regional evaluation process. Five priority performance measures are calculated, weighted and summed using the River of Grass Evaluation Model (ROGEM) for Lake Okeechobee. The Lake Okeechobee ROGEM is comprised of metrics (suitability index variables, or SIVs) that describe the fluctuation and timing of lake stages. The model assumes that restoration of a more natural (within the constraints of the dike system) hydroperiod would result in positive biotic responses of the lake community.

Suitability index variables in the ROGEM range from 0 (worst score) to 1.0 (best score). Relationships between hydrologic attributes and SIVs in this model are not linear. Instead, they reflect expert opinion that the degree of ecosystem stress is exacerbated by an increasing occurrence of undesirable events. This gives rise to a curvilinear relationship between hydrologic attributes and their SIVs; i.e., once the ecosystem has been stressed, further stresses bring about more dramatic responses than were evidenced following the single event. At a certain point (considered here to be 4 events or more per decade), the degree of stress is so severe that the system cannot recover its ecological and societal functions. The five SIVs used in the model are as follows:

1. An <u>extreme low lake stage</u> (less than 11 feet) performance measure (SIV_{MINX}) indicates the frequency of events that: (1) result in a loss of over 95 percent of the littoral zone as habitat for aquatic biota; and (2) promote expansion of exotic plants. The goal is to have a minimal number of these events. A score is calculated as follows:

    - Stage neer falls below 11 feet = 1.0
    - Stage falls below 11 feet on 1 occasion per 10 years = 0.9
    - Stage falls below 11 feet on 2 occasions per 10 years = 0.7
    - Stage falls below 11 feet on 3 occasions per 10 years = 0.4
    - Stage falls below 11 feet on 4 or more occasions per 10 years = 0

2. A moderate low lake stage (less than 12 feet) performance measure (SIV_{MINM}) indicates the frequency of prolonged (greater than 12 continuous month) events that substantially reduce the littoral area available as wildlife habitat, and promote exotic plant expansion. The goal is to have a minimal number of these events. A score is calculated as follows:

    - Stage never falls below the 12 feet per 12 month criterion = 1.0
    - Stage falls below the 12 feet per 12 month criterion on 1 occasion per 10 years = 0.9
    - Stage falls below the 12 feet per 12 month criterion on 2 occasions per 10 years = 0.7
    - Stage falls below the 12 feet per 12 month criterion on 3 occasions per 10 years = 0.4
    - Stage falls below the 12 feet per 12 month criterion on greater than or equal to occasions per 10 years = 0

3. An extreme high lake stage (greater than 17 feet) performance measure (SIV_{MAXX}) indicates the frequency of events that result in wind and wave damage to the shoreline plant communities that provide critical habitat for recreational fish and other wildlife; and transport phosphorus-laden pelagic water into pristine interior regions of the littoral zone. The goal is to have a minimal number of these events. A score is calculated as follows:

    - Stage never exceeds 17 feet = 1.0
    - Stage exceeds 17 feet on 1 occasion per 10 years = 0.9
    - Stage exceeds 17 feet on 2 occasions per 10 years = 0.7
    - Stage exceeds 17 feet on 3 occasions per 10 years = 0.4
    - Stage exceeds 17 feet on greater than or equal to 4 occasions per 10 years = 0

4. A moderate high lake stage (greater than 15 feet) performance measure (SIV_{MAXM}) indicates the frequency of prolonged (greater than 12 continuous months) events. These events limit light penetration to the lake bottom, resulting in a loss of the benthic plants and algae that stabilize sediments and provide habitat for invertebrates and fish; and promote greater circulation of phosphorus-rich turbid waters from mid-lake to less eutrophic near-littoral regions, where phosphorus inputs stimulate algal blooms. The goal is to have a minimal number of these events. A score is calculated as follows:

    - Stage never exceeds the 15 feet per 12 month criterion = 1.0
    - Stage exceeds the 15 feet per 12 month criterion on 1 occasion per 10 years = 0.9
    - Stage exceeds the 15 feet per 12 month criterion on 2 occasions per 10 years = 0.7
    - Stage exceeds the 15 feet per 12 month criterion on 3 occasions per 10 years = 0.4
    - Stage exceeds the 15 feet per 12 month criterion on greater than or equal to 4 occasions per 10 years = 0

5. A spring recession performance measure (SIV_{VAR}) indicates the number of years during which January to May lake levels decline from near 15 feet to 12 feet, without any reversals greater than 0.5 feet. These conditions are favorable to nesting birds and other wildlife in the marsh. They also allow for reinvigoration of willow stands, and permit fires to burn away cattail thatch. The goal is to have a substantial number of events. A score is calculated as follows:

    - Stage recession between January and March from greater than 14 feet to less than 13 feet NGVD, with no reversal greater than 0.5 feet NGVD occurring every year = 1.0
    - Stage recession occurring only in 9 out of 10 years = 0.9
    - Stage recession occurring only in 8 out of 10 years = 0.7
    - Stage recession occurring only in 7 out of 10 years = 0.4
    - Stage recession occurring only in 6 or fewer out of 10 years = 0

A.9.7.1 Suitability Index Variables Priority Weights

The five SIVs address important aspects of how water level and its seasonal variation affect the ecological attributes of Lake Okeechobee. However, the SIVs are not considered of equal importance in regard to indicating an absolute level of stress (or benefit). A weighting scheme was developed, on the basis of best professional judgement, to reflect the relative importance of each SIV as an index of lake ecosystem health. For simplicity, a weighting scale of 1 to 5 (1 being least important, and 5 being most important) was used.

The SIVs associated with the greater than 17 feet and greater than 15 feet per12 month criteria were given priority weights of 5. Extreme or prolonged high water levels have been documented to affect numerous ecosystem attributes, including littoral plant and periphyton communities, benthic plants and periphyton, fisheries habitat, and water quality (including turbidity, phosphorus and algal blooming). These effects are well documented by scientific research (Sheng and Lee 1991, Havens 1997, Steinman et al. 1997b).

The SIVs associated with the less than 11 feet and less than 12 feet per 12 month criteria were given priority weights of 4. Extreme or prolonged low lake stages also may cause harm to the ecosystem, but the impacts are less documented, and are not considered as serious on a lakewide basis; i.e., the effects primarily are restricted to the littoral zone proper, and negative impacts (e.g., loss of fisheries habitat) may in part be compensated for by enhanced growth of submerged plants in the southern near-shore pelagic region.

The SIV for spring lake level recession describes a seasonally-variable hydropattern that is considered by experts to benefit a variety of littoral zone values, including wading birds and certain native plant communities (Smith et al. 1995). It is the only SIV that relates to seasonal variation in lake levels. Therefore, it is given a weight of 5.

A community suitability index (CSI) integrates the scores of five hydrologic SIVs and their respective weighting factors, and has an overall range of 0 to 1.0:

$$CSI = (4*SIV_{MINX} + 4*SIV_{MINM} + 5*SIV_{MAXX} + 5*SIV_{MAXM} + 5*SIV_{VAR}) / 23$$

A.9.8 Ecological Performance Measures

To quantify the current status of Lake Okeechobee and its responses to implementation of CERP components, it is necessary to develop and implement a comprehensive ecological monitoring program. This program will focus on a set of ecological performance measures, which are measures of ecosystem attributes that have quantifiable targets (restoration goals or expectations). A set of specific monitoring parameters will be associated with each performance measure that is included in the program. By adopting this approach, it should be possible to quantify the status of the ecosystem at various scales of resolution, at any point before, during or after completion of the CERP. Assuming that the hydrologic performance measures used in the planning process reflect conditions that are beneficial to the ecosystem, the overall "scores" of ecological performance measures should increase as the project is completed. If ecological scores do not display expected trajectories during the project, this may serve as an indicator that some adaptive management needs to occur (i.e., changes in structural or operational aspects of the project).

The Lake Okeechobee Conceptual Model working group developed a set of performance measures, targets, and monitoring parameters associated with the four ecosystem attributes (lake water quality; fish and aquatic fauna; native vegetation mosaic; and snail kite, wading birds and waterfowl) in the conceptual ecological model. The information is summarized in Table A-6, and details regarding each performance measure are provided in the Draft Performance Measure Documentation Report (RECOVER 2003b). The following text highlights important points that are not explicitly indicated in the tables. The information was a starting point for development of the ecological monitoring program (RECOVER 2003a). Detailed planning will consider the spatial and temporal aspects of sampling that are required for each parameter, the degree to which recommended parameters already are being monitored by certain state and federal agencies, methods to evaluate uncertainty (both for measured values and targets), and standard procedures for data collection, evaluation, reporting and archiving.

A.9.8.1 Water Quality

A number of the water quality parameters relate to the degree of cultural eutrophication of the lake. Given the uncertainty about the lake's natural trophic state, the goals do not correspond with "restoration," but rather, the attainment of water quality conditions as good as observed in a period of record (1973-1999) when quantitative data were collected. During the early 1970s, when total phosphorus concentrations were near 40 ppb and total nitrogen to phosphorus ratios were above 30:1, blooms of blue-green algae were rare, and transparency was higher, especially in the near-shore region. Other parameters relate to toxic materials (Class I and III parameters) that can affect both the lake ecosystem and drinking water quality.

It is important to note that all water quality targets listed in Table A-6 represent lakewide average conditions. Given that the lake is heterogeneous in regard to water quality, the final monitoring program should establish region-specific (littoral, near-shore, and pelagic) performance measures and targets. For example, the lakewide total phosphorus goal is 40 ppb, while appropriate regional goals might be less than 10 ppb for interior littoral, approximately 20 ppb for near-shore, and approximately 70 ppb for central pelagic. Likewise, goals for algal blooms might be zero for the interior littoral region, somewhat higher than the lakewide average for the near-shore region, and close to zero for the central pelagic (light limited) region.

Table A-6: Ecological Performance Measures Associated with the Lake Okeechobee Conceptual Ecological Model, Arranged According to the Four Major Attributes

Lake Water Quality
Total phosphorus concentration
Total nitrogen:phosphorus ratio
Algal bloom frequency
Diatom:cyanobacteria biomass ratio
Nitrogen versus phosphorus limitation
Water clarity as Secchi depth
External phosphorus loading rate
Net lake phosphorus assimilation
Sediment deposition rate
Fish and Aquatic Fauna
Population density and age structure of largemouth bass, black crappie, and other economically important sport fishes; relative abundance of piscivores, planktivores, and omnivores
Abundance of selected pollution-tolerant and "desired" taxa in pelagic and littoral zones
Native Vegetation Mosaic
Spatial extent of exotic plants in the littoral zone
Diverse landscape of native plants in the littoral zone
Continuous stands of willow and/or pond apple
Spatial extent of continuous bulrush stands
Spatial extent of submerged vascular plants
Spatial extent of shoreline organic berm
Snail Kite, Wading Birds and Waterfowl
Number of snail kite nests within the lake proper
Frequency of large feeding colonies of wading birds in the lake during winter/ spring
Number of nests of great egret, white ibis, snowy egret and heron
Frequency of large feeding colonies of waterfowl in the lake during winter/spring

A.9.8.2 Fish and Aquatic Fauna

In addition to performance measures related to fish per se, it is noteworthy that some of the measures related to aquatic fauna and native vegetation mosaic determine the quality of the littoral and near-shore habitat for fish foraging and spawning, and quality of the lake food web from the standpoint of supporting a productive fishery. Without this information it would be impossible to determine the cause of any unexpected fisheries declines during the CERP implementation, and this would seriously compromise adaptive management. As is the case for water quality, the fisheries performance measures should be expanded to specify targets for distinct lake regions.

A.9.8.3 Native Vegetation Mosaic

Performance measures focus on the littoral and near-shore regions, where vascular plants occur in the lake. In the littoral region, the performance measures reflect a primary objective of reducing the spatial extent of exotic and nuisance plant species, and restoring lost native plant communities. In the near-shore region, the performance measures focus primarily on restoring submerged vegetation communities and bulrush stands. Elimination of the near-shore berm also is included as a target.

A.9.8.4 Snail Kite, Wading Birds and Waterfowl

Performance measures related to birds are problematic, because for some key species (including the Everglades snail kite), population dynamics are better evaluated on a system-wide basis, rather than for particular system components such as Lake Okeechobee. Snail kites migrate over much of the Florida peninsula (Bennett and Kitchens 1997), nesting in different areas as a function of habitat availability under different drought-flooding regimes. During some years the lake may provide habitat for a large number of kites and other birds, while in other years, numbers may be substantially reduced. Hence, the overall performance of these attributes may best be determined by a system-wide program.

A.9.9 Model

The diagram for the Lake Okeechobee Conceptual Ecological Model is presented in Figure A-32. The key to the symbols used in the diagram is presented in Figure A-31.

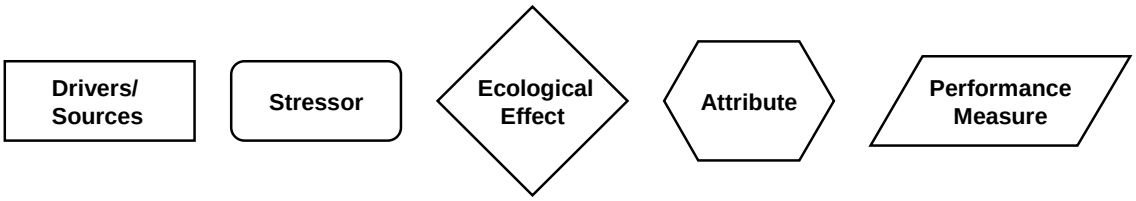


Figure A-31: Key to the Symbols Used in the Following Diagram

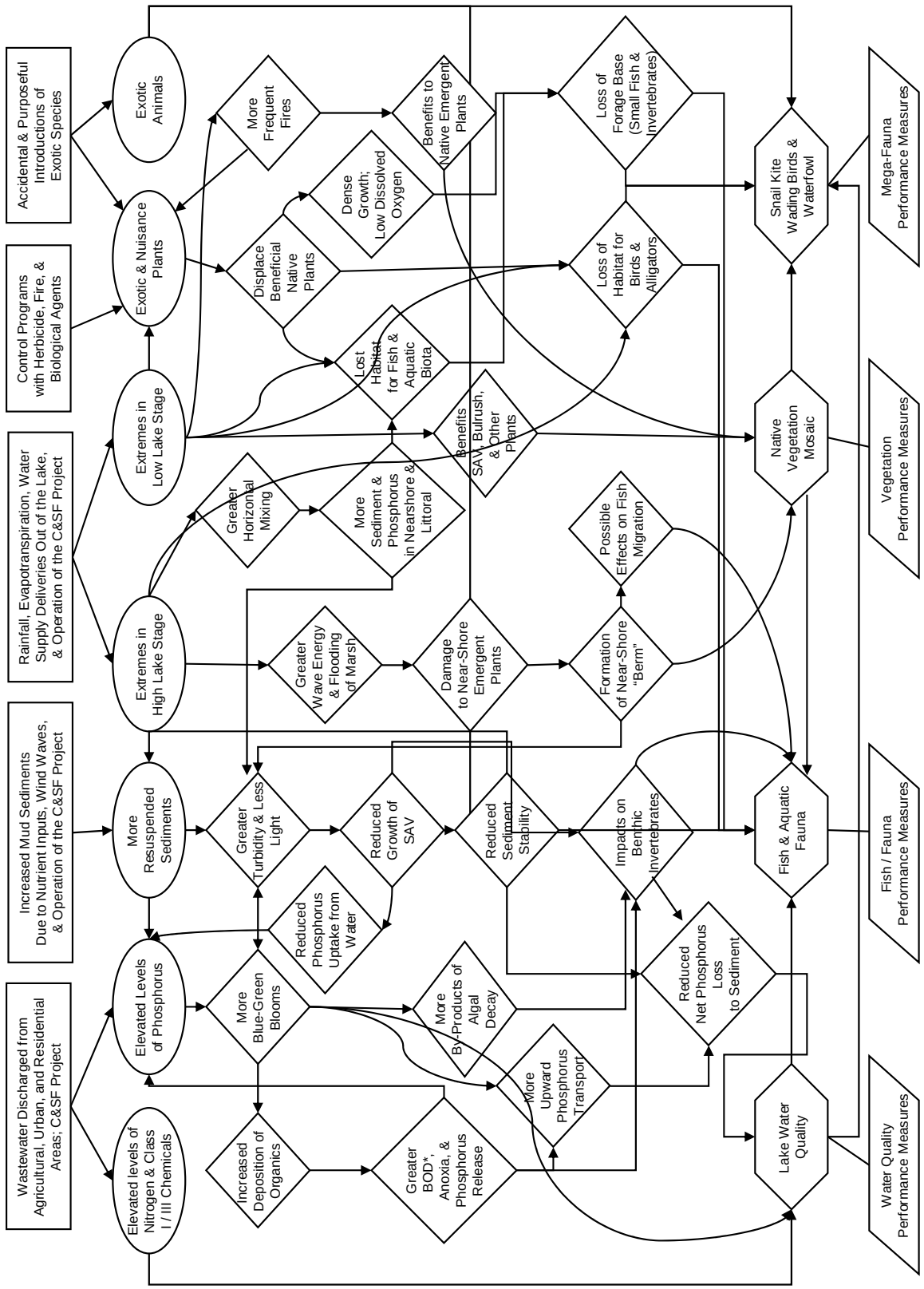


Figure A-32: Lake Okeechobee Conceptual Ecological Model Diagram

A.9.9.1 Literature Cited

Aldridge, F.J., E.J. Phlips and C.L. Schelske. 1995. The use of nutrient enrichment bioassays to test for spatial and temporal distribution of limiting factors affecting phytoplankton dynamics in Lake Okeechobee, Florida. Archiv fur Hydrobiologie, Advances in Limnology 45: 177-190.

Baker, C.D., and E.H. Schmitz. 1971. Food habits of adult gizzard and threadfin shad in two ozark reservoirs. In: Hall, G.E. (ed.). Reservoir Fisheries and Limnology. American Fishery Society, Washington, D.C., pp. 385-395.

Barbiero, R.P., and E.B. Welch. 1992. Contribution of benthic blue-green algal recruitment of lake populations and phosphorus translocation. Freshwater Biology 27: 249-260.

Barnett, B.S., and R.W. Schneider. 1974. Fish populations in dense submersed plant communities. Hyacinth Control Journal 12: 12-14.

Beaver, J.R., and K.E. Havens. 1996. Seasonal and spatial variation in zooplankton community structure and their relation to possible controlling variables in Lake Okeechobee. Freshwater Biology 36: 45-56.

Bell, F.W. 1987. The Economic Impact and Valuation of the Recreational and Commercial Fishing Industries of Lake Okeechobee, Florida. Florida Game and Fresh Water Fish Commission, Tallahassee, Florida.

Bellrose, F.C. 1976. Ducks, Geese and Swans of North America. Stackpole Books, Harrisburg, Pennsylvania.

Bennetts, R.E., M.W. Callopy, and S.R. Beissinger. 1988. Nesting Ecology of Snail Kites in Water Conservation Area 3A. Cooperative Fish and Wildlife Research Unit, Biological Resources Division, United States Geological Survey, Gainesville, Florida.

Bennetts, R.E., and W.M. Kitchens. 1997. The Demography and Movements of Snail Kites in Florida. Technical Report 56, Cooperative Fish and Wildlife Research Unit, Biological Resources Division, United States Geological Survey, Gainesville, Florida

Brezonik, P.L., E.C. Blancher, V.B. Myers, C.L. Hilty, M.K. Leslie, C.R. Kratzer, G.D. Marbury, N.R. Snyder, T.L. Crisman, and J.J. Messer. 1979. Factors Affecting Primary Production in Lake Okeechobee, Florida. Report 07-79-01 to the Florida Sugar Cane League, Clewiston, Florida.

Brezonik, P.L., and D.R. Engstrom. 1999. Modern and historic accumulation rates of phosphorus in Lake Okeechobee, Florida. Journal of Paleolimnology 20: 31-46.

Bull, L.A., D.D. Fox, D.W. Brown, L.J. Davis, S.J. Miller, and J.G. Wullschleger. 1995. Fish distribution in limnetic areas of Lake Okeechobee, Florida. Archiv fur Hydrobiologie, Advances in Limnology 45: 333-342.

Burkholder, J.M., R.G. Wetzel, and K.L. Klomparens. 1990. Direct comparison of phosphate uptake by adnate and loosely attached microalgae within an intact biofilm matrix. Applied and Environmental Microbiology 56: 2882-2890.

Canfield, D.E., and M.V. Hoyer. 1988. The eutrophication of Lake Okeechobee. Lake and Reservoir Management 4: 91-99.

Canfield, D.E., Jr., K.A. Langeland, M.J. Maceina, W.T. Haller, J.V. Shireman, and J.R. Jones. 1983. Trophic classification of lakes with aquatic macrophytes. Canadian Journal of Fisheries and Aquatic Sciences 40: 1713-1718.

Carr, J.F., and Hiltunen, J.K. 1965. Changes in the bottom fauna of western Lake Erie from 1930 to 1961. Limnology and Oceanography 10: 551-569.

Carrigan, R., and J. Kalff. 1982. Phosphorus release by submerged macrophytes: significance to epiphyton and phytoplankton. Limnology and Oceanography 27: 419-427.

Carter, M.R., L.A. Burns, T.R. Cavinder, K.R. Dugger, P.L. Fore, D.B. Hicks, H.L. Revells, and T.W. Schmidt. 1973. Ecosystems Analysis of the Big Cypress Swamp and Estuaries. Ecological Report Number DI-SFEP-74-51, Region IV, United States Environmental Protection Agency, Atlanta, Georgia.

Chamberlain, E.B., Jr. 1960. Florida Water Populations, Habitats and Management. Technical Bulletin No. 7, Federal Aid Project W-19-R, Florida Game and Fresh Water Fish Commission, Tallahassee, Florida.

Chick, J.H., and C.C. McIvor. 1994. Patterns in the abundance and composition of fishes among beds of different macrophytes: viewing the littoral zone as a landscape. Canadian Journal of Fisheries and Aquatic Sciences 51: 2873-2882.

Cichra, M.F., S. Badylak, N. Henderson, B.H. Rueter, and E.J. Phlips. 1995. Phytoplankton community structure in the open water zone of a shallow subtropical lake (Lake Okeechobee, Florida, USA). Archiv fur Hydrobiologie, Advances in Limnology 45: 157-175.

Conrow, R.A., A.V. Zale, and R.W. Gregory. 1990. Distribution and abundance of early life stages of fishes in a Florida lake dominated by aquatic macrophytes. Transactions of the American Fisheries Society 119: 521-528.

Cooke, G.D., and R.E. Carlson. 1989. Reservoir Management for Water Quality and THM Precursor Control. American Water Works Association Research Foundation, Denver, Colorado.

Crisman, T.L., and J.R. Beaver. 1990. Applicability of biomanipulation for managing eutrophication in the subtropics. Hydrobiologia 200: 177-185.

Crisman, T.L., E.J. Phlips, and J.R. Beaver. 1995. Zooplankton seasonality and trophic state relationships in Lake Okeechobee, Florida. Archiv fur Hydrobiologie, Advances in Limnology 45: 213-232.

Darby, P.C., P.L. Valentine-Darby, R.E. Bennetts, J.D. Croop, H.F. Percival, and W.M. Kitchens. 1997. Ecological Studies of Apple Snails (*Pomacea paludosa*). Florida Cooperative Fish and Wildlife Research Unit, Gainesville, Florida.

David, P. 1994. Wading bird nesting at Lake Okeechobee, Florida: an historic perspective. Colonial Waterbirds 17:69-77.

East, T.L., K.E. Havens, A.J. Rodusky, and M.A. Brady. 1999. *Daphnia lumholtzi* and *Daphnia ambigua*: population comparisons of an exotic and a native cladoceran in Lake Okeechobee, Florida. Journal of Plankton Research 21: 1537-1551.

Esler, D. 1990. Waterfowl habitat use on a Texas reservoir with hydrilla. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 44: 390-400.

Erwin, R.M. 1983. Feeding habitats of nesting wading birds: spatial use and social influences. The Auk 100:960-970.

FDEP. Multiple years. Florida aquatic plant survey report. Bureau of Aquatic Plant Management, Florida Department of Environmental Protection. Tallahassee, Florida.

FDEP. 2000. Draft Phosphorus Total Maximum Daily Load (TMDL) for Lake Okeechobee. Florida Department of Environmental Protection, Tallahassee, Florida.

Fisher, M.M, K.R. Reddy, and R.T. James. 2001. Long-term changes in the sediment chemistry of a large shallow subtropical lake. Lake and Reservoir Management 17: 217-232.

Flaig, E.G., and K.E. Havens. 1995. Historical trends in the Lake Okeechobee ecosystem I. Land use and nutrient loading. Archiv fur Hydrobiologie Monographische Beitrage 107: 1-24

Flaig, E.G., and K.R. Reddy. 1995. Fate of phosphorus in the Lake Okeechobee watershed, Florida, USA: overview and recommendations. Ecological Engineering 5: 127-142.

Fox, D.D., S. Gornak, T.D. McCall, D.W. Brown, and C.J. Morris. 1993. Lake Okeechobee Fisheries Investigations Completion Report. Florida Game and Fresh Water Fish Commission, Tallahassee, Florida.

Frederick, P.C., and M.G. Spalding. 1994. Factors affecting reproductive success of wading birds (Ciconiiformes) in the Everglades ecosystem. In: Davis, S.M. and J.C. Ogden (eds). Everglades: the Ecosystem and Its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 659-692.

Fredrickson, L.H., and T.S. Taylor. 1982. Management of seasonally flooded impoundments for wildlife. Research Publication #148, United States Fish and Wildlife Service, Washington, D.C.

Fry, B., P.L. Mumford, F. Tam, D.D. Fox, G.L. Warren, K.E. Havens, and A.D. Steinman. 1999. Trophic position and individual feeding histories of fish from Lake Okeechobee, Florida. Canadian Journal of Fisheries and Aquatic Sciences 56: 590-600.

Furse, J.B., and D.D. Fox. 1994. Economic fishery valuation of five vegetation communities in Lake Okeechobee, Florida. Proceedings of the Annual Conference of Southeastern Association of Fish and Wildlife Agencies 48:575-591.

Gawlik, D.E. 2001. Ecology of wading birds in the Everglades. In: Bronson, S. (ed.). Florida Earth Journal. University of Florida Press, Gainesville, Florida, pp. 217-226.

Gleason, P.J. 1984. Environments of South Florida Present and Past II. Miami Geological Society, Coral Gables, Florida.

Goodwin, T.M. 1979. Waterfowl management practices employed in Florida and their effectiveness on native and migratory waterfowl populations. Florida Scientist 3:123-129.

Gray, P.N. 1993. The Ecology of a Southern Mallard: Florida's Mottled Duck. Ph.D. Dissertation, University of Florida, Gainesville, Florida.

Grimshaw, H.J., K.E. Havens, B. Sharfstein, A. Steinman, D. Anson, T. East, R. Maki, A. Rodusky, and K.R. Jin. 2002. The effects of shading on morphometric and meristic characteristics of Wild Celery, *Vallisneria americana*, transplants from Lake Okeechobee, Florida. Archiv fur Hydrobiologie 155: 65-81.

Gliwicz, Z.M. 1986. Suspended clay concentrations controlled by filter-feeding zooplankton in a tropical reservoir. Nature 323: 330-332.

Hanlon, C.G. 1999. Relationships between total phosphorus concentrations, sampling frequency, and wind velocity in a shallow polymictic lake. Lake and Reservoir Management 15: 39-46.

Hanlon, C.G. 2003. The distribution of bulrush (*Scirpus californicus*) and influence of environmental conditions on plant growth during a 26 year period in a shallow subtropical lake. Aquatic Botany, in review.

Hanlon, C.G., and K. Langeland. 2000. Comparison of experimental strategies for control of torpedograss. Journal of Aquatic Plant Management, 38:40–47.

Hanlon, C.G., R.L. Miller, and B.F. McPherson. 1998. Relationships between wind velocity and underwater irradiance in a shallow lake (Lake Okeechobee, Florida, USA). Journal of the American Water Resources Association 34: 951-961.

Havens, K.E. 1995. Secondary nitrogen limitation in a subtropical lake impacted by non-point source agricultural pollution. Environmental Pollution 89: 241-246.

Havens, K.E. 1997. Water levels and total phosphorus in Lake Okeechobee. Lake and Reservoir Management 13:16-25.

Havens, K.E. 2002. Development and application of hydrologic restoration goals for a large subtropical lake. Lake and Reservoir Management 18: 285-292.

Havens, K.E. 2003. Submerged aquatic vegetation correlations with depth and light attenuating materials in a shallow subtropical lake. Hydrobiologia 493: 173-186.

Havens, K.E., and T.L. East. 1997. Carbon dynamics in the grazing food chain of a subtropical lake. Journal of Plankton Research 19: 1687-1711.

Havens, K.E., and R.T. James. 1997. A critical evaluation of phosphorus management goals for Lake Okeechobee. Lake and Reservoir Management 13: 292-301.

Havens, K.E., and C.L. Schelske. 2001. The importance of considering biological processes when setting total maximum daily loads (TMDL) for phosphorus in shallow lakes and reservoirs. Environmental Pollution 113: 1-9.

Havens, K.E., and W.W. Walker, Jr. 2002. Development of a total phosphorus concentration goal in the TMDL process for Lake Okeechobee, Florida (USA). Lake and Reservoir Management 18: 227-238.

Havens, K.E., C. Hanlon, and R.T. James. 1994. Seasonal and spatial variation in algal bloom frequencies in Lake Okeechobee, Florida, USA. Lake and Reservoir Management 10: 139-148.

Havens, K.E., N.G. Aumen, R.T. James, and V.H. Smith. 1996a. Rapid ecological changes in a large subtropical lake undergoing cultural eutrophication. Ambio 25:150-155.

Havens, K.E., L.A. Bull, G.L. Warren, T.L. Crisman, E.J. Phlips, and J.P. Smith. 1996b. Food web structure in a subtropical lake ecosystem. Oikos 75: 20-32.

Havens, K.E., T.L. East, and J.R. Beaver. 1996c. Experimental studies of zooplankton-phytoplankton-nutrient interactions in a large subtropical lake (Lake Okeechobee, Florida, USA). Freshwater Biology 36: 579-597.

Havens, K.E., T.L. East, A.J. Rodusky, and B. Sharfstein. 1997. Littoral periphyton responses to nitrogen and phosphorus: and experimental study in a subtropical lake. Aquatic Botany 63: 267-290.

Havens, K.E., E.J. Phlips, M.F. Cichra, and B.L. Li. 1998. Light availability as a possible regulator of cyanobacteria species composition in a shallow subtropical lake. Freshwater Biology 39: 547-556.

Havens, K.E., K.A. Work, and T.L. East. 2000. Relative efficiencies of carbon transfer from bacteria and algae to zooplankton in a subtropical lake. Journal of Plankton Research 22: 1801-1809.

