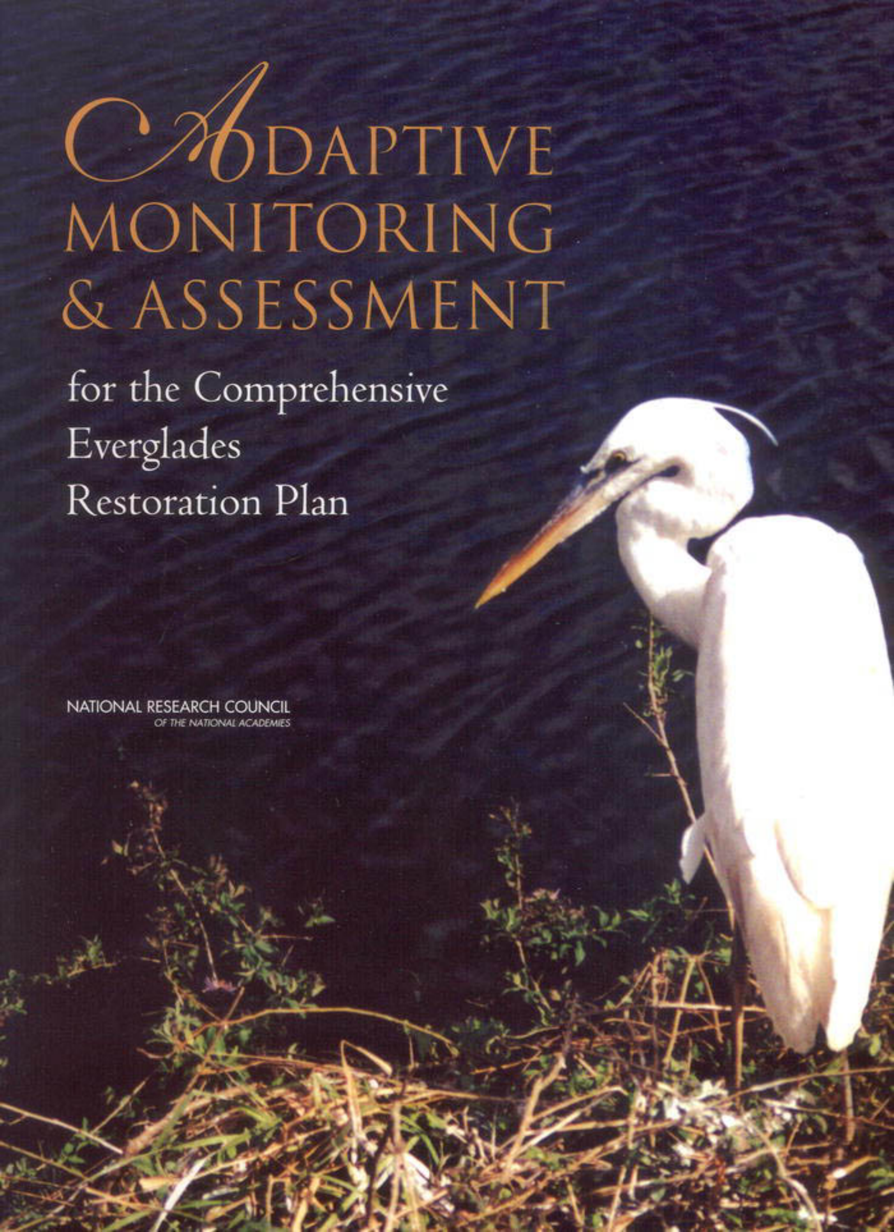
ADAPTIVE MONITORING & ASSESSMENT

for the Comprehensive Everglades Restoration Plan



NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

Adaptive Monitoring and Assessment for the Comprehensive Everglades Restoration Plan

Committee on Restoration of the Greater Everglades Ecosystem
Water Science and Technology Board
Board on Environmental Studies and Toxicology
Division on Earth and Life Studies

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

THE NATIONAL ACADEMIES PRESS 500 Fifth Street, N.W. Washington, DC 20001

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

Supported by the South Florida Ecosystem Restoration Task Force, U.S. Department of the Interior, under assistance of Cooperative Agreement No. 5280-9-9029 and U.S. Army Corps of Engineers. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U. S. Government.

International Standard Book Number 0-309-08892-5

Additional copies of this report are available from the National Academies Press, 500 Fifth Street, N.W., Lockbox 285, Washington, DC 20055; (800) 624-6242 or (202) 334-3313 (in the Washington metropolitan area); Internet, http://www.nap.edu

Cover: Great White Heron in Everglades National Park. Photograph by Patricia Jones Kershaw. Used with permission.

Printed in the United States of America

COMMITTEE ON RESTORATION OF THE GREATER EVERGLADES ECOSYSTEM (CROGEE)[1]

JEAN M. BAHR, *Chair*, University of Wisconsin, Madison
SCOTT W. NIXON, *Vice-Chair*, University of Rhode Island, Narragansett
JOHN S. ADAMS[2], University of Minnesota, Minneapolis
BARBARA L. BEDFORD, Cornell University, Ithaca, New York
LINDA K. BLUM[3], University of Virginia, Charlottesville
PATRICK L. BREZONIK, University of Minnesota, St. Paul
FRANK W. DAVIS[3], University of California, Santa Barbara
WILLIAM L. GRAF, University of South Carolina, Columbia
WAYNE C. HUBER, Oregon State University, Corvallis
STEPHEN R. HUMPHREY, University of Florida, Gainesville
DANIEL P. LOUCKS[3], Cornell University, Ithaca, New York
KENNETH W. POTTER, University of Wisconsin, Madison
KENNETH H. RECKHOW, Duke University
LARRY ROBINSON[3], Florida Agricultural and Mechanical University, Tallahassee
REBECCA R. SHARITZ[2], Savannah River Ecology Laboratory, Aiken, South Carolina, and University of Georgia, Athens
HENRY J. VAUX, JR. University of California Division of Agriculture and Natural Resources, Oakland
JOHN VECCHIOLI, U.S. Geological Survey (ret.), Odessa, Florida
JEFFREY R. WALTERS[3], Virginia Polytechnic Institute and State University, Blacksburg

NRC Staff

STEPHEN D. PARKER, Director, Water Science and Technology Board
DAVID J. POLICANSKY[3], Associate Director, Board on Environmental Studies and Toxicology
WILLIAM S. LOGAN, Senior Staff Officer, Water Science and Technology Board
PATRICIA JONES KERSHAW, Staff Associate, Water Science and Technology Board
ANITA HALL, Senior Project Assistant, Water Science and Technology Board

[1] The activities of the Committee on Restoration of the Greater Everglades Ecosystem (CROGEE) are overseen and supported by the NRC's Water Science and Technology Board (lead) and Board on Environmental Studies and Toxicology (see Appendix B).
[2] Member of the committee through December 31, 2002.
[3] A subgroup consisting of CROGEE members Linda Blum (subgroup chair), Frank Davis, Pete Loucks, Larry Robinson, and Jeffrey Walters, with support from NRC senior staff officer David Policansky, took the lead in drafting this report.

Preface

This report is a product of the Committee on Restoration of the Greater Everglades Ecosystem (CROGEE), which provides consensus advice to the South Florida Ecosystem Restoration Task Force ("Task Force"). The Task Force was established in 1993 and was codified in the 1996 Water Resources Development Act (WRDA); its responsibilities include the development of a comprehensive plan for restoring, preserving and protecting the south Florida ecosystem, and the coordination of related research. The CROGEE works under the auspices of the Water Science and Technology Board and the Board on Environmental Studies and Toxicology of the National Research Council.

The CROGEE's mandate includes providing the Task Force with scientific overview and technical assessment of the restoration activities and plans, while also providing focused advice on technical topics of importance to the restoration efforts. One such topic is the methods by which ecological performance measures and system level conditions are identified for the Comprehensive Everglades Restoration Plan (CERP) Monitoring and Assessment Plan (MAP) and the way that these measures and conditions will be used to assess the restoration process.

To obtain a better understanding of the process for selecting the CERP MAP performance measures, the CROGEE held a one-day "Adaptive Assessment and Monitoring" workshop on November 28, 2001 in Ft. Myers, Florida (see Appendix A for agenda and list of participants). The CROGEE used the March 29, 2001 Monitoring and Assessment Plan developed by the Adaptive Assessment Team (AAT) of the Restoration Coordination and Verification (RECOVER) team as a basis for the workshop. A panel of experts on the plan was assembled to answer questions from the committee. The topics addressed at the workshop included proposed ecological performance measures, measurement of stressors and impact on restoration goals, performance measure prioritization strategies, design of the monitoring program, relationship between construction projects and monitoring, impact of ecological response on construction projects, use of monitoring information to alter management, and reality of applying adaptive assessment. Subsequent to the workshop, the CROGEE deliberated the issues on numerous occasions. I thank the CROGEE members for their work on this report, especially a subgroup led by Linda Blum and including Frank Davis, Pete Loucks, Larry Robinson, and Jeff Walters. With assistance from NRC staff officers David Policansky, William Logan, and Stephen Parker, they took the lead in drafting the report.

The CROGEE is grateful for the assistance of many individuals during the data collection phase of this report. These include Laura Brandt (USFWS),[1] Co-chair Adaptive Assessment Team; Col. Terrence "Rock" Salt, Executive Director of the Task Force; members of the Program Management Committee and the many scientists at the workshop who freely shared their insights.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

We wish to thank the following individuals for their review of this report:

Peter Frederick, University of Florida
John Hobbie, Marine Biological Laboratory, Woods Hole
Michael Newman, Virginia Institute of Marine Science
Gordon Orians, University of Washington (Emeritus)
Nancy Rabalais, Louisiana Universities Marine Consortium
Steven Sanderson, Wildlife Conservation Society
Daniel Simberloff, University of Tennessee
Carol Wicks, University of Missouri-Columbia
Joy Zedler, University of Wisconsin

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by Dr. John Pastor, University of Minnesota. Appointed by the National Research Council, Dr. Pastor was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Jean M. Bahr, Chair
Committee on Restoration of the Greater Everglades Ecosystem

---

[1] Although Laura Brandt was an important contributor, the science panel for the November 2001 CROGEE workshop was chaired by John Ogden (SFWMD) and an important contributor was Steve Davis (SFWMD).

Contents

Executive Summary

The Greater Everglades Ecosystem (GEE) of south Florida has been altered extensively to accommodate humans, industry, and agriculture. Wading bird populations have declined by 85-95 percent; 68 plant and animal species are threatened or endangered; over 1.5 million acres are infested with invasive, exotic plants; and 1 million acres are contaminated with mercury.

In response to these trends, the federal Water Resources Development Act of 1992 authorized a comprehensive review of the Central and South Florida Project to examine the potential for restoration of the Greater Everglades Ecosystem. The result of the review, known as the "Restudy," was the Comprehensive Ecosystem Restoration Plan (CERP, referred here to as "the Restoration Plan")—the largest restoration effort ever pursued. This National Research Council Committee on the Restoration of the Greater Everglades Ecosystem (CROGEE) was established in response to a request from the U.S. Department of the Interior on behalf of the South Florida Ecosystem Restoration Task Force to provide advice on scientific aspects of the design and implementation of the Restoration Plan.

The CROGEE's mandate (see Box ES-1) includes provision of a broad overview and assessment of the restoration activities and plans, and the issuance in reports of focused advice on technical topics of importance to the restoration efforts. One such topic is the methods by which ecological performance measures[1] and system level conditions are identified for the Restoration Plan Monitoring and Assessment Plan (MAP) and the way that these measures and conditions will be used to assess the restoration process. This is an extremely important topic that the CROGEE has been concerned with almost since its inception. This report provides guidance for defining ecological targets for the restored Everglades ecosystem, suggests priorities for hydrologic and ecological monitoring of conditions in the ecosystem, and identifies aspects of establishing and administering a monitoring program that will help assure its usefulness in support of adaptive management in the Restoration Plan.

The Greater Everglades Ecosystem extends from the headwaters of the Kissimmee River southward through Lake Okeechobee and Everglades National Park into Florida Bay and ultimately the Florida Keys. It encompasses more than 46,000 km^2 of subtropical uplands, lakes, wetlands, estuaries, and coastal bays, and a resident human population of 6.5 million that could double over the next 50 years. More than half of the uplands and wetlands have been

[1] These are measures that were chosen in the Restoration Plan specifically to assess ecosystem performance during and after restoration, as opposed to the more general term "indicators."

BOX ES 1

Committee on Restoration of the Greater Everglades Ecosystem
Statement of Task

This activity provides scientific guidance to multiple agencies charged with restoration and preservation of the Central and South Florida aquatic ecosystem, i.e., the Greater Everglades. The NRC activity provides a scientific overview and technical assessment of the many complicated, interrelated activities and plans that are occurring at the federal, state, and nongovernmental levels. In addition to strategic assessments and guidance, the NRC provides more focused advice on technical topics of importance to the restoration efforts when appropriate.

Topics such as the following (to be determined to the mutual agreement of the restoration program management and the NRC) are expected to form the bases for the committee's investigations:

(1) Program goals, objectives, an planning approach;
(2) Data and information aspects, including needs for basic hydrologic and water quality data, environmental resources information, display and dissemination, and monitoring needs;
(3) Use of hydrological and hydroecological simulation models;
(4) Technological aspects of civil works facilities;
(5) Best agricultural and management practices of nutrients management;
(6) Wildlife management;
(7) Decision support systems; and
(8) Research requirements to support analyses for decision making and implementation.

converted to urban and agricultural uses, and the remainder is highly engineered, intensively managed, and tightly bounded by development.

The fundamental premise of the Restoration Plan is that restoring the historical hydrologic regime to the remaining wetlands will reverse declines in many native species and biological communities. To "get the water right"—a major goal of the Restoration Plan that involves quantity, quality, timing, and distribution of water—the plan proposes construction of 68 major projects over an estimated 36 years at a cost of $7.8 billion (1999 estimate). How Everglades ecosystems will respond to the restored water regime is quite uncertain, so extensive ecological research, monitoring, and adaptive management are planned during construction and after the projects are completed.

