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Monitoring and Assessment Plan (MAP), Part 2
2006 Assessment Strategy for the MAP

Final Draft

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RESTORATION COORDINATION & VERIFICATION (RECOVER)

INTEGRATIVE ASSESSMENT SUB-TEAM

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1.0 INTRODUCTION

The Comprehensive Everglades Restoration Plan (CERP or Plan) monitoring program is built upon a strong science foundation that is logistically and economically feasible, sustainable over the long term, and provides data at appropriate spatial and temporal scales to conduct assessments of the status and trends of those physical, chemical, and biological attributes that support the CERP Adaptive Management (AM) 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 (U.S. Army Corps of Engineers [USACE or Corps] and the South Florida Water Management District [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.

Natural and human system attributes prior to, during and following CERP implementation will be compared to the trends or targets established for each performance measure. These comparisons will be used for evaluating how the implementation of CERP projects, individually and collectively meet 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

The purpose of this document is to present a clear understanding of the assessment process that replaces the current Section 2.0 (Technical Assessment Guidance Process) of the MAP. The principal clients for this document are Restoration Coordination and Verification (RECOVER), the Assessment Team (AT), the Integrative Assessment Team (IAT), MAP Module Groups and Leads and their Principal Investigators (PIs) (see

Section 2.2.3) who have the responsibility for conducting the assessment of MAP monitoring information and preparing annual reports on their findings. Because of the continued and rapid development of analytical methods used for the assessments the IAT anticipates that this will be a "living document" in that it will be regularly updated as relevant information becomes available. The technical assessment reports that will be developed by RECOVER using this assessment strategy will be used to satisfy a variety of reporting requirements for CERP.

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 (Figure 1-1). 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 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.

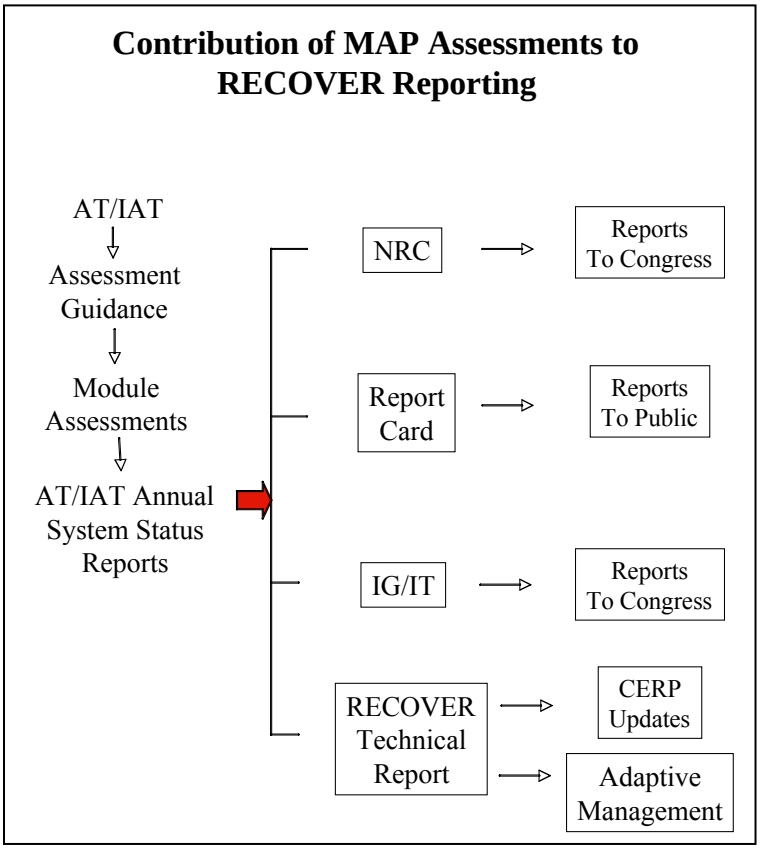

Figure 1-1: RECOVER Reporting Requirements

These technical reports will be consulted and referenced by the Corps and the SFWMD 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.

1.1 Purpose of Technical Assessment Guidance Process

The objective of MAP is to assess the performance of CERP implementation, as described previously. As part of MAP, pre-CERP reference conditions in the South Florida Ecosystem will be characterized and compared with post-CERP conditions using scientifically rigorous analyses of hypotheses and changes in performance measures. The purpose of the MAP technical assessment guidance process is to provide a systematic

framework for analyzing relevant monitoring data and providing feedback to support, improve, or change the CERP monitoring and research design. CERP performance measures are defined by measurable indicators with quantitative targets or assessed by trend analysis (i.e. direction of change). This guidance process is applicable to all adaptive management monitoring tasks within CERP (e.g. MAP Module Groups, Project Delivery Teams [PDTs], and contracts,) and will therefore provides a means of comparable data analyses, minimize debate regarding analyses methods, and subsequently allow decision-makers to focus on the results of the analyses. The characterization of pre-CERP conditions will provide the baseline from which to measure the magnitude and direction of ecosystem responses during and following CERP implementation. The key principles of the technical assessment guidance follow.

1) The guidance is generic and designed to be applicable to a wide range of CERP monitoring components and other CERP programs not included in the current MAP.
2) The guidance provides the MAP Module Groups with a systematic framework and process for analyzing databases.
3) The guidance provides "minimum" criteria to ensure consistency and uniformity in conducting assessments.
4) The guidance process is not intended to be a "cook-book"; it is flexible and allows innovative analysis approaches that are consistent with the overall technical assessment process.
5) The guidance process provides references and/or case-study examples to illustrate the application of important concepts.

1.2 Programmatic Regulations

The Programmatic Regulations (Pro Regs) for CERP authorize the implementation of an adaptive management strategy to improve our understanding of, and subsequently support the restoration of, the natural system and the human environment of the South Florida ecosystem. The guidance process presented here represents a vital part of the Guidance Memorandum for “general directions for the conduct of the assessment activities of RECOVER” required by the Pro Regs [Section 385.31(a)(2)(iv)].

This guidance process will address the three principal RECOVER tasks stipulated in the Pro Regs [Section 385.31(b)(3)] and listed below.

1) Determine if measured responses are desirable and achieving the Interim Goals and the Interim Targets or the expected performance level of the Plan.
2) Evaluate whether corrective actions to improve performance or cost-effectiveness should be considered.
3) Prepare reports on the status of the CERP projects and trends in ecosystem responses to the CERP projects.

The Pro Regs specify that "whenever it is deemed necessary, but at least every five years, RECOVER shall prepare a technical report that presents an assessment of whether the goals and purposes of the Plan, including the Interim Goals and Interim Targets, are being achieved or are likely to be achieved. The technical report shall be submitted to the Corps and to the SFWMD for use in preparing the Interagency Assessment Report for submittal to Congress, as required in Section 385.31(b)(4)(i).

1.3 Adaptive Management

The CERP is a large-scale, long-term plan to restore, preserve, and protect the natural systems in South Florida while addressing other water-related needs in South Florida, including water supply and flood protection. However, ecosystem restoration is inherently uncertain, owing to the complex and often unexpected responses of natural systems to human intervention.

Congress recognized the challenge posed by uncertainty when it approved the CERP and the Water Resources Development Act (WRDA) of 2000 specifically provided funds for an Adaptive Assessment and Monitoring (AA&M) Program, and required the development of Pro Regs, which ensured that new scientific or technical information acquired due to unexpected results, or the application of AM be integrated into the Plan. The Pro Regs direct the Corps and the SFWMD to develop a CERP AM program that includes monitoring and assessment of the ecosystem, as well as periodic updates and necessary changes to the Plan.

The MAP incorporates AM to assess whether CERP projects are meeting restoration goals and targets and refine the Plan based on this assessment. The AM component of CERP is a science and performance based approach to ecosystem management that relies on a continual process of refining and improving the Plan based on new information, rigorous monitoring, and assessment. Consequently, alternative actions can be developed and the best course of action can be selected. Appropriate application of adaptive management improves the likelihood of meeting desired targets and goals by reducing uncertainty, incorporating robustness into project design, and incorporating new information about ecosystem interactions and processes.

1.3.1 Adaptive Management Framework

The CERP AM Framework (Figure 1-2) is composed of four elements or "boxes" that together outline the process for, and the interactions among, the various components of a comprehensive AM program designed to address uncertainty and support collaborative decision making. The four boxes are: (1) Project Development; (2) Performance Assessment; (3) Management and Science Integration; and (4) the CERP Update Process. These elements are discussed further in Section 7.

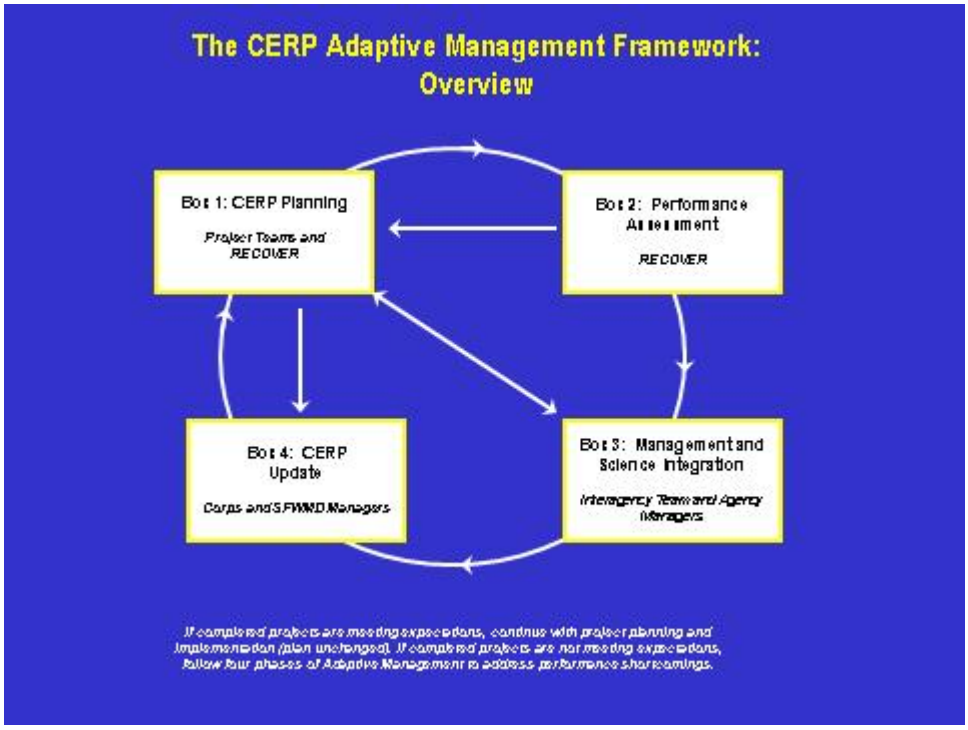

Figure 1-2: The CERP Adaptive Management Framework which illustrates the four elements (boxes) in the AM Framework.

Box 1, Project Development, is defined by the appropriate CERP project and project team. The remaining elements are described in the following sections.

1.3.2 Performance Assessment (Box 2)

An essential element of the CERP AM program is the development and implementation of the integrated system-wide MAP, prepared by RECOVER (Figure 1-3). The implementation of the MAP allows natural and human system responses to be assessed in the context of hypotheses specific to these ecosystems and evaluated relative to established CERP targets using PMs and Interim Goals and Targets (IG/IT). The MAP is a key element of the Performance Assessment component (Box 2) and is essential to CERP success because the monitoring and assessment provide the feedback necessary to identify and implement necessary refinements to the Plan. The scientific and technical information generated from implementation of the MAP provides the technical basis for RECOVER annual system status reports and a five-year technical report that documents the success of the CERP goals, targets and objectives.

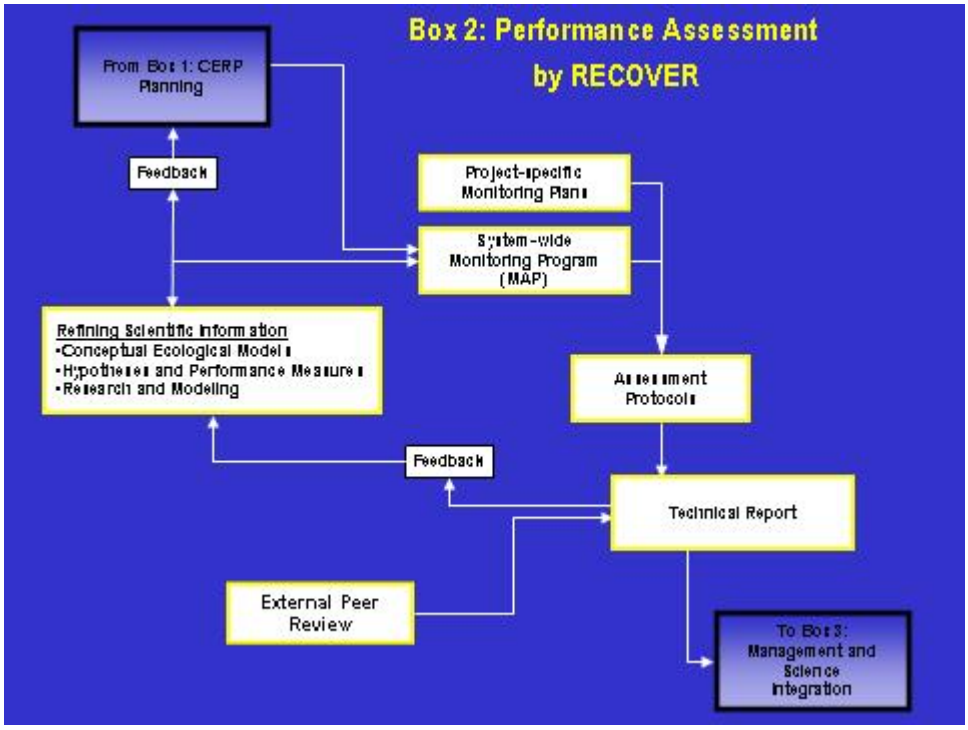

Figure 1-3: Performance Assessment (Box 2) describes how monitoring data is evaluated annually to assess the performance of CERP.

In response to the Pro Regs, the IG/IT have been established to provide a means of documenting CERP progress. Several MAP technical reports will provide RECOVER the means to determine if CERP IG/IT are being accomplished. Additionally, as ecosystem relationships are better understood and predictive capabilities improve, the IG/IT will be refined to more accurately reflect CERP expectations. This incorporation of new information and subsequent Plan refinement to improve performance embodies the ongoing responsiveness of the AM process.

The final product of the Performance Assessment is the RECOVER Technical Report which represents a system wide and science based assessment of CERP performance toward achieving the goals and purposes of the Plan. The RECOVER Technical Report will be compiled at (a minimum of) five year intervals and used, along with policy, legal, and cost considerations (Box 3) to develop the Interagency Assessment Report to be submitted to Congress (Figure 1-3).

2.0 TECHNICAL ASSESSMENT GUIDANCE PROCESS

2.1 Guidance Strategy and Purpose

The technical assessment guidance strategy developed for assessing measurable change(s) in system responses during and following CERP implementation is a multi-step process consisting of monitoring design, data acquisition, data analysis, interpretation, assessment, and subsequent evaluation of system-wide performance. This guidance process presents a strategy for assessing whether measured responses are consistent with the IG/IT established by the Pro Regs (Section 385.38). This strategy also addresses, but is not limited to, questions such as those listed here.

1) Has there been a measurable change in indicators from pre-CERP conditions?
2) If there has been a measurable change, has the direction and magnitude of the change been consistent with CERP goals and targets?
3) Is the change consistent with expected responses described in the CERP hypotheses?

A key part of this strategy is characterizing the variability of pre-CERP ecosystem conditions and establishing reference conditions for each of the hydrologic, water quality, and ecological indicators. This document does not provide guidance on establishing baseline conditions for water supply and flood protection, although guidance on this issue may be found in Guidance Memorandum #3 (Savings Clause Issues) and the pre-CERP baseline document at the following websites:

http://www.evergladesplan.org/pm/progr_regs_guidance_memoranda.cfm#docs
http://www.evergladesplan.org/pm/progr_regs_baseline.cfm.

Background variability and characterizing spatial patterns will be the emphasis of this effort for the first five years before the implementation of specific CERP projects that are expected to influence the ecosystem. A fundamental concept underlying the assessment strategy is the ability to detect *measurable change* of individual and aggregated performance measures. Measurable change is defined as the magnitude and direction of change of a performance measure from the pre-CERP reference condition (i.e., baseline) distinguishable from background variability.

The purpose of this document is to provide guidance to help ensure that the sampling designs and data analyses for the MAP monitoring components are adequate to detect measurable changes in hydrologic (including water supply and flood protection), water quality, and ecosystem indicators. This document is intended to:

1) Reflect the scientific methods necessary to detect and measure variability, status, and trends in individual performance measures
2) Integrate multiple performance measures at the module level

3) Combine module performance measures to provide a system-wide assessment of hypotheses regarding system responses to CERP implementation

2.2 Applied Science in RECOVER

RECOVER is responsible for the coordination and application of an Applied Science Strategy (Ogden and Davis 1999) during CERP implementation. The strategy outlines a process for organizing current scientific understanding literature on wetland and estuarine ecosystems into interrelated components that can effectively support restoration efforts. The major components of the Applied Science Strategy are the:

1) Regional and system-wide conceptual ecological models (CEMs)
2) PMs and restoration targets
3) Development and implementation of a system-wide monitoring program
4) Development of an assessment strategy

Natural and human system responses will be assessed relative to stated hypotheses regarding responses of these systems and evaluated relative to the trends or targets established for the CERP PMs and the objectives of the MAP (RECOVER 2004).

2.2.1 Conceptual Ecological Models

Conceptual ecological models are the foundation of most assessment PMs (Ogden and Davis 1999). CEMs are used to illustrate the links among societal actions, environmental stressors and ecological responses (USEPA 1998) and provide the basis for selection and testing the set of causal hypotheses that best explain how the natural systems in South Florida have been altered (Gentile et al., 2001). CEMs were also developed as a planning and design tool in ecological risk assessment analysis worldwide (Rosen *et al.* 1995; Gentile *et al.* 2001).

The CEMs were developed for eleven physiographic regions defined in the MAP (RECOVER 2004) and provide the scientific basis for the CERP system-wide monitoring design and adaptive assessment process. The CEMs are also a planning tool for translating the overall restoration goals of CERP into the specific PMs that will be used to plan, design, and assess the success of the Plan. In addition to illustrating the ecological links between the physical, chemical and biological elements in specific physiographic regions of South Florida, CEMs provide the scientific foundation for: 1) developing causal hypotheses linking the most important hydrologic and chemical stressors with the major ecological effects; 2) forming the basis for predicting responses to CERP restoration projects and other restoration efforts, and 3) identifying suites of measurable indicators (i.e., PMs for assessing how well the projects achieve the policy-level goals for the regional restoration programs.

2.2.2 Performance Measures

Performance measures consist of ecological attributes or environmental stressors such as hydrology, water quality, and habitat alteration that are indicators of conditions in natural and human systems. PMs are developed in large part from the CEMs and have been integrated into the CERP ecosystem response hypotheses at a module scale (see Section 2.2.3) and subsequently used to assess the system-wide performance of CERP. Additional PMs, including water supply and flood protection, were derived from Federal and Florida State law. Indicators of IG/IT will also be incorporated into the system-wide performance assessment.

RECOVER has operationally defined "assessment" and "evaluation" PMs (Appendix E). CERP PMs are identified in the *CERP System-wide Performance Measures Report*, which can be accessed at: www.evergladesplan.org/pm/recover/eval_team_perf_measures.cfm. Assessment PMs are those that can be directly evaluated by implementation of MAP components and are used to track changes in the condition of the natural and human systems. In contrast, evaluation PMs are used to predict system-wide performance through simulation modeling of the Plan. As our understanding of the ecosystem increases and model development is improved, a larger number of PMs fitting both definitions is anticipated. PMs include hydrological, water quality, biological, water supply, and flood protection measures. Some PMs are related directly to the level of particular stressors, such as the rate of nutrient input, degree of alteration of salinity, and depth of water, while others are related to key attributes of the ecosystem such as fish population size, oyster health, and seagrass spatial extent. Achieving the targets (or trajectories towards restoration) of a well-selected set of PMs is expected to result in system-wide sustainable restoration.

2.2.3 MAP Modules

The MAP modules are represented by four geographic regions in South Florida, with additional modules for hydrology monitoring (to assist in evaluating water supply and flood protection performance measures) and mercury bioaccumulation. The modules are the basic organizing elements and research units of the MAP and form the basis for the scientific teams that interpret and analyze monitoring data (RECOVER 2004). These modules include:

- Greater Everglades Wetlands
- Southern Estuaries (Florida and Biscayne Bays, Southwest Florida Coast)
- Northern Estuaries (St. Lucie Estuary/Southern Indian River Lagoon, Caloosahatchee Estuary, Lake Worth Lagoon, and Loxahatchee River Estuary)
- Lake Okeechobee
- South Florida Hydrology Monitoring (Water Supply and Flood Protection)

The four geographic modules encompass one or more of the CEMs described above. Each module has its own sampling network designed by the appropriate MAP Module Group, with consideration of compatibility and efficiency that was derived from coordination with the other modules. Module Groups are teams of scientists with technical expertise in ecology, hydrology and water quality, and experience relative to the natural or human systems described in the MAP modules. Module Groups combine scientists from participating agencies participating in the development and implementation of the MAP with other scientists from outside the agencies who are recognized in their fields and actively working in South Florida ecosystems.

Each Module Group is led by a member of the RECOVER Assessment Team (AT) who is designated by the AT chairs with the concurrence of the AT membership. Qualifications for a Module Lead include a long history of experience, accomplishment and responsibility in areas of science relevant to the module. The core membership of a Module Group is determined by the Module Lead. That membership includes the Principal Investigators (PIs) for that particular module and others selected by the Module Lead. Participation between the sponsoring agencies and MAP PIs and members who are not direct participants is contractually arranged

The Module Groups and associated PIs are responsible for coordinating the implementation and quality assurance of the MAP monitoring and research projects for each of the modules. Module Groups ensure that implementation of specific monitoring components follows the overall program sequencing developed by the AT. Module Groups are also responsible for assessing non-MAP data already being collected to identify existing efforts can be incorporated or modified to meet MAP criteria.

2.3 Levels of Assessment Guidance

The RECOVER Integrative Assessment Guidance Process establishes a multi-step process for detecting and assessing changes in performance measures, assessing progress toward achieving IG/IT, and evaluating the status of module and system-wide hypotheses. The guidance includes three levels: the MAP component level (e.g., specific monitoring and supporting research projects); the module level; and the system-wide level. The assessment process, outlined in Figure 2-1, applies specifically to the natural system and can be modified, as necessary, to address water supply and flood protection.

2.3.1 MAP Component-Level Guidance

The MAP component-level guidance is directed at the Principal Investigators working within a Module Group. The assessment guidance at the MAP component-level has three parts:

1) Estimating the ability to detect change;
2) Establishing reference conditions; and
3) Measuring changes from reference condition.

At this level, the assessments focus on: 1) selecting the analysis tools necessary to measure the magnitude and direction of change in the performance measures; 2) determining whether changes are consistent with desired trends or targets and MAP hypotheses; and 3) determining if there are indications of unanticipated events that affect desired outcomes. Guidance on these issues may be found in Section 3 and Section 4 of this document.

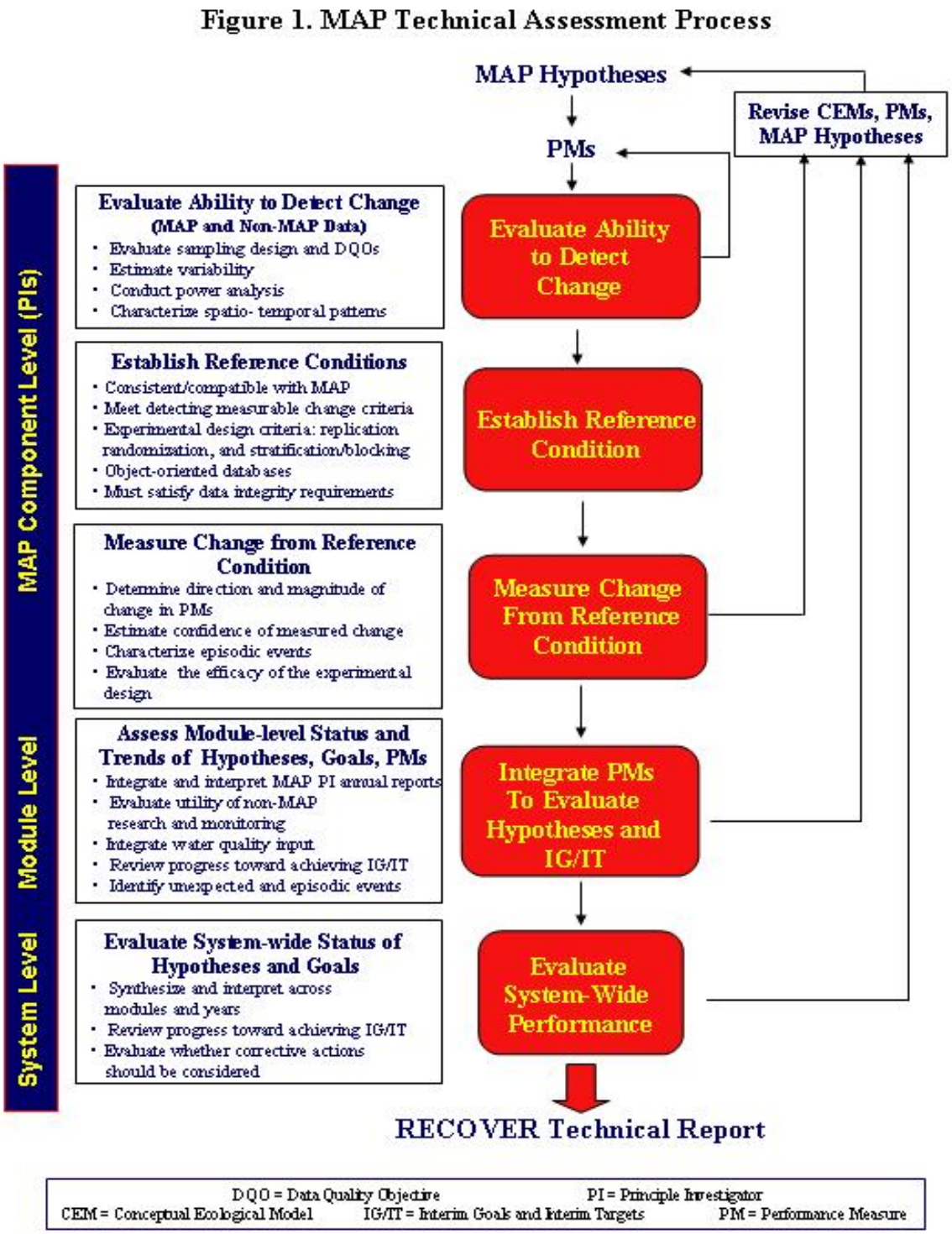

Figure 2-1: MAP Technical Assessment Process

2.3.2 MAP Module-Level Guidance

Module-level analyses focus on the integration of multiple performance measures into the assessment of specific hypotheses and are accumulated and updated annually. Module

Groups interpret the annual reports prepared by each PI, integrate relevant information into module assessments, and evaluate the relevance and utility of non-MAP research for assessment. Module-level assessments are conducted to determine the direction and magnitude of changes in the integrated PMs and to evaluate whether the changes are consistent with expected responses described for the CERP hypotheses. If the trends do not correspond to the expected responses, the Module Groups must provide plausible scientific explanations (Figure 7-1). . Finally, the Module Groups will evaluate progress toward achieving IG/IT, identify unexpected results, address episodic events, and integrate relevant information into project-level monitoring. Guidance on conducting module-level assessments and decision support tools may be found in Section 5 and 6 of this document. Further information on IG/IT may be found in Section 7.3.3 and RECOVER, 2005.

2.3.3 MAP System-Wide Guidance

The results from the system-wide analysis may require the AT and/or RECOVER to address a suite of options to correct or refine the MAP. System-wide analysis includes synthesis and interpretation of data across modules and years, evaluation of progress towards restoration goals, and identification and implementation of corrective actions that may be necessary for improvements. A fundamental assumption is that this guidance process has been applied to analyzing and integrating the performance measures within a module. Guidance on synthesizing and integrating the module-level analysis into a system-wide analysis is may be found in Sections 6 and 7 of this document.

3.0 EVALUATING THE ABILITY TO DETECT CHANGE

The ability to detect change is the first step and is crucial to the technical assessment guidance process. Detecting change, or differences in ecosystem responses to CERP implementation, is a function of three highly correlated factors:

1) The expected (baseline) variability of the hydrologic, water quality and/or ecological indicator
2) The strength of the response being measured
3) The power of the sampling design to detect a change in the response that is significantly different from natural or background variability

Detecting change is inextricably linked to measuring variability and the statistical design of the monitoring program. Consequently, a primary goal of the assessment process is to measure the "baseline" variability with specified degrees of confidence so that we can detect changes when they occur. Further discussion of establishing baseline variability and reference conditions is presented in Section 4.

3.1 Purpose

The objectives of this section of the technical assessment guidance process are as follows: 1) describe the experimental design and the supporting scientific rationale; 2) describe the results of the power analysis for the sampling design; 3) determine the minimum detectable difference of the power analysis and its associated confidence and uncertainty for each of the performance measures in the module; and 4) describe changes in the MAP sampling design and its implications for the power analysis and the minimum detectable differences.

3.2 Experimental Design

Appropriate experimental design is critical to detecting change in PMs. While there are a number of texts on this topic (Fisher 1935, Kempthorne, 1952, Cochran and Cox 1957, Gilbert, R.O. 1987, Krebs 1989, Underwood 1997, Sit and Taylor 1998; and Zar 1999) they all recommend including: 1) a clear statement of the goals and objectives, factors, and factor levels to be investigated; 2) a description of the amount and type of replication; 3) the method of randomization, 4) the rationale for stratification and blocking; 5) hierarchal sampling at different temporal and/or spatial scales; and 6) a discussion of statistical inference.

Statistical inference is particularly important in the experimental design because it describes the set of assumptions that link the data collected on the sampled population to the target population of interest. The validity of statistical inference in an experimental setting should be considered carefully to assure that sufficient data pertaining to the objectives are collected and can be analyzed in the most efficient way (Deming 1953, Box et al. 1978, Hahn and Meeker 1993, and Sit and Taylor 1998).

3.3 Environmental Monitoring Design Criteria

Studies assessing ecological trends using long-term monitoring data (e.g., Olsen 1997, Dixon *et al.* 1998, Schmitt R.J. and Osenberg C.W. 1996, Olsen and Smith 1999, Manly 2000, Olsen *et al.* 1999) also address topics such as stratified and multi-stage sampling, repeated sampling from the same site or new sites each year; design-based and model-based inferences, assessment of status and trends, testing for serial correlation and causation, the role of power analysis, and detection of unforeseen responses (Phillipi 2003). A summary of recommended monitoring design criteria for inclusion in MAP assessments to guide experimental design are outlined here.

- A clear and unambiguous statement of goals and objectives that includes explicit statements of the target population of interest and the environmental variables to be monitored.
- A description of how inferences are to be made about the target population from the sampling design, what types of data will be used, and how representative the sampling sites are (see Section 5: Measuring Change from Reference Condition).
- It is crucial that the sampling design be able to accommodate change as objectives change over time. This is crucial if the results of the sampling design tell the investigator that the sampling design is insufficient to measure change or assess hypotheses. Additionally, management changes may occur over time necessitating the refinement of a sampling design. However, given the considerable spatial variation in the system, complete random sampling is unlikely to be the most powerful design to detect change for a given sampling effort. Stratification and other more general forms of multi-stage sampling are useful for leveraging ancillary data to provide more powerful estimates of variability, but random sampling within strata or sampling units is still required.
- If causation is important (e.g., linking the causal pathways from the conceptual ecological model), the monitoring design should be supplemented by experimental work to address specific hypotheses about causation (Olsen and Schreuder 1997, Olsen et al. 1999).
- It is crucial that the sampling design accommodate change as objectives change over time (Fuller 1999). However, designs that are too finely tuned while being the most powerful to detect specific a priori responses, greatly reduce the ability of the design to capture unforeseen responses (see Section 10: Future Uncertainties) and limit the ability to subsequently restructure the monitoring program in response to modified objectives or resource levels (Overton and Stehman 1996, Olsen and Schreuder 1997). These considerations are particularly important to successfully implementing the adaptive management strategy which is critical to CERP.

3.4 Estimating Variability

Several sources of variability common to monitoring data must be addressed as a prerequisite for determining whether a measured change in the performance criteria is different from its expected variability (i.e., baseline variability). Variability in all indicators should be characterized prior to detailed analyses to measure change. Measuring and characterizing variability are prerequisites for conducting many statistical analyses. However, in the absence of sufficient data to adequately characterize baseline, it will be incumbent upon the scientists to demonstrate that the observed changes are measurably different from baseline variability. As part of measuring variability, it will be important to develop strategies addressing, at the minimum, spatial and temporal (annual and interannual) variability and episodic events (e.g., tropical storms, hurricanes, etc.), that influence variability in South Florida systems.

3.4.1 Parametric and Non-parametric Techniques

When PIs provide data for use in the adaptive assessment process of the CERP, certain basic guidelines must be followed. These guidelines are necessary to ensure that the AT can carry out a timely evaluation of the assessments as well as track progress towards established restoration goals associated with CERP PMs and IG/IT.

A statistically robust monitoring and experimental design is necessary for any analyses. The PIs will be expected to determine the distributional characteristics of the data, providing a histogram plot and information to determine whether the data approximate a normal distribution. Statistical tests for normality (i.e., skewness and kurtosis) must be applied. If it is necessary to transform data, the PI will need to document that the transformation was successful in approximating a normal distribution prior to conducting parametric statistical tests (e.g., mean, standard deviation, standard error, etc.). Two examples are outlined in (Appendices B and C) for phosphorus levels in Lake Okeechobee and fish biomass estimates in Shark River. Both examples appear to meet the normality and homogeneity of variance assumptions.

However, parametric statistics are frequently inappropriate for ecological data, especially for rare, patchily-distributed animal species. Therefore, given that it is highly unlikely that environmental data collected in the MAP are going to be normally distributed, it is likely that non-parametric statistical tests would be an important component of the MAP. While transforming data may reduce variability and the influence of outliers, it does not guarantee normality. Non-parametric approaches, on the other hand, relax the normality assumption and are generally more robust than parametric methods. Regardless of the approach used, the PI is expected to provide a rationale for the selection of the analysis method. Additional resources addressing parametric versus non-parametric techniques are listed in Section 3.7 Additional Applicable Resources.

3.5 Power Analysis

The overall performance of the CERP monitoring program will be evaluated at periodic intervals. A useful tool for conducting this exercise is power analysis, which, depending on data properties and other factors, can be used to detect statistically significant differences in a performance measure. Statistical power can be defined as the probability of correctly detecting an effect (when it exists) or correctly rejecting a false null hypothesis, or avoiding type II error (see Appendix B), and depends on factors such as alpha level, magnitude of the effect, sample size, and sample variance. The appropriateness of the selected hypothesis for testing the ecological feature or process being examined and whether the data meet the assumptions of the selected statistical test are critical to the successful application of any statistic.

Statistical power analysis can be conducted before initiation of data collection programs, experiments, or management actions (*a priori* analysis), or following their completion (*a posteriori* analysis). Both approaches have advantages and limitations. *A priori* analyses, as advocated by most authors (e.g., Peterman 1990), are useful for making sampling intensity and allocation decisions. Limitations of *a priori* analyses stem from poor understanding of: (1) the response variable(s); (2) biologically significant effect sizes; and (3) extent of spatio-temporal variability. *A posteriori* or post-experiment power analyses are usually used to interpret a test that failed to detect an effect (i.e., a statistically non-significant result). This can result either from the *de facto* absence of an effect or from a low probability of detection.

Hoenig and Heisey (2001) argue that *a posteriori* analyses are useful for explaining observed data, but are not useful for data-analysis purposes and can result in seriously flawed interpretations of statistical analyses. They suggest that emphasis should be placed on confidence intervals, appropriate choices of null hypotheses, and equivalence testing.

Power calculations for a number of tests (e.g., t-tests, chi-square tests, ANOVA, ANCOVA, regression, correlation, multivariate methods) are available in the literature (see Appendix B). However, performing power analyses can be problematic when dealing with rare and/or patchily distributed animal abundances, which are typically dominated by zero values. This situation violates the normality assumption and forces the researcher to use a combination of statistical distributions (e.g., delta-log normal, delta-Poisson, etc.) to describe the data and estimate the composite variance of presence/absence and non-zero observations. Power analysis guidance for this common situation is not widely available.

The text that follows serves as guidance in situations where data generally meet (or can meet through transformation) the assumptions of homogeneity of variance and normality. It generally does not apply when nonparametric or multivariate methods are used. Refer to Noether (1987) for sample size determination for some common nonparametric tests.

Conventional power analysis uses the observed variance among replicates to estimate the minimum treatment effect detectable (difference from reference state). If the magnitude of the detectable difference among treatments is larger than the range of differences

expected due to changes in Everglades hydrology/water quality, then revision of the sampling design should be considered to improve the statistical power of proposed analyses . Power analysis can be useful for determining whether data derived from the MAP sampling can be used to detect the desired changes in PMs. In addition, its inclusion in MAP may help determine if the sampling design is robust enough to detect the direction and magnitude of desired change within the desired timeframe. Methods for conducting power analyses can be found in standard statistic textbooks or in a wide range of computer programs and most recently on many university mathematics department web sites (Appendix B).

If variance estimates are not available, then an initial step in the MAP research process is to conduct a pilot study to obtain the information needed to estimate variance. The results from the pilot study will be used to measure and analyze the variability of the specific PM. This measure of variability will be used to conduct a power analysis to determine whether the current sampling design can detect the specified magnitude of change in the PM with the desired degree of confidence.

The utility of power analysis and its application in CERP is illustrated in the analysis of fish data collected in Shark River Slough. Trexler's 1997-2001 sampling data (Trexler, *et al.* 2001) provides an estimate of the across-year standard deviation of roughly 43 percent in raw biomass. Power analysis, conducted using this estimate of variance, shows the percent annual increase in biomass detectable at the 95 percent confidence level as a function of years of sampling.

Table 1. Minimum detectable change (a = .05) in biomass as a function of years of sampling. (After Phillipi 2003.

Years	% Change Detectable
2	171
3	65
4	37
5	25
9	9.5
10	8.1
13	5.4
14	4.8
19	3.0
25	2.0

Figure 3-1: Minimum detectable change in biomass as a function of years of sampling (Phillipi 2003)

This type of analysis is important to understanding the ability of RECOVER to detect quantitative changes in PMs given the current MAP design. For example (Figure 3-1), after two years of sampling using Trexler's experimental design you would only be able to detect a 171 percent change in biomass with 95 percent confidence. Any change less than that would not be considered statistically significant. Similarly, it will require between 9-10 years of monitoring data to be able to detect a 10 percent annual increase in biomass to exclude no trend, 14 years are required for detecting a 5 percent annual increase, and 25 years are required for detecting a trend of 2 percent increase per year in biomass.

However, it is incumbent upon the PI to determine what degree of measurable change is deemed of ecological significance and not just statistical significance. For example, if a population has a large (>25 percent) intrinsic interannual variability the sampling design need not be so rigorous that it requires a detection level at a 10 percent change with 95

percent confidence. Rather, a sampling design that detects 25 percent change with 90 percent confidence might be sufficient given the wide interannual variability. The detection limits and confidence parameters will be expected to vary with individual performance measures.

Andersen (1998) discusses the importance of "errors of inference" relative to drawing erroneous conclusions from the analysis of management experiments and monitoring programs (Appendix B-3). Specific attention is given to Type I and II errors (statistical power analysis) and their importance in AM. A P-value of 0.05 is common practice in science, but it makes change very difficult to detect in highly variable data such as that collected by the MAP. Walker (2000), in his paper on total phosphorus increases to Everglades National Park, uses a P value of 0.10. Currently, the compliance regime for the Park is based on p-value of 0.10. Therefore, a higher P-value (> 0.05) could be considered for routine change detection using field data.

Anderson (1998) provides the following recommendations to scientists and managers for addressing the issue: recognize that errors of inference are unavoidable, but their frequency can be controlled by experimental design; include *a priori* power analysis in all monitoring designs; realize that non-significant results should report the effect of size and power of the design; use *a posteriori* power analysis also; where current experimental designs lack power, replace them with new, more powerful methods (e.g. BACI (Before-After-Control-Impact) - paired designs, Underwood 1994); conduct pilot studies to improve power of large experiments; and finally, because not enough is known about potential response variables (e.g., biologically significant effect sizes and spatial and temporal variability), it is important to conduct long-term monitoring for important variables.

Power analyses are strongly recommended, but their results should not be the only criteria for adoption or rejection of the ability to measure change in a given parameter of interest (i.e., PM). Rather, researchers should design their programs around a given parameter for its ecological relevancy to CERP-related changes. For many of ecological components, responses to CERP activities may well emerge in "fits and starts". Alternatively, some of the best indicators of CERP performance may be highly variable now (i.e., pre-CERP) because they are under stress, but not necessarily later (i.e., post-CERP) if stress is reduced. Power analysis can be an extremely useful tool for designing or modifying a monitoring program, but due caution is warranted before abandoning a given PM based on power analysis results alone. Monitoring programs should strive to collect as much CERP-relevant data as is practical and feasible, and researchers should be mindful that our current understanding of the system and the responses of its components is incomplete.

3.6 Additional Applicable Resources

- South Florida Wading Bird Report – September 2005 (Mark I. Cook & Erynn M. Call, Editors)

- Phillipi, T. 2003. CERP monitoring and assessment plan: stratified random sampling plan. SFWMD Agreement C-C20304A September 24, 2003.
- Society of Landscape Ecology

4.0 ESTABLISHING REFERENCE CONDITION

4.1 Purpose

The establishment of reference conditions prior to implementing CERP project activities is one of the primary goals of the assessment and it is against these reference conditions that changes in the PMs that occur during and following CERP projects will be evaluated. The reference condition, or baseline, will include a minimum of four cumulative years of MAP data supplemented with relevant non-MAP data covering longer time series. In addition, the reference condition must be cumulative in order to include the full range of variability including capturing the extremes. The issue is confounded because of the heterogeneity in the temporal and spatial expression of the different PMs. For example, because hydrology and water quality changes may occur rapidly, changes in these parameters relative to a reference condition can be ambiguous. Changes in ecological responses are generally slower, thereby complicating the establishment of reference conditions as well as detecting change. It is critical that data sets used to establish the reference conditions meet the MAP guidance criteria.

The objectives of this component of the guidance process follow.

1) Describe the non-MAP data sources used in the assessment
2) Ensure that monitoring data meet the guidance criteria or provide rationale that justify their inclusion
3) Ensure that the data have been entered into the CERP's centralized environmental system, and updated appropriately.

4.2 Historic and Current Databases

The availability and quality of the monitoring data used to characterize the CERP reference conditions (baseline variability) for each of the performance measures may vary and may include MAP and non-MAP data (e.g. project level monitoring data). PIs and Module Groups should consider including all appropriate non-MAP data in their assessment efforts and consequently, identification and selection of the monitoring data used for establishing reference conditions and measuring changes in PMs must meet minimum criteria.

4.3 Criteria for the Use of Non-MAP Databases

To ensure that a wide range of data, in addition to those collected by the MAP, is available to estimate reference conditions for the PMs, we propose the following criteria be used to assure the data are comparable to, and consistent with, those being collected by the MAP. Observational data (existing water quality monitoring in the Greater Everglades), should include one or more of the following bullets listed below:

- The data were collected for sufficient duration to provide estimates of both intra- and inter-annual variability.

- Data used to detect change (either alone or in combination with other data) must be sufficient to assess the distributional characteristics of the PM.
- The sampling design used to collect the data should include the following elements: representation, randomization, replication, stratification, and blocking as appropriate.
- The data must be sufficient for power analysis.
- Data should be consistent and compatible with MAP data management.
- The data should be validated according to Quality Assurance Systems Requirements (QASR) procedures and meet CERP Zone criteria and standards whenever possible.
- Model-derived databases should be subjected to calibration and verification before being used to establish reference conditions for PMs.

4.4 Object-Oriented Databases

Sub-regional, regional, and system-wide models for hydrology, water quality, and ecology will be developed by CERP projects over the next few years or decades. These models will require and subsequently generate large amounts of spatial and temporal data for calibration, verification, and application. All the data (pre-and post-processed model simulation data) should be stored in a separate object-oriented database or in a centralized database system. Data quality objectives must be identified early in the process and be consistent with QASR (www.evergladesplan.org/pm/program_documents/qasr.cfm). In addition, these databases must comply with data validation and standardization requirements as described in the CERP Zone to assure accuracy and validity of the spatial and temporal data required by hydrologic, chemical, and ecological models.

Databases that store spatial and time series hydrological parameters (e.g., rainfall, stage, ground-water levels, evapotranspiration, aquifer characteristics), water quality parameters (e.g., nutrients, salinity, contaminants of concern, etc.) and ecological parameters (e.g., species densities and distributions, survival rates, habitat use, and movement, etc.) must meet the criteria to validate their use at appropriate spatial or temporal scales. Criteria include, but are not limited to: data standardization, data documentation, and data quality assurance.

4.4 Data Integrity

The integrity of databases and model output is integral to an accurate assessment of the changes in PMs and the progress of the CERP. The responsibility for assuring data quality will be shared between the individual PIs and the Module Group project managers. The Module Groups will be responsible for identifying data to be used in the assessment. As part of this responsibility, PIs will be responsible for ensuring that all data used in module level assessments satisfy the data integrity guidelines described for the CERP Zone. Ensuring that quality assurance and quality control (QA/QC) and data

validation processes provide accurate, defensible environmental data is critical to the overall success of CERP and each of its projects. The design, development and documentation of a QA program does not of itself ensure the quality of the data generated. Data quality is of utmost importance to the assessment of any data and is facilitated by adherence to the QASR, which provides guidelines for data quality and entities contributing data to CERP are required to conform to these guidelines. The Quality Assurance Oversight Team (QAOT) is responsible for ensuring compliance with the QASR and overall guidance on monitoring procedures, QA/QC and data validation.

4.5 Data Management

The RECOVER team of CERP has reached a point in the development of the program at which integrated assessments need to be initiated. The integrated assessments will depend on accessing and integrating a wide array of biological, chemical, and physical data collected by numerous organizations and scientists. To establish a baseline on which CERP projects can be evaluated, resources and efforts were initially focused on selecting sampling locations and collecting data. As a result, the data collected to this point are held by many PIs, in a variety of databases and with different standards for data quality, documentation, and coding. The purpose of this guidance is to identify the challenges that the Module Groups will face and to begin organizing the data to allow the integrated assessments to be accomplished.

4.5.1 Data Sources

The broad range of data being collected as part of CERP includes biological, chemical, physical, and geological data. Many of the projects within CERP are highly specialized and require interdisciplinary teams to integrate information from many sources. Data collection has focused on specific questions (not on integrated analyses) and data have been collected using different temporal and spatial scales. As the data are integrated the scales will sometimes need to be coordinated and summarized so that physical data on very small time scales but large spatial scales can be integrated with biological data collected on very broad time scales in localized spatial scales. Once these calculations are done they will need to be either stored or documented adequately to ensure that other researchers performing similar analysis know what analyses were done before and how the data normalization and integrations were performed.

The Module Groups face significant challenges in meeting the objectives of the integrated assessment. The first step is to clearly identify the questions/hypotheses that are to be used as the basis of the assessment. The identification of these questions will focus the analyses and will also help the data management staff understand the requirements for data, storage, documentation, analysis, and integration.

Second, a substantial amount of the physical data that will be required is already available in on-line, accessible relational databases. Many of these databases use industry-wide data and coding standards, ensuring that they can be easily integrated into and combined with data collected by PIs.

Third, there is an existing relational information system (ERDP) that houses data similar to the biological monitoring data being collected for CERP. This data management system has been developed, tested, and refined over a period of years and can serve as a prototype for the CERP central data management system that will house the CERP biological data.

Finally, several programs within SFWMD are designed to improve and integrate information systems. These programs receive broad funding and are supported by a staff knowledgeable in the collection and management of Everglades-related data.

4.6.2 Data Access and Distribution

Much of the data required for the MAP assessments is managed in a number of unrelated systems, including individual personal computers and cannot be easily accessed. In many cases the data will only be available by direct request from a PI. Many data sets may not be in relational databases and lack adequate documentation to allow other users to understand the applicable uses and the limitations of the collected data. To assure consistent reporting, the format and requirements for metadata will be coordinated with the RECOVER data stewards.

Different naming conventions (e.g., biological taxonomy, location names) used by the PIs will likely lead to inconsistencies that will make integrating the data difficult. Overcoming these difficulties will require direct input from the PIs and cross-references of different naming conventions before any meaningful integration can be accomplished.

The initial designs for collecting these data are focused on specific projects with little consideration for secondary uses or integration of the data for higher level questions. This will result in a variety of data collection methods, sampling and analytical methodologies, data documentation and spatial and temporal scale sampling. These discrepancies will need to be considered before data can be integrated. In some instances the data will need to be adjusted or summarized before data can be aggregated for integrated assessments.

The RECOVER MAP Statement of Work (SOW) Template presently specifies that PIs must submit all data for contract or interagency agreement closeout. Any data derived from the project will be provided to the AT at predetermined intervals and all data and results must be made available to the AT at the completion of the project.

4.6.3 Guidance Recommendations

To meet the data analysis obligations, the Module and Data Management groups should begin preparing data and resources for integrated assessments as soon as possible. An effective approach would be to develop a set of priority assessment hypotheses that will be used to assess the progress and success of CERP. These hypotheses should then be used to guide the organization of the data and analyses. For each assessment hypothesis,

a group of experts should be brought together who are knowledgeable about the domains of the hypothesis and who can identify relevant data and resources for performing the respective assessments. The core elements that should be addressed include, but may not be limited to, the following:

- Identify major groups of similar data
- Identify specific fields required to adequately describe and accommodate data
- Identify sources of data, for example, who collected them, why they were collected, and how they were organized into a database or table
- Identify locations of the databases (e.g., individual PI computers, government databases, web addresses, notebooks) and how they are currently shared (e.g., on-line, subscription database, CD, sneaker net, hard copies)
- List standards that apply to the data
- Indicate if there are naming conventions for locations, species, fields etc.
- Describe spatial and temporal scales of sampling
- Describe how various data sources will combined for the integrated analyses
- Provide metadata (e.g., written documentation of the original question being addressed, sampling plan, analytical methods, extent of the data, limitations, etc.)
- Document quality assurance performed on the data.

This information can then be used to develop a data analysis plan for the specific hypothesis. The data analysis plan should specify what preprocessing of the data, if any, will be required to combine diverse sources of information in order to conduct an assessment.

5.0 MEASURING CHANGE FROM REFERENCE CONDITION

5.1 Purpose

A primary goal of the MAP assessment is to measure the magnitude and direction of change of ecosystem responses to CERP implementation. In essence, this assessment is a measure of the recovery process. It is therefore appropriate that this section of the technical assessment guidance process address both the underlying concepts and assumptions of ecosystem recovery as they relate to measuring change from baseline/reference conditions and provide an overview of design and analysis strategies that have been used to address this topic. In addition, to assure these analyses are conducted in a systematic manner throughout the MAP, the following guidance is proposed for Principal Investigators:

1) Describe the methods used to estimate the direction and magnitude of change in performance measures from the reference state both annually and cumulatively over multiple years
2) Compare current status of the PMs with its desired trend or target
3) Evaluate consistency of monitoring results with map hypotheses
4) Determine if there are indications of unanticipated events
5) Describe how these events are affecting the desired outcome, the goal for the restoration.

5.1.1 Guidance for PIs and Module Groups

The focus of this section is on approaches to measure change from reference condition. The following outline the specific topics that PIs need to discuss as they conduct their assessments:

1) A description of the methods used to estimate the direction and magnitude of change in PMs from the reference state both annually and cumulatively over multiple years. Section 5 provides narrative descriptions of design and statistical approaches to examine the direction and magnitude of change, including the use of BACI (Section 5.3.4), univariate (Section 5.4.1), multivariate, weight of evidence approaches (Section 5.4.3), and environmental gradient analyses (Section 5.4.4). Section 5.4.6 provides information on where to learn more about time-series analyses, the use of a reference site as a covariate, intervention analysis, application of confidence intervals, decision theory, Bayesian methods, and complicated, non-parametric simulation-based tests of a hypothesis.

2) A comparison of the current status of the PMs and its desired trend or target. Section 5.2.1 describes the importance of understanding the temporal and spatial assumptions used in assessing ecosystem response. The characterization of the status of a PM needs to be made relative to the currently understood desired trend or target (if it exists) as described in the CERP System-wide PM Report

(www.evergladesplan.org/pm/recover/eval_team_perf_measures.cfm) and in the context of Section 5.2.1.

3) An evaluation of consistency of monitoring results with MAP hypotheses.

4) The degree and magnitude of consistency of monitoring results with MAP hypotheses are specific to the ecosystem and hypothesis being studied. Monitoring results at the PI level need to be characterized in the context of the MAP hypothesis as described in Section 9.

5) A determination of any indications of unanticipated events (See Section 10).

6) A description of how any unanticipated events are affecting the monitoring results, and thus the status of the respective MAP hypothesis of interest.

In characterizing the influence of an unanticipated event on monitoring results, it is important to understand whether, and to what extent, the unanticipated event had an ecologically meaningful influence on the PM, and subsequently, the MAP hypothesis. As part of this, it is important to be able to characterize the PM response rate to an unanticipated event such as an environmental disturbance (Fig. 5-1).