Havens, K.E., K.R. Jin, A.J. Rodusky, B. Sharfstein, M.A. Brady, T.L. East, N. Iricanin, R.T. James, M.C. Harwell, and A.D. Steinman. 2001. Hurricane effects on a shallow lake ecosystem and its response to a controlled manipulation of water level. The Scientific World Journal 1: 44-70.

Havens, K.E., M.C. Harwell, M.A. Brady, B. Sharfstein, T.L. East, A.J. Rodusky, D. Anson, and R.P. Maki. 2002. Large-scale mapping and predictive modeling of submerged aquatic vegetation in a shallow eutrophic lake. The Scientific World Journal 2: 949-965.

Havens, K.E., B. Gu, and C. Kendall. 2003. Stable isotope food web analysis of a large subtropical lake: alternative explanations for 15-N enrichment of pelagic vs. littoral fisheries. TheScientificWorld Journal 3: 613-622.

Havens, K.E., R.T. James, T.L. East, and V.H. Smith. 2003. N:P ratios, light limitation, and cyanobacterial dominance in a subtropical lake impacted by non-point source nutrient pollution. Environmental Pollution 122: 379-390.

Hopson, M.S., and P.V. Zimba. 1993. Temporal variation in the biomass of submersed macrophytes in Lake Okeechobee, Florida. Journal of Aquatic Plant Management 31: 76-81.

Horne, A.J. 1977. Nitrogen fixation - a review of this phenomenon as a polluting process. Progress in Water Technology 8: 359-372.

Horne, A.J. 1979. Nitrogen fixation in Clear Lake, California. Diel studies on *Aphanizomenon* and *Anabaena* blooms. Limnology and Oceanography 24: 329-241.

Howard, K.S., W.F. Loftus, and J.C. Trexler. 1995. Seasonal dynamics of fishes in artificial culvert pools in the C-111 basin, Dade County, Florida. Florida International University and National Biological Service, Miami, Florida.

Hwang, S.J., K.E. Havens, and A.D. Steinman. 1998. Phosphorus kinetics of planktonic and benthic assemblages in a shallow subtropical lake. Freshwater Biology 40: 729-745.

James, R.T., and V.J. Bierman, Jr. 1995. A preliminary modeling analysis of water quality in Lake Okeechobee, Florida: calibration results. Water Research 29: 2755-2766.

James, R.T., V.H. Smith, and B.L. Jones. 1995a. Historical trends in the Lake Okeechobee ecosystem III. water quality. Archiv fur Hydrobiologie, Monographische Beitrag 107:49-69.

James, R.T., B.L. Jones, and V.H. Smith. 1995b. Historical trends in the Lake Okeechobee ecosystem II. Nutrient budgets. Archiv fur Hydrobiologie, Monographische Beitrag 107: 25-47.

James, R.T., J. Martin, T. Wool, and P.F. Wang. 1997. A sediment resuspension and water quality model of Lake Okeechobee. Journal of the American Water Resources Association 33: 661-680.

Janacek, J.A. 1988. Literature Review on Fish Interactions with Aquatic Macrophytes with Special Reference to the Upper Mississippi River. Upper Mississippi River Conservation Commission, Rock Island, Illinois.

Jeske, C.W. 1985. Time and Energy Budgets of Wintering Ring-Necked Ducks *Aythya collaris* (L.) in North-Central Florida. M.S. thesis, University of Florida, Gainesville, Florida.

Jin, K.R., J.H. Hamrick, and T. Tisdale. 2000. Application of three-dimensional hydrodynamic model for Lake Okeechobee. Journal of Hydraulic Engineering 126: 758-771.

Johnson, F.A., and F. Montalbano. 1984. Selection of plant communities by wintering waterfowl on Lake Okeechobee, Florida. Journal of Wildlife Management 48: 174-178.

Jones, B. 1987. Lake Okeechobee eutrophication research and management. Aquatics 9:21-26.

Kahl, M.P., Jr. 1964. Food ecology of the wood stork (*Mycteria americana*) in Florida. Ecological Monographs. 34:97-117.

Kushlan, J.A. 1976. Wading bird predation in a seasonally fluctuating pond. The Auk 93:464-476.

Kushlan, J.A. 1981. Resource use strategies of wading birds. Wilson Bulletin 93:145-163.

Lockhart, C.S. 1995. The Effect of Water Level Variation on the Growth of Melaleuca Seedlings from the Lake Okeechobee Littoral Zone. MS thesis, Florida Atlantic University, Boca Raton, Florida.

Loftus, W.F., and A. Eklund. 1994. Long-term dynamics of an Everglades small-fish assemblage. In: Davis, S.M. and J.C. Ogden (eds). Everglades: the Ecosystem and Its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 461-484.

Loftus, W.F., and J.A. Kushlan. 1987. Freshwater fishes of southern Florida. Bulletin of the Florida State Museum, Biological Sciences 31: 147-344.

Maceina, M.J. 1993. Summer fluctuations in planktonic chlorophyll a concentrations in Lake Okeechobee, Florida: the influence of lake levels. Lake and Reservoir Management 8:1-11.

Maceina, M.J., and D.M. Soballe. 1991. Wind-related limnological variation in Lake Okeechobee, Florida. Lake and Reservoir Management 6:93-100.

McCormick, P.V., P.S. Rawlik, K. Lurding, E.P. Smith, and F.H. Sklar. 1996. Periphyton-water quality relationships along a nutrient gradient in the northern Florida Everglades. Journal of the North American Benthological Society 15: 433-449.

McCormick, P.V., S. Newman, S.L. Miao, R. Reddy, D. Gawlick, C. Fitz, T. Fontaine, and D. Marley. 1999. Ecological needs of the Everglades. In: SFWMD. Everglades Interim Report. South Florida Water Management District, West Palm Beach, Florida.

FWC. Midwinter Inventory, Annual Waterfowl Survey. Waterfowl Section, Florida Fish and Wildlife Conservation Commission, Tallahassee, Florida.

Montalbano, F., S. Hardin, and W.M. Hetrick. 1979. Utilization of hydrilla by ducks and coots in central Florida. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 33: 36-42.

Moore, P.A., K.R. Reddy, and M.M. Fisher. 1998. Phosphorus flux between sediment and overlying water in Lake Okeechobee, Florida: spatial and temporal variations. Journal of Environmental Quality 27: 1428-1439.

Moss, B., J. Madgwick, and G. Phillips. 1996. A Guide to the Restoration of Nutrient-Enriched Shallow Lakes. Environment Agency, Broads Authority, United Kingdon.

Murphy, T., K. Hall, and I. Yesaki. 1983. Co-precipitation of phosphate and calcite in a naturally eutrophic lake. Limnology and Oceanography 28: 58-67.

Newman, S., J.B. Grace, and J.W. Koebel. 1996. Effects of nutrients and hydroperiod on *Typha*, *Cladium* and *Eleocharis*: implications for Everglades restoration. Ecological Applications 6: 774-783.

Olila, O.G., and K.R. Reddy. 1993. Phosphorus sorption characteristics of sediments in shallow eutrophic lakes of Florida. Archiv fur Hydrobiologie 129:45-65.

Paerl, H.W. 1988. Nuisance phytoplankton blooms in coastal, estuarine, and inland waters. Limnology and Oceanography 33: 823-847.

Pesnell, G.L., and R.T. Brown. 1976. Map of the vegetation of Lake Okeechobee, Florida. South Florida Water Management District, West Palm Beach, Florida

Phlips, E.J., F.J. Aldridge, and P. Hansen. 1995. Patterns of water chemistry, physical and biological parameters in a shallow subtropical lake (Lake Okeechobee, Florida, USA). Archiv fur Hydrobiologie, Advances in Limnology 45: 117-135.

Phlips, E.J., M. Cichra, K.E. Havens, C. Hanlon, S. Badylak, B. Rueter, M. Randall, and P. Hansen. 1997. Relationships between phytoplankton dynamics and the availability of light and nutrients in a shallow subtropical lake. Journal of Plankton Research 19: 319-342.

Phlips, E.J., and J. Ihnat. 1995. Planktonic nitrogen fixation in a shallow subtropical lake (Lake Okeechobee, Florida, USA). Archiv fur Hydrobiologie, Advances in Limnology 45: 191-201.

Phlips, E.J., P.V. Zimba, M.S. Hopson, and T.L. Crisman. 1993. Dynamics of the plankton community in submerged plant dominated regions of Lake Okeechobee, Florida, USA. Proceedings International Association of Theoretical and Applied Limnology 25: 423-426.

Reddy, K.R., Y.P. Sheng, and B.L. Jones. 1995. Lake Okeechobee Phosphorus Dynamics Study Volume I. Summary. South Florida Water Management District, West Palm Beach, Florida.

RECOVER. 2003a. Monitoring and Assessment Plan. Restoration Coordination and Verification, c/o Jacksonville District, United States Army Corps of Engineers, Jacksonville, Florida, Final Report.

RECOVER. 2003b. Performance Measure Documentation Report. Restoration Coordination and Verification, c/o South Florida Water Management District, West Palm Beach, Florida, May 29, 2003 draft.

Reynolds, C.S. 1984. The Ecology of Freshwater Phytoplankton. Cambridge University Press, United Kingdom.

Richardson, J.R., and T.T. Harris. 1995. Vegetation mapping and change detection in the Lake Okeechobee marsh ecosystem. Archiv fur Hydrobiologie, Advances in Limnology 45:17-39.

Richardson, J.R., T.T. Harris, and K.A. Williges. 1995. Vegetation correlations with various environmental parameters in the Lake Okeechobee marsh ecosystem. Archiv fur Hydrobiologie, Advances in Limnology 45: 41-61.

Rozas, L.P., and W.E. Odum. 1988. Occupation of submerged aquatic vegetation by fishes: testing the roles of food and refuge. Oecologia 77: 101-106.

Sas, H. 1989. Lake restoration by reduction of nutrient loading: expectation, experiences, extrapolations. Academia Verlag Richarz, Germany.

Scheffer, M. 1989. Alternative stable states in eutrophic shallow freshwater systems: a minimal model. Hydrobiological Bulletin 23: 73-85.

Schelske, C.L. 1984. In situ and natural phytoplankton assemblage bioassays. In: Shubert, L.E. (ed). Algae as Ecological Indicators. Academic Press, New York, pp. 15-47.

SFWMD. 2002. Surface Water Improvement and Management (SWIM) Plan – Update for Lake Okeechobee. South Florida Water Management District, West Palm Beach, Florida.

Sharfstein, B., and A.D. Steinman. 2001. Growth and survival of the Florida apple snail (*Pomacea paludosa*) fed three naturally occurring macrophyte assemblages. Journal of the North American Benthological Society 20:84-95.

Sheng, Y.P., and H.K. Lee. 1991. Computation of the Phosphorus Flux between the Vegetation Area and the Open Water in Lake Okeechobee. South Florida Water Management District, West Palm Beach, Florida.

Smith, J.P. 1997. Nesting season food habits of four species of Herons and Egrets and Lake Okeechobee, Florida. Colonial Waterbirds 20: 198-220.

Smith, J. P., and M.W. Collopy. 1995. Colony turnover, nest success and productivity, and causes of nest failure among wading birds (Ciconiiformes) at Lake Okeechobee, Florida (1989-1992). Archiv fur Hydrobiologie, Advances in Limnology 45:287-316.

Smith, J.P., J.R. Richardson, and M.W. Callopy. 1995. Foraging habitat selection among wading birds (Ciconiiformes) at Lake Okeechobee, Florida, in relation to hydrology and vegetative cover. Archiv fur Hydrobiologie, Advances in Limnology 45: 247-285.

Smith, D., M. Smart, and C.G. Hanlon. 2003. Hydrologic influences on torpedograss establishment in Lake Okeechobee, Florida. Aquatic Botany, in press.

Steinman, A.D., R.H. Meeker, A.J. Rodusky, W.P. Davis, and S.J. Hwang. 1997a. Ecological properties of charophytes in a large subtropical lake. Journal of the North American Benthological Society 16: 781-793.

Steinman, A.D., R.H. Meeker, A.J. Rodusky, W.P. Davis, and C.D. McIntire. 1997b. Spatial and temporal distribution of algal biomass in a large subtropical lake. Archiv fur Hydrobiologie 139: 29-50.

Steinman, A.D., K.E. Havens, H.J. Carrick, and R. VanZee. 2002a. The past, present, and future hydrology and ecology of Lake Okeechobee and its watershed. In: Porter, J. and K. Porter (eds). The Everglades, Florida Bay, and Coral Reefs of the Florida Keys: An Ecosystem Sourcebook. CRC Press, Boca Raton, Florida, pp. 19-37.

Steinman, A.D., K.E. Havens, A.J. Rodusky, B. Sharfstein, R.T. James, and M.C. Harwell. 2002b. The influence of environmental variables and a managed water recession on the growth of charophytes in a large subtropical lake. Aquatic Botany 72: 297-313.

Sykes, P.W., Jr. 1987. The feeding habits of snail kite in Florida, USA. Colonial Waterbirds 10: 84-92.

Thayer, P.L., and W.T. Haller. 1990. Fungal pathogens, *Phoma* and *Fusarium*, associated with declining populations of torpedograss growing under high water stress. Proceedings of European Weed Research Society, Eighth Symposium on Aquatic Weeds, pp. 209-214.

Turner, R.L. 1994. The effects of hydrology on the population dynamics of the Florida apple snail (*Pomacea paludosa*). Special publication SJ94-SP3, St. Johns River Water Management District, Pilatka, Florida.

Turner, R.L. 1996. Use of stems of emergent plants for oviposition by the Florida apple snail, *Pomacea paludosa*, and implications for marsh management. Florida Scientist 59: 34-49.

USACE. 1999. Wildlife Survey and Habitat Utilization Study of the Western Littoral Zone of Lake Okeechobee, Florida. Jacksonville District , United States Army Corps of Engineers, Jacksonville, Florida.

USACE and SFWMD. 1999. Central and Southern Florida Project Comprehensive Review Study, Final Integrated Feasibility Report and Programmatic Environmental Impact Statement. United States Army Corps of Engineers, Jacksonville District, Jacksonville, Florida, and South Florida Water Management District, West Palm Beach, Florida.

USEPA. 2000. Total Maximum Daily Load (TMDL) for Lake Okeechobee. United States Environmental Protection Agency, Atlanta, Georgia.

Van der Valk, A.G. 1994. Effects of prolonged flooding on the distribution and biomass of emergent species along a freshwater wetland coenocline. Vegetatio 110: 186-196.

Van Rees, K.C.J., K.R. Reddy, and P.S.C. Rao. 1996. Influence of benthic organisms on solute transport in lake sediments. Hydrobiologia 317: 31-40.

Vermaat, J.E., L. Santamaria, and P.J. Roos. 2000. Water flow across and sediment trapping in submerged macrophyte beds of contrasting growth form. Archiv fur Hydrobiologie 148: 549-562.

Warren, G.L., and D.A. Hohlt. 1994. Lake Okeechobee invertebrate community investigations. Study IV in the Lake Okeechobee-Kissimmee River-Everglades Resource Evaluation Report. Wallop-Breaux Project F-52 Completion Report to the United States Department of Interior, Washington, D.C.

Warren, G.L., and M.J. Vogel. 1991. Lake Okeechobee invertebrate studies. Study II in the Lake Okeechobee-Kissimmee River-Everglades Resource Evaluation Report. Wallop-Breaux Project F-52 Completion Report to the United States Department of Interior, Washington, D.C.

Warren, G.L., M.J. Vogel, and D.D. Fox. 1995. Trophic and distributional dynamics of Lake Okeechobee sublittoral benthic invertebrate communities. Archiv fur Hydrobiologie, Advances in Limnology 45: 317-332.

Werner, E.E., J.F. Gilliam, D.J. Hall and G.G. Mittelbach. 1983. An experimental test of the effects of predation risk on habitat use in fish. Ecology 64: 1540-1548.

White, D.H., and D. James. 1978. Differential use of fresh water environments by wintering waterfowl of coastal Texas. Wilson Bulletin 90: 99-111.

Williges, K.A., and T.T. Harris. 1995. Seed bank dynamics in the Lake Okeechobee marsh ecosystem. Archiv fur Hydrobiologie, Advances in Limnology 45: 79-94.

Zaffke, M. 1984. Wading bird utilization of Lake Okeechobee marshes 1977-1981. Technical Publication 84-9, South Florida Water Management District, West Palm Beach, Florida.

A.9.10 Contributors

Nicholas Aumen, Everglades National Park; Hunter Carrick, Pennsylvania State University; Steve Davis, South Florida Water Management District; Dale Gawlick, South Florida Water Management District; Paul Gray, Audubon of Florida; Charles Hanlon, South Florida Water Management District; R. Thomas James, South Florida Water Management District; Kang-Ren Jin, South Florida Water Management District; Brad Jones, South Florida Water Management District; Frank Mazzotti, University of Miami; Elizabeth Manners, United States Army Corps of Engineers; John Ogden, South Florida Water Management District; Robert Pace, United States Fish and Wildlife Service; Mary Anne Poole, United States Fish and Wildlife Service; Alan Steinman, Grand Valley State University; David Swift, South Florida Water Management District; Todd Tisdale, South Florida Water Management District; Gary Warren, Florida Fish and Wildlife Conservation Service; Herbert Zebuth, FDEP; and Mark Ziminski, United States Army Corps of Engineers.

A.10 LOXAHATCHEE WATERSHED CONCEPTUAL ECOLOGICAL MODEL

A.10.1 Model Leads

Joel VanArman, South Florida Water Management District
Greg Graves, Dana Fike, and Dianne Crigger, Florida Department of Environmental Protection

A.10.2 Introduction

The Loxahatchee River and watershed includes upland, freshwater wetland, riverine and downstream estuary components. Due to the complexity of this system, the conceptual ecological model has been simplified to show general relationships among the various components. The descriptive portion of this document attempts to provide additional detail to provide a more thorough explanation of relationships among the various ecological subsystems.

The basin historically included and drained more than 350 square miles of inland sloughs and wetlands. Today, approximately 270 square miles of the original Loxahatchee River watershed drain to the Jupiter Inlet (Figure A-33).

Historically, the drainage basin was comprised primarily of pine flatwoods interspersed with cypress sloughs, hardwood swamps, marshes and wet prairies. Rain falling on the basin was directed through natural topography into these wetland areas, treated by natural biological and chemical action and slowly released to the ultimate receiving water body, the Loxahatchee Estuary. A number of different types of aquatic environments are present in the watershed and adjacent waters: small freshwater lakes occur primarily within Jonathan Dickinson State Park; extensive wetlands are located primarily on government-owned lands; freshwater and low salinity (oligohaline – from 0 to 5 parts per thousand [ppt]) ecosystems are present in the river and major tributaries; low to moderate salinity waters (5 to 25 ppt) occur in the Loxahatchee estuary; and inlet, adjacent Intracoastal Waterway and offshore reefs are primarily oceanic salinity waters (30-35 ppt).

Major freshwater wetland systems within the watershed include the Loxahatchee Slough, Hungryland Slough, Grassy Waters Preserve, the J.W. Corbett Wildlife Management Area, Pal Mar and Jonathan Dickinson State Park. The southern half of the Loxahatchee Slough, considered historically to be the headwaters of the federally-designated Wild and Scenic Northwest Fork of the Loxahatchee River, has been impounded to form the Grassy Waters Preserve (formerly known as the City of West Palm Beach Water Catchment Area). The Grassy Waters Preserve is a managed wetland ecosystem that also provides drinking water to the City of West Palm Beach, the Town of Palm Beach and other communities south of the Loxahatchee watershed.

The riverine portion includes the area of the Northwest Fork located upstream from the point where the eastern boundary of Jonathan Dickinson State Park intersects the river near a boat ramp, as well as that portion of the North Fork River that lies upstream of the estuary within Jonathan Dickinson State Park boundaries. Some of the major tributary streams, such as the North Fork, the Northwest Fork, and Kitching Creek exist today much within their historic banks. Other tributaries, such as the Southwest Fork, Limestone Creek, Lake Worth Creek and parts of Cypress Creek, have been greatly altered.

Figure A-33: The Boundary of the Loxahatchee Watershed Conceptual Ecological Model

The structure of the floodplain forest canopy is an important feature of the landscape that has been dramatically changed in the Loxahatchee River system. In areas that are dominated by cypress, the forest canopy may extend to heights of 60-80 feet and consists of three or more distinct layers. Each layer has different light levels and provides habitat for epiphytic plants, various mammals, reptiles and birds. In areas where the cypress forest has been replaced by mangroves, the canopy structure is greatly diminished and is generally less than 30 feet, providing much less habitat diversity and a corresponding less rich flora an fauna (SFWMD 2002a).

Mangroves carry out a number of ecological functions, including land formation (Warming 1925, Davis 1940), sediment stabilization, primary productivity, and filtration of land runoff, and they serve as habitats and nurseries (Dawes 1998, MacNae 1968, Odum et al. 1982). In South Florida, mangroves have been destroyed by dredge-fill operations to create real estate, and port and industrial facilities. Mangrove destruction results in a chain of reactions that affect estuarine and offshore production. Mangrove prop roots provide important habitat for estuarine species in brackish waters, providing a supporting substrate for colonization by oysters, algae, barnacles, and associated macroinvertebrates and a diverse associated community of fishes that feed on these organisms. Very little information is available indicating how productivity and diversity of this estuarine prop root community compare with similar communities that exist in fresh water in association with fallen trees and submerged snags (Wallace and Benke 1984, Thorpe et al. 1990) or what communities would utilize mangrove prop roots in a freshwater system.

Within the Loxahatchee watershed, the delineation among riverine miles that support cypress and other freshwater flora and those dominated by mangrove is a function of predominant salinity regime, which in turn is a factor of freshwater flow. Where freshwater flow has been insufficient over a long period of time, mangrove communities have displaced cypress/wetland plant communities. This has affected the type of fish and wildlife that can utilize these areas, most obviously by reducing or expanding the area where fresh or estuarine water predominate (FDNR 1985, FDEP and SFWMD 2000).

The ecological value of mangrove communities has been well documented in the scientific literature. Four species of mangroves occur in the Loxahatchee River system: red mangroves (*Rhizophora mangle*), white mangrove (*Laguncularia racemosa*), black mangrove (*Avicennia germinans*), and buttonwood mangrove (Conocarpus erectus). Mangrove communities provide habitat for marine organisms, protect shorelines from erosion, and enhance water quality by acting as natural filters (Savage 1972). Detrital material produced by mangroves is the basis of the food chain for South Florida's marine and estuarine ecosystems. Mangroves support fish and macroinvertebrate communities by providing protected nursery areas for fishes, crustaceans, and shellfish, and food for a multitude of important commercial and recreational marine species such as snook (*Centropomus undecimalis*), snapper (e.g. *Lutjanus griseus*) , tarpon (*Megalops atlanticus*), jack (e.g. *Caranx hippos*), sheepshead (*Archosargus probatocephalus*), red drum (*Sciaenops ocellatus*), oysters, and shrimp (*Farfantepenaeus duorarum* (Harris et al. 1983, Lindall 1973). Mangrove roots act to trap sediments and prevent shoreline erosion and provide attachment surfaces for various marine organisms. Additionally, mangrove forests provide habitat for a highly diverse population of birds (Odum et al. 1982).

Permanent colonies of seagrasses occur in the outer estuary. Seagrasses are a regular feature in the central embayment and periodically colonize the outer fringes of the North, Northwest and Southwest Forks of the estuary. Seagrass distribution and abundance in the central embayment and outer estuary have probably increased relative to historic (predrainage) conditions due to generally increased salinity. Freshwater grasses such as *Vallisneria*, seem to have never been present in significant amounts in this system. Johnson's seagrass, which is an endangered species, occurs in the outer estuary. Management needs for this species need to be given special consideration if significant changes in freshwater flow are proposed. Seagrasses are a primary food source for manatees.

Oyster bars provide habitat and food for numerous estuarine species including gastropod mollusks, polychaete worms, decapod crustaceans, various boring sponges, fish, and birds, including the endangered oyster catcher. The Eastern oyster (*Crassostrea virginica*) is the dominant species in the oyster reef community. Over 40 species of macrofauna may be living in oyster beds (Bahr and Lanier 1981) with the total number of species exceeding 300 (Wells 1961).

The Jupiter Inlet is a prominent feature of the southeast Florida shoreline. This inlet provides a drainage outlet for the entire watershed via three major waterways, the Loxahatchee River, Lake Worth Creek, and the Indian River Lagoon. Significant changes have occurred within the Loxahatchee watershed, especially since the end of the Second World War. Jupiter Inlet has been stabilized and remains open under all conditions, resulting in a daily influx of saline waters into the Loxahatchee River. The major forks of the Loxahatchee Estuary have been channelized to remove natural sandbars and oyster reefs that historically provided a barrier to the inland migration of salt water. In the late 1950s the C-18 Canal was completed, which drained wetlands in the Loxahatchee Slough and diverted fresh water from the Northwest Fork to the Southwest Fork of the Loxahatchee River.

Over the past sixty years urban, rural and agricultural development in the watershed has resulted in construction of transportation corridors and drainage channels to accommodate growth (FDEP 1998). Although large tracts of natural lands are publicly owned, the hydrology of the entire watershed has been altered by development activities. The Loxahatchee River historically received flow into the Northwest Fork from the Loxahatchee Marsh (Slough) and the Hungryland Slough. Both of these wetland areas drained to the north and east from a low divide or ridge that was located along the grade that was used to construct State Road 710 (Parker et al. 1955). Historically, these areas were characterized by swampy flatlands interspersed with small, often interconnected ponds and streams that produced sheet flow. Flow from the ridge along State Road 710 could be directed north or south, depending on local conditions. Drainage patterns were determined by rainfall patterns and the poorly defined natural landforms of the area.

Altered hydrologic conditions include overdrainage of remaining wetlands throughout much of the watershed; impoundment of water and excessive flooding of natural landscapes in other areas; changes to natural seasonal cycles of flooding and drying; periodic shortages of water for the Northwest Fork; and periods when too much water is dumped into the Southwest Fork during storm events. Stabilization of Jupiter Inlet to the Atlantic Ocean and improvements to navigational channels in the estuary and river and increased the tidal influx of salt water into the river and floodplain (Jupiter Inlet District 1999). The effects of saltwater influx to the river have been further extended due to a rise in sea level of about eight inches since 1900 (Douglas 1991, 1992).

These hydrologic changes have, in turn, resulted in significant ecological changes in the river and adjacent wetlands. Wetlands have been degraded in quality due to excessive flooding or drainage, resulting in increased susceptibility to fires and shifts in vegetation patterns from natural wet prairie and cypress communities to uplands or to cattail- and willow-dominated wetland systems. Large areas of existing and former wetlands have been invaded by exotic vegetation, especially Brazilian pepper *(Schinus terebinthifolia*), melaleuca *(Melaleuca quinquenervia*) and climbing fern (*Lygodium microphylla*).

Riverine ecosystem components have also been altered by watershed alterations. Vegetation along the floodplain was severely altered by timber harvesting in the early to mid 1900s. Remaining cypress trees and understory vegetation have been stressed or killed by changes in river flow patterns and intrusion of saltwater upstream in the river channel. Analysis of macroinvertebrate data has shown a decline in the number and diversity of animals that live in the water of the Northwest Fork downstream of Riverbend Park (Loxahatchee River District 1996). Low dissolved oxygen in the Northwest Fork has resulted in

alterations and stress to macroinvertebrate and fish populations. Recent investigations of dissolved oxygen dynamics in the Northwest Fork have confirmed a statistically significant declining trend (Loxahatchee River District 1996, FDEP 1996).

Surface water quality within the watershed reflects both the changing character of the natural system and the presence of man. Aquatic environments throughout the watershed range from marine ecosystem with salinities above 30 parts per thousand (ppt) to freshwater ecosystems of river, creeks, ponds, lakes and wetlands. Some negative influences on water quality in the watershed include stormwater runoff from developed areas, groundwater inflow and alterations to natural hydrologic flow.

The predrainage wetland and slough mosaic of the Loxahatchee watershed was a shallow, clear-water, low nutrient system. Aside from fire and infrequent frosts, the unique vegetation of the freshwater area of the watershed evolved in response to both low-nutrient water quality conditions and the seasonal fluctuations of water levels driven by rainfall, percolation to ground water, and discharge through naturally meandering sloughs, creeks and rivers. Introduction of nutrients into an oligotrophic freshwater system has been shown to adversely affect the ability of the affected area to maintain adequate dissolved oxygen content due to accelerated vegetative litterfall and decomposition, and this resulted in marked changes in the macroinvertebrate community (Graves et al. 1998).

Increased input of nutrients to the Everglades has resulted in adverse effects and significant changes in species composition of dominant plant communities (Porter and Porter 2002, Lodge 1994, David 1996, Davis 1994, etc.). The Loxahatchee watershed is similarly located in South Florida, developed on similar soils as the ocean receded, and currently sustains similar marsh plant and animal communities to that of the Everglades. Additionally, during high water conditions, Loxahatchee watershed marshes like the Grassy Waters Preserve were physically connected to the Everglades through sheet flow. Due to these similarities and connectedness, similar ecological responses of increased nutrient loads as observed in the Everglades could be expected to occur in similar freshwater systems in the Loxahatchee watershed. Indeed, within the Grassy Waters Preserve, ecological modifications have already occurred adjacent to the M Canal, i.e., an encroaching cattail front is replacing sawgrass marsh (Graves et al. 2003).

The Loxahatchee River is extensively used for canoeing. Restrictions on canoeing have been considered in an effort to control traffic in the upper reaches of the river during peak periods and maintain a suitable “wild and scenic” experience (FDEP and SFWMD 2000).

A conceptual ecological model in the risk assessment framework has been developed for the Loxahatchee watershed that addresses the wetland, limnetic, riverine, estuarine and near-shore components and concerns of this complex and diverse system (Figure A-35, Section A.10.9). The model attempts to incorporate and represent a number of subsystems (i.e., freshwater wetland, river and estuarine), each of which could be expanded into a detailed model.

The ideal circumstance is to evaluate and consider ecological systems as holistically as possible. This is particularly true for the Loxahatchee watershed, which has undeniable unique and immediate inter-relationships among freshwater wetlands, riverine and estuarine systems; among their respective management interests; and the citizens that use or visit these resources. If these systems were considered separately, their management goals and objectives would potentially be at odds. The consensus of scientists that attended the Adaptive Assessment Team, Water Quality Team, and other model review meetings was that a holistic Loxahatchee watershed model was preferable to separating freshwater from estuarine systems into separate models. Therefore, the model was designed to represent the entire Loxahatchee system, based on a common format, drivers and stressors. Although some ecological effects, attributes and performance measures for freshwater systems are distinct from those for estuarine systems, and vice versa, they can often be represented by similar concepts. Freshwater wetlands, rivers and

estuaries all have important macroinvertebrate communities that need to be considered in the evaluation, even though they consist of entirely different species and are subject to different stress factors.