The ultimate success of the Restoration Plan hinges on a well-designed and well-supported program of monitoring and assessment, the subject of this report. Such a program, now in development, is expected to consist of five major sections: 1) identification and measurement of ecological indicators, 2) design of the monitoring network, 3) implementation plan for sampling, 4) analysis of the indicators to assess ecosystem response, and 5) research to support the monitoring and assessment activities. To date, most of the development effort has focused on identifying ecological performance measures. Because the "Monitoring and Assessment Plan" (MAP) is still evolving, this report does not dwell on specific performance measures or protocols but instead reviews the general approach and design of MAP. As a result, it is likely that some of the recommendations of this report are already being pursued.[2]

Implementation of the Restoration Plan is to follow an adaptive management strategy and, appropriately, the MAP is designed to inform the adaptive management process. Accordingly, this report assesses the extent to which the MAP includes four critical elements of an adaptive management scheme[3]: (1) clear restoration goals and targets, (2) a sound baseline description and conceptualization of the system, (3) an effective process for learning from future management actions, and (4) explicit feedback mechanisms for refining and improving management based on the learning process.

SETTING GOALS AND ECOLOGICAL TARGETS FOR THE EVERGLADES ECOSYSTEM

The goals, targets, and measures of the Restoration Plan are based on considerable analysis and political and scientific judgment. However, building broad stakeholder support for the program has been achieved in part by promoting goals and targets that may not be entirely achievable or even internally consistent. In particular, the following issues have emerged from discussions with scientists, managers, and others involved in the restoration endeavor:

- Some of the specific restoration goals may be at odds with the general goal of ecosystem restoration (for example, managing water levels for a particular endangered species).
- Restoration targets have not been reconciled with large-scale forces of change in south Florida, especially population growth, land-use change, and sea level rise.
- Targets and measures have not yet been defined for the broad goal of achieving compatibility of built and natural systems.
- There appear to be competing visions of what "success" actually means.

The Central and South Florida Restudy Alternative Evaluation Team (Restudy Alternative Evaluation Team {AET} 1998) described the desired outcomes of the restoration in qualitative terms that are compatible with long-term, large-scale ecological restoration based on adaptive management. However, a large number of quite specific targets have also been identified and promoted. Scientists involved in the restoration recognize that many of the specific targets, which have been set using historical evidence, conceptual models, and dynamic hydrologic and ecological simulation models, provide little more than educated guesses at where, when, and how populations and communities will respond to restored hydrologic conditions in a reduced system that has been extensively invaded by exotics species. Furthermore, the targets do not incorporate possible ecological tradeoffs as restoration activities operate to benefit one species or locale to the detriment of another.

A challenge for the Restoration Plan, as for any long-term environmental project, is to reconcile goals and targets with exogenous forces of change: regional sea-level rise and climate change, national and international factors that cause local economic change (e.g., sugar

---

[2] A substantially revised version of the MAP, prepared by the RECOVER Adaptive Assessment Team, will be provided by the U.S. Army Corps of Engineers and South Florida Water Management district for public and agency review during April and May 2003.

[3] The Restoration Plan and MAP are using *passive* adaptive management, i.e., they are not using the restoration project as an experiment or deliberate manipulation for scientific purposes.

subsidies and trade regulations), changes in federal law or international treaties, and so on. The Restoration Plan does not consider multiple scenarios of change or how the restoration itself could influence human activities, which could in turn affect the restoration. Also, until targets and measures are set for defining compatibility of the built and natural system, the Restoration Plan will not have explicitly addressed possible tradeoffs and conflicts between ecological restoration and other policies, statutes, and social demands.

In addressing the Restoration Plan's objectives, then, and especially in designing a monitoring and assessment program, scientists involved in the restoration should consider the degree to which the following general issues are important:

- What are the critical human and climatic forces driving or affecting restoration?
- To what extent and with what precision can science and modeling examine proposed alternative restoration project scenarios?
- What social dynamics of importance are outside the management boundary and how should these be analyzed and monitored?

RESTORATION REFERENCE STATE

The restoration reference state—that is, the condition of the ecosystem used as a reference to evaluate the success of the restoration—is important but challenging to establish. The Everglades has changed and will continue to change due to long-term changes in climate and sea level independent of human impacts or restoration efforts. Further, the system is still adjusting to recent changes in drainage and water quality. All these factors make it difficult to choose an appropriate restoration reference state.

Scientists associated with the restoration have sought to define reference conditions using a mix of modeling and empirical studies. Despite considerable progress, there is a need for continued research to better conceptualize and describe the reference state, research that goes well beyond performance monitoring. This does not mean that the Restoration Plan should not proceed without a better-defined conceptualization of the restoration reference state. It does suggest, however, that the adaptive assessment strategy should include monitoring in support of improved "baseline" data and model outputs as well as hypothesis-driven research to validate the underlying cause-effect relationships defined in the MAP conceptual models.

LEARNING THROUGH INTEGRATED MONITORING, MODELING, AND RESEARCH

The MAP has been structured to monitor the hydrologic conditions in the system and the ecosystem response to them. The ecological performance measures will be used to monitor the status of what the Restoration Plan calls five functional groups identified by the program scientists as critical to understanding ecosystem response to the CERP: wetland trophic relationships, wetland landscape patterns, estuarine epibenthic communities and habitats, Lake Okeechobee pelagic and littoral zones, and biota of special concern (i.e., threatened or endangered species).

Hydrologic Performance Measures

The Restoration Plan is guided by solid scientific research and understanding. Nevertheless, there is much that remains unknown about current and historical hydrologic conditions and their relationships to ecological patterns and processes. Knowledge gaps include the role of environmental variability in establishing and maintaining the Everglades, hydrologic linkages between groundwater and surface water, average and extreme water flows and their role in the ecosystem, and the implications of historical and current loss and fragmentation of upland habitats for many species.

An initial list of approximately 900 hydrologic and water-quality performance measures had been reduced to 78 in the MAP at the beginning of this study (fall 2001). These measures are not response variables in the same sense as the ecological performance measures and functional groups. Rather, they are measures of factors identified as stressors in the regional conceptual models. There are several limitations to the existing set of hydrologic performance measures with respect to their use in an adaptive assessment framework. First, the present measures will be of limited value when applied prior to the implementation of critical features of the Restoration Plan. Even after the Restoration Plan has been completed, observed measures will be confounded by temporal variability in water flows and levels due to climatic variability. An additional limitation of the current hydrologic performance measures is that they cannot be aggregated to provide an overall measure of system performance.

Fortunately, these limitations can be readily addressed. The hydrologic model can be used in such a way that observed climate and the status of the Restoration Plan implementation are used as input data for it. An "aggregate" measure can be derived by using hydrologic model outputs as attributes of "ecological habitat suitability functions" for selected ecological indicators.

Ecological Performance Measures

The proposed monitoring plan is based on indicators of the current status of the ecosystem (baseline) and, as the Restoration Plan is implemented, of populations (e.g., threatened, endangered, and invasive species), communities (e.g., tree islands), and ecosystem functioning (e.g., net primary productivity and formation of soil organic matter). This hierarchical approach will provide a relatively comprehensive evaluation of the system's ecological response to restoration projects and changing environmental conditions as well. The challenge in developing the MAP is selecting appropriate, practical, and informative indicators. If they are well chosen, they should also provide a context or framework for choosing and interpreting more specific indicators.

The five chosen categories of performance measures reflect the five restoration goals outlined above. However, they do not fulfill the need for system-wide indicators.

The current monitoring plan would benefit from a few ecosystem-level, system-wide indicators. The number of indicators chosen to monitor could be reduced by concentrating on poorly understood processes, performing sensitivity analyses to see which uncertainties have the largest effects on model outputs, and by aggregating site-specific variables into a smaller number of system-wide variables where possible. The MAP could consider monitoring spatiotemporal patterns of total species diversity as well as of native species diversity. Additionally, given that the Restoration Plan is focused on a well-defined ecosystem, an IBI (Index of Biotic Integrity)-like measure would be appropriate and useful. The purpose of such a measure would be to provide a “multimetric” that would integrate several key indicators to represent the changing structure and functioning of the Greater Everglades Ecosystem. Indicators also are needed to provide information about ecosystem functioning in a broad sense and give information about the ecosystem’s capacity to respond to changes.

Understanding the Relationship of Drivers to Restoration Targets and Measures

Ecosystem drivers (such as climate and sea-level changes, changes in development patterns, and land-use changes) must be monitored in addition to ecological performance measures. The focus should be on system drivers that have long-term excursions from average (e.g., weather cycles) or trends (e.g., sea-level change). This is necessary because system response times may be quite different than anticipated when the ecological models used in the Restoration Plan were developed. Furthermore, to understand the Greater Everglades Ecosystem (and subsystem) response to the Restoration Plan, it will be critical to monitor changes in anthropogenic drivers because of the strong effects they may have on the hydrologic and ecological performance measures. Given the expected long time scales of the Restoration Plan’s activities and ecosystem response to them, hydrologic and ecological models will likely remain a primary design and evaluation tool for projects and monitoring programs. Driving variables for these models should be explored over a range of scenarios to assess the “robustness” of the Restoration Plan to future changes.

Setting Monitoring Priorities

The MAP does well at reducing a large number of possible measures and monitoring objectives down to a much smaller, but still substantial, subset. The MAP should further set priorities within this subset, reflecting the relative utility of elements of the subset in meeting the several monitoring objectives (i.e., adaptive management, report card, and regulatory compliance).

Priorities also are needed for choosing the ecological indicators. Characteristics of indicators that should be considered in setting these priorities include the following:

- relevance to restoration goals,
- potential to help identify critical knowledge gaps that are most critical to the largest number of future projects,
- relevance to predictive models,
- importance to stakeholders,
- sensitivity to the design and operation of the Restoration Plan when “normal” variation is known, and
- technical feasibility.

Annual Report Card

In addition to monitoring for adaptive management, selected variables will be monitored to produce a restoration "report card." Ten indicators of water quality, population abundance, and habitat extent have been identified. The report card is a useful idea, but report cards should make clear that variations in the measures and unexpected results may result from influences unrelated to the Restoration Plan. Monitoring of the report card elements should be accompanied by research that establishes the cause-effect relationships between the measure and environmental variation as well as variation in these "outside" influences.

Regulatory Compliance Monitoring

Several federal environmental laws apply to the Everglades, for example, the Endangered Species Act (ESA), the Clean Water Act, and the National Environmental Policy Act. State laws apply as well. Thus, in addition to focusing on the ecosystem, the MAP will need to meet the information needs of each of the organizations and agencies involved in the Restoration Plan. The Everglades system contains populations of several endangered species, and some of the monitoring described within MAP is necessary to comply with the ESA. Achieving water quality standards is part of "getting the water right," and thus monitoring water quality is not only essential to adaptive management, but it is also a regulatory requirement in some cases.

Modeling and Experimental Research

Hydrologic and ecological simulation models have guided the restoration design and will be important in integration and evaluation of monitoring data and adaptive management. The ecological modeling efforts have not received as much support for development, refinement, and input data as the hydrologic models. A well-supported ecological modeling component that is coordinated with hydrologic modeling and field monitoring is important to the success of adaptive management.

SCIENTIFIC FEEDBACK TO THE RESTORATION PLAN

Although six management options are recognized in the Restoration Plan as being informed by monitoring and assessment activities, in practice, there will probably be limited opportunities for adaptive management in a program as large and complex as the Restoration Plan, because there are long time lags between the design and implementation of restoration activities. In addition, ecosystem response times can be on the scale of decades or more. Well-designed pilot studies and monitoring, with experimental research and modeling, can provide meaningful scientific feedback for management and decision–making. This would require strong communication between scientists and managers, and institutional flexibility to respond to new information.

Synthesis of monitoring data and preparation of adaptive management reports are important to the Monitoring and Assessment Program. While the development of these parts of the program is in its early stages, the following questions should be asked.

- How often should formal reviews of the Restoration Plan's performance be conducted?
- Are there specific ecosystem responses that will trigger a formal review, in addition to scheduled reviews?
- Is enough time for analysis and synthesis of information built into the assessment process?
- How will independent peer review of data collection and synthesis be conducted?
- Who will make sure that monitoring results are incorporated into the implementation of the Restoration Plan, and how will that be done?

DATA MANAGEMENT AND PRODUCTS

The scope and complexity of the monitoring requirements of the Restoration Plan warrant the direction of special attention and resources to a quality assurance/quality control (QA/QC) program whose elements include planning, implementation, assessment, and reporting. Data-quality objectives (DQOs) should be established during the planning stage of the program and used to develop measurable performance criteria. Successful planning will allow managers to identify financial, personnel, and information technology resources needed for implementation, assessment, and reporting. Since monitoring performance indicators and QA/QC performance objectives are intimately related, adding DQOs incrementally to an existing monitoring plan could prove wasteful and inefficient.

The development of a plan for data and information management has lagged behind other elements of restoration planning. But adaptive management cannot succeed without reliable access to well-documented, validated information.

CONCLUSIONS AND RECOMMENDATIONS

Conclusion: The Comprehensive Everglades Restoration Plan (Restoration Plan) Monitoring and Assessment Plan (MAP) is grounded in current scientific theory and practice of adaptive management. The least developed aspects of the planned adaptive management are feedback mechanisms to connect monitoring to planning and management.

Recommendations:

- Adaptive management should not simply mean "flexibility in decision making under uncertainty." When considering a variety of possible strategies, actions should be taken that are informative, reversible, and less uncertain or at least robust to uncertainties.
- Institutional mechanisms should be created and sustained to ensure that scientific information is available and accessible to the decision-making process.

- Opportunities for flexibility in design should be identified and operational features of the Restoration Plan components should be assessed to help prioritize monitoring and assessment activities.

Conclusion: Restoration goals, objectives, and targets for the Everglades are inadequately defined and are not reconciled with the large-scale forces of change in south Florida.