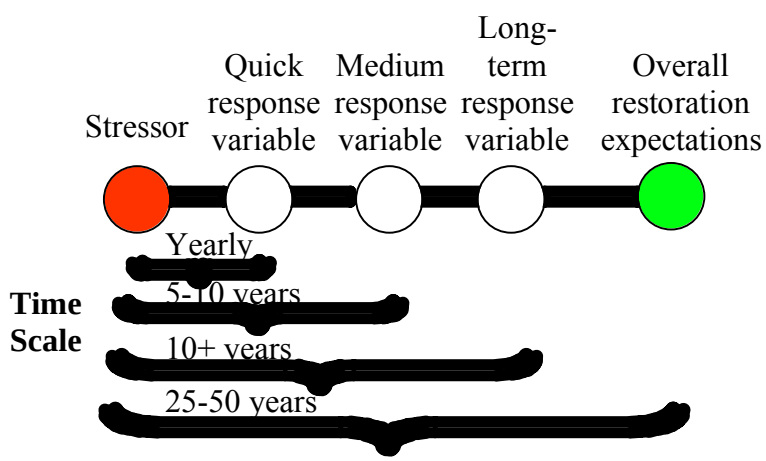

Figure 5.1 Response times for variables

Figure 5-1: Response times for variables

While the intent of these five points is to provide guidance to the PIs, the burden remains on the investigator to use sound judgment (and document the steps in that judgment) in assessing the state of recovery of a biological or environmental resource. Underlying assumptions about equilibrium must be explicitly acknowledged and specified.

5.2 Defining Recovery

Determining the extent to which recovery has occurred requires that the target condition, or the state of the fully ‘‘recovered’’ system, be defined. In an ecological sense, restoration can be defined as ‘‘the return of an ecosystem to a close approximation of its condition prior to disturbance’’ (National Research Council 1992). The goal is to ‘‘emulate a natural, functioning, self-regulating system that is integrated with the ecological landscape in which it occurs’’ (National Research Council 1992) or to reestablish ‘‘a critical range of variability in biodiversity, ecological processes and

structures, regional and historical context, and sustainable cultural practices'' (Society for Ecological Restoration 1996).

Similarly, CERCLA (U.S. Code of Federal Regulations, Revised 2001, Volume 43, Sections 11:14 and 11:72) defines restoration as occurring when the disturbed resource reaches the level it would have been, had the system not been disturbed in the first place and the influence of disturbance-related factors is diminished to the point where the resource varies temporally and spatially in a natural way. Importantly, all these definitions recognize that natural variation and anthropogenic factors are also at play during the period recovery; the recovered state is not necessarily a previous condition but an expected condition based on the recovery process, natural variation, and anthropogenic influences. The inclusion of natural variability and uncertainty in the definition of recovery/restoration has important implications for the conduct of assessments.

5.2.1 Ecological Assumptions

Recovery assessments require assumptions about the temporal and spatial variability of the ecological parameter or process being studied. It is important that these assumptions are acknowledged or tested explicitly since the assumptions one makes about ecological variability determine the feasibility of assessing recovery (Green 1979, Wiens and Parker 1995). To illustrate this point, steady-state spatial equilibrium and dynamic equilibrium and their ecological assumptions will be described within the context of assessment procedures (Parker and Wiens 2005; Fig 5-2A).

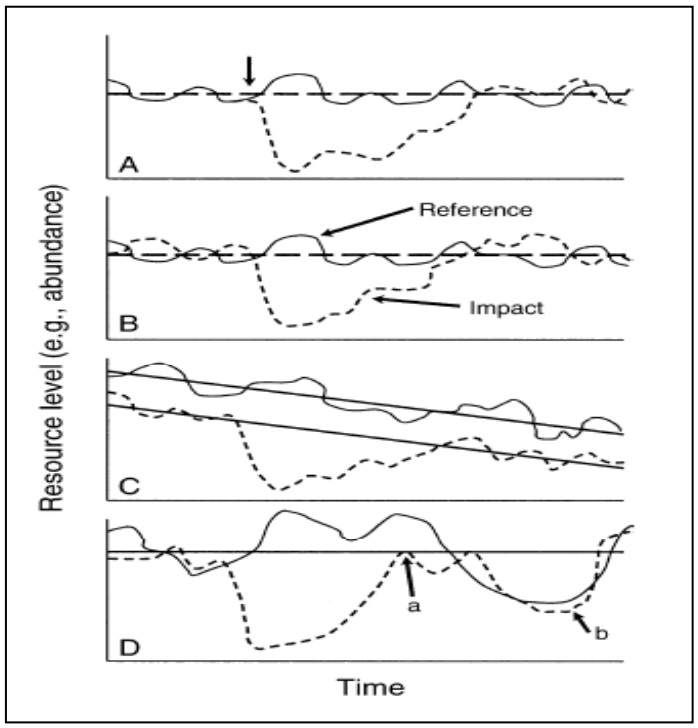

Figure 5-2 A-D: Ecological assumptions affecting recovery.

In the strict sense, steady-state equilibrium implies that system features being considered do not vary in time. In practice, this assumption is usually applied to a single location (e.g., the area impacted by an oil spill or fire) or species. Levels of the resource, and the natural factors controlling them, have a constant mean value over time (Fig. 5-2A). The resource at a given location has a single long-term equilibrium to which it will return if perturbed. The vertical arrow indicates the accident, and the dotted line represents the condition of the affected system; the solid curve indicates the dynamics of the system in the absence of a perturbation, and the solid horizontal line represents the steady-state resource level. Recovery occurs when

the impacted system returns to the steady-state equilibrium.

Spatial equilibrium occurs when two (or more) sampling areas (e.g. disturbed and reference) have equal influence of natural factors on them and, consequently, similar levels of a resource (Fig. 5-2B). Spatial equilibrium implies that mean levels of a resource are equal among areas; in the absence of a disturbance event, differences in means are due to sampling error and stochastic variations. The unaffected system serves as a reference for the disturbed system, and recovery occurs when the disturbed system returns to the point where its dynamics are again similar to those of the reference site

The assumption of dynamic equilibrium recognizes variation in both space and time. Natural factors and levels of resources normally differ between two or more areas being compared, but the differences between mean levels of the resource remain constant over time (Fig. 5-2C). Mean levels can change over time for the areas, but such changes are similar among the areas. In the absence of a disturbance, the systems in different areas will track one another over time. Recovery occurs when the dynamics of the impacted system once again parallel those of the reference system, even though levels of the resource differ between the areas.

In this example (Fig. 5-2D), there is considerable natural variation relative to the long-term steady-state mean. If this long-term variation is not considered or is unknown, the impacted system may erroneously be deemed recovered when it is not (point a) or may be considered still to be disturbed when its dynamics in fact match those of an un-disturbed system (point b).

5.3 Measuring Change

For the purposes of this technical assessment guidance, analysis design and analytical strategies can be grouped into three broad categories: baseline, single year, and multiple year analyses (Parker and Wiens 2005). It is important to understand how each of these analyses addresses the issues of temporal and spatial variation which often confound the assessment process (See Table 5-1, after Parker and Wiens 2005, Appendix E).

5.3.1 Baseline Data Assessments

Baseline data assessment designs compare pre- and post-impact conditions with data from the impacted site only. These designs, which often rely solely on an assumption of steady state equilibrium, are of limited value for assessing recovery of biological resources in temporally varying environments. In these cases, recovery may be confused with temporal variations, leading to false conclusions. Used in conjunction with other single- and multi-year designs, however, baseline data may provide valuable insight into recovery processes. Murphy *et al.* (1997) used a baseline design for assessing recovery of seabirds, but only in concert with BACI, a multiyear design that relies on the more realistic assumption of dynamic equilibrium. In this case, the baseline studies were used more to gain insight into long-term trends in populations than to determine whether or not recovery occurred.

5.3.2 Single-Year Studies

Single year studies typically compare perturbed/impacted and reference areas where the investigator employs design and analytical strategies to control for spatial variation among the areas being compared (i.e., meet the assumption of spatial equilibrium). A disturbance/reference design is valid when sampling efforts are spread over a broad geographic area and conducting multi-year sampling is not feasible. Recovery is identified by the absence of significant differences between disturbed and reference areas; if sampling sites are randomly selected, results of disturbed/reference studies can be extrapolated to the total disturbed area. Single-year studies require acceptance of the assumption of spatial equilibrium, either through covariance analysis of concomitant variables (i.e., physical or chemical variables; Gilfillan *et al.* 1995) or by pairing sites with shared environmental factors (McDonald *et al.* 1995). Regressing measures of biota on a continuous measure of disturbance (e.g., gradient analysis; Wiens and Parker 1995) can also be used. Associated environmental variables should be sampled concurrently with the biological resources of interest; however, some of the ecologically important variables may be unknown and/or un-measurable, and different variables may be needed when multiple species are assessed.

When designing single-year studies, it is also prudent to consider the effects of spatial scale. Stressors are not distributed randomly across habitats, and reference samples are often drawn from a larger area than are the disturbed samples. Differing spatial scales can result in differing scales of environmental variation, further confounding tests of equality in resource levels between the disturbed and reference areas. Ideally, this problem can be addressed by:

1) Randomly sampling similar habitats in both the disturbed and reference areas
2) Using an equal number of samples at environmentally similar sites which will reduce the potentially confounding influences of differing scales
3) Using covariates to help reduce potential differences in variation between the two areas.

In general, single-year studies of this nature are not recommended for assessing components of MAP hypotheses unless these approaches are the only mechanism to provide insight into a particular performance measure.

5.3.3 Multiyear studies

Multi-year studies are necessary for taxa (or environmental factors such as soil phosphorus) that exhibit large temporal variations or have long recovery periods or for multiple taxa with different temporal dynamics. These studies are superior to single-year and baseline studies because they can reduce the confounding effects of natural variation and therefore provide an opportunity to observe the recovery process and evaluate the assumption of dynamic equilibrium.

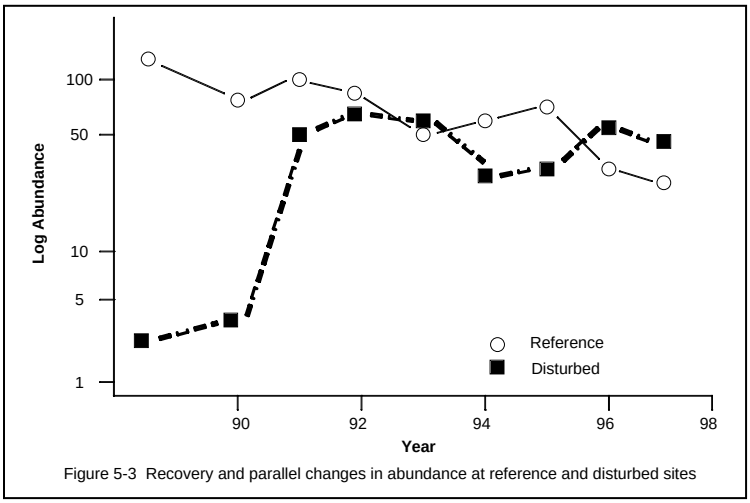

Figure 5-3: Mean abundance for disturbed and reference sites (Skalski *et al.* 2001)

If environmental factors change similarly over time at both disturbed and reference areas then the assumption of dynamic equilibrium holds. Assessing parallel trends in means has the advantage of requiring sampling data for only the ecological resource/attribute being assessed and no measures of concomitant environmental variables are needed.

The following example of a multi-year recovery study illustrates parallelism in temporal trends for two populations of intertidal snails (*Littorina sitkana*) (Skalski *et al.* 2001). In this study, the authors assessed recovery by testing for equal trends in the means of population abundance between a disturbed and reference sites. Figure 5-3 illustrates the mean abundances of the snails for both disturbed and reference sites over a period of seven years (1989-1996). The mean population abundances of the reference site show a general decline over the course of the observation period. Between 1989-1992 the snails repopulated the disturbed area and after 1991 the abundances showed similar trends at the two areas supporting the assumption of dynamic equilibrium. Skalski *et al.* (2001) assessed parallelism between reference and disturbed areas with an ANOVA test of interaction and trends in the ratio of reference means to disturbed means over time. Based on these analyses, Skalski *et al.* concluded that recovery occurred within two to five years after the spill, that is, within the 1992-1994 timeframe.

The BACI-type design (see examples below) is a good example of a multi-year analysis that relies on the assumption of dynamic equilibrium (Stewart-Oaten *et al.* 1986, Green 1979).

5.3.4 Before-After -Control-Impact (BACI) Studies

As discussed above, one of the most important uses of monitoring programs is to evaluate the changes or impacts to ecological systems from a particular event. In fact, the goal of this assessment guidance is to develop a valid measure of the magnitude and direction of changes in performance measures, both temporally and spatially, that result from CERP projects.

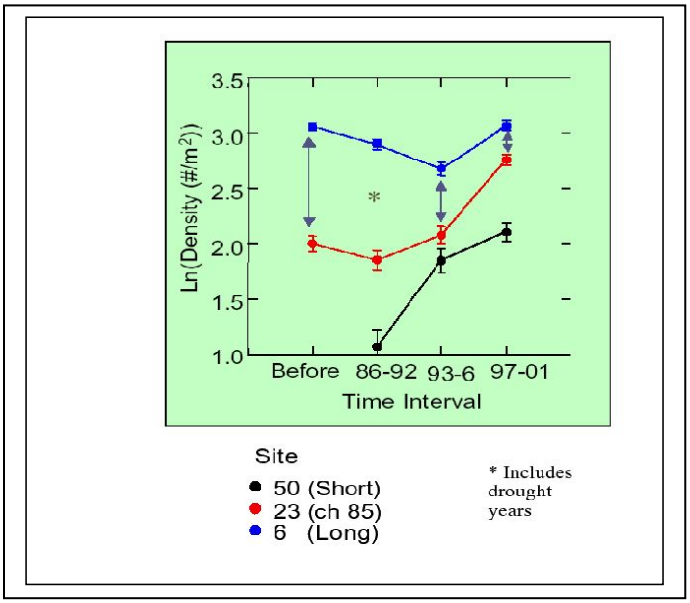

Figure 5-4: Shark River Slough fish data (Trexler *et al.* 2003)

Stewart-Oaten *et al.* (1986) coined the phrase BACI to describe a basic approach which has undergone modification by Underwood (1994) and Downes (1992). While there are limitations that need to be addressed when using this, or any other, design (Hulbert 1984, Smith *et al.* 1993, Underwood 1997), it remains one of the best methods for impact assessment (Smith *et al.* 1993). Smith *et al.* (1993) points out these designs can show that observed differences in ecological variables between the control and impact sites are neither artifacts of sampling nor due to temporal trends unrelated to the impact. Most importantly, the strength of the inference is directly related to the design issues (e.g., frequency of sampling, number of control sites, etc.) that are directly under the control of the managers and researchers.

The following example (Fig. 5-4) illustrates the application of the BACI approach to fish data collected in northeast Shark River Slough (Trexler *et al.* 2001). A monitoring initiative using throw traps to sample fish and macro-invertebrates was begun in 1977. This study ultimately included two reference sites; a long-hydroperiod site (#6) and a short-hydroperiod site (#50) and an impact site (#23). Beginning in 1985, water management practices for Northeast Shark River Slough were altered and the minimum annual water depth increased from a depth similar to site 50 to a depth more similar to site 6.

The density of all fish collected by throw trap is one possible performance measure to assess this change. In the accompanying figure (Figure 5-4), site 6 (blue) is the long hydroperiod reference site, site 50 (black) is the short-hydroperiod reference site, and site 23 (red) is the impact site where hydrological management was changed. The length of the vertical double-headed arrow on the left side of the figure represents the "before" magnitude of difference in fish density between the reference and impact sites for BACI. Note that there is a definite change (decrease) in the magnitude of the arrow as well as direction of the trajectory after the management change has taken place (double-headed arrows on the right side of the figure). This indicates that the management change to lengthen the hydroperiod at site #23 had the desired result, that is, to increase the fish densities to those of the long hydroperiod reference site (#6). As Trexler notes, the short-hydroperiod reference site also converged on the long-hydroperiod reference in the 1993-1996 interval. Thus, only the change in 1997–2001 provides evidence of successful management.

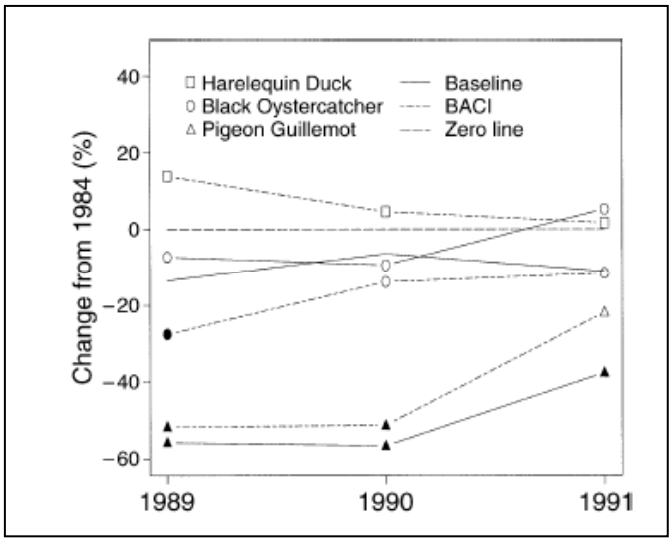

Figure 5-5: Comparison between baseline and BACI analysis.

An analysis of variance can be used to statistically validate the change by testing for a significant interaction between the time (before vs. after impact) and site (reference sites vs. impact site).

A second example of a multi-year BACI analysis is that of Murphy *et al.* (1997) as discussed in Parker and Wiens (2005). Murphy *et al.* (1997) used a baseline study for assessing the recovery of 12 species of seabirds from the *Exxon Valdez* oil spill. For impacted sites, densities for post-spill years (1989 1990 1991) were each compared to pre-spill densities in 1984. To illustrate the difficulties with using baseline studies to assess recovery, they compared the baseline results with those of a BACI analysis (Murphy *et al.* 1997; Tables 1 and 2). Figure 5-5 shows a comparison of percentage changes in density from 1984 under steady-state (baseline study) and dynamic (BACI) equilibrium assumptions. Significant effects are noted by solid symbols.

For Harlequin Ducks (*Histrionicus histrionicus*), BACI analysis showed nominal, non-significant decrease throughout the pre- and post-disturbance period while the baseline remained unchanged. For Black Oystercatchers (*Haematopus bachmani*), the BACI analysis showed a significant decrease in 1989 and subsequent recovery while the baseline analysis showed no statistically significant changes throughout the pre- and post disturbance periods. Baseline and BACI results for Pigeon Guillemots were similar,

showing significant negative impacts through 1990. The absence of significant differences was shown from a BACI analysis in 1991, suggests recovery, even though baseline showed continuing negative effects. When these results were examined with the context of a longer time frame (1984-2001) they showed that the apparent temporal invariance in abundance in abundances of Harlequin Ducks is short-lived and therefore misleading in assessing recovery (Wiens *et al.* 2004).

5.4 Statistical Approaches

As noted above, there are a variety of statistical methods that have been used to assess ecosystem response. While no specific method is recommended for the PI, the investigator must have in-depth knowledge of the selected statistical method to ensure that critical assumptions are met, and that the method has been documented in the peer-reviewed literature as appropriate for the purpose for which it is used. For purposes of illustration we provide a brief discussion of both univariate and multivariate statistical techniques below within the context of studies of the recovery (Gilfillian *et al.* 1995). Here, we also discuss the use of a weight of evidence approach used by Wiens *et al.* (2004) for examining the recovery of shorebirds. Finally, Appendix A provides an example of the statistical approaches used to analyze a 30-year record of pelagic Total Phosphorus.

5.4.1 Univariate Analysis

One application of univariate analysis is to test the null hypothesis that there is "no disturbance effect" by using a model that adjusts the means for important environmental parameters (i.e. concomitant variables). In this case, the disturbance effects on any biological variable of interest (e.g., species abundance, diversity index, etc.) can be estimated on the basis of differences among the model means that have been adjusted among the concomitant variables for the disturbance levels of interest. If the null hypothesis is rejected (i.e., there is a difference), the direction (positive or negative) of the difference from baseline/reference is noted.

The goal of univariate analysis is to use a model that satisfies the appropriate statistical assumptions and has high power to detect differences. For example, a "site mode" that uses among-site variability as an error term can be run to test for disturbance effects. The results from this model can be compared to within-site (transect) variability. If the among-site variability is not significantly greater than the within-site variability, a "transect model" can be run in which the within and among site variability can be pooled into a single error term. Disturbance effects can then be tested against this pooled error term. When this modeling approach was applied to the recovery of shoreline species impacted by the *Exxon Valdez* oil spill, Gilfillan *et al.* (1995) found that the transect model always had greater power to detect differences and was found to be appropriate for about 78 percent of the target species of concern.

It is important to note that testing disturbance effects for individual species (abundance, biomass, etc.) was first done with normal-theory methods on log-transformed data using

one-way analysis of covariance (ANCOVA) data (Gilfillan *et al.* 1995). If the residuals were not normally distributed then non-parametric methods were employed. Non-normal methods can be conducted with General Linear Interactive Models (GLM). This method is analogous to ANCOVA except that the differences in abundances are tested using Poisson, binomial, or negative binomial distributions.

5.4.2 Multivariate Analysis

As an alternative to univariate modeling, multivariate techniques can be used to simultaneously model multiple dependent variables such as individual species abundances. These techniques are useful when individual species abundances have inconsistent or contradictory trends with respect to the disturbance of interest.

One multivariate approach often used to assess disturbance effects on community structure is Detrended partial Canonical Correspondence Analysis (DCCA). This is an ordination technique that arranges samples along axes defined in terms of weighting factors for each parameter in the dataset. In DCCA, the ordination is performed after removing the effects of other physical or environmental variables. In contrast with techniques such as Principle Components Analysis (PCA), the detrending removes the effects of artifacts that tend to distort the scores along the second ordination axis. Another important feature of DCCA is that it does not require sample data to be normally distributed. Multivariate analyses are not limited to biological data. Ordination techniques, for example, are often used for examining suites of water quality data.

5.4.3 Weight of Evidence

Equilibrium assumptions for multi-year data may be uncertain at times. Erratic non-parallel trends in impact and reference values would trigger concerns of uncertainty. Dramatic regional declines in species abundance, shifts in geographic centers of abundance, or zero mean abundances for some years would also call into question equilibrium assumptions. Wiens *et al.* (2004) encountered all these elements of uncertainty and used a weight-of-evidence approach to assess recovery of 25 seabird species over a 12 year period from 1989 to 2001.

Wiens *et al.* synthesized results from four separate analyses, taking into account effects of potentially confounding habitat variables. The four analyses treated ecological assumptions differently, as described here. (1) For each year, densities were regressed on an index of shoreline oiling for 10 bays. It was assumed that the 10 bays were in spatial equilibrium for each year. (2) Covariates of important habitat variables were used in the same regression analyses used in (1). Covariates reduced the potentially confounding effects of spatial non-equilibrium due to environmental differences among the bays by subtracting out covariate effects before testing for continuing effects of oiling. (3) Densities from 1984 were used in a repeated-measures design, which assumed dynamic equilibrium in natural factors among categories of moderately-to-heavily and none-to-lightly oiled bays. (4) Plots of trends in density by oiling category were visually examined. In interpreting plots, either steady-state or dynamic equilibrium was assumed,

depending on whether one considered oiling categories separately over time or relative to each other. Using a weight-of-evidence approach based on all of these analyses strengthened the possibility of finding a continuing effect of oiling under different assumptions.

Common Mergansers (*Mergus merganser*) provide an example of how weight of evidence was used to detect initial spill-caused impacts, followed by recovery. Regressions indicated negative relationships with oiling level that remained after habitat factors were included as covariates in the analysis (Table 1 in Wiens *et al.* 2004). BACI comparisons with the 1984 baseline data yielded weak, nonsignificant indications of reduced abundance in oiled bays in 1989 and 1991. The oiled/unoiled abundance plot (Fig. 5) showed that numbers of mergansers were low in oiled bays in 1984–1991 and that many more mergansers were seen in previously oiled bays in 1996–2001. Wiens *et al.* concluded that merganser habitat use was negatively affected by the spill but had recovered by 1996. This example illustrates that a weight-of-evidence approach is useful for assessing multi-year data for biological resources that do not meet equilibrium assumptions.

Weight-of-evidence approaches are valuable for environmental data as well. For example, a weight-of-evidence-approach was used to sift through potential alternative hypotheses explaining high phosphorus values in the A.R.M. Loxahatchee National Wildlife Refuge in 2005 (http://www.sfwmd.gov/org/ema/toc/archives/2005_10_18/may-june_workgroup_evidence_handout.pdf). The approach assisted in determining whether unanticipated events had a meaningful influence on the environmental parameter of interest.

5.4.4 Sampling Environmental Gradients

Another approach for analyzing trends in recovering ecological systems is to study the changes in the response of ecological attributes along a known stressor gradient (e.g., hydrologic, water quality, etc.). This approach may be particularly suited for cases where the temporal extent of a database (i.e., baseline/reference) is not sufficient to detect statistically significant trends and changes beyond the limits of background variability. This methodology, which would incorporate sampling along environmental stressor gradients, can supplement other approaches to evaluate CERP induced changes.

In this approach, stations should be arrayed in a manner that enables detection of change in an ecological attribute's response along the stressor gradient of interest. Researchers should recognize that the domain necessary to detect change is scale-dependent, with specific spatial and temporal limits set by the particular stressor. The interpretation of data from gradient designs often requires a reference site that has the same physical, chemical, and ecological attributes as the gradient sites but is sufficiently remote so as not to be affected by the stressor of interest. To satisfy this requirement, a sufficiently broad spatial domain has to be incorporated into the sampling design. Alternatively, if a reference site cannot be identified, the interpretation of change will be limited to the sampling stations and be constrained by the threshold for the response of the ecological

attribute. Changes in the response along the gradient can be detected by analyzing the slope or other characteristics of the gradient response curve. The analysis of environmental gradients is not meant to supplant the approaches for determining trends of pre and post-CERP sampling protocols established in this guidance. However, it is offered as an alternative when data are insufficient to conduct BACI, statistical, or other types of analysis.

5.4.5 Other Designs

The examples described above provide sampling and analytical strategies that have demonstrated their usefulness for assessing recovery from environmental disturbance in temporally and spatially varying environments. Which design to apply in order to reduce the confounding effects of varying natural factors depends on several issues, including the availability of data for pre-disturbed conditions, and the financial and personnel resources needed.

Other sampling designs, such as time-series analysis, reference as covariate, and intervention analysis may prove equally useful or better for measuring changes due to CERP implementation, depending on the nature of the disturbance and the reasonableness of the ecological assumptions one makes (see Stewart- Oaten and Bence 2001). In addition to standard tests of hypothesis, assessments of recovery can be performed with at least three other parametric statistical methods, including confidence intervals, decision theory, and Bayesian methods. Confidence intervals provide useful information on how confident one can be of the true state of nature being close to the hypothesized null state.

Decision theory (DeGroot 2004) allows the investigator to adjust type I and II error based on penalties for wrong decisions. Fisheries and wildlife managers use decision theory, in which associated economic and social penalties (e.g., suboptimal fishery yields) are quantifiable. Decision theory would be practical for assessing recovery given penalties for making the wrong decision were quantifiable. In the absence of known or estimable economic, social, and/or ecological value, it is difficult to objectively quantify penalties.
Bayesian statistics (Box and Tiao 1973) rely on prior probabilities (for examining the truth of the null hypothesis). Each dependent variable would likely need its own prior probability, making it difficult to use Bayesian methods for multiple species, e.g., 25 species of seabirds. Such prior probabilities and their influence on results would be difficult to justify, especially for such high-profile assessments as the Everglades restoration.

In addition, nonparametric methods can also be used to test hypotheses, especially for biological data. Bootstrap, jackknife, permutation tests, and other simulation-based tests of hypothesis provide ways to avoid making assumptions about the distribution of residual error. In the examples cited previously, Gilfillan *et al.* (1995, shoreline ecology) and Wiens *et al.* (2004, seabirds) found generalized linear models (McCullagh and Nelder 1989) on members of the exponential family (e.g. negative binomial and Poisson) to be more realistic of natural conditions than computer-intensive nonparametric methods.

5.5 Summary

Recovery from an environmental disturbance involves re-establishment of the physical environment to a non-disturbed state and restoration of complex biological systems. The greater the disturbance and complexity of the system, the longer the anticipated recovery time. Natural environmental variation and the passage of time enlarge the probability field of what a non-disturbed resource would have been had the injury not occurred. Consequently, the longer the time to recovery, the less likely the recovered state will be what it was before the injury occurred.

Moreover, as Pimm (1991) has noted, population variability increases with the length of time considered, increasing the likelihood that one or another of the equilibrium assumptions will be violated. Defining the recovered state of a biological resource and inferring when a recovered state has been reached depends on what one can reasonably assume about natural variation of *both* populations and the environments they occupy.

The appropriateness or inappropriateness of the different assumptions about equilibrium is scale-dependent. This means that there is no single ‘‘best’’ study design or statistical analysis that will fit all situations. The risks of reaching conclusions based on incorrect assumptions about equilibrium are likely to be variable at different scales of investigation. The scales in turn depend on the species, communities, or environments being considered, the temporal and spatial scales of their natural dynamics, and the scale of the environmental disturbance itself. The scale of the impact is usually well defined, whereas scales of interdependencies among biological resources and their environments and of natural dynamics are generally unknown, at least with any degree of precision.

The burden is therefore on the investigator to use sound judgment (and documenting the steps in that judgment) in assessing the state of recovery of a biological or environmental resource. Underlying assumptions about equilibrium must be explicitly acknowledged and specified. There should be a clear *a priori* statement of what represents an acceptable level or end point for recovery. Given natural variation in the environment and the resources of interest, this means that one must consider the width of the envelope of natural variation, which in turn helps to define the appropriate “recovery zone” for the system.

5.6 Additional Applicable Resources

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6.0 EVALUATING HYPOTHESES AND INTERIM GOALS

6.1 Purpose

The guidance in the previous sections has focused primarily on detecting and measuring the magnitude and direction of change in individual performance measures and to determine if the changes are consistent with expected responses described in the CERP hypotheses. The focus of this section is not on the individual performance measures, but on the MAP hypotheses, which explicitly describe the causal pathways (i.e., stressor-response relationships) that explain how the system at the Module level behaves. Since there are multiple performance measures supporting the module-level hypotheses, this section will present a variety of approaches for integrating and interpreting physical, chemical, and ecological data (i.e., multiple performance measures) to assess the causal inferences comprising each hypothesis. If the trends or weight-of-evidence assessments of performance measures or hypotheses do not correspond to predicted responses, the Module Group will be expected to provide a scientific explanation. The assessment of module-level hypotheses will then be used to evaluate progress toward achieving IG/IT. The following sections will present the various methods and models that can be applied to assessing module-level hypotheses.

6.2 Approaches

The MAP is structured around the use of CEMs to develop working hypotheses clusters that describe how various defining ecological components of the system have and will continue to respond to stressors. One or more PMs developed for the critical stressors and defining ecological characteristics are then used to track the progress of the restoration in meeting its goals. The challenge for scientists will be to integrate and interpret the multiple PMs that comprise the hypotheses for that particular spatial domain.

At the module and system level of synthesis and integration, a range of analysis tools will be employed individually and in combination. These tools include, but are not limited to, CEMs, statistical regression models, numerical simulation models, and lines-of-evidence (LOE) and weight-of-evidence (WOE) analyses. The choice of analysis methods will depend on the nature of the performance measures, the hypotheses, the types and quantity of data, and the management goals and context. Thus, a suite of analysis tools will be applied to answer specific questions regarding the performance of various components of the system. The challenge is how to best synthesize and interpret the results of these multiple tools to provide an overall assessment for the Module or Total System.

6.3 Statistical Analysis

A variety of statistical tests and quantitative approaches have been used for investigating possible relationships between independent (stressor) and dependent (effects) variables acquired from monitoring programs. The basic types of statistical methods that can be used to examine the types of relationships that comprise the hypotheses in the CERP CEMs include:

- Simple descriptive statistics (i.e., means, ranges, variances, etc.)
- Exploratory statistics (i.e., multivariate correlation analysis and logistic regression)
- Statistical modeling (i.e., stressor-response relationships)
- Goodness-of-fit or maximum likelihood methods
- Trend analysis.

Patterns and trends in monitoring data can be estimated using parametric and nonparametric statistical tests. Typically a parametric test (e.g., single and multiple linear and non-linear regression, etc.) involves the regression of transformed and non-transformed data with time. Non-parametric tests use non-transformed data.

However, while statistical analysis can reveal relationships among data and provide insight to possible underlying mechanisms, establishing causation requires integration of additional knowledge. Because stressors generally co-occur and co-vary with each other and with natural environmental attributes, relationships between a candidate cause and a biological variable may be due to factors other than the candidate stressor. Statistical hypothesis testing was designed for analyzing data from experiments where treatments are independent, replicated, and randomly assigned. The application of these statistical tests to data from observational field studies, where treatments are: seldom replicated; randomly assigned to experimental units; at best pseudo-replicated; must be viewed with caution.

An overview of parametric tests, non-parametric tests, and the use of censored data are presented in the following section as a "primer" for approaching CERP analyses.

6.3.1 Parametric Tests

Use of statistical correlations, multivariate and logistic regression, and trend analysis are the most common statistical approaches for attempting to identify associations among environmental variables particularly in monitoring studies (Stowe *et al.* 1998, Johnson and Collier 2002). One of the most useful techniques is logistic regression analysis that is commonly applied to binomial or proportional data. A major advantage of logistic and multivariate regression analysis is that they allow the significance of relationships between the stressors and biological effects to be determined while adjusting for possible other influential treatment factors (e.g., season, temperature, etc.).

In time-series analyses, a linear trend is estimated by regressing a response variable (i.e., flow) as a function of an explanatory variable (i.e., time). In most cases, data must be log-transformed in order to improve linearity. If this transformation is used and assumptions of normality, constant variance, and independence are met, then a null hypothesis of zero slope over time can be tested. If the slope is significantly greater than zero, the null hypothesis is rejected and one can conclude that a linear trend over time has occurred. Because regression models do not account for error or dependence in the

estimates, a conservative p-value of 0.01 or less is recommended for determining significance.

For purposes of CERP, a trend may be defined as a change over time in the mean of the parameter of interest. Trends are identified when the magnitude and direction of change in a parameter of interest can be clearly differentiated from natural background variability. Historic datasets or monitoring programs therefore must be of sufficient duration and spatial extent to quantify the range of natural background variability. The length of the time series required to identify a trend will depend on the properties of the ecosystem component under study.

For example, the time-series required to define a trend in fast-response variables (e.g., water quality parameters downstream from a structure) will be shorter than the time-series required to determine trends in slow-response variables (e.g., sediment elevations, biological response, etc.). Many of the changes in CERP will generally occur over long-time scales (e.g., multi-year, decadal). Monitoring programs designed to measure trends in these ecosystem components must be of sufficient duration in order to differentiate the effects of CERP from interannual or inter-decadal variability.

6.3.2 Non-Parametric Tests

The following non-parametric tests are specifically designed to address tends in seasonal data that are particularly relevant to the wet-dry season patterns characteristic of South Florida. The Seasonal Kendall (SK) test (Hirsh 1982 1992) is a non-parametric test for seasonal trends for a mono-tonic linear trend that is resistant to outliers and is not dependent on the normality of the data set. By comparing only the data from similar seasons, the test also reduces seasonal effects when testing for trends

The Kendall-Theil (KT) analysis is another non-parametric test for monotonic linear trend by use of pairwise comparison and a Kendall's tau test for significance, similar to the Seasonal Kendall test. This test accounts for seasonality by calculating pairwise slopes on data within the same season with the overall trend slope computed from the median of the seasonal slopes. The KT analysis differs from the SK in that the KT seasonal adjustment method allows for increased power in the slope estimate when compared with the SK test.

6.3.3 Censored Data

A large number of data values that are below the detection limit (i.e., censored data) can adversely affect the estimation of the slope of a trend by not allowing for corrections because of variations in the variable of interest. The following guidance developed by USGS may be useful when dealing with censored data.

- <5 percent censored data – censored values will be assigned one half of the detection limit. For all trend tests, it is recommended that the p-value, the slope estimate, and the magnitude (percent change over time) will be reported.

- Between 5-20 percent censored data – three separate trend analysis tests of the data will be performed. First, on the raw data file with censored data set to half the detection limit; second, all censored data set to 0 (KT only); and third, all censored data set to the detection limit (KT only). In these instances, it is recommended that the highest p-value, the range in slope estimate, and a range in the magnitude of the trend be reported.
- >20 percent censored data – trend results will not be reported.

6.4 Simulation Modeling

Simulation models are basically mathematical models that attempt to integrate and show the interactions between multiple environmental components (i.e., physical, chemical, and biological) of the ecosystem and are becoming increasingly important in environmental management. However, there is an ongoing debate as to the relative merits of simple models that have been statistically fit to data versus more complex models that attempt to simulate chemical, physical, and ecological processes (Shipley and Peters 1991; Reckhow and Chapra 1999). There are well-founded arguments in support of each approach. If the relevant processes are understood and can be expressed mathematically, then a process-based model should yield reliable assessments and forecasts of system behavior. However, if not, then this approach becomes an exercise in calibrating an over-parameterized model to limited data rather than a true mathematical representation of our process knowledge. Statistical methods, on the other hand, are rooted in empirical observations that rarely have an explicit mechanistic basis. Consequently, no single model is likely to satisfy all needs. The following is a brief description of some of the modeling approaches available to CERP with examples of their applications.

At the module and system level of synthesis and integration, a range of modeling tools, individually and in combination, will have to be employed (e.g., CEMs, statistical regression models, and numerical simulation models) depending on the performance measures, hypotheses, types and quantity of data, and management implications of interest. The challenge is how to best synthesize and interpret the results of these multiple outputs to provide an overall assessment for the Module or System as a whole.

6.4.1 Modeling Approaches

The recovery of the Everglades will be the result of a number of interacting processes operating at multiple spatial and temporal scales. Modeling approaches, representing varying degrees of complexity, data requirements, and spatial scales may be used to assess changes in and the integration of multiple PMs. These include small spatial scale statistical models and habitat suitability index models (HSI), intermediate- scale models (e.g., Adaptive Ecosystem Assessment Models, Bayesian Network Models, Simple Ecological and Social Dynamics Models) and large-scale models driven by extensive data requirements [e.g., Lake Okeechobee Water Quality and Hydrology Models, Across Trophic Level Systems Simulation (ATLSS) and Everglades Landscape Models (ELM)].

However, the individual models developed to appropriately represent each of these scales and processes are not easily combined into a single assessment of evaluation model.

Intermediate scale modeling (as opposed to intermediate scale models) involves constructing a wide variety of models for assessment, parsing out the needed information from each, and then integrating the results. This approach must serve both as a assessment (post-CERP project implementation) and an evaluation tool (prior to project implementation). Evaluation (forecasting) is also done as part of the adaptive management process. The foundation of both evaluation and assessment rests on the ability to predict future results of project implementation while including estimates of uncertainty. The focus of the this Gudiance is to provide the assessment framework (e.g., data, statistical methods and models) that are appropriate for both evaluation and assessment.

Walters *et al.* (1992) demonstrated the use of his Adaptive Environmental Assessment Model (AEAMs) as a tool for screening water policy alternatives for ecological restoration in the Everglades. Carpenter *et al.* (1999), has developed simple ecosystem management integrated simulation models (Ecological and Social Dynamics Models) to explore and illustrate interactive dynamics of socio-ecological systems in a lake subject to phosphorus pollution. The Bayesian network modeling approach employs a graphical structure, analogous to the CEMs, to explicitly represent the variables and causal relationships involved in the relevant processes (Borsuk *et al. in press*). In so doing it provides a framework to integrate a variety of models representing a number of interacting processes operating at multiple spatial and temporal scales. This graphical approach explicitly represents cause-and-effect assumptions between system variables that may be obscured under other approaches. Brief discussions of these types of modeling approaches can be found in the attached Appendix C.

It is unlikely a single model will capture the explicit dynamics of parameters and processes occurring over multiple temporal and spatial scales. However, simulation models should be used as one of a spectrum of quantitative tools in the assessment and evaluation process that can be use to estimate and predict changes in multiple sets of variables. A suite of modeling tools, individually and in combination, may be employed (e.g., CEMs, statistical regression models, and numerical simulation models) depending on the performance measures, hypotheses, types and quantity of data, and management implications.

6.4.1.1 Bayesian Network Models

The basics of Bayesian networks and their application to environmental prediction are well described in the literature (Reckhow 1999, Borsuk *et al.* 2002). The Bayesian network modeling approach employs a graphical structure, analogous to the conceptual ecological models employed in CERP (e.g., Wetlands [2005] Vol. 25, No. 4), to explicitly represent the variables and causal relationships involved in the relevant processes (Borsuk *et al. in press*). In so doing it provides a framework to integrate a variety of models representing a number of interacting processes operating at multiple spatial and temporal scales. This graphical approach explicitly represents cause-and-effect assumptions between system variables that may be obscured under other approaches. Note: hypothesis cluster concept for inferring causal relationships

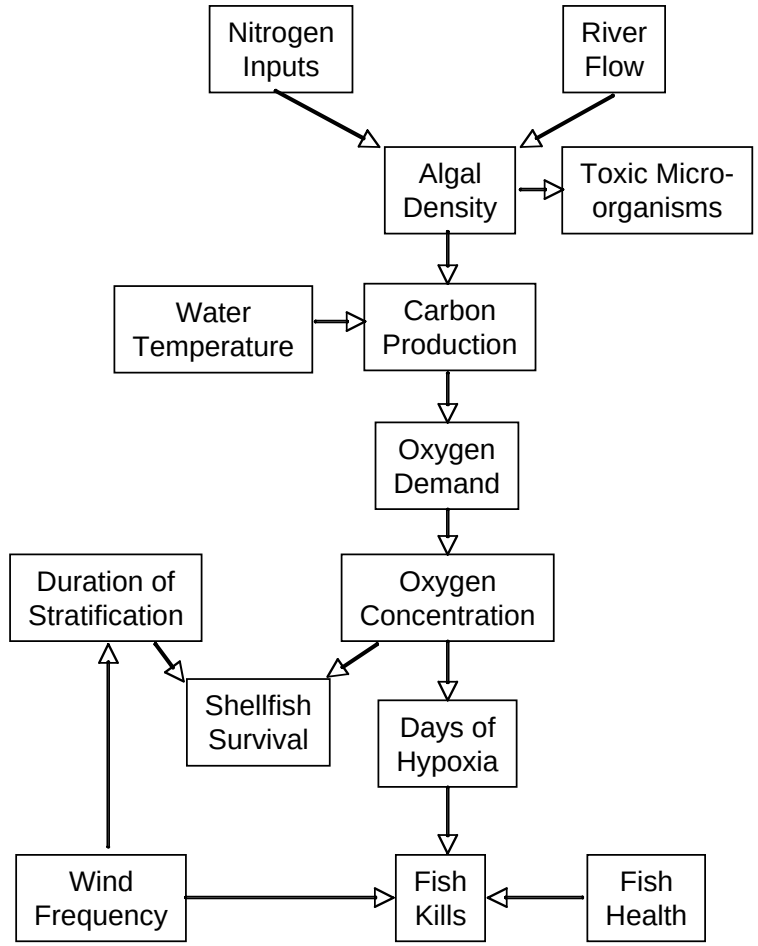

Figure 6-1. Causal network of important factors involved in the eutrophication of the Neuse estuary.

Figure 6-1: Causal network of important factors involved in the eutrophication of the Neuse Estuary

Briefly, a Bayesian network is a graphical depiction of the relationship among the most important variables in the system of interest (Figure 6-1). In this illustration, the variables are represented by square nodes, and dependencies between one variable and another are represented by arrows. The conditional independence, implied by the *absence* of any connecting arrows, greatly simplifies the modeling process by allowing separate sub-models to be developed for each conditional relationship indicated by the *presence* of an arrow. These sub-models may be derived from any combination of

process knowledge, statistical correlations, or expert judgment, depending on the extent of information available about that particular relationship.

In a Bayesian network, each dependency indicated by an arrow is characterized by a conditional probability distribution that describes the relative likelihood of each value of the down-arrow node, conditional on every possible combination of values of its parents. A node that has no incoming arrows is said to have no parents, and such a variable can be described probabilistically by a marginal (or unconditional) probability distribution. A useful practice when developing conditional distributions in the network is to view them as functional relationships among variables [Pearl 1999].

Because the Neuse Estuarine system was studied at multiple scales, a modeling framework was necessary that represented all relevant system processes (Borsuck *et al.* 2004). The Bayesian network analysis framework was chosen in this study because of its ability to integrate sub-models of disparate scales. Choosing the various scales of representation in a Bayesian network should be a dynamic and iterative process. This is because the scales which are chosen to represent key features of the ecosystem are often imposed by observational capabilities, technological, or organizational constraints [Levin 1992] which may evolve over time. Further, the scale of prediction should correspond to the needs of decision-makers, which may also change with time as they gain understanding of the problem.

6.4.2 Model Applications

There are a number of examples of model applications under development or being used in South Florida. Below, three (one from the Greater Everglades, another from Lake Okeechobee, and one from Florida Bay) are presented here that encompass the spectrum of intermediate-scale modeling tools considered for use in modeling ecosystem responses to CERP implementation in South Florida.

6.4.2.1 Greater Everglades Wading Bird Model

The CEM (See Section 9.2.1) provides a description of the causal linkages between hydrological patterns, the abundance and distribution of prey species and the success of wood stork and spoonbill nesting. An example of how the CEM can be used to develop an intermediate-scale modeling framework is illustrated in Figure 6-2. The proposed model for wading birds presents a different way of representing interactions by showing not only the hydrology model, which acts as the foundation, but illustrates the various sub-models that spinoff and quantify the functional relations illustrated by the conceptual model sub-hypotheses for vegetation, fish, and wading birds. The model can be used iteratively by applying five to ten years of data to the previous five to ten years worth of data, allowing scientists and managers to compare model predictions with the annual assessments of the monitoring data. The ability to iteratively refine the model strengthens it as a predictive tool.

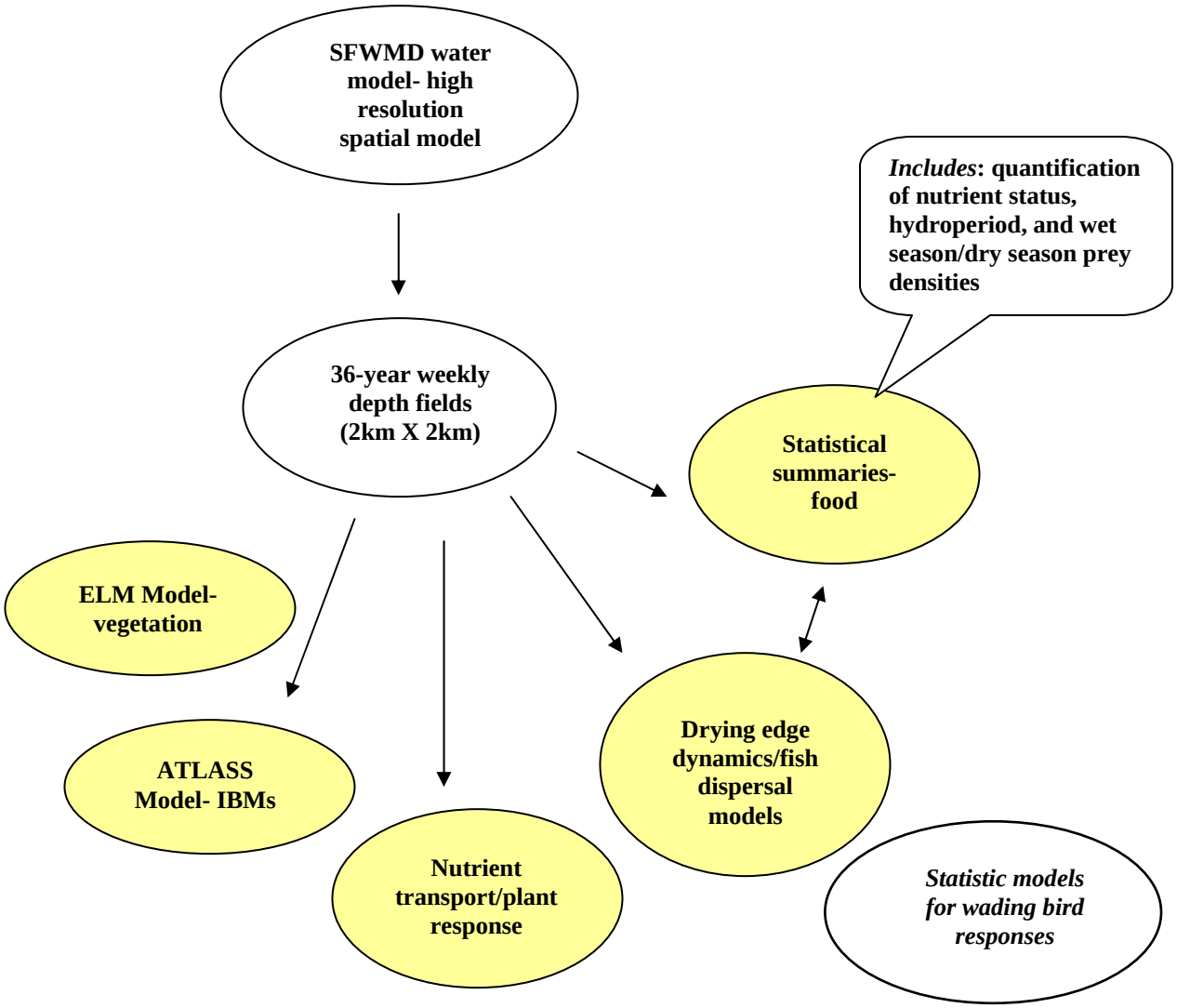

Figure 6-2: Hydrology Effects of CERP on Wading Birds and Their Prey Base

6.4.2.2 Lake Okeechobee (Hypothesis Assessment Model)

A second example can be used to illustrate the testing of a hypothesis from the Lake Okeechobee MAP module: "At lower lake stages, increased light penetration results in an increase in the biomass and spatial extent of submerged aquatic vegetation, and in turn, increased recruitment success of largemouth bass in Lake Okeechobee" (RECOVER 2004). The first component to be analyzed is the relationship between stage and plant biomass. A simple multiple regression model is used to predict plant biomass from measured water depth and suspended solids (Havens *et al.* 2004). In addition, a STELLA[PE1] Model developed for submerged plants in the lake tracks the plant biomass changes as a function of lake stage (e.g., water depth). The third component compares submerged vegetation with largemouth bass size structure. The model predicts successful bass recruitment when biomass of submerged vascular plants becomes high,, and very low recruitment of bass when submerged vascular plant biomass is low (no plants, or dominance by *Chara spp*.) (K. Havens, personal communication).

6.4.2.3 American Crocodile (Evaluation Model)

The American crocodile is an endangered species in the Everglades ecosystem. A key component of the CERP is re-establishing freshwater flows to mangrove estuaries that are critical crocodile habitat (Chartier *et al.* 2005). The purpose of this study is to forecast the crocodilian population responses to alternatives for restoration using integrated hydrological and ecological models. A salinity-based habitat model was developed to evaluate restoration of freshwater flows to the mangrove estuaries and the Southern and Inland Coastal Systems Model (SICS) was used to generate alternative freshwater flows, depths, and salinity for the ecological habitat model. The habitat model is comprised of three processes: hatchling growth and survival, forage production, and forage availability (Chartier *et al.* 2005). The SICS and habitat models were used to investigate: 1) how does the amount of freshwater entering Florida Bay affect suitability of crocodile habitat; and 2) what would be the impact of restoring the historical water flow into the ecosystem? By using the coupled intermediate scale models, the authors concluded that the relative suitability of crocodile habitat in northeastern Florida Bay is driven by the amount of freshwater flow to the Bay. Second, the location and delivery of water may be less important than the amount of freshwater flow. This study illustrates the concept of integrating statistical relationships between salinity and flow forecasts from a hydrodynamic, physically based simulation model and a habitat suitability index to determine the areal extent of suitable habitat for the crocodile (Chartier *et al.* 2005).

6.5 Causal Inference: Lines-of-Evidence Approach

The focus of the MAP assessments is to evaluate hypotheses that describe the functional relationship between one or more stressors and ecological attributes of interest Implicit in the MAP hypotheses is the concept of causation. While it is often difficult to establish causation definitively from environmental data, one can develop criteria for supporting or rejecting the hypothesis using weight-of-evidence or multiple-lines-of-evidence strategies.

Lines-of-Evidence (LOE) (sometimes referred to as Weight-of-Evidence [WOE]) approaches have a long history in courts of law. While criminal law in the United States refers to proof beyond a reasonable doubt, civil law refers to "preponderance of evidence". Both criminal and civil actions depend on a WOE approach (Chapman *et al.* 2002). Formalized use of WOE frameworks for integrating and interpreting multiple lines of evidence in environmental sciences is relatively recent and includes individual LOE as well as combined LOE. Hill (1965) suggested nine criteria for inferring causality: strength of association, consistency, specificity, temporality, biological gradient, plausibility, coherence, experimental evidence, and analogy. Mosteller and Tukey (1977) noted three criteria: consistency, responsiveness, and mechanism that must be satisfied to infer cause-effect relationships. Table 6-1 summarizes different lines of evidence for inferring potential causal relationships.

Table 6-1: Comparison of criteria for establishing causality from different sources

Fox (1991); Suter *et al.* (2000); Burton *et al.* (2002)	**US EPA (2002)**	**Suter *et al.* (2002)**	**Hill (1965)**
Strength of association (between stressors(s) and effects (s))	Effect magnitude (strength of link)	Complete exposure pathway	Strength of stressor effects association
Consistency of association (between stressor(s) and effects(s))	Consistency of association (at multiple sites)	Consistency of association	Consistency of response in different circumstances
Gradient (spatial or temporal concentration or dose-response relationship.	Co-occurrence (spatial/temporal correlation)	Co-occurrence Temporality Biological gradient	Temporality – stress precedes response Biological gradient
Plausibility (probable cause-effect mechanism)	Experimental confirmation (field or lab)	Plausibility Experimental	Plausibility – stress response relationship is consistent with theory
Specificity (association specific between stressor(s) and effects(s))	Specificity (stressor causes unique effect)	Specificity of cause Predictive performance	Specificity – uniqueness (diagnostic) of stressor-effect relationship
Analogy (other cases with same relationship of stressor(s) to effects(s)	Plausibility (likelihood of stressor-effect linkage)	Analogy	Analogy – similar stressors associated with similar effects
These cells intentionally left blank			Coherence – stressor effects hypothesis consistent with available evidence Experimental evidence supports stressor-effect causal relationship

Often these criteria are weighted equally when assessing causality. However, Menzie *et al.* (1996) used a weighted approach in an ecological risk assessment (ERA) context. Here WOE is defined as a weighted multiple-lines-of-evidence for assessing the strength of the relationship by which measurement endpoints (e.g., PMs) are related to assessment

endpoints (e.g., valued ecological attributes, defining ecological characteristics) based on weight, magnitude and occurrence. Ten separate judging attributes are used, which may be equal or weighted: degree of association; stressor/response; utility of measure; data quality; site specificity; sensitivity; spatial and temporal representativness; quantitative measure, and standard methods of measure. The Menzie *et al.* (1996) approach also allows for varying degrees of best professional judgment, which allows the quantitative matrix approach for weighting attributes to be replaced by a qualitative weighting system. This approach might be particularly applicable to assessing the importance of multiple PMs for evaluating specific hypotheses clusters when data is not sufficient for a quantitative assessment.