The model depicts the general pathways by which driving forces (in rectangles), particularly those related to modern human culture, affect "attributes" of the ecosystem (in hexagons) that are intrinsically important to ecosystem function or are generally viewed by humans as valuable and important to maintain. Drivers are manifested as stressors (ovals) that have various "effects" (diamonds) on the ecosystem that are reflected in changes to ecosystem attributes (pentagons). "Performance measures" (parallelograms) identify features or parameters about the attributes that can be measured to determine the direction (positive or negative) and intensity of response to ecosystem drivers and stressors.

A.10.3 External Drivers and Ecological Stressors

A.10.3.1 Drivers

Sea Level Rise / Climate Change

Hydrologic conditions throughout the watershed are dominated by high average annual rainfall, wet and dry seasonal rainfall variations and periodic events of extreme flooding (e.g., hurricanes), severe droughts and freezes. Extreme droughts, and associated fires, and floods may have dramatic effects on ecological conditions in the watershed and river, resulting in degradation of large areas of native vegetation or replacement by exotic or nuisance species. Vegetation in the watershed consists of a mixture of tropical, subtropical and temperate species. Severe freezing conditions occur infrequently, but when they do occur, can result in changes to vegetation communities that may persist for several years. Such stresses can provide opportunities for invasion or replacement of tropical species (such as red mangroves) by more cold-tolerant species such as cypress (*Taxodium distichum*) or maples (*Acer rubrum*) or by invasive exotic species such as Brazilian pepper.

Sea level rise has had a significant effect on the river and estuary during the past century (McPherson et al. 1982) and is expected to have even greater effects during the next 50 years. Changes in sea level will result in changes to upstream hydrology and salinity conditions in the river as rising sea level forces more salt water to move upstream in the river (Hu 2002) and water management actions such as the raising of water levels downstream of the major coastal control structures. Future sea level rise (Douglass 1991, 1992) may also affect the exchange of sediment through the inlet and deposition of sediment in the river channel.

Water Management

Water management activities in the watershed during the past century, including construction of major canals and secondary drainage systems, have had major effects on water levels within the watershed and the timing and distribution of flows from the Loxahatchee River, resulting in short periods of very large discharge and prolonged periods of very low discharge. Water tables have been lowered throughout much of the watershed to provide drainage for urban development and agricultural use. Discharge characteristics have been modified to provide flood protection, resulting in rapid decline of water levels in the basin, saltwater intrusion in the river and adjacent aquifer during dry periods and high rates of discharge during wet periods (McPherson et al. 1982, Birnhak 1974, SFWMD 2002a, SFWMD 2002b).

Water management actions have also altered water quality in the watershed. Construction and operation of canals and ditches have resulted in increased transport of sediment, organic materials and agricultural chemicals, resulting in periodic low levels of dissolved oxygen, bacterial contamination and high concentrations of nutrients in the river and estuary (FDEP 1998, FDEP 2000a).

Land Use and Development

Significant portions of the watershed have been converted from upland forests and wetlands to urban, residential and agricultural development. This has resulted in changes in hydrology, loss or degradation of natural ecosystems, increased severity of fires, loss and degradation of shoreline and bottom communities due to dredging and filling, and adverse water quality conditions (Alexander and Crook 1975, McPherson and Sabanskas 1980, TCRPC 1999).

A.10.3.2 Stressors

Altered Hydrology

Hydrology of the system has been extensively altered by construction and stabilization of the inlet and dredging of the estuary and river channel, and construction of major canals. These alterations deliver freshwater runoff to the estuary more rapidly and abruptly, flushing the estuarine portions with higher maximum flows. During dry periods, the drained marshes and lowered water tables are also unable to provide the historic base flows of fresh water, and thus cannot prevent upstream encroachment of saline estuarine waters (Rodis 1973, Alexander and Crook 1975). These hydrologic conditions have, in turn, altered hydroperiods in floodplain wetlands and flow patterns, salinity, and water quality conditions in the river (Land et al. 1972, Mote Marine Laboratory 1990b, Birnhak 1974).

The total loss of water storage in the basin due to water management is significant. Overall lowering of the water table throughout the watershed, due to canal construction and the need to maintain lower water levels to protect subsequent land development, has resulted in a net loss of an estimated 8,000 acre-feet of storage in the C-18 basin alone (SFWMD 2002b).

Fresh water that historically flowed from the Loxahatchee Slough through the Northwest Fork to the estuary has been diverted by construction of the C-18 canal and S-46 water control structure. These facilities allow flows from the watershed to be shunted past the Northwest Fork, directly into the estuary through S-46 to the Southwest Fork. For a number of years from the early 1960s until 1974, very little water was allowed to flow into the Northwest Fork. It was during this period that most of the damage to floodplain plant communities in the river is thought to have occurred. In 1974, the G-92 water control structure was placed in operation to provide a hydrologic reconnection from the C-18 canal and Loxahatchee Slough to the Northwest Fork of the Loxahatchee River (SFWMD 2002a).

Adverse impacts to natural systems that have occurred as a result of reduced dry season flow include changes to the distribution, extent, species composition and health of freshwater wetlands throughout much of the watershed. Due to the altered hydrology, wetlands are subject to more severe fires, resulting in a conversion from sloughs to prairies and from wet prairies to pineland communities. Significant portions of the natural wetlands in the system have been drained and converted to urban, residential and agricultural land uses (TCRPC 1999, Martin County Planning Department 2000). Remaining wetlands in the watershed and floodplain have been altered or degraded by changes in dry season flows and have provided conditions for the invasion of exotic species and adverse effects on water quality (Duever and McCollom 1982, Alexander and Crook 1975, Zahina et al. 2001b). The reduction of flow to the Northwest Fork and consequent upstream intrusion of salt water in the river, have also resulted in the loss of cypress trees in the floodplain and replacement by mangroves (Rodis 1973, Alexander and Crook 1975).

Excessive discharges of fresh water occur during very wet periods when much of the flood water from the upper (southern) end of the Loxahatchee River watershed is collected by the C-18 canal and shunted into the Southwest Fork through the S-46 structure. Under these conditions, rapid changes in salinity occur in

the estuary and adjacent marine waters resulting in destruction of benthic and seagrass communities and displacement of fishes. Significant erosion can also occur in the watershed and along the river channel during these excessive discharge events, which may cause trees to fall and block the river channel, produce a loss of floodplain vegetation, and create adverse shoaling conditions in the estuary. Flood control discharges have also caused erosion of stream channels, altered channel morphology, and caused deposition of sand and mud further downstream (Law Environmental 1991b, USACE 1966).

Elevated Loads of Nutrients and Pollutants

Nutrient enrichment has been identified as a water quality problem throughout the Loxahatchee watershed. Nutrients are carried by stormwater runoff and ground water flow to wetlands and canals and eventually reach the river and estuary. Excessive nutrients occur in the watershed as a by-product of human activities such as the application fertilizers to urban and agricultural lands and the processing of human and agricultural waste products. Nutrients are also derived from natural breakdown processes in soils and water, through rainfall and ground water inflow.

Water quality impacts many features in this system including wetlands in the watershed, sediment accumulation, trophic status, color, turbidity, and oxygen levels (Sontag and McPherson 1984, SFWMD 1991, FDEP 1998). Coliform contamination also occurs periodically in certain parts of the river, tributaries and adjacent coastal waters. High levels of pesticides are detected in agricultural canals in the watershed.

The predrainage wetland and slough mosaic of the Loxahatchee watershed was a shallow, clear water, low nutrient system. Aside from fire and infrequent frosts, the unique vegetation of the freshwater area of the watershed evolved in response to both low-nutrient water quality conditions and the seasonal fluctuations of water levels driven by rainfall, percolation to ground water, and discharge through naturally meandering sloughs, creeks and rivers. Historically, major wetlands of the Loxahatchee watershed were physically connected to the Everglades through sheet flow and have experienced similar ecological responses due to disturbance and increased nutrient loads as have been observed in the Everglades. Such changes include replacement of sawgrass (*Cladium jamaicense*) marsh by cattails (*Typha domingensis*) and invasion of wetland forests and tree islands by melaleuca and climbing fern. The Grassy Waters Preserve has experienced ecological modifications adjacent to the M Canal, where an encroaching cattail front is replacing sawgrass marsh due to disturbance of the substrate and influx of nutrients (Graves et al. 2003). The Loxahatchee Slough and adjacent wetlands have been extensively invaded by melaleuca and the Loxahatchee Slough, Loxahatchee River floodplain and adjacent wetlands in Jonathan Dickinson State Park have been extensively invaded by climbing fern.

Periodic large releases of fresh water, construction activities in the watershed, and formation and movement of large rafts of floating aquatic plants (i.e., water lettuce) have resulted in formation of undesirable sediment deposits in the Northwest Fork. Muck deposits (aggregations of clay and fine silt-sized particles that tend to have a high content of organic materials and form a soft, unstable ooze that covers the underlying sand or mud substrates) occur in the North Fork of the estuary, and are presumably the result in part of the migration of these riverine deposits. Sand deposits also occur due to transport through the inlet. These deposits primarily affect seagrass communities, benthic invertebrates and sandbar formation (Sontag and McPherson 1984, FDEP 1998, Antonini et al. 1998).

Dissolved oxygen levels frequently do not meet criteria for freshwater Class III waters. Declining dissolved oxygen concentration within the Northwest Fork has been documented and is a continuing concern. Low oxygen levels primarily affect fish and invertebrate populations (FDEP 1996, FDEP 1998, FDEP 2000a). The Loxahatchee River and its tributaries drain extensive areas with organic soils, and stormwater runoff from areas with these types of soils possess high color content. Periodic discharges of

agricultural and urban stormwater runoff also contribute high levels of turbidity. Both of these factors influence oxygen levels and water clarity, with resultant implication on the viability of plankton, macroinvertebrate and submerged plant communities (Dent 2002, FDEP 1998).

Physical Alterations

The Loxahatchee River historically received flow into the Northwest Fork from the Loxahatchee Marsh (Slough) and the Hungryland Slough. Both of these wetland areas drained to the north and east from a low divide or ridge that was located along the grade that was used to construct State Road 710 (Parker et al. 1955). Historically, these areas were characterized by swampy flatlands interspersed with small, often interconnected ponds and streams that produced sheet flow. Flow from the ridge along State Road 710 could be directed north or south, depending on local conditions. Drainage patterns were determined by rainfall patterns and the poorly defined natural landforms of the area.

Drainage patterns in the basin have been significantly altered to provide flood protection and drainage for agricultural and urban development. The major features that presently influence drainage in the river basin are the C-18 canal, the Florida Turnpike, Interstate 95 (I-95), Beeline Highway (State Road 710) and Bridge Road (State Road 708), now act as important unnatural subbasin divides, and the extensive system of secondary canals developed by special drainage districts and landowners within the basin. Since the turn of the century, human activities have altered almost all of the natural drainage patterns within the basin. Many areas that once were wetlands, ponds and sloughs, are now traversed by networks of drainage canals, ditches, roads, super highways, well-drained farms, citrus groves, golf courses and residential developments. The drainage network has lowered ground water levels and significantly altered surface water flows to the estuary (McPherson and Sabanskas 1980).

In the1930s and 1940s, cypress trees were harvested from large areas of the floodplain for timber. During this period, major roads and networks of secondary drainage canals were constructed in the basin. Low dams (Masten Dam and Lainhart Dam) were constructed in the Northwest Fork to maintain higher water tables in the upstream basin and prevent overdrainage of the river floodplain and adjacent lands (Cary Publications 1978).

In 1957-1958, the C-18 canal was constructed through the central portion of the Loxahatchee Slough (the headwaters of the Loxahatchee River) for flood protection purposes. This project redirected almost all freshwater flows away from the Northwest Fork and into the Southwest Fork from the early 1960s up to 1974. In 1974, the G-92 structure was constructed to reconnect the C-18 canal and Loxahatchee Slough with the Northwest Fork.

Coastal development has also greatly affected the hydrology of the Loxahatchee River and upstream wetlands. The natural mouth of the estuary, the Jupiter Inlet, opened and closed many times as the result of natural conditions. Historically, the inlet remained open due to flows from the Loxahatchee River, Jupiter Sound, Jupiter River and Lake Worth Creek. Near the turn of the century, some of this flow was diverted by the construction of the Intracoastal Waterway and the Lake Worth Inlet, and modification of the St. Lucie Inlet. Subsequently, the Jupiter Inlet remained closed much of the time (except when it was periodically dredged) until 1947 when it became permanently opened by the United States Army Corps of Engineers (McPherson and Sabanskas 1980).

In addition to the hydrologic effects of water management activities (described above) coastal development has resulted in the loss or conversion of significant portions of the mangrove and saltmarsh habitats that historically existed in the Southwest, North and Northwest Forks of the estuary. The onshore effects of fill on coastal wetlands are severe (DOI 1974). Saline and brackish marshes and mangrove swamps are indispensable components of the estuarine system and processes of South Florida. They are

the primary producers of the estuarine food web and cleanse and filter terrestrial runoff waters. By removing the filtering action of coastal wetlands, development has resulted in increased turbidity and a decline in water quality (Law Environmental 1991b, Vines 1970).

Boating and Fishing Pressure

Use of the Loxahatchee River and Estuary by motorized craft is essentially limited by channel depth and width, and vertical clearance of bridges. Boats much larger than 25 to 30 feet are limited to the lower portions of the river by both lack of depth and vertical clearance (Law Environmental 1991b). The estuary central embayment is a shallow water region. Over 50 percent of this area is less than two feet deep. The main river channel is the only improved access channel in the central embayment (Antonini et al. 1998).

Boating pressure is a stressor to the estuary through direct impacts such as seagrass scarring, sediment resuspension, wake erosion, and construction of boating channels. The river and estuary are extensively used for navigation and recreation. Channels have been dug in the river and estuary and sandbars and oyster bars have been removed to improve boat access. The Jupiter Inlet has been widened, deepened and stabilized. All of these changes have resulted in greater saltwater penetration upstream in the river (Hill 1977, Law Environmental 1991b, USACE 1966). Extensive dredging of the Loxahatchee River Inlet and Estuary and filling of adjacent wetlands have resulted in the loss and degradation of natural coastal ecosystems, increased saltwater penetration upstream in the river, increased turbidity, decreased oxygen levels and loss of shoreline and benthic habitats (Cary Publications 1978, Antonini et al. 1998, Vines 1970). Dredging activities, generally associated with providing improved boat access, are enormously destructive to estuarine biological systems (DOI 1974). Benthic organisms and submerged aquatic vegetation (SAV) are eliminated by dredging. The borrow areas are rarely recolonized by SAV due to excessive depths, where an insufficient amount of light reaches the bottom to allow photosynthesis to occur. Suspended solids created by dredging may cover productive adjacent bottom communities, suffocating organisms that reside there. Water circulation within these borrow areas is typically poor causing these depressional areas to act as sinks for silt and other suspended materials.

Fishing pressure from sport and commercial fisheries has also impacted standing stocks of many species (Post, Buckley, Schuh, and Jernigan, Inc. 1999), with resultant potential impact to dependent piscivores. Recent resource trends for local fisheries show some increase as a result of changes in the management process (Muller et al. 1996, FDNR 1985, FDEP 2000a, FDEP 2000b).

A.10.4 Ecological Attributes

A.10.4.1 Wetland and Upland Habitats

Currently, portions of the drainage basin have been drained or flows have been redirected to discharge into other water bodies. Wetland distribution and function have been affected by a drainage system that lowers the water table and rapidly transfers untreated runoff to the estuary as needed to afford drainage and flood protection. The loss of adequate water to and through historic wetlands has resulted in loss of extent and quality of fish and wildlife habitat in the Loxahatchee watershed ecosystem (Martin County 2000). Progress of management efforts in this watershed can be determined by monitoring changes in the distribution extent and quality of remaining wetlands

The species composition and distribution of plant communities in a given locale are primarily functions of climate, soil type and suitable water conditions, including depth of water table, length and frequency of inundation and water quality. These plant communities, in turn, provide food and/or habitat for various birds, fish and wildlife. Thus changes in the distribution, abundance and species composition of plant

communities have a direct effect upon the type and quality of associated animal communities (Sharitz and Gibbons 1989, Kraus et al. 1999, McPherson et al. 1982, Alexander and Crook 1975).

A.10.4.2 Shoreline and Floodplain Habitat

The overall distribution and abundance of mangroves is a reflection of the extent of saltwater penetration into the river system. All four species of mangroves contribute to productivity in this system although red mangroves tend to provide better habitat for estuarine species (Heald and Odum. 1970).

Cypress and other wetland and slough vegetation satisfy unique habitat requirements of a variety of fish and wildlife. Within the Loxahatchee watershed, the delineation, based on riverine miles, between areas that support support healthy cypress trees and associated hardwood species and understory vegetation and other freshwater flora, and areas that are dominated by mangrove is a function of predominant salinity regime, which in turn is a factor of freshwater flow (FDNR 1985, FDEP and SFWMD 2000).

A.10.4.3 Birds, Amphibians, Reptiles and Mammals

The combination of climate, vegetation and water bodies in the Loxahatchee River area has resulted in a high diversity of animal species. The area surrounding the Northwest Fork is inhabited by numerous vertebrate species identified as endangered, threatened or of special concern by the Florida Fish and Wildlife Conservation Commission, or listed as threatened or endangered by the United States Fish and Wildlife Service. Aquatic vertebrates are numerous in the marshes, lakes and streams in the river area. Freshwater fish include largemouth bass, speckled perch, bluegill, shellcracker, redbreast, warmouth, bowfin, gar, channel catfish and many species of minnows. The manatee, an endangered aquatic mammal, frequents the Loxahatchee River Estuary. The entire Loxahatchee River has been designated by United States Fish and Wildlife Service as a critical habitat for the West Indian manatee. Numerous turtles also live in and around the river. Saltwater fish include snook, tarpon, mullet, bluefish, jack, sheepshead, drum, sand perch, grouper, snapper and flounder. Mammals and birds are frequently encountered along the riverbank. The more commonly seen species include raccoon, opossum, whitetail deer, osprey, barred owl, egrets, herons and ibis (SFWMD 2002a)

Additional species have been identified as being either endangered, threatened or of special concern by the Florida Committee on Rare and Endangered Plants and Animals. The threatened osprey often nests in dead cypress trees in the lower Northwest Fork. The great egret, the black-crowned night heron and the yellow-crowned night heron, classified as “species of special concern”, are also found in the Loxahatchee River area.

The Loxahatchee National Wild and Scenic River and Jonathan Dickinson State Park contain 52 federal and state species that are endangered, threatened or of special concern (23 animals and 29 plants). Those species having a federal designation found within this area are the American alligator, eastern indigo snake, Florida scrub jay, bald eagle, wood stork, Everglades snail kite and West Indian manatee (FDEP 1998). Wading birds observed in freshwater marshes and wetlands in these areas include wood storks, herons and white ibis. Amphibians are also abundant, including frogs and sirens in freshwater reaches of the system.

A.10.4.4 Phytoplankton and Zooplankton

Zooplankton play an important role in ecosystems, transferring energy from primary producers to predators and suppressing the abundance of phytoplankton. Higher trophic levels depend on a healthy distribution, abundance and balance between the underlying phytoplankton and zooplankton communities for sustenance, growth and reproduction. In a healthy aquatic system, seasonal cycles of nutrient influx

from the watershed, increased phtypoplankton productivity and subsequent zooplankton blooms in the river and estuary provide a food base for the development of juvenile fishes. When grazing pressure is intense, zooplankton can substantially reduce total phytoplankton biomass and productivity, with concomitant effects on water clarity (Havens et al. 1996).

A.10.4.5 Oysters and Other Benthic Communities

Benthic organisms provide essential ecological and biological functions in the estuary and can influence the quality of the environment. These communities can filter/trap particulates, serve as refuge, and provide a food source for fish and macroinvertebrates. Benthic communities can serve as important indicators of environmental quality that respond to changes in freshwater inflow or water quality via change in cover, density or community composition. Certain changes in fixed benthic communities (i.e., density, distribution and composition of mollusks) are readily discernable and may be relatable to specific directions and magnitudes of change.

Macroinvertebrates provide an ideal measure of the response of the benthic community to environmental perturbations (Boesch and Rosenberg 1981, Reish 1986). These organisms are primarily sedentary, thus, have limited escape mechanisms to avoid disturbances (Bilyard 1987). They provide a record of effects of short- and long-term environmental changes through species composition and abundance changes. Therefore, they are often used as water-quality indicators. They are relatively easy to monitor and tend to reflect the cumulative impacts of environmental perturbations, thereby providing good indicators of the changes in ecosystems over time. They have been used extensively as indicators of impacts of both pollution and natural fluctuations in the estuarine environments (Gaston et al. 1985, Bilyard 1987, Holland et al. 1987, Boesch and Rabalais 1991).

Benthic macroinvertebrate communities in the Loxahatchee Estuary are sensitive to bottom type, water quality and salinity fluctuations. Furthermore, the fluctuation between periods of high and low discharge causes alternating shifts between estuarine and freshwater species, as described by Haunert and Startzman (1985) in the St. Lucie Estuary. Dent et al. (1998) profiled the macroinvertebrate community present in the Loxahatchee Estuary.

Oysters are a particularly important component of the benthic invertebrate community in the Loxahatchee Estuary. Oysters serve an important function by creating substrate to support other species and by filtering water to remove suspended materials. Under natural conditions oyster reefs can be very large and provide extensive attachment area for oyster spat and numerous associated species such as mussels, tunicates, bryozoans and barnacles (Woodward-Clyde 1998). Several studies (Pearse and Wharton 1938, Wells 1961, Bahr and Lanier 1981) have found from 40 to over 300 faunal species in oyster beds, including other mollusca, crustacea, annelida, nemertea, platyhelminthes, porifera, coelenterata and protozoa. Distribution and abundance are influenced by availability of planktonic food, water quality, salinity and the presence of a suitable substrate for attachment of veligers. In the Northwest Fork, the largest living oysters (80 - 90 millimeters) occurred between river miles 4.0 and 6.0, where average high tide surface salinities were between 7 and 22 ppt, and ranged from about 2 to 28 ppt. The river delta (also known as "S-Bar") located at approximately river mile 4.5, played a controlling role in upriver salinities and was the most active oyster ground (Law Environmental, Inc. 1991a). Oysters and other bivalves are sensitive to salinity and siltation. Estuaries are depositional features, dominated by soft sediments with little surface structure or roughness.

Previous studies of oysters indicate slightly different preferred ranges and mortality thresholds, depending on age, condition, temperature and other factors (Woodward-Clyde 1998). Generally, adult oysters require salinity levels above 3 ppt, thrive at 12-20 ppt, and are adversely affected by diseases, predators and algal blooms at seawater salinity conditions. Thus oyster distribution, health and abundance reflect

the quality of estuary condition, integrating water quality, salinity and substrate factors (Andrews et al. 1959, Sellers and Stanley 1984, Lenihan 1999, Livingston et al. 2000).

A.10.4.6 Submerged Aquatic Vegetation

Seagrass beds provide habitat for myriad animals, including the juveniles of many commercially and recreationally valuable species (Zieman 1982). Like all plants, seagrasses require adequate sunlight, and this is a function of water clarity. All species of SAV have a preferred and tolerable salinity range. They respond unfavorably when salinity alterations exceed these ranges. Degraded water quality and physical alterations have been shown to negatively impact seagrasses, with a regional decrease in coverage (Chamberlain and Doering 1998a).

Four species of seagrasses are commonly observed in the Loxahatchee Estuary. Shoal grass (*Halodule wrightii*) tends to be the most abundant species. Stargrass (*Halophila* sp.) sometimes occurs with shoal grass, but its biomass tends to be insignificant except in localized areas. The presence of Johnson's seagrass (*Halophila johnsonii*) in the Loxahatchee Estuary was noted by Kenworthy (1992). Manatee grass (*Syringodium filiforme*) and turtlegrass (*Thalassia testudinum*) occur rarely in the estuary. Various species of macro-algae occur occasionally in the estuary on an occasional basis, either attached to rocks or shell or forming discrete patches within the seagrass communities (Ridler et al. 1999).

The distribution and composition of seagrass communities changes considerably from year to year. A comparison of grass bed distributions performed 1994, 1996 and 1998 showed that over half of the 84 acres of seagrass present in 1994 had been lost by 1996, and that a slight recovery had occurred by 1998 when 45 acres were present (Ridler et al. 1999). This change in seagrass cover was attributed to scouring which deepened the Northwest and Southwest Forks during the fall of 1995, whereupon the sediments thus removed were transported and deposited in the central embayment area of the estuary (Jupiter Inlet District 1999). Shoal grass is the most abundant of the seagrasses in the Loxahatchee Estuary. Johnson's seagrass and stargrass are considerably less abundant. Turtle grass occurred in only one area of the estuary and was observed to be in poor condition (Kenworthy 1992).

Shoal grass has the broadest salinity tolerance, followed by turtle grass and manatee grass. *Halophila* spp. are the most stenohaline species of those in the study area (Zieman 1982). Turtlegrass has an optimum range of 24-35 ppt. Salinity, temperature and water clarity are quite variable in the estuary compared with the north arm of the Intercoastal Waterway where inflow of ocean water maintains relatively high salinity, moderate temperature and relative high water clarity. Manatee grass and turtlegrass are dominant under these conditions and form dense stands just north of the estuary in the north arm of the Intercoastal Waterway.

A.10.4.7 Fisheries Species

In 1965, 267 species of fishes, consisting of 169 genera and 78 families were observed in and along the river and its estuary (Christensen 1965). At least 70 percent of Florida's recreationally and commercially sought fishes depend on estuaries for part of their life histories (Harris et al. 1983, Estevez 1998, Lindall 1973). Within the estuary, seagrass communities, mangroves, oyster reefs and stable benthic communities provide critical refugia and food sources for juvenile fish such as redfish, grouper, snook, and spotted seatrout. The decline in juvenile abundance and distribution of these and other species, along with the overall decline in species richness may be related to fishing pressure and a decline in suitable habitat and/or a result of alterations in the salinity regime and the timing of the freshwater discharges (Hedgepeth et al. 2001, Christensen 1965, Browder and Moore 1981).

A.10.4.8 Near-Shore Reef

Coral reef systems are highly oligotrophic, and potentially vulnerable to changes resulting from increased nutrients. Reef development is typically slow and occurs over geologic time scales, so impacts to reefs may cause ecological problems that require long time frames for recovery. These reefs provide habitat to a variety of animals many of which have socio-economic implications through tourism, recreational and commercial activities, therefore ensuring the health of Florida's reef system is of paramount concern. Significant well-developed coral reef systems occur near Jupiter Inlet, and are the northern extreme of zoogeographic distribution (Jaap and Hallock 1990). The quantity and quality of water discharged from the Loxahatchee watershed has effects on near-shore habitats near the Jupiter Inlet, and changes to the water management strategies may alter the current conditions. River discharges may transport sediments to near-shore reef areas, decrease light penetration through alteration of watercolor, clarity, and nutrients. These factors may directly or indirectly affect the health of corals through increased sedimentation directly on corals, stimulation of phytoplankton or macro-algal species which may shade or overgrow corals colonies, and through decreased light availability or alteration of color frequencies needed by symbiotic zooxanthellae in hard coral tissues.

A.10.5 Ecological Effects

Critical Linkages between Stressors and Attributes/Working Hypotheses

It is important to note that all of the interwoven ecological systems in the watershed and river (freshwater wetlands, riverine floodplain communities, mangroves and salt marshes) collectively provide important habitats for fishes, wildlife and other associated fauna (TCRPC 1999, Law Environmental 1991b). The construction of the C-18 canal, major roads and the water control structures maintained by the South Indian River Water Control District has greatly reduced the dry season base flows that the Northwest Fork of the Loxahatchee River once received from these sources. These changes have resulted in the gradual reduction in the number and geographic extent of freshwater floodplain swamp and bald cypress, and their replacement by mangroves (SFWMD 2002a). Virtually all of the cypress in the lowermost area of the "wild and scenic river" segment have either died or ceased reproduction. Approximately one mile upstream from Kitching Creek, the number of live trees increases with increasing distance up the river. Based on studies conducted as part of the Wild and Scenic River Management Plan (FDEP and SFWMD 2000) it was concluded that the decline of cypress in the river was primarily due to the upstream movement of salt water (Pezeshki 1987, SFWMD 2002a, McPherson et al. 1982, McPherson and Sabanskas 1982).

Altered estuarine salinity has resulted from man-made hydrological modifications that have dramatically changed the natural quantity, quality, timing and distribution of freshwater inflows, often without proper regard to the biological integrity of the estuary (Haunert et al. 2000). The estuarine environment is sensitive to freshwater releases; disruption of the volume, distribution, circulation and temporal patterns of freshwater discharges have placed severe stress on the entire ecosystem. Such salinity patterns affect productivity, population distribution, community composition, predator-prey interactions and food web structure in the inshore marine habitat. Salinity is this considered as a master ecological variable that controls important aspects of community structure and food web organization in coastal systems (Myers and Ewel 1990).

During the wet season, rainfall runoff that was historically retained within the undeveloped watershed now reaches the estuary in greater volume and less time through the S-46 structure on the C-18 canal. During the dry season, this structure restricts freshwater flows to the upper reaches of the Northwest Fork of the Loxahatchee River. Alterations in the delivery of fresh water at S-46 cause salinity to vary widely. Rapid and unnatural fluctuations in salinity have contributed to severe impacts on submerged plant

abundance and distribution. Other adverse conditions created by water management practices include the reduction of the oligohaline (low salinity) habitat within the estuary and central embayment and movement of estuarine and saline conditions upstream in the Northwest Fork into areas that historically were freshwater environments. Periodically, the system is impacted by massive releases of fresh water that destroy estuarine and marine communities throughout the river, estuary and adjacent coastal waters (Rodis 1973b, Dent and Ridler 1997, Allen et al. 1997).

The concept of a natural distribution of salinity gradients and variability acceptable to and supportive of aquatic life is an import prerequisite for environmental health. Dramatic changes in salinity, either rapid or sustained, have been implicated in adverse environmental consequences. Death and/or impairment have been documented in many species exposed to salinities outside their ideal ranges (Kingsford and Gray 1996). For example, very low flow conditions in the Northwest Fork have resulted in upstream migration of estuarine fauna into formerly freshwater species-dominated benthic communities (Dent et al. 1998).