Recommendations:

- Targets should be set as soon as possible that define the extent of compatibility between the built and natural systems and that address possible conflicts between ecological restoration and other policies, statutes, and social demands.
- Research and monitoring should continue to better conceptualize and describe current conditions in the Greater Everglades Ecosystem. Continued support and coordination of hydrologic and ecological monitoring and coordination among them are important components of monitoring and assessment. Integrated modeling is the best method for extrapolating findings over large areas and long periods.
- Since the Everglades can never be fully restored, probable conflicts among desired ecological targets should be identified, necessary compromises should be acknowledged, and the scope of the MAP should contemplate this line of inquiry continuing for the duration of the restoration (so emergent conflicts can be resolved appropriately).

Conclusion: Adaptive management requires an effective process for learning from management actions. The primary reliance on passive adaptive management planned for the restoration may be the only feasible approach given the large time and space scales of the project and constraints such as those imposed by endangered species. Passive adaptive management uses science to formulate predictive models, makes policy according to the models, and revises the models as data become available. But monitoring is done without controls, replication, and randomization, and thus it lacks statistically valid experimental design, and therefore cannot always be used to infer cause and effect. Policy effects are not distinguishable from other human forces or from natural processes.

Recommendation:

The MAP should be augmented with active adaptive management wherever possible to enable conclusions about cause and effect to be made. As soon as possible, additional expertise in sampling design and analysis of environmental data should be engaged. Opportunities should be identified for active adaptive management that compares alternative policies by means of deliberate experiments. The experiments should use controls, paired comparisons, replication, and randomization.

Conclusion: The MAP needs a rigorous quality assurance/quality control (QA/QC) program to ensure that monitoring data are of high quality and utility.

Recommendation:

To ensure the quality of RECOVER environmental data and related data products, a QA/QC program with clearly defined roles and responsibilities should be established. The current Restoration Plan Program Management Plan for Data Management calls for such a function, but it appears that there has been little substantive progress in this important area. The National Institute of Standards and Technology or other similar organization should be consulted to provide guidance as a QA/QC plan is developed.

Conclusion: Including combinations of ecological performance measures and environmental variables hypothesized to impact those measures is critical for the MAP given the adaptive management approach being implemented.

Recommendations:

- More ecosystem-level, system-wide performance measures or indicators (such as defined by NRC, 2000) should be identified and set. For example, more use could be made of the nine broad targets developed by the Restudy Adaptive Assessment Team (AAT). Other possibilities include land-cover and land-use measures, an Index of Biotic Integrity, and system-wide diversity measures.
- Monitoring of invasive species, mercury, and other contaminants should be added.
- Hydrologic performance measures useful in designing the Restoration Plan should be modified to better serve adaptive management. New aggregated performance measures will be especially critical.

Conclusion: Region-wide monitoring of ecosystem drivers is essential to reducing the uncertainties associated with the Restoration Plan but these drivers appear to have received comparatively little attention by the Monitoring and Assessment Program.

Recommendations:

- To understand better the potential effects of restoration decisions in the Greater Everglades Ecosystem and the Restoration Plan, the external human and environmental drivers of the system, such as human population growth, water demand, and long-term climate, should be monitored and their contributions to ecosystem response should also be assessed through experimentation as well as modeling. Many of them already are monitored by local, state, and federal agencies and so the main challenge will be to coordinate an integrated modeling, monitoring, and experimentation effort that makes good use of such data.
- Given the expected long time scales of ecosystem response (as well as the extended implementation time scales), models of hydrologic processes and ecological responses, adaptable to new situations and new stressors, will remain a primary design and evaluation tool

for projects and monitoring programs. External drivers for these models should be varied over a range of scenarios to assess the “robustness” of the Restoration Plan to future changes.

Conclusion: Effective adaptive management requires an explicit feedback mechanism for learning from management actions. Scientists developing the monitoring and assessment plan need an explicit understanding of what information to management needs and how monitoring results will be used

Recommendations:

- To create a basis for scheduling and sequencing of projects within the Restoration Plan, an assessment of the design and operational flexibility of the 68 proposed major projects could be used to prioritize monitoring, experimental, and modeling activities. Therefore, it should be determined which project components have the greatest impact on decisions, and hence on monitoring activities. In other words, the relative ease with which projects could be modified in an adaptive management process should be assessed. Therefore, monitoring and process studies should include hydrologic and ecological features for which improved prediction of response could lead to project modification that will improve the restoration outcome.
- Formal linkages should be established to connect the RECOVER Senior Management Team and the Science Coordination Team to the CERP decision-makers to keep them informed of the changing state of knowledge, so that they can make decisions based on current scientific information.

Conclusion: In addition to serving adaptive management, the monitoring program must also serve compliance monitoring and report card functions.

Recommendations:

- The strategy of integrating, but differentiating, performance measures used for adaptive management, compliance monitoring, and the report card is a worthy one. The MAP should determine on a continuing basis the most effective ways of communicating and explaining scientific information to the decision makers and various stakeholders related to the restoration of the Everglades using adaptive management.
- System-wide performance measures sensitive to restoration activity and associated with low uncertainty should be included in the report card. It is appropriate to use visible measures of interest to the public, such as abundance of endangered species, in the report card but these will not be sufficient to show positive progress toward restoration.
- It is appropriate to include compliance monitoring in the adaptive management framework when the performance measures involved will be affected by the Restoration Plan. However, in other cases performance measures will be driven by other factors (e.g., populations of some endangered species), and monitoring of these should be clearly labeled as compliance in nature.

Conclusion: The overall design and funding of the Restoration Plan obviously requires adequate and continued support of long-term monitoring and scientific studies throughout the restoration. At this time funding of monitoring activities appears secure and ample. Still, funding is never unlimited, and it is therefore critical that Adaptive Assessment Team develop strategies for prioritizing monitoring needs of all kinds. This includes prioritizing the importance of the various ecological indicators. The Adaptive Assessment Team has done an excellent job of winnowing a large number of possible indicators and monitoring objectives down to a much smaller, but still substantial, subset.

Recommendation:

The Adaptive Assessment Team should prioritize within this subset of monitoring objectives, and consider the relative utility of elements of the subset in meeting the several monitoring objectives (i.e., adaptive management, report card, and regulatory compliance).

1
Introduction

For much of the 20th Century the Everglades epitomized the American conflict between unbridled economic development and environmental conservation. Now the region has become a 21st Century symbol of the nation's commitment to sustainability achieved by protecting and restoring native species and ecosystems while meeting human needs for space and natural resources.

A BRIEF HISTORY OF THE EVERGLADES

The South Florida ecosystem (Figure 1-1 and 1-2) stretches from north of Lake Okeechobee to the Florida Reef Tract, and includes parts of 16 counties (USACE and SFWMD, 1999). While part of the system lies on ancient limestones, the Everglades peatland formed only during the past 5,000 years as sea level rose from its Ice Age low to its present level (Gleason and Stone, 1994). Alteration of the natural system began on a small scale in the mid-1800s, as over 50,000 acres north and west of Lake Okeechobee were ditched, drained, cleared, and planted for agriculture (Trustees, 1881). In 1907 Governor Napoleon Bonaparte Broward created the Everglades Drainage District (Blake, 1980), and by the early 1930s, 440 miles of canals dissecting the Everglades had been constructed (Lewis, 1948).

At least as early as the 1920s, private citizens had been calling attention to the degradation of the Florida Everglades (Blake, 1980). However, by the time Marjorie Stoneman Douglas' classic book *The Everglades: River of Grass* was published in 1947 (the same year that Everglades National Park was dedicated), the Greater Everglades Ecosystem had already been altered extensively to accommodate human habitation of the region, industry, and agriculture.

This trend only accelerated when disastrous floods of 1947-1948 led to the Central and Southern Florida Project for Flood Control and Other Purposes. This initiative employed levees, water storage, channel improvements, and large-scale pumping to supplement gravity drainage of the Everglades. It also created a 100-mile perimeter levee to separate the Everglades from urban development, effectively eliminating 160 square miles of Everglades that had historically extended east of the levee to the coastal ridge (Light and Dineen, 1994;

Lord, 1993). The project then partitioned the remaining northern sawgrass and wet prairie (Figure 1-1) into conservation areas (Figure 1-2), separated by levees, designed primarily for water supply and flood control, with some provision for wildlife habitat and recreation. The Everglades Agricultural Area (EAA) was created just south of Lake Okeechobee (Figure 1-2), facilitated by the construction of a dike spanning the entire circumference of the lake.

These and other projects were undertaken primarily for flood control, to support agriculture, and to provide dry land for development, and they have led to severe ecological consequences. Currently, by comparison with the earliest available estimates of the ecosystem and its components, populations of wading birds have declined by 85-95 percent; 68 plant and animal species are threatened or endangered; over 1.5 million acres are infested with invasive,

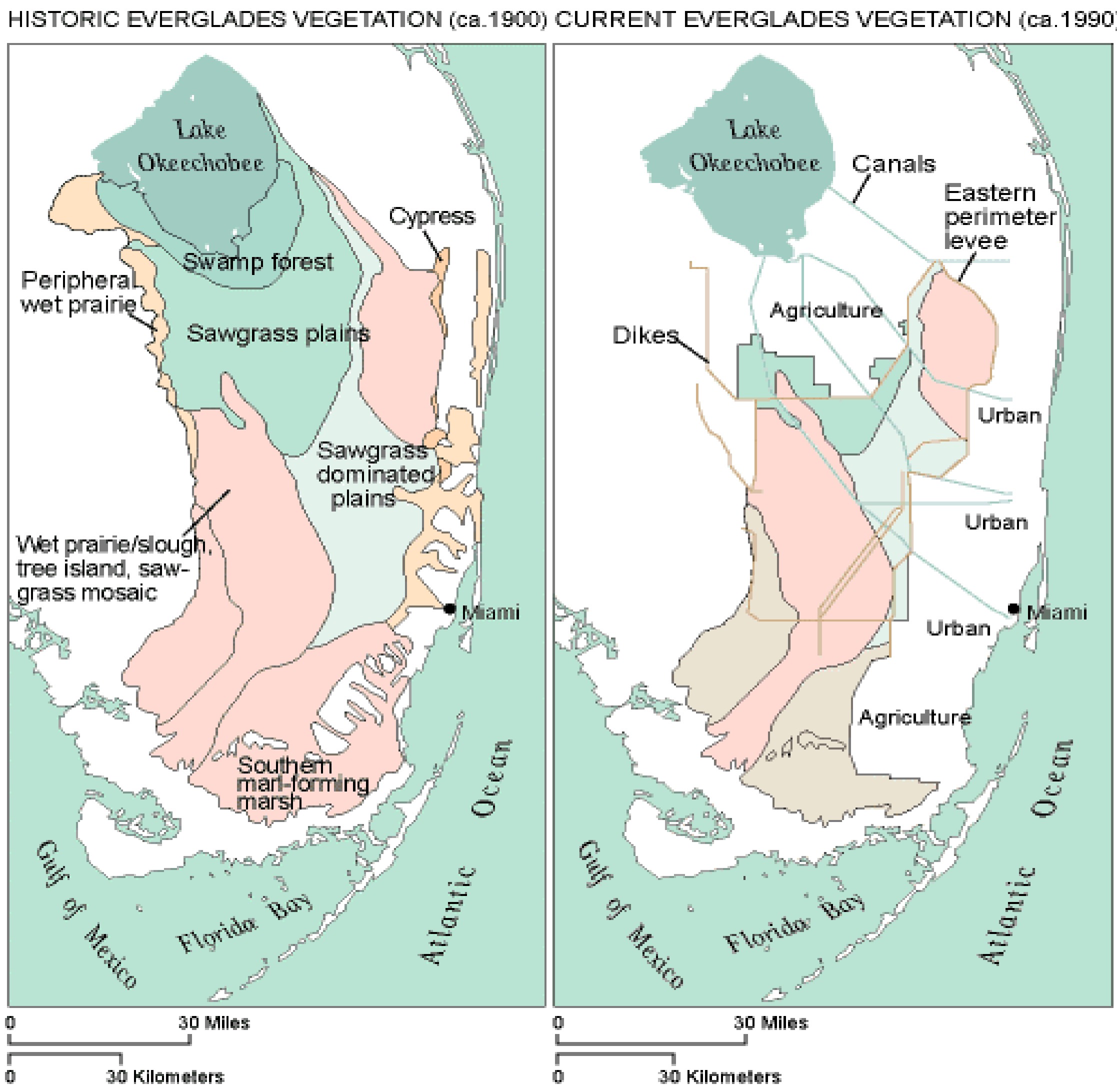


FIGURE 1-1. Historic and current Everglades vegetation. Source: Galloway et al., 1999.

exotic plants; and 1 million acres are contaminated with mercury (McPherson and Halley, 1996).

In response to these alarming ecological trends, the federal Water Resources Development Act of 1992 (WRDA) authorized a massive and comprehensive review of the Central and Southern Florida Project to examine the potential for restoration of the Greater Everglades Ecosystem. The result of the review, known as the Restudy, was the Comprehensive Everglades Restoration Plan (CERP). The National Research Council's (NRC's) Committee on the Restoration of the Greater Everglades Ecosystem (CROGEE) was established in response to requests from the U.S. Department of the Interior and the U.S. Congress to provide advice on scientific aspects of the design and implementation of the restoration plan. The charge to the CROGEE that resulted in this effort is describe in the executive summary. The WRDA of 2000 required an "assessment of ecological indicators and other measures of progress in restoring the natural system," and this report also provides some basis for such an assessment.