Approaches for combining lines of evidence can be broadly divided into five different categories: indices, statistical summarization, scoring systems, logic systems, and best professional judgment (Burton *et al.* 2002, Chapman 1996). Similarly, a variety of analytical methods can be used for analyzing each line of evidence including: trend analysis using regression analysis; ANOVA methods including BACI, covariate analysis, and multivariate regression analysis.

6.5.1 Decision Frameworks Based on Weight-of-Evidence (WOE) Methods

The linkage of multiple variables within a hypothesis (LOEs) to inform a decision is a multi-step process that involves weighing the strength of evidence that supports each relationship. This strength of relationship is established using criteria outlined in Koch's postulates (Suter 1993) that were originally developed to infer causality between pathogens and the manifestation of disease. These postulates are:

- The adverse effect must be regularly associated with exposure to the stressor
- The stressor must be found to co-occur in space and time with the receptor
- The adverse effect must be manifest in unimpaired species (i.e. healthy) following exposure to the stressor
- The stressor must be found in the affected species

Koch's causal postulates can be satisfied by applying the causal criteria described in Table 6-1. After these evaluations are conducted, individual expert qualitative judgments interpreting the relationships (i.e., potential causality) can be integrated using a tabular decision matrix. The results of these expert judgments can be summarized in a tabular decision matrix. For example, converting to ranks (e.g., 1 to 4 or "+" and "-" values) per Chapman (1990 1996) Grapentine *et al.* (2002), USEPA (2000).

There are a variety of qualitative and quantitative approaches for integrating multiple LOE into a weight of evidence based decision (Burton *et al.* 2002). The following table summarizes these approaches and discusses the strengths and limitations of each approach.

Table 6-2: Advantages and Limitations of Different WOE Approaches for Combining LOEs

	Robustness	**Method**	**Sensitivity**	**Appropriateness**	**Transparency**
Qualitative	Low	High	Low	High	Low
Expert Ranking	Low	Moderate	Moderate	High	Low
Consensus Ranking	Low	Moderate	Moderate	High	High
Semi-quantitative ranking	Low	Moderate	Moderate	High	Low
Broad Scale Multiple WOE	Moderate	Low	Moderate	High	Moderate
Quantitative Likelihood	Moderate	Low	High	High	Moderate
Tabular Decision Matrices	Moderate	Moderate	High	High	High

All WOE approaches depend on data quality, study design, and expertise used in a manner to best infer the causal links between stressors and effects. The advantages and limitations of each approach can be generally characterized using the evaluation criteria in Table 6-2 where:

- **Robustness** = consistency in interpretation and decision-making irrespective of when and where conducted
- **Method** = ease of use, if the approach is to complex or expensive it is unlikely to be widely used
- **Sensitivity** = providing good discrimination not only between extremes but also for intermediate situations
- **Appropriateness** = broadly applicable, not restricted to specific conditions of environments
- **Transparency** = readily understandable at both the LOE and WOE levels.

Most of the literature on WOE or multiple LOE approaches simply "lump" the various LOE results in a non-quantitative manner. The effectiveness/accuracy of any LOE/WOE approach is contingent on: 1) the quality of the data; 2) the quality of the study design; 3) expertise of the principal investigator(s); 4) the severity of the disturbance/impact; and 5) a matching of the objectives to the data. Accurate WOE conclusions require excellence in factors 1, 2, and 3. In general, qualitative approaches for combining multiple LOEs can be categorized as having low robustness, high ease of use, low sensitivity, high appropriateness and application, and low transparency (Table 6-2).

A variety of expert ranking methods have been proposed (e.g., Swanson and Socha 1997, Calabrese *et al.* 1997, Bombadier and Bermingham 1999) that all rely on a panel of experts using Best-Professional-Judgment (BPJ) to arrive at an integrated assessment. However, the expert ranking system is not very robust, moderately difficult to use, moderately sensitive, highly appropriate/applicable, and not readily transparent.

The consensus ranking approach derives from the desire to include stakeholders in the decision-making process. The most common method to inform stakeholders is to use ranking methods displayed as tabular decision matrices (Chapman 1990,Chapman *et al.* 1996, and Menzie *et al.* 1996). Because of both variability and acceptability factors, ranking has evolved into a consensus-based process where stakeholders agree to the study design and how the data will be interpreted. Menzie *et al.* (1996) describes a consensus-based process for WOE that has both weighting and scaling factors that are agreed upon, a priori, by mangers, stakeholders, and scientists. The primary advantage of the consensus-based metric ranking approach is that it can achieve, *a priori,* a general consensus between stakeholders on the study design and interpretation in a WOE approach.

Semi-quantitative ranking approaches have been widely used both within LOE (e.g., benthic and fish metrics, etc.) and between LOE (physical, chemical, and toxicological data) for sediment toxicity. Other semi-quantitative approaches permit the adjustment of metrics for certain non-stressor covariates, such as stream size, in the computation of the Index of Biotic Integrity (Karr 1981). This approach varies widely in its design; however, in general it is not very robust, has moderate levels of methodology and sensitivity, while the appropriateness/applicability is high but the transparency is moderate to low.

Broad-Scale WOE incorporates multiple WOE approaches (e.g., qualitative, ranking, or semi-quantitative) to varying degrees. A variety of methods can be incorporated under this rubric that demonstrate how knowledge gained through time from a variety of case studies with similar stressors and comprised of multiple LOE may be used to establish causality and link environmental components in a decision-making framework (Lowell *et al.* 2000, Culp *et al.* 2000). The US EPA (2002) and Sture *et al.* (2002) describe a non-quantitative stressor identification evaluation process that sets out a framework for establishing the basis for impact using a WOE process. In this process, BPJ is used to score the several causal criteria (Table 6-1) using ranks (e.g., 1 to 4; or "+" or "-") but does not permit summing because that would imply equal weighting. This type of approach is moderately robust with methods being somewhat complex. Its sensitivity is moderate, however its appropriateness and application are high and the level of transparency is low.

Quantitative likelihood takes advantage of the fact that many LOE involve quantitative measurements. While this is often viewed as an advantage over qualitative information, the issue of interpreting the ecological importance of statistical significance must be addressed (Goodman 1999). The details of this approach are beyond the scope of this guidance but can be found in Burton *et al.* (2002) and cited references.

Tabular decision matrices for WOE were first proposed by Chapman (1990) and continue to be developed and refined (Chapman *et al.* 1996, Grapentine *et al.* 2002, Menzie *et al.* 1996). The advantage of tabular decision matrices is to provide information on individual LOE relative to, at the simplest level, a binary classification (e.g., altered or not). The tabular ranking approach has many advantages over the other ranking

approaches, being moderately robust, has moderate methodology, and high degrees of sensitivity, appropriateness/applicability and transparency.

6.5.2 Application of Integration Approaches

For the purposes of illustration (Figure 6-3) we have selected one of the conceptual model MAP hypotheses from the Greater Everglades Wetlands Module that links MAP field data on hydrology, aquatic prey fauna, and wading birds. The measurable change, between pre- and post-CERP conditions is then estimated for each of the physical, chemical, and biological variable and/or their metrics using either statistical or modeling approaches. The outcomes from these analyses are referred to as lines-of-evidence (LOE) which are then combined into a weight-of-evidence (WOE) decision.

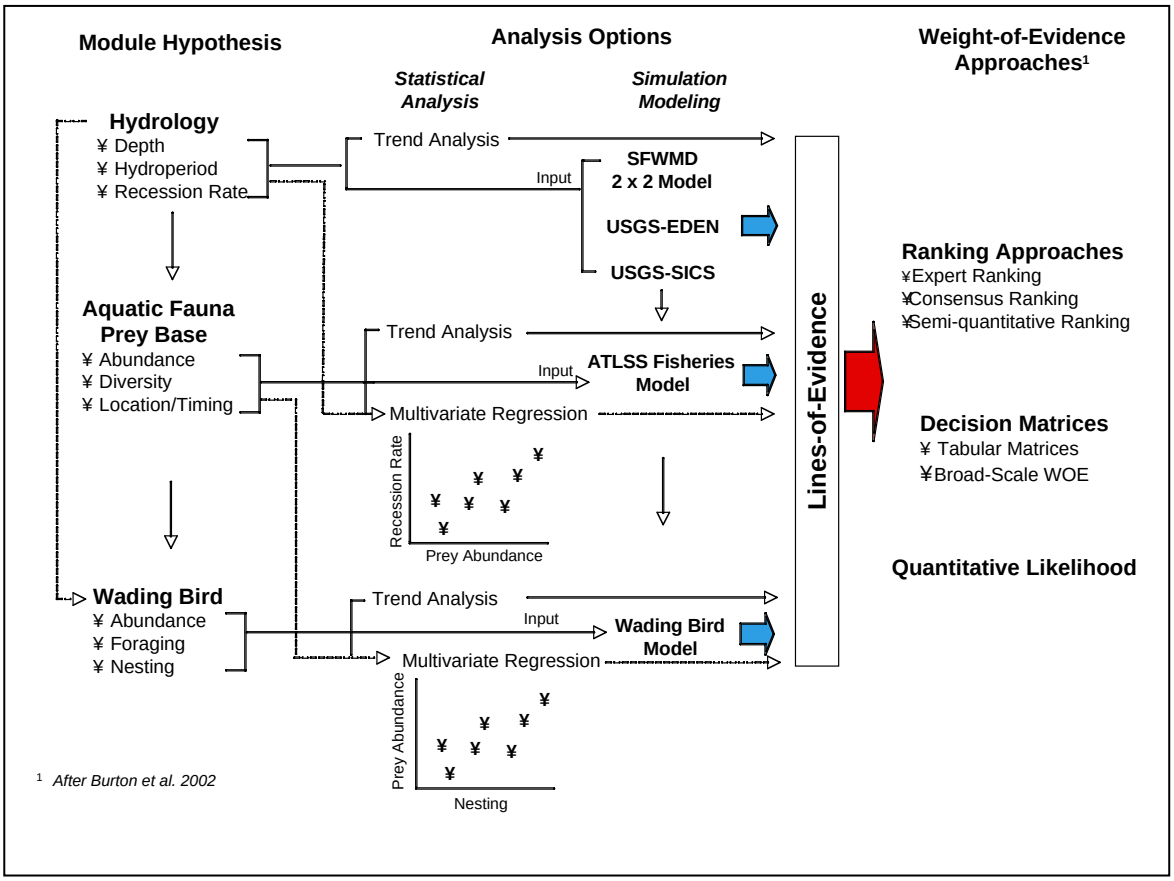

Figure 6-3: LOEs and WOEs for the Greater Everglades

In this example, all the attributes (physical, chemical, and biological) can be analyzed using a variety of parametric and non-parametric statistical approaches as discussed above. At the very least, each variable, nine in this example, will be examined over time to illustrate the trends for pre- and post-CERP time. In addition, multiple variables can be analyzed using multivariate statistical methods to examine relationships between stressor and response variables (e.g., as many as twelve in this example, as well as their important non-stressor covariates to understand and interpret the status of the hypotheses.

Each of the nine variables can be used as input terms to various modeling modules that can be combined to address a specific hypothesis. In addition, the output from the simulation modeling is considered a LOE and will be available for interpretation. Each of these analyses can be treated as a line-of-evidence (LOE) and combined into a weight-of-evidence (WOE) assessment to determine the status of the hypothesis or interim goals.

In the example illustrated in Figure 6-3, recession rate was chosen as a hydrological variable because of its importance in controlling the density and spatial distribution of aquatic prey species. Information on this variable, generated from field data or modeling, can be used in three ways: 1) it can be analyzed as a trend (pre- and post-CERP) using a BACI or similar approach; 2) as input data into an ecological model; and 3) as the independent variable in a multivariate regression analysis with data on prey abundance. Similarly, aquatic prey abundance can be analyzed as a trend; as input into a spatially explicit model (ATLSS); or as the dependent variable in a multivariate regression analysis with nesting success. Together, these analyses form lines-of-evidence (LOE) that contribute to our understanding of how well the hypothesis captures the functional relationships between the variables. However, there remains the issue of synthesizing and interpreting the information from each LOE to inform a decision.

6.6 Environmental Indices

Indices are widely used to convey clear and simple messages about what is happening to the environment to decision/policy makers and the public at large (www.wwf.org; www.heinzctr.org, www.epa.gov). Most indices are built from environmental indicators and serve to: (1) reduce the number of measurements and parameters that normally would be required to give an "exact" presentation of a situation; and, (2) simplify the communication process by which the results of measurement are provided to the user. Indices are included here as one more option for integrating the diverse suite of variables and multiple lines of evidence that form the basis of specific CERP hypotheses regarding the restoration of the South Florida ecosystem.

An index can be defined as an aggregated and weighted assemblage of one or more like elements that can be used to track the overall performance of these elements. For example, economists use the Dow Jones Industrial and S&P 500 indices to follow the performance of the stock market. Each of these indices represents a sub-set of stocks in the total stock market. If your interest is in an aggregate measure of large capitalization stocks then the S&P 500 index will provide that information. However both within the index and outside (stocks not included as part of index) there can be stocks that have totally different trajectories (i.e., rates of growth). If knowing the performance of one specific stock is important to you the index will not provide you that information. Consequently, both the composition (scale) and degree of aggregation used to develop the index must be relevant to the questions needing to be addressed.

Applying this concept to CERP indicates that an index designed to assess the health of a specific module may be quite different than that designed for the total South Florida ecosystem. The same argument applies to performance measures – if we index them

we'll get an aggregate view but if a particular property is critically important (e.g., dry-season recession rate) and it either isn't included or properly weighted in the construction of the index then something very important will not be properly evaluated.

Indices are being widely and successfully used for environmental management, however, there utility is dependent upon the management question being asked and whether you can adequately characterize the health of the system using a sub-set of data. Multi-metric indices (i.e., diversity, similarity, and biotic) have become the standard in the United States for accurately assessing watershed health (www.epa.gov/bioindicators). The index of biotic integrity (IBI) for freshwater streams includes: species richness and composition metrics; indicator species metrics; trophic function metrics, reproductive function metrics, and abundance and condition metrics.

There are five activities that are central to constructing effective multi-metric biological indexes. The first is classifying environments to define homogeneous sets within or across similar habitat types (e.g., streams, lakes, or wetlands; large or small streams; warm-water or cold-water lakes; high- or low-gradient streams). The second is selecting measurable attributes (i.e., metrics, performance measures, etc.) that provide relevant and reliable signals about the ecological effects of stressors. The third is developing sampling protocols and designs to ensure that those physical, chemical, and biological attributes are measured accurately. The fourth is devising analytical procedures to extract and understand relevant patterns in those data. The fifth is communicating the results to the decision-makers, policy-makers, and the public.

6.6.1 Aggregation of Variables

The aggregation of variables is crucial to developing an index that accurately reflects the state of the ecosystem. The term aggregation is used to refer to the grouping and amalgamation of two or more different variables into one index. It is not used to refer to the grouping of the values of the same variable at different sites to achieve some overall representative value of that variable over a larger area. Nevertheless, most indices are also based on some kind of geographical aggregation that requires classification systems, definitions, nomenclatures, data production methodologies, measurement methods, etc., be consistent among the contributing data sources. One generally distinguishes:

- Spatial aggregation that is dependent on geographic scale. Regional and national environmental statistics are often based on the compilation and aggregation of data produced at sub-national level. The choice in geographic scale influences the area over which monitoring results can be estimated and whether the data can be aggregated on an ecosystem, administrative boundary or other geographic level and be representative of conditions over that area.

- Temporal aggregation is linked to the natural "variability" of the parameters monitored and to the need for more synthesized and usable information (e.g. annual averages for parameters measured daily or even hourly).

- Thematic aggregation is linked to the need for more readable and digestible information. Thematic aggregation establishes totals based on data for subcategories (e.g. total SOx emissions based on emission inventories, or total water resources based on water accounts). It may further be used to establish indices of urban air quality, global warming potential, acidifying substances, nutrient balances, etc., through the use of proper conversion factors

6.6.2 Aggregation Methods

Aggregation can be defined as the process of combining variables (e.g., physical, chemical, and biological performance measures) or units with similar properties to produce a single metric that represents the approximate overall value of its individual components. Even though each of indices may use its own unique aggregation methodology, the aggregation of two or more variables into one index typically involves the following steps: 1) selection of variables that are representative of the topic, policy issue or phenomenon of interest; 2) transformation of data is necessary when the selected variables do not have the same dimension ("apples and oranges") and to ensure that changes in one variable do not dominate those of the others in the final score of the index. This requires the use of a common metric as well as normalization and/or standardization to produce a common scale.); 3) weighting of the constituent variables before combining them, and 4) valuation of index scores by comparing them with a predetermined classification of what constitutes acceptable or unacceptable values.

The use of indices is offered here as one more approach to the integration of multiple-lines of evidence for the purposes of informing decision-makers and the public as to the status and trajectory of the South Florida ecosystem restoration.

6.7 Summary

The integration and interpretation of the impacts of multiple physical and chemical stressors on a specific ecological attribute, as described in a CERP hypothesis, will require the application of quantitative statistical and modeling methods as well as integration methods such as multiple-lines-of evidence (LOE) and weight-of-evidence (WOE) approaches. There is no "silver bullet" or single model that can address the complex issues of the temporal and spatial scales that characterize CERP. The intent of this guidance has been to present a very brief overview of statistical, modeling, and WOE approaches that have been used to analyze, integrate, and interpret monitoring data for the purposes of inferring the relationships between the stressors and effects described in the MAP hypotheses. Given the limitations of the various analysis approaches discussed above, it is evident that combinations of statistical, modeling and LOE/WOE methodologies will be needed to evaluate the MAP hypotheses and provide the information needed for interim goals and adaptive management.

6.8 Additional Applicable Resources

Human and Ecological Risk Assessment (December 2002, Volume 8, Number 7). Weight of Evidence Debate and Commentary. While papers in this volume focus on the application of WOE approaches and assessments of sediment quality issues the concepts and methodologies are applicable to or can be tailored to CERP assessments. It is a useful resource on the topic.

Human and Ecological Risk Assessment (December 2003, Volume 9, Number 1). Causal Relationships between Exposure (Stressors) and Effects in Field Studies: Debate and Commentary. There are 14 papers in this discussion that are relevant and can be tailored to making an assessment of the MAP hypotheses.

Details on the development, comparisons of approaches, applications at various scales, examples from different habitats, as well as recommendations of useful statistical methods for constructing and analyzing multi-metric indices can be found at the following websites. (www.epa.gov/bioindicators, www.wwf.org, and www.heinzctr.org/ecosystems/report.html)

7.0 SYSTEM-WIDE PERFORMANCE ASSESSMENT

The purpose of this section is to describe the synthesis of findings across modules and across years to provide a holistic description of the status of the system and interpret the results relative to supporting system-level hypotheses and meeting IG/IT. It is at this point that a summary is prepared of those changes that are consistent with goals and hypotheses and those that are not. If necessary, a scientific explanation should be provided as to why the goals and hypotheses are not being achieved (see Section 7.2).

7.1 Across-Module Integration of Performance Measures

The integration of information across modules to provide a system-wide synthesis of the information and an evaluation of CERP progress presents conceptual and analytical challenges to completing the system-wide assessments. Consequently, this initial guidance will focus on framing the appropriate questions and process for approaching system-level synthesis. This process begins with a clear definition of the system-level goals and expectations for the restoration as defined by CERP. The Technical Assessment and Reporting Timelines section of this guidance (Section 8.0) outlines a reporting structure that is hierarchal in scale and integration culminates in a system-wide synthesis of information. The minimum reporting requirements provide general guidance on what is to be expected at each level of reporting but do not provide clear strategy and process for identifying the goals and expectations for the assessment process at each level or scale (e.g., PI, Module, and System). This is particularly difficult at the system-level which is where we will focus the following discussion.

The primary question is "How do we want to characterize "system-wide" success?" To do this requires identifying those physical, chemical, and ecological attributes that are critical to measuring restoration success at the system level and which will be reported to the Public and Congress as the keys to assessing the success of the restoration. However, this level of aggregation and synthesis must be coupled to the actual scientific assessments in a meaningful and transparent manner.

For example, one of the defining characteristics of the pre-drainage Everglades was the wide and expansive populations of wading birds. For purposes of illustration let us assume that the restoration of the wading bird populations is one of the system level goals of the restoration and that both the public and Congress are expecting to know how the program is progressing towards that goal. This goal has then been translated, scientifically, to one of the dominant hypothesis-clusters for the Greater Everglades Module where most of the actual research will be conducted. Consequently, a system-wide assessment of this "defining characteristic" will rely heavily on the results from the Greater Everglades Module with additional relevant information from other modules.

The System Level assessment of the status and condition of wading birds will then be a compilation of the quantitative results reported by the Greater Everglades Module along with other relevant information from the modules and the literature to provide an overall assessment that illumines our current understanding of how well we are moving toward

System-wide goals associated with this attribute in a general, semi-quantitative manner. The following are some recommendations that might prove useful in assessing the interface among multiple modules. First, identify the points of interface and interconnections and overlap between modules, or the effects of changes in one module on another (e.g. Greater Everglades effects on Southern Estuaries). These inter-module connections should be identified in advance of the synthesis to facilitate the synthesis. Second, highlight successes and when possible link them to an IG and the defining attributes not as statements of fact but as inferences that remain to be verified as the program continues. Third, identify emerging issues: those relevant to the validity of our hypotheses; and, those issues that are totally unanticipated and require attention.

Interconnections among modules should be placed in the context of the overall restoration effort and articulated by the module level hypotheses, IGs, or the system-wide "defining characteristics" of the pre-drainage Everglades. This implies a "hierarchy" for the reporting presented in the Reporting and Timelines Section. As the process moves through the hierarchy, it decreases in analytical robustness, i.e. the models may progress as far as the Module Group individual hypothesis clusters (e.g., intermediate scale) but not much beyond.

However, one approach for addressing our current analytical limitations is to use the "defining characteristics" as the highest level and then identify those critical system-level structures and processes that are necessary to move the system trajectory closer to the pre-drainage condition for each of the defining characteristics identified in the Total System CEM (Ogden et al. 2005). Using this as a point of departure, identify all the lines of evidence needed to evaluate the defining characteristic or the IG. Then identify which modules are contributing this information. This will determine the points of interface and connection between the modules that will be used in a synthesis statement for that defining characteristic. We can also "weigh" the relative importance of the lines of evidence as part of the synthesis to make it more robust. This approach obviates the need for a traditional analysis framework or models but does present a "transparent" process for reaching conclusions at the system level.

7.2 System-wide Synthesis and Interpretation of Assessment Results

Three plausible alternatives for interpreting system-wide assessments are illustrated in Figure 7-1. For this discussion, it is important to note that system-wide assessments do not account for the effects of stochastic events.

The first alternative recognizes that there was insufficient data or time to determine a pattern or trend. Two possible explanations can be postulated: (1) insufficient time for either the performance measure or the system to respond in a measurable manner allowing for the MAP hypothesis to be critically examined; or (2) incorrect metrics are being measured and reported. In the former case, the monitoring should continue until the performance measure being assessed is adequately characterized. In the latter case, the option is to modify the MAP.

The second alternative is that the monitoring trends and research results are inconsistent with and/or do not support the hypotheses or the IG/IT. This could result in the following options: (1) modify the hypotheses, conceptual ecological models and/or the associated performance measures; (2) modify the tools (e.g., hydrologic models); and/or (3) identify system-wide hydrological and/or ecological needs to improve performance of the Plan.

The last option would provide the basis for initiating the next phase of the adaptive management process, which addresses alternatives for modifying water management operations and/or the Plan. No action is needed because the trend detected that is consistent with the hypotheses and the IG/IT.

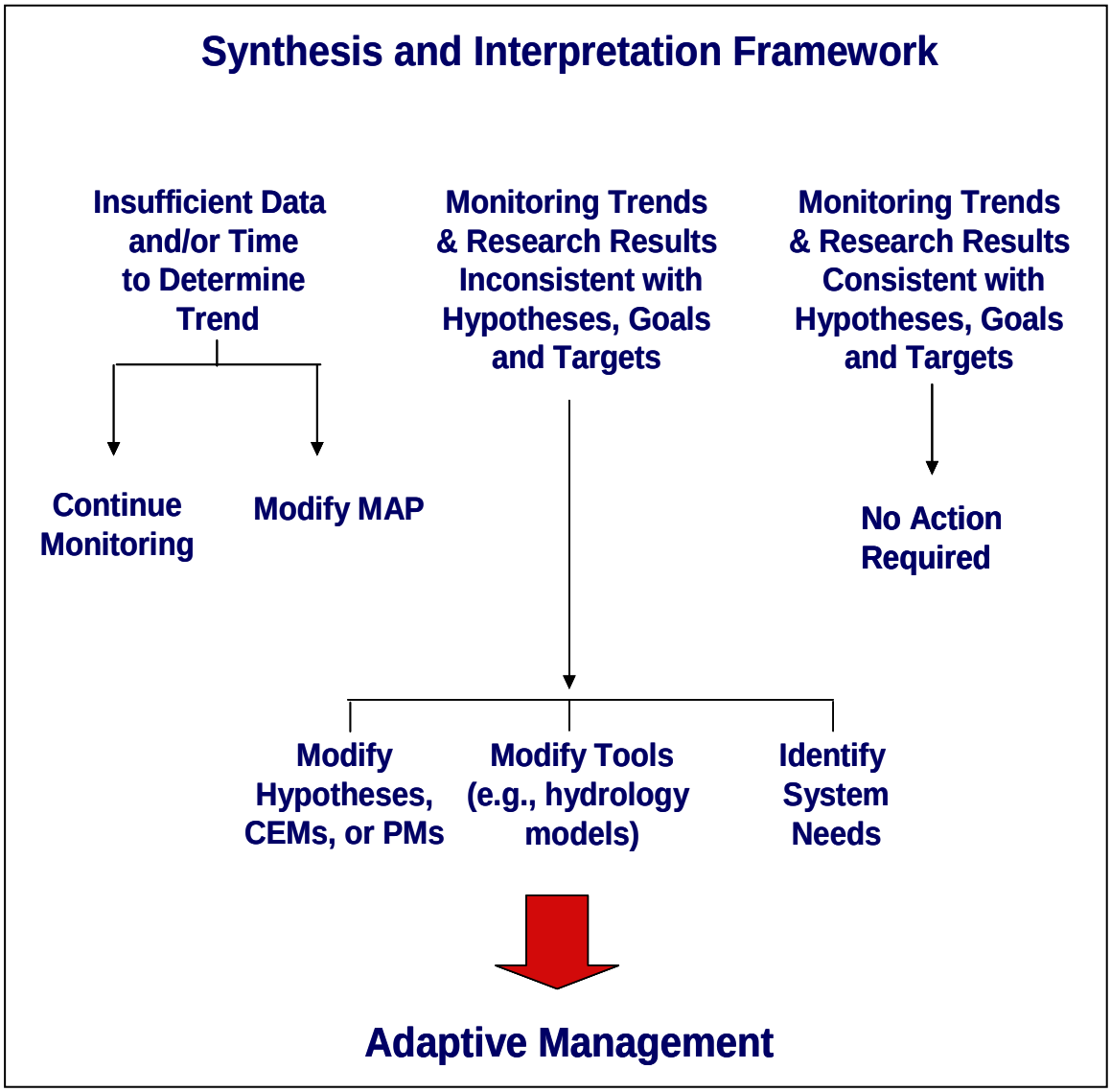

Figure 7-1: Framework for Interpreting System-Wide Assessments
**Please note the decision framework does not consider the influence of stochastic events.

The AT System Status Annual Report and the RECOVER Technical Report will encompass this interpretation of the system-wide assessment and develop conclusions based on the science that may. These conclusions may include whether corrective actions for MAP modifications or CERP performance should be considered.

7.3 Linkages to Adaptive Management

7.3.1 Introduction

Development of an AM program is a critical element of CERP. AM for the Plan is defined in the Pro Regs as "the continuous process of seeking a better understanding of the natural system and human environment in the South Florida ecosystem, and seeking continuous refinements in and improvements to the Plan to respond to new information resulting from changed or unforeseen circumstances, new scientific and technical information, new or updated modeling; information developed through the assessment principles contained in the Plan; and future authorized changes to the Plan in order to ensure that the goals and purposes of the Plan are fulfilled." The AM program is intended to guide the implementation of CERP and will be used to assess the responses of the South Florida ecosystem to CERP implementation and to determine whether these responses match expectations, including expected performance levels.

To address the requirement of the Pro Regs to establish an AM program, a multi-agency team has been formed to begin the task of developing an AM implementation strategy for the Plan. The team has organized a series of interagency, management, and science collaborative workshops, which have created an AM Framework (see Figure 7-2). The AM Framework is designed to identify the major components of a comprehensive AM strategy and the connections among the components. The framework currently contains four elements or "boxes" that outline the process for the various components of a comprehensive adaptive management strategy.

7.3.1.1 Project Development (Box 1)

The goal of this first element is to apply AM principles during CERP planning activities whether at the system-wide or project levels by anticipating and planning for performance uncertainties, incorporating opportunities for learning and flexibility into the project design, and incorporating these considerations into project management plans and the final Project Implementation Report (PIR) during the planning and implementation of Plan projects. The lead responsibility for Box 1 activities is with the PDT in coordination with RECOVER.

7.3.1.2 Assessment (Box 2)

This element includes the system-wide assessment process for measuring and reporting actual system responses to the effects of the Plan, including progress towards meeting the IG/IT. The results of these assessments are provided by RECOVER in technical reports

to the Corps and SFWMD in accordance with the Pro Regs. The assessment process is discussed in detail in this guidance memorandum.

7.3.1.3 Management and Science Integration (Box 3)

This element is the link of "decision-makers" with scientists in a collaborative review process to produce the assessment report required by the Pro Regs. This box creates a management and integration team led by the Corps and the SFWMD for the purpose of reviewing the technical reports on assessment prepared by RECOVER, and for identifying and evaluating options for resolving any significant performance problems in the Plan. The management/science team will help produce the assessment report, required by the Pro Regs that will describe these options and the potential benefits from each. The AM framework has also created a shortcut from project planning (Box 1) to Box 3 to assist in solutions to system-wide problems that may arise in the project planning phase. The management and integration team will include members of RECOVER and management from participating agencies and tribal governments.

7.3.1.4 CERP Update Process (Box 4)

The final element of the AM Framework involves using the assessment report as the basis for selection of the preferred option to either make changes or adjustments in project plans, operations, and/or sequencing of projects, including modification of the Plan or to continue on the present course. The actions in this box occur under the guidance of senior management in the Corps and the SFWMD in consultation with other agencies and tribal governments. The newly formed System Planning and Operations Team (SPOT) is expected to play a major role in Box 3.

7.3.2 Initiating Adaptive Management Activities

There are a number of factors or events that will occur during the implementation of CERP that may trigger the initiation of the adaptive management process to be initiated. This section describes these factors and events.

7.3.2.1 Periodic CERP Updates

The programmatic regulations require that the Plan be evaluated periodically using new or updated modeling that includes the latest scientific, technical, and planning information. As appropriate, the results of this evaluation may be used to initiate adaptive management activities.

7.3.2.2 Shortfalls in Water Made Available by CERP Projects

In the event that a Plan project does not perform as planned and designed (i.e., there is a "shortfall" in the quantity or quality of water that the project produces), the Corps and the SFWMD will initiate AM activities, including preparation of an assessment by RECOVER (Box 2) as described in this guidance memorandum.

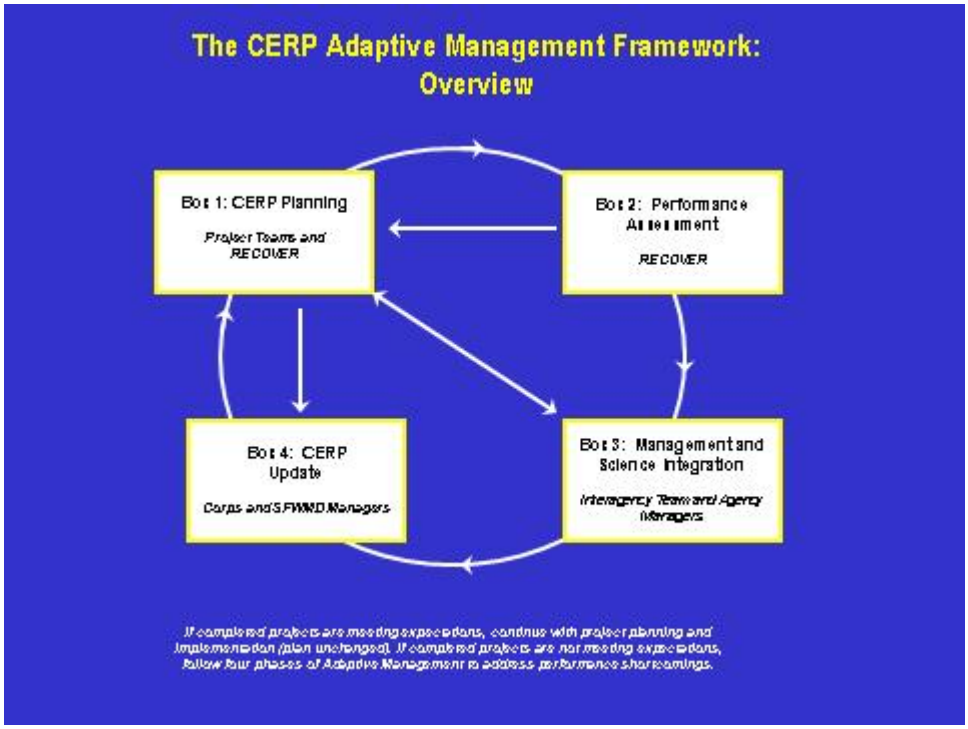

Figure 7-2: CERP Adaptive Management Framework Overview

To assist RECOVER in conducting assessment activities, the PDT should provide documentation in the PIR (see Guidance Memorandum #1) that describes the identification of water for the natural system and other water-related needs contained in the PIR. The PDT may prioritize these benefits and reiterate the goals and purposes of the project in order to provide information to decision-makers in their resolution of a shortfall.

7.3.3 Achievement of Interim Goals and Interim Targets

The interim goals provide a means by which the restoration success of the Plan may be evaluated at specific points throughout the overall planning and implementation process of CERP and are established to facilitate inter-agency planning, monitoring, and assessment. Similarly, the interim targets provide a means by which the Plan's progress towards providing for other water-related needs of the region may be evaluated. If the Corps and SFWMD find that the interim goals or interim targets are not met or are unlikely to be met, then the AM process may be initiated in accordance with the programmatic regulations.

For the purposes of assessing Interim Goals, RECOVER proposed a total of 23 indicators, which included hydrologic, water quality and biological indicators in the four sub-regions of the South Florida ecosystem that the CERP is designed to influence. Eight indicators were chosen for Interim Targets. The primary criterion for the selection of

indicators was whether that indicator is expected to be highly responsive to the changes in water regime that will be brought about by the CERP. In addition, indicators that represent short-term, intermediate, and long-term responses are represented. Interim Goal indicators from all levels of the trophic web are also represented.

For the purposes of Interim Goal assessment processes carried out by RECOVER, the entire suite of indicators will be examined. Where quantitative estimates are available, these will be compared with numerical analysis. Where qualitative descriptions are available, these will be analyzed in narrative fashion. For specific quantitative and qualitative predictions for IG/IT indicators on a five year time step applicable to a particular module, reference should be made to the IG/IT Recommendations Document prepared by RECOVER (RECOVER 2005)." This document can be found at: http://www.evergladesplan.org/pm/recover/igit_subteam.cfm

The Pro Regs indicate that the potential exists to create a higher level of performance than that described in the originally authorized Plan, and that this potential should be realized during CERP implementation. This higher level of performance can be defined as a "desired restoration goal." The desired restoration goal or condition is not necessarily equal to the historic condition. It reflects optimal characteristics of the indicator given that some irrevocable changes have occurred in the South Florida ecosystem (such as loss of spatial extent, and the existence of the eastern levee system). It must be possible to measure the desired restoration goal using data collected from the field. It is also possible to estimate Interim Goal values for the desired restoration goals; these values would reflect the estimated trajectory of the condition of the indicator throughout CERP implementation.

7.3.4 Required Periodic Assessments

In accordance with the Pro Regs, RECOVER is required to prepare a technical report, not any less often than every five years, that presents an assessment of whether the goals and purposes of the Plan are being achieved, including whether the interim goals and interim targets are being achieved or are likely to be achieved. At the project level, in accordance with Guidance Memorandum #1, each project PIR will include a description of project contributions toward achieving IG/IT.

8.0 REPORTING FRAMEWORK & TIMELINES

The Technical Assessment Reporting Framework (reporting framework) outlines reports and report sequencing designed to ensure that the synthesis, analysis, and assessment of monitoring data are conducted in a scientifically sound manner and provide a means to assess system responses to CERP projects.

8.1 Purpose and Strategy

In contrast with monitoring programs that often focus on data acquisition alone, with minimum attention to the analysis, synthesis and interpretation the reporting framework (Figure 8-1), MAP places considerable emphasis on the annual analysis, synthesis, and interpretation of the monitoring and research data in a comprehensive, systematic, and logical manner. The monitoring database is appended each year to include the previous year of data, thereby providing a cumulative database for timely synthesis of all the available data. This framework assures the early identification of potentially unexpected results as well as for assessments of the magnitude and direction of changes in ecosystem responses.

The reporting framework provides the process for assessing CERP restoration goals including Interim Goal indicators, and meeting RECOVER reporting obligations to the NRC, Congress, and the public. The annual PI, Module Groups, and AT and the five-year RECOVER Technical Report are the reporting components of the framework that provide feedback to the monitoring and research component (Figure 8-1).

The MAP reporting framework is built on two principles: (1) the importance of annual assessments of all relevant monitoring and experimental data and (2) reliance on the PI and Module Group as the technical foundation for the MAP. The reporting framework described here focuses on the minimum requirements for assessing changes in the status and trends of ecosystem components potentially affected by CERP projects.

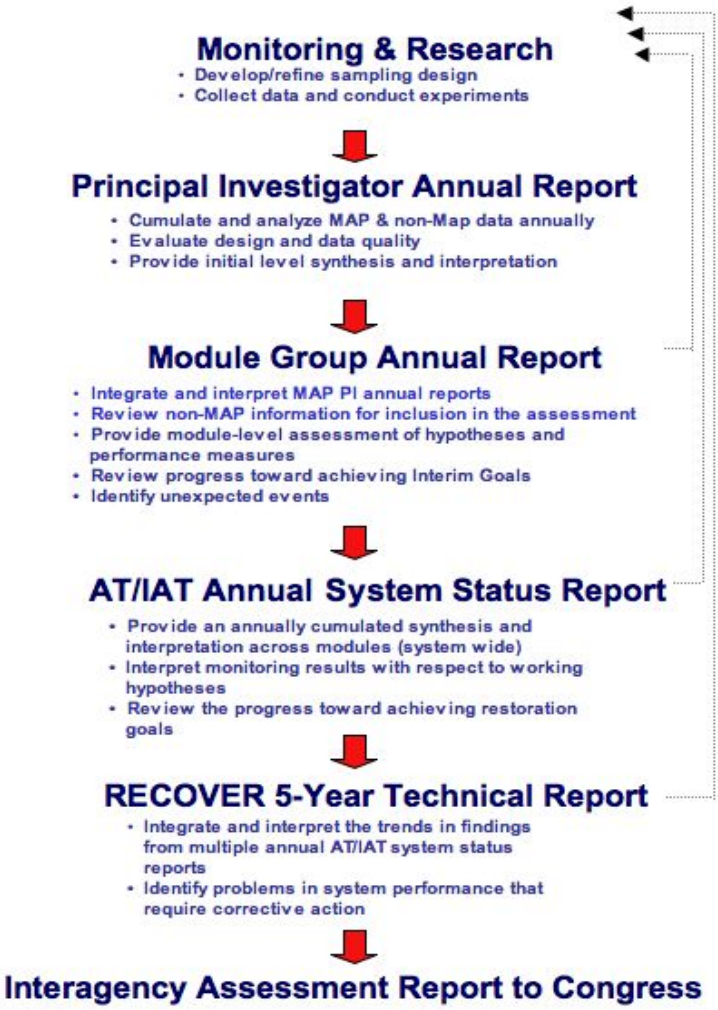

Figure 8-1: MAP Technical Assessment Reporting Framework

8.2 MAP Technical Assessment Reporting Framework

The reporting framework developed for this technical assessment guidance identifies three reporting cycles: annual, bi-annual, and five-year cycles. While this is an ambitions schedule, the AT recognizes the need for cumulative compilation and analysis of data on an annual schedule to allow the detection of any unexpected deviations from the CERP goals.

The annual reports provide the technical foundation for assessing status and trends in goals and PMs and, most importantly, for evaluating the status of restoration hypotheses at local, module, and system level spatial scales. Importantly, the framework recognizes that water quality and hydrologic assessments may be reported on different, often shorter,

time scales and addresses these differences. Following completion of several reporting cycles, the reporting framework timeline will be evaluated based on its ability to: (1) assess the efficacy of the sampling designs; (2) capture trends in system responses; (3) detect unexpected responses; (4) assess progress toward achieving Interim Goals; and (5) determine whether problems in the system require corrective actions.

8.2.1 Annual Reporting Cycle

The Technical Assessment Reporting Framework includes three types of annual reports: the MAP PI Annual Report; the MAP Module Group Annual Report; and the Annual AT System Status Report. The PI Annual Report is the first level of the MAP and non-MAP data analysis and interpretation that will be required annually. The MAP PI Annual Report will cumulate data on an annual basis to provide a cumulative assessment of the hypotheses and performance measures at the MAP component and module level. Data used in these reports must comply with QASR, including applicable data validation and standardization.

The Annual Module Report, prepared by the Module Groups, will be a compilation of the annual PI reports with the addition of an integration and interpretation chapter that will qualitatively assess the success of the module relative to associated hypotheses, PMs, and interim goals. As data are accumulated over several years, the application of more sophisticated analysis of the data (e.g. trends, etc.) is anticipated. The objectives of this report are to integrate and interpret the information in the PI reports, review non-MAP data for its inclusion in the assessment and provide a module-level status of the hypotheses, interim goals and PMs based on a multi-year analysis of trends. Finally, the integration of all module data will afford the opportunity to identify unexpected or episodic events.

The Annual AT System Status Report provides a synthesis of current and previously collected hydrological, water quality, and ecological data across modules. It is a compilation of the Module Group Annual Reports with a synthesis and interpretative chapter that provides a quantitative assessment of the system-level hypotheses and PMs, and the progress made toward achieving system-wide Interim Goals. Each year the AT Annual System Status Report will be updated with another year of information from the Module Group Annual Reports, resulting in an annually updated assessment and report. This report also identifies those changes from the previous year(s) that are inconsistent with the goals and hypotheses and system performance for which corrective action may be required. The Annual AT System Status Report, therefore, provides the technical foundation for the RECOVER Technical Report that will be prepared at least every five years.

8.2.2 Bi-Annual Reporting Cycle

The Annual AT System Status Reports are the foundation for a variety of RECOVER reporting milestones, including the NRC report, the CERP Report Card, the Interim Goal Report, the RECOVER Technical Report, and linkages to AM (Figure 2). These

RECOVER obligations require multiple reporting cycles on different time frames. For example, the NRC Report and CERP Report Card are on a bi-annual cycle and therefore require reporting every two years. However, this does not mean conducting additional analyses or creating a new report. Rather, the most recent Annual AT System Status Report, which will include the most current analysis and integration of cumulated multiple years of data, will be used to satisfy these reporting requirements. However, this report may be subject to RECOVER Leadership Group (RLG) review before it is submitted by the Corps and SFWMD to the NRC or it is to be used to prepare a CERP Report Card (Figure 8-2)

8.2.3 Five Year RECOVER Technical Report

The RECOVER Technical Report is a synthesis of the technical findings derived from the Annual AT System Status Reports accumulated (e.g., rolled up), and reported at least every five years. This Technical Report provides an assessment of progress toward achieving restoration goals and an interpretation of monitoring results with respect to the system-wide restoration hypotheses. It is important to note that the AT contribution to the RECOVER Technical Report is simply the most recent Annual AT System Status Report that includes an analysis and interpretation of multiple years of cumulated data.

The report will also include an assessment of whether the Interim Goals are being achieved or likely to be achieved and will evaluate whether corrective actions should be considered based on scientific findings of system-wide or regional ecological needs. This report will also provide the technical and interpretive summaries that are the links to AM. Pursuant to the Pro Regs [Section 385.31(b) (4)] this report will be prepared at least every five years. However, preparation of RECOVER Technical Reports within the five-year window may be triggered more frequently depending on cumulative findings documented in the Annual Module Group and AT System Status Annual Reports (Figure 8-2).

8.3 Minimum Technical Assessment Process Reporting

The following is a discussion of the minimum reporting guidance for PIs, Module Groups, and the AT that parallels the assessment process (Figure 2-1). This minimum reporting guidance applies specifically to the natural system and can be modified, as necessary, to address water supply and flood protection.

A. Evaluate Ability to Detect Change - Principal Investigator Level

- Describe and discuss the results of the power analysis for the sampling design.
- Determine the minimum detectable difference of the power analysis and its associated confidence and uncertainty.
- Describe any recommended changes in the MAP sampling design and its implications for the power analysis and the minimum detectable difference.

B. Establish Reference Condition – Principal Investigator Level

- Describe non-MAP monitoring and research data sources used in the assessment.
- Determine if non-MAP data used in the assessment meet the criteria outlined in this guidance? If non-MAP data were used and did not meet the guidance criteria, provide a rationale to justify the inclusion of the data.
- Describe how representative the data are in space and time.
- Describe the approaches used to address measuring variability.
- Enter the data into a system-wide data management system.

C. Measure Change from Reference Condition – Principal Investigator Level

- Describe the methods used to estimate the direction and magnitude of change in performance measures from the reference state both annually and cumulatively for multiple years.
- Compare current status of the performance measure with its desired trend or target.
- Evaluate consistency of monitoring results with the MAP hypotheses.
- Determine if there are indications of unanticipated events; describe the probable causes and how they may be affecting the desired outcome.
- External peer review will consist primarily of drafted journal articles that relate to completed studies and other research associated with CERP activities.

D. Integrate Performance Measures to Evaluate Module Hypotheses - Module Group Level

- Integrate multiple performance measures to provide an assessment of module-level hypotheses.
- Describe the direction and magnitude of change in the integrated performance measures and determine if the changes are consistent with expected responses described in the CERP hypotheses.
- Provide a plausible rationale or explanation for the findings, if trends do not correspond to expected responses,
- Evaluate progress toward achieving module-level Interim Goals.

E. System-Wide Performance Evaluation – AT/IAT Level

- Synthesize findings across modules and across years to provide a holistic description of the status of the system.
- Evaluate the results in relationship to supporting system-level hypotheses and achieving system-wide Interim Goals.
- Summarize those changes that are consistent with goals and hypotheses and those that are not.
- Discuss reasons the goals and hypotheses are not being achieved.
- Discuss issues relevant to adaptive management.

- Because this system status report will be incorporated into a five-year peer-reviewed RECOVER Technical Report, data and analysis contained in the annual report will be subject to peer review that is consistent with CERP guidance (e.g., CERP Guidance Memorandum 27.00; RECOVER 2003).

8.4 Technical Assessment Guidance Reporting Timelines

The reporting timeline provides guidance for the production of annual reports by MAP PIs, Module Groups, and the AT (Figure 8-2). This guidance does not identify fixed reporting dates because of variations in starting times for different MAP PI contracts. However, over time, we anticipate that reporting timelines at the MAP PI Reports will become more synchronized. At such time, the reporting timelines should follow the sequence specified for each block (Figure 8-2). The following discusses how this reporting timeline will function.

At the MAP PI level, data will be collected and processed on an annual basis. After each 12-month data collection/processing period, the PIs will prepare an analysis and interpretation of each year's new data plus previous year's data (MAP PI Annual Report). This analysis should be complete within nine months from the end of the 12-month data collection period. This analysis phase will include incorporation of physical (e.g., hydrology, geomorphology, etc.) and chemical (e.g., water quality, contaminants, etc.) data where appropriate. Encompassed within the nine-month analysis period is a 6-month time lag in availability of physical and chemical data because of QA/QC and data management requirements. As of April 2004, the time lags in accessing some data sets do not allow us to meet the reporting milestones established in this guidance. In these cases, time lags must be shortened to no more than 6 months in order to meet reporting milestones. Additionally, multi-agency physical and chemical data have inherent issues such as consistent reporting mechanisms, data formatting and data availability. These issues create constraints on incorporation of physical and chemical data for the MAP analysis that must be resolved to complete the assessments required for the 2010 RECOVER Technical Report.

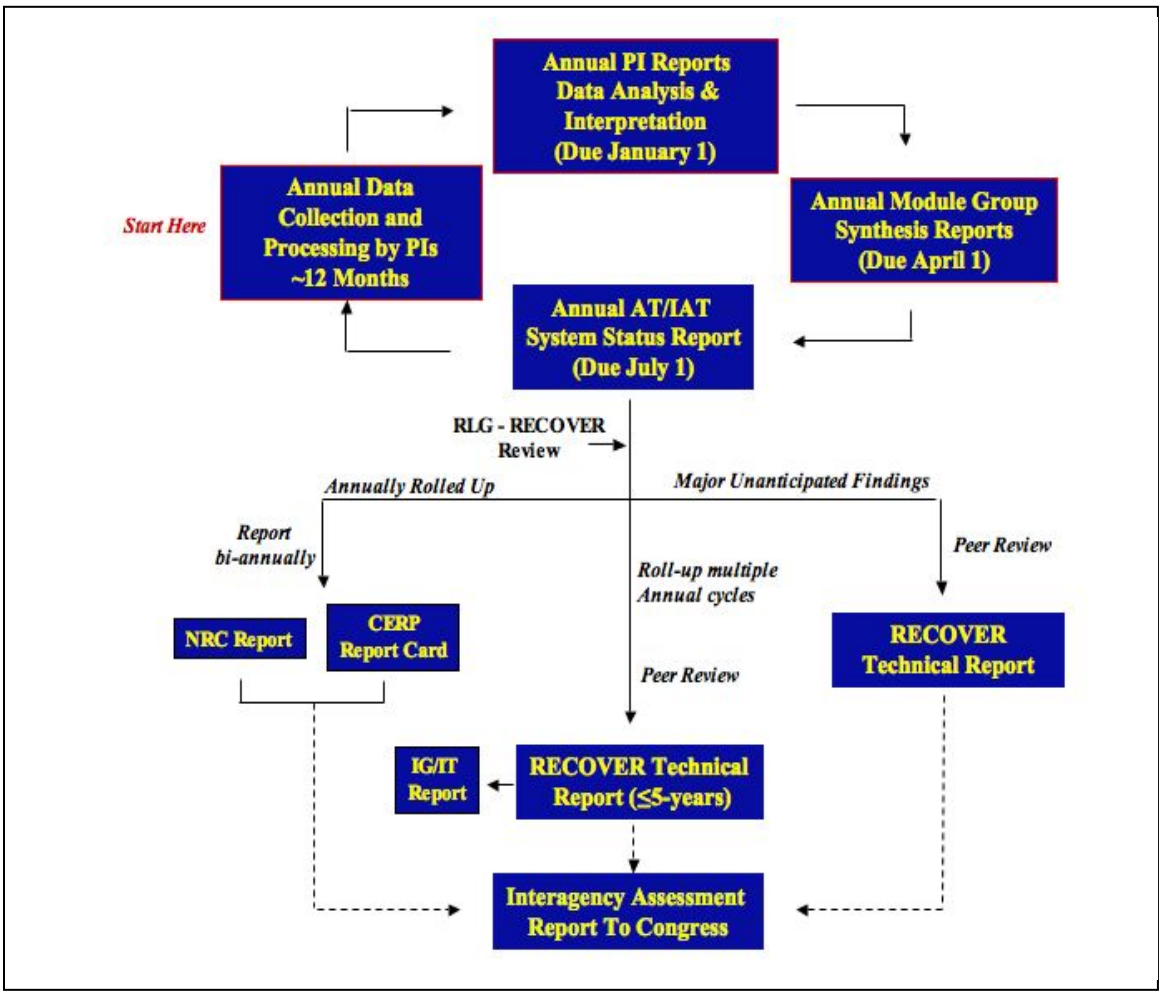

Figure 8-2: Assessment Reporting Timeline

The individual MAP PI Annual Reports, which will eventually include several years of accumulated data that are analyzed annually, are then synthesized at the Module Group level to address the module hypotheses, relevant PMs, and interim goals. A three month preparation period following the receipt of the PI Annual Reports is anticipated for the Module Group Annual Reports, which will include a compilation of the individual PI Annual Reports and presents the synthesis, assessment, and interpretation of the status of the relevant module hypotheses and Interim Goals. The annual analysis of hydrology and water quality status and trends is anticipated to be cumulative, integrating historical (pre-MAP) databases and the annually acquired MAP databases, and providing the interpretative context for assessing the status of Module level hypotheses.

Each year the Module Group Annual Reports will be summarized and combined with previous years' reports (e.g., rolled up) to create an Annual AT System Status Report that will address the overall status of the system relative to system level hypotheses, PMs and restoration goals. This report will be prepared by the AT within three months of receipt of the Module Group Annual Reports.

It is evident from Figure 8-2 that the Annual AT System Status Report provides the technical interface between the scientific foundation of the restoration (e.g., PI and Module Group Reports), the reporting requirements of RECOVER. Though not included in Figure 8-2, the RECOVER Technical Report provides an important interface with the Adaptive Management process.

The Annual AT System Status Reports have three functions. First, at least every two years, the Annual AT System Status Report will be used to provide information to the NRC and for the CERP Report Card. There are no new analyses involved in this activity; rather it is a simple "packaging" of the existing report with an appropriate interpretive cover letter to the NRC. However, it is anticipated that this report will be required to follow RLG guidelines and procedures including RLG approval which is anticipated to take ~ 1 month and would make the report available to the NRC by August 1st (Figure 8-2). This schedule would be helpful to the public as well as the CERP Independent Science Review Panel.