Large flood control discharges may create a plume of fresh water that prevents tidal marine waters from entering the inner estuary. The low salinity plume described above may act as a "plug" or barrier to successful colonization of habitats in the Loxahatchee by many organisms. In a typical natural scenario, offshore areas provide larvae and juveniles to the estuary, and in turn, the estuary provides adult fish to spawn offshore. Salinity disruption or blockage could interfere with both processes. The early larval and juvenile stages are particularly vulnerable to being adversely affected by poor water conditions (including lowered salinity). Some organisms may potentially avoid the low salinity area, and thus delay settling in nursery habitats (and therefore may be exposed to enhanced risk of predation), or they may die or suffer reduced fitness due to exposure to deleterious salinity levels. Low salinity exposure may cause eggs or larvae to settle prematurely in inappropriate habitats, leading to reduced fitness or death (Forward 1989, Reagan 1985). The halocline produced by the low salinity front may cause larval organisms to gather along the edge of the plume, exacerbating the afore-mentioned risks (Kingsford and Gray 1996).

The ecological effects of increased nutrient loading, particularly phosphorus, on lakes and rivers have been well documented (e.g., Likens 1972, Harper 1992, Havens and Steinman 1995). Such limnologic effects include **excessive productivity**, reduced dissolved oxygen, and **changes in species composition**. Because wetlands possess higher biological activity than most other aquatic systems, they can transform or capture many constituents that might otherwise enter and adversely affect both limnetic and estuarine systems (Kadlec and Knight 1996). Where wetlands have been either reduced in area or function, or bypassed by construction of canals, water and the contaminants it may carry are delivered untreated to receiving waters with adverse consequence. However, the ability of even the healthiest wetlands to ameliorate increased pollutant loads is finite (Zahina et al. 2001b).

Development of plan for enhancement of resources in the Loxahatchee watershed is based on the concept that ecological changes will result from redirection and increased freshwater flow to currently poorly hydrated wetlands, and to the Northwest Fork resulting in a movement seaward of the mesohaline zone. This change in salinity conditions will, in turn, result in reestablishment of freshwater habitat while maintaining or reducing current nutrient concentrations. Several of these relationships are based purely on the volume, timing and distribution of the fresh water itself, while others include consideration of elevated loads of nutrients, toxins, dissolved organics materials and sediments that may be associated with these flows coming off the developed watershed.

The ecological effects and critical linkages described above are based on key hypotheses. The hypotheses are presented below, organized by attribute.

A.10.5.1 Floodplain and Wetland Communities

Watershed Wetlands Have Been Lost and Degraded Due to Altered Water Levels and Hydroperiods

Land development, construction and operation of drainage and flood control facilities, and consumptive use withdrawals in the watershed, especially during the past fifty years, have resulted in localized and region-wide changes in major wetland systems in the watershed (TCRPC 1999, Martin County Planning Department 2000). Lowering of the water table throughout the watershed due to canal construction and the need to protect land development has resulted in a net loss of an estimated 8,000 acre-feet of storage in the C-18 Basin alone (SFWMD 2001). Major wetland systems have been drained for agricultural and urban development. Other, mostly adjacent, wetlands have been altered to become upland dry prairies or pine forests or have been extensively invaded by cattails, willows and melaleuca. All of these factors affect the overall distribution and health of freshwater wetlands in the watershed. (McPherson et al. 1982, Pezeshki et al. 1987, Duever and McCollom 1982). Some areas such as the J.W. Corbett Wildlife Management Area, Grassy Waters, and Jonathan Dickinson State Park are owned by the state or local government entities and have management plans in place to protect these areas from further harm or restore damaged wetland systems. Other areas such as Pal Mar and the Atlantic Coastal Ridge property are in the process of acquisition (SFWMD 2000).

Level of certainty - high

Riverine Flows and Water Levels Determine the Distribution, Health and Extent of Floodplain Vegetation Communities

Changes in the structure of a stream channel, its sinuosity, substrate, amount of overhanging and instream cover, channel morphology, gradient and riparian vegetation all play an important role that influences the biological community (Karr 1993). Similarly, reduced water tables and changes in water flow directions have resulted in altered vegetation types, invasion by exotics, abnormal fire patterns, subsidence, and changes to microbial, macroinvertebrate, fish and bird populations (Sklar et al. 2002).

Loxahatchee River floodplain dimensions have decreased due to changes in water levels throughout the basin and flow in the Loxahatchee River and its major tributaries (SFWMD 2002a, Appendix B). Reductions of dry season water levels and flow rates have resulted in a decrease in the overall area of wetlands within the watershed and overall flow to the river. This effect has been counteracted to some extent and an overall increase in water levels of about 1 foot during the past century due to sea level rise. Where wetlands have been overdrained, conversion to upland habitats has occurred. In areas where water levels have been maintained artificially high for decades, there is evidence that the quality of wetlands has been degraded and some species such as cypress have failed to recruit (SFWMD 2001a, Appendix C).

Natural wetland species in the Southwest Fork have been largely displaced by canal construction and development. The floodplain of the North Fork within Jonathon Dickinson State Park is very narrow, but seems to be relatively undisturbed (Allen et al. 1997, Dent and Ridler 1997, McPherson and Sabanskas 1980). Recent studies suggest that providing high rates of sustained flow from the Loxahatchee Slough into the Northwest Fork, as a means to reduce saltwater intrusion, may result in maintenance of flow rates and water levels in the uppermost segment of the river channel that will adversely affect the cypress forest community that now dominates this section of the river (SFWMD 2001a, Appendix N). A better approach to management is to provide higher rates of flow to the river by increasing the contributions from all the major tributaries

Level of certainty – moderate

Changes in Ground Water Levels Result in Changes to Regional Wetlands, River Flow and Floodplain Plant Communities

A major ecosystem driver in the Loxahatchee system is the role that ground water discharge from the surficial aquifer has on maintenance of water levels in regional wetlands, tributary and river flow and the health of floodplain communities. Historically, ground water levels throughout the watershed were maintained at higher levels than they are today. This resulted in higher water levels in regional wetlands, and higher rates of ground water discharge to the river and its major tributaries. Such flow was probably a significant component of base flow in the river during dry periods. The actual magnitude of ground water flow to the Northwest Fork in recent decades is uncertain, but has been estimated at about 40 cubic feet per second (cfs) (SFWMD 2002). However, there is a significant amount of uncertainty associated with this estimate.

In addition, ground water discharge from the surficial aquifer is thought to have occurred directly into the river floodplain at various locations and helped protect floodplain plant communities against the effects of saltwater intrusion. The amount of such flow, locations where it presently occurs, and effects of this flow on floodplain vegetation are presently unknown.

Level of certainty - low

Changes in Salinity Concentrations in the Loxahatchee River Result in Changes to Floodplain Vegetation

Increased saltwater intrusion, due to construction of Jupiter Inlet, navigational improvements to the estuary and river, and drainage of the watershed, has been associated with a loss or degradation of freshwater plant communities and expansion of saltwater tolerant plants upstream, especially in the Northwest Fork (McPherson and Halley 1996).

The primary mechanism that has been proposed for the replacement of freshwater tree species in the floodplain by salt tolerant mangroves has been the toxic effects of saltwater penetration into floodplain soils. Salt is thought to penetrate into the soils as a result of increased upstream of saltwater in the river channel and a reduction in the amount of fresh ground water that seeps from adjacent uplands into the river floodplain soils and channel.

Recent studies have shown that one of the first signs of stress in the freshwater swamp community as one moves closer to the saltwater interface is the reduction in the number of seedlings and saplings of canopy species (SFWMD 2001a). Another early change is the dramatic reduction in the diversity and abundance of understory plant species (SFWMD 2001a). The most dramatic effect is the loss (death) of mature cypress trees and replacement by mangroves (Duever and McCollom 1982, McPherson unpublished, Alexander and Crook 1975).

These effects are thought to be related to periodic exposure of the soils to salt water. Very little direct evidence is available to document either the increase in salt concentration in the soils in areas where freshwater communities are stressed or a reduction in ground water levels or flows relative to historic conditions. A recent study has shown that there is an apparent relationship between observed tree and understory species diversity and long-term salinity levels in the river channel as predicted by a hydrodynamic model.

Various studies and management plans for the river that have been developed during the past 20-30 years have identified this transition as a major concern in the river. The primary mechanism that has been proposed for the death of large cypress trees in lower reaches of the river and upstream migration of mangroves has been the intrusion of salt water upstream in the river channel, penetration of the salt water

into the floodplain soils and the toxic effects of saltwater exposure on mature cypress trees. Although the likelihood is very high that these are the causative factors, there is little explicit evidence from the field or from the literature to determine either the salinity or exposure thresholds at which damage to cypress trees occurs or the extent or rate that salt from the river channel penetrates into floodplain soils. This conclusion is derived primarily from anecdotal and circumstantial evidence.

Loss of mangrove communities from the Loxahatchee River channel, due to restoration efforts that result in an increase in freshwater flow during dry periods, would result in overall loss of regional mangroves, because there are no suitable downstream locations for mangrove colonization. Such areas have already been altered by development and bulkheading of shorelines. However, within the Indian River Lagoon region there is a much greater overall abundance of mangrove habitat than cypress habitat. Therefore, even if mangroves communities are more productive, an increase in cypress may be more desirable in this particular location to more closely represent conditions that occurred prior to development and to improve fresh and brackish water habitat diversity throughout the region.

A major ecological process that drives trophic structure and productivity in estuarine and coastal systems is the transport of biological material from the adjacent watershed and river into the estuary and conversion of this material to estuarine and marine biomass. This process is initiated by ingestion of leaf litter by secondary consumers and microbial decomposition of leaf litter. The quality and quantity of leaf litter material produced in the floodplain and transported by the river thus directly influence productivity in estuary and coastal waters. Mangroves are known to be an excellent source of high quality leaf litter (Odum et al. 1982). Less is known about the quantity and quality of leaf litter produced by cypress and other freshwater swamp trees. A shift from a mangrove-dominated river shoreline to a cypress dominated shoreline is thus likely to have a significant, although largely unpredictable, effect on productivity and diversity of downstream coastal ecosystems.

Level of certainty – moderate

Excessive Concentrations of Nutrients Have Adverse Effects on Wetland Structure and Function

Nutrient inputs to oligotrophic wetland systems in the Everglades (Davis 1994, Browder et al. 1994, McCormick et al 2002, etc.) and the Savannas Marsh Preserve (Graves et al. 1998) have been shown to alter the normal vegetative community and function, resulting in proliferation of undesirable species and exotic vegetation. Similar oligotrophic wetland communities are present in the Loxahatchee watershed, and similar environmental effects are expected to occur as has been documented elsewhere. The influx of elevated concentrations of nitrogen and phosphorus has been associated with expansion of cattail growth along the sides of the M-Canal and invasion of sawgrass marshes in Grassy Waters Preserve by cattails and willows.

Level of certainty - high

Habitat Disturbance Provides Opportunities for Invasion by Exotic Species

Exotic species are thought to be most successful invading in areas where the dominant native vegetation has been damaged or stressed. Such damage often opens up the soil to light allowing the seeds of exotic species to germinate. Also, lowered water tables result in transition from wetland to upland environments and the corresponding stress allows plants such as melaleuca to become established. In freshwater areas, the introduction of nutrients allows cattails to proliferate and displace other littoral zone emergent species and causes water hyacinths or water lettuce to expand in open waters. These changes result in degradation

of aquatic habitat and formation of floating mats of vegetation that may be transported downstream to create deposits of rotting vegetation in the estuary.

Level of certainty – low

A.10.5.2 Shoreline Habitat

An Overall Decrease in the Total Amount of Mangrove Habitat in this System Due to Development Has Been Partly Offset by Expansion of Mangroves into Areas That Formerly Consisted of Freshwater Swamps and Marshes

Ecological functions of the mangrove system, which include their filtering, stabilizing, habitat and protective roles, have decreased through fragmentation of the mangrove community due to shoreline development and dredge and fill activities. In the Loxahatchee River and Estuary, approximately 40 percent of the shoreline is bordered by mangroves. Extensive areas of mangrove and salt marsh land have been lost due to construction and resultant turbidity from runoff and pollution (Law Environmental Inc. 1991b). Losses of mangrove throughout the region have been linked to declines in sport and commercial fisheries (Christenson 1965, Gilmore 1995). Specifically, urbanization and shoreline development have resulted in an extensive loss of mangrove habitat. These native shorelines perform important functions, which include absorbing floodwaters, recharging floodwaters, assimilating waste and excess nutrients, and provide food and cover for a multitude of fish and wildlife. These functions help to maintain water quality, recycle nutrients and control erosion (Harris et al. 1983). Coastal saltmarsh and mangrove communities have been almost completely eliminated from the estuarine portion of the North Fork and Southwest Fork due to shoreline development. Remaining mangroves are located primarily in areas where colonization of freshwater marshes and forests has occurred upstream along the Northwest Fork in conjunction with increasing salinity. Mangroves provide important habitat for fishes and invertebrates. Mangrove leaves support an extensive association of fungi, bacteria and invertebrates that feed on the decomposing leaves (Heald and Odum 1970, McPherson and Halley 1996, McPherson and Sabanskas 1980).

Level of certainty – high

A.10.5.3 Phytoplankton

Influx of Dissolved Nutrients Results in Increased Plankton Productivity

Phytoplankton are important components of aquatic food chains since they convert dissolved nutrients into organic material and provide food for zooplankton, small fishes and invertebrates. Excessive concentrations of nutrients result in **phytoplankton blooms** that may be toxic and can have adverse effects on oxygen concentrations, **benthic communities and seagrasses**. Plankton populations in the Loxahatchee River have not been studied to a great extent. Inferences about phytoplankton levels can be made from observations of nutrient levels and chlorophyll concentrations. Plankton populations typically increase during dry periods when runoff water has relatively higher levels of nutrients, water clarity is greater and retention time in the system is increased.

Level of certainty – moderate

A.10.5.4 Oysters and Other Benthic Communities

Relationship between Changes to Benthic Invertebrates and Plant Communities

Several studies have examined the distribution, abundance and species composition of macroinvertebrates in the Loxahatchee system. Changes in **species composition** have been noted in the river in conjunction with **periodic influx of salt water** upstream and these changes seem to persist, even after conditions have been restored to fresh water. The greatest diversity of benthic macroinvertebrates occurs in seagrass beds and in areas that have well-oxygenated bottom sediments. **Benthic invertebrates provide a food source for fishes** and are especially abundant in seagrass communities (Dent et al. 1998, DeSzalay and Resh 2000).

Level of certainty - moderate

Effects of Water Quality and Salinity Changes on Benthic Community

Sudden and severe shifts in salinity lead to changes in the diversity and species composition of benthic invertebrates in the estuary. Benthos are often used as indicators of perturbations in the estuarine environment because they are relatively nonmobile, and therefore cannot avoid environmental problems. The response of benthic communities to alterations in sediment and water quality is relatively well understood and is often expressed as changes in community structure, density and diversity (EPA 1999). For example, **excess nutrients can create enhanced feeding opportunities for organisms, causing an imbalance among competing types**. Different species may be better adapted than other less tolerant types to endure low oxygen conditions. Rapid deposition of new sediments or sudden shifting of unstable sediments during major freshwater discharge events or storms can make conditions inhospitable for certain classes of sessile organisms which require stability for survival and reproduction.

Level of certainty - moderate

Effects of Toxins and Contaminants on Benthic Communities

Since macroinvertebrates physically live either on or in the sediments, they are directly exposed to and affected by the heavy metals, pesticides and other toxins in the sediment. Many of these substances are either insoluble in water or tend to associate with particulate matter that flocculates, often resulting in concentrations much higher in the estuarine sediments than that observed within the overlying water column. This increase in toxins can cause a shift to more pollutant tolerant species. Toxins can also bioaccumulate in benthic species and in higher trophic level predators, causing a decline in the health of these communities.

Level of certainty - high

Sediment Composition and Stability Influence Distribution and Species Composition of Benthic Communities

Benthic communities need suitable substrate for successful recruitment and establishment. Hard substrates such as shell and rock provide excellent surfaces for colonization by oysters, barnacles and sponges and attached algae. Coarser sands and dense silt and mud provide a relatively stable environment for burrowing worms, molluscs and fishes. Very fine sediments, (clay size particles or less (that are referred to in this particular context as “muck”), especially in areas that have high wave action or low dissolved oxygen levels, provide unsuitable habitat.

Discharges from the Northwest Fork result in shoaling at the point where the river discharges to estuary (S-shoals). Sandbars form in the central embayment apparently primarily due to sand carried into the river through the inlet. Sandbar formation affects benthic communities and oysters as well as providing habitat for floodplain species and seagrasses (Hill 1977, Law Environmental 1991b, Antonini et al. 1998). Deposits of muck, which resulted from these discharges, have displaced or modified normal substrate in the river and estuary and have contributed to the decrease in extent of SAV beds. Fine sediments also become resuspended during discharge events or due to wave action, resulting in increased turbidity and decreased light penetration.

Level of certainty – high

A Decline in Oysters has Occurred during the Past 100 years, Resulting in Degradation of Water Quality and Reduced Availability of Habitat for Other Estuarine Species

Oysters, clams, and scallops are natural components of estuaries and were documented to be abundant in the system (Estevez 1998, Leverone 2000). Although currently less abundant and less commercially and recreationally important than they were in the early 1900s (Chamberlain and Doering 1998a, Sackett 1888), oysters continue to be an important resource due to their ability to filter suspended materials from the water column and form stable substrate for colonization by other organisms. The reduction in oyster coverage occurred largely due to shell mining, dredging of channels and for bar removal, altered freshwater inflow, and changes in hydrodynamics. This decrease has resulted in an overall decline in health, abundance and distribution of the oyster reef community within the estuary (Law Environmental 1991b).

Level of certainty - high

Relationship of Oysters to Sediment Loads

The decrease in the populations of oysters and other filter feeding bivalves in the Loxahatchee system is also influenced by increased sediment loads, which have occurred due to land development, dredging and filling activities in the watershed. High concentrations of turbidity and suspended solids are destructive to oyster communities due to clogging of the filter-feeding and respiration mechanisms (Cake 1983) and reduced light penetration that may result in low concentrations of dissolved oxygen (Woodward-Clyde 1998). Adult oysters have morphological adaptations that allow them to tolerate high levels of suspended solids for short periods (Kennedy 1991). Oysters from relatively turbid estuaries appear to be capable of feeding at total solids concentrations as high as 0.4 grams per liter but significantly reduce their pumping rates at as low as 0.1 grams per liter (Loosanoff and Tommers 1948).

Level of certainty - moderate

Relationship of Salinity to Oysters

Salinity is important in determining the distribution of coastal and estuarine bivalves. Although oysters can tolerate exposure to a wide range of salinities for short periods of time, they require a smaller range of salinity variation to remain healthy and reproduce. Adult oysters in the Gulf of Mexico tolerate a salinity range of 2 to 40 ppt, but normally occur at salinities between 10 and 30 ppt (Gunter and Geyer 1955). Short pulses of freshwater inflow can greatly benefit oyster populations by killing predators, such as the southern oyster drill and the welk, that cannot tolerate low salinity water (Owen 1953), while excessive freshwater inflows may kill entire populations of oysters (Gunter 1953, Schlesselman 1955, MacKenzie 1977). Changes in salinity can also affect the structural and functional properties of these bivalves through changes in 1) total osmotic concentration, 2) relative proportions of solutes, 3) coefficients of

absorption and saturation of dissolved gases, and 4) density and viscosity (Kinne 1964). These bivalve physiological processes translate to functional processes in ecosystems (Dame 1996).

Alterations of flows have caused dry season increases in salinity in the estuarine portion of the Loxahatchee River. This increase in salinity has negative physiological effects on oysters and promotes predation by saltwater organisms. Protozoa are probably the most common cause of epizootic outbreaks that result in mass moralities on oysters. One of the most important is deermo, a disease caused by *Perkinsus marinus.* It is characterized by emaciation of the digestive gland of the oyster. The oyster vector dermo has limits imposed by salinity and temperature (Dame 1996) and is more intense in areas of higher salinities (Burreson and Ragone, Calvo et al. 1996).

Level of certainty - moderate

A.10.5.5 Submerged Aquatic Vegetation

Changes in Salinity and Water Quality Will Affect the Abundance, Distribution and Species Composition of Submerged Aquatic Vegetation Communities

Changes in estuarine salinity that result from hydrologic changes in the watershed, inlet stabilization, dredging of the estuary and sea level rise have likely had significant effects on SAV species composition and distribution, although no data is available prior to the 1960s. Different species of SAV have different desirable salinity ranges and salinity tolerances. Shoal grass has the broadest salinity tolerance, followed by turtle grass and manatee grass. *Halophila* spp. are the most stenohaline species of those in the study area (Zieman 1982). Turtlegrass has an optimum range of 24-35 ppt. Salinity, temperature and water clarity are quite variable in the estuary compared with the north arm of the Intracostal Waterway, where inflow of ocean water maintains relatively high salinity, moderate temperature and relative high water clarity. Manatee grass and turtlegrass are dominant under these conditions and form dense stands just north of the estuary in the north arm of the Intracostal Waterway. When salinity falls outside of these ranges, the SAV is negatively impacted and may result in a reduction in densities and distribution (Chamberlain and Doering 1998b). Increases or decreases in salinity may give one species a competitive advantage over another (Livingston 1987). Tabb et al (1962) stated, “Most of the effects of man-made changes on plant and animal populations in Florida estuaries are a result of alterations in salinity and turbidity” (see also Mote Marine 1990b, Ridler et al. 1999, Zieman 1982).

The increased influx of nutrients into the estuary, as runoff from urban and agricultural lands, has had negative impacts on SAV through **increased epiphytic growth** (Murray et al. 1999) and **stimulation of phytoplankton growth** (Livingston 1987), which decrease light penetration. Increased epiphyte growth can also be caused by changes in faunal composition of the benthic community that result in a decrease in grazers that would otherwise remove epiphytes from the SAV. Reduction in penetration of light into the water column causes the disappearance and diminishing of previously healthy seagrass meadows (USEPA 1983). Because seagrasses are rooted plants attached to the bottom, reduced light reduces photosynthesis, growth and reproduction. This condition is a major source of seagrass decline in Florida estuarine systems (Durako 1988). Increased nutrients, such as nitrogen and phosphorous, can lead to light deprivation by stimulating the **growth of phytoplankton**. Even relatively minor changes in nutrient concentrations can lead to sharp reductions in the productivity of seagrasses that can lead to broad habitat changes (Livingston 1984).

Level of certainty – moderate

Boating Pressure Impacts Shorelines and Submerged Aquatic Vegetation

The increase in the numbers of boats and boat usage in the estuary have contributed to the decrease in stability of shorelines and the extent of SAV beds. Shallow areas, which normally contain the healthiest and most abundant beds, are most likely to be impacted by channel dredging, grounding of boats, or damage by boat propellers. Construction of docks, piers and access channels also impacts SAV beds and shoreline vegetation. The effects of increased wave action due to boat wakes is also significant, especially in areas where natural shorelines have been replaced by bulk heads and seawalls.

Level of certainty – high

A.10.5.6 Fish and Benthic Communities

Salinity Conditions Affect Fish and Benthic Communities

Changes in salinity in the river channel due to changes in river configuration or flow result in changes to benthic invertebrate and fish populations, with a shift from freshwater species dominated by insects and oligochaetes to more estuarine assemblages dominated by polychaetes and molluscs. Data form the Loxahatchee River system indicate that once such a transition has occurred, estuarine species will continue to dominate the assemblages even after freshwater conditions have been restored (Dent 1997, Dent et al. 1998).

Level of certainty – moderate

Reduced Levels of Dissolved Oxygen Have Adverse Effects on Fish and Benthic Communities

Increased loadings of nutrients, suspended solids and dissolved organic material from the watershed result in higher BOD in the river and lower ambient dissolved oxygen concentrations. Water quality in the river is periodically below state standards for Class III Waters. Such reduced levels of dissolved oxygen primarily affect the species composition, health and distribution of fish and benthic invertebrate communities in the river, resulting in a decline in species diversity and an increase in abundance of pollution tolerant species.

Level of certainty - moderate

A.10.5.7 Fish Communities

Changes in Submerged Aquatic Vegetation Affect Distribution and Abundance of Important Fisheries Species

The dense seagrass blades and rhizomes associated with the grasses provide cover for invertebrates and small fishes while also interfering with the feeding efficiency of their potential predators (Zieman 1982). Changes in SAV community health, abundance, distribution, structure and species composition, along with changes in the natural salinity regime, have resulted in substantial losses of mollusk populations and a decrease in larval and adult fish recruitment in Florida estuaries. Reductions in size and health of SAV beds affect the location, abundance and speciation of fisheries in the estuary. Fish densities are typically greater in grass bed habitat than in adjacent habitats (Reid 1954, Tabb et al. 1962, Roessler 1965, Yokel 1975, Weinstein et al. 1977). Declines in SAV also destabilize sediments and cause a shift in primary productivity from benthic macrophytes to phytoplankton, which reduce light penetration and provide a negative biofeedback that further affects seagrass beds.

Level of certainty - moderate

Effects of Salinity on Changes in Fish Populations

The Loxahatchee system supports a diverse population of freshwater, estuarine and marine fishes. Seagrasses and low salinity habitats in this system provide a nursery function for species that live in Lake Worth Lagoon, the Indian River Lagoon and offshore coastal waters. Changes in flow from the Northwest Fork have resulted in increased penetration of estuarine and marine species upstream in the river during dry periods, a decreased extent of freshwater habitat and a decline in diversity and abundance of native freshwater fish species in the lower reaches of the river (Christensen 1965, Hedgepeth et al. 2001, Mote Marine 1990b).

Level of certainty - moderate

Loss of Mangrove Shoreline Habitat Leads to a Decline in Fishes and Higher Vertebrates

The oligohaline and mesohaline wetlands of the mangrove estuary support resident communities of small fishes that are an important intermediate trophic level for support of wading birds and other higher consumers (Lorenz 2000). Mangrove shoreline habitats and **benthic communities** provide nursery grounds for sport and commercial fisheries including spotted seatrout, common snook and pink shrimp. Mangrove habitats have functional value to fishery species by providing food resources and protection from predators. Mangroves also provide litter that supports estuarine and near-shore secondary productivity via detrital-based food chains (Porter and Porter 2002). Mangrove roots entrap sediment and organic matter that provide a rich substrate for colonization by macroinvertebrates. Research has shown many taxa of fish including important fisheries species utilize mangrove habitats during significant portions of their life histories (Porter and Porter 2002). Three species, gray snapper (*Lutjanus griseus*), blue striped grunts (*Haemulon sciurus*), and great barracuda *(Sphyraena barracuda*) seem especially dependent upon mangrove habitat and are permanent residents within its root structure (Porter and Porter 2002). Mangrove roots also serve as staging habitat for certain residents of estuarine transients which are resident on coral reefs as adults.

Freshwater Discharges Affect the Distribution and Abundance of Juvenile Fish

The production and seasonal concentration of wetland fishes appear to vary with salinity, hydrology and nutrient status in the estuary (Trexler and Loftus 2000, Lorenz 2000), all of which are controlled by freshwater flow and sea level. Alterations in the natural salinity regime and timing of freshwater discharges have resulted in a decline in juvenile fish abundance, distribution and species richness. Alterations in the salinity regime can have adverse effects on the sensitive life history stages of many estuarine species (Emery and Stevenson 1957, Odum 1970, Lindall 1973, Perry and McIlwain 1986, Chamberlain and Doering 1998b). While estuarine species are generally well adapted to cope with varying salinity conditions and cycles, they are not so robust as to accommodate large shifts the timing cycle of salinity regimes. A simple case in point is the egg stage of spotted seatrout. Trout eggs are neutrally buoyant at about 20-22 ppt (Pattillo et al. 1997). Trout spawn during the warmer months of the year (Lassay 1983) and thus depend on the presence of high salinity concentrations during the summer months. The occurrence of large and protracted reductions in salinity during this period could thus lead to the reduction or elimination of an entire year-class of spotted seatrout.

Level of certainty - moderate

Toxins Have Adverse Effects on Fish Communities

Toxins, especially pesticides and heavy metals, that are periodically introduced to the estuary with the freshwater inputs from agricultural canals in the watershed can bioaccumulate in the fish causing increased levels, above what is thought to be normal "background" levels. In other South Florida systems, such increased levels of toxic materials have been linked to fish abnormalities and potential threats to human health. Certain species of fish seem to be more prone then others to bioaccumulation and the effects of toxins

Level of certainty - low

A.10.5.8 Near-Shore Reef

Altered Freshwater Flow Regimes Have Important Effects on Near-Shore Reef Communities

The Loxahatchee River Estuary, seagrass beds and benthic communities, as well as the low salinity mangrove habitat that exists within the Northwest Fork of the river, provide habitat and food sources for juveniles of a number of species that spend their adult lives on offshore reefs (Haunert and Starzman 1985). Changes in salinity in the estuary that affect the utilization of these areas as a nursery for species that later inhabit the reefs, will thus have an effect on species composition of reef communities.

Increased freshwater flows during major discharge events from the C-18 canal and S-46 structure result in increased loads of turbidity, sediment and nutrients, dramatic decreases in salinity, and have concomitant impacts on the health and species composition of near-shore reefs. Highly turbid water and fallout of suspended solids directly impact the survival of coral animals. Competition is an important process that determines the structure and composition of reef communities. Macro-algae compete with the zooxanthellae of corals for light and nutrients. Thus overcolonization of reefs by macro-algae, often associated with or stimulated by, excessive concentrations of dissolved nutrients in the water column, is an important step during reef degradation (McCook et al. 2001). Even slight increases in nutrients can present catastrophic consequences, and can result in blooms of macro- and filamentous algae (Lapointe 2000).

Level of certainty - low

A.10.6 Research Questions

The general working hypothesis stated above, is that ecological changes will result from redirection and increased freshwater flow, resulting in reestablishment of freshwater habitat in the river and changes to estuarine ecosystems. As noted above, the prediction of the specific effects of these changes on particular species and communities is associated with various degrees of uncertainty. Research is needed to gain a better understanding of these relationships, with emphasis on or priority given to those relationships have the greatest associated uncertainty.

Relationship of Salinity Conditions in the Loxahatchee River and Estuary to Sea Level Rise

The relationship of sea level rise to the estuary's salinity envelope needs to be determined. Also, the effect sea level rise will have on the ability of increased flows to maintain freshwater conditions within designated Wild and Scenic sections of the Loxahatchee River needs to be determined.

Relationship of Mangroves to Freshwater Inflow Changes and Sea Level Rise

Research is needed to determine the 1) effects of freshwater inflow change and sea level rise on mangrove distribution, 2) the difference in quantity and quality of habitat afforded to resident fish and wildlife between freshwater floodplain flora versus mangrove stands remaining within riverine zones where freshwater conditions have been restored, and 3) the optimum balance for overall ecological recovery between freshwater and estuarine plant communities.

Relationships among Altered Hydroperiod, Restored Wetland Function and Health, Areal Expanse of Restoration, and Estuary Water Quality

The optimum hydroperiod that would maximize bird and wildlife utilization of restored wetlands needs to be determined. Research is also needed to determine the optimum balance between hydroperiod and expanse of wetlands rehydrated and loads of nutrients and dissolved organic matter delivered to the estuary.