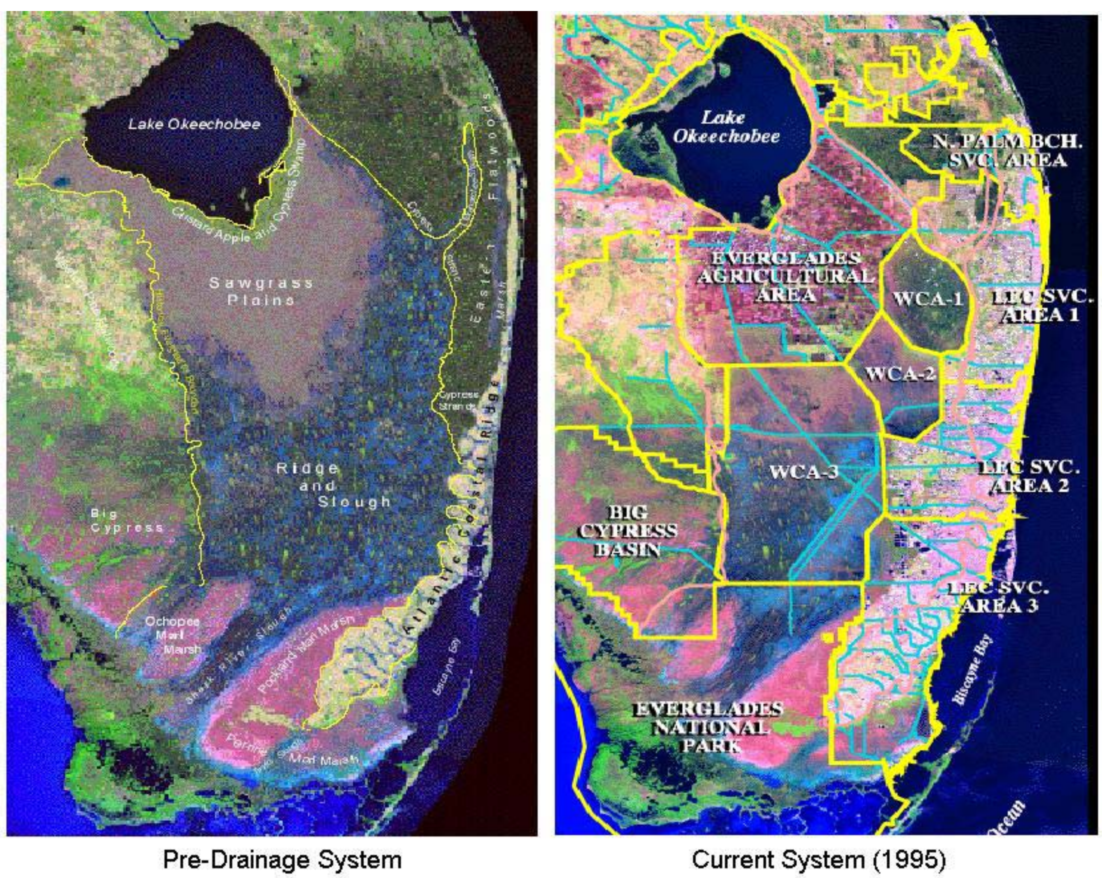


FIGURE 1-2. Historic and current Everglades major features. WCA = Water Conservation Area [1, 2, and 3], LEC SVC. = Lower East Coast Service [Areas 1, 2, and 3]. Source: Adapted from Robert Johnson, Everglades National Park, presentation given to NRC Panel to Review the Critical Ecosystem Studies Initiative, 2002.

THE RESTORATION PLAN

The Comprehensive Everglades Restoration Plan (hereafter referred to as "the Restoration Plan") is the largest restoration effort ever pursued from the standpoint of the size of the ecosystem (28,000 square kilometers) and the number of individual construction/destruction projects (nearly 200). The current Restoration Plan and its individual projects are designed to achieve more natural controls of the half of the Everglades ecosystem that remains after more than a century of extensive human alterations to the ecosystem (Figure 1-1). The broad goals of the Restoration Plan are "to restore the natural hydrology of south Florida, to enhance and recover native habitats and species, and revitalize urban core areas to reduce the outward migration of suburbs and improve the quality of life in core areas" (SFERTF, 1998) (Box 1-1). The plan is led by a federal agency, the U.S. Army Corps of Engineers, and a state agency, the South Florida Water Management District.

As broad an effort as the Restoration Plan is, it is only part of a larger restoration effort involving research by a myriad of federal, state, and local agencies, universities, and native American tribes. The South Florida Ecosystem Restoration Task Force (http://www.sfrestore.org/tf/index.html) is charged with developing the strategic plan that will integrate the projects into a single framework to restore the south Florida ecosystem.

A fundamental premise of the Restoration Plan is that restoring the historical hydrologic regime to the remaining Everglades system will reverse well-documented declines in many native species and biological communities. The cornerstone of the overall effort to restore the ecosystem is to restore the natural hydrology of the ecosystem. The basic strategy of the Restoration Plan is to capture and store freshwater currently discharged to the ocean for use during the dry season; 80 percent of the captured water is to be used for the natural system while 20 percent is for agricultural and urban uses (Central and South Florida Restudy, April 1999). The plan calls for removal of 240 miles of levees and canals and building a network of reservoirs, underground storage wells, and pumping stations that would capture water and redistribute it to replicate natural hydroperiods. To "get the water right"—the mantra of the Restoration Plan—the plan proposes construction of 68 major projects over an estimated 36 years at a cost of $7.8 billion (1999 estimate). These projects are expected to recreate historical quantities, quality, timing, and distribution of water in the natural system while meeting the needs of the built environment (and its people) for freshwater and flood protection. Clearly, getting the water right by this strategy and with these constraints will require that the Everglades continue to be an intensively managed ecosystem even after the projects outlined in the Restoration Plan are complete.

The Restoration Plan was conceived and designed based on extensive monitoring, experimental research, and modeling. However, scientists and managers involved in the restoration recognize that there are very large scientific, engineering and political uncertainties associated with a restoration project of this scope and complexity. In particular, the relationship between the historical hydrologic regime and modern ecosystem composition, structure, and functioning remains somewhat hypothetical given the greatly reduced size and altered proportions and flow ways of the modern system and the degradation of water quality. Exogenous factors such as sea-level rise, continuing human development of southern Florida, the spread of invasive exotic species, and atmospheric mercury deposition may confound the best restoration designs. There is the added uncertainty associated with some of the proposed engineering solutions such as large-scale aquifer storage and recovery, not to mention the uncertainty of project funding over its 30-year plus duration. Some uncertainties can only be resolved by taking action; even without full knowledge of how the ecosystem will respond. Interventions themselves will create change, which can only be understood in retrospect. Comprehension will always lag behind observation.

In the face of these uncertainties and surprises, the ability of the Restoration Plan to achieve its stated restoration goals depends on fully incorporating and maintaining scientific research throughout the restoration program (Box 1-1). In the last decade, science's role in Everglades restoration has been formalized in two main ways. The first of these is the Science Coordination Team or SCT (http://www.sfrestore.org/sct/index.html), which has evolved from the Science Subgroup established in 1993 by the South Florida Ecosystem Restoration Task Force as an interagency science advisory team. The second is called Restoration, Coordination, and Verification, or RECOVER (http://www.evergladesplan.org/pm/recover/recover.cfm), an entity created by the agencies leading the Restoration Plan. RECOVER's goals are to evaluate and assess plan performance, recommend improvements in the plan's design and operational criteria, review the effects of other restoration projects on the plan's performance, and ensure a system-wide perspective. This focus on the Restoration Plan rather than on the broader multi-agency restoration effort makes RECOVER's mandate somewhat narrower than that of the Science Coordination Team.

The Restoration planners, scientists, and managers must develop and promote a culture of healthy skepticism, openness and learning. A well-designed and well-supported program of monitoring and assessment is critically important to this process. Accordingly, the Adaptive Assessment Team (AAT) was created by RECOVER and given lead responsibility to develop a Monitoring and Assessment Plan (MAP) for the project. The AAT has defined monitoring as "the systematic process of collecting and storing data related to particular natural and human systems at some specified locations and times" and assessment as the interpretation of monitoring data "in the context of particular questions and issues." The Restoration Plan is to

BOX 1-1

Goals for the South Florida Restoration Effort

Greater South Florida Restoration Goals. The broad goals are "to restore the natural hydrology of south Florida, to enhance and recover native habitats and species, and revitalize urban core areas to reduce the outward migration of suburbs and improve the quality of life in core areas." (SFERTF, 1998).

Central and South Florida Restudy Goals. The overarching goal of The Restudy was to determine how best to:

- Enhance Ecological Values
  - Increase the total spatial extent of natural areas
  - Improve habitat and functional quality
  - Improve native plant and animal species abundance and diversity
- Enhance Economic Values and Social Well Being
  - Increase availability of fresh water (agricultural/municipal and industrial)
  - Reduce flood damages (agricultural/urban)
  - Provide recreational and navigational opportunities
  - Protect cultural and archeological resources and values (USACE and SFWMD, 2002b).

be implemented in an "adaptive assessment" framework that allows for changes in project design and management based on knowledge provided through synthesis of information that has been collected by a monitoring and assessment program.

The AAT envisions the Monitoring and Assessment Plan as a single, integrated system-wide monitoring and assessment program that will be used to determine if ecosystem response to the Restoration Plan is progressing towards the objective of restoration, preservation and protection of the ecosystem while providing for other water-related needs of the region. Ultimately, the AAT envisions that the final monitoring and assessment plan will consist of five major sections: 1) identification and measurement of ecological indicators, 2) design of the monitoring network (e.g. temporal and spatial scales of measurement), 3) implementation plan for sampling, 4) analysis of the indicators to assess ecosystem response, and 5) research needs in support of the monitoring and assessment. To date, most of the effort of the AAT has focused on ecological performance measures.

COMPREHENSIVE EVERGLADES RESTORATION PLAN GOALS

The overarching goal of the CERP is to "get the water right" by restoring historic hydrologic conditions in the natural ecosystem. The objectives of the CERP are to create historic quantities, quality, timing, and distribution of water in the natural system while at the same time providing fresh water to the built environment and protecting the built environment from flooding.

The CROGEE recognizes that the monitoring and assessment process for the Restoration Plan provides the critical scientific basis for plan evaluation and improvement (mid-course corrections in the lexicon of adaptive management). Together with scientists and staff of the AAT, the CROGEE devoted several meetings to the subject, culminating in an Adaptive Monitoring and Assessment Workshop in November 2001. This report summarizes the perspectives and findings of the CROGEE regarding the Restoration Plan Monitoring and Assessment Plan dated March 29, 2001 and supplemental materials published at http://www.evergladesplan.org/ as of June 1, 2002. The introduction to the Monitoring and Assessment Plan (at http://www.evergladesplan.org/pm/recover/recover.html) is in Appendix E. Because the Monitoring and Assessment Plan is still evolving, this report does not dwell on specific indicators or protocols (the performance indicators in the 2001 version of the plan are provided in Appendix E for information). Instead, it reviews the general approach and design of MAP in order to highlight the major strengths of the program as well as issues of potential concern. As a result, it is likely that some of the recommendations of this report are already being pursued. The CROGEE expects to continue to focus considerable attention on this aspect of the Restoration Plan.

2
The Restoration Plan's Adaptive Management Strategy

ADAPTIVE ASSESSMENT

The adaptive framework for implementation of the Restoration Plan has been referred to in project documents prior to 2002 as "adaptive assessment". Recently, there was a decision to replace this term with "adaptive management" (Appelbaum, 2002), a more commonly-used term. However, this change in terminology does not imply a change in strategy. The following discussion of the strategy includes quotations from project documents that used the "adaptive assessment" terminology. It also provides a brief comparison of "active adaptive management" to "passive adaptive management" or "adaptive assessment" to clarify the type of adaptive strategy that the Restoration Plan will attempt to use.

> "Adaptive assessment is a process for evaluating how well the phases of the Comprehensive Plan achieve their expected objectives, and for using these evaluations as a basis for refining future phases of the program. To be successful, an adaptive assessment process requires that the Comprehensive Plan be implemented iteratively, that a pre-determined set of targets be appropriately monitored, that it be possible to make changes in the design and sequencing of the plan in response to information learned from the monitoring program and from new research and modeling, and that a specific protocol for conducting the adaptive assessment process be in place throughout the life of the program." (USACE and SFWMD, 1999).

The adaptive assessment strategy and monitoring principles for the Restoration Plan are outlined in the Recommended Comprehensive Plan (USACE and SFWMD, 1999) and in a draft white paper dated November 14, 2001 (AAT, 2001). The draft Monitoring and Assessment Plan dated March 29, 2001 describes the performance measures[1] and parameters that will

[1] These are measures specifically chosen by the Restoration Plan to assess ecosystem performance during and after restoration, as opposed to the more general term "indicators."

inform the Restoration Plan adaptive assessment process. These documents, together with miscellaneous reports and several meetings between the CROGEE and Restoration Plan personnel, form the basis for the discussion that follows.

Adaptive management is a general concept that could refer to a broad range of approaches to achieving ecosystem restoration. However, the minimal elements of any truly adaptive management scheme include (1) clear restoration goals and expectations, (2) a sound conceptualization of the system, (3) an effective process for learning from future management actions, and (4) explicit feedback mechanisms for refining and improving management based on the learning process[2]. The extent to which the Restoration Plan will meet the restoration goals and expectations rests in large part on a well-designed framework for creating and supporting these four elements. After a brief comparison of active and passive adaptive management, the Restoration Plan adaptive assessment strategy is examined from these perspectives. Overall, the conceptual planning for the Restoration Plan and the Restoration Coordination, and Verification (RECOVER) process are well grounded in the theory and practice of adaptive management. Likewise, current scientific theory and information, for the most part, have been well applied in formulating a strategy for the Restoration Plan Monitoring and Assessment Plan. Nevertheless, in moving towards implementation, there are some specific actions that can be taken to strengthen the monitoring and assessment program with respect to all four elements of the adaptive assessment process, especially with respect to feedbacks between the monitoring information and decisions concerning the implementation of the Restoration Plan.

TYPES OF ADAPTIVE MANAGEMENT

Walters and Holling (1990) defined three general ways to structure adaptive management: (1) trial-and-error, (2) active adaptive management, and (3) passive adaptive management. According to these authors, the trial-and-error or evolutionary approach (also referred to as disjointed incrementalism by Linblom, 1968) involves haphazard choices early in system management while later choices are made from the subset of choices yielding more desirable results. Active adaptive management strategies use the available data and key interrelationships to construct a range of alternative response models (scenarios) that are used to predict short-term and long-term responses based on small- to large-scale "experiments." The combined results of scenario development and experimentation are used by policymakers to choose among alternative management options to identify the best management strategies. Passive adaptive management is based on historical information that is used to construct a "best guess" conceptual model of the system. The management choices are based on the conceptual model with the assumption that this model is a reliable reflection of the way that the system will respond. Passive adaptive management is based on only one model of the system and monitors and adjusts, while in active adaptive management a variety of alternative hypotheses are proposed, examined experimentally, and the results applied to management decisions.