Second, at least every five years, the current cumulative AT Annual System Status Report, which represents multiple years of data "rolled up" into one report, will be peer-reviewed before being used as one of the major components of the RECOVER Technical Report which is mandated by the Pro Regs to provide an assessment of the Interim Goals. In addition, this Report will provide the following: 1) a synthesis of findings across modules and across years to provide a holistic description of the status of the system; 2) an evaluation of the results in relationship to supporting system-level hypotheses and achieving system-wide Interim Goals; 3) a summary of those changes that are consistent with goals and hypotheses and those that are not; 4) a discussion of why the goals and hypotheses are not being achieved; and 5) identify those issues relevant to AM.

The third function of the Annual AT System Status Report is the identification and reporting of major unanticipated findings that have been identified and "flagged" by the Module Group Annual Reports and may require correction. The Module Groups would identify these "red flags" as they synthesize the PI reports and prepare the Module Group Annual Reports. If an unexpected and undesirable response, with respect to the goals of CERP or the hypotheses, is detected at the module or system scale, a technical report can be generated immediately.

The Annual AT System Status Report must address two factors; a clear description of the problem and an analysis and interpretation that indicates the potential causes of the problem. This information would be essential information provided to the AM Team responsible for formulating options to address unforeseen problems that arise during implementation. Reporting of this information will require the PIs and Module Leaders to re-evaluate the CEMs, the stressor – effects pathways, associated PMs in order to provide a plausible explanation for the observed results. In this case, the Annual AT System Status Report goes to both the RLG and RECOVER for review prior to becoming a RECOVER Technical Report.

This category of RECOVER Technical Report would trigger an AM response that explores alternative analysis to reformulate CERP to address the "red flags"/unexpected responses. This alternative analysis/option selection is not the responsibility of the AT but rather that of the AM teams who will develop and rank technical options for addressing the performance problem (Figure 7-2; Box 3). The resulting AM Assessment Report, which identifies a range of solutions for a performance problem, links to policy where decision makers would then choose the preferable option.

It is important to emphasize that the schedules proposed in Figure 8-2 are not intended to be prescriptive, rather they are intended to provide guidance for the PIs, Module Leaders and the IAT to facilitate meeting RECOVER reporting requirements. The assessment process is intended to document responses and then understand and interpret them at appropriate spatial and temporal scales on an annual basis. The annual reporting concept is intended to facilitate the addition of new data and the detection of unexpected results.

8.5 Peer Review of Assessment Process

Peer review provides a process for enhancing the scientific credibility of assessment documents by providing a means for independent experts to offer constructive criticism and scientific and technical advice. Peer review of RECOVER documents is discussed at length in CERP Guidance Memorandum 27.00 dated December 18 2003 and provides an example of guidance for this Guidance Memorandum. Although the Pro Regs for CERP only specify the necessity of external peer review for the draft assessment report produced by the Corps and the SFWMD [Section 385.31(b)(4)(ii)], other assessment documents and processes may also benefit from external peer review.

The assessment process is divided into logical progression levels (See Figures 1 and 2). Peer review should be considered at several of these levels as described below.

Principal Investigator Level. This level of external peer review would consist primarily of drafted journal articles that relate to completed studies and other research associated with CERP activities. These activities will be identified in individual scopes of work for individual MAP components.

Annual AT System-Status Report Level. External peer review at this level should occur on a case by case basis as deemed appropriate by the AT. These may include situations such as when the annual AT system status report indicates that: 1) changes in MAP components (e.g., CEMs, PMs or MAP hypotheses) are warranted; 2) there are unresolved and significant technical disputes; or 3) there are significant new findings that are relevant to ecosystem responses. Because this system status report will be incorporated into a five-year RECOVER Technical Report which will be peer reviewed (see below), data and analysis contained in the annual report will be subject to peer review at that time.

RECOVER Technical Report. This RECOVER report will contain scientific information and interpretations and potentially present scientifically and technically

controversial issues and findings. The process leading to the report involves a large, long-term investment and multiple projects. Therefore, peer review at this level should be consistent with the guidance in CERP Guidance Memorandum 27.00.

Once completed, the comments, feedback and other information (constructive criticism and scientific and technical advice) from peer review must be incorporated and documented. This information should be included as an attachment or appendix to the final version of the report. The report should also include a section addressing how the peer review comments were incorporated, including an explanation and rationale for not incorporating specific suggested changes if this is the case, as well as making any recommendations for inclusion or consideration in following report iterations. The peer reviewers should be included in the distribution list for the report to allow them to see how their comments or input were addressed.

9.0 APPLICATION OF THE TECHNICAL ASSESSMENT GUIDANCE TO MODULES

The Module Groups have the primary responsibility for conducting CERP assessments. Consequently, acquainting the Module Groups with the assessment guidance process was an importance step to moving the guidance from concept and theory into actual practice. To accomplish this, the AT conducted a series of workshops with the Northern Estuaries, Greater Everglades, and Southern Estuaries Module Groups. The objectives of these workshops were to:

- Provide an overview of the Guidance process
- Explain the reporting requirements and schedules
- Review the current assessment hypotheses and relevancy to CERP
- Determine the basic types of data management resources needed to support the Module assessments
- Facilitate the communication and team-building process for each of the Modules.

The general format for these workshops included a review of the IAT guidance followed by a detailed examination of the MAP hypotheses. The current set of hypotheses are derived from the MAP and were subsequently re-examined to eliminate redundancy, identify opportunities to aggregate similar hypotheses, and ascertain whether the hypotheses remained valid and relevant to CERP restoration. Each Module Group selected an example hypothesis that represented a sub-model from the module CEM. This sub-model was then subjected to a detailed pathway analysis to identify the specific components and measures that were essential for assessing the status the hypothesis. Once the major components of the hypothesis were identified, the specific data needs were determined. This was followed by a preliminary data inventory to ascertain the need for MAP data, both MAP and non-MAP data, and/or data derived from specific experiments. Once completed, the Module Groups began the process of applying the Assessment Guidance.

Workshops provided a forum in which Module Groups convened as functioning units for conducting the CERP Assessments and developed a systematic strategy for the Module Groups to conduct MAP assessments using their own examples as the template. Initial assessment guidance for each Module is presented in the following sections and the following topics are addressed for each Module:

- Module background
- Monitoring project status
- Ecological models for specific hypothesis clusters
- Hypothesis cluster descriptions and graphics
- Sub-hypothesis descriptions where appropriate.

9.1 Northern Estuaries Module

9.1.1 Module Location Description and Background Information

The Northern Estuaries include the Caloosahatchee, St. Lucie, Loxahatchee, and Lake Worth Lagoon (Figures 9-1-1 and 9-1-2). Within Florida, nearly 70 percent of recreational and commercial fisheries species (i.e., oyster, pink shrimp, blue crab, gray snapper, red drum, snook, stripped mullet, and spotted sea trout) rely on estuaries for at least part of their life span. Major stressors currently impacting these estuaries include damaging freshwater inflows, degraded water quality, and habitat loss.

The Caloosahatchee Estuary is located on the southwest coast of Florida. Most of the freshwater flowing into the estuary comes from the Caloosahatchee River. Historically the Caloosahatchee River was a meandering system with numerous oxbows, flowing from its headwaters at Lake Hicpochee to the Gulf of Mexico (Figure 9-1-1). Activities that led to its degradation, beginning in the1890s, include channelization, connection to Lake Okeechobee, and construction of an extensive canal network associated with agricultural development in the watershed. The channelized portion of the Caloosahatchee River (C-43) the associated canal network have altered the timing, quantity, and direction of runoff in the watershed and led to abnormal salinity fluctuations. The tidally influenced portion of the estuary has been reduced by the operation of the S -79 control structure (Figure 9-1-2) which allows periodic large regulatory releases from Lake Okeechobee.

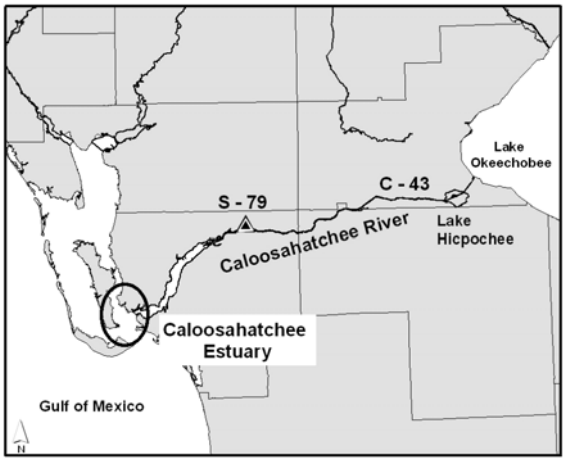

Figure 9-1-1: The Caloosahatchee estuary.

Prior to these impacts, the Caloosahatchee estuary was a highly productive system with an abundance of aquatic plants and animals. Today, the abundance, health, and functionality of these species have been greatly reduced. Submerged aquatic vegetation (SAV) and the eastern oyster (*Crassostrea virginica)*, important components of the biological community, have been reduced from a widespread distribution to a sparse occurrence.

The St. Lucie Estuary (SLE), located on the southeast coast of Florida, flows into the Indian River Lagoon and the Atlantic Ocean. Historically, this estuary was a freshwater system influenced by ephemeral ocean inlets. When the St Lucie Inlet was permanently established in 1898, salinities increased and the system became estuarine, characterized by abundant mangroves, submerged oyster bars, and SAV.

Agricultural and urban drainage projects that began in the 1900s expanded the historic SLE watershed, to almost 775 square miles, almost three times its historic size. Major drainage canals constructed in the watershed include the C-23 and C-24 canals (Figure 9-2). The SLE is connected to Lake Okeechobee by the C-44 canal which is used for navigation and receives regulatory water releases from Lake Okeechobee. As a result, freshwater flow into the estuary tends to be excessive in the wet season and lower than normal in the dry season.

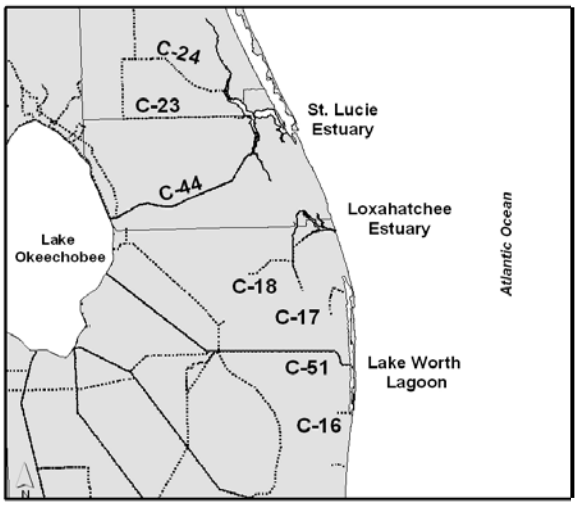

Figure 9-1-2: The St. Lucie, Loxahatchee, and Lake Worth Lagoon estuaries.

Thick deposits of mucky silt that cover large portions of the bottom of the SLE are unsuitable for SAV and oysters. These sediments also become resuspended by wind, current and boat traffic resulting in diminished light penetration in the water column and decreased light availability for SAV.

The Loxahatchee River is located on the southeast coast of Florida. The Loxahatchee Basin has been extensively altered by construction of canals, channelization of natural waterways, drainage and/or impoundment of wetlands, and stabilization of the Jupiter Inlet.

Construction of the C-18 canal disconnected the Northwest Fork from its headwaters Loxahatchee Slough (Figure 9-1-2). This has resulted in periodic shortages of water for the Northwest Fork and increased flows into the Southwest Fork during storm events. Saltwater intrusion upstream into the Northwest Fork has resulted in the loss of six river miles of cypress swamp and freshwater swamp and floodplain vegetation. The extent of oysters and seagrass beds is limited to smaller areas than they were historically.

Lake Worth Lagoon, located on the southeast coast of Florida, was historically a freshwater lake and receiving water from wetlands along its western edge. Creation of permanent inlets to the lagoon increased the tidal influence and the lake sifted to an estuarine lagoon. Cumulative impacts of human activities over the past 100 years have also altered the regionally important natural resources associated with the previously freshwater system. Changes affecting the hydrology include construction of major drainage canals (C-51, C-17, and C-16), shoreline bulkheads, a causeway, channels, and port development (Figure 9-1-2). Freshwater discharges from the C-51 canal produce excessive periodic releases of fresh water that adversely impact estuarine biological communities as well. A limited numbers of oysters remain in the lagoon and SAV populations are unhealthy and reduced in number.

Consequently, the three hypotheses clusters addressed in this section are:

- Oysters
- Fish
- Submerged aquatic vegetation (SAV)

9.1.2 Status of Monitoring Program in the Northern Estuaries

The table presented here is a list of existing monitoring program and components and their status in the northern estuaries.

Table 9-1-1: Monitoring Components and Key Uncertainties and Supporting Research for the Northern Estuaries.

Monitoring Components	MAP Section	STATUS
Salinity Monitoring Network	3.3.3.1	On-going
Water Quality and Phytoplankton Monitoring Network	3.3.3.2	Partially implemented
SAV Mapping from Aerial Photography	3.3.3.3	Underway in all but LWL
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	Underway
Juvenile Fish Community Monitoring Network (Caloosahatchee Estuary, St. Lucie Estuary/Indian River Lagoon)	3.3.3.7	Underway in Caloosahatchee, Pilot project underway in SLE/IRL with proposed FY06 start
Benthic Macroinvertebrate Monitoring (St. Lucie Estuary, Loxahatchee River Estuary)	3.3.3.8	Underway in SLE/IRL, planned FY06 start in Loxahatchee
Key Uncertainties and Supporting Research		
Reconnaissance Study of Caloosahatchee	3.3.4.1	Complete
Fish Health and Pathology in the St. Lucie Estuary	3.3.4.2	Underway
Bottlenose Dolphin Health Assessment in St. Lucie Estuary	3.3.4.3	No proposed start date
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	No proposed start date

9.1.3 Oyster Conceptual Ecological Model

The model below summarizes environmental interactions that are known to effect oyster health and abundance. Many of these parameters are currently being monitored and will be used in the assessment process based on the hypotheses listed below.

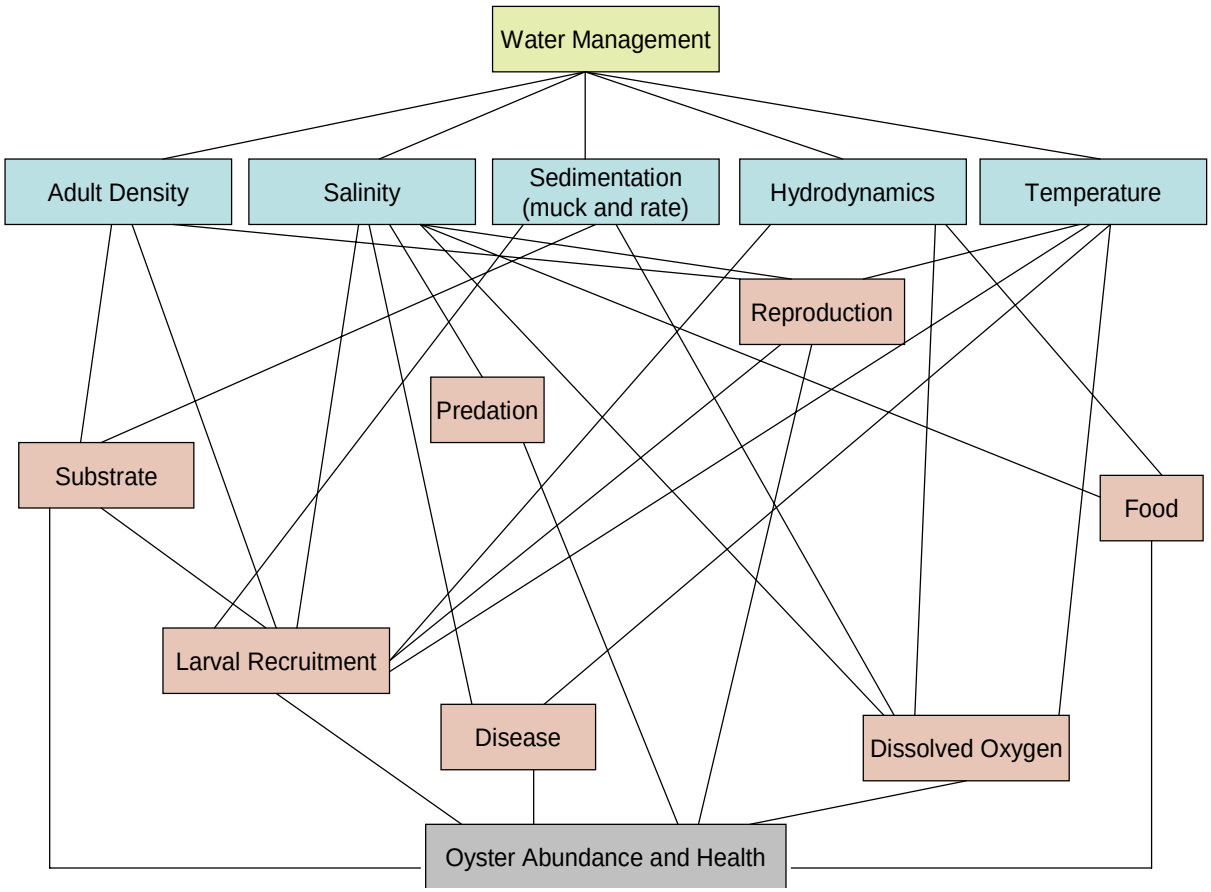

Figure 9-1-3: Oyster Conceptual Ecological Model

9.1.4 Oyster Hypotheses

Hypothesis 1
Undesirable shifts in the estuarine salinity envelope result in decreased survival, reproduction, spat recruitment, growth and increased susceptibility to predation and diseases such as *Perkinsus marinus* (DERMO) and *Haplosporidium nelsoni* (MSX) in the southeast estuaries oysters.

Rationale: Large rainfall events and subsequent watershed run-off, or large volume releases from Lake Okeechobee cause large volumes of freshwater 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, changes in food type and availability and

decreased growth, reproduction, and spat recruitment. Extreme droughts can also negatively impact oysters by making them prone to disease and predation.

Hypothesis 2
Accumulation of muck (high organic content depositional matter) on available substrate or nearby areas will make substrate unsuitable for oyster larval settlement and thus recruitment and growth of larval oysters. In addition, accumulation of muck may also impact the dissolved oxygen content making the area / substrate unsuitable for larval settlement and growth.

Rationale: Oyster recruitment is negatively effected by the accumulation of mucky sediments in the estuary. Muck is unsuitable substrate for spat settlement. Areas that once contained sand and/or shell have been covered by these very soft, unconsolidated sediments. Freshwater inflow carries sediments with silt, clay and high organic content. Freshwater inflow from canals can also result in an increase in the transport of floating aquatics, which then degrade and contribute to the rate of muck accumulation.

Hypothesis 3
Increased sediment loads in the water column impair respiration and feeding of oysters resulting in decreased growth and condition index or reproductive health of oysters. In addition, sediment accumulation on oyster shell negatively affects spat recruitment.

Rationale: Oyster populations are affected by increased sediment loads resulting from alterations to 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. Oysters from relatively turbid estuaries appear to be capable of feeding at total suspended solid concentrations as high as 0.4 g/l but significantly reduce their pumping rates at concentrations as low as 0.1 g/l. Suspended solids may clog gills and interfere with filtering and respiration of oysters. Deposition of sediment on oyster shells also makes them unsuitable for spat settlement.

Hypothesis 4
Increase in oyster reef coverage will enhance secondary habitat for other estuarine species resulting in increased diversity and abundance.

Rationale: Oysters are natural components of South Florida estuaries and were documented to be abundant in the system. Although currently less abundant, they continue to be important. Reduction in oyster coverage was largely due to altered freshwater inflow, shell mining, and changes in hydrodynamics. This decrease has resulted in a loss of oyster reef community and the estuarine species that use this habitat.

9.1.5 Fish Conceptual Ecological Model

The model below summarizes environmental interactions that are known to effect fish abundance. Many of these parameters are currently being monitored and will be used in the assessment process based on the hypotheses listed below.

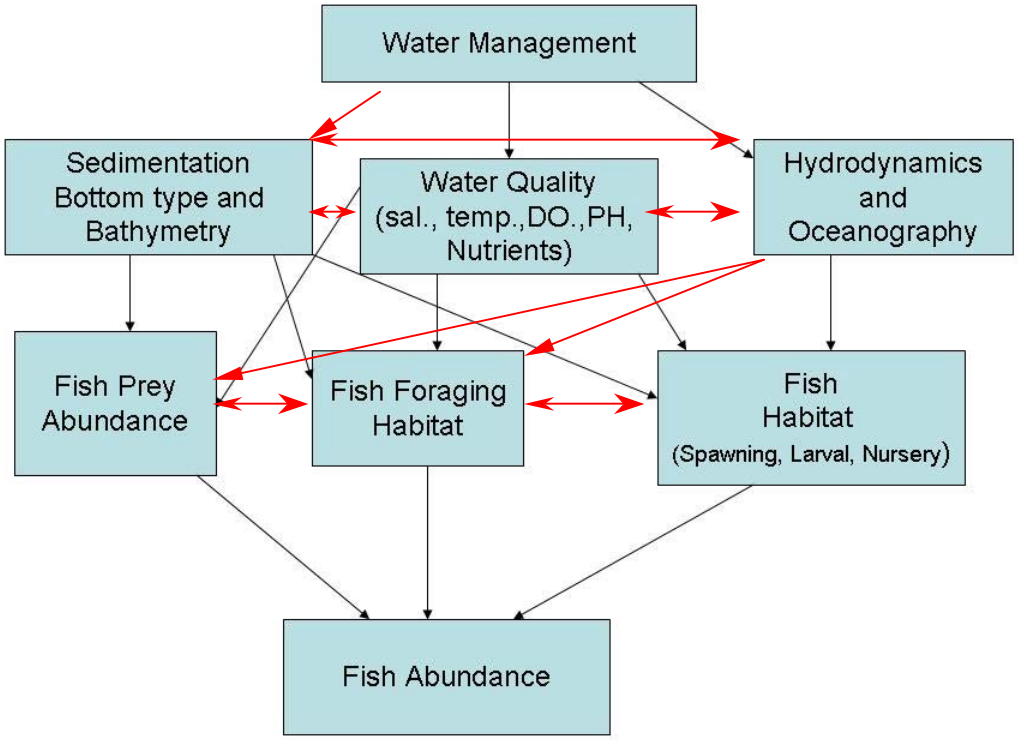

Figure 9-1-4: Fish Conceptual Ecological Model

9.1.6 Fish Hypotheses

The fish model ranks water quality parameter hypotheses in order based on their importance and value to fish physiology in a subtropical/tropical setting. This ranking is based on research results in northern estuary seagrass, mangrove and freshwater tributary studies. Relevant parameters are ranked as follows: 1- Dissolved oxygen; 2- Nutrients; 3 - Salinity; 4 - pH; 5 - Temperature.

Hypothesis 1
Dissolved oxygen levels within the northern estuaries will directly influence fish population dynamics within these estuaries.

Rationale: Dissolved oxygen. Tropical/subtropical systems are warm thus reducing the oxygen carrying capacity of water. Warm water systems often have high productivity if sufficient nutrients are present, thus often eutrophicating aquatic systems, increasing BOD. Since prolonged extreme (< 18 C) cold water periods are rare, particularly in the St. Lucie River system, primary production and detrital production occurs year round. This environmental condition is common throughout the world tropics. For this reason the indigenous tropical fish community shows physiological adaptations to low DO conditions. For instance: tarpon, gar, and mudfish are obligate air breathers; snook, bigmouth sleepers, fat sleepers, crested gobies, rivulus, mosquitofish, and tropical mullet species are facultative air breathers and surface water sippers, all capable of withstanding DO levels as low as 1.0 ppm or lower. Most temperate to warm temperate fishes, spotted seatrout, red drum, black drum, sand seatrout, and Atlantic toadfish apparently do not have the capability to withstand low oxygen conditions. This complex scenario with a complex indigenous fish fauna means that our studies of water quality impacts on fish populations will have to be examined at the species level.

Hypothesis 2

Nutrient concentrations in the Northern Estuaries are directly associated with fish health and mortality in these estuaries.

Rationale: Nutrients. It is apparent from resent observations over the past 30 yrs that plankton and harmful algal blooms (HABs) fed by nutrient loading have had substantial impacts on fish health and survival in the northern estuaries. The list of impacted species continues to grow annually to the point that no species can be left out of this analysis. Initially 1970's observations indicated that mullet were most likely to be impacted by HABs. We assume that nutrient levels, water turbulence and sediment resuspension produce conditions that are favorable for algal blooms. Nutrient levels can have substantial impact on HAB production and primary production levels in general, thus increase BOD/system eutrophication and decrease dissolved oxygen.

Hypothesis 3

Rapid and substantial water salinity changes as a result of water management and at levels not typically observed under natural dry season conditions will have a significant deleterious effect on stenohaline fish egg/larval, juvenile survival at northern estuary spawning and nursery sites.

Rationale: Salinity. Since larval fish and eggs require specific salinity conditions for survival and fish spawning sites are located within the Northern Estuaries. There is a direct relationship between freshwater flow and quantity, ambient salinities, and potential egg/larval survival. There is a very species rich resident and migratory fish fauna that is distinctly marine, particularly on the Florida east coast, which is very sensitive to salinity change as larvae, juveniles and adults. Stenohaline larval stages and species use of the northern estuaries is directly associated with ambient water quality with salinity thought to be the most relevant. In contrast, many euryhaline members of the indigenous estuarine fish fauna of south Florida are notorious for not being reliant on specific salinity patterns. They have the capability as juveniles and adults, but not necessarily as eggs and

larvae, to enter freshwater tributaries from the Ocean or Gulf with little or no acclimation. Species that show this marine-freshwater migratory pattern are snook, tarpon, bull sharks, sheepshead, striped mullet, various gobies and gray snapper.

Hypothesis 4
Maintenance of water pH levels above 5.0, and near neutral, 7 - 8.0 in the Northern Estuaries is beneficial to fish survival, health and mortality in these estuaries.

Rationale: pH: There is little information on pH effects on Florida fish physiology other than major fish mortalities documented in association with phosphate-gypsum storage mound leaks into the Peace River and Alafia River in recent decades. Extremely low pH levels (< 3.0) are lethal. We do not believe pH will be a problem in the northern estuaries. Florida freshwater tributaries typically contain large enough concentrations of carbonates that the water appears to be buffered. Sulfides in mangrove swamps and backwater sloughs may reduce both DO and pH in localized areas.

Hypothesis 5
Water management impacts on ambient water temperature do not show a direct correlation with fish population dynamics, life history, survival and mortality in the northern estuaries.

Rationale: Temperature: Since there is apparently very little ambient water temperature change in the northern estuaries associated with water management, water temperature is predicted to not be of much concern. However, it is recognized that there is a very distinct biogeographic difference between the Gulf and Atlantic estuarine fish faunas principally due to very different ambient water temperature regimes and ocean current patterns associated with both coastal systems (Caloosahatchee River/Charlotte Harbor: @ 250 fish species versus St. Lucie River/Indian River Lagoon: @ 500 fish species). Because of this, a stenothermic tropical fish fauna is found in the St. Lucie ecosystem that is not present in the Caloosahatchee ecosystem. Due to the endemism of these species within the St. Lucie/Indian River Lagoon systems relative to the United States as a whole, many of these east coast fish species have been of concern for listing as rare, endangered and threatened species by regional and national biologists over the past 30 years.

Hypothesis 6
Water flow rates and volumes within the St. Lucie and Caloosahatchee estuaries have a direct influence on fish population dynamics, distribution and migration within these estuaries.

Rationale: Arrows have been added from the "Hydrodynamics and Oceanography" box in the Fish Conceptual Ecological Model box connecting these physical conditions to the "Fish Prey" and "Fish Foraging" boxes as hydrodynamics and oceanography (water level, bathymetry, tides, winds, current flow rates) have direct influence on fish population dynamics, distribution, migration and survival. This is particularly true for fish eggs and larvae.

Hypothesis 7
Changes in the salinity envelope in the northern estuaries will not have a detrimental effect if they mimic natural climatically driven salinity regimes (e.g., wet season vs. dry season), and if salinity shifts are more gradual and extreme rapid changes are avoided.

Rationale: Estuarine populations of stenohaline fishes are most sensitive to atypical salinity regimes as either larvae (spotted seatrout), juveniles (tropical reef fish: yellowtail, lane and mutton snapper) or adults (spawning spotted seatrout and common snook). Therefore the timing and severity of salinity fluctuations becomes an important factor in reproduction and growth. Euryhaline fish populations that often associate with oligohaline habitats show a positive association with increased freshwater flows relative to food availability (e.g., feeding adult common snook).

Hypothesis 8
Soft sediments that occur naturally in estuarine systems support healthy estuarine fish communities while excessive anthropogenically accelerated accumulations of anoxic muck can have a negative influence on the community.

Rationale: Soft sediment (mud) fish communities have a positive association with healthy fine sediments, mud and their benthic animal communities as a food source (primarily gerreids, mugilids and engraulids) and habitat source (gobioid fishes). Benthic soft sediment invertebrate communities support the largest biomass component of indigenous St. Lucie/Loxahatchee River fish communities. In contrast, abiotic fine sediments ("muck") do not support this same soft sediment (mud) fish community and can create a bottom devoid of life often accompanied by anoxic conditions.

Hypothesis 9
Riverine and estuarine sediment composition and dynamics dictates recruitment success in centropomids, gerreids, and gobioids dependent on the northern estuaries.

Rationale: Sediment deposition and distribution is directly associated with stream configuration (e.g., meander vs. straightened) and topography, flow dynamics, water depth and stream bank location and proximity, thus directly influencing the population status of fish species that associate with shallow marginal sediment deposits (centropomids, gerreids, and gobioids).

Hypothesis 10
Health oyster bed habitat is essential for the survival of oyster reef dwelling fish. Population dynamics in *Gobiosoma bosc* (Gobiidae) is influenced by: (1) oyster reef structure; (2) live vs. dead oyster reef structure; (3) age and degradation/deterioration of oyster reef systems.

Rationale: *Gobiosoma bosc* plays a major trophic role in northern estuaries due to its numerical dominance of riverine ichthyoplankton and as the major vertebrate species directly associated with oyster reefs as critical habitat, feeding and spawning sites.

G*obiosoma bosc* is a major prey item for planktivorous fishes, chaetognaths, ctenophora, and as an adult prey for juvenile gray snapper *Lutjanus griseus*.

Hypothesis 11
Populations of juvenile reef fish (lutjanids, serranids, scorpeanids, gobiids, blenniids and labrisomids) that are dependent on estuarine seagrass and nearshore hardbottom show a positive relationship with salinity, ex. higher densities at higher salinities,

Rationale: Spawning populations of seagrass and reef associated marine/ mesohaline/ polyhaline fish species are most affected by atypical (aseasonal) reduced salinities during their spawning period. Life history, growth and mortality of marine/ mesohaline/ polyhaline seasgrass/reef associated fish species are negatively influenced by atypical and/or aseasonal reduced salinities which occur both from the overly ditched and drained watershed as well as from Lake Okeechobee discharges.

Hypothesis 12
Healthy freshwater emergent herbaceous vegetation is directly related to oligohaline fish populations.

Rationale: Population dynamics, distribution and survival in syngnathids (opossum pipefish, *Microphis brachyurus lineatus*), eleotrids (fat sleeper, *Dormitator maculatus*; spinycheek sleeper, *Eleotris pisonis*), poeciliids and centrarchids are influenced by freshwater emergent vegetation species distribution quantity and vegetative structure. The ability to obtain and maintain a healthy freshwater emergent vegetation zone depends on being able to avoid large fluxuations in salinity in the riverine portions that feed into the main estuary.

9.1.7 Submerged Aquatic Vegetation Conceptual Model

The model below summarizes environmental interactions that are known to affect the cover, abundance and productivity of submerged aquatic vegetation. Many of these parameters are currently being monitored and will be used in the assessment process based on the hypotheses listed below.

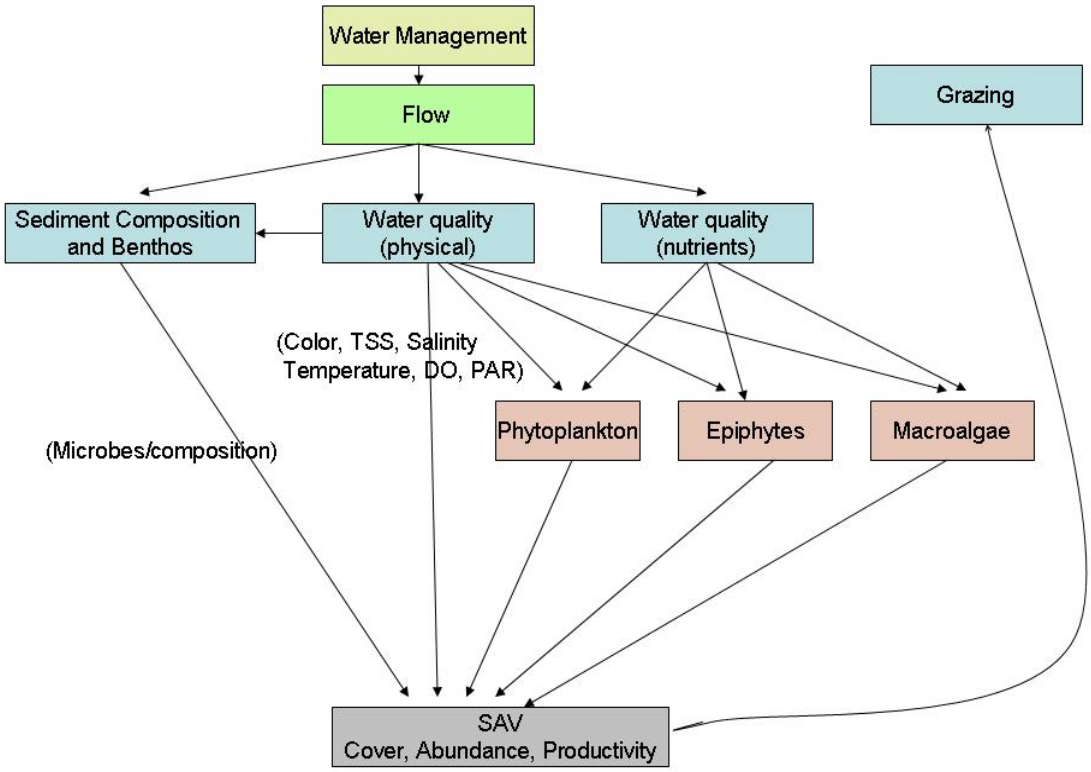

Figure 9-1-5: Submerged Aquatic Vegetation Conceptual Ecological Model

9.1.8 SAV Hypotheses

Hypothesis 1
Extreme fluctuations in estuarine salinity resulting from hydrologic alterations, water management practices, and sea level rise have had a negative effect on SAV function and have resulted in large decreases in spatial extent of SAV in the Northern Estuaries.

Rationale: Species composition and density of SAV communities are directly linked to the mean salinity and the variation around the mean at any given location. In the upper estuary, the naturally occurring submerged grass species, *Vallisneria americana,* will not survive prolonged periods of elevated salinity that occur as a result of manipulated freshwater flow. *Halodule wrightii* persists in areas with high variation in salinity. *Thalassia testudinum* and *Syringodium filiforme* will not tolerate prolonged periods of reduced salinity as a result of freshwater discharges from the local basin or Lake Okeechobee, and persist in areas with relatively low variation in salinity.

Hypothesis 2
Large deposits of organic, fine silt, and clay materials, i.e., muck, have displaced normal sandy substrate in the Northern Estuaries, thereby contributing to the decrease in extent of SAV beds.

Rationale: Sediment characteristics (e.g. nutrients, oxygen, microbial communities) are important to SAV survival; these characteristics will be altered by the increased deposition of fine silts and organic matter. Fast growing SAV (e.g. *Halodule wrightii*) requires higher nutrient levels in the sediment, than slower growing forms (e.g. *Thalassia testudinum*). Anoxic sediment will lead to sulphide intrusion in SAV rhizomes leading to die-back. Microbial communities are important to the biochemical reactions occurring around the SAV rhizomes.

Hypothesis 3

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.

Rationale: Sediment loads (turbidity), color and chlorophyll increase light attenuation which is directly correlated to decreased depth distribution and shoot density of SAV. Seagrasses require more light than macro-algae or phytoplankton, therefore decreased light (increased light attenuation) will reduce the ability of seagrass to compete with these other species. *Halodule wrightii* and *Syringodium filiforme* require less light than *Thalassia testudinum*, therefore a prolonged increase in light attenuation will lead to a shift in species composition. Sulphide toxicity occurs as a result of increased light attenuation and a decreased ability for plants to photosynthesize and oxygenate the sediments surrounding the rhizomes.

Hypothesis 4

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 in the Northern Estuaries.

Rationale: There is a quantifiable relationship between fish and seagrass habitat that is influenced by ambient salinity regimes. Estuarine seagrass and nearshore hardbottom dependent populations of juvenile tropical reef fish (lutjanids, serranids, scorpeanids, gobiids, blenniids and labrisomids) show a positive relationship with salinity, e.g. higher densities at higher salinities. Extreme and rapid salinity fluctuations degrade SAV habitat that many estuarine dependant fish rely on for spawning, nursery and foraging habitat.

Hypothesis 5

Increased epiphyte growth can be caused by both increases in available nutrients that accelerate growth and/or a decrease in grazing pressure.

Rationale: SAV losses have been associated with over-enrichment of estuarine waters, which stimulates growth of epiphytes, resulting in reduction of photosynthetically active radiation (PAR) at the SAV blades. Herbivorous grazing on epiphytes can partially relieve SAV growth inhibition at moderate nutrient loading rates but does not seem to significantly alter plant response at higher nutrient levels.

9.1.9 Benthic Infaunal Community Conceptual Ecological Model

The model below summarizes environmental interactions that are known to effect benthic community structure. Many of these parameters are currently being monitored and will be used in the assessment process based on the hypotheses listed below.

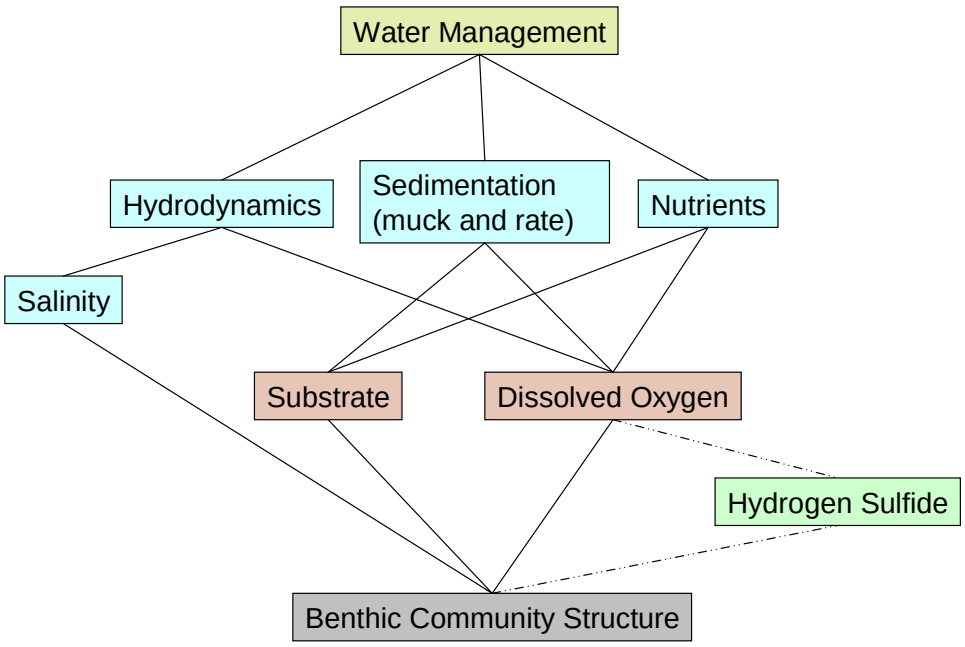

Figure 9-1-6: Benthic Infaunal Community Conceptual Ecological Model

9.1.10 Benthic Infaunal Community Hypotheses

Hypothesis 1
Irregular and extreme shifts in salinity in the St. Lucie Estuary prevent the establishment of a natural healthy estuarine infaunal community

Rationale: In contrast to a natural estuary where the riverine input is relatively stable, and/or relatively predictable, throughout the year, resulting in a wedge-shape bottom layer of higher salinity (strong pycnocline), the irregular and massive freshwater releases from the primary SFWMD canals which drain the estuary's expanded basin and regulatory releases from Lake Okeechobee to both the Caloosahatchee and St. Lucie Estuaries lead to sudden and dramatic drops in salinity in the entire water column. These unstable conditions prevent the establishment of a diverse and healthy estuarine benthic infaunal community (a very important food source for many fish and bird species). Benthic animals are directly or indirectly involved in most physical and chemical

processes that occur in estuaries, processes that will be disturbed by these salinity changes.

Hypothesis 2
The anthropogenically exacerbated accumulation of soft unconsolidated and strongly reducing sediments in the estuary inhibits the establishment of infaunal species resulting in an impoverished community characterized by low diversity and density.

Rationale: Abiotic factors, such as sediment grain size and quality determine broad-scale benthic community patterns. Fine sediment deposits are a typical characteristic feature of most estuaries; however, wide scale predominance of fine sediments at the expense of other typical estuarine sediment types, as is present in the St. Lucie estuary, constitutes a patently man-induced geologic imbalance that is necessarily reflected in both the benthic community and the higher trophic level species which rely on the benthos.

Hypothesis 3
The frequent re-suspension of fine sediments in the St. Lucie Estuary severely impacts certain infaunal species important for the ecosystem stability.

Rationale: Suspension feeders, such as many bivalves tend to predominate in sandier sediments. They feed and eliminate wastes by either pumping water through their burrows, where it is filtered out and pumped out, or by extending feeding structures above the bottom through which water is pumped and filtered. The increase in suspended sediments likely clogs the filtering apparatus of the suspension feeders, resulting in a community dominated by deposit feeders, i.e., a community not in balance among functional groups.

Hypothesis 4
Low oxygen concentrations, and at times significant concentrations of H_2S in the waters adjacent the bottom sediments often occurs resulting in mass mortality and prevents the settling of larvae, adversely affecting the infaunal communities.

Rationale: As a result of the widespread deposition of typically strongly reducing fine unconsolidated sediments, bottom waters are likely to exhibit depressed oxygen concentrations, and in some events contain significant quantity of sulfide from decomposition processes occurring in the sediment. Such conditions may likely be extensive on occasions when temperatures are higher (during the summer) or when wind induced mixing is low. Low oxygen concentrations have also been associated with freshwater discharge (Stanley and Nixon 1992). Such hypoxic, anoxic, and/or toxic conditions result in mortality of the sessile benthic communities, which may be followed by a rapid establishment of opportunistic species. Overall these conditions result in a severe disturbance of the entire estuarine ecosystem.

Hypothesis 5
Increases in nutrient concentrations may directly or indirectly seriously impact benthic abundance, biomass, diversity and species composition.

Rationale: All benthic heterotrophs regenerate nutrients that can stimulate primary production. This primary production may be beneficial for some benthic animals (e.g. suspension feeders), but a high primary production caused by nutrient increases can often lead to lower oxygen concentrations near, and at the bottom. This may be devastating to a large number of infaunal species, and lead to higher relative abundances of species tolerant to low oxygen levels. This community will also usually wind up dominated by a few opportunistic (r-strategists) species. These species usually occur in large numbers, but with a very low diversity, and may impact other species (fish, large invertebrates) that are dependent on a diverse bottom community as the food source.

9.2 Greater Everglades Wetlands Module

9.2.1 Module Location Description and Background Information

The remaining portion of the Greater Everglades Wetlands includes a mosaic of inter-connected freshwater wetlands and estuaries (Figure 9.2.1). 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
4) Big Cypress Basin eastern portions that will be influenced by the CERP

Major stressors currently impacting Greater Everglades Wetlands include disruption of sheet flow and associated hydropatterns, sea level rise, nutrient inputs and eutrophication, and non-native plants and animals. The Greater Everglades Wetlands Module includes five clusters of interrelated hypotheses:

- Integrated Hydrology And Water Quality
- Coastal Transgression, Tidal Channel Characteristics, Salinity Gradients, and Mangrove Forest Productivity
- Wetland Landscape and Plant Community Dynamics
- Predator-Prey Interactions of Wading Birds and Aquatic Fauna Forage Base

- Everglades Crocodilian Populations

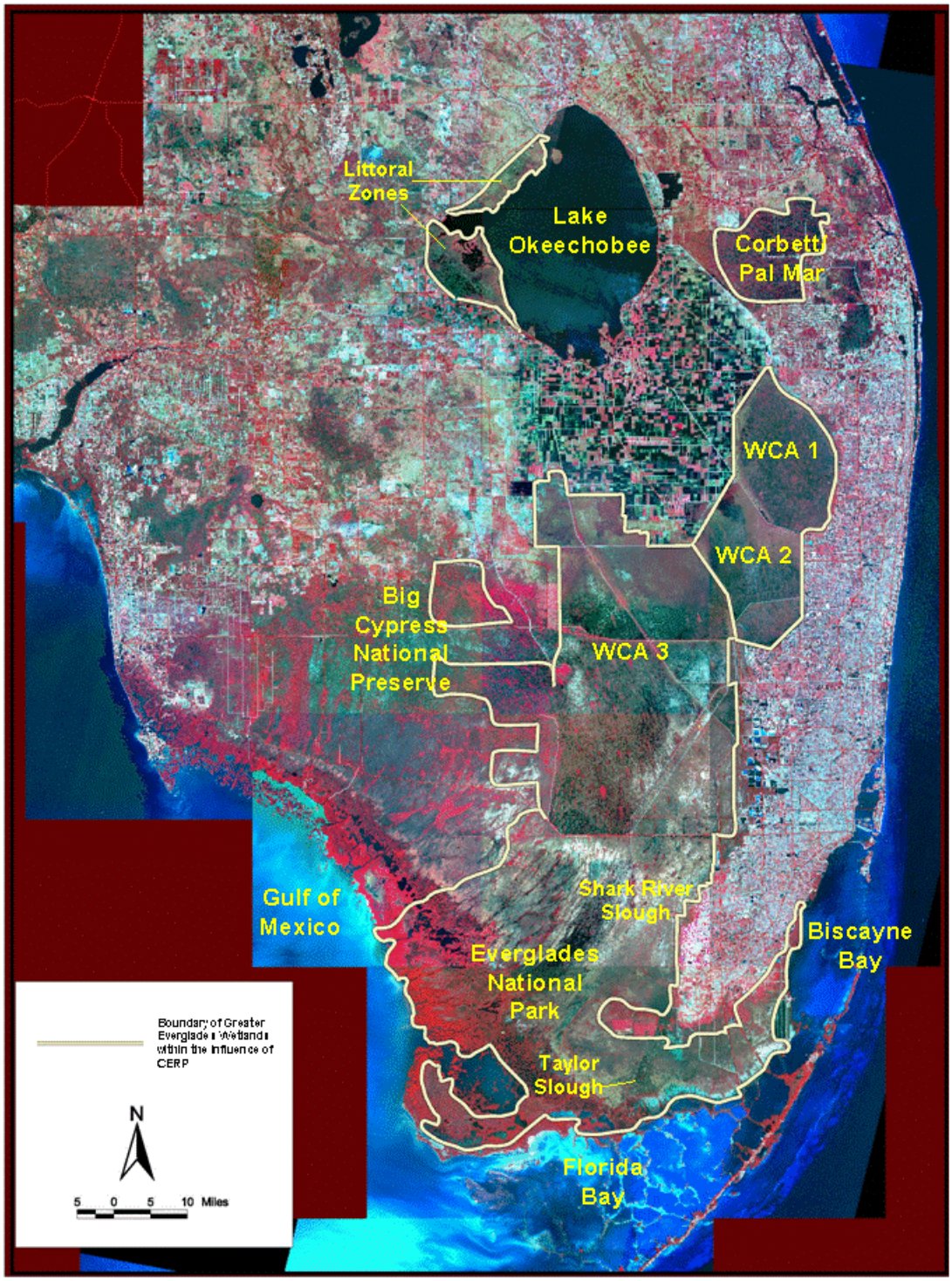

Figure **9-2-1**: Greater Everglades Wetlands Boundary.

9.2.2 Status of Monitoring Program for the Greater Everglades

Table 9-2: Monitoring Components and Supporting Research for Greater Everglades

Monitoring Components	MAP Section	STATUS
Interior Gradients of Flow and Water Quality	3.1.3.1	Implementation planning underway as a joint effort between NPS, SFWMD, and USGS
Regional Distribution of Soil Nutrients	3.1.3.2	Ongoing; SFWMD lead
Coastal Gradients of Flow, Salinity, and Nutrients	3.1.3.3	Ongoing; USGS lead
Landscape Pattern – Vegetation Mapping	3.1.3.4	Water Conservation Areas completed; ENP vegetation mapping to begin Sept. 2005
Landscape Pattern – Marl Prairie/Slough Gradients	3.1.3.5	Underway (ENP/FIU), started March 2005
Landscape Pattern – Ridge, Slough, and Tree Island Gradients	3.1.3.6	Planning for EDEN (Everglades Depth Estimation Network) project by USGS underway, to be implemented by Spring 2006. SFWMD planning to begin this monitoring in the first quarter of FY06
Landscape Pattern – Tidal Creek Delineation	3.1.3.7	Completed Fall 2004
Trophic Level – Primary – Periphyton Mat Cover and Composition	3.1.3.8	Underway, started in November 2004
Trophic Level – Primary – Mangrove Forest Soil Accretion	3.1.3.9	Proposed for USACE FY06 budget
Trophic Level – Secondary – Aquatic Fauna Regional Populations	3.1.3.8, 3.1.3.10	Underway, started in November 2004
Development and Testing of Protocols for Sampling Fishes in Forested Wetlands	3.1.3.10	Underway (USGS, ENP), started August 2004
Use of Amphibian Communities as Indicators of Restoration Success	3.1.3.10	Proposed for USACE FY08 budget
Trophic Level – Secondary – Aquatic Fauna Seasonal Concentrations	3.1.3.11	Underway, started March 2004
Trophic Level – Wading Bird Foraging Distribution and Abundance	3.1.3.12	Underway, Modwaters Project
Trophic Level – Wading Bird Nesting Colony Location, Size, and	3.1.3.13	Underway (USGS/UF, ENP/ FAU), started July 2004

Timing		
Trophic Level – Wood Stork and Roseate Spoonbill Nesting Success	3.1.3.14	Underway (USGS/UF, ENP/ FAU), started July 2004
American Crocodile Juvenile Growth and Survival	3.1.3.16	Underway (USGS/UF), started July 2004
Factors Affecting Successful Snail Kite (Rostrhamus sociabilis plumbeus) Nests in the Kissimmee-Okeechobee Everglades Basin		Proposed for USACE FY06 budget
Key Uncertainties and Supporting Research		
Coastal Wetland 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.	SFWMD to implement research in FY06
Technology Development: NASA Vegetation Mapping	3.1.4.5	
Crayfish Population Dynamics – Hydrological Influences	3.1.4.6	Underway, started June 2004
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	Proposed for USACE FY06 budget
Synthesis of Wading Bird Distribution Surveys 1985-2001	3.1.4.9	Contract currently in amendment for time due to modeling delays
Sub-lethal Effects of Contaminants on Wading Bird Reproduction	3.1.4.10	Phase I underway-Aviary construction and stocking with White Ibis

9.2.3 Integrated Hydrology and Water Quality

Direct rainfall and discharge from Lake Okeechobee onto a vast wetland landscape of low topographic relief, a pervious limerock geological setting, and a subtropical climate resulted in sheet flow and low levels of phosphorus and other chemical constituents in the pre-drainage Everglades. Together, these physical-chemical drivers defined the Everglades as a unique ecosystem and are a major influence on all of its ecological processes and attributes.

Restoration of the Everglades ecosystem depends on restoration of the volume, timing, and distribution of sheet flow and on restriction of inputs of phosphorus and other chemical constituents to levels approximating those in direct rainfall.

Sheet flow and inputs of phosphorus and other chemical constituents fundamentally affect all working hypotheses for greater Everglades wetlands ridge and slough landscape dynamics, plant community distributions along elevation gradients, predator-prey interactions of wading birds and their aquatic fauna forage base, crocodilian population dynamics, coastal salinity gradients, coastal transgression, and mangrove forest production.