Relationship of Macroinvertebrate Community Shift to Altered Salinity Envelope

Research is needed to determine the effect shifts in salinity will have on the diversity and community species composition of macroinvertebrates in the freshwater and estuarine part of the Loxahatchee watershed.

Relationship of Depressed Dissolved Oxygen Concentrations in Northwest Fork and Aquatic Plant Controls

Research is needed to determine the role the large rafts of aquatic vegetation that enter the river primarily from the Jupiter Farms development lateral canals will have on the continuing downward trend in dissolved oxygen and deposits of muck that occur in certain parts of the river and the estuary.

Relationship of SAV to Input of Nutrients and Dissolved Organic Matter

Resarch is needed to determine 1) the effect increased loads of nutrients and dissolved organics, from increased flows, will have on light attenuation and 2) its subsequent effect on the distribution, health and abundance of SAV in the estuarine part of the Loxahatchee watershed. Also, the relationship of the amount of epiphyte coverage found on SAV to the location, abundance and diversity of species in the estuarine part of the Loxahatchee watershed needs to be determined.

Relationship between Altered Water Management Practices and Shoaling

Both CERP implementation and other water management changes are expected to affect shoaling. Research is need to determine 1) how the final design of CERP projects in the watershed will affect shoaling and loss of seagrass during normal operations and episodic high flow events, 2) how changes in water management will affect recolonization of areas depauperated by past discharges and shoaling events, and 3) how changes in water management will affect sustainability of existing seagrasses.

Relationship of Estuarine Fish Communities to Increased Levels or Loads of Toxins

The functional relationship between toxins and abnormalities and/or lesions observed on fish in the estuarine part of the Loxahatchee watershed needs to be determined. Also, research is needed to determine whether impacts to fish health will increase or decrease in response to land use, structural or operational changes made in the watershed.

Relationship of Water Quality in Loxahatchee Watershed to Water Management

The quantitative link between water management and flow at the freshwater-saltwater boundary of the ecosystem needs to be determined. Also, research is needed to predict the effects changing the quantity, timing, and distribution of freshwater inflows will have on the quantity and quality of estuarine habitat.

Relationship of Estuarine Fish Communities to Habitat Distribution and Loss

Research is needed to determine the appropriate salinity gradient that should be maintained, from interior coastal wetlands through the near-shore zone, to optimize the diversity and abundance of estuarine fish species and salt-tolerant freshwater fish in the estuarine part of the Loxahatchee watershed. Also, the dominant communities of fishes that utilize the freshwater and mangrove floodplain forests within the Loxahatchee River and Estuary need to be determined.

Relationships among Riverine Flow, Water Levels and Vegetation Communities

Sufficiently high water levels and river flows are needed to support native swamp and understory plant communities in the fresh water sections of the floodplain, but excessive flows may drown existing communities, prevent recruitment or erode the underlying substrate. What effects do changes in river flows and water levels have on vegetation communities in the floodplain, particularly on recruitment of new floodplain vegetation?

Effects of Salinity on Floodplain Vegetation

In spite of a relatively extensive literature on salinity and certain species of floodplain vegetation, the working hypotheses that would explain the distribution species that occur in the Loxahatchee River floodplain, especially cypress, seem to be very uncertain. Site specific studies of effects of salinity on plants from this river system are necessary because the effects of salinity on many of the species in this system have not been studied and there is evidence to suggest that particular genetic strains may differ significantly in their tolerance to salinity stress (SFWMD 2002a). A salinity threshold of 2 ppt has been proposed as a criterion for protection of freshwater communities in the Loxahatchee River system, but this concentration has not been verified by field or laboratory data, nor have appropriate levels of exposure (frequency and duration) been determined for floodplain vegetation species in this system.

Effects of Ground Water Seepage on Floodplain Vegetation

Ground water seeps into the floodplain at many points along the Northwest Fork of the Loxahatchee River and is a significant component of the overall water budget for this system. The presence of significant ground water seepage is likely a controlling factor that limits the amount of salt water that penetrates from the river channel into the adjacent floodplain soils. Little is known about salt concentrations in floodplain soils of the Loxahatchee, including the actual concentrations achieved, the length of time that salt remains in the soil, and the role of ground water seepage.

A.10.6.1 Loss of Cypress Trees in the Lower Portions of the River and Replacement by Mangroves

Observations and data over the past fifty years indicate that mangroves have encroached approximately 3 miles upstream in the Northwest Fork. The mechanisms responsible for this shift are not well understood. The ability of cypress to replace mangrove forests and the rate at which such replacement might occur, if additional fresh water is provided to this system are also not known. The general principle is well established that a more diverse canopy structure in the forest will support a greater diversity of plants and animals. The species that utilize the canopy in the Loxahatchee River have not been

documented to any extent. Effects of shifts in river shoreline habitat between mangrove prop root communities and forested shorelines with a predominance of cypress knees, submerged tree trunks, fallen trees and snags in the Loxahatchee River are unknown. Similarly, the effects of a shift in primary production by vegetation in the floodplain forest, between cypress and mangrove communities on productivity of downstream estuary and coastal ecosystems in the Loxahatchee River are unknown.

Relationship between Habitat Disturbance and Exotic Invasives

The general principle that habitat disturbance or stress provides an opportunity for invasion by exotics is generally agreed upon. However, it appears that exotic species (especially *Lygodium*) are also successfully invading healthy plant communities. Additional research is needed to identify other factors that need to be considered in the development of exotic species eradication and control programs.

Effect of Ground Water Levels on Regional Wetlands, River Flow and Floodplain Plant Communities

Additional studies are needed to identify and quantify the historic and existing sources of ground water flow to the river and floodplain and how best to manage surface water levels and flows in the watershed or to compensate for changes in ground water conditions.

A.10.7 Hydrologic Performance Measures

The premise for enhancement and future management of the Loxahatchee River system is similar to the premises used for restoration of the Kissimmee River (Toth et al. 1995) and the Greater Everglades ecosystem (USACE and SFWMD 1999): if proper hydrologic conditions are provided, appropriate biological communities will develop in response. Additional assumptions include some forms of active management may also be necessary, on a short-term or limited basis, to provide suitable substrates for colonization and to control exotic or nuisance species that might otherwise invade or colonize newly-stabilized or newly-created areas. The overarching issue for the CERP is to define the specific future management goals and objectives for the Loxahatchee system and what particular actions or projects will be requested from CERP to achieve these goals and objectives. The CERP monitoring components have been (RECOVER in prep) and will continue to be defined to determine the effectiveness of those actions.

In freshwater lakes, wetlands and streams within the watershed, the primary measures relate to maintenance of proper water levels, hydroperiods and seasonal distribution of water. General hydrologic requirements need to be defined for each of the major communities identified within the region. Specific indicator regions, sites or plant communities need to be identified within each of the major subbasins or management areas where monitoring will occur and specific hydrologic performance criteria need to be developed for each area.

For the Loxahatchee River, seasonal flow rates and water levels need to be monitored at specified locations along the river. The targets are to rehydrate, protect and restore key floodplain habitat quality and function, to cause a seaward shift in the current location of the oligohaline and mesohaline zones, to reduce erosion and subsequent shoaling during high flow events, and to maintain natural seasonal distribution patterns of water delivery. Definitions of criteria for these parameters will depend on the results of supporting research and the future development of management goals and objectives for the river that establish the desired distribution of plant and animal communities.

A.10.7.1 Soil Salinity and Ground Water Interactions in Wetlands

Water levels, salinity and mineral concentrations should be measured in wetlands adjacent to the river floodplain to document ground water influence and saltwater intrusion. Ground water levels in the

freshwater portion of the river floodplain should be maintained at or above the water level in the river at all times. Surface and ground water levels in regional wetlands in the watershed should be monitored and maintained at levels that are consistent with historical and existing vegetation communities and soil types.

A.10.7.2 Salinity Pattern and Stability

Improving the timing, quantity and duration of freshwater discharges is the primary mechanism controlling salinity patterns within the Loxahatchee River and Estuary. The management targets are to provide freshwater flow rates and seasonal distribution patterns that will maintain or enhance the quality and function of estuarine plant and animal communities, especially mangrove and seagrass habitats that provide an important source of primary productivity and a nursery function for organisms that live throughout the Indian River Lagoon and on near-shore reefs.

Flow volumes are presently being monitored at the major tributary inflows on the Northwest Fork and the S-46 structure on the Southwest Fork. Additional monitoring may be needed on Northwest Fork tributaries and the North Fork. Salinity monitoring at critical points in the estuary will also be needed to calculate total freshwater inflow to the system. River, watershed and estuary models are presently being developed that will be used to determine an overall water budget for the system.

Previous studies (SFWMD 2002a) identified an area along the Northwest Fork of the Loxahatchee River that is a transition zone between freshwater floodplain plant communities and saline water (mangrove) communities. A salinity and flow monitoring station has been installed near this location. Salinity and vegetation patterns at this site are expected to change during the next few years as projects that are currently underway are completed.

A two-dimensional model of the river and estuary is presently being completed as a tool to evaluate the effects on salinity conditions of proposed changes to this system. Efforts to develop a three-dimensional model, which can be used to analyze water quality impacts, are presently underway. A salinity threshold of 2 ppt has been proposed as a criterion for protection of freshwater communities. The appropriate limits of oligohaline and mesohaline conditions in the river and estuary need to be established as future management goals through the CERP process

A.10.8 Ecological Performance Measures

Ultimately, successful performance of management efforts in the watershed will be evaluated based on the distribution, species composition and health of plant and animal communities. Efforts to define appropriate criteria for the attributes discussed below are presently underway. As with the hydrologic measures, specific ecological measures, including water quality measures, need to be defined that will measure the success of the various CERP projects in terms of achieving overall management goals and objectives.

A.10.8.1 Sediment and Water Quality

Downward trends in dissolved oxygen in the Northwest Fork are reversed. Historical background levels of surface water nutrient (total phosphorus and total nitrogen) concentrations and loads must be maintained or reduced. Existing water clarity, as measured by photosynthetically-active readiation (PAR), must be maintained or improved in those regions where reduced water clarity is limiting growth of seagrasses. Loads of nutrients, toxins, dissolved organic matter and total suspended solids that originate from agricultural and urban land use practices and are exacerbated by regulatory and flood releases during wet periods, and enlargement of the historic drainage basins must be reduced. Toxic metals and pesticides buildup in sediments must be avoided. Sediment deposition rates must not accelerate. Redox

characteristics of sediment must not decline. Appropriate steps should be taken to identify and control sources that lead to periodic occurrence of high levels of coliform bacteria and low levels of dissolved oxygen in the river and estuary.

A.10.8.2 Acres and Quality of Freshwater Wetlands

Activities to rehydrate wetlands and to increase and maintain freshwater flows down riverine sections of the watershed should result in increased acreage or quality wetland and floodplain vegetation. Periodic monitoring is needed to determine the distribution, acreages and percent cover of major plant communities in the watershed and floodplain. Short-term criteria should be based on herbaceous plant communities that comprise the forest understory. Longer-term criteria include the health and continued reproduction of the major tree species.

A.10.8.3 Wetland Community Structure

In addition to the distribution and health of wetlands, the structure of these communities needs to be evaluated. Such attributes include the examination of the following: 1) the distribution of seedlings and saplings (is recruitment ongoing to ensure future viability of the community), 2) the distribution, abundance and diversity of canopy and understory species, and 3) the structure of the canopy (total height, light levels, etc.). A series of monitoring locations will need to be identified within the river and watershed that includes the full range of wetland communities, including both floodplain and freshwater marshes and swamps. Also, conditions need to be monitored in specific areas such as Loxahatchee Slough, J.W. Corbett Wildlife Management Area, Pal-Mar wetlands, Jonathan Dickinson State Park lakes and wetlands, and Grassy Waters Preserve.

A.10.8.4 Freshwater and Estuarine Benthic Communities

The targets for freshwater and estuarine benthic communities are to 1) increase species richness, abundance and diversity of benthic species to that typically found in healthy aquatic systems, and 2) provide an appropriate distribution and balance within the river of oligohaline and freshwater benthic communities. Within the River portion of the system, for example, healthy freshwater benthic communities occur upstream of river mile 10.0 and typically estuarine communities occur downstream of river mile 6.5. The area between these two points is exposed to more variable conditions and should monitored at regular spatial intervals to document anticipated changes in the freshwater-estuarine community boundary as freshwater flows to the river are increased over time.

A.10.8.5 Diversity, Abundance and Health of Submerged Aquatic Vegetation

The performance measure for SAV is based on cover and composition. The target is to reestablish SAV beds in areas that have suitable substrate and/or depth, but are presently devoid of seagrass, to improve cover where currently inhibited, and to maintain existing cover in areas where grasses currently flourish. It is hoped that as water clarity and substrate quality improve over time, that desirable SAV communities will proliferate in both fresh water and saline areas of the system.

A.10.8.6 Mangrove and Emergent Saltmarsh Distribution and Community Utilization

The indicators for performance measures related to mangroves and salt marshes are the overall distribution, the acreage and percent of these shoreline habitats, and the quality of habitat as defined by plant height, depth, density, growth rates and successful reproduction. Specific monitoring parameters include the observed increases in spatial extent of mangroves and emergent saltmarsh plant communities in those areas where salinity conditions are appropriate, and decreased coverages of these species in areas

where salinity intrusion has occurred in recent years due to prolonged decreased average flows. Indicators of community utilization include documentation of fish and invertebrate populations within these areas.

A.10.8.7 Freshwater Floodplain Forest and Understory Species Diversity and Distribution

The performance measure for cypress and freshwater floodplain plant distribution is the percent of restored floodplain, quality, depth, density, growth rates and successful reproduction of freshwater floodplain species, especially in areas where mangrove invasion has occurred in recent years due to prolonged lowered flows.

A.10.8.8 Fishery Health and Abundance

The performance measure for fishery species includes both fish and shellfish abundance and species composition throughout water systems in the watershed. The target is to increase the diversity and density of fish and shellfish assemblages at benchmark locations. Indicators and targeted trends for specific species include increases in the following:

- Increase representation of juvenile stages of reef and freshwater, recreationally-important fishes, including the silver snapper species (mutton, yellowtail and lane) parrot fish, gag grouper, sailors choice, snook, redfish, and spotted sea trout from present baseline conditions
- Abundance of mullet, menhaden and anchovy based on catch per unit effort
- Post-larval and juvenile densities of spotted seatrout in representative seagrass beds
- Juvenile settlement rates of the common and fat snook at representative sites
- Abundance of juvenile and adult redfish at representative sites

A.10.8.9 Phytoplankton Community Composition

The indicator for the phytoplankton performance measure is the species composition, density and frequency of algal blooms. One target is to improve or maintain existing levels of light penetration in those regions where reduced water clarity is limiting growth of seagrasses. Another target is to provide an appropriate spatial and seasonal balance between desirable species of phytoplankton and zooplankton in the estuary to ensure adequate food supplies for support of higher trophic level species.

A.10.8.10 Oyster Distribution and Sediment Quality

Oysters are important component of the Loxahatchee Estuary ecosystem because they filter large quantities of suspended materials from the water column and provide substrate for colonization by other species. The distribution, abundance and health of oysters are indicators of salinity, water quality and substrate conditions in the estuary. Contaminant in sediments and oyster flesh are also indicators of estuarine health. The management target for the Loxahatchee estuary is to increase the abundance of oysters in the estuary as a means to filter suspended materials from the water and stabilize sediments. Over time, the intent is to decrease the geographic extent and concentration of sediment contamination and decrease the extent of unstable or muck sediments (see below) that inhibit formation of balanced benthic communities.

Periodic surveys are needed to monitor the health and distribution of oysters and their associated macrofaunal communities. Monitoring of the distribution and composition of muck sediments is also

suggested. Periodic measurement of pesticides and other contaminants in oyster tissues and sediments is a proven means to assess levels of toxic substances in the system.

A.10.8.11 Exotic Species

The performance measure for exotic species includes evaluating the distribution, abundance, and diversity of exotic invasive plants within the watershed. The target is to decrease the abundance of, or eliminate, these species within the system. Presence and distribution of these species need to be continually monitored as means to focus control efforts and to develop a better understanding of factors that contribute to their spread.

A.10.8.12 Near-Shore Reef Health

The health of near-shore reefs is an issue of importance to local fishermen and to maintenance of biodiversity within the Atlantic Ocean, the Loxahatchee Estuary and the Indian River Lagoon. The target is to protect these systems from further degradation and hopefully to improve their condition over time. Periodic observations of near-shore reef health are needed, including assessments of the condition and species composition of associated coral, algal, fish and invertebrate communities. Water clarity, sediment quality, and deposition rates should also be monitored near shore to ensure that changes in these parameters do not adversely affect the reef system.

A.10.8.13 Distribution, Diversity and Abundance of Migratory and Wading Birds

Bird species, numbers and utilization within the Loxahatchee system need to be monitored on a periodic basis. The target, over time, is to increase the extent and quality of wetland habitat that is suitable for bird utilization in the watershed and floodplain resulting in increased species diversity, number of birds and occurrence of rookeries.

A.10.9 Model

The diagram for the Loxahatchee Watershed Conceptual Ecological Model is presented in Figure A-35. The key to the symbols used in the diagram is presented in Figure A-34.

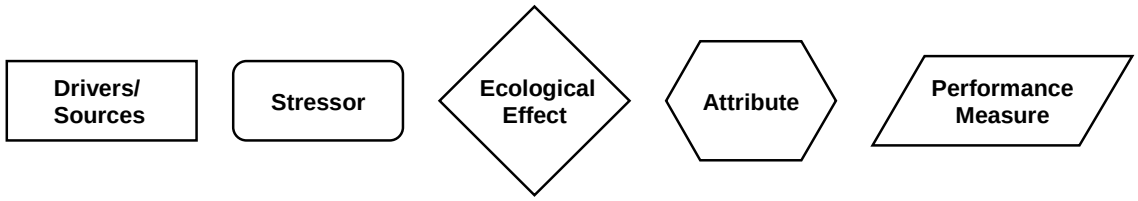


Figure A-34: Key to the Symbols Used in the Following Diagram

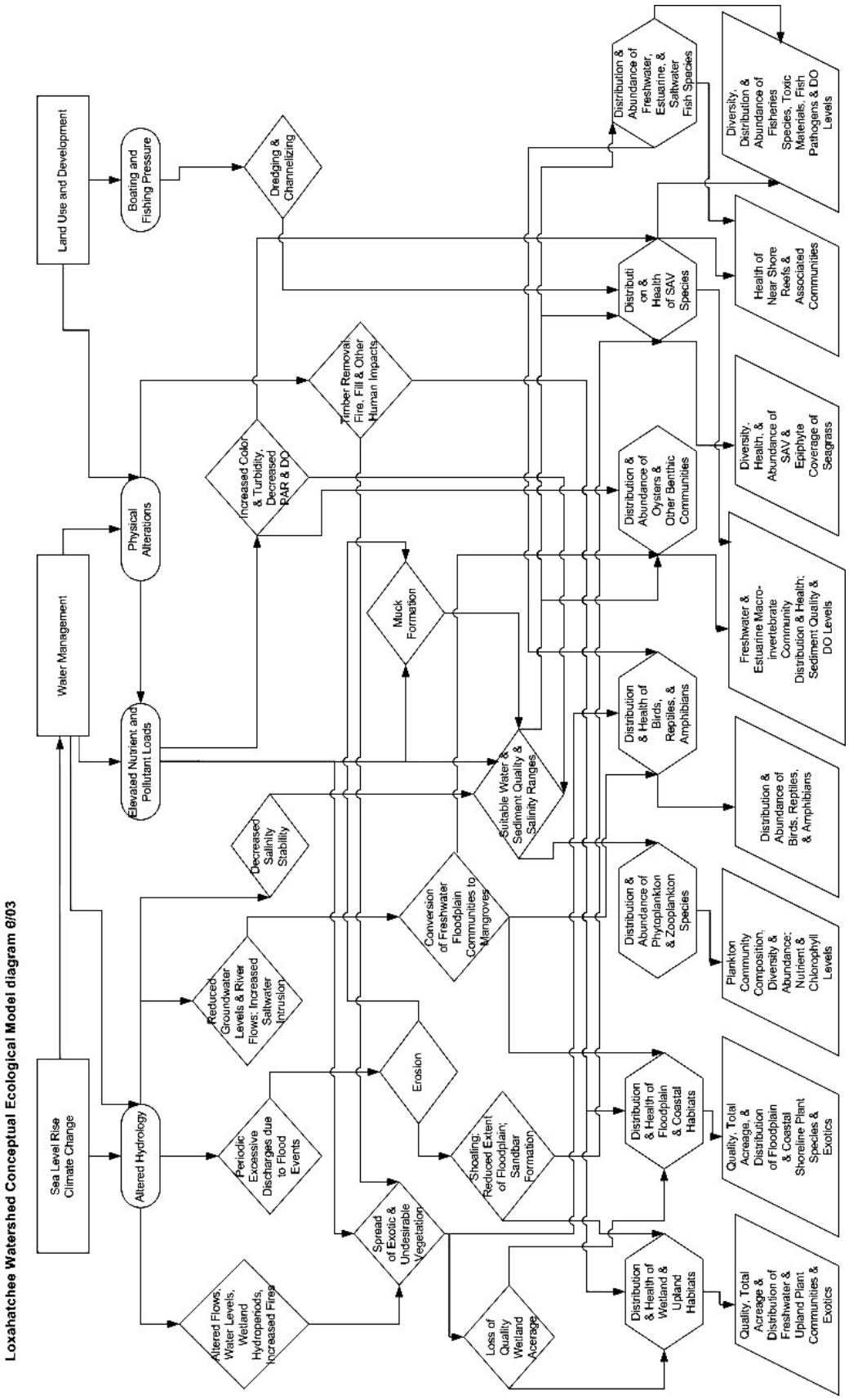


Figure A-35: Loxahatchee Watershed Conceptual Ecological Model Diagram

A.10.10 Literature Cited

Alexander, T.R., and A.G. Crook. 1975. Recent and Long-Term Vegetation Changes and Patterns in South Florida. Part II. PB-264-462, South Florida Ecological Study, University of Miami, Coral Gables, Florida. .

Allen, J.A., J.L. Chambers, and S.R. Pezeshki. 1997. Effects of salinity on bald cypress seedlings: physiological responses and their relation to salinity tolerance. Wetlands 17(2):310-320.

Andrews, J.D., D. Haven, D.B. Quayle. 1959. Freshwater kill of oysters in James River, Virginia. 1958. Virginia Fisheries Laboratory, Gloucester Point, Virginia.

Antonini, G.A., P.W. Box, D.A. Fann, and M.J. Grella. 1998. Waterway Evaluation and Management Scheme for the South Shore and Central Embayment of the Loxahatchee River, Florida. Technical Paper TP-92, Florida Sea Grant College Program, University of Florida, Gainesville, Florida.

Bahr, L.M., and W.P. Lanier. 1981. The Ecology of Intertidal Oyster Reefs of the South Atlantic Coast: A Community Profile. Office of Biological Services Report FWS/OBS-81/1, United States Fish and Wildlife Service, United States Department of the Interior, Washington, D.C.

Bilyard, G.R. 1987. The value of benthic infauna in marine pollution monitoring studies. Marine Pollution Bulletin. 18(11) 581-585.

Birnhak, B.I. 1974. An Examination of the Influence of Freshwater Canal Discharges on Salinity in Selected Southeastern Florida Estuaries. Report No. DI-SFEP-74-19, South Florida Environmental Project, United States Department of the Interior, Atlanta, Georgia.

Boesch, D.F., and N.N. Rabalais. 1992. Effects of Hypoxia on Continental Shelf Benthos: Comparisons between the New York Bight and the Northern Gulf of Mexico. Geological Society, Special Publication 58:27-34.

Boesch, D.F., and R Rosenberg. 1981. Response to stress in marine benthic communities. In: Barrett, G.M., and R. Rosenberg (eds). Stress Effects on Natural Ecosystems, John Wiley, New York, pp. 179-200.

Bonham, C.D. 1989. Measurements for Terrestrial Vegetation. John Wiley & Sons, Inc., New York.

Breedlove Associates, Inc. 1982. Environmental Investigations of Canal 18 Basin and Loxahatchee Slough, Florida. Final Report to United States Army Corps of Engineers, Gainesville, Florida.

Browder, J.A., and D. Moore. 1981. A new approach to determining the quantitative relationship between fishery production and the flow of fresh water to estuaries. In*:* Cross, R., and D. Williams (eds.). Proceedings of the National Symposium on Freshwater Inflow to Estuaries. FWS/OBS-81/04, United States Fish and Wildlife Service, Department of the Interior, Washington, D.C., pp. 403-430.

Browder, J.A., P.J. Gleason, and D.R. Swift. 1994. Periphyton in the Everglades: spatial variation, environmental correlates, and ecological implications. In: Davis, S.M., and J.C. Ogden (eds). Everglades, the Ecosystem and its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 379-416.

Brown, S. 1984. The role of wetlands in the Green Swamp. In: Ewel, K.C., and H.T. Odum (eds), Cypress Swamps. University Presses of Florida, Gainesville, Florida, pp. 405-415.

Burreson, E.M., and L.M. Ragone Calvo. 1996. Epizootiology of *Perkinsus marinus* disease of oysters in Chesapeake Bay, with emphasis on data since 1985. J. Shellfish Res. 15(1): 17-34.

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

Cary Publications Inc. 1978. Loxahatchee Lament. Jupiter, Florida.

Chamberlain, R.H., and P.H. Doering. 1998a. Freshwater inflow to the Caloosahatchee Estuary and the resource-based method for evaluation. In: Treat, S.F. (ed.). Proceedings of the Charlotte Harbor Public Conference and Technical Symposium. Technical Report No. 98-02, Charlotte Harbor Estuary Program, North Fort Myers, Florida, pp. 88-91.

Chamberlain, R.H., and P.H. Doering. 1998b. Preliminary estimate of optimum freshwater inflow to the Caloosahatchee Estuary: A resource based approach. In: Treat, S.F. (ed.). Proceedings of the Charlotte Harbor Public Conference and Technical Symposium. Technical Report No. 98-02, Charlotte Harbor Estuary Program, North Fort Myers, Florida, pp. 111-120.

Chiu, T.Y. 1975. Evaluation of Salt Intrusion in Loxahatchee River, Florida. Report No. UFL/COEL – 75/013, Coastal and Oceanographic Engineering Laboratory, University of Florida. Gainesville, Florida.

Christensen, R.F. 1965. An Ichthyological Survey of Jupiter Inlet and Loxahatchee River. MS Thesis. Florida State University. Tallahassee, Florida.

Comp, G.S., and W. Seaman. 1988. Estuarine habitat and fishery resources of Florida. In: Seaman, W. (ed). 1988. Florida Aquatic Habitat and Fishery Resources. Florida Chapter of the American Fisheries Society, Eustis, Florida.

Dame, R.F. 1996. Ecology of marine bivalves: an ecosystem approach. CRC Press, Boca Raton, Florida.

David, P.G. 1996. Changes in plant communities relative to hydrologic conditions in the Florida Everglades. Wetlands 16/1: 15-23.

Davis, S.M. 1994. Phosphorus inputs and vegetation sensitivity in the Everglades. In: Davis, S.M., and J.C. Ogden (eds). Everglades, the Ecosystem and its Restoration. St. Lucie Press, Delray Beach, Florida, pp. 357-378.

Davis, J.H. 1940. The Ecology and Geologic Role of Mangroves in Florida. Publication No. 517, Carnegie Institute, Washington, D.C.

Dawes, C.J. 1998. Marine Botany, Second Edition. John Wiley & Sons, Inc., New York.

Dent, R.C. 1997. Salinity Changes in the Northwest Fork of the Loxahatchee River Resultant from the Re-Establishment of Meandering Flow Patterns. Loxahatchee River District, Jupiter, Florida.

Dent, R.C., L.R. Bachman, and M.S. Ridler. 1998. Profile of the Benthic Macroinvertebrates in the Loxahatchee River Estuary. Wildpine Ecological Laboratory, Loxahatchee River District, Jupiter, Florida.

Dent, R.C., and M.S. Ridler 1997. Freshwater Flow Requirements and Management Goals for the Northwest Fork of the Loxahatchee River. Loxahatchee River District, Jupiter, Florida.

Dent, R.C. 2002. Personal communication -- Letter to Matthew Morrison, South Florida Water Management District from Rick Dent, Executive Director, Loxahatchee River District, dated March 5, 2002 with attached map and four tables.

DOI. 1974. The Biological Impact of Residential Real Estate Development in the South Florida Coastal Wetlands. United States Department of the Interior, Washington, D.C.

DeSzalay, F. A. and V. H. Resh. 2000. Factors influencing macroinvertebrate colonization of seasonal wetlands: responses to emergent plant cover. Freshwater Biology, 45, 295-308.

Dierberg, F E., and P. L. Brezonik. 1984. The effect of wastewater on the surface water and groundwater quality of cypress domes. *In:* Ewel, K. C.. and H. T. Odum (eds.). Cypress Swamps. University Presses of Florida, Gainesville, FL. pp. 83- 101.

DOI. 1974. The Biological Impact of Residential Real Estate Development in the South Florida Coastal Wetlands. United States Department of the Interior, Washington, D.C.

Douglas, B.C. 1991. Global sea level rise, J. Geophys. Res. 96(C4): 6981-6992.

Douglas, B.C. 1992. Global sea level acceleration, J. Geophys. Res. 97(C8): 12,699-12,706.

Duever, M., and D. McCollom. 1982. Cypress Wetland Forest. Information presented at Loxahatchee Environmental Assessment Workshop, South Florida Water Management District, West Palm Beach, Florida, June 15, 1983.

Durako, M.J. 1988. The seagrass bed: a community under assault. Florida Naturalist, Fall 1988, pp. 6-8.

Earth Tech, Inc. 2000. Final Hydraulic Report, Kitching Creek Water Quality Improvement Project. Report to Martin County. Stuart, Florida.

Emery, K.O., and R.E. Stevenson. 1957. Estuaries and lagoons: 1. Physical and chemical characteristics. In: Hedgpeth, J.W. (ed., Treatise on Marine Ecology and Paleoecology, Volume 1. Geol. Soc. Am. Mem. 67, pp. 673-639

Estevez, E. 1998. The Story of the Greater Charlotte Harbor Watershed. Charlotte Harbor National Estuary Program, Fort Myers, Florida.

FDEP. 1996. Water-Quality Assessment for the State of Florida. Technical Appendix, South and Southeast Florida. Report submitted in accordance with the Federal Clean Water Act Section 305(b). Standards and Monitoring Section, Bureau of Surface Water Management, Division of Water Facilities, Florida Department of Environmental Protection, Tallahassee, Florida.

FDEP. 1998. Loxahatchee River Watershed Action Plan. Florida Department of Environmental Protection, West Palm Beach, Florida. Second Draft, October 1998.