The restoration strategy outlined in the Restudy abandons the idea of large-scale, management experiments with controls and replicates, opting instead for incremental implementation in which "each incremental step in the plan is viewed as an experiment

[2] Successful application of an adaptive management framework requires more than these four elements (e.g., collaborative working relationships, trust, a champion). These elements assure that the basis for adaptive management has been established; they are thus necessary but not sufficient conditions (Holling, 1978; Walters and Holling, 1990).

accompanied by one or more hypotheses that predict how that step will improve the system" (USACE and SFWMD, 1999). Pre- and post-implementation monitoring will be used to evaluate the effectiveness of that step of the restoration. In environmental impact assessment this approach is referred to as "Intervention Analysis," because no control sites, which are presumed to be unaffected by the manipulation, are identified and monitored. This contrasts with "Before-After, Control Impact Analysis" or "Impact versus Reference Sites" designs that include simultaneous monitoring of control or reference sites (Stewart-Oaten and Bence, 2001). The latter may be especially important when inadequate baseline (pre-project) data are available. A major challenge faced by the Adaptive Assessment Team as it continues to design the MAP will be to maximize the information derived from this type of passive-adaptive approach that builds incrementally on one initial model. It is important to establish experimental controls wherever possible. This includes designing interventions so that their results can be interpreted as if they were controlled experiments.

One of the justifications used for taking the passive approach to the Everglades restoration is that an active approach may be too risky for rare species (e.g., Cape Sable seaside sparrow). A reality of the restoration is that the Endangered Species Act (ESA) prohibits any action that jeopardizes the continued survival of listed species. As a result, this must be a primary consideration in the Restoration Plan's design, implementation, and operation. Still, perceived risk to rare species is one of the most frequent causes of failure of adaptive management programs (Walters, 1997), and the Restoration Plan will be challenged to prevent concerns for rare species from crippling its attempt to manage adaptively. Some mechanisms are available to reduce the severity of such conflicts, such as the multi-species habitat-conservation plans allowed under the 1982 amendments to Section 10 of the Endangered Species Act (NRC 1996a).

Another justification for a passive approach is that it is simpler than an active one because it limits the number of choices available to managers if undesirable ecosystem responses occur at any point in the restoration. However, taking this simple approach at a critical juncture could complicate later management options and hamstring subsequent actions. While limiting management options in a system as complex as the Everglades may be desirable from the management point of view, this lack of flexibility is also a fundamental drawback of the passive adaptive management approach (Walters and Holling, 1990). Another drawback is the inability to attribute any given ecosystem response to a specific causal factor, particularly in large-scale projects like the Everglades where there are multiple stressors or drivers acting on the ecosystem.

RESTORATION GOALS AND TARGETS

> "In its original meaning, and when used with reference to a natural system under anthropogenic stress, 'restoration' means a return to a system that is not under anthropogenic stress. When used in the context of the south Florida wetland system, 'restoration' has come to mean the recovery of sustainable wetland systems at some higher level of ecological health than characterizes the current impacted systems. The broad goal is to recover and sustain the major defining ecological characteristics of the pre-drainage south Florida wetland systems over as large an area of the remaining wetlands as possible" (Ogden et al., 1997).

Science-based restoration will occur only if science is strongly integrated into the decision-making processes that most critically impact the state of the ecosystem. As discussed by Harwell et al. (1999), linking science and decision-making depends on how restoration goals, targets*,* and measures are arrived at and related to one another. Harwell et al. point out that society must define the restoration goals although the goals need to be constrained by scientific knowledge. In addition, scientists should make clear to stakeholders the degree to which achieving restoration goals will require allocation of finite resources. It is then up to scientists and stakeholders to translate those goals into explicit restoration targets*,* that is, the set of observable ecological and societal attributes that characterize the restored system; yet, the uncertainties associated with these attributes must be recognized. Finally, the choice of restoration measures, the actual variables used to evaluate restoration progress, is essentially a scientific problem. Science has the potential to inform ongoing restoration policy and management decisions to the extent that restoration targets and measures actually capture and measure progress towards society's goals and objectives.

As the Restoration Plan was developed, a great deal of analysis and political and scientific judgment were invested in specifying restoration goals, targets, and measures. Perhaps inevitably, building broad stakeholder support for the program has been achieved in part by promoting goals and expectations that may not be entirely achievable or even internally consistent. In particular, the following issues have emerged during discussions with RECOVER personnel and continue to be discussed by the Task Force. Each of these is discussed in more detail in the following subsections.

- Some of the specific restoration goals could be construed to be at odds with the general goal of ecosystem restoration.
- Restoration targets have not been reconciled with overarching forces of change in south Florida, especially population growth, land-use change, and sea-level rise.
- Targets and measures have not yet been defined for the broad goal of achieving compatibility of built and natural systems.
- There appear to be competing visions of what success actually means, in part because there is no agreement on how to define a "healthy" Everglades.

What "restoration" of the Greater Everglades ecosystem consists of is not entirely clear, which makes it difficult for scientists to establish explicit restoration targets and measures. That in turn makes it difficult to develop an effective monitoring and assessment plan and to apply adaptive management. In the absence of clear and agreed-on restoration goals, scientists must use short-term management objectives to set interim targets and measures. Even though the Everglades is a water-driven ecosystem, the goal of "getting the water right" is somewhat ambiguous, and as a strict and only goal, it might be incomplete. It is somewhat ambiguous because it is difficult to know what historical water levels, quality, timing, and distribution were in a system that has been so altered by local, regional, and global human activities. It has the potential to be incomplete because the Everglades ecosystem has a highly variable hydrologic regime that invites over-management to achieve the non-ecological goals of the restoration. Further, focus only on this one factor risks excluding other important factors from considering. Also, because irreversible changes have occurred in the system, historical water levels might not be optimal at all locations for restoration of the remnant Everglades.

RESTORING SPECIES AND HABITATS OR THE ECOSYSTEM?

The South Florida Ecosystem Restoration Task Force (SFERTF) established three strategic restoration goals: (1) get the water right, including both hydrologic regime and water quality; (2) restore, preserve, and protect natural habitats and species, including control of invasive exotic plants; and (3) foster compatibility of the built and natural systems (SFERTF, 2000). The stated goals and objectives of the Central and South Florida Restudy were to:

- Enhance ecological values.
- Improve habitat and functional quality.
- Improve native plant and animal species abundance and diversity.
- Increase the total spatial extent of natural areas.
- Enhance economic values and social well being.
- Increase availability of fresh water (agricultural/municipal & industrial).
- Reduce flood damages (agricultural/urban).
- Provide recreational and navigation opportunities.
- Protect cultural and archeological resources and values.

These goals and their components—four ecological and five societal—were crafted to achieve a broad consensus among disparate stakeholders and the committee does not challenge them. However, there is potential for different interpretations of the ecological goals and a tension between those goals, which refer to natural areas, habitats, and species, and the larger aim of "restoring the Everglades *ecosystem*." Habitat is an organism-specific concept and refers to the set of resources and conditions that allow an organism to occupy an area (Pianka, 1978). Thus, use of the term *habitat* in the restoration goals potentially puts the emphasis on restoration of a place to its former condition as opposed to restoration of desirable ecosystem processes that may or may not produce a return to the historical conditions in that place (Bradshaw, 1996). Similarly, setting goals for communities or species places sole emphasis on biological composition rather than on biological and physico-chemical processes that are associated with restoration of ecological functioning. In this sense, the Restoration Plan goals contrast with restoration goals for the Kissimmee River Project, which were framed in terms of ecological functioning instead of discrete taxonomic components or conditions (Light and Blann, 2001 working draft).

Focusing on habitat and species restoration could impede adaptive, large-scale ecosystem restoration, especially in a setting such as the Everglades where places deemed critical habitats for threatened and endangered species could become locally less suitable for those species during plan implementation. An alternative approach is to aim more broadly for restoration of ecosystem processes at a large spatial scale (Walters, 1997; Cairns, 1988; Bradshaw, 1996). "In a general sense, do not attempt to restore the system (Everglades) to what it supposedly 'was' where it 'was', but attempt to restore critical functions and structures" (Holling et al., 1994).

In establishing restoration targets, the Central and South Florida Restudy Alternative Evaluation Team (AET) defined restoration of the Everglades in a broad conceptual sense that is consistent with Bradshaw's ecosystem restoration viewpoint: (1) low nutrient levels in marshes; (2) healthy plant mosaics; (3) strong food chains at middle trophic levels; (4) viable populations of animals with large spatial requirements; (5) an abundance of certain upper trophic level animals; (6) recovery of endangered species; (7) extensive, low-salinity estuaries;

(8) large spatial extent; and (9) dynamic water storage and sheet flow. These restoration expectations recognize that targets are a temporary set of expectations that will be found wanting, and replaced in time as new understanding of the ecosystem emerges through the process of adaptive assessment. However, the Task Force and RECOVER have also identified and promoted a large number of quite specific targets, for example:

- A 90 percent recovery of the acreage and number of tree islands existing in 1940, and a health index of 0.90 (where 0 = death is imminent, 1 = completely stress free). (Interim target: A 20 percent improvement in the general health index of the tree islands, and no further loss in the total number of tree islands by 2020.)
- Four thousand nesting pairs of wood storks in the Everglades and Big Cypress basins. (Interim target: Fifteen hundred nesting pairs by 2010.)
- Nesting Roseate Spoonbills in the coastal zone of the southwestern Gulf Coast between Lostman's River and the Caloosahatchee River; and 1,000 nesting pairs in Florida Bay, including 250 nesting pairs in northeast Florida Bay.
- A 65-75 percent coverage of Florida Bay with high-quality seagrass beds.
- A long-term commercial harvest of pink shrimp on the Dry Tortugas fishing grounds that equals or exceeds the rate that occurred during the years 1961-1962 to 1982-1983; and an amount of large shrimp in the long-term average catch exceeding 500 pounds per vessel-day (McLean and Ogden, 1999).

By producing a long list of specific targets, RECOVER has attempted to provide both specificity and accountability to the broader restoration goals and also to prominently identify criteria that are meaningful to various stakeholders and the public at large. Restoration Plan scientists recognize that many of the specific targets, which have been set using historical evidence, conceptual models, and dynamic hydrologic and ecological simulation models, are little more than "best guesses" at where, when and how populations and communities will respond to restored hydrologic conditions (Restudy AET, 1998). There is the danger that nonscientists will take these targets too literally and challenge the credibility of the restoration if those specific targets are not met. Furthermore, the way the targets are currently defined does not recognize possible ecological tradeoffs as restoration activities operate to benefit one species to the detriment of another, even though there is evidence that no one management strategy is best for all species (e.g., Curnutt et al., 2000). Finally, it is important that targets not be chosen if it is known in advance that they are unrealistic. Further refinement of the MAP targets will be limited by the lack of broad consensus on what Everglades restoration means, let alone how to achieve those goals.

RECONCILING TARGETS WITH EXTERNAL FORCES OF CHANGE

The Everglades ecosystem is not a closed system. It was an open system in the past and remains one. Its dynamics are driven in part by global processes that affect local weather and climate, introductions of exotic species through foreign trade, and periodic extreme weather events that are at least regional if not hemispheric in origin. Its surrounding environments also are affected by global and regional economic, political, and societal forces. Incorrect assumptions can slowly changing drivers and attributes like topography, climate, atmospheric pollutants, human population dynamics, land use, economic trends (including sugar supports and trade policies), politics, etc., that create problems with monitoring and assessment projects. It is these slowly changing aspects of the system that can be expected to constrain the more rapidly changing elements of the system—the ones most frequently identified as restoration targets. Most of the performance measures identified in the MAP are variables that change on relatively short time scales (e.g., wading bird and alligator population size). Reducing uncertainty associated with the Restoration Plan depends on understanding the constraints imposed by these overarching forces of change on rapidly changing variables.

ACHIEVING COMPATIBILITY OF THE BUILT AND NATURAL SYSTEMS

Until targets and measures are set for defining compatibility of the built and natural systems, the Restoration Plan will not have explicitly and fully addressed possible tradeoffs and conflicts between ecological restoration and other policies, statutes, and social demands. Establishing these targets and measures depends on the ability to conceptualize and make credible forecasts (*scenario analysis* in adaptive-management terminology) of socioeconomic change in south Florida (e.g., population growth and distribution, land use change, changes in water demand, transportation networks). To date restoration planning has been driven by sophisticated hydrologic and ecological models dedicated to describing the internal dynamics of the Everglades ecosystem, either original or remnant. These models treat the social drivers that have produced the current diminished and ecologically degraded state of the Everglades as exogenous variables that will maintain constant or linear trends over the next half-century. For example, in the Restudy, the population of the lower east coast of Florida is assumed to increase by 72 percent by 2050 and the number of residents in the 16-county study area to increase from 6.3 to 11 million people. Leaving aside for the moment that this estimate might not be appropriate over the long run, or even now, it appears that the Restudy used a "future without plan" scenario for the human system, assuming that the Restoration Plan would not appreciably influence the future number or distribution of people and anthropogenic ecological stressors in south Florida. This approach is not scientifically credible. Experience in south Florida demonstrates the importance of scenario analysis. The Central and South Florida project required major modifications as conditions and assumptions changed[3] based on population dynamics, climate change, etc. (Light and Dineen, 1994; Light et al., 1995).

Conceptually separating the future dynamics of natural and human systems decouples the biophysical driving forces of the Everglades and its restoration from the dynamics of human habitability. To date, the difficult task of analyzing to what degree the built and natural systems are compatible has not been undertaken. Ultimately, demographic and economic dynamics will need to be brought into restoration planning and implementation to better anticipate, monitor and respond to the effects of the restoration on social and political systems, and vice versa.

[3] For example, at first the Central and South Florida system was not constructed to deliver water to the Everglades National Park. Then the assumption was made that monthly allocations were sufficient. Finally, in 1980 the drought of record exceeded design specifications and expectations.