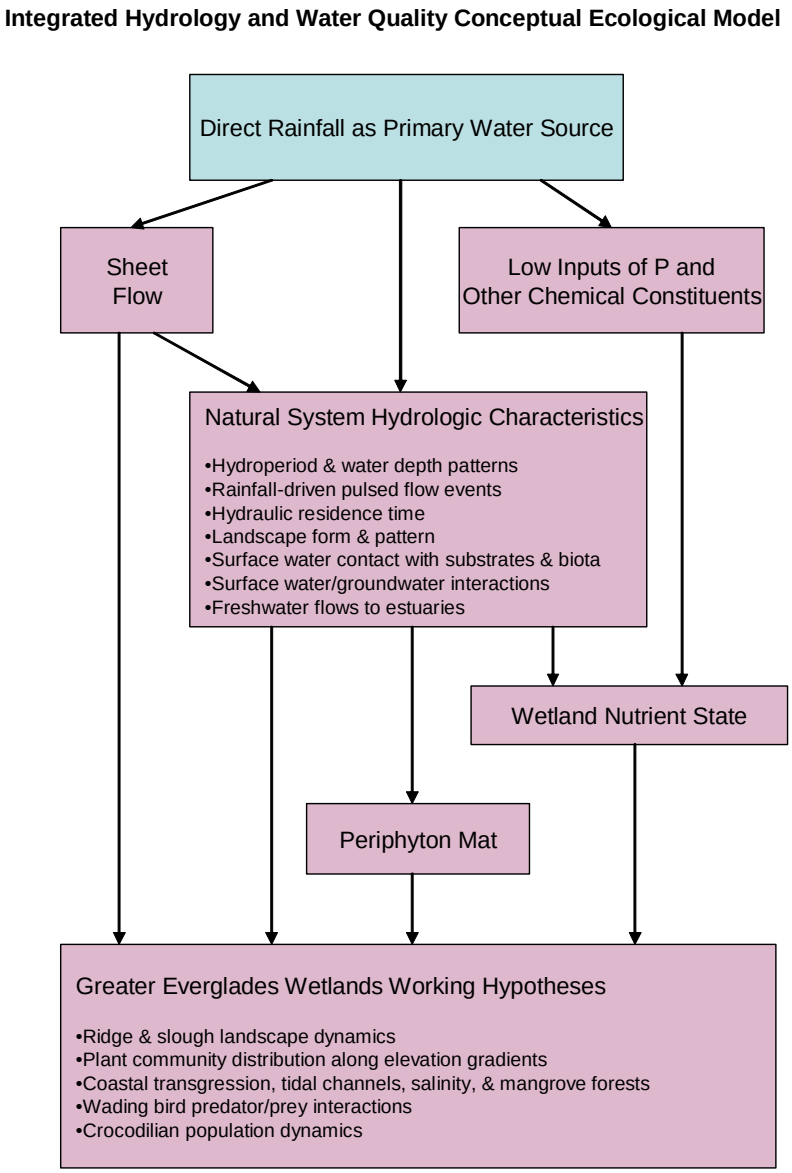

Figure 9-2-2: Integrated Hydrology and Water Quality Conceptual Ecological Model

Hypothesis 1
Rainfall and Sheet Flow as Determinants of Natural System Hydrologic Characteristics in the Everglades

The volume, timing, and distribution of sheet flow, in combination with direct rainfall, produced fundamental hydrologic and landscape characteristics of the pre-drainage Everglades that can be described by the following parameters:

- Hydroperiod and water depth patterns
- Rainfall-driven pulsed flow events
- Hydraulic residence time
- Landscape form and pattern
- Surface water contact with substrates and biota
- Surface water/groundwater interactions
- Freshwater flows supporting beneficial salinity patterns in the mangrove estuaries of Florida Bay and the Gulf of Mexico

Compartmentalization has altered or eliminated sheet flow and related natural system hydrologic and landscape characteristics throughout the Everglades. Decompartmentalization, combined with resumption of natural volume, distribution, and timing of freshwater delivery is expected to restore sheet flow and pre-drainage hydrologic and landscape characteristics to an undivided ecosystem encompassing much of Water Conservation Area 3A, Water Conservation Area 3B, eastern Big Cypress, and Everglades National Park.

Rationale: Specific hydrologic restoration targets associated with the resumption of sheet flow and related hydrologic characteristics include:

- Multi-year hydroperiods in ridge and slough landscape
- Conditions conducive to peat formation in ridge and slough landscape
- Hydropatterns that sustain co-existing sloughs and sawgrass ridges in the ridge and slough landscape
- No distinct or persistent changes in water levels across boundaries such as canals, levees, or roads
- Large-scale surface water flow directions that follow the historic landscape directionality
- Hydropatterns that support the long-term stability of tree islands in ridge and slough landscape
- Hydroperiods from two months to less than one year conducive to marl formation and muhly grass (*Muhlenbergia filipes*) community persistence in Southern marl prairies

- Persistent pools of fresh to oligohaline water along the interface of the freshwater Everglades and the mangrove ecotone of Florida Bay and the Gulf of Mexico
- Dry season water recession patterns conducive to successful wading bird foraging
- Multi-year flood and drought cycles supporting formation of wading bird super-colonies
- Absence of harmful regulatory releases of excess fresh water to the Greater Everglades
- Freshwater flow discharges to Florida Bay and the Gulf estuaries that maintain a near shore salinity gradient characteristic of pre-drainage conditions.

Natural system hydrologic restoration targets are necessarily qualitative due to uncertainty regarding pre-drainage hydrology. Successive iterations of the Natural System Hydrology Model (NSM) quantify these targets for planning purposes despite high levels of uncertainty. Successful restoration of natural system hydrologic characteristics as CERP is implemented ultimately must be guided by AM based on measured responses of the ecosystem to hydrologic changes.

Hypothesis 2
Nutrient Inputs and Sheet Flow as Determinants of Wetland Nutrient State in the Everglades

The dominance of direct rainfall as the primary source of water and phosphorus, in combination with sheetflow and related hydrologic and climatic characteristics, resulted in an oligotrophic, phosphorus-limited nutrient state throughout the greater Everglades wetlands prior to drainage.

Rationale: Increased phosphorus concentrations and loads in agricultural runoff water, and replacement of sheet flow with canal flows and point-source discharges, have produced phosphorus concentration gradients downstream of canal discharge structures, shifting wetlands from oligotrophic to eutrophic states. Water column total P concentrations are below ~10 ppb under non-enriched conditions in the Everglades. Most harmful ecological responses to P enrichment occur within a range of mean annual water column total P concentrations between ~10-30 ppb.

Reduction of the magnitude of nutrient inputs to the Greater Everglades will have the following effects:

- Reductions in phosphorus in inflow waters to the Greater Everglades will influence the downstream rate of recovery of ecosystem components.
- Existing gradients of phosphorus, nitrogen and sulfur will decrease between input locations and Everglades National Park.

- Where water quality constituent gradients currently do not exist, none will form.
- Non-impacted areas immediately downstream of impacted areas may be affected by phosphorus currently present in the impacted areas, *i.e.,* presently enriched zones in WCAs will continually move south, especially under sheet flow conditions.
- Phosphorus and nitrogen concentrations in soil, flocculent organic matter, and periphyton will reflect patterns and trends in surface water concentrations, integrated over various time scales, from months to years.

Hypothesis 3
Nitrogen Dynamics in the Everglades

Nitrogen dynamics, such as rates of nitrification, denitrification, uptake of inorganic nitrogen species, and production of organic nitrogen, are dominated by local cycling and processing under natural conditions in the Everglades.

Rationale. The importance of local nitrogen cycling and processing presently increases with distance from surface water inflow locations, while the importance of surface water nitrogen loading concurrently decreases. This trend is expected to continue under restored water inflows and associated nitrogen loadings.

Hypothesis 4
Periphyton Mat as an Indicator of Integrated Hydrology and Water Quality in the Everglades

Periphyton mat structure and community composition integrate hydrology and water quality across the entire wetland system of the Everglades. Hydrology and water quality interact to create a mosaic of periphyton community types throughout the Everglades.

Rationale: Periphyton responds quickly (weeks to months) to alterations in water management and can serve as early warning indicators of ecosystem change.

Shortened hydroperiods cause:

- Reduced proportion of diatoms and green algae relative to cyanobacteria
- Increased calcareous blue-green algae, possibly reducing food value of periphyton
- Increased proportion of sediment or plant-stem associated mats as opposed to floating mats attached to floating macrophytes (such as *Utricularia purpurea*).
- Decreased organic ash weight ratio of periphyton

Phosphorus enrichment through increased loading causes:

- Elevated nutrient content of periphyton material
- Increased organic content of periphyton communities

- Reduced calcareous floating and epiphytic periphyton mats
- Replacement of low nutrient-tolerant species by non-mat forming filamentous green algal species

Periphyton productivity is very high in the oligohaline zone of the southern Everglades. Increased freshwater delivery may broaden this zone of high periphyton productivity.

Detection of periphyton response to changes in hydrology and water quality needs to be based on comparison to a habitat-specific baseline (i.e. ridge and slough, marl prairie, rocky glades, or oligohaline zone). In addition, the effects of grazing on the periphyton community composition should be quantified.

9.2.4 Coastal Transgression, Tidal Channel Characteristics, Salinity Gradients, and Mangrove Forest Productivity

Ecological processes and attributes in the mangrove coastlines of the southern Everglades are hydrologically controlled by interactions between overland sheet flow from freshwater wetlands and the waters of the Gulf of Mexico and Florida Bay. Changes in freshwater flow from the implementation of CERP projects are relatively short-term in comparison to the longer-term, progressively increasing changes in salinity and coastal hydrologic budgets resulting from relative sea level rise.

The rate of relative sea-level rise in south Florida increased began increasing in about 1930. Since that time, relative sea-level in south Florida has increased about 23 centimeters (9 inches), or 30 cm (one foot) per century. Anticipated responses of sea level rise to global warming is projected to result in a global increase in sea level of about 60 centimeters (two feet) in the coming century.

The CEMs presented in this section differ from the others in this document in that the endpoints are the results of the impact of the stressors as manifest through the causal pathways.

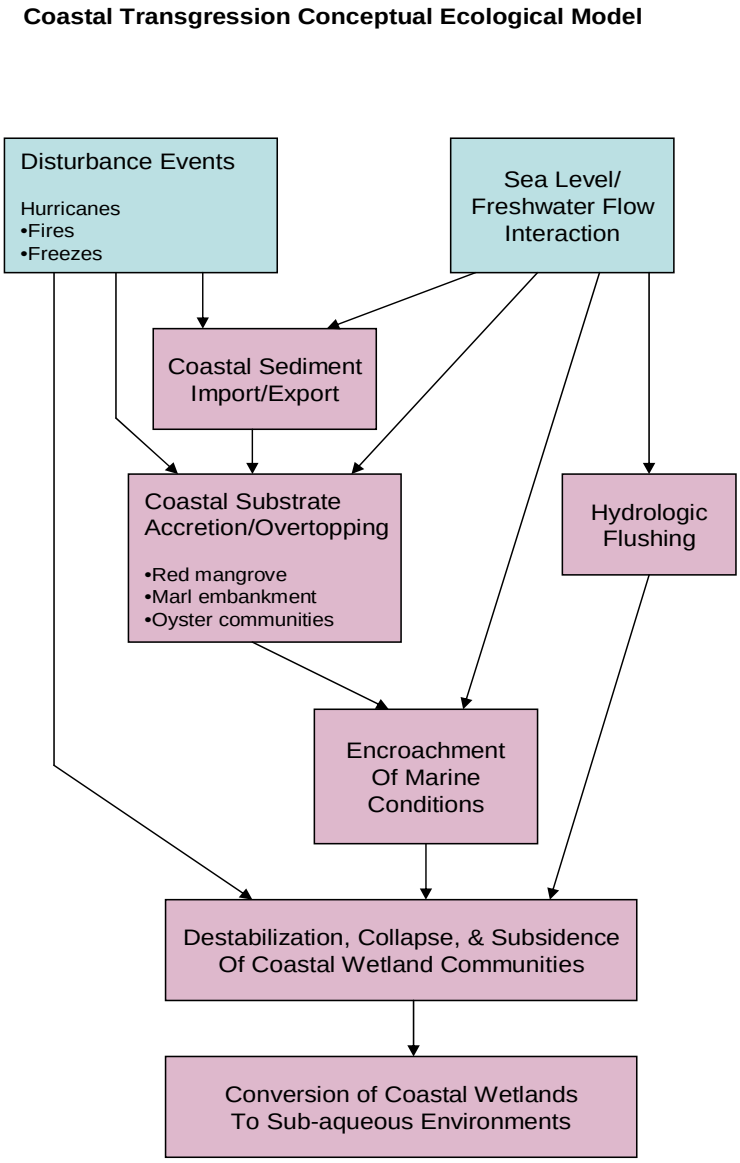

Figure 9-2-3: Coastal Transgression Conceptual Ecological Model

Hypothesis 1

Sea Level and Freshwater Flow as Determinants of Coastal Transgression

Sustained substrate buildup by physical and biological processes in many coastal marl and mangrove environments of South Florida may not be capable of keeping up with rates of sea-level rise during the 21st century.

Where rates of peat or marl elevation buildup do not keep up with rates of sea level rise, shoreline transgression and landward salinity intrusion into mangrove and freshwater wetlands will occur.

Rationale: Red mangrove forests in south Florida can potentially accrete organic peat substrate at 2-6 mm/year. Disturbances (major hurricanes, fire, freeze, and changing flushing) disrupt these peat accretion rates and commonly result in alternating phases of substrate subsidence and decay. Salinity stress may also reduce accretion rates. In this time of rapidly rising sea level, most mangrove communities are presently losing area of coverage. In the coming century the coastal mangrove community may be expected to become increasingly dissected. Sustained rates of accretion of coastal marl shorelines of Florida Bay may also be incapable of keeping up with the rate of sea level rise, and over-topping and breaching of embankments during storm events are likely under future scenarios of rising sea level.

Where rates of peat or marl elevation buildup do not keep up with rates of sea level rise, shoreline transgression and landward salinity intrusion will lead to mangrove erosion along shorelines and mangrove movement into interior landscapes. Saline intrusion into freshwater wetlands underlain by peat substrate may lead to wetland community collapse and transformation to open, saline ponds and estuaries. Saline intrusion into marl substrate wetlands results in an advancing zone of diminished productivity (this is often called the "white zone"). Restoration of freshwater flow volume, timing, and distribution may slow the inland movement but it is not expected to change the rate of erosion along the shoreline.

Hypothesis 2
Sea Level and Freshwater Flow as Determinants of Tidal Channel Characteristics

The dendritic pattern, channel width and depth, flow volume, and material transport of tidal watercourses and channels through the coastal mangrove estuaries are controlled by sea level interacting with the volume, timing, and distribution of sheet flow and channel flow from the southern Everglades.

Rationale: Restored freshwater inflow from the Everglades is expected to help sustain open watercourses through the estuary that will more closely resemble historic patterns, and re-open some channels that have partly filled because of reduced flow. Sea-level rise is expected to modify the patterns of connectivity and channel patterns through the coastal wetlands and create increased sediment loads.

With rising sea level, offshore marine waters become connected to interior depressions (interior lakes and collapsed freshwater marsh areas) by a combination of connecting channels, sheet flow through wetlands, and/or flow across inundated ridges, such as the buttonwood embankment. These connections increase the flood tidal prism (area and volume of flood tidal water) and result in enhanced flood and especially ebb tidal flow. This process is expected to result in stronger tidal currents through channels resulting in enhanced erosion and widening of those channels. Such conditions are expected to result

in an increased import and/or export (depending on setting) of particulates, nutrients and dissolved organics. Sea-level rise is expected to destabilize many coastal and nearshore marine sedimentary environments resulting in increased movement of fine-grained sediment in the coastal zone. Significant portions of this sediment probably will be moved inwards through tidal channels into interior coastal bays and wetlands.

Tidal Channel Characteristics Conceptual Ecological Model

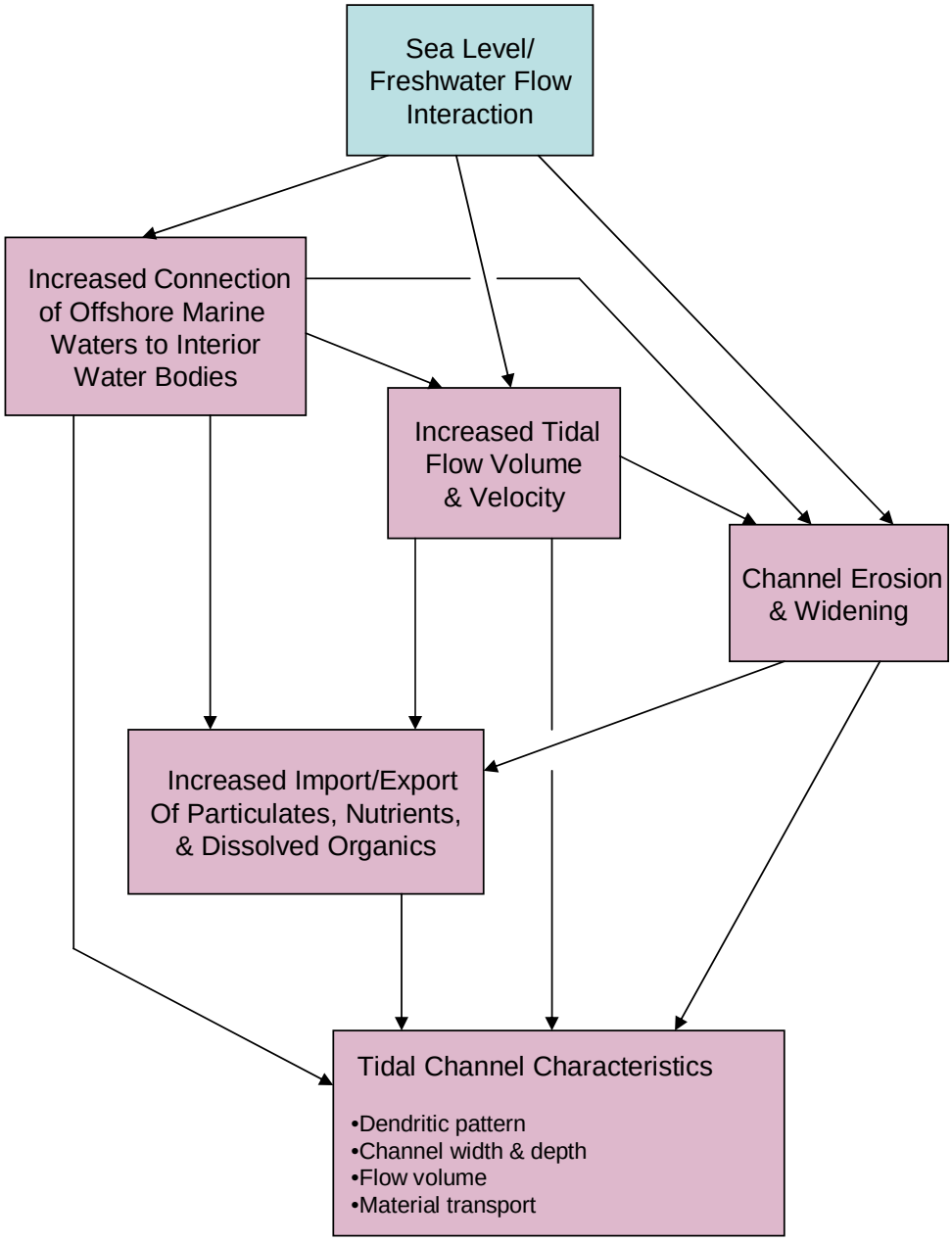

Figure 9-2-4: Tidal Channel Characteristics Conceptual Ecological Model

Hypothesis 3
Sea Level and Freshwater Flow as Determinants of Coastal Salinity Gradients

Sheet flow in the southern Everglades prior to drainage produced prolonged pooling of fresh water 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.

A combination of historical reduced freshwater flow and increased relative sea level rise has resulted in higher salinities in the formally estuarine mangrove zone and significant saline intrusion into former freshwater marshes of the lower Everglades.

Rationale: Increasing seasonal freshwater sheet flow to the lower Everglades is expected to provide a broader zone of salinity gradients in the lower Everglades and coastal wetlands and should, in the short term, re-establish an oligohaline zone in the coastal wetlands.

Although surface water salinities fluctuate laterally through the wet and dry seasons, saline groundwater intrusion has moved and remains far inland of the position at the turn of the last century. The freshwater/saltwater interface in the shallow aquifer is slower to respond. The response or movement of the interface depends on the intensity and duration of freshwater flow stoppage to the lower Everglades during the dry season.

Over a long-term period, rising sea level is expected to result in high tides overtopping coastal marl ridges and saline waters penetrating more deeply through tidal channels and mangrove forests, shifting inland the areas of fresh and lower salinity waters.

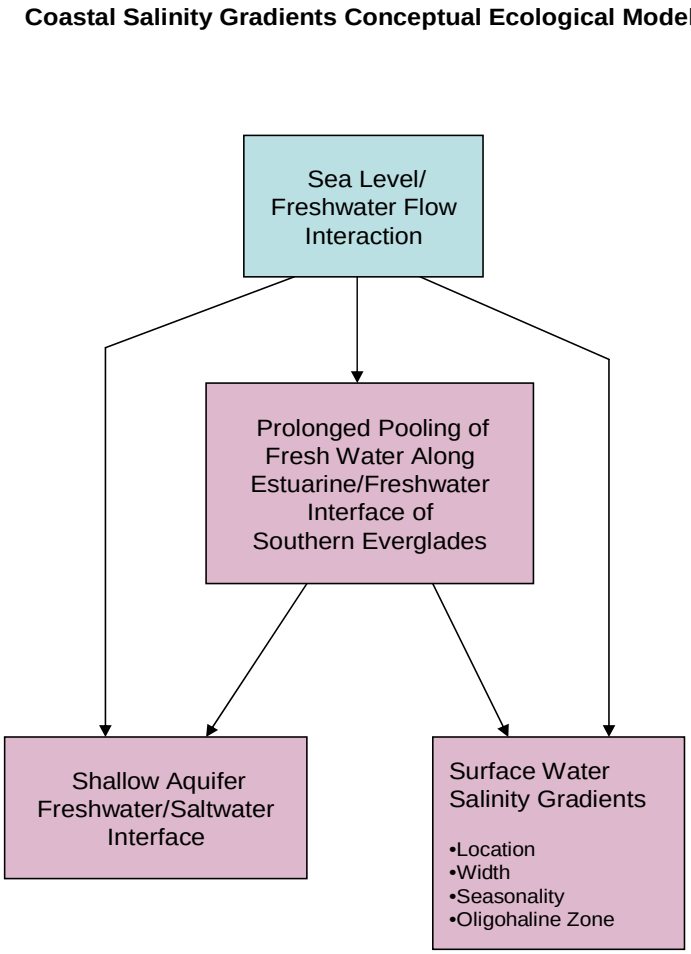

Figure 9-2-5: Coastal Salinity Gradients Conceptual Ecological Model

Hypothesis 4

Sea Level, Freshwater Flow and Phosphorus inputs as Determinants of Above and Belowground Production, Organic Soil Accretion, and Resilience of Coastal Mangrove Forests

Production and organic soil accretion in the mangrove forests of the coastal Everglades are controlled by phosphorus availability, with relatively high inputs from marine sources and low inputs from freshwater sources. Phosphorus availability, mangrove production, and soil elevation are thus driven by the opposing influences of sea level and sheet flow from the Everglades.

Resilience of the mangrove forests of the coastal Everglades after disturbance is dependent on hydrologic flushing by either fresh or saline water, which is driven by sea level and sheet flow from the Everglades. Resilience also varies with soil fertility.

Rationale: Aboveground biomass and production in the mangrove forests of Shark River Slough and other Gulf estuaries increase from the ecotone toward the Gulf of Mexico, reflecting the direct connection of these systems to the marine phosphorus source. Trees in the forests near the Gulf are able to allocate more biomass to aboveground growth. The dwarf mangrove forests along the northern margin of Florida Bay reflect suppressed levels of aboveground productivity, as influenced by minimal P supply from either the oligotrophic marshes of the southern Everglades or Florida Bay. High belowground production rates in the dwarf mangrove forests appear to be a biomass allocation phenomenon in which mangroves in the oligotrophic southern Everglades are foraging for nutrients. The counter-intuitive expectation is that maintenance of oligotrophic conditions in the southern Everglades [by increased freshwater inflows] may promote peat accretion in these mangroves.

Increased freshwater sheet flow caused by implementation of CERP projects is expected to maintain low nutrient conditions in the southern Everglades mangrove estuaries and in the oligohaline ecotone forests of the western mangrove estuaries. These low nutrient conditions are expected to enhance belowground productivity by mangroves, which will maintain peat production and soil elevation increases—ultimately enhancing the ability of these low salinity forests to maintain themselves against sea level rise.

An important feature for maintenance of an existing wetland environment, its recovery following disturbance events such as hurricanes, freezes, fires, or salinity changes, or the successful shift from one wetland type to another is maintenance of good flushing by either fresh or saline waters. This leads to an inland expansion of the white zone, or the mangrove-freshwater interface. Contraction and expansion of this “white zone” are regulated by freshwater flow dynamics and sea level rise. This phenomenon has implications for the long-term maintenance of mangrove communities and for mangrove communities trying to move into former sawgrass wetlands. Improved freshwater flow and flushing through the lower Everglades and coastal wetlands (through both channel and sheet flow) are expected to aid in recovery of wetlands from catastrophic setbacks (from hurricanes, fire, freeze and salinity changes).

Mangrove Forest Production, Organic Soil Accumulation, and Resilience Conceptual Ecological Model

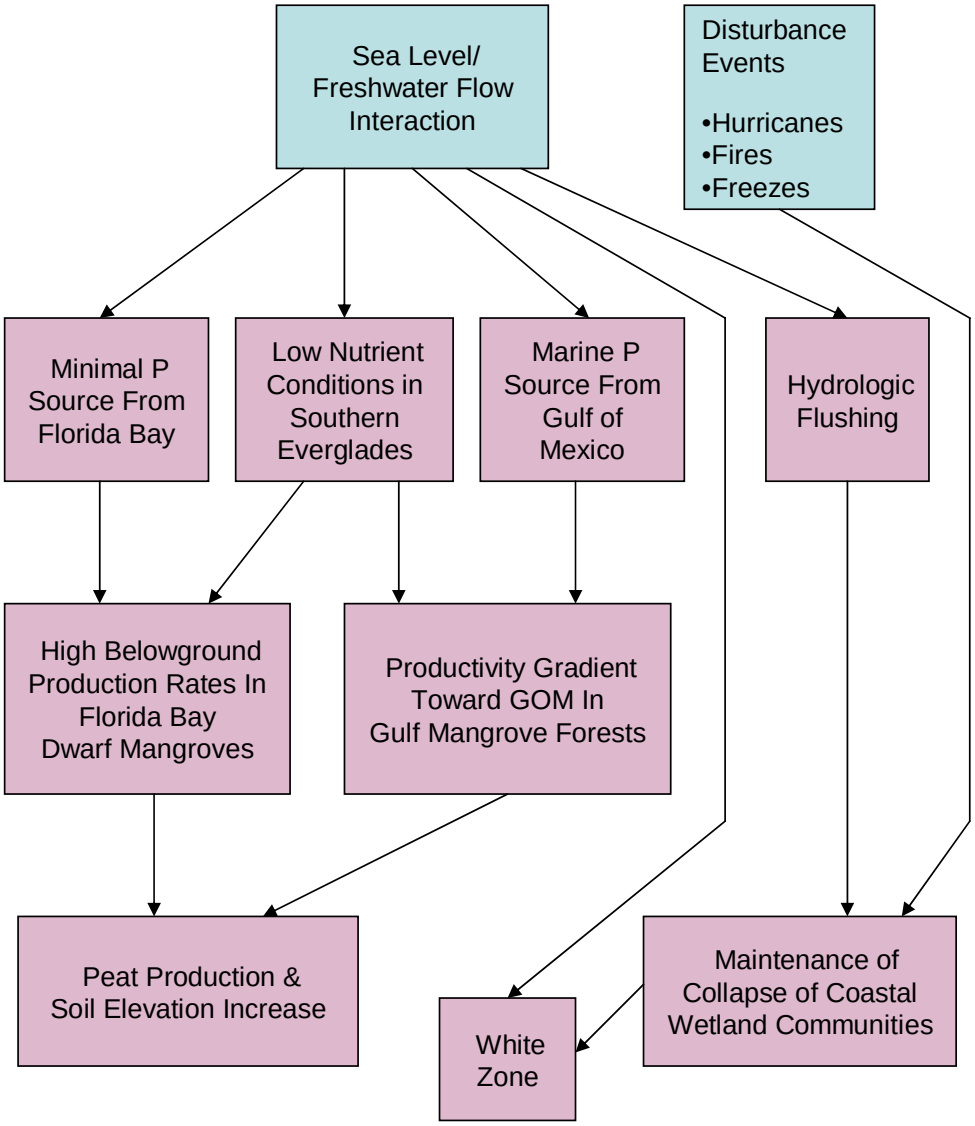

Figure 9-2-6: Mangrove Forest Production, Organic Soil Accumulation, and Resilience Conceptual Ecological Model

9.2.5 Wetland Landscape and Plant Community Dynamics

Hypothesis 1
Everglades Ridge and Slough Micro-topography in Relation to Organic Soil Accretion and Loss

Sheet flow interacts with hydroperiod, water depth, fire, and nutrient dynamics to maintain organic soil accretion and loss in a state of dynamic equilibrium.

Rationale: The dynamic equilibrium involves a balance of particulate organic matter transport, and the accumulation, oxidation, and combustion of organic soil. Altered magnitude, duration, and direction of sheet flow causes disequilibrium of accretion and loss processes. The disequilibrium is exacerbated by eutrophication. Disequilibrium of accretion and loss processes causes degradation in the ridge, slough, and tree island micro-topography toward a flattening of the landscape.

Restoration of sheet flow in combination with related hydrology, water quality, and fire patterns will re-establish the feedback conditions that sustain the micro-topography of ridges, sloughs, and tree islands.

Hypothesis 2
Everglades Ridge and Slough Landscape Pattern in Relation to Micro-topography

Degradation of micro-topography, changes in hydroperiod, water depth, eutrophication, fire, and vegetation, especially nonnative and invasive species, can reduce the diversity and stability of habitats which were previously long-term, large-scale features of the ridge and slough landscape.

Rationale: Decline in ridge and slough habitat diversity and stability includes expansion of sawgrass into sloughs and wet prairies, tree island drowning, tree island burn-out, conversion to cattail under eutrophic conditions, and takeover by exotic species, such as, *Melaleuca quinquenervia* and *Lygodium microphyllum*.

Resumption of sheet flow and related patterns of hydroperiod, water depth, water quality, and fire will significantly restore and sustain the microtopography, directionality, and spatial extent of ridges and sloughs and improve the health of tree islands in the ridge and slough landscape.

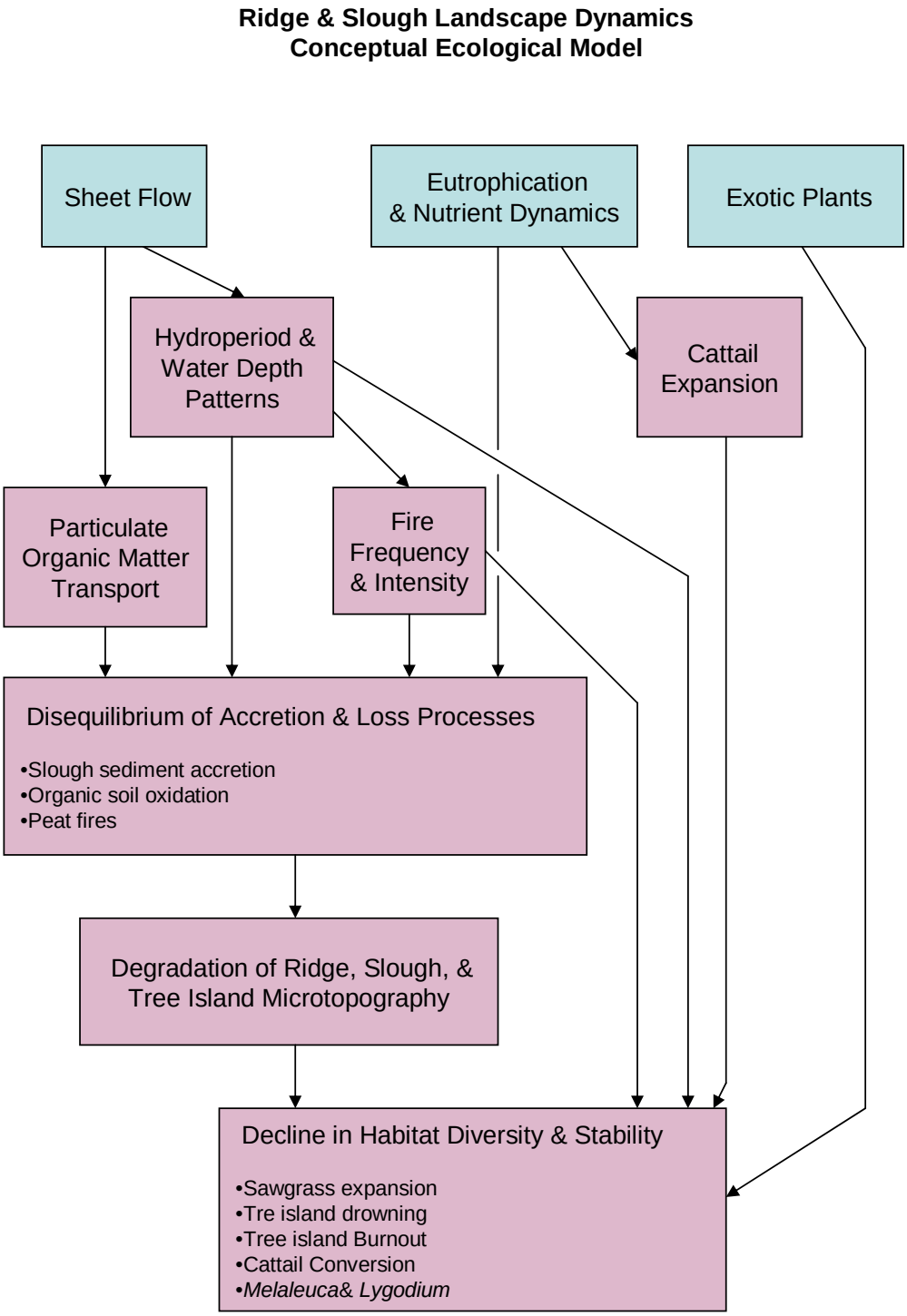

Figure 9-2-7: Ridge and Slough Landscape Dynamics Conceptual Ecological Model

Hypothesis 3
Plant Community Dynamics along Elevation Gradients

The composition and distribution of plant communities along elevation gradients are determined by patterns of hydroperiod, water depth, nutrient dynamics, and fire patterns throughout freshwater wetlands of the Greater Everglades.

Rationale: The dynamic equilibrium of the vegetation mosaic in relation to elevation gradients is maintained if biogeochemical processes in the soil support the physiological requirements of the vegetation. The dynamic equilibrium is altered if water depths or hydroperiods decrease or increase. Anthropogenic disturbances (i.e. past 100+ years) of hydroperiods, water depths, eutrophication, fire patterns, land use change, and the spread of exotic plants and animals have shifted the vegetation mosaic away from the historic dynamic equilibrium. These hypotheses are designed to focus monitoring and modeling at the ecotone boundaries between vegetation types which may be an early location of change.

In most of the greater Everglades wetlands where hydroperiods and water depths have decreased, the hydrologic tolerances of the surviving plant communities are adapted to greater hydroperiods and water depths than are currently maintained. For example, with regional drainage and altered fire regimes in the Big Cypress region there has been a gradual shift in landscape patterns, resulting in an increase in mesic rather than hydric-dominated communities.

Vegetation gradients between higher elevation marl prairies and lower elevation ridge and slough communities are of particular concern in the southern Everglades. Although a potential trade-off exists between ridge and slough habitat restoration and the extent and quality of habitat in adjacent marl prairies. It is thought that longer hydroperiods, greater water depths, and appropriate flow regimes will re-establish and sustain ridge and slough landscape patterns without significantly infringing on adjacent marl prairies, where short-hydroperiod, tussock growth habitats will persist.

Plant Communities/Elevation Gradients Conceptual Ecological Model

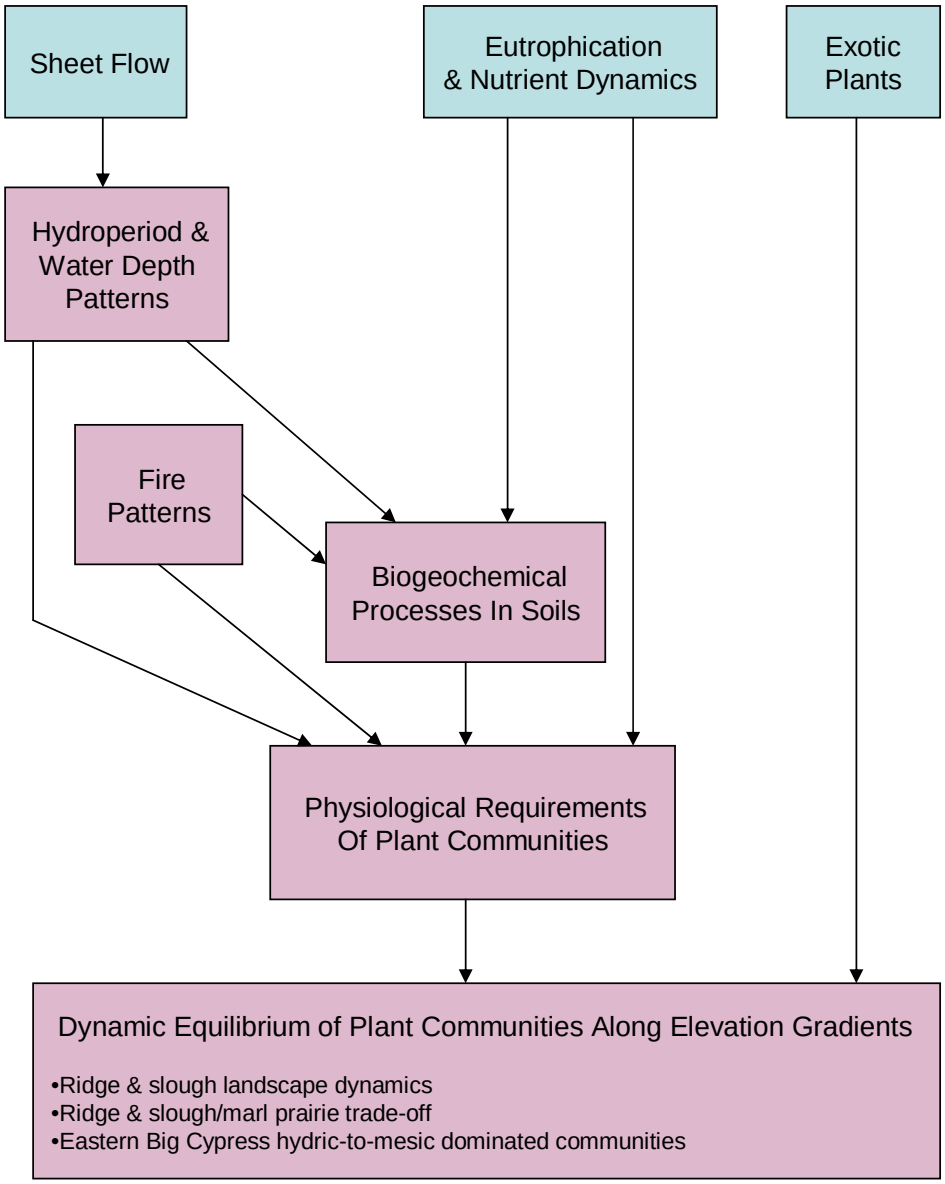

Figure 9-2-8: Plant Communities/Elevation Gradients Conceptual Ecological Model

9.2.6 Predator-Prey Interactions of Wading Birds and Aquatic Fauna Forage Base

The collapse of wading bird nesting colonies in the southern Everglades is attributed to declines in population densities and seasonal concentrations of marsh fishes and other aquatic prey organisms.

Restoration of natural hydrologic conditions will re-establish distributions of prey densities and concentrations across the landscape that in turn will support the return of large, successful wading bird nesting colonies to the southern Everglades.

Hypothesis 1
Aquatic Fauna Wet Season Prey Population

The wet-season density, size structure, and relative abundance of marsh fishes and other aquatic wading bird prey are directly related to the time since the last dry-down and the length of time the marsh was dry. Aquatic prey populations are further affected by salinity in coastal ecotones and by site nutrient status. Responses are non-linear and species specific.

Rationale: Persistent pools of fresh water, with multi-year hydroperiods and gradual water recession rates, occurred in ridge and slough landscapes and adjacent coastal ecotones of the southern Everglades under pre-drainage conditions. Expansive, naturally occurring pools in the southern Everglades have been replaced by artificial impoundments in the lower ends of Water Conservation Areas. As a result, population densities of aquatic fauna are low in much of the southern Everglades, while densities have increased in the artificial pools of the Water Conservation Areas, which now favor larger, longer-lived species.

Resumption of natural volume, timing, and distribution of freshwater flow will restore historical hydroperiods and salinity distributions to the southern Everglades. These changes are expected to increase wet-season density and size structure of wading bird prey in the southern Everglades within a four to seven year timeframe.

Predator-Prey Interactions of Wading Birds and Aquatic Fauna Forage Base Conceptual Ecological Model

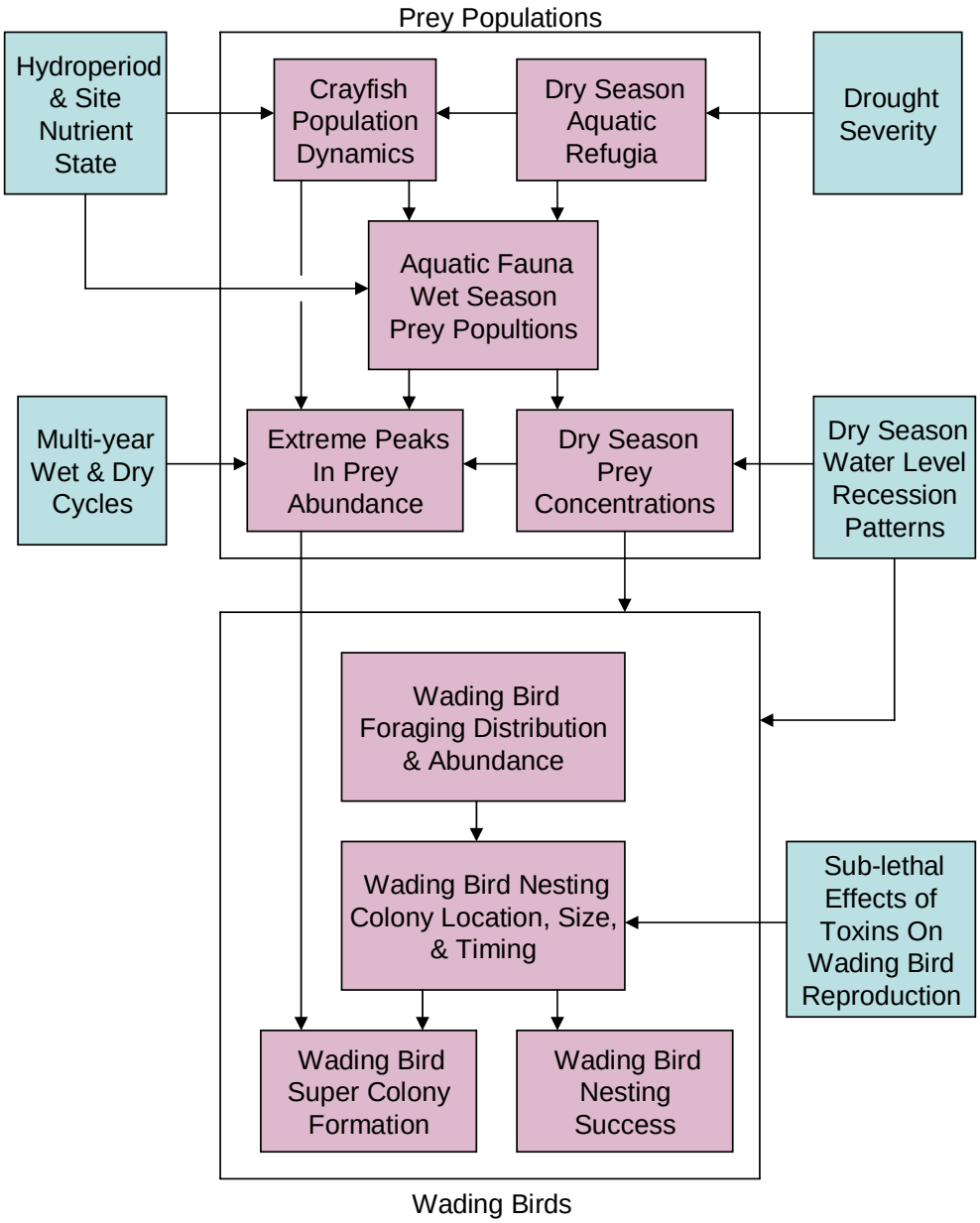

Figure 9-2-9: Predator-Prey Interactions of Wading Birds and Aquatic Fauna Forage Base Conceptual Ecological Model

Hypothesis 2
Aquatic Fauna Dry Season Prey Concentration

The concentration of marsh fishes and other wading bird prey into high-density patches where wading birds can feed effectively is controlled by the rate of dry-season water-level recession and local topography/habitat heterogeneity.

Rationale: Erratic water-level fluctuation in the remaining managed system, particularly in the Water Conservation Areas, commonly cause drying pattern interruptions, ultimately leading to ill-timed, fewer or less dense concentrations of aquatic fauna that serve as wading bird prey.

Drying edges extended along elevation gradients from upland pine flatwoods, and moved across marl prairies, to the lower-elevation ridge and slough and coastal landscapes as dry seasons progressed under pre-drainage conditions in the southern Everglades. The drying edges concentrated aquatic prey organisms and made them available to wading birds. Urban and agricultural development of the higher elevation eastern fringes of the southern Everglades, in combination with drying of marl prairies earlier in the dry season, have truncated in time and space the drying marsh edge and the concentration of aquatic prey organisms. During very wet years, the edge no longer occurs or occurs only briefly at the end of the dry season. In years with more typical rainfall, the edge may occur throughout the dry season, but it passes through the marl prairies very early and is well into the center of Shark Slough by the time it is needed to fuel wading bird nesting.

Resumption of natural volume, timing, and distribution of freshwater flow to the Everglades is expected to restore historical patterns of water level recession and drying edges, which will concentrate wading bird prey into a succession of high-density patches throughout the dry season in the remaining ridge and slough, marl prairie, and coastal landscapes.

Hypothesis 3
Wading Bird Nesting Colony Location, Size, and Timing

The collapse of wading bird nesting colonies in the tributary headwaters and southern mainland of the Everglades, the abandonment of Roseate Spoonbill nesting colonies in islands of northeast Florida Bay, and delay in the annual initiation of Wood Stork nesting have been caused by:

- decreased population densities of marsh fishes and other aquatic prey organisms in the southern Everglades, as described under Hypothesis 1
- a shift in the location and timing of seasonal concentrations of marsh fishes and other aquatic prey organisms, as described under Hypothesis 2
- reduced shallow-water foraging options for wading birds along elevation gradients

Rationale: Increased prey densities in artificial pools of the Water Conservations Areas have attracted wading bird nesting colonies to those areas after the collapse of the coastal

colonies. However, drying pattern interruptions in the Water Conservation Areas often disrupt prey concentrations that are required for successful foraging by the wading birds, resulting in failure of nesting colonies.

Restoration of historic spatio-temporal patterns of prey production and concentration is expected to reestablish wading bird nesting colonies in the coastal and tributary regions of the southern Everglades and Roseate Spoonbill nesting colonies in northeast Florida Bay. This restoration is also expected to increase numbers and success of nesting wading birds, Wood Storks, and Roseate Spoonbills and to cause Wood Storks to initiate nesting no later than January in most years.

Hypothesis 4
Wading Bird Super Colony Formation

Unusually large aggregations of nesting wading birds (super colonies) consisting of mostly White Ibis formed in the pre-drainage system in response to the effects of extreme, natural patterns of drought prior to colony formation.

Rationale: Super colonies periodically formed along the freshwater-estuarine transition zone (sawgrass-mangrove ecotone) at the lower reaches of the Everglades and Big Cypress basins. A substantial reduction in frequency of super colonies is attributed to disrupted multi-year wet and dry cycles, due to altered volume, timing, and distribution of flow in the managed system. Reduction in the size of super colonies may be related to reductions in wading bird prey populations due to reduced hydroperiods and disrupted water level recession patterns as described under Hypotheses 1 and 2.

Periods of extreme drought in natural multi-year wet and dry cycles appear to cue the occurrence of large pulses of secondary productivity that support the large nesting colonies which form after such droughts. The mechanisms by which these pulses are organized are poorly understood, but the effects of droughts on crayfish, predatory fishes, or nutrient dynamics may be involved. Population dynamics of crayfish (*Procambarus alleni* and *P. falax*) may play an important role, since the super colonies form when marsh fish populations would be expected to be minimal, and because White Ibis feed primarily on crayfish.

Resumption of natural patterns of volume, timing, and distribution of flow to the southern Everglades, in combination with interannual variation in rainfall, will restore natural multi-year wet and dry cycles as they would have occurred prior to drainage the southern Everglades. This is expected to stimulate pulses of secondary productivity that will likely involve Everglades crayfish populations. The pulses in secondary production are expected to result in an increase in the return frequency and size of ibis-dominated super colonies in the tributary headwaters of the Shark River and other Gulf of Mexico mangrove estuaries at a frequency of two or more events per decade.

Hypothesis 5
Linkage of Periphyton to Higher Trophic Levels

The floating mat comprised of the periphyton complex and various bladderworts provides critical support of the oligohaline Everglades food web, both as a food source and a refuge for aquatic invertebrates that are consumed by small fish, crayfish, and grass shrimp.

Rationale: The floating mat provides both food (algae and detritus) and habitat structure (hiding places) for macroinvertebrates, including midge larvae, nematodes, amphipods, and juvenile snails. The floating mat complex harbors much higher density of macroinvertebrates than epiphyton and benthic substrates; the daytime water column of oligotrophic Everglades wetlands is remarkably devoid of plankton, and relatively low densities of invertebrates emerge into the water column at night, compared to other North American ecosystems. These small invertebrates serve as a critical food source for Everglades consumers, including small fish, crayfish, and grass shrimp. Lengthened hydroperiods expand the aerial coverage of habitats where these food-rich mats are abundant. Shortened hydroperiod reduces the area of extensive floating mats and decreases the length of the season when habitat is available for aquatic organisms. These losses decrease standing crops available for consumption by higher trophic levels.

Higher nutrient levels stimulate invertebrate productivity, but change community composition to favor pollution-tolerant taxa. Short-lived low-level phosphorus enrichment leads to higher periphyton TP, which stimulates increased biomass and density of floating mat macroinvertebrate infauna. Macroinvertebrate community composition (relative abundance) changes with low-level nutrient enrichment, well below amounts favoring loss of the periphyton mat. The relative abundance of oligochaetes increases with enrichment, while amphipods and chironomids decline. However, sustained TP enrichment leads to dissolution of the floating mat, and loss of that habitat.

This hypothesis links the Everglades floating mat, and particularly periphyton primary productivity and detrital production, to higher trophic levels, which are the focus of management action.

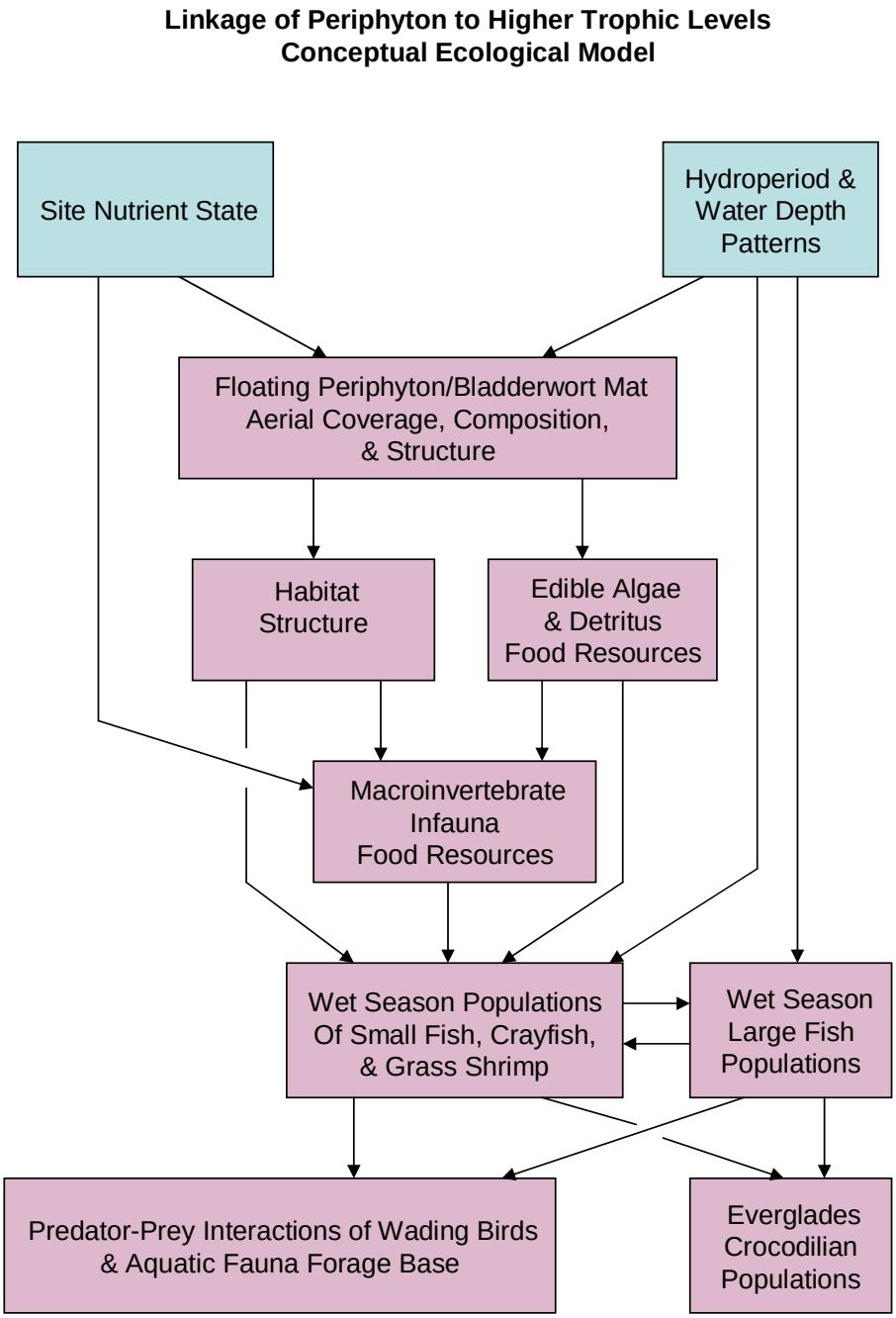

Figure 9-2-9: Linkage of Periphyton to Higher Trophic Levels Conceptual Ecological Model

9.2.7 Everglades Crocodilian Populations

Hypothesis 1
American alligator populations in relation to hydroperiod, water table, water depth, and salinity in the Everglades.

American alligator distribution, abundance, reproduction, and body condition in the Everglades are controlled by hydroperiod and water table in the Rocky Glades, salinity in the mangrove estuaries, and water depth patterns in the ridge and slough system, all of which were driven by direct rainfall and sheet flow prior to drainage.