FDEP. 2000a. Water-Quality Assessment for the State of Florida. Technical Appendix, South and Southeast Florida. Report submitted for Federal Clean Water Act Section 305(b), Florida Department of Environmental Protection, Tallahassee, Florida.

FDEP. 2000b. Jonathan Dickinson State Park Unit Management Plan. Jonathan Dickinson State Park, Florida Department of Environmentalo Protection, Division of Recreation and Parks, Hobe Sound, Florida.

FDEP and SFWMD. 2000. Loxahatchee River Wild and Scenic River Management Plan, Plan Update. Florida Department of Environmental Protection and South Florida Water Management District, West Palm Beach, Florida.

FDNR. 1985. Loxahatchee River National Wild and Scenic River Management Plan. Florida Department of Natural Resources, Tallahassee, Florida.

FDNR. 1994. Jonathan Dickinson State Park Unit Management Plan. Jonathan Dickinson State Park, Florida Department of Natural Resources, Division of Recreation and Parks, Hobe Sound, Florida.

Forward, R. 1989. Behavioral responses of crustacean larvae to rates of salinity change. The Biological Bulletin. June 1989 v176 N3.

Gaston, G.R., P.A. Rutledge, and M.L. Walther. 1985. Effects of hypoxia and brine on recolonization by microbenthos off Cameron, Louisiana (USA). Contributions in Marine Sciences 28:79-93.

Gilmore, R.G. 1995. Environmental and biogeographic factors influencing ichthyofaunal diversity: Indian River Lagoon. Bulletin of Marine Science 57: 153-170.

Graves, G.A., D.G. Strom, and B.E. Robson. 1998. Stormwater impact to the freshwater Savannas Preserve marsh, Florida, USA. Hydrobiologia 379:111-122.

Gunter, G. 1953. The relationship of the Bonnet Carre spillway to oyster beds in Mississippi Sound and the Louisiana marsh, with a report on the 1950 opening. Publ. Inst. Mar. Sci. Univ. Tex 3(1): 17-71.

Gunter, G., and R.A. Geyer. 1955. Studies of fouling organisms in the northeastern Gulf of Mexico. Publ. Inst. Mar. Sci. Univ. Tex. 4(1): 39-67.

Harper, D. 1992. Eutrophication of Freshwater: Principles, Problems, and Restoration. Chapman and Hall, London, United Kingdon.

Harris, B.A., K.D. Haddad, K.A. Steidinger, and J.A. Huff. 1983. Assessment of Fisheries Habitat: Charlotte Harbor and Lake Worth, Florida. Florida Department of Natural Resources, Bureau of Marine Research, St. Petersburg, Florida.

Haunert, D.E., and K. Konyha. 2000. Establishing St. Lucie Watershed Inflow Targets. Internal memorandum, South Florida Water Management District, West Palm Beach, Florida.

Haunert, D.E., and R.J. Startzman. 1985. Some Short Term Effects of a Freshwater Discharge on Biota of the St. Lucie Estuary, Florida. Technical Publication DRE-213, South Florida Water Management District, West Palm Beach, Florida.

Havens, K.E., T.L. East, and J.R. Beaver. 1996. Experimental studies of zooplankton-phytoplankton-nutrient interactions in a large subtropical lake (Lake Okeechobee, Florida, USA). Freshwater Biology, No. 36, pp. 579-597.

Havens, K.E., and A.D. Steinman. 1995. Aquatic Systems, in Soil Amendments: Impacts on Biotic Systems. Rechcigl, J.E., (ed). Lewis Publishers, Boca Raton, Florida.

Heald, E.J., and W.E. Odum. 1970. The contribution of mangrove swamps to Florida fisheries. Proceedings of the Gulf and Caribbean Fisheries Institute 22:130-135.

Hedgepeth, M.Y., (unpublished) Ecological Comparisons of Ichthyofaunal Communities in Lake Worth and Loxahatchee River, Palm Beach and Martin Counties, Southeastern Florida with Special References to the Effects of Anthropogenic Changes. Florida Marine Research Institute, St. Petersburg, Florida.

Hedgepeth, M., T. Fucigna, and S. Myers. 2001. The Relationship Between Ichyofaunal Communities and Salinity on the Loxahatchee River. Paper presented on February 21-22 at the Loxahatchee River Science Symposium, Jupiter, Florida.

Hill, G.W. 1977. Loxahatchee River Oyster Bar Removal Project: Salinity Monitoring Phase. Final Letter Report to Water Resources Division, United States Geological Survey, Jupiter, Florida.

Holland, A.F. et al. 1987. Long term variation in mesohaline Chesapeake Bay macrobenthos: spatial and temporal patterns: Estuaries 10:227-245

Hu, G. 2002. The effects of freshwater inflow, inlet conveyance and sea level rise on the salinity regime in the Loxahatchee Estuary. In: Proceedings of 2002 Environmental Engineering Conference, Environmental & Water Resources Institute, American Society of Civil Engineers-Canadian Society of Civil Engineers, Niagara Falls, Ontario, Canada, July 21-24, 2002.

Japp, W.C., and Pamela Hallock. 1990. Chapter 17, Coral Reefs. In: Myers, R.L., and J.J. Ewel (eds). Ecosystems of Florida, University of Central Florida Press, Orlando, Florida, pp. 574-616.

Jupiter Inlet District. 1999. Environmental Restoration Program for the Loxahatchee River Central Embayment. Jupiter Inlet District, Jupiter, Florida.

Kadlec, R.H., and R.L. Knight. 1996. Treatment Wetlands. Lewis Publishers, Boca Raton, Florida.

Karr, J.R. 1993. Measuring biological integrity: lessons from streams. In: Woodley, S., J. Kay, and G. Francis (eds). Ecological Integrity and the Management of Ecosystems, St. Lucie Press, Delray Beach, Florida.

Kenworthy, W.J. 1992. The Distribution, Abundance, and Ecology of *Halophila johnsonii* (Eisman) in the Lower Indian River, Florida. Final Report to the Office of Protected Resources, National Marine Fisheries Service, Silver Spring, Maryland.

Kingsford, M.J., and C.A. Gray. 1996. Influence of pollutants and oceanography on abundance and deformities of wild fish larvae. In: Schmitt, R.J., and C.W. Osenberg (eds). Detecting Ecological Impacts: Concepts and Applications in Coastal Habitats. Academic Press, New York.

Kinne, O. 1964. The effects of temperature and salinity on marine and brackish-water animals II. Salinity and temperature salinity combinations, Oceanogr. Mar. Biol. Annu. Rev. 2: 281-339.

Krauss, K.W., J.L. Chambers, J.A. Allen, B.P. Luse, A.S. DeBosier. 1999. Root and Shoot responses of *Taxodium distichum* seedlings subjected to saline flooding. Environmental and Experimental Botany 41:15-23.

Land, L.F., H.G. Rodis, and J.J. Schneider. 1972. Appraisal of the Water Resources of Eastern Palm Beach County, Florida. Geological Survey Open File Report 73006, Geological Survey, Tallahassee, Florida.

Lapointe, B.E. 2000. Nutrient over-enrichment of South Florida's coral reefs. Proceedings, Fourth Bay of Funcy Science Workshop, New Brunswick, Canada.

Lassuy, D.R. 1983. Species profiles: life histories and environmental requirements (Gulf of Mexico)-spotted seatrout. FWS/OBS-82/11.4, United States Fish and Wildlife Service, Division of Biological Services, Department of Interior, Washington, D.C.

Law Environmental, Inc. 1991a. West Loxahatchee River Management Plan. Submitted to Jupiter Inlet District, Jupiter, Florida.

Law Environmental, Inc. 1991b. Technical Assessment Report for the West Loxahatchee River, Volume I. Environmental, Recreation, and Engineering. Project No. 55-9743.

Lenihan, H.S. 1999. Physical-biological coupling on oyster reefs: how habitat structure influences individual performance. Ecological Monographs 69(3): 251-275.

Leverone, J.R. 2000. Use of Shell Remains to Determine Historical Bay Scallop Population Distributions in the San Carlos/Tarpon Bay-Pine Island Sound. Technical Report No. 667, Mote Marine Laboratory, Sarasota, Florida.

Lewis III, R.R., and E.D. Estevez. 1988. The Ecology of Tampa Bay, Florida: An Estuarine Profile, Biological Report 85, United States Fish and Wildlife Service, Washington, D.C.

Likens, G.E. 1972. Nutrients and Eutrophication, Volume 1. Special symposium, Amercan Society of Linmnology and Oceanography, Allen Press, Lawrence, Kansas.

Lindall, W.N. Jr. 1973. Alterations of Estuaries of South Florida: A Threat to Its Fish Resources. Marine Fisheries Review 35(10): 1-8.

Livingston, R.J. 1987. Historic trends of human impacts on seagrass meadows of Florida. In: Proceedings of the Symposium on Subtropical-Tropical Seagrasses of the Southeastern United States,

Livingston, R.J. 1984. The relationships of physical factors and biological response in coastal seagrass meadows. Estuaries 7(4A): 377-390.

Livingston, R.J., F.G. Lewis, G.C. Woodsum, X.F. Niu, B. Galperin, W. Huang, J.D. Christensen, M.E. Monaco, T.A. Battista, C.J. Klein, R.L. Howell IV, and G.L. Ray. 2000. Modelling oyster population response to variation in freshwater input. Estuarine, Coastal and Shelf Science 50:655-672.

Loosanoff, V.L., and F.D. Tommers. 1948. Effect of suspended silt and other substances on rate of feeding of oysters. Science 107: 69-70.

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

Loxahatchee River District. 1996. Dissolved oxygen concentrations and relationships in waters of the Loxahatchee River near Riverbend Park. Wildpine Ecological Laboratory, Jupiter, Florida.

Lucas, L.V., J.R. Koseff, J.E. Cloern, S.G. Monismith, and J.K. Thompson. 1999. Mar. Ecol. Prog. Ser. 187: 1-15.

Lukasiewicz, J, and K.A. Smith. 1996. Hydrologic Data and Information Collected from the Surficial and Floridan Aquifer Systems, Upper East Coast Planning Area, Part 1. Technical Publication 96-02, South Florida Water Management District, West Palm Beach, Florida.

Martin County Planning Department. 2000. Loxahatchee River Basin Wetland Planning Project for Martin County. Final Report to United States Environmental Protection Agency, Atlanta, Georgia.

MacKenzie, C.L., Jr. 1977. Development of an aquacultural program for rehabilitation of damaged oyster reefs in Mississippi. U.S. Natl. Mar. Fish. Serv. Mar. Fish Rev. 39(8): 1-3.

MacNae, N. 1968. A general account of the fauna and flora of mangrove swamps and forests in the Indo-West Pacific region. Adv. Mar. Biol. 6: 73-270.

McCook, L.J., J. Jompa, and G. Diaz-Pulido. 2001. Competition between corals and algae on coral reefs: a review of evidence and mechanism. Coral Reefs 19:400-417.

McCormick, P.V., S. Newman, S. Miao, D.E. Gawlik, D. Marley, K.R. Reddy, and T.D. Fontaine. 2002. Effects of anthropogenic phosporus inputs on the Everglades. In: Porter, J.W., and K.G. Porter. 2002. The Everglades, Florida Bay, and Coral Reefs of the Florida Keys: An Ecosystem Sourcebook. CRC Press, Boca Raton, Florida.

McMichael, R. 1997. Fisheries-Independent Monitoring Programs, 1996 Annual Data Summary Report. I-viii.

McPherson, B. (unpublished). The Cypress Forest Community in the Tidal Loxahatchee River Estuary: Distribution, Tree Stress, and Salinity. United States Geological Survey, Tallahassee, Florida.

McPherson, B., and R. Halley. 1996. The South Florida Environment: A Region under Stress. Circular 1134, United States Geological Survey, Tallahassee, Florida.

McPherson, B.F., and M. Sabanskas. 1980. Hydrologic and Land-Cover Features of the Loxahatchee River Basin, Florida. Open-File Report 80-1109, Water Resources Division, United States Geological Survey, Tallahassee, Florida.

McPherson, B.F., M. Sabanskas, and W.A. Long. 1982. Physical, Hydrological, and Biological Characteristics of the Loxahatchee River Estuary, Florida. Open-File Report 82-350 M, Water Resources Investigations, United States Geological Survey, Tallahassee, Florida.

McPherson, B.F., W.H. Sonntag, and M. Sabanskas. 1984. Fouling community of the Loxahatchee River estuary, Florida, USA, 1980-1981. Estuaries 7 (2):149-157.

Mote Marine Laboratory. 1990a. Environmental Studies of the Tidal Loxahatchee River. Technical Report No. 181, Mote Marine Laboratory, Sarasota, Florida.

Mote Marine Laboratory. 1990b. Historical Salinity Assessment of the Tidal Loxahatchee River, Palm Beach and Martin Counties, Florida. Technical Report No. 193, Mote Marine Laboratory, Sarasota, Florida.

Muller, R.G., M.D. Murphy, and M.P. Armstrong. 1996. Florida's Inshore and Nearshore Species: Status and Trends Report. Florida Marine Research Institute, Department of Environmental Protection, St. Petersburg, Florida.

Murray, L M., Kemp, and D. Gurber. 1999. Comparative studies of seagrass and epiphyte communities in Florida Bay and two other south Florida estuaries in relation to freshwater inputs. In: 1999 Florida Bay and Adjacent Marine Systems Science Conference Program and Abstracts, Florida Bay Program Management Committee, c/o Everglades National Park, Homestead, Florida.

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

National Marine Fisheries Service. 2000. Recovery Plan for Johnson's Seagrass (*Halophila johnsonii*). Prepared by the Johnson's Seagrass Recovery Team for the National Marine Fisheries Service, Silver Spring, Maryland.

Odum, W.E. 1970. Insidious alteration of the estuarine environment. Trans. Am. Fish. Soc. 99: 836-847.

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, United States Fish and Wildlife Service, Washington, D.C.

Owen, H.M. 1953. The relationship of high temperature and low rainfall to oyster production in Louisiana. Bull. Mar, Sci. Gulf Caribb (1): 34-43.

Packard, J.M. 1981. Abundance, distribution, and feeding habits of manatees (*Trichechus manatus*) wintering between St. Lucie and Palm Beach Inlets, Florida. Final Report. United States Fish and Wildlife Service, Vero Beach, Florida.

Parker, G.G., G.E. Ferguson, N.D. Hoy, M.C. Schroeder, M.A. Warren, D.E. Bogart, C.C. Yonker, C.C. Langbein, R.H. Brown, S.K. Love, and H.C. Spicer. 1955. Water Resources of Southeastern Florida, with Special Reference to the Geology and Ground Water of the Miami Area. Water Supply Paper 1255, United States Geological Survey, Washington D.C.

Pattillo, M.E., T.E. Czapla, D.M. Nelson, and M.E. Monaco. 1997. Distribution and abundance of fishes and invertebrates in Gulf of Mexico estuaries, Volume II: Species life history summaries. ELMR Report 11. Strategic Environmental Assessments Division, National Ocean Service, National Oceanic and Atmospheric Administration, Silver Springs, Maryland.

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

Perry, H.M., and T.D. McIlwain. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Gulf of Mexico)--blue crab. Biol. Rep. 82 (11.55), United States Fish and Wildlife Service, Vero Beach, Florida.

Pezeshki, S.R., R.D. Delaune, and W.H. Patrick, Jr. 1987. Response of bald cypress (*Taxodium distichum*) to increases in flooding salinity in Louisiana's Mississippi River deltic plain. Wetlands 7: 1-10.

Pezeshki, S.R., R.D. Delaune, and W.H. Patrick, Jr. 1990. Flooding and saltwater intrusion: potential effects on survival and productivity of wetland forests along the U.S. Gulf Coast. Forest Ecology and Management 33/34:287-301.

Pickard, G.L., and W.J. Emery. 1990. Descriptive Physical Oceanography: An Introduction. Fifth Enlarged Edition. Pergamon Press, New York.

Porter, J.W., and K.G. Porter. 2002. The Everglades, Florida Bay, and Coral Reefs of the Florida Keys: An Ecosystem Sourcebook. CRC Press, Boca Raton, Florida.

Post, Buckley, Schuh, and Jernigan, and W. Dexter Bender and Associates, Inc. 1999. Synthesis of Technical Information Volume 1: A Characterization of Water Quality, Hydrologic Alterations, and Fish and Wildlife Habitat in the Greater Charlotte Harbor Watershed. Charlotte Harbor National Estuary Program, Fort Myers, Florida.

Reagan, R.E. 1985. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Gulf of Mexico) - red drum. Biological Report 82(11), United States Fish and Wildlife Service, Washington, D.C.

RECOVER. 2003b. Performance Measure Documentation Report. Restoration Coordination and Verification, c/o South Florida Water Management District, West Palm Beach, Florida, May 29, 2003 draft.

Reid, G.K., Jr. 1954. An ecological study of the Gulf of Mexico fishes in the vicinity of Cedar Key, Florida. Bulletin of Marine Science of the Gulf and Caribbean. 4(1): 1-94.

Reish, D.J. 1986. Benthic Invertebrates as indicators marine pollution: 35 Years of Study. *Oceans 86* 3:885-888.

Ridler, M., R.C. Dent, and L. Bachman, L. 1999. Distribution, density and composition of seagrasses in the southernmost reach of the Indian River Lagoon. Wild Pine Ecological Laboratory, Loxahatchee River District, Jupiter, Florida.

Rodis, H.G. 1973. Encroaching salt water in northeast Palm Beach County, Florida. United States Geological Survey, Tallahassee, Florida, and Palm Beach County Board of Commissioners, West Palm Beach, Florida. Map Series no. 59.

Rodis, H.G. 1973. The Loxahatchee - A River in Distress. United States Geological Survey, Tallahassee, Florida.

Roessler, M.A. 1965. An analysis of the variability of fish populations taken by otter trawl in Biscayne Bay, Florida. Trans. Am. Fish. Soc. 94: 311-318.

Russell, G.M., and B.F. McPherson. 1984. Freshwater Runoff and Salinity Distribution in the Loxahatchee Estuary, Southeastern Florida, 1980-82. Water Resources Investigations Report 83-4244, United States Geological Survey, Washington D.C.

Sackett, J.W. 1888. Survey of Caloosahatchee River, Florida. Report to the Captain of the United States Engineering Office, St. Augustine, Florida.

Savage, T. 1972. Florida Mangroves as Shoreline Stabilizers. Professional Paper No. 19, Florida Department of Natural Resources, Tallahassee, Florida.

Schlesselman, G.W. 1955. The gulf coast oyster industry of the United States. Geograph. Rev. 45(4): 531-541.

Sellers, M.A., and J.G. Stanley. 1984. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (North Atlantic) -- American Oyster. FWS/OBS-82/11.23, United States Fish and Wildlife Service, Washington, D.C.

SFWMD. 1991. Analysis of river flow and water quality data. In*:* Law Environmental, Inc. (eds). Technical Assessment Report for the West Loxahatchee River, Volume I, Environmental, Recreation, and Engineering. Project No. 55-9743.

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

SFWMD.2000. Save Our Rivers – 2000 Land Acquisition and Management Plan. South Florida Water Management District, West Palm Beach, Florida.

SFWMD. 2002a. Technical Criteria to Support Development of Minimum Flow and Levels for the Loxahatchee River and Estuary. Water Supply Department, Water Resources Management, South Florida Water Management District, West Palm Beach, Florida, November 2002 final draft.

SFWMD. 2002b. Northern Palm Beach County Comprehensive Water Management Plan. South Florida Water Management District, West Palm Beach, Florida, final draft.

Sharitz, R.R., and J.W. Gibbons. 1989. Freshwater Wetlands and Wildlife. Savanna River Ecological, Laboratory, University of Georgia.

Sklar, F., C. McVoy, R. VanZee, D.E. Gawlik, K. Tarboton, D. Rudnick, and S. Miao. 2002. The effects of altered hydrology on the ecology of the Everglades. In: Porter, J.W., and K. G. Porter (eds). The Everglades, Florida Bay, and Coral Reefs of the Florida Keys: An Ecosystem Sourcebook. CRC Press, Boca Raton, Florida.

Sonntag, W.H., and B.F. McPherson. 1984. Sediment Concentrations and Loads in the Loxahatchee River Estuary 1980-82. Water Resources Investigations Report 84-4157, United States Geological Survey, Washington, D.C.

Strom, D., and H. Rudolph. 1990. A Macroinvertebrate and Water Quality Survey of the Freshwater Portion of the Northwest Fork of the Loxahatchee River in Palm Beach and Martin Counties, Florida, in January, 1989, pecial Monitoring Project. Florida Department of Environmental Regulation. Port St. Lucie, Florida.

Tabb, D.C., D.L. Dubrow, and R.B. Manning. 1962. The ecology of Northern Florida Bay and adjacent estuaries. Florida State Board Conserv. Tech. Ser. 39: 1-81.

Thorpe, J.H., E.M. McEwan, M.F. Flynn, and F.R. Hauer 1990. Invertebrate colonization of submerged wood in a cypress-tupelo and blackwater stream. American Midland Naturalist 113:56-68.

Toth, L.A., D.A. Arrington, M.A. Brady and D.A. Musick. 1995. Conceptual Evaluation of Factors Affecting Restoration of Habitat Structure within the Channelized Kissimmee River Ecosystem. Restoration Ecology 3(3):160-180.

TCRPC. 1999. Loxahatchee River Basin Wetland Planning Project for Palm Beach County. Treasure Coast Regional Planning Council, Final Report to United States Environmental Protection Agency Atlanta, Georgia.

USACE. 1966. Survey Report on Jupiter Inlet, Florida: Memorandum Report. Jacksonville District, United States Army Corps of Engineers, Jacksonville, Florida.

USACE and SFWMD. 1999. Central and Southern Florida Project Comprehensive Review Study, Final Integrated Feasibility Report and Programmatic Environmental Impact Statement. United States Army Corps of Engineers, Jacksonville District, Jacksonville, Florida, and South Florida Water Management District, West Palm Beach, Florida.

USFWS. 1996. Florida Manatee Recovery Plan. United States Fish and Wildlife Service, Atlanta, Georgia.

USFWS. 1999. South Florida Multi-Species Recovery Plan - an Ecosystem Approach. Southeast Region, United States Fish and Wildlife Service, Atlanta, Georgia.

USGS. 1987. Simulation of Tidal Flow and Circulation Patterns in the Loxahatchee River Estuary, Southeastern Florida. Water-Resources Investigations Report 87-4201, United States Geological Survey, Tallahassee, Florida.

NPS. 1982. Loxahatchee River: Draft Wild and Scenic River, Draft Environmental Impact Statement. National Park Service, United States Department of Interior, Atlanta, Georgia.

NPS. 1984. Final Wild and Scenic River Study, Environmental Impact Statement, Loxahatchee River Florida. National Park Service, United States Department of Interior, Atlanta, Georgia.

USEPA. 1999. The Ecological Condition of Estuaries in the Gulf of Mexico. EPA 620-R-98-004, Office of Research and Development, United States Environmental Protection Agency, Washington, D.C.

Vines, W.R. 1970. Surface Waters, Submerged Lands, and Water Front Lands. Area Planning Board, Palm Beach County, West Palm Beach, Florida.

Wallace, J.B., and A.C. Benke 1984. Qauntification of wood habitat in subtropical coastal plain streams. Canadian Journal of Fisheries and Aquatic Sciences 41:1643-1652.

Wanless, H., V. Rossinsky, Jr., and B.F. McPherson. 1984. Sedimentologic History of the Loxahatchee River Estuary, Florida. Water Resources Investigative Report 84-4120, United States Geological Survey, Washington, D.C.

Ward, T.H., and R.E. Roberts (unpublished). Vegetation Analysis of the Loxahatchee River Corridor. Florida Department of Environmental Protection, Tallahassee, Florida.

Warming, E. 1925. Oecology of Plants. Oxford University Press, Oxford.

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

Weinstein, M.P., C.M. Courtney, and J.C. Kinch. 1977. The Marco Island Estuary: a summary of physiochemical and biological parameters. Fla. Sci. 40(2): 98-124.

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

Yokel, B.J. 1975. Rookery Bay Land Use Studies: Environmental Planning Strategies for Development of a Mangrove Shoreline, No. 5, Estuarine Biology. Conservation Foundation, Washington, D.C.

Zahina, J.G., K. Liudahl, T. Liebermann, K. Saari, J. Krenz, and V. Mullen. 2001a. Soil Classification Database: Categorization of County Soil Survey Data within the South Florida Water Management District, Including Natural Soils Landscape Positions. Technical Publication WS-6, South Florida Water Management District, West Palm Beach, Florida.

Zahina, J.G., K. Saari, and D. Woodruf. 2001b. A Functional Assessment of South Florida Freshwater Wetlands and Models for Estimates of Runoff and Pollution Loading. Technical Publication WS-9, South Florida Water Management District, West Palm Beach, Florida.

Zieman, J.C. 1982. The Ecology of the Seagrasses of South Florida: A Community Profile. United States Fish and Wildlife Service, Washington. D.C.

A.11 LAKE WORTH LAGOON CONCEPTUAL ECOLOGICAL MODEL

A.11.1 Model Leads

Dianne Crigger, Greg Graves, Dana Fike

A.11.2 Introduction

The Lake Worth Lagoon is the principal estuarine water body in Palm Beach County. Historically, Lake Worth Lagoon was a freshwater lake with drainage from swamps along its western edge. The barrier island to the east separates Lake Worth from the Atlantic Ocean. In the late 1800s, settlers arrived on the banks of Lake Worth and immediately began making changes to the lagoon environment that continue to this day. Extreme high tides, waves, high lake water levels, and storms occasionally caused the formation of temporary inlets. Several early attempts were made to create navigable inlets from the ocean, and in 1877 construction of a stable inlet was achieved. This inlet had an immediate effect on the freshwater dynamics and the lake began to change to a saltwater lagoon system. During the 1890s the completion of a navigation canal from the north end of Lake Worth Lagoon to Jupiter Inlet resulted in increased freshwater discharges to the lagoon. Also, during this decade developers began filling the wetland edges of the lagoon, an activity that continued into the 1970s.

In the early 1900s, the Atlantic Intracoastal Waterway was completed from the south end of the lagoon to Biscayne Bay. By 1915, the Port of Palm Beach created a permanent inlet four feet deep at the north end of Lake Worth Lagoon. In 1925, the inlet was deepened to 16 feet, and dredge spoils deposited in Lake Worth Lagoon resulted in the creation of Peanut Island. In 1917, the South Lake Worth Inlet was created in a failed effort to improve tidal circulation and provide flushing to the south end of the lagoon. The completion of the West Palm Beach Canal (C-51) in 1925 resulted in significant freshwater inflow to Lake Worth Lagoon and provided the drainage necessary for the development of the west shore of the lagoon.

Today, Lake Worth Lagoon is connected to the Atlantic Ocean by two permanent inlets (Figure A-36). The Lake Worth Inlet is 800 feet wide by 35 feet deep; the South Lake Worth Inlet is 130 feet wide by 6 to 12 feet deep. The Atlantic Intracoastal Waterway runs the entire length of the lagoon. Eight causeways and bridges connect the mainland to the barrier island. Twenty-eight marinas and hundreds of private docks are scattered along the shoreline. Approximately 65 percent of the shoreline is bulkheaded; only 19 percent of the shoreline remains fringed by mangroves (PBCERM 1992). While the cumulative impact of the anthropogenic activities over the past 100 years has significantly altered the Lake Worth Lagoon from its previous character and diminished its value as a healthy estuarine ecosystem, significant regionally important natural resources remain. The fish and wildlife, water quality and recreational values that remain are being identified and evaluated, for protection under the auspices of the Lake Worth Lagoon Management Plan (PBCERM and FDEP 1998).

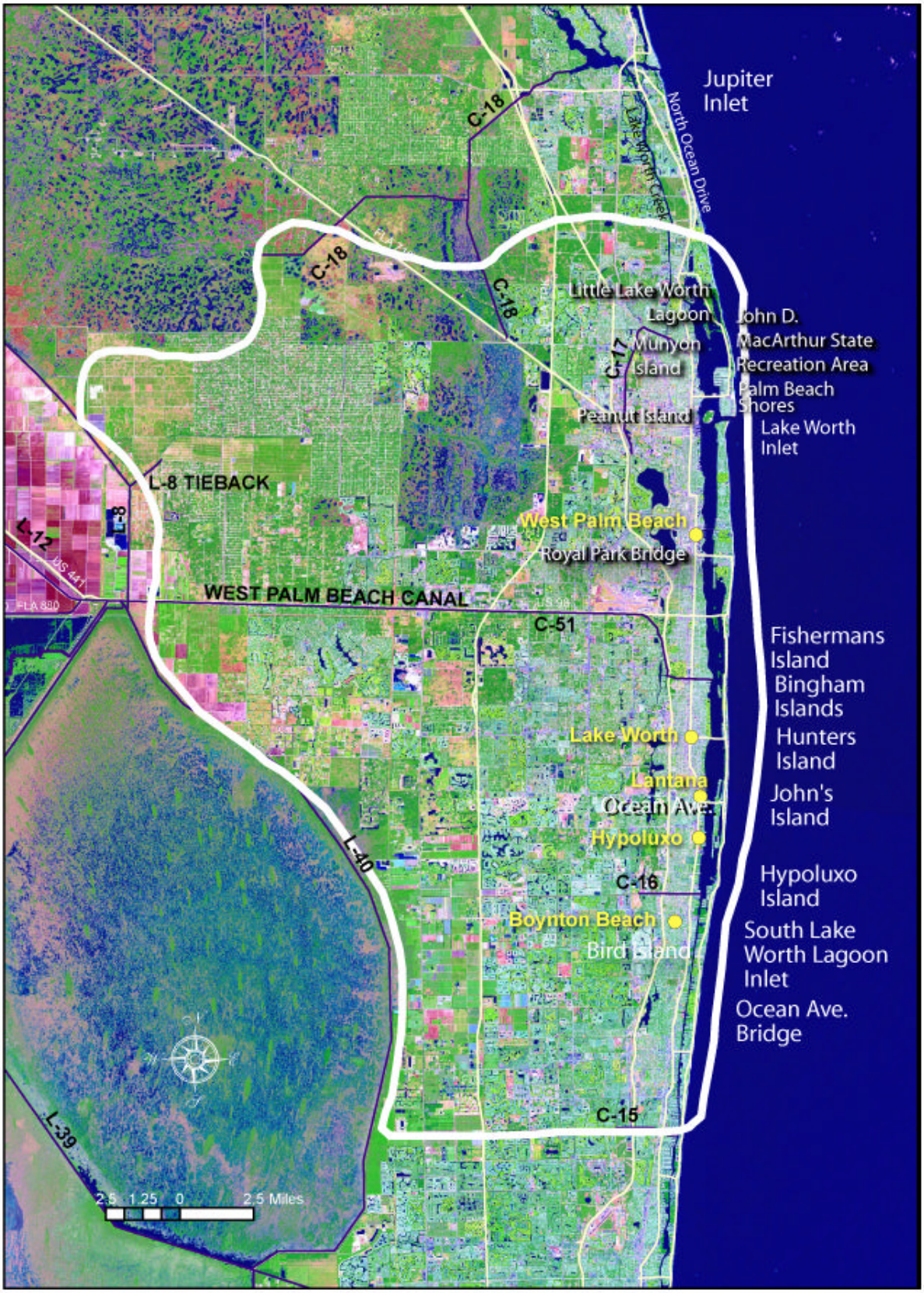


Figure A-36: The Boundary of the Lake Worth Lagoon Conceptual Ecological Model

Recreational and commercial fish species, invertebrates, birds, species of special concern and endangered species utilize the existing natural estuarine communities of the lagoon. The West Indian manatee is an endangered marine mammal found in Florida's rivers, estuaries and inshore areas. The section of Lake Worth Lagoon just south of the Lake Worth Inlet has the greatest overall abundance of manatees during the winter season. Palm Beach County waters provide major warm water refuge and travel corridors for the entire East Coast population of manatees. Several bird sanctuaries and/or rookeries are also located in the Lake Worth Lagoon, including Bingham Islands, Bird Island, Fisherman's Island, Hunter's Island, John's Island, and Munyon Island. A list of protected plant and animal species that have been identified in Lake Worth Lagoon or are likely to naturally inhabit the lagoon was compiled in the Lake Worth Lagoon Natural Resources Inventory and Enhancement Study (Dames and Moore and PBCERM 1990). This list includes a total of 40 species including 13 plants, 1 mammal, 4 reptiles, 18 birds and 4 fishes.