DEFINING "ECOLOGICAL HEALTH" FOR THE EVERGLADES ECOSYSTEM

The Restoration Plan's Adaptive Assessment Team (AAT) is developing a monitoring program based on a standardized set of monitoring and data-management protocols over spatial and temporal scales that are relevant to the Restoration Plan implementation schedule and to ecosystem responses. A challenge of defining those protocols is that neither current ecosystem conditions nor those that predated the Restoration Plan are well understood. The restoration is currently defined by a list of more than 100 hydrologic and ecological interim targets, as there is general agreement by scientists that the Everglades restoration should be thought of as an open-ended process (e.g., Davis and Ogden, 1994). It is within this context that scientists are striving to develop the MAP.

What is lacking is agreement about which of these ecosystem features should receive the highest priority and the extent to which these features can be restored. The most immediate hurdle facing the AAT in development of the monitoring program is defining "ecological health" of the Everglades. What are the attributes of a "healthy" Everglades? The "health" of an ecosystem is not definable scientifically (e.g., NRC, 2000), and so the choices are to identify biological parameters as goals or to use societal values. Whatever the approach, the goals must be measurable and identifiable so that it is possible to determine whether they have been achieved or not. A focus on improving specific aspects of ecological functioning seems likely to be useful and also to help integrating biological parameters with societal values.

Without definable goals or targets, it will be extremely difficult to select appropriate indicators and the performance measures needed to monitor progress towards those targets. That is, it is impossible to measure ecological recovery if ecological recovery is not clearly defined. Simply selecting variables to measure because they are likely to respond to altered hydroperiod is not a good basis for choosing a performance measure unless the objective is to demonstrate that the system will change as a result of altered hydroperiod and thus management is a "success". Even the language of the South Florida Ecosystem Restoration Task Force's documents shows a predisposition to reporting success, as for example, "success in the making" and "coordinating success." An emphasis on "success" should not influence the selection of one type of performance measure over others.

RESTORATION REFERENCE STATE

> "Baseline information provides the benchmark against which the progress of the restoration plan can be measured, and to understand the ranges of natural variability necessary to confirm when change has actually occurred. While some regions of the Everglades ecosystem have well-established monitoring programs, other areas have little or no baseline data. Plugging the gaps in baseline conditions is one of the critical components of the monitoring and assessment plan." (USACE and SFWMD, 2001a)

The committee defines the restoration "baseline" for the Restoration Plan broadly to include not only the record of observational data, but also the current state of understanding. That understanding includes conceptual and simulation models that have been used to define two "pre-Restoration Plan" reference states: the "pre-drainage" and "post-drainage, pre-Restoration Plan" Greater Everglades Ecosystem. The reference states provide the basis for assessing the magnitude and desirability of system responses to the Restoration Plan (NRC, 2000). The Restoration Plan design is supported by a large body of scientific research, but the general question "What is the ecological reference state for the Restoration Plan?" remains unresolved.

There is no simple answer to this question. The Everglades System has changed and will continue to change due to long-term variations in climate and sea level even with no further direct human impacts or restoration attempts. These forces and factors such as regional land-use change, pollution from remote sources, and invasive exotic species, will exert continuing effects on the system. Furthermore, the current system is still adjusting to recent historical changes in drainage and water quality (e.g., nutrient cycling, extent and distribution of tree islands) and one would expect significant lags in the system's response to the proposed modifications in hydrologic regime and water quality. Given these dynamics, what constitutes the restoration reference condition trends and variability for the Restoration Plan? What period of record is appropriate for specific targets and measures? What quality standards will be applied to select the data used to quantify the restoration reference state?

Scientists associated with the restoration have sought to define reference conditions using a mix of modeling and empirical studies. Despite considerable progress there is a great need for continued research to better conceptualize and describe the reference state, research that goes well beyond performance monitoring. This is not to say that the Restoration Plan should not proceed without a better-defined conceptualization of the restoration reference state, but only to point out that the adaptive assessment strategy should include monitoring in support of improved "baseline" data and model outputs as well as hypothesis-driven research to validate the underlying cause–effect relationships identified in the MAP conceptual models.

The reference state for the pre-drainage Everglades has been reconstructed from paleoecological information and historical observations along with extensive use of the Natural Systems Model (NSM). The uncertainties associated with the use of the NSM are relatively well known, notably those related to specification of pre-drainage topography, patterns of precipitation and evapotranspiration, and surface roughness as well as the artifacts of the discrete space and time in the numerical model (Bales et al., 1997). Reviewers of the model have cautioned that in its current form the NSM can only indicate broad regional patterns of inundation over time as opposed to local discharges and flows. Despite these limitations, spatial hydrologic patterns predicted by the NSM have played a significant role in setting spatially explicit reference conditions for the Restoration Plan.

The Restoration Plan has used both NSM and complex simulation models like the Across Trophic Level System Simulation (ATLSS) model (http://atlss.org) and the Everglades Landscape Model (ELM; http://www.sfwmd.gov/org/wrp/elm) to represent current understanding of the relationship between the hydrologic and ecologic variables of the historical Everglades system, to describe pre-restoration conditions of most ecological targets, and (in conjunction with the South Florida Water Management Model) to compare the ecological benefits of restoration alternatives. Although they are advanced and important restoration tools, ATLSS and ELM are still unreliable for establishing reference conditions and for forecasting outcomes of the restoration because of the complexity of the ecosystem. (For example, hydrologic data alone predict patterns of fish abundance at least as well as ATLSS does (J. Trexler, Florida International University, personal communication, 2001).

Given the incomplete historical evidence, imperfections of the NSM, and the severe limitations of current ecological data and models, there is a healthy scientific debate over definition of the pre-drainage hydrologic and ecological reference conditions for the Restoration Plan. Some reference conditions, such as the historical vegetation, water quality and ecosystem processes in what is now the Everglades Agricultural Area and the relationship of that area to the rest of the system, must remain somewhat speculative. Some responses of the biota in the current highly modified system might not accurately represent the way they would have responded to changes in the pre-drainage system. However, other scientific issues of critical importance to understanding ecosystem response to the Restoration Plan are more tractable. They include the following:

- Improving the resolution and accuracy of hydrologic model input data (e.g., surface topography and evapotranspiration parameters).
- Improving ecological model specifications for species and community ecological requirements and functional relationships to hydrologic regimes and water quality.
- Conducting empirical and modeling analyses to evaluate the importance of extreme events and variability as opposed to the mean and range of annual conditions in climate, hydrologic regimes and associated disturbance processes such as flooding and fire in maintaining the ecological characteristics of the Everglades.
- Investigations of hydrologic linkages between surface water storage and flows and near-surface groundwater flows and seepage processes.
- Research to determine the relative importance of water velocity versus hydroperiod in controlling plant and animal communities.
- Analysis of trends in key hydrologic and ecological variables due to recent climate change and modern sea level rise.
- Understanding the role of modern fragmentation of wetland and surrounding upland habitats on the ability to achieve desired conditions.
- Investigation of contaminant accumulation and transformation in soils/sediments and mobilization, and especially their effects on the biota.
- Research to better integrate social system dynamics into the conceptual and simulation models used for adaptive assessment (discussed in more detail in the next section).

CONCEPTUALIZING THE HUMAN DYNAMICS OF THE EVERGLADES RESTORATION

As discussed in the section on the Restoration Plan's Goals and Targets, human dynamics were treated relatively simplistically in the Restudy as exogenous to and uncoupled from the Restoration Plan. Despite recommendations from social scientists for alternative approaches (e.g., Harwell et al., 1999), this view has also pervaded the reference state conceptualization of the Everglades Ecosystem as represented in both simulation models and conceptual models that have been used to set targets and choose performance measures. Two questions are raised by this approach. The first is how robust the Restoration Plan is to alternative scenarios of human dynamics in and around the Greater Everglades Ecosystem. The second is whether there is any possibility for strong feedbacks between implementation of the Restoration Plan and social dynamics that could significantly impact the ability to achieve the restoration goals.

Future population growth and its distribution in the Restudy are based on current conditions and on the recent past, with assumptions that recent trends will continue. Much of the information is derived from local comprehensive planning documents. However, it is clear from the demographic and sociological analyses that the major social drivers such as population change, urban growth, agriculture, long-term change in economic activity, and tourism have changed through time in ways that defy simple extrapolation (Solecki et al., 1999). How robust is the Restoration Plan to alternative scenarios of these exogenous drivers?

For example, one could make a general case that land uses and other human activities are likely to change a great deal between now and the year 2050, if not sooner, based on very reasonable assumptions about physical factors (e.g., soil subsidence, peat loss and climate change) and socioeconomic factors (e.g., changes in the price and costs of production of sugar, citrus, winter vegetables, and cattle; the relative prices of land for other uses; competing hydrologic demands from both the natural system and the built environment; changes in political systems; or changes in societal values), all of which could profoundly influence the way humans interact with the Everglades, with or without the Restoration Plan.

Social dynamics will likely interact with other exogenous drivers, like an accelerated rate of sea-level rise or increasing frequency of extreme weather events, that have been predicted to occur with ongoing global climate change. Such changes could create differential pressures on flood control, human fresh water demand, and water requirements for the coastal estuaries. These kinds of considerations lead us to conclude that the human dynamics of Everglades restoration require greater research, modeling and monitoring. This need has been recognized by social scientists involved in the restoration and is specifically addressed in the Restoration Plan Environmental and Economic Equity Program Management Plan (USACE and SFWMD, 2001b), which contains specific objectives for establishing socioeconomic and environmental justice baseline data (including alternative scenarios). That plan also calls for improved social-science research.

In addressing the Restoration Plan's objectives, then, those responsible for designing a monitoring and assessment program should consider the degree to which the following general issues are important.

- What are the critical human forces driving or affecting restoration? For example, how might changes in the size and distribution of human populations in south Florida affect restoration?
- To what extent can science and modeling examine the alternative restoration scenarios proposed in the Environmental and Economic Equity Program Management Plan?
- What social dynamics of importance are outside the management boundary? How should these be analyzed and modeled? For example, how should the Restoration Plan model and analyze such externally influenced factors as the price of agricultural commodities and energy, even though they cannot currently be predicted accurately?

LEARNING THROUGH INTEGRATED MONITORING, MODELING, AND EXPERIMENTAL RESEARCH

Learning is a critical part of adaptive management; if the agencies and scientists involved in the Restoration Plan emphasize adaptive management and assessment as a learning vehicle for the restoration efforts, the restoration is likely to be more effective than it would otherwise be. The learning process that will guide the "adaptive implementation" of the Restoration Plan will depend on a research strategy that effectively combines monitoring, modeling, and experimental research, with a high level of attention to information management, data synthesis and periodic re-synthesis of information throughout the implementation and operation of the Restoration Plan. As with any long-term environmental project, but especially one committed to an adaptive approach, learning depends on the continuity of adequate funding. This is a major concern given that the time frame for restoration is 40 years for the restoration projects' designs implementation and more than a century for the ecosystem to respond fully. Most of the monitoring and research being done in the Greater Everglades Ecosystem is funded independently of the Restoration Plan by federal and state agencies (e.g., National Park Service, Environmental Protection Agency, National Oceanic and Atmospheric Administration, National Science Foundation, South Florida Water Management District) and this situation is likely to continue during CERP implementation. The RECOVER will obviously need to take maximal advantage of non- Restoration Plan programs. Nevertheless, overall design and funding of the MAP should include adequate and continued support of core, long-term monitoring and experimental studies throughout the restoration.

The National Research Council (1999) recommended three tools for embedding learning into long-term restoration projects like the Restoration Plan: integrated assessment models, long-range development scenarios, and a regional information synthesis system.

Integrated assessment models include information about the natural biophysical environment as well as an evolving understanding of how the environmental-society system works. Thus they help to define problems and inform the policy process. Like all models, they also can reveal uncertainties in our understanding and evaluate the potential implications of these uncertainties for decisions; they are good at identifying key research needs. The MAP's conceptual ecological models provide a framework for developing simulation models that could be used as for integrated assessment. As integrated assessment models, the simulation models have the potential to help in interpreting ecosystem responses to the south Florida restoration projects and guide adaptive management. Such assessment will be especially valuable if they focus on dynamics across time and space scales and conceptual integration of physical, chemical, and biological processes.

Long-range development scenarios are not predictions of the future or mere projections from the present. Rather, they are alternative long-range visions of how the system could change given what is known about trends, desires, uncertainties and possible surprises and they describe the pathways by which conditions might change. They allow for the testing of assumptions about many environmental and social drivers and they help to reveal the range of possible futures that should be contemplated. For example, in the south Florida restoration, development and population growth will continue to affect the environment in many ways, and long-range scenarios can help to bracket a range of possible outcomes, preparing the restoration planners for unforeseen changes. Given an unknown future and the long-term commitment to the Greater Everglades Ecosystem restoration, long-term development scenarios should be a central component of adaptive management.

Synthesis is the process of accumulating, interpreting, and articulating scientific results to increase understanding. Regional synthesis is required to bring scientific knowledge into the Restoration Plan's adaptive management program. Synthesis also contributes to negotiation and conflict resolution, so that learning can continue as construction and implementation proceed. A recent National Research Council report (NRC, 2003) pointed out that strong synthesis and management of information is essential to make it possible to learn from interactions among restoration projects and across the whole ecosystem, and to enable managers to adapt to new information, correct mistake, and reduce waste of money. Synthesis also reveals risks and uncertainties so that resiliency can be incorporated into restoration plans. The NRC committee concluded that "Synthesis is essential to the Greater Everglades restoration as it will enable ongoing learning when change is common and uncertainty is high."

In support of scenario development, it is crucial that ecosystem drivers be monitored. The focus should be on system drivers that have long-term excursions from average (weather cycles) or trends (sea-level change) (see next section). This is necessary because system response times may be quite different than anticipated when the ecological models used in the Restoration Plan were developed. Furthermore, to understand the ecosystem's response to the Restoration Plan, it will be critical to monitor changes in anthropogenic drivers because of the strong confounding interaction they may have on the hydrologic and ecological indicators. Many of the socioeconomic factors are likely to be monitored at some level by city, county, and state agencies, and it is important to have a strategy for inclusion of these data in the overall ecological monitoring plan. Inclusion of the socioeconomic stressors as important variables in the conceptual models indicates the importance of these stressors to the ecosystem.