Compartmentalization, disrupted sheet flow, and regulatory water releases restrict alligator populations in the ridge and slough landscape by causing nest flooding, unsuitable over-drained and pooled habitats in the Water Conservation Areas, and low hatchling and juvenile survival in canals during low water periods.

Rationale: Shortened hydroperiod and lowered water table in the rocky glades have reduced alligator abundance and reproduction because of loss of aquatic habitat required for survival and reduced aquatic prey base. A positive feedback loop of increased alligator populations and alligator holes (aquatic refugia) leading to increased aquatic fauna density (alligator prey) has been disrupted. That feedback loop is assumed to have been functional under pre-drainage conditions in the rocky glades where alligators were formerly abundant, although it is clearly not functional in the drained marshes today.

Reduced freshwater flow into the mangrove estuaries of the southern Everglades has resulted in succession of former freshwater mangrove areas to saltwater systems, reducing American alligator populations in tidal rivers and tributaries.

American alligator populations remain viable throughout most of the ridge and slough system. However, increased water depths during nesting seasons particularly near canals, the southern ends of each Water Conservation Area (1, 2, and 3), and Shark River Slough have led to high levels of nest flooding in some years. Alligator body condition is poor throughout the system during prolonged periods of increased water depth. Alligator density at the northern ends of the WCA's is low due to overdrained conditions leading to poor rates of survival and growth. Finally, a large portion of the adult population exists in canals but does not contribute to population growth due to the combination of increased nest flooding and decreased hatchling and juvenile survival during low water periods (predation and cannibalism).

With the resumption of natural patterns of volume, timing, and distribution of flow to the Everglades, the American alligator is expected to repopulate and resume nesting in the rocky glades and the freshwater reaches of tidal rivers in the mangrove estuaries and will increase in population size and body condition throughout most of the Greater Everglades wetlands.

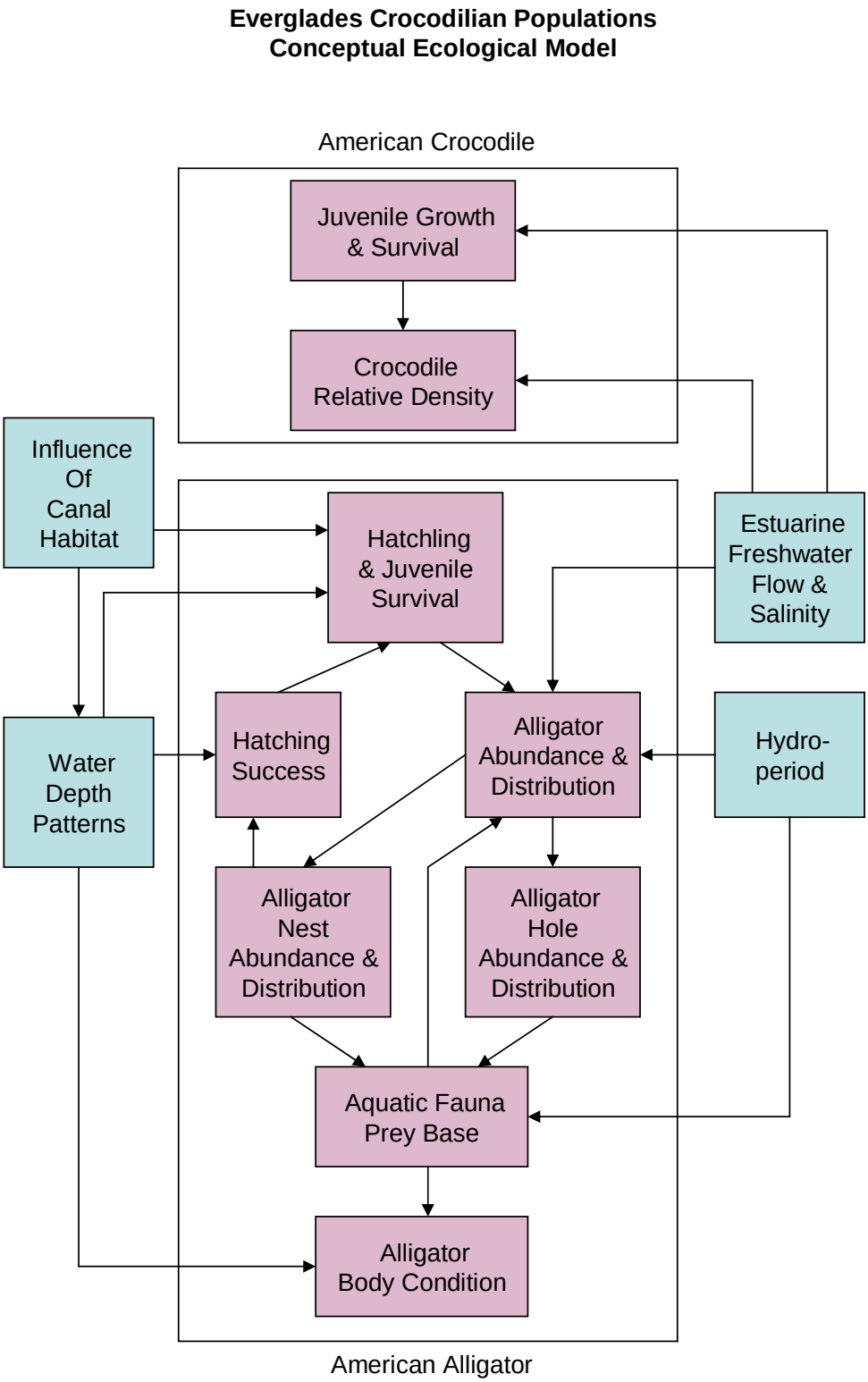

Figure 9-2-11: Everglades Crocodilian Populations Conceptual Ecological Model

Hypothesis 2
American Crocodile Relative Density and Juvenile Growth, Survival, and Condition in Relation to Salinity in Everglades Mangrove Estuaries

American crocodile relative density and juvenile crocodile growth, survival, and condition increase when salinity fluctuates below 20 ppt in shoreline, pond, and creek habitats in Everglades mangrove estuaries.

Rationale: Availability of freshwater limits the distribution and abundance of reptiles in estuaries. In estuaries, crocodilians of all species orient towards areas of low salinity and sources of freshwater. The American crocodile is a flagship endangered species that charismatically represents this relationship. In northeastern Florida Bay, diversion of freshwater flow, crocodiles have poorer growth rates and higher mortality than elsewhere in Florida.

Restoration of location of freshwater flow will result in an increase in relative density of crocodiles in areas of restored flow, such as Taylor Slough/Taylor River drainage. Reestablishing the salinity gradient in the estuary will increase growth and survival of juvenile crocodiles throughout the estuary.

9.3 Southern Estuaries Module

9.3.1 Module Location Description and Background Information

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 1). 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.

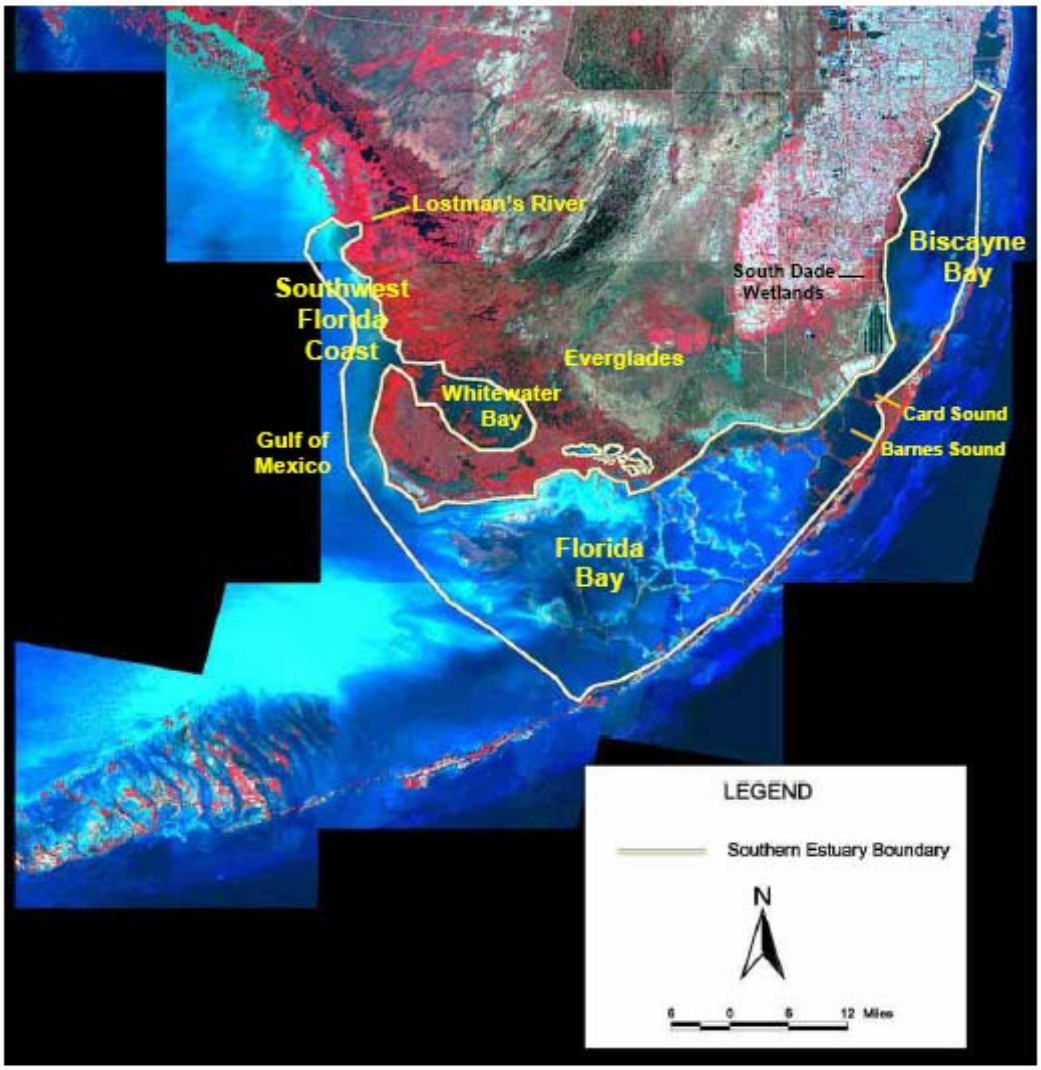

Figure 3-22: Southern Estuaries within the Influence of CERP

Florida Bay is a triangularly shaped estuary, with an area of about 2200 km^2 that lies between the southern tip of the Florida mainland and the Florida Keys (Figure 9.3.1). About 80 percent of this estuary is within Everglades National Park's boundaries and much of the remainder is within the Florida Keys National Marine Sanctuary. A defining feature of the bay is its shallow depth, which averages about 1 meter (Schomer and Drew 1982). Light sufficient to support photosynthesis can reach the sediment surface in almost all areas of the bay, resulting in dominance of seagrass beds as both a habitat and a source of primary production. The shallowness of Florida Bay also affects its circulation and salinity regime. Its' interior is generally well-mixed vertically with an isothermal and isohaline water column. On the other hand, its' complex network of shallow mud banks restricts horizontal water exchange among the bay's basins and between these basins and the Gulf of Mexico (Smith 1994, Wang *et al.* 1994).

In areas with long residence times, the salinity of Florida Bay water can rapidly rise during drought periods due to excess of evaporation over precipitation and freshwater inflow (Nuttle *et al.* 2000). Salinity levels as high as twice that of seawater have been

measured (McIvor *et al.* 1994). Another defining feature of the bay is that its 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 and stable system, with clear water, lush seagrass beds, and highly productive fish and shrimp populations. In the mid-1980s, however, catches of pink shrimp declined dramatically (Browder *et al.* 1999) and in 1987, a mass mortality of turtle grass (*Thalassia testudinum* Banks & Soland ex. Koenig) beds began (Robblee *et al.* 1991). By 1992, the ecosystem appeared to change from a clear water system, dominated by benthic primary production to a turbid water system, with algae blooms and resuspended sediments in the water column.

Biscayne Bay is a naturally clear-water bay with tropically enriched flora and fauna. Prior to the development of Miami-Dade County, much of the bay was bordered by mangroves and, otherwise, with herbaceous wetlands. The bay was once connected to the Greater Everglades ecosystem hydrologically through tributaries, sloughs, and ground-water flow. It possessed not only a marine habitat and fauna but also a substantial area of estuarine habitat and associated fauna. Because of the bay's shallow depths and naturally clear waters, its productivity is largely benthic-based (Roessler and Beardsley 1974). Benthic communities in the central and southern bay (i.e., south of the Rickenbacker Causeway) consist of several species of seagrasses, a mix of soft and hard corals, attached macroalgae and sponges, and coral-algal bank fringes that alternate in dominance in different areas. Benthic communities in northern Biscayne Bay are dominated by seagrasses intermixed in some cases with calcareous green algae.

While no comprehensive Conceptual Ecological Models have been developed as yet for these regions, it is well recognized that Whitewater Bay and the rivers connecting the Shark River Slough to the Southwest Florida Shelf (Shark, Harney, Lostman's etc.) are critical components of the integrated Southern Estuaries Ecosystem. Whitewater Bay is a very important nursery area for many recreationally and commercially significant fisheries species and the Southwest Florida shelf has repeatedly been shown to be dynamically connected to western Florida Bay. MAP sampling is underway in these regions and they willbe included in our integrated assessment of the Southern Estuaries.

These estuaries and embayments are the downstream recipients of most freshwater flow through the Greater Everglades. The primary (most direct) CERP projects that potentially affect 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 Re-use projects.

Decompartmentalization will also dramatically affect flows to Shark River and the other rivers discharging to the Southwest Florida Shelf as well as flows into Whitewater Bay. The CERP projects that will most directly affect Biscayne Bay 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.

9.3.2 Status of the Monitoring Program in the Southern Estuaries

Table 9-3: Monitoring Components and Key Uncertainties and Supporting Research for the Southern Estuaries

Monitoring Components	MAP Section	STATUS
Water Quality and Phytoplankton Monitoring Network	3.2.3.1	Underway and currently being conducted by FIU, Miami-Dade DERM and NOAA/AOML.
South Florida Fish Habitat Assessment Program	3.2.3.3	Underway and currently being conducted by FWC/FMRI and UNC/Wilmington
Large-Scale Remote Sensed SAV Monitoring Program	3.2.3.4	Underway and currently being conducted by FWC/FMRI
Seagrass Fish, Pink Shrimp, and Invertebrate Assessment Network	3.2.3.5	Underway and being conducted by NOAA/NMFS and the USGS
Shoreline Fish Community Visual Assessment		Underway and being conducted by NOAA/NMFS
Juvenile Spotted Seatrout Monitoring	3.2.3.7	Underway and being conducted by NOAA/NMFS
Surface Water Discharges to Biscayne Bay	3.2.2.1	
Coastal Gradients: Flow, Salinity, Nutrients	3.2.2.1	Underway and being conducted by the USGS
Key Uncertainties and Supporting Research		
Measurement of Submarine Groundwater Discharge to Biscayne Bay	3.2.4.2	Starting Date uncertain
Biological Availability of Organic Nitrogen in Florida Bay	3.2.4.3	Completed by SFWMD contractors at FIU
Present and Past Distribution of Oysters in South Florida Coastal Complex	3.2.4.4	Starting in FY06
Factors Controlling Epibenthic Communities in Nearshore Biscayne Bay	3.2.4.5	Underway and being conducted by NOAA/NMFS and the USGS
Salinity Relationships of Epifaunal Species – Oysters in Biscayne Bay	3.2.4.6	Planned to start in FY07
Salinity Relationships of Epifaunal Species – Pink Shrimp in Biscayne Bay		Planned to start in FY07
Empirical Research on Fishery Resources in Biscayne Bay	3.2.4.7	Starting Date uncertain
Manatee Abundance and Distribution Relative to Freshwater Inputs	3.2.4.10	Underway and being conducted by Miami DERM and FWC.

9.3.3 Water Quality Conceptual Ecological Model

Water quality in South Florida estuaries is dependent upon the volume, distribution, and quality of freshwater flowing to the system. The biotic components (e.g., phytoplankton, benthic habitats) of estuaries are sensitive to nutrient loading which may be modified by CERP. Complex interactive mechanisms between water quality and hydrologic drivers as well as internal nutrient cycling will influence CERP effects.

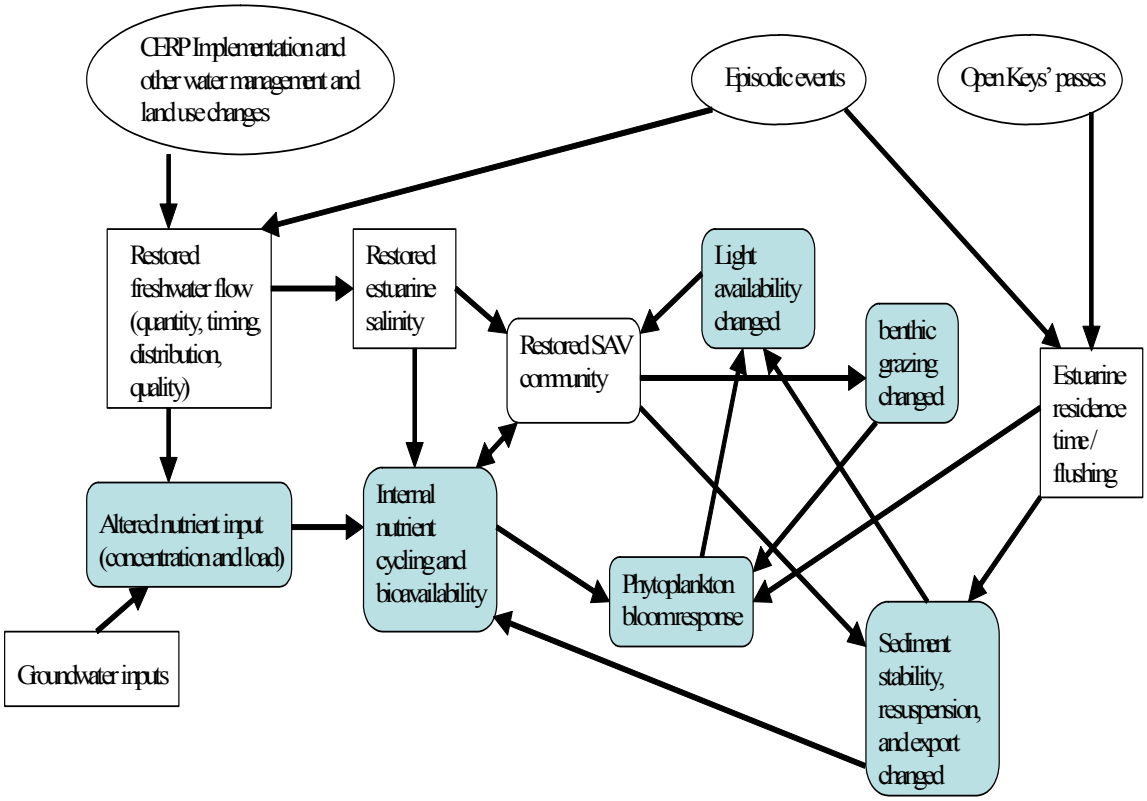

Figure 9-3-1: Water Quality Conceptual Ecological Model

9.3.4 Water Quality Hypotheses

- Through modifications of quantity, quality, timing and distribution of freshwater, CERP implementation will affect dissolved and particulate nutrients delivered to the estuaries and alter estuarine water quality. These modifications will affect primary production and food webs in estuaries. These modifications include:

  1) *changes in the distribution and timing* of nutrient inputs through increased flow via Shark River Slough and diversion of canal flows from 'point source' to more 'diffuse' delivery through coastal wetlands and creeks;

2) *changes in the quantity* of nutrient inputs to the estuaries through alteration of the mobilization and release of nutrients from developed and agricultural areas, through nutrient uptake in treatment areas, and through changes in nutrient processing and retention in the Everglades;

3) *changes in the* bioavailability of nutrients which depend on both the *quality* of nutrients (e.g., inorganic nutrients and DOM) from the watershed and internal estuary mechanisms (e.g., P limitation of DOM decomposition);

- Internal nutrient cycling rates (e.g., nitrogen fixation and denitrification) and biogeochemical processes, such as phosphate sorption, will change with CERP implementation because of salinity and benthic habitat changes.

- Nutrient accumulation and retention in estuaries is affected by episodic storm events, which can export nutrient rich sediments. CERP implementation will modify benthic habitats and nutrient loading which will affect this export.

- The spatial extent, duration, density, and composition of phytoplankton blooms are controlled by several factors that will be influenced by CERP. These include:

    1) external nutrient loading;
    2) internal nutrient cycling (seagrass productivity/die-off, sediment resuspension);
    3) light availability (e.g., modified by sediment resuspension and CDOM);
    4) water residence time; and
    5) biomass of grazers (e.g., zooplankton, benthic filter-feeders).

- Nutrients inputs from groundwater discharges may affect water quality in coastal wetlands and estuaries. CERP implementation will modify these discharges in the coastal zone which will alter nutrient loads to the estuaries.

9.3.5 Benthic Submerged Aquatic Vegetation Conceptual Ecological Model

Seagrasses, along with attached and drifting macro algae and *Chara* (in the coastal lakes inland from Florida Bay), comprise most of the benthic submerged aquatic vegetation (SAV) within the Southern Estuaries region. Seagrasses are the dominant biological community in South Florida coastal waters (Fourqurean *et al.* 2002), including Florida Bay (Zieman *et al.* 1989, Fourqurean and Robblee 1999, Durako *et al.* 2002) and Biscayne Bay. Seagrasses form a highly productive ecosystem that is the basis of the food web and provides habitat for most recreationally- and commercially-important fisheries species in the SEM region (Zieman 1982, Thayer *et al.* 1999). Seagrasses also have a major effect on water quality and clarity through nutrient uptake and storage and by increasing sedimentation and sediment stabilization via their physical structure (Prager and Halley 1999).

The catastrophic die-off of seagrasses, primarily *Thalassia testudinum*, in the late 1980's was accompanied by a cascade of ecological changes, including widspread and persistent phytoplankton blooms, increased turbidity, and dramatic faunal changes (Butler et al. 1995, Philips and Badylak 1996, Matheson et al. 1999, Prager and Halley 1999). The cause of the widespread die-off is not known, but is thought to have been related to changes in salinity, nutrient availability, sulfide toxicity, and disease (Robblee et al 1991, Carlson et al 1994, Durako and Kuss 1994, Rudnick et al 1999). Recent evidence suggests that one mechanism of *Thalassia* short-shoot mortality is the result of internal oxygen stress and sulfide toxicity (Borum et al. 2004), but how these are related to growth conditions or if this is the proximal cause of the initial die-off are still unknown.

Because of their benthic habit and persistence, seagrasses and macro-algae integrate and respond to changes in water quality. Thus, benthic SAV distribution and abundance are valuable ecological indicators of the "health" of the SEM region. In Florida Bay, the state of the seagrass communities is being used as a success criterion for CERP implementation. By altering the volume, timing, and spatial distribution of freshwater inflow, one goal of CERP is to restore and maintain the estuarine character of Florida Bay and in turn to produce a more diverse and sustainable seagrass community.

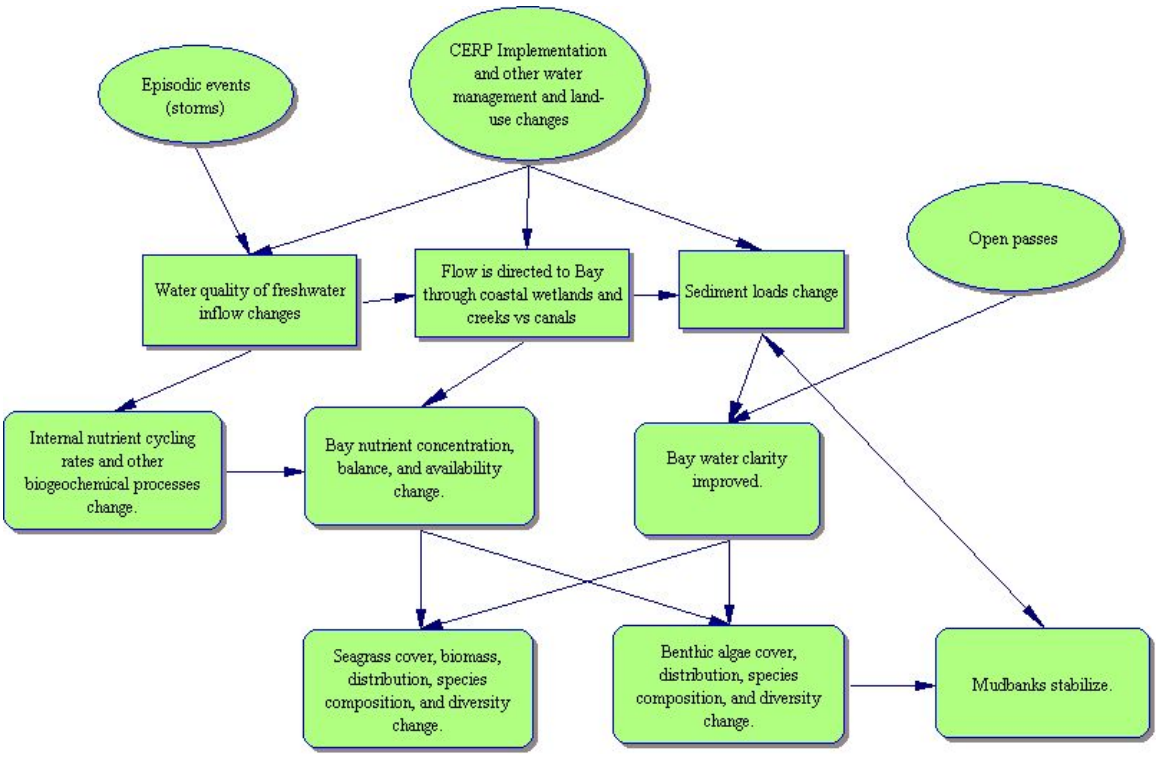

Figure 9-3-2: SAV Conceptual Ecological Model

9.3.6 Benthic Submerged Aquatic Vegetation Hypotheses

- Changes in both salinity and water quality resulting from CERP implementation are expected to result in changes in seagrass cover, biomass, distribution, species composition and diversity though the combined and interrelated effects of light penetration, epiphyte load, nutrient availability, salinity, hypoxia/anoxia, sulfide toxicity, and disease.

- Changes related to CERP implementation will include an expansion of areas with *Halodule* and *Ruppia* cover and a reduction in areas of *Thalassia* monoculture along the northern third of Florida Bay. Based on forecasted changes in hydrology, seagrass density and species composition in the southern two thirds of Florida Bay are not expected to change.

- Changes in both salinity and water quality resulting from CERP implementation are expected to change benthic algae cover, biomass, distribution, species composition and diversity though the combined and interrelated effects of light penetration, nutrient availability, salinity, temperature, and changes in seagrass density and species composition .

- Significant changes in benthic algae and seagrass distribution and density can affect susceptibility to sediment resuspension and the stability of mudbanks as well as nutrient availability to other primary producers.

9.3.7 Nearshore Nursery Function Conceptual Ecological Model

Estuaries provide critical nursery habitat for many species of fish and macroinvertebrates, many of which are spawned offshore. Some, such as pink shrimp, are harvested primarily in offshore fisheries, although inshore live bait fisheries target juveniles in Biscayne Bay. Shoreline and bottom configuration, vegetation, and salinity patterns are characteristics that define nursery habitat and determine their productive capacity, thereby the abundance of favored species. The fundamental assumption of CERP is that the alteration of volume, timing, and spatial distribution of freshwater inflow that occurred with past water management practices has decreased the productive capacity of estuarine nursery grounds by altering both bottom and shoreline vegetation and salinity patterns and the area over which favorable zones of bottom vegetation and salinity overlap. One purpose of CERP is to expand, in both space and time, favorable conditions for the estuarine species that were historically characteristic of the coastal wetland and nearshore zone. This includes oysters, red drum, pink shrimp, spotted seatrout, and species of snappers and grunts that use this habitat at various life stages. Increased availability of complex mangrove-shoreline and seagrass habitat (including a wider representation of seagrass species, e.g., *Ruppia* and *Halodule*, as well as *Thalassia*) and a broadened salinity gradient will increase the diversity of fish and macroinvertebrates that will be accommodated. Complex habitats increase productive capacity by reducing predation, providing a wider variety and abundance of food organisms, reducing physical disturbance, and providing substrates for attachment. The formulation and monitoring of

performance measures that adequately reflect nursery function are essential elements of the CERP monitoring program.

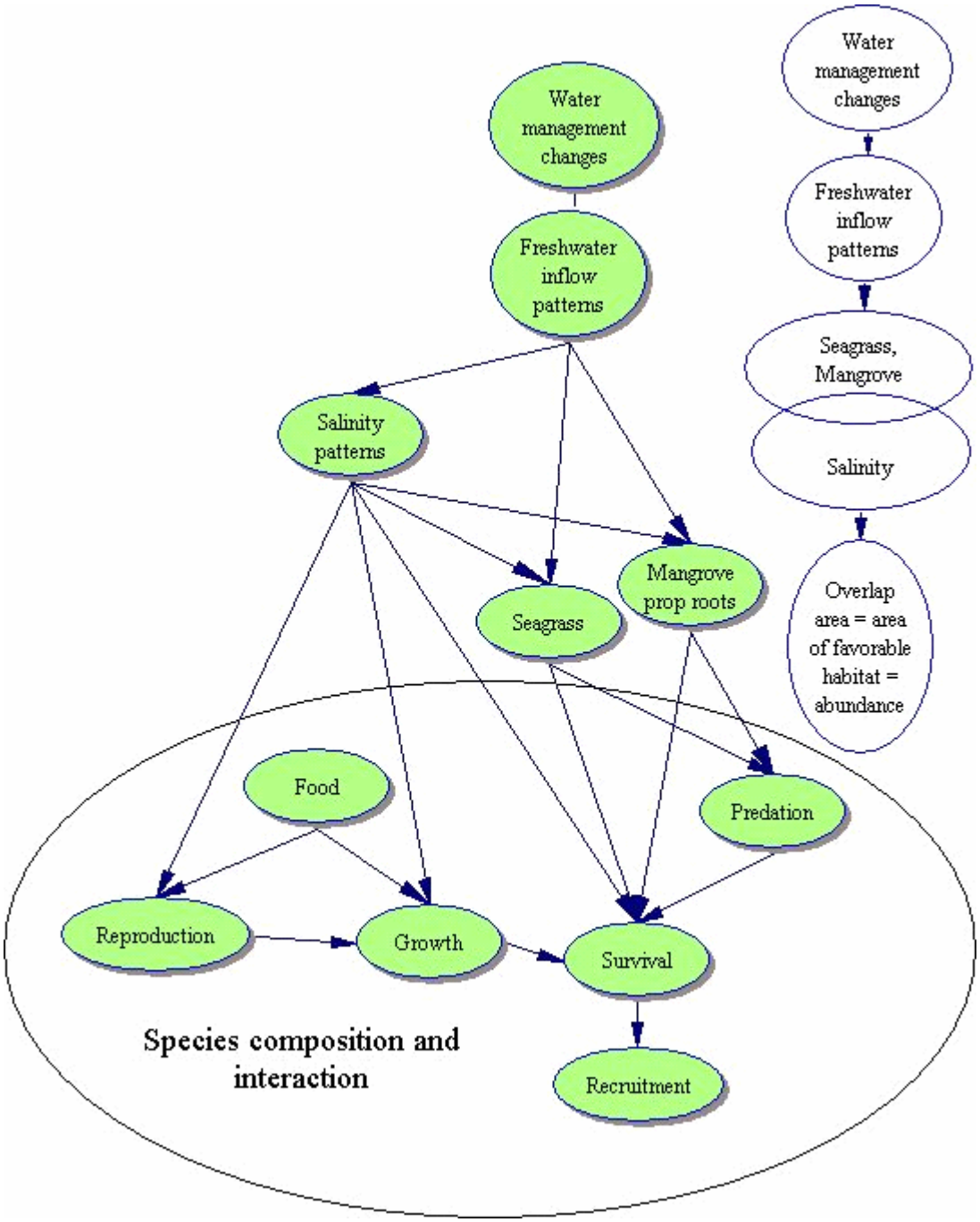

Figure 9-3-3: Nearshore Nursery Function Conceptual Ecological Model

9.3.8 Nearshore Nursery Function Hypotheses

Hypothesis 1
The implementation of CERP will affect the life cycle and abundance of fishery species not only through habitat dependencies (e.g., regarding food availability and shelter) but also through the direct physiological effects of salinity upon growth and survival.

***Rationale*:** Species abundance and recruitment to adult populations is a function of the area of overlap of favorable habitat and favorable salinities for each species. Maintaining a discernable spatial salinity gradient with persistent salinities in the lower range will result in an expansion of the area of optimal nursery habitat for estuarine dependent species and this, in turn, will increase the overall abundance (density x area) of invertebrate and vertebrate species, including pink shrimp, pinfish, rainwater killifish, mojarras, gray snapper, and spotted seatrout.

Hypothesis 2
Responses to change in both biotic (vegetation structure and cover) and abiotic (salinity pattern) aspects of habitat may vary.

***Rationale*:** Responses may vary by life stage because habitat use and salinity requirements often differ depending on life stage. Responses vary by species both because of different salinity tolerances and because of life-history differences that affect requirements and when required conditions are needed. Responses may be stepwise for some species/stages versus continuous for others because of physiological or behavioral influences.

Hypothesis 3
There is a direct quantitative relationship between the abundance of small juvenile pink shrimp in Biscayne Bay and Florida Bay and catch per unit effort of larger juveniles and adult pink shrimp in fisheries.

***Rationale*:** Small juvenile pink shrimp become recruits to the fisheries.

Hypothesis 4
The annual production of small prey fish in nearshore shallow water habitat, as determined by salinity patterns and other factors affected by freshwater inflow, will be reflected in annual production rates of their consumers in the mangrove prop-root habitat of coastal creeks and shorelines (e.g., gray snapper and other species).

Rationale: The fish that shelter in mangrove prop-root habitat of coastal creeks and shorelines are thought to forage in grassbeds; therefore the abundance of small prey species in nearshore flats may be reflected in the growth rates of the consumers.

Hypothesis 5
Redistribution of flow from canals to coastal creeks and a reliable supply of fresh water to the creeks during the dry season will increase the epifaunal abundance and substrate coverage (percent available). Species composition will include oysters and their associates.

***Rationale*:** A change in the spatial and temporal distribution of freshwater inflow will result in changes in the abundance, substrate coverage, and species composition of epifauna on mangrove prop-roots.

9.3.9 Nearshore Community Structure Conceptual Ecological Model

Many of South Florida's estuarine habitats have been diminished or eliminated by past and current water management practices. Waters that are consistently of intermediate salinity (e.g., 5-20 psu) tend to support highly productive, but relatively low diversity, plant and animal communities. In many nearshore areas of Biscayne and Florida Bays, freshwater flow is so variable that downstream salinity regimes are suboptimal for freshwater, brackish and marine organisms alike. Among the objectives of the CERP is to restore the function of the coastal creeks that once supplied diffuse, but consistent, freshwater flow to southern Biscayne Bay. The restoration of a more natural freshwater delivery regime and associated salinity patterns would be accomplished by diverting a portion of the surface flow carried to the bay area by canals. An understanding the interaction of salinity pattern and habitat with the species composition, diversity and abundance of the nearshore fish, invertebrate and seagrasss communities is critically needed to develop appropriate performance measures.

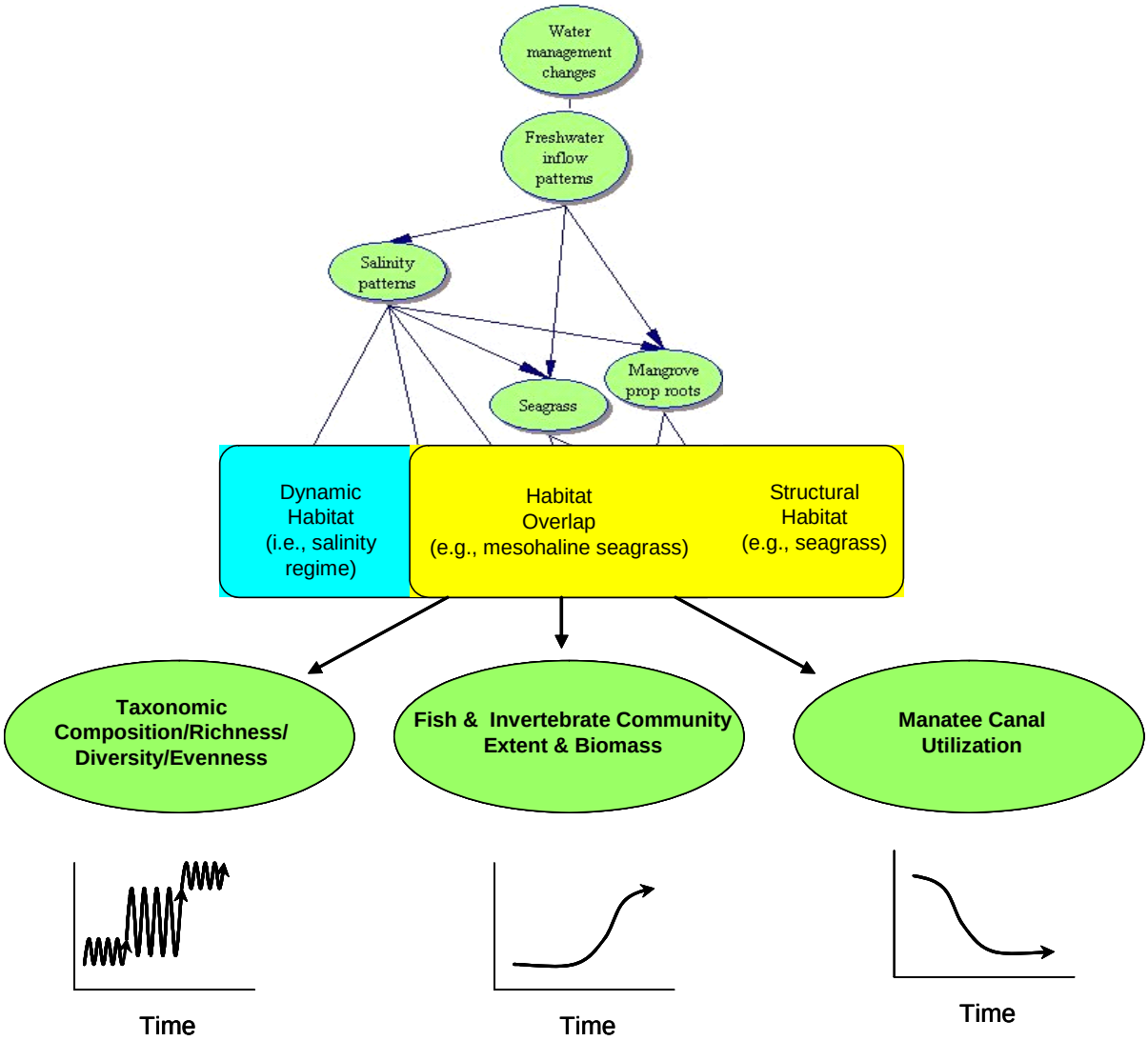

Figure 9-3-4: Nearshore Community Structure Conceptual Ecological Model

9.3.10 Nearshore Community Structure Hypotheses

Hypothesis 1
Shoreline and nearshore benthic communities are directly impacted by (and to some degree reflect) the volume, timing and variation in freshwater inflow, salinity patterns, and the range and rapidity of salinity fluctuation.

***Rationale*:** Even estuarine species are more abundant somewhere within the full salinity range found in south Florida estuaries (i.e., 0-70 psu), rather than across the entire range. Few estuarine species can tolerate rapid high amplitude fluctuations in salinity.

Hypothesis 2
Reestablishing a persistent nearshore positive salinity gradient will increase the optimal habitat and abundance of estuarine fishes, oysters and other species.

***Rationale*:** Estuarine species presently are limited by the lack of a persistent positive salinity gradient in both Biscayne Bay and Florida Bay.

Hypothesis 3
CERP implementation will lead to an expanded community of estuarine species and new estuarine habitat will be created (e.g., oyster beds).

***Rationale*:** Plant and animal diversity will increase as more natural freshwater flows, and salinity regimes, are restored.

Hypothesis 4
Oyster populations will increase when fresh water destined for estuaries is routed through new/restored coastal marshes, which will reduce sediment loads and areas with soft, unconsolidated substrate.

***Rationale*:** High sediment loads and benthic "muck" accumulation can deleteriously affect oyster recruitment, growth and survival. Reducing the loads will improve oyster spat recruitment and oyster growth.

Hypothesis 5
Changes in timing, location and volume of freshwater inflow will affect manatee distribution and manatee use of canal habitat, which will in turn affect their susceptibility to mortality from motorboats and water control gates.

***Rationale*:** Manatees are attracted to freshwater sources. Presently the sources are the canals. When freshwater creeks provide a more continuous source of fresh water, the manatees will orient toward the creek mouths and away from the canals.

9.3.11 Toxins and Contaminants

Because contaminants are conveyed to the estuaries through surface and ground-water flux, changes in distribution or sources of freshwater or ground-water stages may affect the fate, amount, and pattern of toxicants and other contaminants introduced to bay waters sediments and biological resources which will in turn affect estuarine organisms, populations, and communities as follows: Accumulated toxicants and other contaminants will eventually cause stress in organisms. Stress would initially be expressed biochemically as changes in osmoregulation, clinical hematology, immunology, and histopathology, etc. Biochemical and physiological changes could lead to adverse effects on survival, growth, development and reproduction. The level of stress created by divalent metals would depend upon their bioavailability, a function of partition coefficients and factors influencing equilibrium (e.g., redox potential); Organismal

affects can affect populations and population changes in turn can result in community shifts.

9.3.12 Status of Toxins/Contaminants MAP Monitoring

Revised MAP Monitoring Components:

Monitoring Components	MAP Section	STATUS
Sediment Contaminants		Proposed; no funding source.
Contaminant Loading		Proposed

Existing MAP Key Uncertainties and Supporting Research

Monitoring Components	MAP Section	STATUS
Causal Factors of Fish Abnormalities in Biscayne Bay	3.2.4.8	No funding
Bottlenose Dolphin Health Assessment in Biscayne Bay Mercury Module	3.2.4.9	Funding uncertain and inadequate at present

Revised MAP Key Uncertainties and Supporting Research

Monitoring Components	MAP Section	STATUS
Risk assessment for Biscayne Bay		Proposed

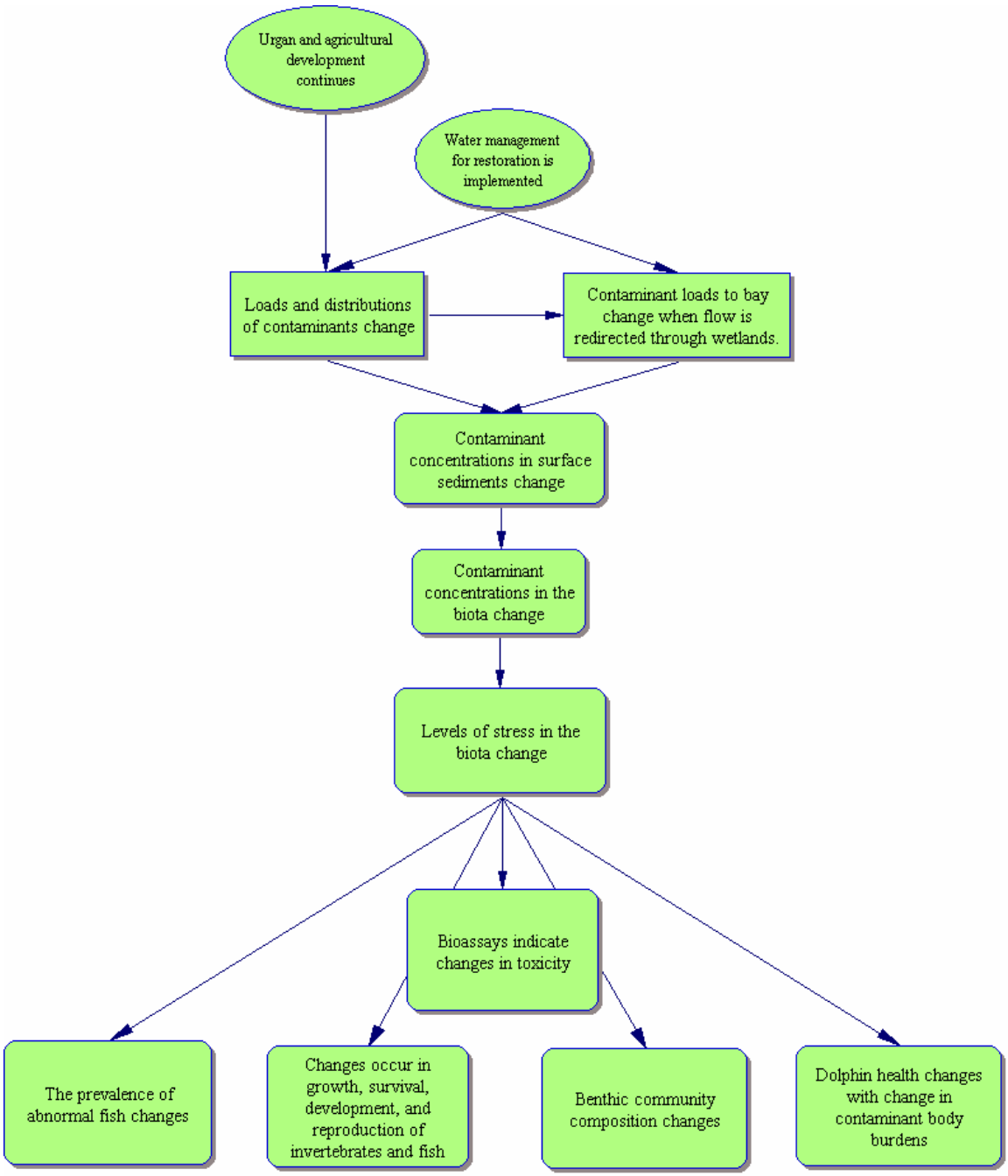

Figure: 9-3-5: Hypothesis Flow Chart for Toxins and Contaminants in the SE

9.3.13 Toxins and Contaminants Hypotheses

- CERP is going to change the quantity, timing and distribution of in flow to the southern estuaries and the source of this freshwater is expected to include waste water reuse and both urban and agriculture runoff, which may increase the contaminant load to the estuaries.
- Water will be routed through areas undergoing rapid urban development and redevelopment which will may also increase contaminant loads
- Contaminant loads to the bays will also be affected by the planned rerouting of water through coastal wetlands. Coastal wetland soils and vegetation may take up and retain organic contaminants and heavy metals, reducing loads to the bays and associated contaminant concentrations in surface sediments.
- With the increased input loading sediment concentrations and associated sediment toxicity, as indicated in bioassays (.e.g., clam bioassays), is expected to change.
- Organic contaminant and heavy metal burdens in the biota will change over time reflecting changes in contaminant loading and concentrations in surface sediments.
    - Body burdens and biochemicals in sentinel organisms with limited mobility (e.g., mollusks) will reflect sediment chemical concentrations, and biological effects, if occurring, will be indicated by biochemical markers.
- Increasing body burdens will eventually result in increased stress upon the organisms
- This stress will be reflected in the following changes in monitored parameters:
    - Benthic community composition (i.e., of burrowing, infaunal, epibenthic species) will change in response to changes in sediment contamination.
    - Filter feeders (e.g., oysters) and organisms in the water column (e.g., zooplankton, fish, shrimp) will be affected (survival, growth, etc.) by resuspension of contaminants from sediment.
    - The prevalence of fish with morphological abnormalities will change in response to changes in sediment toxicants and other contaminants.
    - The health of the resident bottlenose dolphin population will change in response to exposure, as reflected by changes in body burdens, and body burdens will reflect sediment concentrations of heavy metals and organic contaminants.

9.4 Lake Okeechobee Module

9.4.1 Module Location Description and Background Information

Lake Okeechobee is a large (1,730 km^2) freshwater lake located at the center of the interconnected south Florida aquatic ecosystem (Figure 1). The lake is shallow (average depth < 3 m), originated about 6,000 years ago during oceanic recession, and under pre-settlement conditions probably was slightly eutrophic with 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 (Steinman et al. 2002). 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. T he 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. 1996). 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 1990). 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.

Ecosystem conceptual models were developed for Lake Okeechobee restoration planning purposes. These models indicate, *via* simple box-and-arrow diagrams, how key biological components of the ecosystem are affected by various cultural stressors. The models for Lake Okeechobee are 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. The lake conceptual models were developed in the context of this heterogeneity. The models also reflect the lake's present spatial extent, rather than the larger historical boundaries.

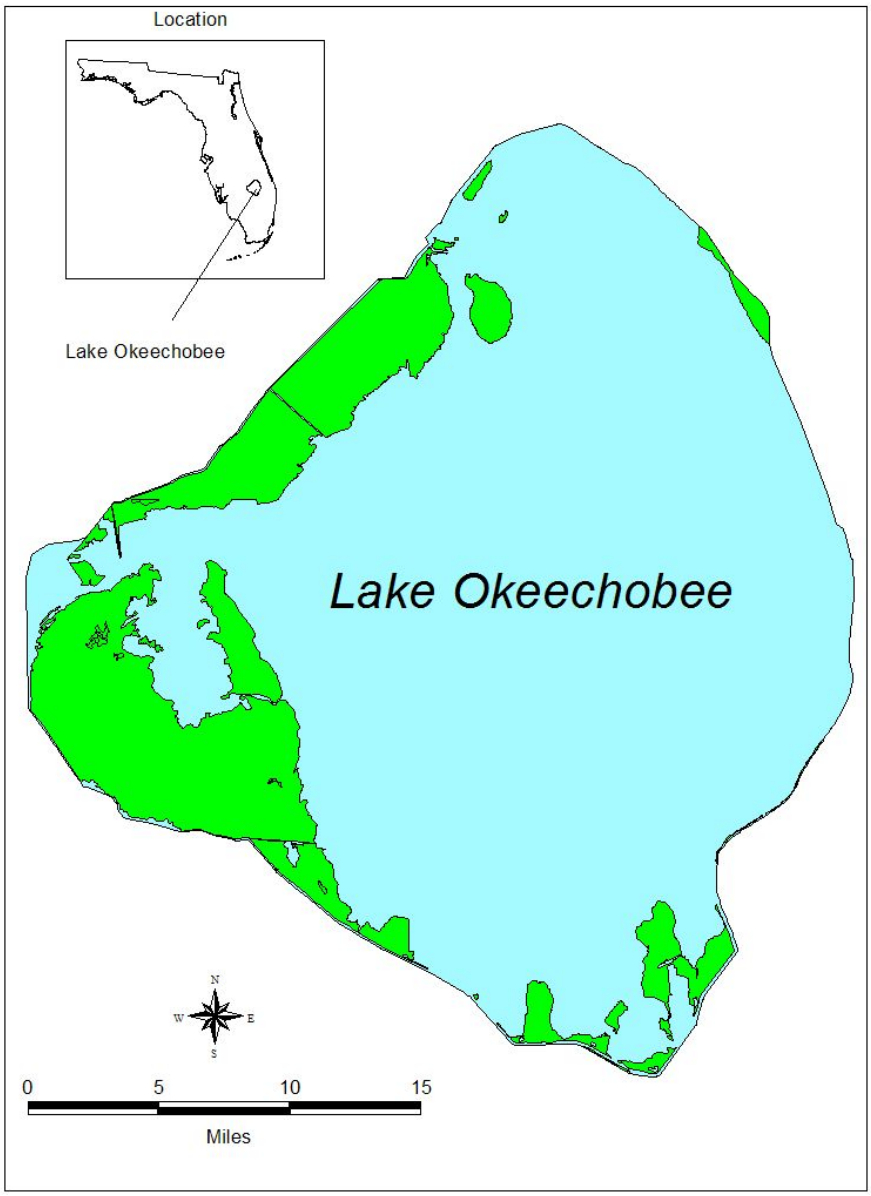

Figure 9-4-1: Lake Okeechobee

9.4.2 Status of MAP Monitoring Program in Lake Okeechobee

Monitoring components are related to the conceptual model outputs and reflect performance measure goals (Table 9-4). Additional planned, or ongoing research listed under **Key Uncertainties- Supporting Research** have been designed to elucidate or quantify model relationships for which specific quantitative information is insufficient, or lacking altogether.

Table 9-4: Monitoring Components and Key Uncertainties and Supporting Research for Lake Okeechobee

Monitoring Components	MAP Section	Status
Water Quality		
YREG and OLIT Programs	3.4.3.1	Ongoing
Fish Fauna		
Fish Community Structure and Trophic Relationships in Submerged and Emergent Plant Communities	3.4.4.1	FY 06 If funded
Fish Population Density, Age Structure, and Condition Assessment	3.4.3.6	Pending GB approval
Vegetation		
Annual SAV mapping, Quarterly SAV monitoring	3.4.3.3	ongoing
Littoral Zone Vegetation Mapping	3.4.2.2	FY 06 If funded
Quarterly Periphyton Monitoring	3.4.4.4	ongoing
Quarterly Phytoplankton and Zooplankton Monitoring	3.4.3.1/3.4.3.4	ongoing
Megafauna		
Macroinvertebrate Monitoring	3.4.3.5	FY 06
Key Uncertainties- Supporting Research		
Influence of SAV beds on current velocity, and related sediment and nutrient transport	3.4.4.4	completed
Irradiance Requirements of SAV by species	3.4.4.4	ongoing
Irradiance Requirements for SAV germination by species	3.4.4.4	ongoing
Competitive interactions between SAV species	3.4.4.4	ongoing
Effects of hydroperiod on bulrush germination and growth	3.4.2.2	ongoing
Torpedograss methods of reproduction and dispersion	3.4.2.2	completed
Effects of hydroperiod and herbicide type on efficacy of Torpedograss control	3.4.2.2	ongoing

9.4.3 Submerged Aquatic Vegetation Conceptual Ecological Model

The model below summarizes environmental interactions that are known to affect SAV areal distribution and density in Lake Okeechobee. Many of these parameters are currently being monitored and will be used in the development of assessment tools based on the hypotheses listed below.