Water quality, sediment quality and hydrology of the Lake Worth Lagoon reflect a highly altered and stressed environment resulting from decades of nonpoint and direct discharges from the surrounding urban development. Alterations affecting hydrology include construction of canals, channelization of natural waterways, filling, drainage, and/or impoundment of wetlands, and stabilization and creation of inlets to the Atlantic Ocean. Creation of permanent inlets to the lagoon changed its character from freshwater to estuarine. Connection of the G-51 canal led to episodic inflows of large amounts of fresh water that disrupt the estuarine biological communities of Lake Worth Lagoon.

A conceptual ecological model in the risk assessment framework has been developed for the Lake Worth Lagoon (Figure A-38). The model depicts the general pathways by which driving forces (in rectangles), particularly those related to modern human culture, affect "attributes" of the ecosystem (in hexagons) that are intrinsically important to ecosystem function or are generally viewed by humans as valuable and important to maintain. Drivers are manifested as stressors (ovals) that exert their impact on the ecosystem in various ways, or "effects" (diamonds). "Performance measures" (trapezoids) provide the parameters about the attributes that can be measured to determine the direction (positive or negative) and intensity of effects.

A.11.3 External Drivers and Ecological Stressors

Sources of ecological stressors in the Lake Worth Lagoon originate from agricultural and urban development and the concurrent construction and operation of water management systems. Sea level rise is also a factor that affects the ecology of the lagoon and must be taken into consideration during restoration efforts. The resultant major stressors to the Lake Worth Lagoon are **altered hydrology**; **altered estuarine salinity**; **elevated loads of nutrients**, **suspended and dissolved organic matter**; **input of contaminants and toxins**; **boating and fishing pressure**; and **physical alterations**.

Altered hydrology results from altered freshwater flow volume and timing. The interconnected network of canals, often across natural drainage basin boundaries, and the need to provide adequate flood protection for those areas developed as a result of the network of canals, has resulted in unnatural discharges during basin flood releases. Additionally, water withdrawals for irrigation and other water supply purposes reduce flow volumes to the lagoon during drought conditions. **Altered estuarine salinity** is a direct result of the altered hydrology but is also affected by sea level rise.

Elevated loads of nutrients, suspended and dissolved organic matter has resulted from the transformation of the lagoon drainage basin from one dominated by wetland mosaics and forested areas to urban and agricultural land uses. In addition, the drainage basin has been extended and cross-connected to

afford flood protection; however, the absence of adequate storage and treatment facilities requires delivering flood waters rapidly into the lagoon with little potential for amelioration of nutrient and dissolved organic matter loads. High peak flow rates also scour canal bottoms as well as exacerbate erosion of canal banks, thus delivering elevated suspended solids loads to the lagoon during sporadic rain-driven events.

Input of contaminants and toxins result from the establishment of pathways whereby substances commonly used within both urban and agricultural settings are delivered to the lagoon via overland flow or through canal discharges. Such substances include pesticides, metals and oils from wear and use of automobiles, as well as from other industrial and urban practices.

In addition to the construction of water management system canals, many other **physical alterations** have been made to the laggon. These include opening and widening of inlets, dredging and maintenance of navigation channels, development of the shoreline and interior basin, and draining and filling wetlands.

The extensive basin drainage modifications made possible an increase in population and facilities along the laggon. This has resulted in increased **boating and fishing pressure** from both recreational and commercial demands.

A.11.4 Ecological Attributes

A.11.4.1 Salinity Envelope

The Lake Worth Lagoon is a system dominated by polyhaline conditions adversely affected by large volume freshwater releases. The ideal restoration scenario may thus be to minimize perturbation from those large-scale canal discharges. Natural estuaries tend to reach a steady state where the salinity gradient remains relatively stable in position, subject to seasonal and tidal oscillations (Pickard and Emery 1990). The concept of a natural distribution of salinity gradients and variability acceptable to and supportive of aquatic life is an important prerequisite for environmental health. Mortality and/or impairment have been documented in many species exposed to salinities outside their ideal ranges (Kingsford and Gray 1996).

Prolonged discharge events may create a plume of fresh water that prevents tidal marine waters from entering the lagoon. The low salinity plume described above may act as a "plug" or barrier to successful colonization of habitats in the lagoon by many organisms. In a typical natural scenario, offshore areas provide larvae and juveniles to the lagoon, and in turn, the lagoon provides adult fish to spawn offshore. Salinity disruption or blockage could interfere with both processes. The early larval and juvenile stages are particularly vulnerable to being adversely affected by poor water conditions including lowered salinity. Organisms may potentially avoid the low salinity area, and thus delay settling in nursery habitats exposing them to enhanced risk of predation, or they may die or suffer reduced fitness due to exposure to deleterious salinity levels. Low salinity exposure may cause eggs or larvae to settle prematurely in inappropriate habitats, leading to reduced fitness or death (Forward 1989, Reagan 1985). The halocline produced by the low salinity front may cause larval organisms to gather along the edge of the plume, exacerbating the life-history risks (Kingsford and Gray 1996). The potential for deleterious effects is greater when discharges occur closer to the inlets that provide tidal marine water, because a larger portion of the lagoon is unavailable for the normal migrations of colonizing species.

A.11.4.2 Water Quality

The Lake Worth Lagoon receives major inflows of fresh water from the regional canals. The C-17 canal discharges to the upper segment of the Lake Worth Lagoon. The C-51, C-16, and C-15 canals discharge to the middle and lower segments of the lagoon (Figure A-36). While inlets provide some mechanism for flushing and restoration of salinity equilibrium, the middle and lower segments of the lagoon are subject to less circulation and have longer periods of low salinity (Zarillo 2003). Canal influences extend to nutrient and sediment loads as well.

The Lake Worth Lagoon and Palm Beach Coast Basin Status Report (FDEP 2003) contains data from a recent water quality assessment for the Lake Worth Lagoon that indicates that the northern and southern segments of the lagoon are potentially impaired for copper. The northern segment was also identified as potentially impaired for lead. The report shows that ecological data gathered for the Lake Worth Lagoon in recent years reflect the degraded state of the lagoon that have been caused by canal inflows and the altered shoreline. However, some data do indicate moderate improvement in water quality with respect to nutrients, possibly due to reductions in point source discharges. The data in the Impaired Waters Rule database was insufficient to evaluate water quality in the central segment of the lagoon.

A.11.4.3 Submerged Aquatic Vegetation

Submerged bottom resources in the Lake Worth Lagoon include seagrass beds, macro-algae, oyster habitat, corals and sponges. Seagrasses first became established in Lake Worth Lagoon when the system was converted from freshwater to marine due to the influences of permanent inlets. Many areas that would otherwise be suitable for seagrass colonization have been lost due to dredging and filling activities; however seagrasses reportedly have never been abundant (Harris et al. 1983). In general, seagrasses are most common and dense in shallow areas and in areas that maintain good water clarity due to sheltering or tidal flushing.

Seagrass beds provide habitat for myriad animals, including the juveniles of many commercially and recreationally valuable species. Like all plants, seagrasses require adequate sunlight, and this is a function of water clarity. A 1940 inventory found 4,271 acres of seagrass within the lagoon. In 1975, a survey found a mere 161 acres. However, in 2001, some 1,630 acres were documented, indicating that conditions amenable to seagrass recolonization had improved (Applied Technology and Management, Inc. 2002).

All submerged aquatic vegetation (SAV) species have a preferred and tolerable salinity range. They respond unfavorably when salinity alterations exceed these ranges. Degraded water quality and physical alterations have been shown to cause a regional decrease in coverage (Chamberlain and Doering 1998a). This decline negatively impacts fish and invertebrate communities. It also causes destabilization of sediments and a shift in primary productivity from benthic macrophytes to phytoplankton, both of which provide negative biofeedback that further affect seagrass beds.

Seagrass communities can be found throughout Lake Worth Lagoon. Six species of seagrasses are known to occur in Lake Worth Lagoon. Turtle grass (*Thalassia testudinum*) is capable of forming dense beds. Shoal grass (*Halodule wrightii*) is the most tolerant of temperature and salinity changes. Manatee grass (*Syringodium filiforme*) mixes with other species in small beds. *Halophila engelmannii*, *Halophila johnsoni*, and *Halophila decipiens* populate deeper areas. In Lake Worth Lagoon, *Halodule wrightii* is the most abundant species of seagrass in terms of coverage, and occurs primarily in shallow areas. A 2001 seagrass survey identified 70 percent of the seagrasses in the northern segment of the lagoon (Little

Lake Worth just north of North Ocean Drive), 20 percent of the seagrasses in the central segment of the lagoon (Royal Park Bridge to Ocean Avenue bridge in Lantana), and 10 percent of the seagrasses in the southern segment of the lagoon (Ocean Avenue bridge in Lantana to Ocean Avenue bridge in Boynton Beach). Corresponding seagrass coverage within each segment is 30 percent in the northern, 12 percent in the central and 15 percent in the southern segment of the lagoon. *Halophila engelmanni* was observed in a single occurrence in north Lake Worth Lagoon (PBCERM and Dames and Moore1990).

Species of macro-algae also become attached to the bottom or form drifting mats. Seagrass and macro-algal communities are very important habitat for many marine species. Their continued survival in Lake Worth Lagoon is dependent upon protection from direct impacts and maintenance of good water quality.

While not as abundant as seagrass communities, other types of bottom resources including oyster bars, corals and sponges also provide important habitat functions for marine organisms. Oyster bars can be found in the vicinity of John D. MacArthur State Recreation Area, and in the vicinity of the Bingham Islands and at the north end of Hypoluxo Island. Corals and sponges are limited in occurrence to areas within close proximity to the inlets.

A.11.4.4 Benthic Communities

The Lake Worth Lagoon benthic community composition varies with the substrate encountered. Every animal has limits of salinity extremes and rates of salinity change beyond which the organism will not survive. Benthic organisms provide essential ecological and biological functions in the lagoon and can influence the quality of the environment. These communities filter/trap particulates, serve as refuge, and provide a food source for fish and macroinvertebrates. Benthic communities can serve as important indicators of environmental quality that respond to changes in freshwater inflow or water quality via change in cover, density or community composition. A healthy benthic community represents an important habitat that will support diverse fish and motile invertebrate populations. Degradation or loss of benthic communities will diminish the ability of the lagoon to maintain the mosaic of conditions that support high habitat diversity and productivity.

Macroinvertebrates provide an ideal measure of the response of the benthic community to environmental perturbations (Boesh and Rosenberg 1981, Reish 1986). Benthos are primarily sedentary, thus, have limited escape mechanisms to avoid disturbances (Bilyard 1987). They provide a record of effects of short and long-term environmental changes through species composition and abundance changes. Therefore, they are often used as water-quality indicators. They are relatively easy to monitor and tend to reflect the cumulative impacts of environmental perturbations, thereby providing good indicators of the changes in ecosystems over time. They have been used extensively as indicators of impacts of both pollution and natural fluctuations in the estuarine environments (Gaston et al. 1985, Bilyard 1987, Holland et al. 1987, Boesh and Rabalais 1991).

The theory underlying use of species indicators to assess water quality condition assumes that benthic assemblages, which are often comprised of a variety of species across multiple phyla, represent a range of predictable biotic responses to potential pollutant impacts. Their use in water-quality studies requires assumptions that communities remain at steady state except when influenced by human activity. Long-term studies show that natural variation over a variety of time scales often masks anthropogenic (human-induced) changes. Therefore, species indicator(s) associated with changes and shifts in biota diversity are used to access the status of a habitat.

Benthic macroinvertebrate communities in the Lake Worth Lagoon are sensitive to bottom type, water quality and salinity fluctuations. Furthermore, the fluctuation between periods of high and low discharge causes alternating shifts between estuarine and freshwater species (Haunert and Startzman 1985). Reed (1975) reported that species diversity and species richness values from sites sampled both near canal outfalls and from mud-dominated areas were low, similar to those reported from pollution-stressed areas in other studies. Deis et al. (1983) attributed differences in macroinvertebrate community structure to physical effects arising primarily from the West Palm Beach Canal.

A.11.4.5 Fishery Species

At least 70 percent of Florida's recreationally sought fishes depend on estuaries for at least part of their life histories (Harris et al. 1983, Estevez 1998, Lindall 1973). Within the lagoon, seagrass communities provide critical refugia for juvenile fish such as redfish (*Sciaenops ocellatus*), grouper, snook (*Centropomus undecimalus*), and spotted seatrout (*Cynoscion nebulosus*).

Several studies of Lake Worth Lagoon's fish populations have been conducted over the past twenty years. A total of 261 species of fish have been collected in Lake Worth Lagoon including fish species found in the vicinity of the inlets. Both resident and transient populations are found in the lagoon, but population sizes as well as timing and nature of utilization by various species are largely unknown.

The greatest numbers of fish species have been collected near Munyon Island, northwest of Palm Beach Shores, near the Lake Worth Inlet, near Hunters Island and in the vicinity of South Lake Worth Inlet. These areas contain some of the lagoon's most diverse marine habitats and are essential nursery habitats for juvenile marine reef fishes (Gilmore et al. 1981).

The total number of species collected in Lake Worth Lagoon (195), and in the lagoon including the vicinity of the inlets (261), is comparable to the total for the Loxahatchee River area where 286 species have been collected (Christensen 1965), the Indian River Lagoon where 286 species have been collected (Gilmore et al. 1981), and Biscayne Bay where 193 species have been collected (DERM 1984).

While conclusive data documenting the population trends of various fish species in Lake Worth Lagoon are not available, it is clear from review of historical accounts and catch records that commercial and recreational fisheries resources in the lagoon have greatly declined over the past forty years (Harris et al. 1983, Lewis et al. 1985, McCray et al. 1985, WPB Fishing Club 1989, Woodburn 1961). The most likely reasons for fisheries declines are habitat destruction and water quality degradation (PBCERM and Dames and Moore 1990). Improperly regulated fish harvesting is also probably a contributing factor.

A.11.4.6 Shoreline Habitat Functionality

The ecological value of mangrove communities has been well documented in the scientific literature. Mangrove communities provide habitat for marine organisms, protect shorelines from erosion, and enhance water quality by acting as natural filters. Detrital material produced by mangroves is the basis of the food chain for South Florida's marine and estuarine ecosystems. Mangroves support fish and macroinvertebrate communities by providing protected nursery areas for fishes, crustaceans, and shellfish, and food for a multitude of important commercial and recreational marine species such as snook, snapper, tarpon, jack, sheepshead, red drum, oyster and shrimp (Harris et al. 1983, Lindall 1973). Mangrove roots act to trap sediments and prevent shoreline erosion and provide attachment surfaces for various marine organisms. Additionally, mangrove forests provide habitat for a highly diverse population of birds (Odum et al. 1982).

Mangroves are sensitive to alterations in upland drainage. In some areas, drainage for agricultural and urban development has reduced overland flows of fresh water to the mangroves. This results in an increased amount of concentrated runoff, which in turn changes the salinity balance, reduces the flushing of detritus, and washes nutrients directly into the lagoon without the benefit of filtration by the mangrove system (Estevez 1998).

Most of the Lake Worth Lagoon shoreline has been altered by dredging, filling and bulkhead construction. Between 1940 and 1975, an estimated 87 percent of shoreline mangroves were eliminated by shoreline development (Harris et al. 1983). Currently only about 19 percent of the shoreline (including islands) has fringing mangroves. Bulkheads have been constructed on approximately 65 percent of the shoreline (including canals).

A.11.4.7 Near-Shore Reef

Coral reef systems are highly oligotrophic, and potentially vulnerable to changes resulting from nutrient enrichment. Reef development is typically slow and occurs over geologic time scales, so impacts to reefs may cause ecological problems that require long time frames for recovery. The areas near North and South Lake Worth Inlets (i.e., Palm Beach and Boynton Inlets) are unique and important resources for the State of Florida. The extensive hard coral systems present within a few kilometers of the shoreline provide habitat for many marine species of socio-economic value to tourism and local fisheries. These reefs represent the most northward extension of tropical reefs on the east coast of the United States, and transition into worm reef/limestone habitat near the Jupiter Inlet (Japp and Hallock 1990). The recreational and commercial importance for this area of northern Palm Beach County cannot be overstated, and the health of Florida's reef system is of special concern. The quantity and quality of water discharged from the Lake Worth Lagoon has effects on near-shore habitats near the ocean inlets of the Lake Worth Lagoon, and changes to the water management strategies as a result of Comprehensive Everglades Restoration Plan (CERP) activities may alter the current conditions. Alteration of flows delivered to C-16, C-17 and C-51 will directly affect the transport of sediments to near-shore reef areas, as well as light penetration through alteration of watercolor and clarity. These factors may directly or indirectly affect the health of corals through a variety of mechanisms. Decreasing the volume of fresh water "put to tide" through existing water conveyances will most likely be beneficial to the overall health of these hardgrounds. System-wide effects expected as a result of the implementation of the CERP include decreased nutrient and sediment transport to these tropical reefs, and decreased color, which will improve the light regime needed by symbiotic zooxanthellae found in many sessile invertebrates (e.g., stony corals, octocorals, sponges and tunicates). Indirectly, these reef animals will benefit from an expected decrease in overgrowth by macro-algal species that readily respond to increased nutrients.

A.11.5 Ecological Effects

Critical Linkages between Stressors and Attributes/Working Hypotheses

The most significant ecological impact to the Lake Worth Lagoon is the alteration of estuarine salinity regime. Salinity is one of the principal factors influencing the distribution and abundance of organisms inhabiting estuaries (Kennish 1990). Changes in the distribution, timing and rapidity of change of salinity include low saline events, primarily due to regulatory water releases from the S-155 structure, but also include discharges from the S-41 and S-44 structures.

The large-scale water releases transport massive volumes of organic and inorganic sediments, which contribute to deposits of muck in the estuaries (Shrader 1984, Gunter and Hall 1963, Pitt 1972). The large

accumulations of muck covering the bottom of the lagoon dramatically decrease the quality and quantity of habitat for benthic macroinvertebrates, oysters and finfish. Together, altered salinity and siltation can have negative impacts to important components of estuarine and near-shore reef ecosystems, including SAV, phytoplankton, fish and macro-invertebrate communities, fish-eating birds, and reef-building polychaetes (Haunert 1988). Changes in temporal and spatial patterns of salinity envelopes can be significant stressors to fish and shellfish populations.

The above conditions are exacerbated by the loss and fragmentation of shoreline habitat and by the input of toxins, nutrients,and dissolved organics (Haunert et al. 1994). The loss and fragmentation of habitat due to human development results in the direct loss of mangrove wetlands and emergent bank vegetation upon which fish and macro-invertebrate communities depend. Increased inputs of nutrients and dissolved organics degrade water quality, contribute to the accumulation of muck, which in turn covers hard bottom habitat, and contributes to changes in phytoplankton and SAV communities. Increased levels of toxicants, from agricultural run-off, urban development and the boating industry including metals, pesticides and their residues, can cause adverse impacts to aquatic food chains leading to fish-eating birds.

The ecological effects and critical linkages described above are based on key hypotheses. The hypotheses are presented below, organized by attribute.

A.11.6 Submerged Aquatic Vegetation

Effects of Altered Salinity on Submerged Aquatic Vegetation

Tabb et al (1962) stated: "Most of the effects of man-made changes on plant and animal populations in Florida estuaries are a result of alterations in salinity and turbidity." Altered estuarine salinity resulting from hydrologic alterations, water management practices, and sea level rise has had a negative effect on SAV and has resulted in large decreases in the spatial extent of SAV in the Lake Worth Lagoon. Different species of SAV have different desirable salinity ranges (Zieman 1982, Doering et al. 2002). When salinity falls outside of these ranges, the SAV is negatively impacted and may result in a reduction in densities and distribution (Chamberlain and Doering 1998b). Increases or decreases in salinity may give one species a competitive advantage over another (Livingston 1987).

Level of certainty - moderate

Relationships among Submerged Aquatic Vegetation, Salinity and Fishes.

Negative changes in SAV community structure and function along with changes in the natural salinity regime have resulted in a decrease in larval and adult fish recruitment into the lagoon. Fish densities are typically greater in grass bed habitat within South Florida's estuaries and coastal lagoons than in adjacent habitats (Reid 1954, Tabb et al. 1962, Roessler 1965, Yokel 1975, Weinstein et al. 1977). The SAV beds provide protection from predation for animals living in it. The dense seagrass blades and rhizomes associated with the grasses provide cover for invertebrates and small fishes while also providing sanctuary from predators (Zieman 1982). Reduction in size and health of SAV beds effects the location, abundance and speciation of fisheries in the lagoon.

Level of certainty - moderate

Effects of Nutrients, Turbidity and Dissolved Organic Matter on Submerged Aquatic Vegetation

The input of increased levels of nutrients, dissolved organic matter and turbidity affect SAV abundance and health by increasing phytoplankton levels and water color which in turn decreases the amount of light that penetrates the water column to become available to SAV.

Level of certainty - moderate

Effects of Increased Epiphyte Growth on Submerged Aquatic Vegetation

Increased epiphyte growth can be caused by both increases in available nutrients that accelerate their growth and/or a decrease in grazing pressure. This increase in epiphytes can shade the blade of the SAV, thus decreasing the amount of light that can be absorbed by the plant and used for photosynthesis.

Level of certainty - moderate

Effects of Muck Accumulation on Submerged Aquatic Vegetation

Large deposits of highly organic, silt and clay materials, i.e., muck, have displaced normal sandy substrate in the lagoon contributing to the decrease in extent of SAV beds. SAV need suitable substrate for successful recruitment and establishment. Muck sediments are easily resuspended in the water column by boat wakes, wind and wave action, decreasing the amount of light which penetrates the water column to become available to SAV.

Level of certainty - moderate

Effects of Boating Pressure on Submerged Aquatic Vegetation

The increase in the numbers of boats in the lagoon has contributed to the decrease in extent of SAV beds. Shallow areas, which normally contain the healthiest and most abundant beds, are most likely to be impacted when boats run aground, or boat props come in close proximity to the grass beds.

Level of certainty - low

Effects of Physical Alterations in the lagoon to Submerged Aquatic Vegetation Distribution, Abundance and Health.

The physical alterations in the lagoon that have an adverse impact on SAV include the destruction of natural shoreline and replacement with hardened shoreline such as bulkhead and seawalls. As the shallow sloping shorelines are eliminated, the area available with the correct depth for SAV recruitment and growth declines.

Level of certainty - high

A.11.7 Benthic Communities

Effects of Altered Salinity Envelope on Macroinvertebrate Community

Sudden and extreme shifts in salinity lead to changes in the diversity and species composition of benthic invertebrates in the lagoon. Community composition varies with the substrate encountered, however, for any animal there are limits of salinity extremes and rates of salinity change beyond which the cells and the organs will not function (McLusky 1971).

Level of certainty – high

Effects of Elevated Nutrients on Macroinvertebrate Community

Benthic infaunal organisms are often used as indicators of perturbations in the estuarine environment because they are relatively nonmobile, short-lived, and, therefore, cannot avoid environmental problems. The response of benthic communities to alterations in sediment and water quality is relatively well understood and is often expressed as changes in community structure, density, and diversity (USEPA 1999). For example, excess nutrients can create enhanced feeding opportunities for some tolerant organisms, while eliminating niches, habitats and food supply for other sensitive organisms.

Level of certainty – moderate

Effects of Shift in Sediment Characteristics on Macroinvertebrate Community

Rapid deposition of new sediments or sudden shifting of unstable sediments during excessive stormwater discharges can make conditions inhospitable for certain classes of sessile organisms that require stability for survival and reproduction.

Level of certainty - moderate

Effects of Shift to Toxic Substances and Contaminants on Macroinvertebrate Community

Since macroinvertebrates physically live either on or in the sediments, they are directly exposed to and affected by heavy metals, pesticides and other toxins in the sediment. Many of these substances are either insoluble in water or tend to associate with particulate matter that flocculates, often resulting in concentrations much higher in the estuarine sediments than that observed within the overlying water column. This increase in toxins can cause a shift to more pollutant tolerant species. Toxins can also bioaccumulate causing a decline in the health of the communities.

Level of certainty - moderate

Effects of Shift to Anoxic and Hypoxic Conditions on Macroinvertebrate Community

Different species may be better adapted than other less tolerant types to endure low oxygen conditions. Sustained low dissolved oxygen levels will generally result in extirpation of more sensitive taxa, such as bivalves, with a resultant shift toward a macroinvertebrate community dominated by less sensitive taxa such as Oligochaeta the polychaete Capitellidae.

Level of certainty - moderate

A.11.7.1 Fishery Species

Effects of Reduced Coverage and Health of Submerged Aquatic Vegetation on Fishery Species

Economically and ecologically valuable fishery species include both fish and shellfish (e.g., lobster and shrimp). Reduction in size and health of SAV beds effects the location, abundance and speciation of fisheries in the lagoon. SAV provide nursery grounds for many fish and invertebrate communities and the destruction of these nursery grounds has a negative effect on the estuarine fish communities.

Level of certainty - moderate

Effects of Toxic Substances on Fishery Species

Toxic substances that can deleteriously affect fish health include pesticides, various heavy metals, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), etc. These substances are delivered to the lagoon with freshwater inflows from both agricultural and urban stormwater runoff, or released in situ via various maritime activities and practices. Such substances can affect fish health either singly, additively or synergistically, such that a clear understanding of the potential ramifications of often low level concentrations is difficult. Additionally, toxic compounds can compound the effects of biological toxins produced by certain species of algae, either during blooms or during minor species shifts in algal communities, or permit opportunistic organisms to adversely affect fish health. Fish health effects include avoidance, fish abnormalities such as lesions, genetic changes, and loss of reproductive success. Documented pathways for toxic substances to affect fish health include bioaccumulation through the underlying chain of foodstuffs, direct exposure to compounds in the water column, and/or exposure to contaminated surficial sediments. Certain species of fish appear to be more prone then others to the effects of toxic materials.

Level of certainty - low

Effects of Loss of Mangrove Habitat on Fishery Species

Destruction of the mangrove shoreline that once lined large areas of the lagoon has negatively impacted fisheries. Mangroves supply a structural refuge for juvenile fish, a substrate for fish food sources, and are an important component in the detrital food chain for the lagoon. In large areas of the lagoon, natural shoreline has been lost to development.

Level of certainty – high

A.11.7.2 Shoreline Habitat Functionality

Relationship of Loss of Mangroves to Physical Alterations to the Lagoon

Physical alterations to the lagoon caused by increased population in the coastal zone has lead to the conversion of natural shoreline, both mangrove and freshwater floodplain, to seawalls, bulkheads and other types of hardened shoreline. This loss of habitat impacts many other important components of the lagoon including fisheries, crabs, benthic invertebrates and birds.

Level of certainty - high

A.11.7.3 Near-Shore Reef

Relationship of Near-Shore Reef to Altered Freshwater Flows

Increased flows may also equate with increased loads and a concomitant increased potential impact to the health and abundance of near-shore reefs. Competition is an important process determining the structure and composition of benthic communities on reefs, and competition from macro-algae is an important step during reef degradation (Mcook et al. 2001). Even slight increases in nutrients can present catastrophic consequences, and can result in blooms of macro- and filamentous algae (Lapointe 2000).

Level of certainty - low

A.11.8 Research Questions

Research questions were developed for the critical linkages discussed in Section A.11.4 and displayed in the conceptual ecological model (Figure A-38, Section A.11.9) based on relative importance to project outcome in consideration of relative certainty of those linkages. Ecological changes resulting from the reduction of stormwater discharges to the Lake Worth Lagoon will be influenced by interrelated causal relationships with low levels of certainty. All of these uncertainties involve the estimated reductions in freshwater flow and sediment loading into the lagoon. Several of these relationships are based purely on the volume, timing and distribution of the fresh water itself, while others involve reductions of nutrient, toxin, suspended solids and dissolved organic loads that are associated with discharges from the developed watershed.

Effects of Altered Salinity on Submerged Aquatic Vegetation

What effect do undesirable salinity shifts have on the diversity and community species composition of *Syringodium filiforme* and macro-algae?

Relationships among Submerged Aquatic Vegetation, Salinity and Fishes

What is the temporal utilization of SAV by fish and how is that interaction affected by salinity?

Relationship of Submerged Aquatic Vegetation to Input of Nutrients, Turbidity and Dissolved Organic Matter

What effect does increased levels of nutrients and dissolved organics have on light attenuation and its subsequent effect on the distribution, density and abundance of SAV in the Lake Worth Lagoon?

Relationship of Submerged Aquatic Vegetation to Increased Epiphyte Growth

What is the relationship of the amount of epiphyte coverage found on SAV with the location, abundance and diversity of different species in the Lake Worth Lagoon?

Relationship of Submerged Aquatic Vegetation to Accumulation of Muck

What is the present distribution of muck deposits and how do they relate to SAV reestablishment?

Relationship of Physical Alterations in the Lagoon to Submerged Aquatic Vegetation Distribution, Abundance and Health

What is the best way to reestablish SAV in areas that have been physically impacted?

Relationship of Macroinvertebrate Community Shift to Altered Salinity Envelope

What effect do undesirable salinity shifts have on the diversity and community species composition of macroinvertebrates in the lagoon?

Relationship of Macroinvertebrate Community Shift to Elevated Nutrients

What effect do elevated nutrients have on the diversity and community species composition of macroinvertebrates in the lagoon?