The value of the monitoring and assessment process for the restoration does not depend solely on an effective Monitoring and Assessment Plan. It depends also on the ability implement lessons from the plan. The challenge will be to ensure that scientific information generated by monitoring and assessment is effectively communicated to stakeholders so that it can be integrated into management and policy decisions. It seems likely that such information will include the lesson that a successful restoration of the Greater Everglades ecosystem—however "success" is defined—will need to include consideration of the larger context of regional environmental and societal factors as well as careful management of structures and biota within the ecosystem itself.

MONITORING IN SUPPORT OF ADAPTIVE MANAGEMENT

The ultimate goal of restoration monitoring is to provide the information necessary to answer specific management objectives. In the case of the Restoration Plan, water (quantity, quality, and timing) will be managed to produce a desired ecosystem response. An adaptive management approach like that envisioned for the Restoration Plan depends on a robust monitoring program, an efficient data-storage and retrieval system, and synthesis of the monitoring information to provide the scientific knowledge needed for informed management decisions.

The monitoring plan for the Restoration Plan should be designed with the following three distinct information needs in mind:

- Measuring progress towards meeting the restoration targets,
- Reducing scientific uncertainty should be reduced, and
- Providing information for specific management options and decisions.

In selecting performance measures for the MAP, the Adaptive Assessment Team has not clearly distinguished which specific information need is being met. Measuring progress towards stated restoration targets is clearly specified by the nature of the targets. If the target is to produce "four thousand nesting pairs of wood storks in the Everglades National Park and Big Cypress basins," then the performance measure is obvious. However, reducing scientific uncertainty about the relationship between hydrologic regime and wood-stork population dynamics in those areas presumably will require observation, experimentation, and modeling of hypothesis-based hydrologic and ecological variables at several scales. The water-management problem of actually achieving the desired distribution and timing of water to benefit wood storks in the park and Big Cypress Basin may require yet another kind of learning to tune the operation of the water-delivery system (e.g., a denser network of water-level and precipitation gauges).

The March 29, 2001 version of the MAP describes the basis for selection of the variables or performance measures that will be required to assess hydrologic conditions in the ecosystem and the ecosystem response to hydrologic conditions. Two aspects of the monitoring plan will need to be addressed in the future: 1) spatial and temporal distribution of the performance measure sampling effort and 2) integration of monitoring supported by the Restoration Plan with ongoing long-term monitoring conducted by groups like South Florida Water Management District, U.S. Environmental Protection Agency, U.S. Geological Survey, National Park Service, university projects (e.g., Florida Coastal Long Term Ecological Research (LTER) project), the Tribes, and private organizations (e.g., The Audubon Society).

The March 29 version of the MAP list of 156 performance measures—including hydrologic, soil, water-quality, and ecological performance measures—have not yet been integrated into a coherent monitoring plan. Rather, the list of performance measures is held together only very loosely by regional conceptual models. True ecological indicators of Greater Everglades ecosystem functioning (see NRC 2000) have not been developed. However, efforts to integrate the performance measures into five categories called functional groups by the Restoration Plan (wetland trophic relationships, wetland landscape patterns, estuarine epibenthic communities and habitats, Lake Okeechobee pelagic and littoral zones, and biota of special concern) were ongoing when this report was written. Comments specific to the hydrologic and ecological performance measures are discussed in following sections.

Hydrologic Performance Measures

The basic premise common to the wide variety of published restoration goals is that water management to mimic pre-drainage hydrologic conditions can provide sustainability of the human system and improvement in the ecological "health" of the natural system. This hypothesis led to development of the South Florida Water Management Model and Natural System Model used to design the Restoration Plan. Many of the 78 hydrologic performance measures included in the MAP are essential variables to understanding the spatial and temporal distribution of water in the natural system and water supply to the human system. These measures are being updated; for the latest version of them, please see the RECOVER web site for a draft report: http://www.sfwmd.gov/org/ema/everglades/consolidated_03/ecr2003draft/ (as of February 2003). Other hydrologic performance measures included in the MAP are important water quality measures.

Originally, the list of hydrologic performance measures included approximately 900 hydrologic and water-quality performance measures. These measures were developed by the Restudy Alternative Evaluation Team to evaluate alternative plans for achieving the water management targets set out in 1998/1999 during the Central and South Florida Restudy process. This number was reduced to 24 hydrologic and 54 water-quality performance measures by the time the MAP workshop was held. These 78 measures will be used to monitor water management as restoration proceeds and will provide information about water levels, water flow, duration of flooding, and water quality (especially P and less frequently N). The hydrologic performance measures are not response variables in the same sense as the ecological performance measures and "functional groups." Rather, they are measures of factors identified as stressors in the regional conceptual models. Although socioeconomic drivers are prominent in all of the conceptual models, only the hydrologic stressors are included in the current list of performance measures.

The hydrologic performance measures were largely developed for the purpose of designing the Restoration Plan. In this context they were very effective. However, their use in future applications, such as refinement of the Restoration Plan's design and adaptive assessment, would benefit from some adaptations.

One limitation of the current hydrologic performance measures derives from the fact that their use in designing the Restoration Plan is a very different exercise than their use in adaptive assessment. In the former, the measures are applied to the results of multi-year model simulations of the performance of alternative formulations. Each simulation is based on a single sample of the relevant hydrologic variables under the assumption that a particular formulation has been completely executed. Adaptive assessment is a much more difficult problem. To be effective for adaptive assessment, measures must provide information early enough to allow for corrective action. But the present measures will be of limited value when applied in the first decades of the Restoration Plan, largely because many critical features of the CERP will not have been implemented. Even after the Restoration Plan has been completed, observed measures will be confounded by temporal variability in water flows and levels due to climatic variability. For example, it may take many years before there are climatic conditions that provide opportunities to test measures involving maximum and minimum limits, such as limits on water levels in Lake Okeechobee. Furthermore, the value of the "test" will depend on the severity of the conditions. For measures depending on mean values of hydrologic variables, such as the duration of flood conditions, their variability will limit their usefulness for many years.

Another limitation of the current hydrologic performance measures is that they cannot be aggregated to provide an overall measure of system performance. This is because they do not quantify the "damage" associated with failure to meet the targets on which they are based. An aggregate measure was not required in the initial Restoration Plan design, apparently because the design was based on the assumption that all objectives would be met. However, future decisions on the design may require compromises in the face of budget limitations and ecological realities; an aggregate measure would enable such compromises to be effected in a consistent and efficient manner.

Fortunately, these limitations can be readily addressed. The hydrologic model can be used in such a way that observed climate and the status of the Restoration Plan implementation are used as input for it. This would be most useful for adaptive assessment. Furthermore, hydrologic model outputs can be the attributes of ecological habitat suitability functions for selected ecological indicators. Composite values of these time series of habitat-suitability-index values can serve as surrogate indicators of "damage" functions, indicating the relative benefit or loss associated with water management outcomes. These can be compared to previous values to enable the development of an aggregate performance measure. Such a measure would enable refinement of the Restoration Plan design based on multi-year simulations (Tarboton et al., 2003).

Hydrologic modeling can be used readily to account for the dynamic elements of the restoration, such as climatic variability and implementation. As various features of the Restoration Plan are implemented, the model could be modified accordingly. On an annual basis the evolving model could be used to simulate the system based on the observed meteorological conditions. Hydrologic performance measures could be computed from the simulation results, and compared to performance measures computed from actual field data. For each measure, error analysis could be used to evaluate the significance of the observed difference between the two values. Significant differences could trigger studies to determine their causes, such as errors in model input, parameters, or structure. These errors could involve the natural system, such as estimation of flow resistance, or the engineered system, such as components of the Restoration Plan. In any case, periodic comparisons of predicted and actual hydrologic variables would enable continual improvement of the hydrologic model.

ECOLOGICAL PERFORMANCE MEASURES

Conceptual Models for the Restoration Plan

Conceptual models of each of the Greater Everglades Ecosystem's nine major physiographic regions in south Florida (e.g., ridge and slough, marl prairies) are the basis of the Restoration Plan ecological monitoring program. The March 29, 2001 Monitoring and Assessment Plan lacks system-wide performance measures (see Appendix E for lists of the performance measures as of that time).[4] Thus, these broad-scale measures are not evaluated in this report. However, suggestions are provided about a useful approach for developing such a set of measures. Since the November 2001 monitoring and assessment workshop, some progress has been made towards development of a system-wide conceptual model that will be the basis for incorporating system-level performance measures into the Restoration Plan's Monitoring and Assessment Plan.

The conceptual models were intended to offer a non-quantitative conceptualization of the causal linkages between ecosystem drivers and attributes of the physiographic regions. These models differentiate variables hierarchically into "drivers", "stressors", "ecological effects", "attributes", and "performance measures" (USACE and SFWMD, 2001a). The drivers represent the major external forces that have large-scale (spatial and temporal) impacts on the natural system, such as climate change or sea-level rise. Stressors are physical or chemical changes to the natural system that are caused by the drivers, which ultimately lead to biological and ecological effects. Attributes and performance measures represent known effects of the stressors and are features that can be monitored to determine progress towards restoration goals and objectives (e.g., number of nesting wading birds). It is the attributes and measures of the conceptual models that form the basis of the monitoring program and are described as ecological performance measures. Some of the attributes and measures have characteristics of ecological indicators--measures of ecological condition, ecosystem functioning, or ecological capital—as described by the NRC (2000). A specific example would be extent of plant cover. Other attributes and measures do not measure ecological condition, such as phosphorus concentration.

Development of the conceptual models began in 1996 (Ogden et al., 1997) and the models were refined in the summer of 1999 during meetings among experts working in each of the Everglades subsystems (i.e., the conceptual model teams) during workshops held in summer 1999 (see RECOVER AAT homepage, http://www.evergladesplan.org/??/recover/aat/cfm).

---

[4] A total system conceptual model was completed in 2003, and will be used as a basis for developing system-wide performance measures.

These conceptual models and the 150+ ecological performance measures that were derived from the models were the focus of the July 6-7, 2000 CROGEE meeting.

Further refinement of the ecological performance measures occurred during the summer of 2000, when each conceptual model team reviewed the model it had produced during the previous summer. As part of the reevaluation, the teams were asked to refine and rank the performance measures to (1) produce a relevant, practical, and parsimonious set of performance measures that would indicate the ecological health and recovery of their region, and (2) specify parameters and locations for monitoring the performance measures. They were also asked to identify, for each performance measure, experts to write a 1-2 page document describing uncertainties behind the performance measure and their impact on understanding the results of the restoration monitoring program. Additionally, each team was asked to identify research that would be essential for interpretation of the changes in the performance measures. Based on the summer 2000 workshops and the 1-2 page performance measure documents, the AAT reevaluated the ecological performance measures and produced the draft (March 29, 2001) of the MAP reviewed at the MAP workshop. This draft includes 61 performance measures distributed among the five "functional groups" (i.e., wetland trophic relationships, wetland landscape patterns, estuarine epibenthic communities and habitats, Lake Okeechobee pelagic and littoral zones, and biota of special concern).

The conceptual models are not simulation models of the subsystems. Rather, they were an exercise designed as a first step in designing the monitoring program. These models are based on a "best guess" about how the major Greater Everglades Ecosystem physiographic regions function. They are crucial to identifying gaps in knowledge that might impact design of a monitoring program and are important tools for synthesis and integration of scientific information into the adaptive management process. The ecological performance measures included those attributes of the physiographic regions that the conceptual model teams judge to be the most likely to respond to the proposed water management scheme described in the Restoration Plan.

Assessment of Conceptual Models and Ecological Performance Measures

Given the incomplete characterization of pre-drainage conditions of the Greater Everglades Ecosystem, the Adaptive Assessment Team has no alternative but to develop a monitoring plan based on indicators that will provide an assessment of the current status of the ecosystem. As the Restoration Plan is implemented, this reference condition will be used to assess the trajectories of populations (e.g., organisms of special concern including threatened, endangered, and invasive species), communities (e.g., tree islands), and ecosystem processes (e.g., net primary productivity, formation of soil organic matter). This type of hierarchical approach will provide a relatively comprehensive evaluation of the system's ecological response to restoration projects and changing environmental conditions (e.g., sea level rise, climate change). The difficulty facing the Adaptive Assessment Team is selecting appropriate, practical, and informative performance measures. If they are well chosen, they should also provide a context or framework for refining the series of conceptual models that are currently the basis of the monitoring plan. In turn, as the conceptual models are refined they should provide a context or framework for choosing and interpreting more specific performance measures.

The process of documentation of the uncertainties associated with each of the performance measures is ongoing and will be essential to decisions about the usefulness of each measure. Even with this documentation, the choice of performance measures may be difficult because many of the regions covered by the conceptual models currently are not well understood. While the conceptual models are useful tools for identification of ecological performance measures, these models do not provide insight into the temporal or spatial sensitivity of the measure's response to altered hydroperiod. How can data on performance measures and the associated variation be used in combination with mechanistic models to insure that performance measures are monitored at appropriate temporal and spatial scales?

Most of the ecological performance measures currently under consideration are area and species- or community-specific. A few system-wide measures are currently included in the MAP's list of potential ecological performance measures, but these focus primarily on endangered or threatened species to the exclusion of ecosystem functioning. The current monitoring plan would benefit from a few ecosystem-level, system-wide indicators (as opposed to performance measures). The NRC (2000) proposed a suite of such indicators that were intended for national-scale assessment but also are applicable to regions like the Everglades. That report recommended indicators that would help assess the extent and status of an ecosystem type, ecological capital, and ecological functioning or performance. Indicators such as land cover and land use that have powerful influences on landscapes and adjacent ecosystems can be used to define the extent and status of an ecosystem (or subsystem type). Indicators of ecological capital include total species diversity, native species diversity, nutrient runoff, and soil organic matter. Such whole-system indicators could also be usefully applied to the Greater Everglades Ecosystem. The MAP should consider monitoring spatiotemporal patterns of total species diversity as well as of native species diversity. Additionally, given that the Restoration Plan is focused on a well-defined ecosystem an Index of Biotic Integrity-like measure (Karr and Chu, 1999; NRC, 1994; NRC, 2000) would be appropriate and useful. The purpose of such a measure would be to provide a "multimetric" that would integrate several key indicators to represent the changing status of the Greater Everglades Ecosystem.