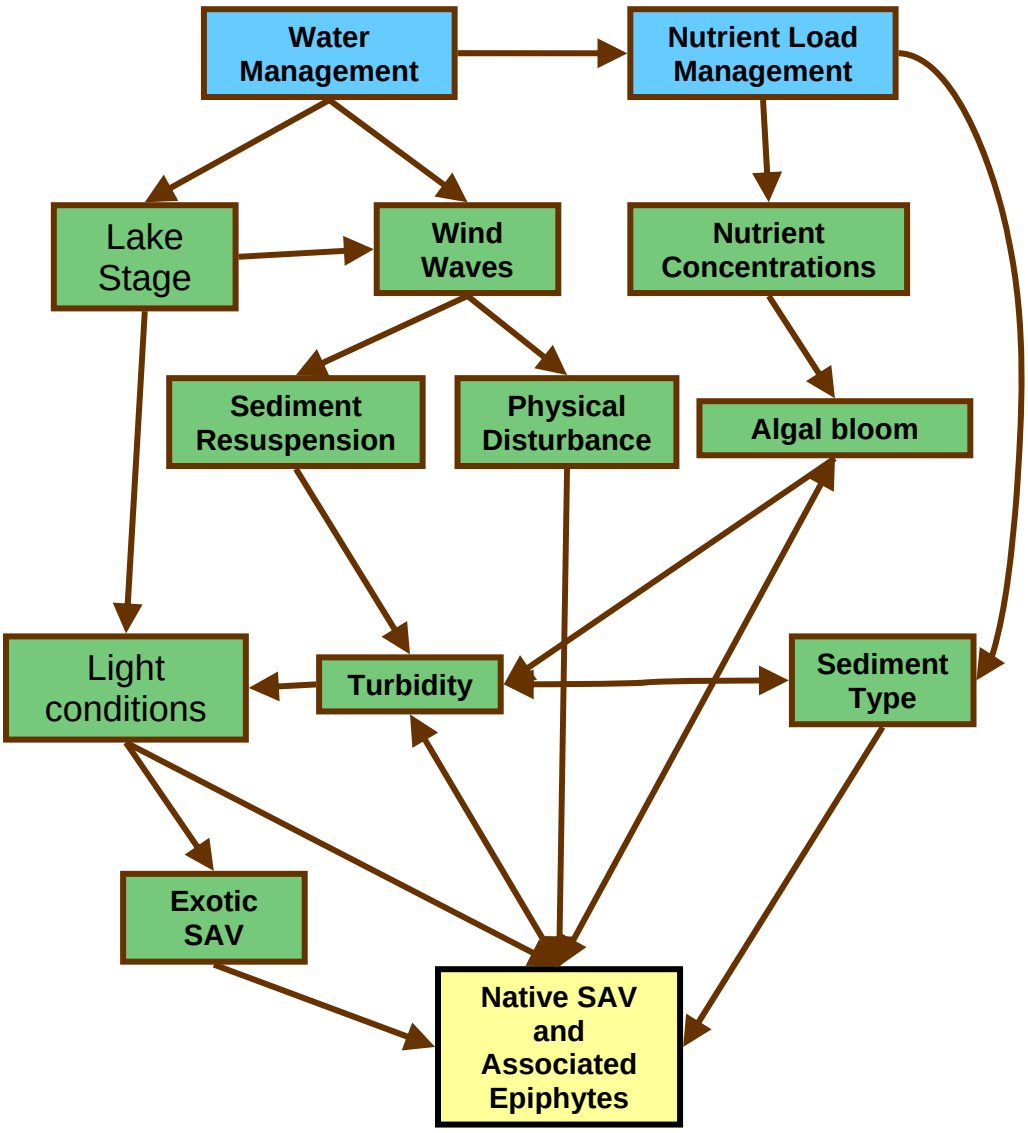

Figure 9-4-2: SAV Conceptual Ecological Model

9.4.4 Submerged Aquatic Vegetation Hypotheses

Hypothesis 1
Lake stage is a major determining factor in the aerial extent and density of SAV in the littoral-pelagic fringe zone of Lake Okeechobee.

Rationale: At higher lake stages, light penetration to the bottom is reduced and the area capable of supporting dense SAV is smaller. In addition, at higher lake stages the pelagic and littoral fringe zones of the lake become hydrologically connected resulting in increased turbidity which further decreases light availability for SAV growth (James and Havens 2005). Conversely, at lower lake stages, larger areas of the lake bottom receive adequate light to support SAV growth and much of the potential SAV growth zone becomes partially hydrologically uncoupled from the pelagic zone, and sheltered from prevailing wave action. This results in reduction in turbidity and further improvements in the light climate.

Hypothesis 2
Major wind and wave events can result in large scale destruction of SAV by direct physical tearing and uprooting of plants.

Rationale: Following hurricanes Frances and Jeanne in 2004, and Wilma in 2005 observational and monitoring data indicated a rapid and nearly instantaneous decline in SAV density and distribution. Although this phenomenon would occur sporadically and is independent of CERP effects, it has potential major consequences for the ecological health of Lake Okeechobee.

Hypothesis 3
Nutrient concentrations influence SAV areal coverage and density through their effects on phytoplankton density.

Rationale: Elevated nutrient concentrations stimulate dense phytoplankton blooms which reduce the light available for SAV growth. This causes reductions in SAV areal coverage and density and can lead to the development of a persistent turbid water state. When SAV density is high, or nutrient concentrations are low, plants out compete phytoplankton thereby maintaining a persistent clear water state (Philips et al. 1993).

Hypothesis 4
Under physical conditions that result in low light levels the exotic SAV species *Hydrilla* may have a competitive advantage over more desirable native SAV species.

Rationale: Mesocosm experiments conducted under natural light indicate that *Hydrilla* has a lower light requirement than any of the major native SAV species of Lake Okeechobee.

Hypothesis 5
Changes in the extent of mud sediments in the littoral-pelagic fringe zone of Lake Okeechobee resulting from changes in nutrient loading and runoff influence the potential area available for colonization by SAV.

Rationale: In Lake Okeechobee SAV colonizes peat and sand sediment but does not grow in mud sediment. Changes in nutrient loading and runoff are expected to reduce and/or cap mud sediments and increase the area potentially available for colonization by SAV.

9.4.5 Macroinvertebrate Conceptual Ecological Model

The model below summarizes environmental interactions that are known to affect macroinvertebrate distribution, abundance and species diversity in Lake Okeechobee. A number of these parameters are currently being monitored and will be used in the development of assessment tools based on the hypotheses listed below.

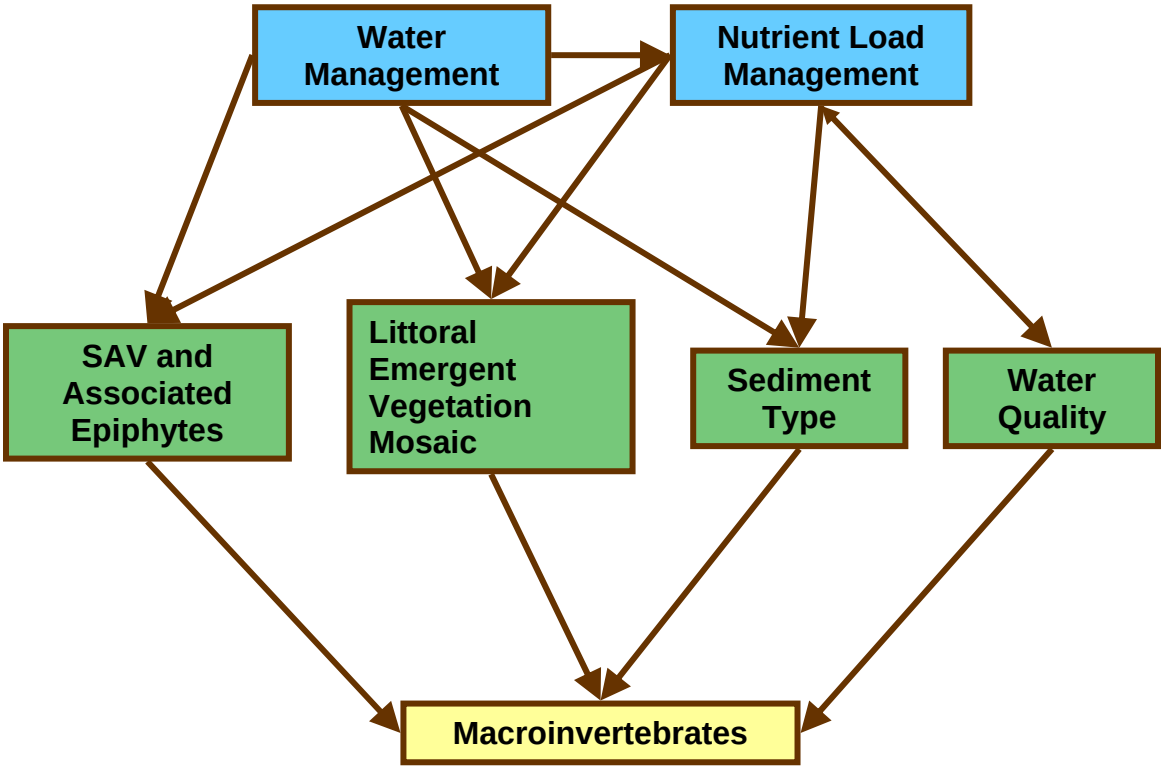

Figure 9-4-3: Macroinvertebrate Conceptual Ecological Model

9.4.6 Macroinvertebrate Hypotheses

Hypothesis 1
The presence of dense SAV and emergent plant beds results in higher macroinvertebrate diversity and fewer pollution-tolerant organisms.

Rationale: Research has suggested that macroinvertebrate densities in eutrophic lakes are higher in vegetated areas than they are in non-vegetated areas (Edwards and Cowell 1992, Petridis 1993, Kurashov et al. 1996). In Lake Okeechobee, Warren and Vogel (1991) have found that macroinvertebrate biomass and diversity were highest in dense plant beds under low to moderate lake stage (Havens and Gawlik 2005). The presence of dense SAV and emergent plant beds as a result of water management and nutrient load reduction activities should result in more habitat and improved water quality, thus facilitating a reduction in the density and number of pollution-tolerant macroinvertebrate taxa.

Hypothesis 2
The macroinvertebrate assemblage is more diverse and comprised of fewer pollution-tolerant taxa in regions of the lake underlain by sand and peat sediments than it is in areas underlain by mud sediments.

Rationale: The 1990-91 Lake Okeechobee benthic macroinvertebrate survey conducted by Warren et al. (1995) showed that the macroinvertebrate assemblage inhabiting the mud sediments was comprised of a small number of organic pollution- and low dissolved oxygen-tolerant species. They also found that species richness was higher at sites located in sand and peat sediments, relative to those found at the sites located in mud sediments. Changes in nutrient loading and runoff are expected to reduce and/or cap mud sediments thereby increasing the percentage of the macroinvertebrate assemblage comprised of non pollution-tolerant taxa.

Hypothesis 3
Reduction in nutrient loads will result in increased macroinvertebrate diversity and a reduction in the number of pollution-tolerant macroinvertebrate taxa.

Rationale: Macroinvertebrate diversity in a Lake Champlain wetland declined as nutrient loading increased (Schwartz and Gruendling 1985). In Lake Erie decreased diversity and increased number of pollution-tolerant taxa occurred with increased nutrient loading (Krieger 1984). Warren et al. (1995) documented a large decrease in Lake Okeechobee benthic macroinvertebrate diversity compared to measurements made 20 years previously (Joyner 1974). Reducing nutrient loading in Lake Okeechobee is expected to result in a reversal of this trend and a return to an increasingly diverse macroinvertebrate community with a reduced number of pollution-tolerant taxa.

9.4.7 Phytoplankton Conceptual Ecological Model

The model below summarizes environmental interactions that are known to affect phytoplankton distribution, abundance and species diversity in Lake Okeechobee. Phytoplankton has been routinely monitored in Lake Okeechobee for more than a decade and the results will be used in the development of assessment tools based on the hypotheses listed below.

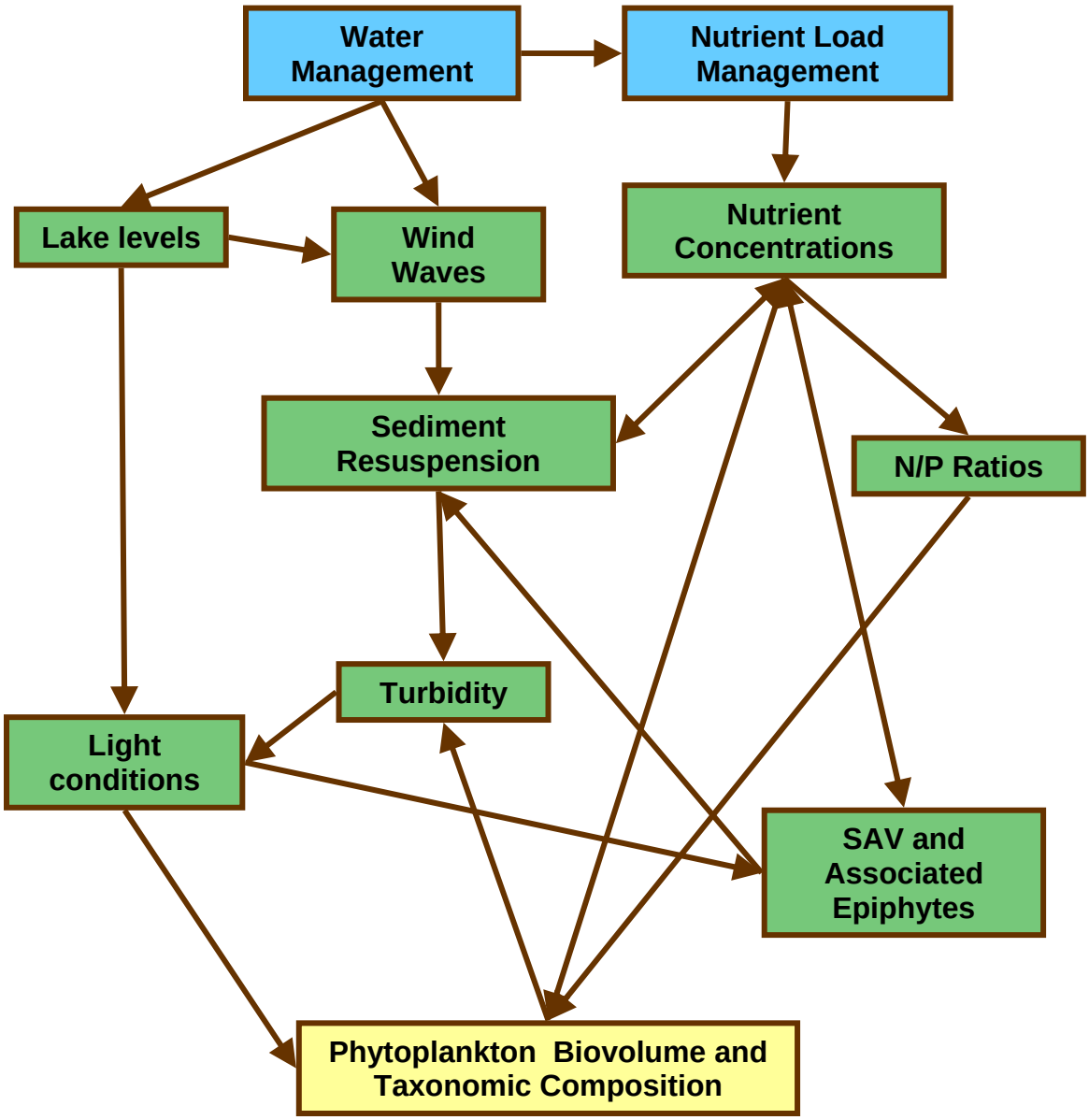

Figure 9-4-4: Phytoplankton Conceptual Ecological Model

9.4.8 Phytoplankton Hypotheses

Hypothesis 1
Lake water levels influence phytoplankton growth.

***Rationale*:** At high lake stage both turbidity and phosphorus levels are elevated in the pelagic region due to wind driven resuspension of phosphorus laden mud sediments. The reduced irradiance levels that prevail under these conditions have a negative impact on phytoplankton growth. High lake levels also result in greater horizontal mixing which increases nutrient transport into the less turbid near-shore and littoral areas thereby increasing phytoplankton growth rates and the frequency of occurrence and intensity of algal blooms in these areas (Maceina 1993, James and Havens 1996).

Hypothesis 2
Nutrient concentrations directly influence phytoplankton biovolume and taxonomic composition.

***Rationale*:** Prolonged high rates of external loading of phosphorus (P) from the watershed have resulted in a surplus of phosphorus relative to algal demands. The enrichment of P has altered the nitrogen to phosphorus ratio (N:P) shifting conditions from a P limited to an N limited system, whenever the system isn't light limited (East and Sharfstein 2006). P limitation favors dominance of the more desirable non bloom-forming algal species while N limitation favors dominance by undesirable noxious bloom-forming cyanobacteria. These bloom-forming cyanobacteria can remain buoyant in the water column and obtain nitrogen from the atmosphere by the process of nitrogen fixation (Horne 1977) thus having a competitive advantage over the non nitrogen-fixing, non bloom-forming species. Consequently, the frequency of severe cyanobacterial blooms increases under these conditions.

Hypothesis 3
Underwater irradiance (light level) regulates phytoplankton taxonomic composition.

***Rationale*:** Low light conditions favor the proliferation of low light adapted non bloom-forming species while high light conditions are dominated by the high light adapted bloom-forming species. Although the N:P ratio in the lake provides nutrient conditions that are potentially favorable for dominance by the bloom-forming cyanobacteria, their occurrence is often restricted by low light availability (Havens et al. 2003). Therefore, in the shallower, less turbid near-shore region N limitation prevails (Aldridge et al. 1995, East and Sharfstein 2006) and the bloom-forming cyanobacteria dominate while in the deeper more turbid pelagic region light is the limiting factor so the non bloom-forming cyanobacteria dominate.

Hypothesis 4
The presence or absence of submerged aquatic vegetation (SAV) and associated epiphytes has an impact on phytoplankton biovolume.

***Rationale*:** SAV and its associated epiphytes have the ability to reduce water column P concentrations by direct uptake or by mediating changes in pH causing coprecipitation of P with calcium. Rooted SAV also stabilizes the sediment preventing the resupension of sediment and P back into the water column. SAV and epiphytes also compete for nitrogen and other nutrients with phytoplankton. Therefore the presence of submerged plants in the littoral-pelagic fringe has the potential to inhibit phytoplankton growth and algal bloom frequency and intensity when nutrient concentrations are high.

9.4.9 Native Fish Species Conceptual Ecological Model

The model below summarizes environmental interactions that are understood to affect native fish abundance and diversity in Lake Okeechobee. A number of these parameters are currently being monitored, and some, such as sport fish abundance and recruitment have been monitored by The Florida Fish and Wildlife Conservation Commission (FFWCC) for decades. Monitoring results will be used in the development of assessment tools based on the hypotheses listed below.

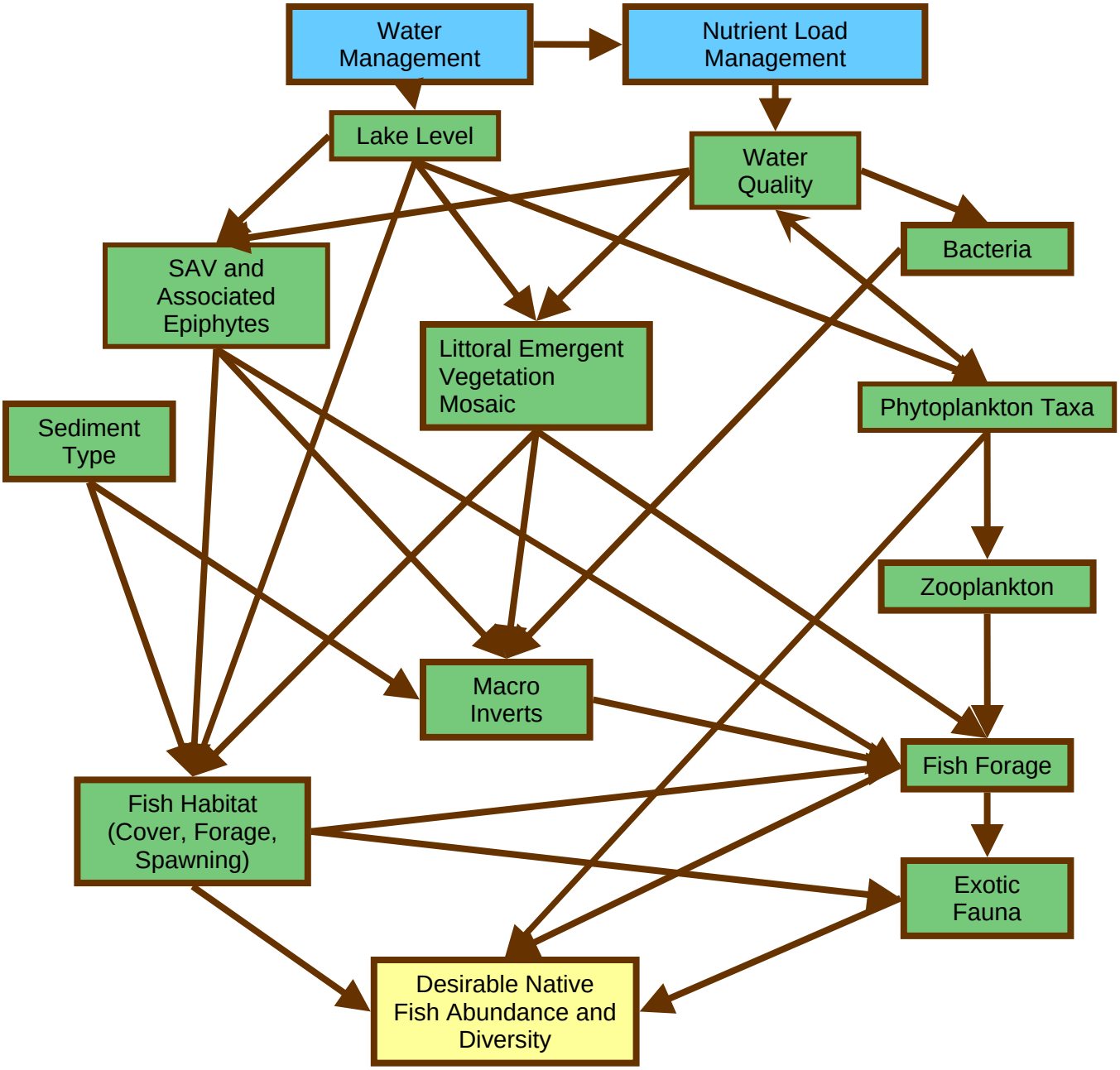

Figure 9-4-5: Native Fish Species Conceptual Ecological Model

9.4.10 Native Fish Species Hypotheses

Hypothesis 1
Increases in SAV density, biomass, and aerial coverage improve fish habitat and fish foraging opportunities and improve desirable native fish abundance and diversity.

Rationale: Havens et al. (2005) observed a significant recruitment of largemouth bass in Lake Okeechobee that coincided with improved diversity and complexity of the SAV and emergent vegetation in 2002, after years of high water and low SAV. Similar results for Lake Okeechobee were reported by Chick and McIvor (1994, 1997) and Furse and Fox (1994). Increasing complexity of the areas for fish forage, fish spawning, and shelter for prey species, will increase fish abundance and diversity.

Hypothesis 2
Decreases in nutrient loads and improvements in water quality will result in increased fish diversity and a shift from less desirable rough fish to more desirable game fish.

Rationale: Reduced nutrient loads will lead to improved water quality and shifts in phytoplankton taxa from cyanobacteria, which are often inedible, toxic, or indigestible by zooplankton, to diatoms, which are preferred foods. Load reduction will also lead to a change in the relative proportion of heterotrophic carbon production to autotrophic carbon production which will lead in turn to an increase in food for zooplankton and forage fish and a shift from planktivorous and benthivorous species to more desirable piscivores.

Hypothesis 3
Competition from introduced exotic fauna exerts negative pressure on desirable native fish.

Rationale: Exotic animals in Lake Okeechobee now include fish, amphibians, reptiles, mollusks and macroinvertebrates, as well as avifauna and mammals. Each of these species exerts different impacts on the ecosystem. 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. While the specific effects of exotic animals on Lake Okeechobee are for the most part unknown, results from other ecosystems suggest that exotic fauna displace native species, disrupt established trophic relationships and may serve as reservoirs or vectors for disease.

Hypothesis 4
Reduction in mud sediment as a consequence of water management will improve macroinvertebrate species diversity resulting in a positive impact on the food web and in an increase in desirable fish species.

Rationale: The macroinvertebrates surviving in Lake Okeechobee mud sediments are burrowing species (primarily oligochaetes) that are common in polluted and anoxic

sediments (Warren et al. 1995). Reducing and or capping mud sediments will shift the taxonomic composition of macroinvertebrate fauna towards more pollution-sensitive species that will enhance the available macroinvertebrate food supply for fish.

Hypothesis 5
Prolonged low lake stage, particularly during the breeding season, removes large areas of fish foraging and spawning habitat from use and negatively impacts recruitment and ultimately fish abundance.

Rationale: When lake stage declines to 12 feet approximately 17 percent of the littoral zone is dry. When lake stage is 11 feet, the entire littoral zone is dry. At these low lake stages vast areas normally available for use as fish spawning and foraging habitat are gone. It is worth noting that while excessively high lake stages remove littoral fringe habitat from use by fish due to negative impacts on submerged and emergent aquatic vegetation, high lake stages have a compensatory mechanism in that they open up more upland marsh habitat to potential use by fish, and may therefore not be as damaging as prolonged low lake stages.

Hypothesis 6
Elevated nutrient loads and high water levels favor the development of dense algal blooms which can result in fish kills and negative impacts on other wildlife either through development of anoxic condition when blooms senesce and decay or through the direct effects of cyanotoxin production.

Rationale: As algal blooms decline, oxygen is consumed and ammonia is released as the mass of algae degrades. Fish exposed to anoxic conditions or high ammonia concentrations will die if there is no escape. In addition, the dominant cyanobacteria in Lake Okeechobee, *Microcystis spp*. is capable of producing toxins that are directly harmful to fish and other wildlife if present in sufficient concentrations.

9.4.11 Littoral Zone Emergent Vegetation Mosaic Ecological Conceptual Model

The model below summarizes environmental interactions that are known to affect emergent vegetation density, aerial distribution and species composition in the littoral zone of Lake Okeechobee. Emergent vegetation mapping using aerial photography has been conducted at approximately annual intervals in the Lake Okeechobee marsh since 1999. Results from this work will be used in the development of assessment tools based on the hypotheses listed below.

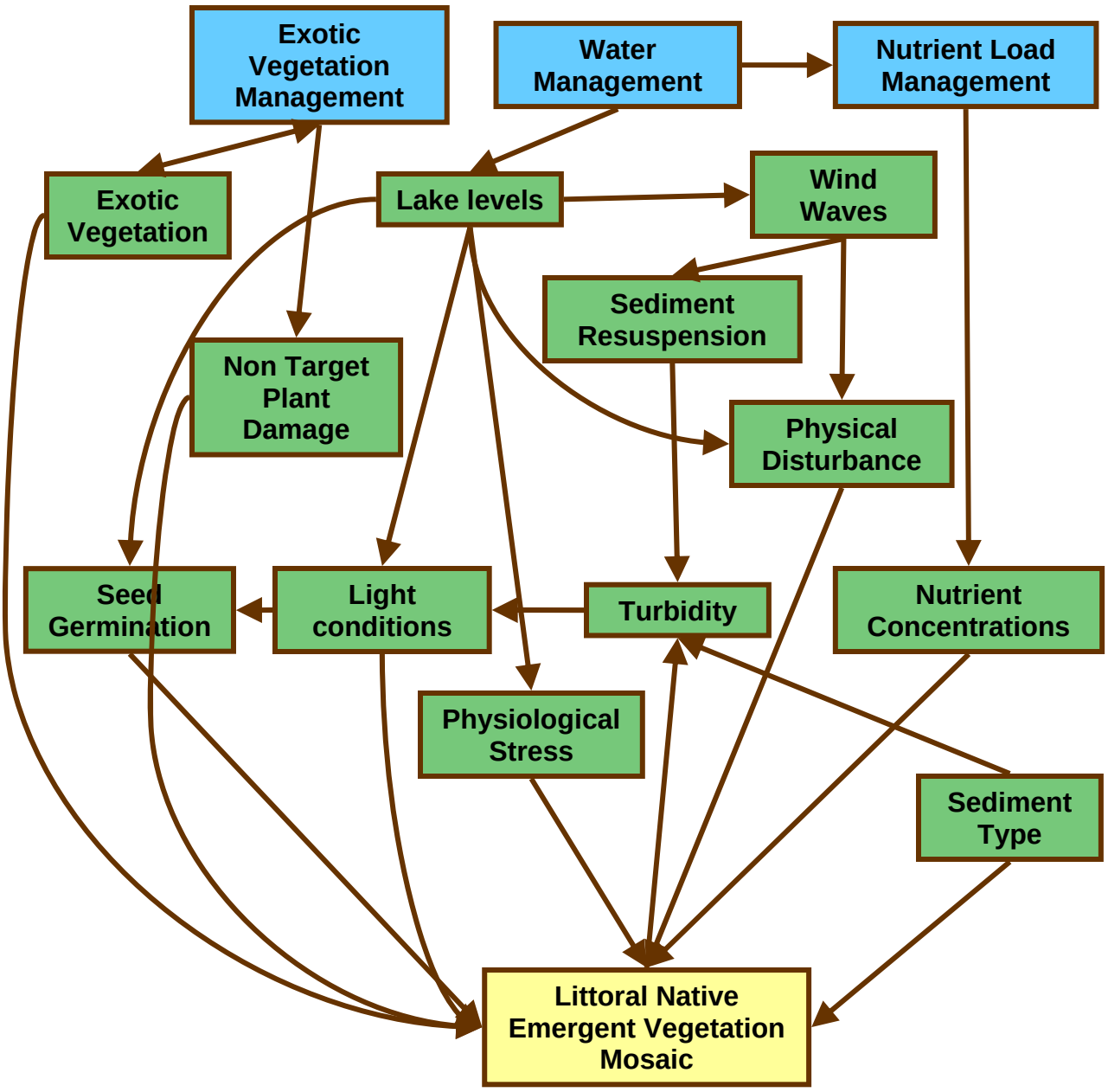

Figure 9-4-6: Littoral Zone Emergent Vegetation Mosaic Conceptual Ecological Model

9.4.12 Littoral Zone Emergent Vegetation Mosaic Hypotheses

Hypothesis 1
Prolonged periods of high lake stage have direct and indirect negative impacts on shoreline and interior marsh vegetation.

***Rationale*:** Desirable native shoreline vegetation including bulrush (*Scirpus californicus*) and SAV are more likely to be uprooted by wind driven waves when lake stage is high. Following a reduction in the spatial extent of rooted macrophytes, turbidity will increase, light availability will be reduced and plant growth will be inhibited due to poor water quality conditions. Additionally, the transport of pelagic water (TP > 100 ppm) into interior regions of the marsh where TP concentrations are often less than 15 ppm occurs most often at high lake stage. An increase in nutrients in the interior marsh will result in the loss of desirable vegetation such as spikerush and the expansion of cattail and other less desirable vegetation.

Physically, rooted macrophytes help stabilize bottom sediments thereby reducing sediment resuspension during wind/wave events. During the late 1990s shoreline vegetation was commonly exposed to inundation depths > 2 m. This resulted in the uprooting and elimination of 1000s of acres of emergent macrophytes. The loss of shoreline vegetation also was accompanied by an increase in turbidity and a decrease in light availability. The negative feed back loop associated with high lake stage, decreases in the spatial coverage of rooted macrophytes, and declines in water quality will further inhibit the growth of desirable rooted vegetation.

Depth and duration of flooding are important in determining the distribution of emergent macrophytes. In deep water, emergent species may not have enough leaf area above the surface of the water to obtain the oxygen needed for respiration and/or the carbon dioxide needed for photosynthesis. Reduced oxygen uptake through the leaves can lead to inadequate supplies of oxygen to the roots and rhizomes and eventually lead to plant death. Thus, high lake stage creates physiological stress in rooted emergent macrophytes that can result in plant death if the water depth exceeds a plants flood tolerance (Van der Valk 1994).

Seeds of a number of desirable emergent species (bulrush for example) will not germinate under flooded conditions. Therefore, in the absence of draw downs, recruitment of new plants from the seed bank will not occur. Prolonged high lake stage inhibits/prevents the germination of many desirable plant species in the marsh (Williges and Harris 1995). Without recruitment of new plants from the seed bank, the expansion and persistence of desirable marsh vegetation will occur only from vegetative reproduction.

Operating Lake Okeechobee at lower overall lake stages and providing periodic recession events will reverse these trends and encourage the expansion of desirable native emergent vegetation.

Hypothesis 2
The occurrence of low water events accelerates the spread of exotic and nuisance invasive vegetation such as torpedograss, *Melaleuca* and cattail. However, low water events also will stimulate the germination of desirable native vegetation (e.g., spikerush, beakrush, and bulrush) and encourage the occurrence of fire which may help control non-desirable exotic and invasive species.

***Rationale*:** Exotic and invasive species including torpedograss, *Melaleuca* and cattail grow well in exposed moist soil environments and shallow water habitats. These species commonly form dense monodominant communities that out compete and displace native plant communities, due in part to the absence of their native biocontrol organisms that prevent the exotic plants from becoming invasive weeds in their original range. Although low water conditions favor the growth of many non-desirable species, it also promotes seed germination of desirable native plants and allows for natural and controlled fires which can be effectively used with other management tools to control exotic and invasive species. Periodic low water events occurring with a frequency of approximately once per decade are postulated to provide an appropriate balance between the positive and negative effects of low water events.

Hypothesis 3
Floating exotic vegetation can have a negative impact on bulrush and other native plants which is further exacerbated under high lake stage conditions.

***Rationale*:** High lake stage enhances the wind driven transport of floating exotics (water hyacinth and water lettuce) from previously isolated locations (interior areas of Torry and Kreamer Islands) and from the watershed into open shoreline regions of the marsh. These exotics, especially water hyacinth, commonly form large floating mats that exceed 50 m in length. These mats can cause extensive physical damage through uprooting and/or breaking emergent plant stems (e.g., bulrush) as they are pushed around the lake by wind and waves.

Hypothesis 4
Exotic vegetation management activities can have a negative impact on bulrush and other native non-target species.

Rationale: Floating mats of water hyacinth and water lettuce commonly occur along the littoral-pelagic interface (shoreline). To reduce the areal coverage of these exotic species and maintain navigational access to the lake, these mats are often sprayed with herbicide. Because the mats are commonly entangled in stands of bulrush and other native vegetation, some non-target plant damage is likely to occur during treatment. While it is recognized that chemical control of exotics is an unavoidable necessity on Lake Okeechobee (see section 9.4.7) at times, the non-target damage can be extensive.

9.4.13 Exotic Vegetation Ecological Conceptual Model

The model below summarizes our current understanding regarding control of exotic and/or invasive vegetation in the littoral zone of Lake Okeechobee. Despite the environmental changes that will eventually be brought about by CERP projects, it seems clear that ongoing vegetation management activities will nevertheless continue to be an essential component of lake management activities for the foreseeable future.

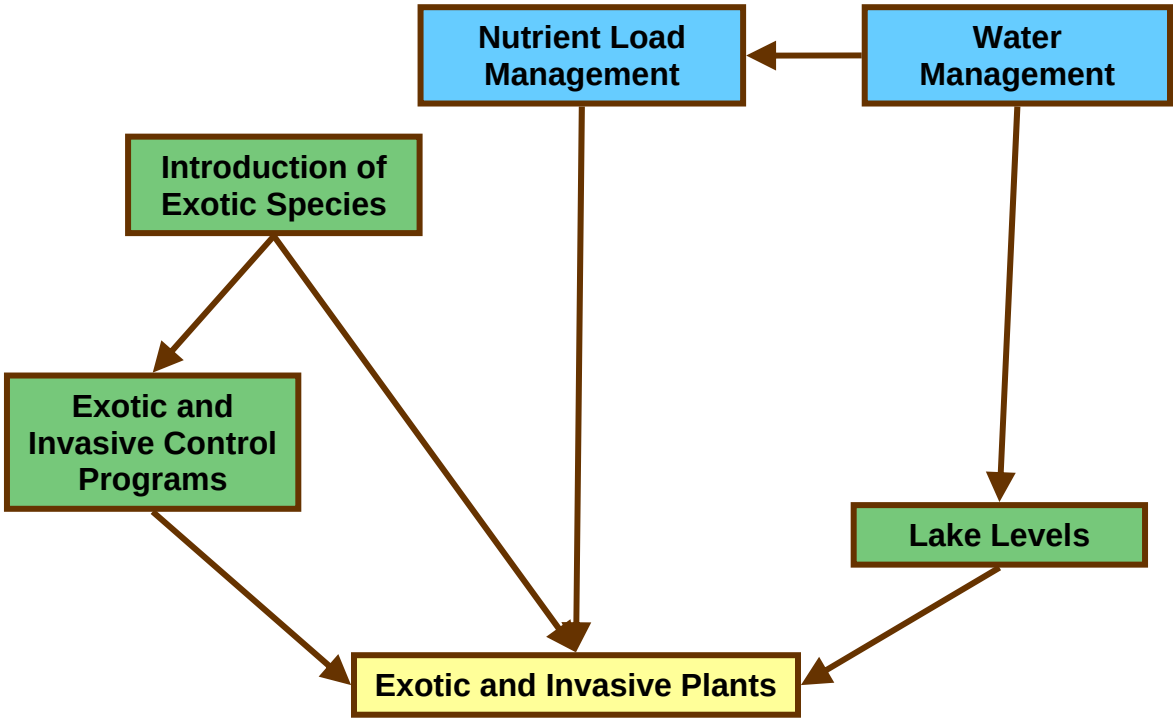

Figure 9-5-7: Exotic Vegetation Conceptual Ecological Model

9.4.14 Exotic Vegetation Hypotheses

Hypothesis 1
Vegetation management activities can effectively control exotic and invasive plant species in Lake Okeechobee. When exotic vegetation is removed from the landscape, native plants are likely to become reestablish in previously impacted areas.

***Rationale*:** Floating mats of water hyacinth and water lettuce and monodominant stands of torpedograss, *Melaleuca*, and Brazilian Pepper trees have effectively been controlled with herbicides. Both aerial and ground based treatments have been effective. However, in some areas non-target damage to native vegetation may be a serious concern.

Spikerush and other native plants have become established in many areas previously impacted by torpedograss.

Hypothesis 2
The transport of pelagic water (TP > 100 ppm) into interior regions of the marsh where TP concentrations are often less than 15 ppm occurs most often at high lake stage. Eutrophication of the interior marsh will result in the loss of desirable vegetation such as spikerush and sawgrass and lead to the expansion of cattail and other non-desirable vegetation.

***Rationale*:** The expansion of cattail into Moonshine Bay in the 1980s first occurred along open airboat trails and in Cochran's pass. These areas were connected to the littoral-pelagic interface and likely received periodic inputs of P rich water during periods of high lake stage. Since the 1990s, hundred's of acres of fragrant water lily also have become established along the lake's shoreline and at interior marsh sites including Moonshine Bay.

9.5 Water Supply and Flood Protection

The AT currently does not have guidance for the assessment of water supply and flood protection. However, Renken et al. (2005) have prepared a review of the impacts of anthropogenic development on the coastal ground-water hydrology in Southeastern Florida from the period 1900-2000. The following is a summary of the findings of this study and will served as an introduction to the problem of conducting assessments on this topic.

The urban and agricultural corridor of southern Florida lies between the Everglades and water-conservation areas to the west and the Atlantic Ocean to the east. The area, which includes eastern Miami-Dade, Broward, and Palm Beach Counties, has experienced explosive population growth (from less than 4,000 residents in 1900 to 5 million residents in 2000), and as such is subject to widely conflicting stresses on the environment. A highly controlled water-management system evolved during the 20th century largely to provide drained land for a rapidly expanding population. Reclamation of Everglades wetland areas provided the opportunity for westward expansion of agricultural, mining, and urban activities. Surface water is impounded in water-conservation areas that lie west of the protective levee system, partly to: (1) sustain an Everglades ecosystem, (2) keep overland sheetflow from moving eastward and flooding urban and agricultural areas, and (3) use for water supply.

Parallel environmental interests exist in coastal areas of the urban-agricultural corridor. Coastal residential and urban areas must be drained for flood control, whereas the underlying surficial aquifer system must simultaneously serve as the principal source for water supply, and ground-water heads must be maintained to prevent saltwater intrusion. Changes in predevelopment ground-water flow patterns and the associated reduction in ground-water discharge to coastal bays have altered salinity and affected the local ecology. Active since the early 1920s, extractive mining has increased considerably,

largely to satisfy urban construction needs. The limited availability of limestone that meets construction requirements and simultaneous competition for land by both industries place both in direct conflict.

Surface- and ground-water systems were altered considerably by the construction of a complex system of canals and levees as well as by heavy municipal withdrawals. Between 1900 and 1948, uncontrolled canal drainage increased the rate of flow from the Everglades, reduced the extent of inundated land, and lowered ground-water levels. These canals failed, however, to transport the load imposed during flood events and worsened drought conditions through over-drainage of the surficial aquifer system. Drought and hurricane-related flooding provided the impetus for the 1949 establishment of the Central and Southern Florida Flood Control Project and District; canals were enlarged, conveyance structures and controls were installed, and protective levees were constructed. The southern Dade conveyance system was completed as the final phase of the project during the 1980s, and involved redirecting surface-water flow and controlling ground-water levels in southeastern Miami-Dade County.

Ground water represents the principal source of water for municipal supply in the tri-county area of Miami-Dade, Broward, and Palm Beach Counties and has increased from three well fields producing about 66 Mgal/d in 1930 to about 65 well fields producing 770 Mgal/d in 1995. West Palm Beach is the only large municipality that uses surface water for supply purposes. Miami-Dade County uses a centralized well-field infrastructure in which five large-capacity well fields withdraw the majority of the supply. A decentralized well-field infrastructure has been constructed in Broward and Palm Beach Counties, in which municipalities have relied on developing their own source of supply to meet local demand. On the basis of temporal analysis of well-field locations and production levels, there has been a historic shift from large well fields near the coast to more western facilities partly designed to mitigate saltwater intrusion.

Surface water is the primary source of water for cultivation of sugar, field, and row crops in much of Palm Beach County, particularly in the Everglades Agricultural Area; conversely Miami-Dade agricultural growers primarily rely on ground water withdrawn from shallow wells and conveyed using truck-mounted pump and spray irrigation systems. The agricultural industry of Broward County has been largely displaced by residential and urban development, despite once having been the Nation's primary winter producer of tomato, pepper, and bean crops, between the 1920s and 1940s. Broward County producers mostly relied on surface-water supplies until about 1960, when they converted to the use of ground water. Whereas agricultural activities in Broward County had become a minor factor in the county economy, cultivated lands expanded considerably in Miami-Dade and Palm Beach Counties between 1953 and 1988. Damage caused by Hurricane Andrew, which resulted in an agricultural financial loss exceeding $1 billion, appears to have contributed to the decline in cultivated lands in Miami-Dade County since 1992. Agricultural water use in the tri-county area increased from 505 Mgal/d in 1953 to almost 1,150 Mgal/d in 1988, declining to 764 Mgal/d in 1995.

The surficial aquifer system, the principal source of ground water in southeastern Florida, is a wedge-shaped, eastward thickening sequence of limestone, quartz sand, shell, and terrigeneous mudstone of Pliocene to Holocene age. The prolific Biscayne aquifer, a sole-source aquifer, is the most transmissive of three separate aquifers that comprise the surficial aquifer system. Transmissivity of limestone-rich areas is greater than 1,600,000 square feet per day but decreases to 54,000 square feet per day where the surficial aquifer system mostly consists of sand; yields of 1,000 to 7,000 gallons per minute are reported from some wells completed in the cavernous part of the surficial aquifer system.

Well fields have been constructed farther inland during the latter part of the 20th century because of coastal saltwater intrusion. Competition between agriculture, the Everglades ecosystem, and mining interests ultimately limits construction of new well fields along the western margin of the urban corridor.

Unlimited utilization of unconfined freshwater aquifers is no longer permitted under current State regulatory authority. It is reasonable to assume that an expanded, widespread use of the Floridan aquifer system for multiple and conflicting uses will eventually result in unforeseen hydrologic consequences. Competition for the Floridan aquifer system as a water resource has become dramatically apparent during the last decade or more. The Upper Floridan aquifer is targeted as the major new source for potable supplies, either through direct withdrawals, brackish and shallow aquifer blending operations, reverse osmosis (RO) withdrawals, and aquifer storage and recovery (ASR). A large network of ASR wells is being evaluated for Everglades restoration purposes if regional hydrologic and local geotechnical, hydraulic, and water-quality issues can be resolved.

Alternatively, the Lower Floridan aquifer is used for purposes of municipal and some industrial, and reverse-osmosis concentrate wastewater disposal. Increased demand for the limited brackish-water resources of the Upper Floridan aquifer has placed deep well wastewater injection under increased surveillance, because there is concern that a stressed Upper Floridan aquifer will promote upward leakage of buoyant municipal wastewater injectate from the Lower Floridan aquifer.

More than 20 Class I injection wells were operating in the Broward, Miami-Date, and Palm Beach area by 2000, injecting treated wastewater into the Boulder Zone at depths of 2,000 to 3,000 ft below NGVD 1929. As a wastewater management option, Lower Floridan aquifer deep well injection has been under increased environmental, regulatory, scientific, and public review in recent years. Florida's Counties and municipalities are increasingly challenged to ensure safe disposal wastewater or its reuse. In 2002, more than 277 MGD were being injected in the tri-county area. Proposed EPA regulations allow continued wastewater injection in Lower Floridan aquifer wells showing evidence of upward leakage if operators can provide adequate protection. But public and environmental activists have expressed concern that injected wastewater will eventually commingle with shallower ground water used for public supply purposes. Monitoring wells near some deep well injection facilities in Miami-Dade, Broward, and Palm Beach County indicate wastewater has migrated upward from the wastewater injection zone into

overlying strata. Traditionally, the risk of effluent leakage has been considered to be greatest through or around the outside of the injection well itself (Talbot 1972). However, an EPA (2003, pg. ES-11) report states that evidence of deep injection well mechanical failures is lacking, concluding that efficacy of overlying confining units are in question. The current understanding of the fate and transport of the wastewater plume migration and its cumulative impact on the existing physical system is poor. The general, but unproven assumption has been wastewater becomes diluted and rendered safe biogeochemically.

Few data are available to accurately document the predevelopment conditions within the surficial aquifer system; the water table probably subtly reflected the Atlantic Coastal Ridge topography. Peat and muck deposits, an important predevelopment component of Everglades surface- and ground-water hydrology, functioned as a storage reservoir to a water column that extended upward from the underlying aquifer and maintained a higher water table that prolonged the hydroperiod and restricted movement of a coastal saltwater interface. Surface-water stage within the adjoining Everglades was sufficient to allow water to discharge through traverse glades areas, and shoreline and submarine springs discharged freshwater.

Uncontrolled canal drainage and a lengthy drought in 1945-46 caused water levels to reach their lowest recorded levels, exacerbating municipal well-field saltwater intrusion problems. The modern-day water table largely reflects the hydrologic influence of numerous engineering features, including primary and secondary canal systems, gated control structures, levees, impoundments, pump systems, and the drawdown effects of the larger well fields. Ground-water movement is largely coastward and water levels are highest near the water-conservation areas, except locally in southeastern Palm Beach County and northeastern Broward County, where surface water is pumped from the Hillsboro Canal into secondary canals to artificially maintain water levels. Regional water-level comparison maps of the difference in "average conditions" show that improved drainage systems built during the 1950s lowered inland ground-water levels and increased land areas for urban and agricultural development.

Gated coastal canal structures are used to retard landward movement of saline water during the dry season through maintenance of stage higher than local water levels, inducing seepage into the aquifer. Management of canal stage has helped to increase ground-water levels in some coastal areas. Long-term canal coastal discharge appears to have declined, but coastal canal stage has been maintained gradually at higher levels, presumably to impede saltwater intrusion. Diminished coastal discharge is attributed to the rerouting of surface water to secondary canals, and induced recharge to the aquifer caused by increased municipal withdrawals.

Calcium bicarbonate water is dominant in shallow parts of the surficial aquifer system, whereas sodium bicarbonate and sodium chloride water are dominant in more deeply buried parts of the aquifer system or along the coast. Chloride concentrations generally are less than 100 mg/L at depths shallower than 50 ft, except in coastal areas and southeast of Lake Okeechobee. Chloride concentrations are less than 100 mg/L at the

150-ft depth in eastern Palm Beach County, eastern Broward County, and much of central and northwestern Dade County.

A broad zone of diffusion characterizes the saltwater interface in southeastern Florida in which the position of the interface is a consequence of three principal mechanisms: westward lateral movement of seawater within the surficial aquifer system, seepage from tidal canals, and upconing of relict seawater. Prior to 1945, uncontrolled drainage contributed considerably to lowering the water table of the surficial aquifer system along the Miami Canal. Water levels were lowered further by heavy municipal withdrawals, inducing tidal seepage into the aquifer system. Canal drainage contributed greatly to intrusion of the saltwater interface in Broward County, lowering ground-water levels with the subsequent landward movement of saltwater in the surficial aquifer system from the Atlantic Ocean. Well-field withdrawals and tidal seepage are an important, but less important, source of saltwater intrusion.

Predevelopment freshwater spring discharge in Biscayne Bay diminished considerably following the emplacement of canal drainage networks and the loss and compaction of inland peat deposits that formerly maintained higher water levels in the ecosystem, and stored excess surface water that helped to recharge the underlying aquifer. Changes in land use and water-management practices have greatly impacted the marine ecosystem of Biscayne Bay, resulting in increased nutrient loads and other pollutants, and increased turbidity. Prior to construction of the major canals, the salinity of the southernmost part of Biscayne Bay was much lower than normal marine salinity, especially near the coastline from Manatee Bay to possibly as far north as the Coral Gables Canal. The increase in salinity interpreted for both Biscayne and Florida Bays in the early 1900s through the 1970s is likely related to the increased development of the canal system and modifications in surface-water drainage. This is consistent with the progressive inland saltwater intrusion. Post-1940 water-management practices to control water discharge greatly affected the Biscayne Bay ecosystem by increasing the frequency, and particularly the magnitude, of salinity fluctuations. By altering the natural variability in freshwater discharge to Biscayne Bay, the natural cycles of the nearshore marine organisms were disrupted, resulting in biotic fluctuations similar to the frequency and magnitude of the salinity changes.

9.6 South Florida Hydrology Module

The Water Resources Development Act (WRDA) of 2000 authorized theCERP as a framework for modifications and operational changes to the Central and Southern Florida Project needed to restore the south Florida ecosystem. Provisions within WRDA 2000 provide for specific authorization for an adaptive assessment and monitoring program. A Monitoring and Assessment Plan (MAP) has been developed as the primary tool to assess the system-wide performance of the CERP by the RECOVER program. The MAP presents the monitoring and supporting enhancement of scientific information and technology needed to measure the responses of the South Florida ecosystem.

Restoration of the Everglades system depends on the restoration of the volume, timing, and distribution of sheet flow as simulated in the Natural Systems Model for the pre-drainage greater Everglades ecosystem. Compartmentalization has altered or eliminated sheet flow and impacted landscape characteristics, surface-water/ground-water interactions, ecological processes and water quality. An approach to facilitate interaction, feedback, and support among monitoring, modeling, and management components of the restoration is needed. Developing a reliable mechanism to facilitate comparisons among metrics of hydrology, species monitoring data, and model outputs is the key to making adaptive management decisions.

The goal of the South Florida Surface Water Monitoring Network in Support of the MAP Projects (known as EDEN, Everglades Depth Estimation Network) is to develop a single integrated network that provides real-time stage data across the greater Everglades landscape to guide large-scale field operations, to integrate hydrologic and biologic responses, and to support MAP assessments by scientists and PIs across disciplines all of which are founded on the hydrology.

To address the needs of the MAP assessments, a real-time surface-water data network requires adequate spatial coverage that transmits data in every landscape unit in the greater Everglades including Water Conservations Areas (WCA1, WCA2, and WCA3), eastern Big Cypress National Preserve, and Everglades National Park. The water-level network consists of the existing network of stage gages operated and funded by others including SFWMD, National Park Service, US Fish and Wildlife service, the Corps and US Geological Survey. Additional water-level gages are installed to fill gaps in the existing data network. The assessment portion of the MAP assessments will require PIs to make rapid assessment of biological communities and their responses based on the hydrology in selected landscape units.

Currently, water level gages have different vertical datums and are served on multiple websites or not available real-time without special FTP transfers and pre-arrangements. Scientists and investigators in the greater Everglades have used a wide variety of methods with varying consistency and success to transfer hydrologic data from gages to their study areas. The EDEN project will provide consistent, document-able, and easily accessible real-time hydrologic data throughout the greater Everglades. Other geospatial data, such as soils and water quality data will be integrated with project hydrologic data on a website for access by scientists and managers.

The objectives of the EDEN project are to:

1) Relate water-level data at real-time stage gages to ungaged areas and, using ground elevation data, computed water depths throughout the greater Everglades.
2) Gain an understanding of microtopography as it relates to vegetation and use vegetation to define water depth differences.
3) Develop a “clickable” web-based GIS map to assess real-time water-level data for all gages by RECOVER agencies in the greater Everglades.

4) Develop a dynamic web-based GIS tool for access to user-specified hydrologic data for study sites, such as computed water depth, hydrograph recession rates, slope, and hydroperiod; including other GIS information such as soils, water quality parameters, rainfall, and periphyton densities.

Real-time hydrologic data, such as water depth, recession rates, day since last dry period, and water-surface slope, present investigators and managers with an opportunity for decision making and adaptive management not previously possible. Sufficient characterization of surface water hydrologic conditions aids in interpreting the water quality and ecological data in the wetlands. A hydrologic network must provide the necessary information to link changes in the physical components to changes in chemical and ecological components of the system. Therefore, the first step is the adequate baseline monitoring of hydrologic data before a fully integrated multidisciplinary assessment of the ecosystem can be accomplished.