Relationship of Macroinvertebrate Community Shift to Sediment Characteristics

What effect do sediment characteristics have on the diversity and community species composition of macroinvertebrates in the lagoon?

Relationship of Macroinvertebrate Community Shift to Toxins and Contaminants

What effect do contaminants have on the diversity and community species composition of macroinvertebrates in the lagoon?

Relationship of Macroinvertebrate Community Shift to Anoxic and Hypoxic Conditions

What effect does oxygen regime have on the diversity and community species composition of macroinvertebrates in the lagoon?

Effects of Reduced Coverage and Health of Submerged Aquatic Vegetation on Fishery Species

What is the relationship of habitat loss and fishery species?

Effects of Increased Levels of Toxins on Fishery Species

To what extent do fish within the lagoon exhibit the abnormalities and/or lesions documented in nearby associated waters (i.e., Loxahatchee Estuary, St. Lucie Estuary and the Indian River Lagoon)? What is the functional relationship between toxins and abnormalities and/or lesions found on fish in the Lake Worth Lagoon?

Effects of Loss of Mangrove Habitat on Fishery Species

What is the effect of loss of mangrove habitat on fishery species? What is the best way to enhance or reestablish viable shoreline habitat?

Relationship of Tidal Inundation into the Lake Worth Lagoon Due to Sea Level Rise

What is the relationship of sea level rise to the lagoon's salinity regime?

Relationship of Macroinvertebrate Community Shift to Altered Salinity Envelope

What effect do undesirable salinity shifts have on the diversity and community species composition of macroinvertebrates in the Lake Worth Lagoon?

Relationship of Water Quality in Lake Worth Lagoon to Water Management

What is the quantitative link between water management and flow at the boundary of the lagoon ecosystem?

Relationship between Turbidity and Nutrient Concentrations and the Reestablishment of Seagrasses in Lake Worth Lagoon

What limits seagrass distribution in the central and southern segments of the lagoon and are changes in water management going to improve this?

Relationship between Actual Freshwater Inflow to Lake Worth Lagoon and Water Management

Is there a direct relationship between the inflow of fresh water to Lake Worth Lagoon and water management practices in the watershed?

Relationship of Habitat Loss and Estuarine Fish Communities

What is the appropriate salinity gradient to maintain from interior coastal wetlands through the near-shore zone in order to optimize the diversity and abundance of estuarine fish species in Lake Worth Lagoon?

Relationship of Freshwater Flow to Estuarine Habitat

How is estuarine habitat affected by the quantity, timing and distribution of freshwater inflow?

Relationship of Mangroves and Freshwater Inflow Changes and Sea Level Rise

What are the effects of freshwater inflow change and sea level rise on mangrove distribution?

A.11.9 Hydrologic Performance Measures

A.11.9.1 Polyhaline Pattern and Stability

Improving the timing, quantity and duration of freshwater discharges is the primary mechanism for changing salinity patterns within Lake Worth Lagoon. The goal is to moderate wet season flood releases and augment dry season inflows to provide an ecologically appropriate salinity envelope. The goal is maximize the balance, diversity and distribution of the polyhaline and stenohaline community, and to reduce to the extent possible of mesohaline conditions. The central and southern segments of the lagoon should more closely resemble conditions currently present in the northern segment.

The preliminary salinity target performance measure for the Lake Worth Lagoon is an inflow of 500 cubic feet per second (cfs) during the wet season. This inflow is expected to achieve minimum bottom salinity of 23 parts per thousand (ppt) during the wet season at a distance of 0.5 miles north of the mouth of the C-51 canal.

A target salinity envelope is being developed by the North Palm Beach Comprehensive Everglades Restoration Project Delivery Team. The team has established a Receiving Waterbodies Focus Group that will use an integrated modeling approach to develop a salinity gradient that would result in a more stable and persistent natural biological communities in the lagoon. The modeling approach will be completed by December 2003.

A.11.10 Ecological Performance Measures

A.11.10.1 Water Quality

Water quality performance measures for Lake Worth Lagoon includes the following indicators: nutrients, algal bloom frequency, and water clarity measured by photosynthetically-active radiation (PAR). Current levels of surface water nutrient (total phosphorus and total nitrogen) concentrations and loads must be maintained or reduced to historical background levels. Frequency of algal bloom occurrences must not increase. Existing water clarity must be maintained or improved in those regions where reduced water clarity is limiting growth of seagrasses. Reduce loads of nutrients, toxins, dissolved organic matter and total suspended solids that originate from agricultural and urban land use practices and are exacerbated by regulatory and flood releases during wet periods and from the enlargement of the local drainage basins.

A.11.10.2 Sediment Quality

Restoration efforts and changes in water management practices may affect the conveyance of contaminants in sediments; therefore, toxicant concentrations are also a recommended indicator for a performance measure. The target is to decrease the geographic extent and concentration of sediment contamination and decrease the extent of unstable or muck sediments, which inhibit formation of balanced benthic community.

A.11.10.3 Benthic Community

Benthic performance measures recommended for the lagoon include increased species richness, abundance and diversity of benthic species. Unstable salinity, low dissolved oxygen, presence of toxic substances and elevated concentrations of nutrients (via algal response to nutrient enrichment) can separately or in concert with one another adversely affect the composition of the lagoon's benthos. Maintenance of suitable conditions will allow establishment of sensitive groups (e.g., filter feeders such as Pelecypoda and Porifera, and grazers such as Telmatogetoninae), resulting in an overall balanced and diverse benthic community typical of that of a healthy lagoonal system.

A.11.10.4 Submerged Aquatic Vegetation

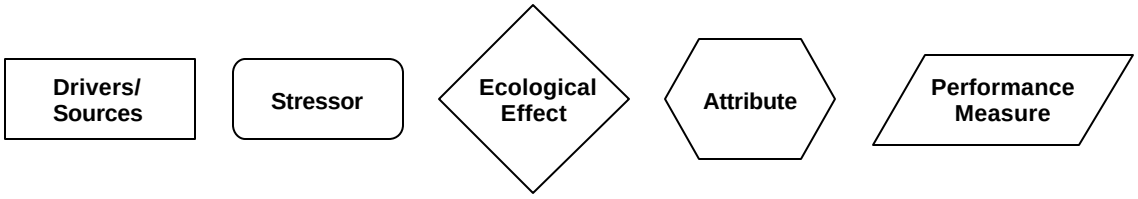
The indicators for a SAV performance measure include cover, density and species composition. The target is to reestablish SAV beds in areas presently devoid of SAV, to improve cover where currently inhibited, and to maintain existing cover in areas where plants currently flourish.

A.11.10.5 Fishery Species

Indicators recommended for performance measures relative to the fish and shellfish communities include abundance, density and species composition. The overall target is to increase the diversity and density of fishery assemblages at benchmark locations in the Lake Worth Lagoon. More specifically the target is as follows:

- Increase representation of juvenile stages of reef and recreationally important fishes, including gray snapper (*Lutjanus griseus*), mutton snapper (*Lutjanus analis*), yellowtail snapper (*Ocyurus chrysurus*), lane snapper (*Lutjanus synagris*), yellowtail parrot fish (*Sparisoma rubripinne*), gag grouper (*Mycteroperca microlepis*), grunt (*Haemulon* sp.), snook (*Centropomus undecimalis*), red drum (*Sciaenops ocellata*), and spotted seatrout (*Cynoscion nebulosus*) from present baseline conditions.

- Increase abundance of mullet (*Mugil* sp.), menhaden (*Brevoortia* sp.) and anchovy (*Anchoa* sp.) based on catch per unit effort.



- Increase post-larval and juvenile densities of spotted seatrout in representative seagrass beds, particularly shoalgrass from present baseline conditions.

- Increase juvenile settlement rates of the common and fat snook (*Centropomus parallelus*) at representative sites in the Lake Worth Lagoon from present baseline conditions.

- Increase abundance of juvenile and adult red drum at representative lagoon sites from baseline conditions.

A.11.10.6 Shoreline Habitat Functionality

The indicators for a performance measure shoreline habitat functionality is the percent of restored shoreline mangrove habitat, species diversity, and quality of habitat as defined by height, depth and density of fringing mangrove stands. The target or restoration expectation is to increase spatial extent of mangrove and emergent shoreline plant communities.

A.11.10.7 Near-Shore Reef Health

Indicators recommended for performance measures relative to the near-shore reef system include coral density, diversity and abundance. Water clarity, sediment quality and deposition rate must not inhibit or adversely affect the near-shore reef system such that there is a net loss or degradation of coral.

A.11.11 Model

The diagram for the Lake Worth Lagoon Conceptual Ecological Model is presented in Figure A-38. The key to the symbols used in the diagram is presented in Figure A-37.

Figure A-37: Key to the Symbols Used in the Following Diagram

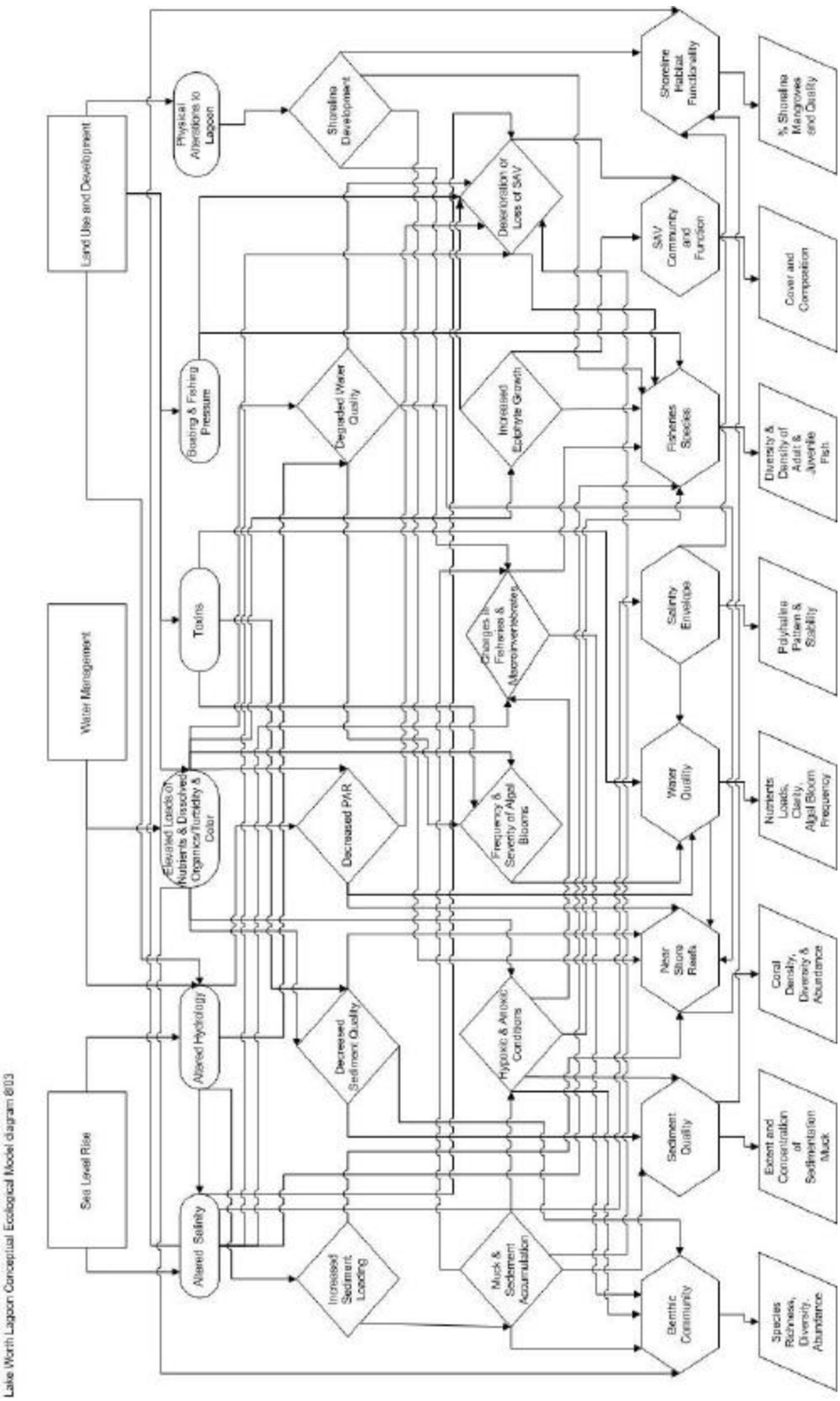


Figure A-38: Lake Worth Lagoon Conceptual Ecological Model Diagram

A.11.12 Literature Cited

Applied Technology and Management, Inc. 2002. Seagrass Monitoring in Lake Worth Lagoon Report for 2000 and 2001. Prepared for Palm Beach County Department of Environmental Resources Management, West Palm Beach, Florida.

Bilyard, G.R. 1987. The value of benthic infauna in marine pollution monitoring studies. Marine Pollution Bulletin. 18(11) 581-585.

Boesch, D.F., and N.N. Rabalais. 1992. Effects of Hypoxia on Continental Shelf Benthos: Comparisons between the New York Bight and the Northern Gulf of Mexico. Geological Society, Special Publication 58:27-34.

Boesch, D.F., and R Rosenberg. 1981. Response to stress in marine benthic communities. In: Barrett, G.M., and R. Rosenberg (eds). Stress Effects on Natural Ecosystems, John Wiley, New York, pp. 179-200.

Chamberlain, R.H., and P.H. Doering. 1998a. Freshwater inflow to the Caloosahatchee Estuary and the resource-based method for evaluation. In: Treat, S.F. (ed.). Proceedings of the Charlotte Harbor Public Conference and Technical Symposium. Technical Report No. 98-02, Charlotte Harbor Estuary Program, North Fort Myers, Florida, pp. 88-91.

Chamberlain, R.H., and P.H. Doering. 1998b. Preliminary estimate of freshwater inflow to the Caloosahatchee Estuary: A resource based approach. In: Treat, S.F. (ed.). Proceedings of the Charlotte Harbor Public Conference and Technical Symposium. Technical Report No. 98-02, Charlotte Harbor Estuary Program, North Fort Myers, Florida, pp. 111-120.

Christensen, R. F. 1965. An Ichthyological Survey of Jupiter Inlet and Loxahatchee River, Florida. M.S. Thesis, Florida State University, Tallahassee, Florida.

Dames and Moore and PBCERM. 1990. Lake Worth Lagoon Natural Resources Inventory and Resource Enhancement Study. Palm Beach County Environmental Resources Management, West Palm Beach, Florida.

Deis, D.R., R.E. Walesky, and H.D. Rudolph. 1985. A Reevaluation of the Benthic Macroinvertebrate Associations in Lake Worth, Florida. Tropical Ecosystems, Inc., West Palm Beach, Florida.

DERM. 1984. Fisheries Assessment. Miami-Dade Department of Environmental Resource Management, Miami, Florida.

Gilmore, R.G., Jr. 1988. Subtropical Seagrass Fish Communities: Population Dynamics, Species Guilds and Microhabitat Associations in the Indian River Lagoon, Florida. PhD dissertation, Florida Institute of Technology, Melbourne, Florida.

Gunter G., and G.E. Hall. 1963. Biological investigations of the St. Lucie Estuary (Florida) in Connection with Lake Okeechobee Discharges through the St. Lucie Canal. Gulf Research Reports 1(5), Gulf States Marine Fisheries Commission, Ocean Springs, Mississippi.

Doering. P.H., R.H. Chamverlain, and D.E. Haunert. 2002 Using submerged aquatic vegetation to establish minimum and maximum freshwater inflows to the Caloosahatchee Estuary, Florida. Estuaries 25(6b): 1343-1354.

Esteves, E 1998. The Story of the Greater Charlotte Harbor Watershed. Charlotte Harbor National Estuary Program, Fort Meyers, Florida.

FDEP. 2003. Basin Status Report, Lake Worth Lagoon and Palm Beach Coast. Florida Department of Environmental Protection, West Palm Beach, Florida.

Forward, R. 1989. Behavioral responses of crustacean larvae to rates of salinity change. The Biological Bulletin. June 1989 v176 N3.

Gaston, G.R., P.A. Rutledge, and M.L. Walther. 1985. Effects of hypoxia and brine on recolonization by microbenthos off Cameron, Louisiana (USA). Contributions in Marine Sciences 28:79-93.

Gilmore, R.G. C.J. Donahoe, D.W. Cooke, and D.J. Herema. 1981. Fishes of the Indian River lagoon and adjacent waters, Florida. Technical Report 41, Harbor Branch Foundation, Fort Pierce, Florida.

Harris, B., K.D. Haddad, R.A. Steindinger, and J.A. Huff. 1983. Assessment of Fisheries Habitat: Charlotte Harbor and Lake Worth. Florida Department of Natural Resources, Tallahassee, Florida

Haunert, D.E. 1988. Sediment Characteristics and Toxic Substances in the St. Lucie Estuary, Florida. Technical Publication DRE-259, South Florida Water Management District, West Palm Beach, Florida.

Haunert, D.E., and R.J. Startzman. 1985. Some Short-Term Effects of a Freshwater Discharge on Biota of the St. Lucie Estuary, Florida. Technical Publication DRE-213, South Florida Water Management District, West Palm Beach, Florida.

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

Holland, A.F. et al. 1987. Long term variation in mesohaline Chesapeake Bay macrobenthos: spatial and temporal patterns. Estuaries 10:227-245.

Japp, W.C., and Pamela Hallock. 1990. Chapter 17, Coral Reefs. In: Myers, R.L., and J.J. Ewel (eds). Ecosystems of Florida, University of Central Florida Press, Orlando, Florida, pp. 574-616.

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

Kingsford, M.J., and C.A. Gray. 1996. Influence of pollutants and oceanography on abundance and deformities of wild fish larvae. In: Schmitt, R.J., and C.W. Osenberg (eds). Detecting Ecological Impacts: Concepts and Applications in Coastal Habitats. Academic Press, New York.

Lapointe, B.E. 2000. Nutrient over-enrichment of South Florida's coral reefs. Proceedings, Fourth Bay of Funcy Science Workshop, New Brunswick, Canada.

Lewis, R.R., III, R.G. Gilmore, Jr., D.W. Crewz, and W.E. Odum. 1985. Mangrove habitat and fisheries resources of Florida. In: Seaman, W., Jr. (ed). Florida Aquatic Habitat and Fishery Resources. Florida Chapter, American Fisheries Society, Kissimmee, Florida, pp.281-336.

Lindall, W.N., Jr. 1973. Alterations of Estuaries of South Florida: A Threat to Its Fish Resources. Marine Fisheries Review 35(10): 1-8.

Livingston, R.J. 1987. Historic trends of human impacts on seagrass meadows of Florida. In: Durako, M.J., R.C. Phillips, and R.R. Lewis, III (eds). In: Proceedings of the Symposium of Subtropical-Tropical Seagrasses of the Southeastern United States. Publications No. 42, Florida Marine Research Institute, St. Petersburg, Florida, pp. 139-152.

McCook, L. J., J. Jompa, and G. Diaz-Pulido. 2001. Competition between corals and algae on coral reefs: a review of evidence and mechanism. Coral Reefs 19:400-417.

Mclusky, D. 1971. Ecology of Estuaries. Heineman Educational Books Limited.

McCrary, J.P., J.W. Jolley, C. Tapp, and R.E. Waldner. 1985. Overview of the Habitat Degradation in Florida. Palm Beach County Chapter, Florida Conservation Association, Florida.

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, United States Fish and Wildlife Service, Washington, D.C.

PBCERM and Dames and Moore. 1990. Lake Worth Lagoon Natural Resources Inventory and Resource Enhancement Study. Palm Beach County Environmental Resource Management, West Palm Beach, Florida.

PBCERM. 1992. Palm Beach County, Florida Estuarine and Natural Resources Inventory and Enhancement Study. Palm Beach County Environmental Resource Management, West Palm Beach, Florida.

PBCERM and FDEP. 1998. Lake Worth Lagoon Management Plan. Palm Beach County Environmental Resource Management and Florida Department of Environmental Protection, West Palm Beach, Florida.

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

Pickard, G.L., and W.J. Emery. 1990. Descriptive Physical Oceanography: An Introduction. Fifth Enlarged Edition. Pergamon Press, New York.

Pitt, W.A., Jr. 1972. Sediment loads in canals 18, 23, 24 in southeastern Florida. Open File Report 72013, United States Geological Survey, Tallahassee, Florida.

Reagan, R.E. 1985. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Gulf of Mexico) - red drum. Biological Report 82(11), United States Fish and Wildlife Service, Washington, D.C.

Reed, J.K. 1975. Benthic macrofaunal associations in Lake Worth, Florida, and their use as indicators of water quality. Masters of Science Thesis, Florida Atlantic University, Boca Raton, Florida.

Reid, G.K., Jr. 1954. An ecological study of the Gulf of Mexico fishes in the vicinity of Cedar Key, Florida. Bulletin of Marine Science of the Gulf and Caribbean. 4(1): 1-94.

Reish, D.J. 1986. Benthic Invertebrates as indicators marine pollution: 35 Years of Study. Oceans 86 3:885-888.

Roessler, M.A. 1965. An analysis of the variability of fish populations taken by otter trawl in Biscayne Bay, Florida. Trans. Am. Fish. Soc. 94: 311-318.

Shrader, D.C. 1984. Holocene sedimentation in a low energy microtidal estuary, St. Lucie River, Florida. Masters thesis, University of Florida, Gainesville, Florida.

Tabb, D.C., D.L. Dubrow, and R.B. Manning. 1962. The ecology of Northern Florida Bay and adjacent estuaries. Fla. State Board Conserv. Tech. Ser. 39: 1-81.

TCRPC. 1995. Boat Facility Siting Plan for Palm Beach County. Treasure Coast Regional Planning Council, CITY, STATE.

USEPA. 1999. The Ecological Condition of Estuaries in the Gulf of Mexico. EPA 620-R-98-004, Office of Research and Development, United States Environmental Protection Agency, Washington, D.C.

Weinstein, M.P., C.M. Courtney, and J.C. Kinch. 1977. The Marco Island Estuary: a summary of physiochemical and biological parameters. Fla. Sci. 40(2): 98-124.

Woodburn, K.D. 1961 Biological Survey of North Lake Worth (Palm Beach County) with Special Reference to Bulkhead Lines. Marine Lab, Salt Water Fish Division, Florida State Board of Conservation, Florida.

WPB Fishing Club. 1989. Letter to Riviera Beach City Council from the West Palm Beach Fishing Club concerning Proposed Ordinance No. 2011883.

Yokel, B.J. 1975. Rookery Bay Land Use Studies: Environmental Planning Strategies for Development of a Mangrove Shoreline, No. 5, Estuarine Biology. Conservation Foundation, Washington, D.C.

Zarillo, G. 2003. Salinity Distribution and Flow Management Studies for Lake Worth Lagoon. SEA, Inc. Proceedings of Lake Worth Lagoon Symposium, January 29, 2003.

Zieman, J.C. 1982. The Ecology of the Seagrasses of South Florida: a Community Profile. FWS/OBS-82/25, United States Fish and Wildlife Service, Office of Biological Services, Washington, D.C.

APPENDIX B: PROJECT INFLUENCE ON MONITORING AND ASSESSMENT PLAN MODULES

Comprehensive Everglades Restoration Plan projects are expected to influence many of the physical and biological elements described in the regional modules presented in this Monitoring and Assessment Plan. Table B-1 lists the projects alphabetically by region, along with the scheduled start and end date for each project, and indicates if the project will have an effect (direct and indirect) within a module region. A description of each project can be found at http://www.evergladesplan.org. Note: The Northern Estuaries region is divided into the four estuaries discussed in Section 3.3 of the document.

Table B-1: Project Influence on Monitoring and Assessment Plan Modules

Project Name	Start	End	Greater Everglades Wetlands	Southern Estuaries	Caloosahatchee Estuary	St Lucie Estuary	Lake Worth Lagoon	Loxahatchee River and Estuary	Lake Okeechobee
Lake Okeechobee Watershed									
C-43 Basin ASR[1] - Part 2	Aug 2008	Feb 2018			Direct				Indirect
C-43 Basin Storage Reservoir - Part 1	Mar 2001	Apr 2011			Direct				Indirect
Caloosahatchee Backpumping with Stormwater Treatment	Mar 2005	Jul 2014			Direct				Indirect
Lake Istokpoga Regulation Schedule	Jan 2002	Dec 2003							Indirect
Lake Okeechobee ASR	Nov 2009	Oct 2026	Indirect		Direct	Direct	Direct		Direct
Lake Okeechobee Watershed	Nov 2000	Feb 2013			Indirect	Indirect	Indirect		Direct
North of Lake Okeechobee Storage Reservoir	Feb 2006	Feb 2013	Indirect		Indirect	Indirect	Indirect		Direct
Taylor Creek / Nubbin Slough Storage and Treatment Area	Mar 2005	Jun 2009	Indirect		Indirect	Indirect	Indirect		Direct
Lake Okeechobee Watershed Water Quality Treatment Facilities	Feb 2006	Feb 2013	Indirect		Indirect	Indirect	Indirect		Direct
Lake Okeechobee Tributary Sediment Dredging	Feb 2006	Aug 2008			Indirect	Indirect	Indirect		Direct
Upper East Coast									
Indian River Lagoon South	Oct 2001	Aug 2010				Direct			
C-44 Basin Storage Reservoir	Apr 2002	Oct 2007				Direct			Indirect
C-23, C-24 Storage Reservoirs	Nov 2002	Aug 2009				Direct			
C25, North & South Fork Storage Reservoirs	Nov 2003	Aug 2010				Direct			
Everglades Agricultural Area									
Everglades Agricultural Storage Reservoirs – Phase 1	Jan 2001	Sep 2009	Direct	Indirect	Indirect	Direct	Direct		Direct
Everglades Agricultural Storage Reservoirs – Phase 2	Sep 2004	Sep 2014	Direct	Indirect	Indirect	Direct	Direct		Direct
Flow to Northwest & Central WCA[2] 3A	Oct 2002	Sep 2011	Direct	Direct					Indirect
Modify Holey Land WMA[3] Operation Plan	Oct 2003	Mar 2008	Direct						Indirect
Modify Rotenberger WMA Operation Plan	Oct 2003	May 2006	Direct						Indirect
Lower West Coast									
Big Cypress / L-28 Interceptor Modifications	Mar 2005	Jun 2015	Direct	Indirect					
Henderson Creek/Belle Meade Restoration	Nov 2000	May 2008							
Lakes Park Restoration	Feb 2000	Jan 2007							

[1] ASR – Aquifer Storage and Recovery
[2] WCA – Water Conservation Area
[3] WMA – Wildlife Management Area

Project Name	Start	End	Greater Everglades Wetlands	Southern Estuaries	Caloosahatchee Estuary	St Lucie Estuary	Lake Worth Lagoon	Loxahatchee River and Estuary	Lake Okeechobee
Southern Golden Gate Estates Hydrologic Restoration	Jan 2001	Nov 2006		Direct					
Northern Palm Beach County									
Loxahatchee National Wildlife Refuge Internal Canal Structures	Mar 2003	Dec 2007	Direct						
North Palm Beach County - Part 1	Apr 2001	Mar 2014	Direct				Direct	Direct	
Pal-Mar and J.W. Corbett WMA Hydropattern Restoration	Mar 2004	Mar 2009	Direct				Direct	Direct	
L-8 Basin	Mar 2004	Mar 2011	Direct				Direct	Direct	Indirect
C-51 & Southern L-8 Reservoir	Mar 2004	Mar 2014	Direct				Direct	Direct	Indirect
Lake Worth Lagoon Restoration	Mar 2004	Mar 2008	Direct				Direct		Indirect
C-17 Backpumping & Treatment	Mar 2004	Mar 2010	Direct				Direct	Indirect	
C-51 Backpumping & Treatment	Mar 2004	Mar 2010	Direct				Direct	Indirect	
North Palm Beach County - Part 2	May 2009	Oct 2020	Direct				Direct	Direct	
C-51 Regional Groundwater ASR	Apr 2012	Oct 2020	Direct				Direct	Indirect	Indirect
L-8 Basin ASR	Apr 2012	Oct 2018	Direct				Direct	Direct	Indirect
Winsberg Farm Wetland Restoration	Oct 2000	Sept 2007							
Water Preserve Areas									
Acme Basin B Discharge	Jan 2002	Apr 2007	Direct				Direct		
Bird Drive Recharge Area	Jun 2006	Dec 2014	Direct						
Broward County Secondary Canal System	Oct 2001	Jun 2009	Indirect						
Broward County Water Preserve Areas	Jan 2002	Oct 2008	Direct						
WCA 3A/3B Levee Seepage Management	Jul 2002	Oct 2008	Direct	Indirect					
C-11 Impoundment	Jul 2002	Jan 2006	Direct	Indirect					
C-9 Impoundment	Jul 2002	Jan 2006	Direct	Indirect					
C-4 Structure	Jan 2002	Apr 2006	Direct						
Hillsboro ASR - Part 2	May 2009	Mar 2017	Direct						
Site 1 Impoundment	Jan 2002	Oct 2007	Direct				Indirect		
Palm Beach County Agriculture Reserve Reservoir - Part 1	Dec 2005	May 2016	Direct				Direct		
Palm Beach County Agriculture Reserve ASR - Part 2	May 2009	Jul 2019	Direct						
Strazzulla Wetlands	Jan 2002	Apr 2007	Direct						
WCA 2B Flows to Everglades National Park	Feb 2004	Feb 2021	Direct						
Water Preserve Area Conveyance	Feb 2004	Feb 2001	Direct						
Miami-Dade County									
Biscayne Bay Coastal Wetlands	Oct 2001	Dec 2015		Direct					
Central Lake Belt Storage Area	Mar 2011	Nov 2036	Direct	Direct					
Flow to Eastern WCA	Mar 2009	Feb 2017	Direct						
North Lake Belt Storage Area	Mar 2011	Jun 2036	Direct	Direct					
South Miami-Dade Reuse	Jun 2011	Jun 2020							
WCA 3A/3B Flows to Central Lake Belt	Jul 2003	Feb 2016	Direct						
West Miami-Dade Reuse	Jul 2011	Jun 2020							
Everglades, Florida Bay and Florida Keys									
C-111 Spreader Canal	Oct 2000	Mar 2009	Direct	Direct	Direct				
Everglades National Park Seepage Management	Jun 2006	Sep 2013	Direct	Direct					
Florida Keys Tidal Restoration	Apr 2001	Dec 2006		Direct					
Restoration of Pineland & Tropical Hardwood Hammocks in C-111 Basin	Mar 2011	Sep 2016							
WCA 3 Decompartmentalization & Sheet Flow Enhancement – Part 1	Jan 2001	Oct 2010	Direct	Direct					Indirect
WCA 3 Decompartmentalization & Sheet Flow Enhancement – Part 2	May 2006	Apr 2015	Direct	Direct					Indirect