Using the network of 200-250 existing and 23 new water-level stations in the greater Everglades, water levels will be extrapolated to ungaged areas based on hydraulics, statistical analysis, and water surface modeling. The network of high accuracy ground surface elevation data collected by the USGS over nearly the entire greater Everglades provides elevations at approximately 50,000 points on a 400-square-meter grid spacing. Subtraction of ground elevation from the real-time water level elevation provides computation of water depth throughout the greater Everglades.

Vegetation impacts ground elevation in response to varying flow conditions, differential sediment deposition and biologically-influenced processes. The 400-square-meter grid cells will be overlain by a mosaic of vegetation where vegetation is lumped into four major categories 1) slough or open water, 2) ridge or saw grass, 3) tree islands, and 4) other which includes all vegetation types that do not fit into the first three types. Differences in ground elevation, or microtopograhy, will produce varying vegetation-influences water depths, flow paths, and flow resistance.

Coupling EDEN's real-time data approach with biological models, such as ATLSS and others, can contributed to our evaluation of how well the simulated relationships driving both biotic and abiotic models reflect and anticipate real-world events. The integration of real-time data and modeling can provide timely feedback to refine and corroborate model rules, a process that now faces significant impediments due to time lags in availability of calibration hydrologic data.

Three web-based GIS data access sites will be developed and linked to provide users with access to real-time water level gage data, computed water depth and other hydrologic data, and existing GIS coverage that allow users to integrate biological response and seasonal changes to hydrology. The websites are described below and details of the website functions will be finalized based on input from GE module PIs.

- Website with "click-able" access to real-time water level data from 200 to 250 existing and 23 new stage gages with telemetry or radio transmission capacity and

NAVD88 datum corrections. The site will display daily hydrographs and ground elevation data by vegetation community.

- Website to access all relevant GIS data coverage from the greater Everglades from any published source including EPA's REMAP water quality data, SFWMD coverage of landscape units boundaries and soils data, and USGS vegetation data, to name a few. Additionally, a list of relevant publications documenting these data coverage will be retrievable by searchable attributes.
- Website for access to temporal and spatial water depth maps with user-specified capability to select areas, time periods, and associated GIS coverage. The interface will include algorithms and methods for calculation of additional hydrologic characteristics, such as recession rates, days since last dry period, number of dry events over time, and water level deviations.

10.0 FUTURE UNCERTAINTIES

The Conceptual Ecological Models developed for the MAP are retrospective in nature, that is, they focus on those sources and stressors that were relevant to the deterioration of the South Florida Ecosystem over the past 100 years. Consequently, when developing the restoration plan these were the stressors that needed to be controlled and mitigated to return the current system to a pre-drainage state. However, these are not the only stressors that are operative on the system today, there are others. The IAT feels that these can be classified as "Future Uncertainties" and believes that these categories of stressors may pose a significant threat to the success of the restoration. The IAT has chosen to highlight three categories of stressors: contaminants, exotic species, and climate change. The intent is to have the Module Groups examine the role of these stressors in their assessments. Clearly, this is not a complete listing but serves only as a point of departure for the PIs to begin to think beyond the stressors in the current MAP CEMs.

10.1 Exotic Species

Successful restoration of the South Florida ecosystem, which includes the last vestiges of a once vast Everglades wetland, hinges on being able to reverse the environmental degradation that has occurred from human activities over the last 100+ years and prevent degradation from future human activities. While it is clear through the efforts of the Comprehensive Everglades Restoration Plan (CERP) and Restoration Coordination and Verification (RECOVER) programs that numerous factors (e.g., water quantity and quality, and abundance of flora and fauna) are involved in the restoration effort, the potential impact of invasive species has only recently become a high priority for the CERP planning.

It is estimated that over 32,000 exotic species (25,000 plants & 7,000 animals) have been introduced into Florida (Stein, Kutner & Adams 2000). Florida has approximately four to five thousand native species of plants and animals. The number of exotic species that have been introduced is eight times the total number of native species in the entire state.

Of the total of 32,000 exotic introductions, about 2,000 plant and 400 animal species have been documented as having reproducing free-living (naturalized) populations established in Florida. Of the 2,000 plant species 66 are documented as serious threats to natural areas, and an additional 63 are considered as serious potential threats and require careful monitoring. Of these, forty-eight species are documented to cause ecosystem level impacts, 14 species are documented to be directly impacting threatened and endangered species and rare habitats within Florida and 19 species are documented as being among the world's worst weeds (Holm 1977). Land management agencies in Florida spend a combined total of approximately $91 million each year trying to manage just a few of those 129 plant species.

Within the Central and Southern Florida Restudy Area just six species of invasive exotic plants have replaced approximately 1.9 million acres of habitat (Doren and Ferriter 2001). One species alone, Old World Climbing fern has spread exponentially during the last two years. Its current range covers over 125,000 acres across 7 South Florida

counties in Everglades habitat, and model predictions for this species estimates over 5 million acres covered by 2014.

The SFWMD in its 2006 South Florida Environmental Report provides an in depth discussion of the status of non-indigenous species in South Florida (Chapter 9). This report describes the extent of this problem within the context of each of the major Modules. This approach is particularly important in that it provides the Module Groups, module specific information that they will need to factor into their assessments.

The following are issues that the Module Groups should consider when conducting their assessments.

1) A major concern of the assessments is the need to consider the potentially irreversible alterations in ecological community structure and function caused by the replacement of native plants and animals.

    a. Carbon sequestration
    b. Nutrient cycling and nutrient mineralization
    c. Alterations in geomorphology including soil erosion, soil deposition and sediment accumulation, soil composition (i.e. soil types), soil decomposition, and changes in soil elevation
    d. Alterations of natural fire regimes (e.g., intensity, frequency, and seasonality
    e. Alterations in surface water flow, quantity and quality
    f. Alterations in salinity of soil and water
    g. Alteration in primary productivity, food web structure and energy flow patterns
    h. Alterations in channelization of wetlands, estuaries and coastal marshes
    i. Decreased recruitment of native plants and animals
    j. Alterations in water and nutrient uptake
    k. Alterations in population and stand structure in plants and animals
    l. Alterations in competitive ability and selective pressures on native species
    m. Increases in the natural background rate of species extinctions (natural rate is approximately 1 to 10 million years per species, current extinction rate due to habitat loss and invasive exotic species is approximately 500 years per species).

2) The irreversible reorganization of the Everglades' ecosystem resulting in a new altered stable state (structural and functional) that is entirely manifested by and dependent on invasive exotic species.

3) The loss of native habitat.

4) The development and implications of anoxic bacteria and low level of dissolved oxygen in wetlands and waterways resulting from infestations of exotic vegetation.

5) The alteration or elimination of natural vegetation community structure or abundance.

6) The occurrence of faunal shifts.

7) The potential hydrologic impacts.

8) The potential loss of biodiversity within the Everglades ecosystem.

9) The impacts and physical damage and loss to water control and conveyance structures such as canal banks, pumps, etc.

10) The reduction of habitat available for native and migratory birds.

Given the current and potential impacts of non-indigenous organisms in South Florida, scientists are obliged to begin to factor these species into restoration models, and research must be carried out to understand the distribution, biology, and impacts of these non-indigenous organisms. The idea of dealing with non-indigenous organisms in an all-taxa approach is a nascent study, but it is sure to emerge as an important field of science given global trade and the virtual "open barn" situation. Organisms will continue to arrive and will continue to establish breeding populations in South Florida. The abundance of non-indigenous plants in South Florida may be accelerating this process, as animals are arriving not only without their natural enemies but also into a hospitable environment that includes plant species from their native range. It is probably no coincidence that the Burmese python prefers levees covered with Burma reed in the Everglades.

10.2 Implications of Climate Change and Climate Variability upon CERP

Given its geographic scope and multi-decadal planning and implementation horizons, the success or failure of CERP will to no small degree be determined by the degree to which management decisions are consistent with and adapt to not only global climate change (e.g., sea level rise, sea surface temperature change, atmospheric carbon-dioxide and large scale changes in precipitation patterns) but also inter-decadal climatic variability in the coupled ocean-atmosphere (e.g. the Atlantic Multi-decadal Oscillation (AMO), El Nino/La Nina, Sahel drought and tropical storm impacts). Local "climatically relevant" phenomena such as desertification will not only complicate interpretation but will have to be specifically considered with regard to CERP assessments, evaluations and recommended management alternatives.

With its low relief and extended coastline, South Florida is particularly sensitive to sea level rise (Titus and Richman, 2000). Global models vary widely but predictions for global sea level rise by 2050 range from 6" to as much as two feet. Limited data suggests local sea level rise over the same period may be as much as 6" although the geophysical mechanism for this rise is unclear and it may represent a more temporary steric phenomenon. Together this rise would markedly change the mangrove estuarine shorelines and move them well inland along the northern perimeter of Florida Bay and

the Southwest Florida Shelf (Maul and Martin, 1993; Wanless et al, 1994). It could also deepen basins in Florida Bay and significantly alter residence times and flushing rates (Rudnick et al, 2006).

Global changes in precipitation pattern for the entire North American continent are forecast in conjunction with global warming and a rise in atmospheric (and upper mixed layer) carbon dioxide concentration. The condition of the coral reefs off the Florida Keys has been proposed as an indicator of overall ecosystem condition. With increasing dissolved carbon dioxide the calcification upon with coral growth depends is significantly depressed (Langdon et al, 2005).

Perhaps even more significant than these global climate change trends is climate variability. The phase of the AMO is closely correlated with rainfall over South Florida indeed with inflow into Lake Okeechobee (Enfield et al, 2001) Recent results indicate a greater than 90% probability of a phase shift in the AMO over the thirty year span of CERP construction (Enfield and Cid-Serrano, 2006). In addition, both AMO phase and drought conditions in the Sahel desert in West Africa have been linked to the incidence of major tropical storms (Wang et al, 2005; Goldenberg et al, 2000). These patterns suggest that the 30 year model runs on which the design of the Comprehensive Everglades Restoration Plan is based encompassed a period of much lower rainfall than we can expect during the coming decades of CERP implementation.

Tropical storms can not only markedly affect water supply and flood protection but can significantly impact shallow estuarine tropical ecosystems in particular their retention of sediment. Model studies suggest that changes in land use in Florida related to increased population pressures and agricultural development have already markedly reduced convective rainfall as much as 10% (Pielke et al, 1999).

In short, restoration alternatives need to be evaluated in light of both systematic trends (both global and regional) and regional climate variability to encompass the range of conditions the ecosystem is likely to experience.

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APPENDIX A - LAKE OKEECHOBEE PHOSPHORUS EXAMPLE

The following example, using total phosphorus (TP) data collected in Lake Okeechobee, can help to illustrate some of these points. The data considered here are monthly surface water samples from eight pelagic stations, averaged by month for two time periods: 1973-1977 and 1997-2001.

Raw Data – the following graphs contain the raw data collected from the sampling program (Figure A-1). These data are of the type that might be entered into the CERP database. In this case, there was considerable seasonal variation, and 5-year blocks of data were considered suitable for representing the two periods of time. Visual inspection of the graphs suggests that TP has increased, but this requires formal statistical testing.

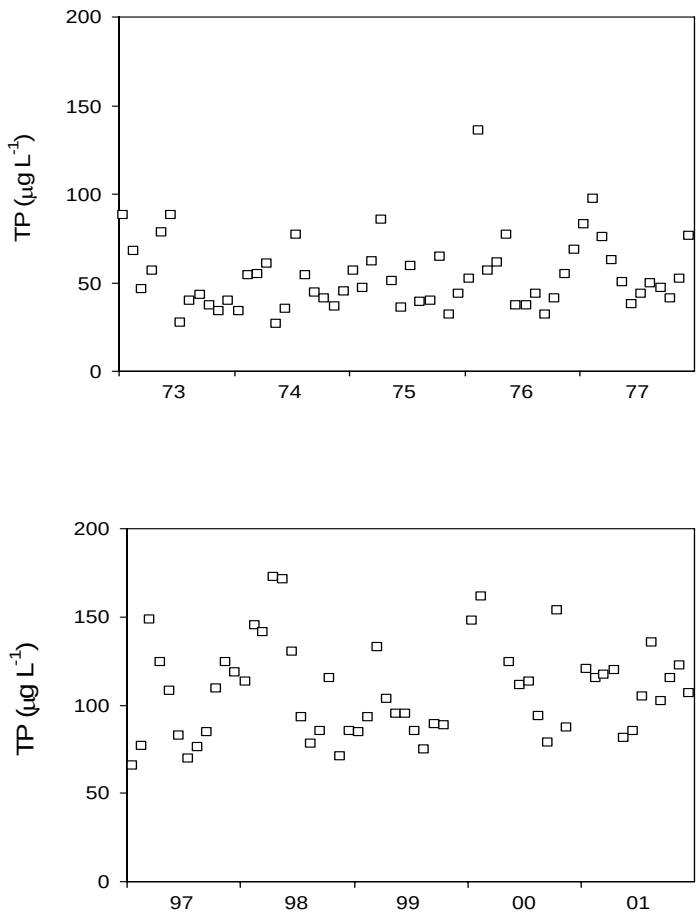

Figure A-1: Raw data collected from sampling in Lake Okeechobee.

Basic Statistics – the following table contains the basic statistics for the two time periods (Table A-1).

Table A-1.

Period:	73-77	97-01
N	60	55

Mean ($\mu g\ L^{-1}$)	54	108
Median ($\mu g\ L^{-1}$)	50	107
Max ($\mu g\ L^{-1}$)	136	173
Min ($\mu g\ L^{-1}$)	27	66
Standard Deviation ($\mu g\ L^{-1}$)	20	27
Skewness	1.5	0.6
Kurtosis	3.5	0.3

These data support the notion that TP has substantially increased. However, the 73-77 data are significantly different from normal, based on standard tests of Skewness and Kurtosis, whereas the 97-01 data are not significantly different from normal.

Data distributions – the following graphs indicate the distribution of data into deciles for the two time periods (Figure A-2).

1973-77 1997-01

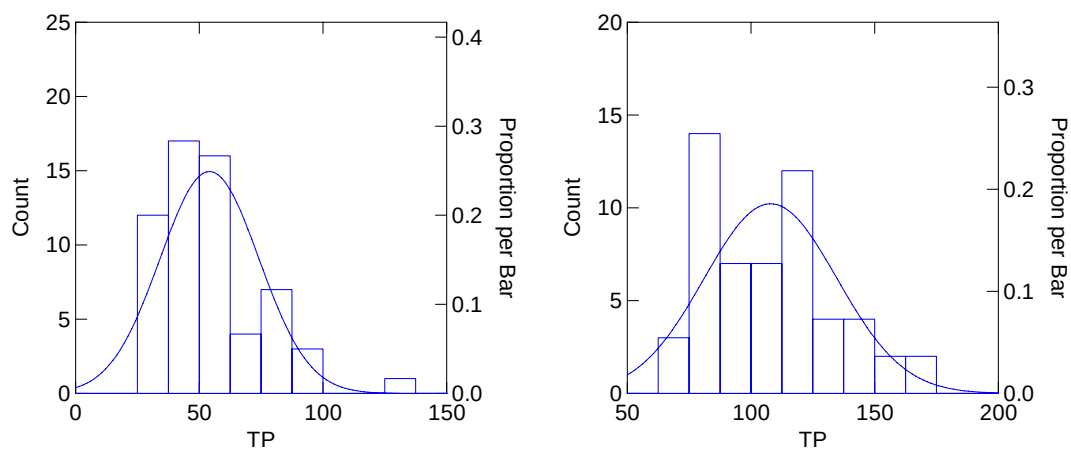

Figure A-2: Distribution of data into deciles for two time periods

Power Test – a formalized power test could be run on the data from either time period, to identify how much the mean concentration of TP would need to change in the next period of record for it to be significantly higher or lower. Most statistical packages have this feature, and a general explanation can be found in any basic statistics book. As a general rule of thumb, and a quick preliminary test, the power to detect a change is approximately twice the 95 percent confidence interval of the data, assuming that the distributional characteristics do not change. In the case of the 1997-01 data from Lake Okeechobee, this corresponds to approximately 20 µg L-1 TP.

Evaluating Change – a variety of methods may be used by the investigator to determine whether or not there has been a change in the measured attribute over time, and/or whether the data are approaching some quantitative performance goal established in the Monitoring and Assessment Plan. No specific method is recommended by the AT;

however, for any method that is used the investigator must ensure that critical assumptions are met and the method has been documented in the peer-reviewed literature as being appropriate for purpose for which it is used.

In the case of Lake Okeechobee, there actually is a 30-year record of pelagic TP concentrations that has been examined by trend analysis (there has been a significant increase). The investigators dealing with that dataset used a non-parametric trend test because of the seasonal variation in the data. In the example provided here, however, we could compare the TP concentration of the two time periods with a simple Student's *t*-test, working with log-transformed TP concentrations (log-transformation substantially reduces the skewness and kurtosis of the 1973-77 data, such that both distributions approximate normality).

The following are results of the T-test, including a graphical display of the data from the two time periods, which better allows for a sense of data overlap (Figure A-3).

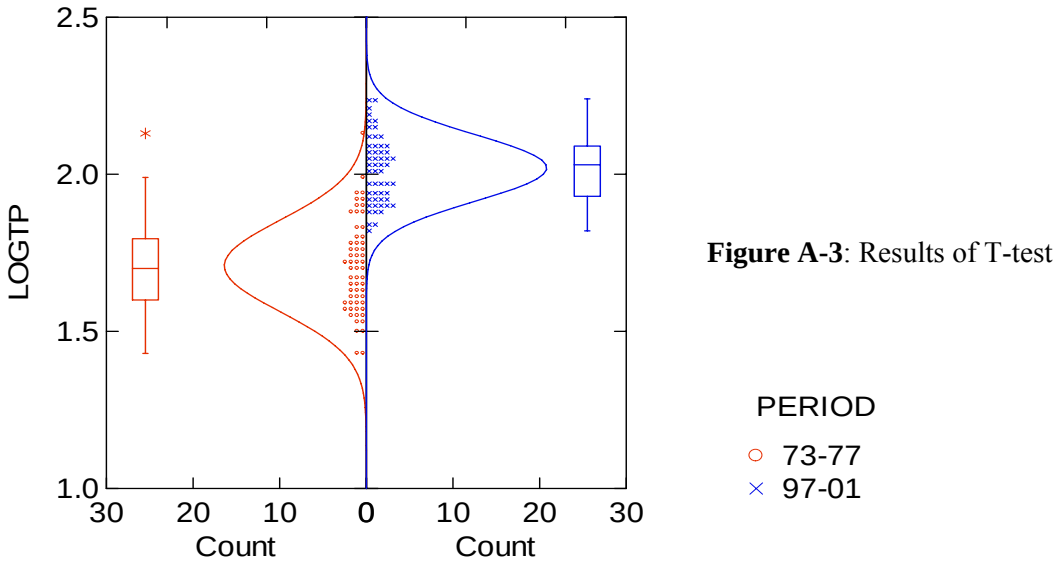

Figure A-3: Results of T-test

T-test results:

T	13.3
Degrees of Freedom	113
Significance	0.001

Variability Issues with Long-Term Trends – in addition to a need for identifying seasonal patterns for statistical purposes, it is critical that the investigator have good knowledge of long-term natural variability in his/her dataset, so that erroneous trends are not reported to the AT. The Lake Okeechobee dataset for TP concentrations serves as an excellent example (Figure A-4):

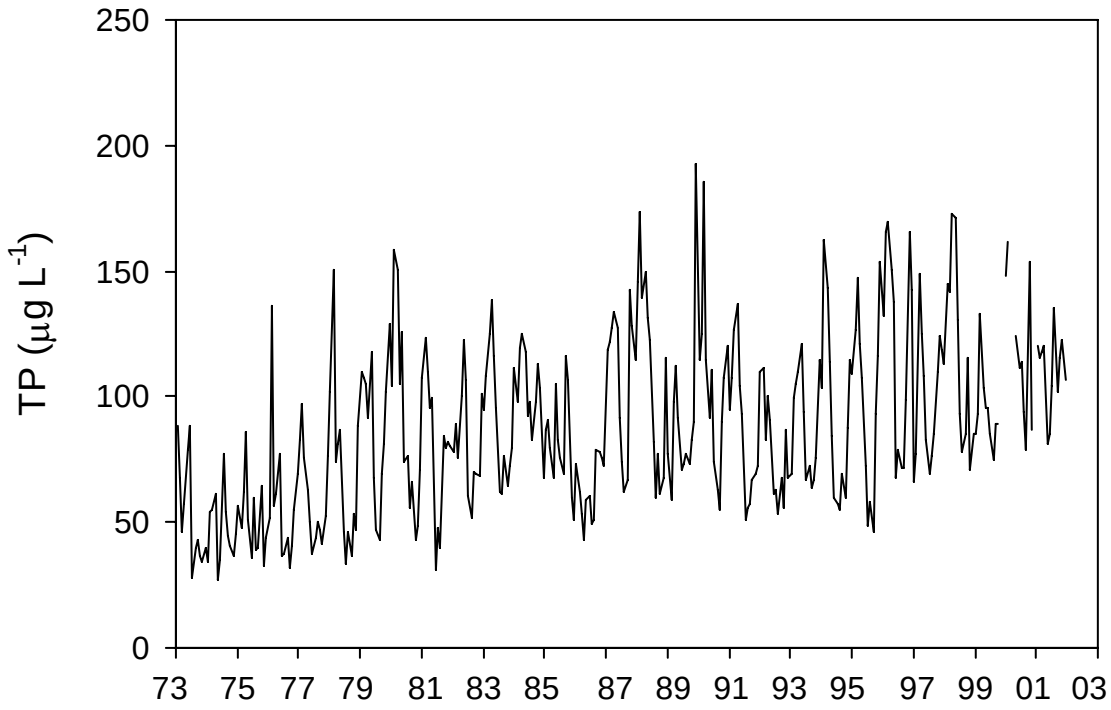

Figure A-4: Variability in long-term trends for Lake Okeechobee

These data have seasonal spikes, associated with wind-resuspension of P-rich bottom sediments during winter months, year-to-year variation associated with differences in rainfall, inflow and intensity of windstorms, and multi-year variation that in part tracks changes in water level. If one considers as an example the time period from 1980 to 1987, which is quite long (7 years) by most standards, investigators may have reached the erroneous conclusion that water quality had been substantially improved by certain P control programs implemented in the watershed in the early 1980s. In reality, the lake TP was displaying a transitory excursion and later increased.

APPENDIX B - POWER ANALYSIS RESOURCES

The importance of power analysis can be illustrated by examining the possible outcomes associated with hypotheses testing (U.S. EPA 1992). The alternatives, familiar from statistical hypothesis testing but applicable to our performance measures, are as follows:

- Type I error: the hypothesis is actually true but it is rejected. By convention, the investigator accepts a small probability, ≤ 0.05, of incorrectly concluding there are differences when in fact there are no differences. Lower or higher confidence values can be selected, depending on the severity of the consequences for rejecting the hypothesis. In the case of a hydrologic parameter that is critical to the recovery of an endangered habitat or species we might want to set the confidence level at 0.01 for example.

- Type II error: The hypothesis is actually false yet it is accepted. Interestingly the probability of accepting the hypothesis when it is not true is almost never reported with statistical test results. Furthermore, the consequences of a Type II error are not always fully understood by many investigators. The compliment of the Type II error is often referred to as the power of the test. Therefore, *statistical power can be viewed as the probability of correctly detecting an effect.*

Consideration of these outcomes from examining hypotheses leads to the following considerations. First, the failure to reject the hypothesis does not justify its acceptance for the following reasons: 1) there really is no effect; 2) the power of the test is too low due to the high variance in the variable of interest or insufficient sampling (i.e., "n" is too small); and 3) the expected power of the statistical test has not been evaluated prior to implementing the sampling program.

Most statistical texts address the concepts of hypothesis testing and power analysis. The power of all statistical tests is dependent upon the following design parameters:

- Significance level of the test (alpha)
- Level of sampling effort (i.e., number of sampling stations and sample replicates)
- Minimum detectable difference or change in the performance measure that can be detected
- The "natural variability" of the performance measure within the sampling environment

Therefore the relationship between power and design parameters affords the opportunity to conduct a variety of power analyses and can be determined as a function of any of these design parameters. Likewise, the value of any individual design parameter required to obtain a specified power can be determined as a function of the other parameters.

B-1 Fixed Design Power Analysis: PCB Fish Tissue Concentrations

Power analyses generally fall into two broad categories: 1) determining the minimum difference in the variable of interest (i.e., performance measure) as a function of the level of sampling effort (size of "n" or degree of replication); and 2) the power of the test (probability of detection) is illustrated as a function of the minimum detectable difference that can be detected between samples over time.

This example of a fixed design power analysis design illustrates the relationships between the minimum detectable changes as percent of the mean PCB tissue concentration (U.S. EPA 1987). This study used historical data for liver concentrations of PCBs in winter flounder to evaluate the expected performance of alternative sampling designs and illustrates the case of minimum detectable differences vs. number of replicates for a fixed set of design parameters.

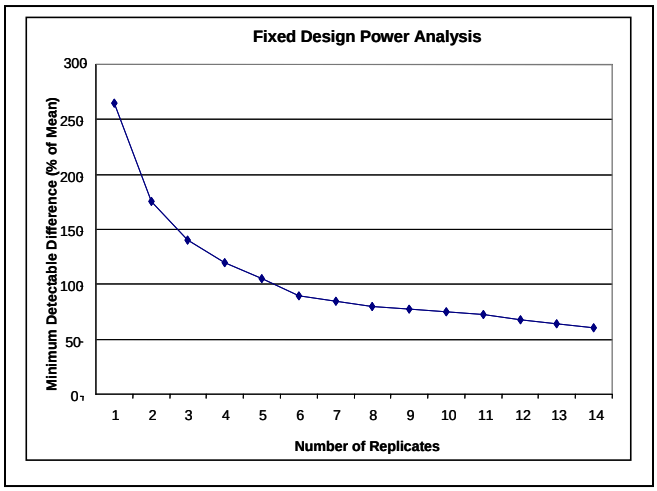

Figure B-1: Minimum difference in tissue concentration of PCBs

The results, illustrated in Figure B-1, indicate that the minimum difference in tissue concentration of PCBs (as percent of the mean – 4.9 mg/kg) that could be detected between sampling locations for different numbers of replicates. The data on individual fish show substantial variation over all the stations as would be expected from a mobile fish whose historical exposure is likely to be highly variable. Thus using a sampling design of five fish from each location would only be able to detect a difference of approximately 120 percent of the overall mean value of 4.9 mg/kg. To detect a 50 percent change in tissue PCB concentrations with this sampling design would required in excess of 15 individual fish from each sampling location which would be prohibitively expensive (U.S. EPA 1992). However, additional power analyses indicated that the collection of replicate composite samples would reduce the within sample station variance significantly thus permitting the detection of substantially smaller differences (percent of mean PCB tissue concentrations) among stations at a much lower cost.

B-2 Power as a function of minimum detectable difference

This example is taken from the analysis of water quality data that were collected in Chesapeake Bay (U.S. EPA 1992). In this case a minimum performance criterion for the monitoring program was that ability to detect a difference in dissolved oxygen equal to 1.6 mg/l. Historical data were used to estimate measurement variability and power

analyses were conducted using estimates of the maximum and minimum variance. The results indicate the minimum trend in dissolved oxygen concentration that can be detected with a probability of 0.80 and ten years of historical data is on the order of 0.06-0.13 mg/l-yr which is within the existing power of detection for the current monitoring program (Figure B-2).

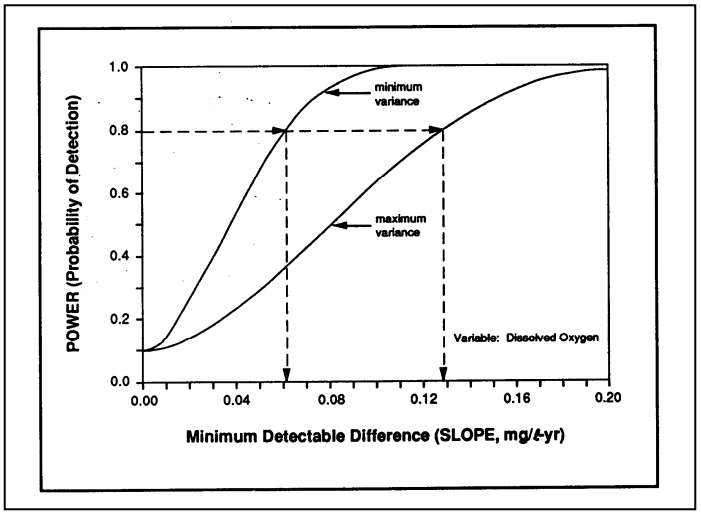

Figure B-2: Minimum trend in dissolved oxygen concentration

The relationship between power and minimum detectable difference provides the information required to evaluate the probability of a Type II error and the probability of detecting specific levels of effects in a proposed sampling program.

B-3 Power Analysis in Adaptive Management

Anderson (1998) in her paper *Errors of Inference* presents a comprehensive discussion of power analysis both in experimental sampling and adaptive management. The following is a summary of recommendations relative to adaptive management.

Several authors have surveyed experimental literature and found few examples that address Type II error (Sedlmeier and Gigerenzer 1989; Peterman 1990a 1990b; Fairweather 1991; Searcy-Bernal 1994). Although there has been some discussion about reconsidering the arbitrary limit on Type I error (a < 0.05), that limit is rarely reviewed in discussions of either power analysis or significance testing. However, the number of journal articles reporting new theoretical developments in the application of power analysis to ecological problems and the increasing variability of software for the purpose suggest that errors of inference will be easier to estimate and interpret in the future. The following recommendations apply to all ecological research, but especially to large-scale management experiments:

- Experimenters and decision-makers should embrace the concept that some errors of inference are unavoidable, but their frequency can be controlled by astute design of experiments and monitoring systems.

- *A priori* power analysis, with an explicit statement of desirable levels of a and b, should be included in the design process for all experiments and monitoring programs.
- All reports of non-significant results should mention the effect size and power of the experiment. Where appropriate, *a posteriori* power analysis may be used.
- Where potential costs of the errors of inference to various stakeholders can be quantified, these costs should be included in decisions about acceptable levels of a and b.
- Where currently available experimental designs lack power, research should be directed toward developing new, powerful methodologies, such as Before-After-Control-Impact paired designs (Underwood 1994).
- Resources should be allocated to pilot studies that will help to improve the power of large experiments.
- *A priori* power analyses are often difficult because not enough is known about potential response variables, biologically significant effect sizes, and spatial and temporal variability. It would be useful to carry out large-scale, long-term monitoring of these variables in ecosystems, with the express purpose of estimating them for use in future power analyses and choices about experimental design (Osenberg et al. 1994).

A few key references guide experimenters through power analysis for the most frequently used statistical tests (Anderson 1998). The classic reference to statistical power is Cohen (1988). Cohen provides clearly written instructions for calculating standardized effect size and other input parameters to power and sample size tables. He provides these tables for *t*-tests, tests involving correlation coefficients, tests involving proportions, the sign test, chi-square tests for goodness of fit and contingency, analysis of variance and covariance, multiple regression and correlation, and set correlation and multivariate methods (e.g., canonical correlation, MANOVA, and MANCOVA).

Zar (1996) presents a graph of power and sample size for analysis of variance, as well as formulas for calculating power and required sample size for a variety of other tests. While he does not include tabled values the formulas are discussed with the details of the tests themselves, including biological examples. In addition, Zar discusses examples of *a posteriori* power analyses.

Nemec (1991) introduces power analysis using examples from forest research. Included are example routines for the SAS statistical software package that compare the power of completely randomized and randomized block analysis of variance designs, and calculate power for one- and two-sample *t*-tests and one- and two-way ANOVA.

Over the last few years, the variety of software packages that perform power analysis, sample size determination, and effect size operations has greatly increased. Thomas (1997) maintains an annotated list of software packages on the World Wide Web. Many of these packages are reviewed in Thomas and Krebs (1997). For other discussions of

software, see Goldstein (1989), Borenstein et al. (1990, 1992), Rothstein et al. (1990), Steiger and Fouladi (1992), and Meyer (1995). In addition, on-line power calculations are available for ANOVA (Friendly 1996) and for correlation coefficients and tests of parameters for normal, Poisson, and exponential distributions (Bond 1996).
Numerous examples are available of power analyses for complex designs, including factorial and repeated measures—analysis of variance (Bittman and Carniello 1990; Muller and Peterson1984), moderated multiple regression (Stone-Romero et al. 1994), and multivariate general linear hypotheses (Muller and Peterson 1984). These papers focus on practical methods for addressing questions related to power, effect size, and sample size.

Finally, many ecological analyses involve specialized statistics or experimental designs for which no analytical formulas exist for calculating power. In such cases, Monte Carlo simulation can be used to produce many simulated data sets generated from distributions with known parameter values corresponding to given null and alternative hypotheses. The experimenter can then estimate statistical power by tallying the frequency with which H_o is correctly rejected by the simulated data.

Acknowledgement: This is to acknowledge that this material on power analysis was taken in large measure from Anderson (1998).

APPENDIX C - INTERMEDIATE SCALE MANAGEMENT MODELS

The concept of AM (Holling [editor] 1978) is steadily gaining wider acceptance in ecosystem management, especially in Canada and the United States (e.g., Schmiegelow and Hannon 1993; Nyberg and Taylor 1995). As a hybrid of scientific research and resource management, AM blends methods of investigation and discovery with deliberate manipulations of managed systems. Through observation and evaluation of the ways that human interventions affect managed systems, new knowledge is gleaned about system interactions and productive capacities. This new knowledge is then applied to future decisions in a cycle of continuous improvement of policies and field practices.

In adaptive management, statistical methods also play a critical role. Adaptive managers will often want to measure the initial state or status of the systems they administer, and they will usually need to monitor trends over time that show the system's responses to management policies or practices. In evaluating outcomes, they will want to draw inferences about the causes of any changes that are detected in the system to decide how and when to adjust actions in the future or at comparable sites. Statistical analyses allow managers to discern small but important differences in data sets, and to distinguish patterns of correlation and interaction from background variation and sampling errors.

Careful design of management experiments is the first step towards gaining data from which reliable inferences can be drawn. Whenever possible, AM studies should include experimental controls, unbiased sampling and allocation of treatments, and replication of treatments. However, it is important to recognize that the operational scale and setting of AM studies may constrain the level of statistical rigor that can be achieved. It may be impossible, for example, to find multiple areas that are sufficiently homogeneous to serve as replicates of operational-scale treatments. In other cases, it may not be feasible to meet some of the critical assumptions of the classical methods of statistical analysis, including random allocation of treatments, homogeneity of variance, and independence of sample variances.

Perhaps even more significant is the fact that statistical methods such as ANOVA and regression analysis are not designed to answer common management questions such as "What is the probability of a 50 percent increase in wading bird densities after increasing the hydroperiod by a factor of two?" As a result, classical methods will be useful in some AM studies but not in others. When classical methods are not appropriate, a proposed study may still be worthwhile if alternative types of analyses can reveal important insights from the data.

The following examples illustrate three approaches to developing intermediate scale models specifically designed to address issues of scale and changing management priorities.

C-1 Adaptive Environmental Assessment Model

One example of an "intermediate" level model that might be applicable for integrating the diverse spatial and temporal scale processes characteristic of the Everglades is the AEAM

approach (Walters et al. 1992; Walters and Gunderson 1994). This approach employed a "simplified" hydrology model that was computationally faster that the detailed numerical models to "screen" broad water management options. The AEAM approach utilized "scenario" analysis which focused on simple indicators comparing simulated water depth patterns in the natural system to water depth and phosphorus distribution patterns under various management and restoration strategies. The AEAM was used to evaluate both the reconstruction of the historical system and for screening restoration policy options. The lessons learned from using the AEAM for examining policies for water management in the Everglades suggest that the success of this screening approach is that different models should be used for different purposes and that policies should be robust to the uncertainties inherent in both approaches. One limitation of the AEAM approach in this application is that little effort was devoted to defining biological indicators or objectives for restoration, such as increasing biodiversity of maintaining particular endangered or threatened species, habitats, or ecosystems (Walters et al. 1992).

C-2 Simple Models for Ecosystem Management

These simulation models were developed to explore and illustrate interactive dynamics of socio-ecological systems (Carpenter et al. 1999). The ecosystem used to illustrate these integrated models is a lake subject to phosphorus pollution. Phosphorus flows from agriculture to upland soils, to surface waters, where it cycles between water and sediments. The ecosystem is multi-stable, and moves among domains of attraction depending on the history of pollutant inputs. The alternative states yield different economic benefits. Agents form expectations about ecosystem dynamics, markets, and/or the actions of managers, and choose levels of pollutant inputs accordingly. Agents have heterogeneous beliefs and/or access to information. Their aggregate behavior determines the total rate of pollutant input. As the ecosystem changes, agents update their beliefs and expectations about the world they co-create, and modify their actions accordingly. For a wide range of scenarios, we observe irregular oscillations among ecosystem states and patterns of agent behavior. These oscillations resemble some features of the adaptive cycle of panarchy theory (Carpenter et al. 1999).

These models can also be used as caricatures of reality that spark imagination, focus discussion, clarify communication, and contribute to collective understanding of problems and potential solutions (Holling 1978, Walters and Gunderson 1994). The role of such models is similar to the role of metaphor in narrative. T he models are designed to illustrate general patterns of system behavior, rather than to make specific predictions. They should be usable and understandable by diverse participants, and easily modified to accommodate unforeseen situations and new ideas. This paper presents models of the metaphorical type. The interactive software for these types of models are available for download, on line from Conservation Ecology at http://www.consecol.org/vol3/iss2/art4.

C-3 Bayesian Network Model for the Neuse Estuary

There are several "intermediate-scale" modeling approaches that might be applicable for evaluating changes resulting from the implementation of CERP. The recovery of the

Everglades is the result of a number of interacting processes operating at multiple spatial and temporal scales. Thus, the individual models developed to appropriately represent each of these processes are not easily combined into a single predictive model. Borsuk et al. (2001) suggest that a system based on Bayesian networks can provide a possible solution to this scale problem. The Bayesian network employs a graphical structure, analogous to the CEMs, to explicitly represent the variables and causal relationships involved in the relevant processes. In so doing it provides a framework to integrate a variety of models representing a number of interacting processes operating at multiple spatial and temporal scales. This graphical approach explicitly represents cause-and-effect assumptions between system variables that may be obscured under other approaches. These assumptions allow the complex causal chain linking management actions to ecological consequences that characterize the CERP, to be factored into an articulated sequence of conditional relationships. Each of these relationships can then be quantified independently using an approach suitable for the type and scale of information available. In addition, probabilistic functions describing the relationships allow key known or expected mechanisms to be represented without the full complexity, or information needs, of highly reductionist models.

Thus the key to successful prediction lies in choosing scales at which predictable patterns emerge rather than trying to model all scales for all processes. Choosing the various scales of representation in a Bayesian network should be a dynamic and iterative process. While it is desirable to choose scales that will represent key features of the natural system, often the scales are imposed by observational, technological, or organizational constraints (Levin 1997). Finally, the scale of prediction should correspond to the needs of the decision-makers, which may change with time as they gain understanding of the problem.

To demonstrate the application of this approach, Borsuk, et al. (In Press) develop a Bayesian network representing eutrophication in the Neuse River estuary, North Carolina from a collection of previously published analyses. Relationships among variables were quantified using a variety of methods, including: process-based models statistically fit to long-term monitoring data; Bayesian hierarchical modeling of cross-system data; multivariate regression modeling of mesocosm experiments; and probability judgments elicited from scientific experts. We use the fully quantified model to generate predictions of ecosystem response to alternative nutrient management strategies.

APPENDIX D - ADAPTIVE ASSESSMENT CONCEPTS

The concept of AM (Holling [editor] 1978) is steadily gaining wider acceptance in ecosystem management, especially in Canada and the United States (e.g., Schmiegelow and Hannon 1993; Nyberg and Taylor 1995). As a hybrid of scientific research and resource management, AM blends methods of investigation and discovery with deliberate manipulations of managed systems. T hrough observation and evaluation of the ways that human interventions affect managed systems, new knowledge is gleaned about system interactions and productive capacities. This new knowledge is then applied to future decisions in a cycle of continuous improvement of policies and field practices.

Careful design of management experiments is the first step towards gaining data from which reliable inferences can be drawn. Whenever possible, adaptive management studies should include experimental controls, unbiased sampling and allocation of treatments, and replication of treatments. However, it is important to recognize that the operational scale and setting of adaptive management studies may constrain the level of statistical rigor that can be achieved. It may be impossible, for example, to find multiple areas that are sufficiently homogeneous to serve as replicates of operational-scale treatments. In other cases, it may not be feasible to meet some of the critical assumptions of the classical methods of statistical analysis, including random allocation of treatments, homogeneity of variance, and independence of sample variances. Figure D-1 illustrates the design and analysis of an adaptive management experiment (Nemec 1991). While the first several steps in the design are common, the issue of replication results in a bifurcation of the flow of the design because of its implications for the types of statistical analyses that can be performed.

The role of classical statistics in AM can, depending on the types of data and questions being asked, be very important. Adaptive managers will often want to measure the initial state or status of the systems they administer, and they will usually need to monitor trends over time that show the system's responses to management policies or practices. In evaluating outcomes, they will want to draw inferences about the causes of any changes that are detected in the system to decide how and when to adjust actions in the future or at comparable sites. S tatistical analyses allow managers to discern small but important differences in data sets, and to distinguish patterns of correlation and interaction from background variation and sampling errors.

Adaptive management requires a suitable model for predicting transitions of a system from one state to another and a set of rules for deciding the best action at any given time. In the case of non-replicated experiments (Figure D-1), various analytical methods have been developed (see Walters 1986, Chap. 4–9). These methods are based on the theory of stochastic processes, Bayesian statistics (Bergerud and Reed 1998), and decision theory (Peterman and Peters 1998). When data arise from replicated systems (left side of Figure D-1), the problem is considerably more complicated. Responses of individual systems and the overall response of systems managed under the same plan (i.e., replicates) must be considered (see Walters 1986, Chap. 10).

Perhaps even more significant is the fact that statistical methods such as ANOVA and regression analysis are not designed to answer common management questions such as "What is the probability of a 50 percent increase in wading bird densities after increasing the hydroperiod by a factor of two?" This problem has no simple solution because the link between classical methods (e.g., ANOVA) for the analysis of replicated designs and decision analysis for non-replicated management strategies is not well developed. As a result, classical methods will be useful in some adaptive management studies but not in others. When classical methods are not appropriate, a proposed study may still be worthwhile if alternative types of analyses can reveal important insights from the data.

Meta-analysis (see Mann 1990 for an interesting and non-technical discussion of meta-analysis) or alternative methods for integrating the results from several experiments might be useful in such situations, although a piece-meal analysis of large, complex, and dynamic systems has obvious drawbacks.

Proponents of AM (e.g., Walters 1986; Walters and Holling 1990; Taylor et al. 1997) argue that successful management of complex biological systems requires full scale testing. These experiments, which are known as adaptive management experiments, are used to test entire management unit, where the management unit is equivalent to the experimental unit. In an AM experiment, one or more systems are monitored regularly over time and decisions about treatments or other interventions are made as the experiment progresses. However, because management units are large and complex, ultimately they must be broken down into suitable sampling or experimental units for observation and evaluation. In this respect, AM experiments resemble classical research experiments and therefore should meet experimental design criteria.

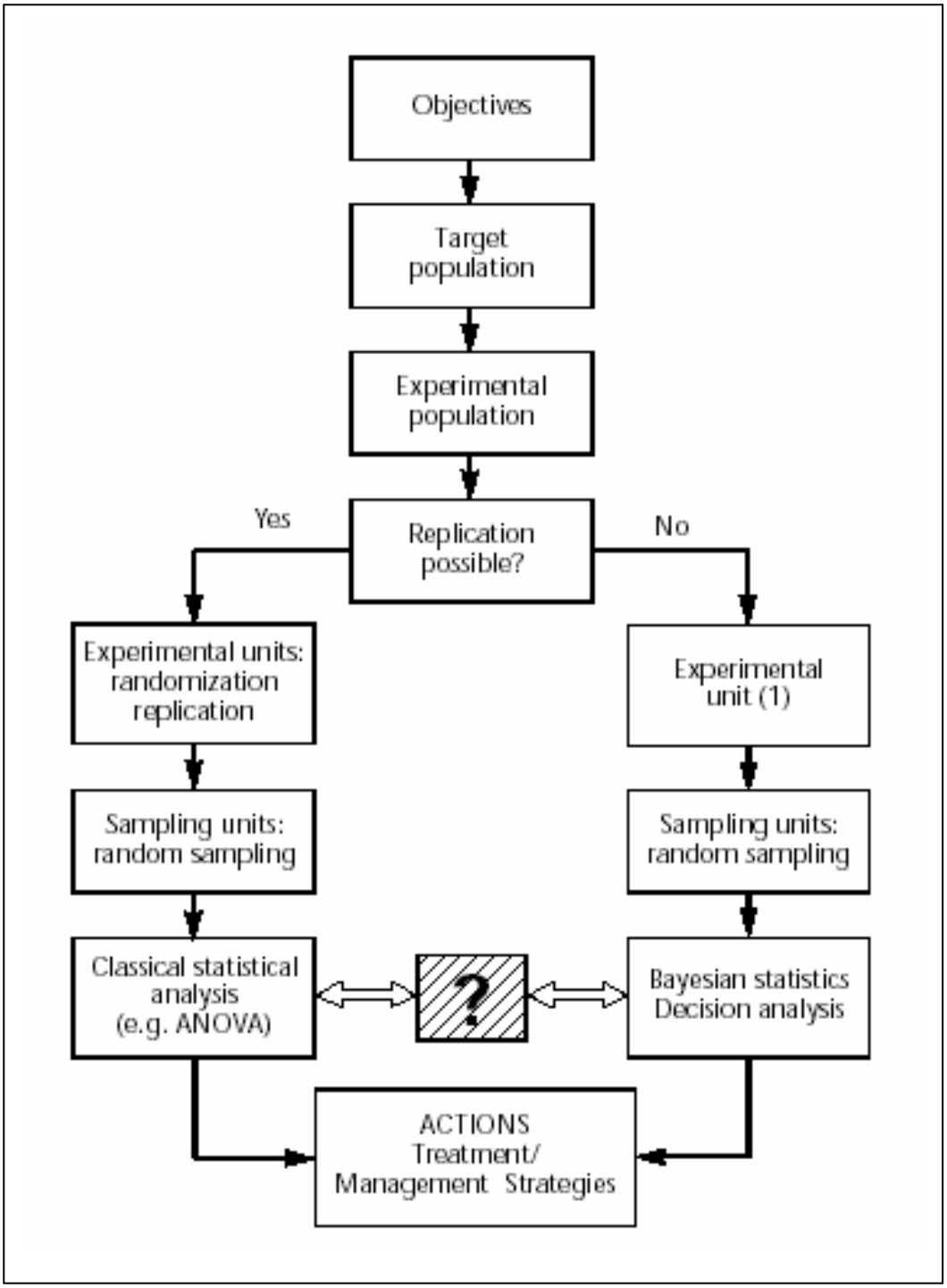

Figure D-1. Design and analysis of an adaptive management experiment (Nemec 1991).

APPENDIX E - ASSESSMENT AND EVALUATION PERFORMANCE MEASURES

Introduction

The AT guidance for conducting MAP assessments has expanded on the original CERP concept of PMs. Assessment and evaluation PMs derive from CERP's Regional and Total System CEMs. MAP monitoring/research elements, and consequently, PMs generally correspond to ecological attributes, physical and chemical stressors, as well as critical intermediate processes comprising the stressor - response pathways developed from the CEMs.

The current PM philosophy, developed for the MAP, was determined before an AT assessment strategy had been developed. Consequently, it is likely that there will be PMs that may not fit within the current assessment strategy. Currently, PMs as defined by CERP are comprised of the following components: 1) a particular physical, chemical, or ecological attribute of importance to the functioning and restoration of the system; 2) a measurable parameter of that attribute; 3) a metric by which to measure and/or model the parameter of interest, and 4) a desired target value for the parameter. The target value is the desired end-state for the parameter, which indicates when restoration is deemed to be successful in regard to that parameter. For example, an ecological attribute could be the health of the wading bird population; the parameter used to assess health could be nesting success, the metric for nesting success could be the number of nests per square kilometer and the target value could be 10 nests. The PM then is "nesting success" and the desired target value is 10 nests.

Ideally, there should be correspondence between the PMs developed for the monitoring plan, the assessments, and the evaluations. However there are important distinctions that will be discussed further detail below.

Evaluation Performance Measures

Simulation models are frequently used in CERP to estimate the effects of water management operations and features (e.g. canals, levees) on the ecosystems of South Florida. These simulation models, by definition, contain simplified representations of existing conditions (e.g. topography, vegetation) and processes (e.g. rainfall, evapo-transpiration, levee seepage). All are designed to operate at very specific spatial and temporal scales, and they are often optimized to accurately represent, at most, only a few features of the natural system. As such, these models cannot, and should not be expected to accurately simulate all the complex interactions occurring between Everglades' climate and hydrologic cycles, trophic webs, and vegetative communities. This modeling limitation is particularly relevant to the CERP planning process because it is these complex interactions that will determine the response of the natural system to restoration activities.

Hydrologic simulation models such as the SFWMM are useful for approximating water levels and hydro patterns in the natural system that may result from a particular rainfall distribution and set of water management practices. In some cases, estimates of habitat suitability (HSI) and water quality are derived from the hydrologic output, though these features are not modeled explicitly within the SFWMM domain. These properties make the SFWMM (and other models) useful planning tools for the CERP process. However, because the SFWMM and other CERP models are run with a historic (36 yr or less) climate record, the hydrologic output, the HSI values and the water quality estimates can not be interpreted as predictions of actual conditions expected to occur at a given time in the future. Rather, the SFWMM and its derivatives (HSI, WQ relationships) only approximate how certain features of the natural system would have responded to the rainfall conditions present in the 36 yr period of record in combination with a fixed set of land use characteristics and water management practices. This same constraint applies to all models, in addition to the SFWMM that utilize the historic climate record in the CERP process. While the output from these models are not predictions *per se*, these models *are* intended to provide some estimates of how the average values of certain features of the natural system can be expected to respond over the long term to a particular set of water management practices and land use characteristics.

Model simulations of alternative water management strategies and land use practices are central to the CERP planning process. A primary function of the evaluation performance measures is therefore to provide metrics that quantify changes in select natural system features that result from the alternative model scenarios. As mentioned above, these features may include average water levels, hydro patterns, and in some cases water quality and habitat suitability. However, because the evaluation performance measures rely on model output, they are constrained by the same limitations exhibited by all the models currently used in the CERP process. Namely, 1) that thePMs are not predictions *per se*, but are intended only to estimate how the natural system would have responded under the 36 yr climate record combined with a unique set of control structures and operations, and 2) they are not intended to represent all the dynamic interactions between climate, hydrology, nutrient cycles, and the biota that characterize the Everglades ecosystem. It is also important to remember that the information generated by evaluation PMs on features such as water levels, hydro patterns, habitat suitability, etc. is often constrained by spatial resolution of the model domain in which they were generated. In the case of the SFWMM, the spatial resolution is 2 by 2 square miles.

Assessment Performance Measures

The RECOVER Assessment Team is charged with assessing progress towards restoration at regular intervals as CERP is implemented. The IAT (as sub-team of the RECOVER AT) could have concluded that it would suffice to simply provide a compendium of the status of each PM with respect to its individual target, which might be called a “report card.” However, with a view towards the gradual refinement and improvement of the CEMs, the near certainty of unexpected ecosystem responses and the plethora of non-linear relationships amongst the great many parameters being monitored, the IAT elected a different approach.

The AT Assessment Guidance has expanded the concept of individual PMs as described in the MAP to a hypothesis-based approach which is more robust, flexible, and more consistent with the AM process. Rather than focusing upon individual PMs, the decision was made to focus upon "hypotheses" (expected responses and relationships captured in the CEM) which ecological attributes, multiple stressors, and intermediate processes in various combinations to determine if the underlying CEM hypotheses are being validated or if they need to be modified. The hypothesis based approach recognizes the complexities of ecological responses by assessing their status and trends using multiple measures (clusters of physical, water quality, and ecological attributes) which reflects a more holistic approach that attempts to capture the mechanistic interactions of multiple stressor-response pathways rather than relying on one metric to characterize ecological complexity. Further, the hypothesis-based approach is more scientifically robust and increases the likelihood of detecting unexpected responses of the ecosystem. Interpreting performance of ecological systems, then, can be best accomplished within the context of a set of hypotheses and can be reported based on the cumulative or combined performance of multiple indicators (e.g., performance measures.

The assessment performance measures, developed from hypothesis clusters, are contained in the MAP. These hypotheses clusters are intended to represent the dynamic interactions occurring between the Everglades' climate, hydrologic cycles, and biota. In effect, these hypothesis clusters represent the complex causal linkages existing between ecosystem stressors such as water management practices and the biological attributes of the Everglades' communities. These hypotheses thus form the basis of predictions about how the biological attributes of the Everglades are likely to change in the future with CERP water management scenarios and climate patterns. In turn, the assessment PMs and their associated metrics applied in the MAP are derived from these hypothesis clusters. In some cases, the metrics applied in both the assessment and evaluation PMs will be the same. For example, average annual water levels or dry season recession rates are two metrics that might apply to both sets of PMs. However, the full set of assessment PMs utilized in the MAP will necessarily be more comprehensive than the evaluation PMs that are applied to the simulation model results. This is because the assessment PMs are intended to quantify, to the fullest extent possible, both the changes in the biological and physical attributes of the natural system, as well as the causal mechanisms leading to these changes.

Summary

Ultimately, the success of the restoration will be determined by how well the indicators perform either individually or collectively. Performance measures currently are required for the interim goal process and to support adaptive management (i.e., actual performance can only be judged in the context of some desired level of performance). Clearly, individual performance measures are applicable for measuring changes in physical and chemical stressors (e.g., hydrologic features and nutrients). However, because of the complexities associated with ecological attributes it is problematic whether one can assess or evaluate ecological change using this approach given non-linearity's, natural

variability, and stochasticity that characterize ecological systems. It is important to recognize that performance measures, as currently being applied in CERP, are being used for two different purposes: assessments and evaluations. The assessments are dealing with empirical data derived from MAP and non- MAP monitoring programs, historical data, and experimental data. Thus the assessments reflect the reality of the current status of the system. The evaluations, on the other hand, are modeled constructs of reality that are more simplified than those of the assessments and deal with prediction of future states of the system or its individual components.