Indicators also are needed to provide information about ecosystem functioning in a broad sense and to provide information about the ecosystem's capacity to respond to changes. They should include indicators of production capacity, such as total chlorophyll per unit area (or in aquatic regions, chlorophyll per unit volume). Carbon storage, particularly in wetlands, as indicated by sediment organic matter, is also informative about ecosystem functioning. Indicators of nutrient balance would provide information about environmental loading of nutrients to the ecosystem.

Remote sensing using today's operational systems provides relatively inexpensive and consistent estimates of several key ecosystem parameters that are common to all subsystems. Digital aerial photography and Landsat Thematic Mapper (TM) imagery have already proven useful in mapping and monitoring plant communities, land use and land cover (Doren et al., 1999). Vegetation classification can, however, be complicated by factors such as water depth or color, effects of fire, periphylon species composition, and growth morphology within a single species (Rutchey and Vilcheck, 1999).

NASA's suite of Earth Observing System sensors offers greatly expanded abilities for synoptic monitoring. For example, the MODIS (the Moderate Resolution Imaging Spectrometer) sensor provides an excellent opportunity for synoptic monitoring of land use/land cover, surface reflectance, spectral vegetation indices such as the Normalized Difference Vegetation Index (NDVI), the absorbed fraction of photosynthetically active radiation (FPAR), leaf area index (LAI), net primary productivity (NPP), and land surface temperature. The MODIS instrument acquires image data in 36 spectral bands at spatial resolutions from 250 m to 1 km over the entire globe every two days. A series of standard land products are being produced from these data by the MODIS Land Discipline Group (MODLand). Several NSF Long Term Ecological Research (LTER) sites are involved in coordinated field research and monitoring efforts to validate standard MODIS products (e.g., Lefsky, 2001). The Restoration Plan, in collaboration with the newly established Florida Coastal Everglades LTER, could serve a similar role for the Greater Everglades Ecosystem.

The higher-resolution data provided by IKONOS satellite imagery is presently being evaluated for use in mapping Everglades vegetation, especially invasive exotic plants, using the spectral reflectance characteristics of various vegetation species. These results are being compared to those using aerial photography. Information on this can be found on: http://www.sfwmd.gov/org/wrp/wrp_evg/projects/ikonos_satellite.html.

Synthetic Aperture Radar (SAR) imagery and radar altimetry may provide a means for system wide monitoring of water level and inundation patterns. For example, Alsdorf et al. (2000) have demonstrated that interferometric processing of SAR phase data can be used to infer stage changes of less than 0.1 m in Amazon floodplains, and a similar approach may be feasible over much of the Everglades. (This technique has been tested in the Everglades by Kasischke and Bourgeau-Chavez, 1997).

Although remote sensing is a valuable tool for monitoring, it does not eliminate the need for ground-based monitoring (NRC, 2000). Rather, these two approaches are complementary. A well-designed ground-based monitoring and experimental plan should provide the process information necessary to interpret remotely sensed instantaneous information about ecosystem condition and to provide the resolution needed to detect and characterize changes in ecosystem heterogeneity.

Indicators of populations and ecosystem functioning sensitive to the restoration efforts need to be identified. Based on the workshop discussions, it is clear that the Adaptive Assessment Team recognizes the importance of selecting meaningful ecological indicators of populations, communities, and ecosystem functioning. Additionally, it is clear that the restoration effort will be considered a success only if the effects of altering water hydroperiod result in measurable improvement of the "ecological health" of the Everglades.

Setting Monitoring Priorities

Strategies are necessary for prioritizing the importance of the ecological performance measures. Given that the resources available for monitoring are limited, are there measures that are more important to monitor than others? In the ideal monitoring program, all aspects of community structure and ecosystem functioning would be monitored. However, because it is unrealistic to measure everything everywhere—let alone interpret all the data that would result—ecological/biological performance measures are the only practical way to inform us about the status of the ecosystem and/or the response of the system to changing conditions.

The working hypotheses associated with the conceptual models of ecosystem functioning have been ranked as low-moderate-high certainty based on whether or not the hypotheses are supported by published, peer-reviewed quantitative relationships or predictive models versus best professional judgment. This is useful in understanding the amount of science supporting the conceptual models, but it is less useful for understanding the relative importance/relevance of particular hypotheses and ecosystem dynamics. Additionally, a goal of the monitoring program is to determine the progress of the Restoration Plan towards meeting the restoration goals and objectives. Therefore, it is critical that the Monitoring and Assessment Plan identify the guidelines for deciding how funding priorities will be established for the monitoring effort. It also is important to consider how often a measure needs to be taken and at what season or seasons might be most informative. Characteristics of the measures that should be considered in setting these priorities include the following:

- relevance to restoration goals,
- sensitivity to the Restoration Plan's design and operation; "normal" variation is known,
- potential to help identify knowledge gaps that are most critical to the largest number of future projects,
- relevance to predictive models, and
- importance to stakeholders.

EXPERIMENTAL RESEARCH AND MODELING

Experimentation must be a critical component of monitoring and assessment to improve understanding of cause-effect relationships. Thus, experimentation is needed for adaptive assessment to be an effective management tool. Monitoring is not enough; there is a need to understand processes, mechanisms, and inventories and use this information to construct mechanistic models. The Monitoring and Assessment Plan should seek to create a proper balance between modeling, monitoring, and experimentation. Each effort should support the others. All three are cornerstones of adaptive assessment.

The key to addressing the uncertainties associated with a best-guess model is to integrate experimentation and monitoring with modeling to provide a more mechanistic understanding of the ecosystem. An additional advantage of incorporating mechanistic models into the Restoration Plan is that they are flexible in that they can be efficiently adapted to new situations and new stressors (or even drivers). Thus, when a new ecosystem stressor arises or there is a significant change in a recognized driver, these mechanistic models provide a means for incorporating the effects of the stressor into our understanding of the system. Even so-called quasi-experimental design, in which there is not random assignment of experimental and control groups, can be useful (e.g., Gribbons and Herman, 1997), especially in a situation like the Everglades, where experiments are only partially controllable.

The best examples of experimental programs in the current Restoration Plan are the pilot studies to assess aquifer storage and recovery and seepage management (Sidebar 2-1). However, care must be taken in the development of implementation plans to assure that the pilot studies provide opportunities to improve understanding of processes as well as simply demonstrating that the techniques are feasible.

MODEL REFINEMENT AND SENSITIVITY ANALYSES

DeAngelis et al. (2003) described three reasons for close integration of models into a monitoring program. First, models may be required to relate restoration targets to indicators or measures that can be directly and practically monitored. Second, models formalize and make explicit assumptions and hypotheses about causal mechanisms that link restoration actions to ecological outcomes. Third, models are the only credible means of forecasting to evaluate the possible ramifications of a restoration or management plan. Models may also facilitate understanding and they can provide the basis for a shared vision among all stakeholders of what alternatives are best according to their economic and social costs and their ecosystem and political impacts.

The Restoration Plan provides a case study in the implementation of computer-based decision-support systems combining mathematical models describing the natural phenomena with the human interface for effective communication among the models and humans. These interactive modeling systems are being used to explore, identify, and evaluate various aspects of multiple restoration alternatives and their impacts. Models range from regional to local scales and together include ground water, surface water quality and ecosystem variables and indicators. The models also vary in resolution and applicability to the questions that need to be resolved in order to develop detailed designs and an operation plan for the region.

While hydrologic and water-quality modeling are relatively advanced and sophisticated, modeling for ecological outcomes is much less complete. The population dynamics of a few species can be adequately simulated (e.g., Cape Sable seaside sparrow and alligators), but most cannot be. If ecological outcomes are to be evaluated on the basis of models, these ecological models must be improved through additional research/experimentation and through monitoring designed to define mechanistic relationships. One useful approach is to monitor some ecosystem process or processes or changes that are inputs (including parameters, values, and drivers) to ecosystem models. One example of this is the work of Robert B. McKane and

SIDEBAR 2-1
Role of ASR pilot projects in adaptive assessment.

The Restoration Plan includes a set of "pilot projects" associated with proposed aquifer-storage-and-recovery (ASR) systems, in-ground reservoirs, and seepage control technologies. These projects are designed to serve a variety of purposes, including demonstration that particular technologies are feasible and to acquire information needed for detailed engineering designs. They may also serve as the first step of a phased implementation. For example, the wells that will be constructed during the ASR pilot studies are intended to be permitted as operational ASR wells as part of the final regional systems. The Restoration Plan pilot studies provide a variety of opportunities for learning through active experimentation, but these opportunities can only be realized through careful design of the projects to allow testing of hypotheses that can enhance understanding of critical processes. This committee reviewed initial plans for ASR pilot studies (NRC, 2001) and identified a number of improvements that could be made in their potential to contribute to improved design and implementation of regional scale ASR systems. An ASR Regional Study has also been added to the project to address questions raised with respect to predicting the regional scale changes in aquifer hydrodynamics. This regional study is also intended to reduce uncertainties related to water quality changes during subsurface storage and to effects of aquifer heterogeneity on recovery.

colleagues at the Western Ecology Division of the U.S. EPA's Ecology Laboratory on the effects of stressors, such as pollutants, climate change, or forest management practices, on the structure and quality of wildlife habitat, using the General Ecosystem Model (GEM). The value of this approach is that there is a cause-effect relationship established between what is being measured and the result (in this case, tree growth predicted for the next 20 years).

Two other examples of this approval derive from the Everglades restoration program itself. The first is the ATLSS model (Curnutt et al., 2000), described earlier in this report. Some of the ATLSS submodels are relatively sophisticated, being spatially explicit. The second is work by Tarboton et al. (2003) linking hydrologic model outputs to habit-suitability-index models (used to predict species' demographic or behavioral responses to various sets of environmental conditions) for selected ecosystem indicators. The values of these habitat-suitability functions depend on hydrologic attributes that can be managed. Thus different time-series of hydrologic attributes resulting from different water-management policy simulations can be converted to time-series of habitat suitability function values, each of which can then be combined and averaged in various ways to provide quantitative indications of the relative ecological impacts of alternative water-management policies.

SCIENTIFIC FEEDBACK TO GUIDE AND REFINE IMPLEMENTATION OF THE RESTORATION PLAN

The usefulness of an adaptive assessment program in improving the potential for the Restoration Plan to meet its hydrologic and ecological restoration goals depends on the opportunities available to modify design or operational features of components as understanding of drivers and system responses improves through monitoring, experimentation, and modeling. Some Restoration Plan components will be designed and put into operation early in the project life. These components may not benefit directly from the adaptive assessment program in the design phase, but any flexibility introduced in a later redesign phase might improve their performance later in the project. These projects can be used as experiments to maximize learning. The Canal-111 (C-111) project—a pre-Restoration Plan project authorized in the Water Resources Development Act of 1994—has served many such purposes. The C-111 project is designed to restore the hydrologic conditions in the Taylor Slough and Eastern Panhandle areas of Everglades National Park and eliminate damaging freshwater flows to Biscayne National Park, while maintaining flood protection. Components include the degrading of existing spoil mounds of the canal to promote sheet flow, and the construction of new pump stations, bridges, and detention areas. The project has served many such purposes by allowing National Park Service scientists to monitor ecosystem response and establish a "footprint" of impact on the natural system. This project is an example of how trade-offs between seepage, infiltration, and water quality are being addressed in the basin. The C-111 project also will provide an opportunity to look at the groundwater/surface water interface and impacts on woody vegetation and ecology of the park west of the project. Additionally, C-111 has served as a test case for learning how to work through scientific and institutional differences to reach tentative consensus that will allow implementation of the Restoration Plan to go forward (USACE, 2002).

Other components of the Restoration Plan, which are not scheduled for construction until later years, could be significantly modified to take advantage of learning from the adaptive assessment process. Some components, such as the regional ASR systems and the seepage-control strategies, are specifically planned to include pilot projects and a phased implementation in order to make use of the pilot study results in the final design (see Sidebar 2-1). Completion of some projects should be viewed as providing tests of important mechanisms in hydrologic and ecological models. At the very least, possible outcomes of a project should be articulated a priori, as well as the appropriate response to each outcome in terms of alterations in design of future projects.

The less reversible a planned action is, the greater is the incentive to reduce uncertainty about its potential effectiveness and effects, because the consequences of being wrong are greater. However, sometimes bold, irreversible actions have greater potential for success than smaller ones. This is a challenging problem for a sequential restoration program like that planned for the Everglades. The committee has no clear solution to this problem except to suggest that it may be helpful to take an incremental approach and couple it with focused research and adaptive management to reduce uncertainty associated with major actions that are likely to be difficult to reverse. To the degree that it is possible and consistent with the program schedule, postponing major actions whose consequences are both uncertain and difficult to reverse would provide additional time to reduce the uncertainty associated with them. In addition, a careful evaluation of the degree of reversibility of major components of the Restoration Plan would be helpful, as well as consideration of whether more reversible options might be available for those components that appear to be least reversible. As described above, the ability to learn from these actions and associated monitoring and research should be a major consideration in planning them.

There is likely to be considerable variability among components of the Restoration Plan in the potential for flexibility in design or operational features. Some components may present a range of design choices but only limited flexibility to modify operations once a specific design is selected and the component is put into operation. For example, decompartmentalization for some portions of the water conservation areas could be accomplished by strategies ranging from installation of a few opening and control structures through an existing levee to complete breach of a levee and filling of the adjacent canal. Removal of the levee would provide the maximum connection between formerly compartmentalized storage areas. However, this strategy would offer no options to control flow between the areas if it is later determined that such flow has undesirable consequences such as transfer of excess nutrients into a nutrient-poor region.

As part of an overall evaluation of the likely success of the monitoring and adaptive assessment program in the Restoration Plan, it would be useful to conduct a preliminary, but systematic, inventory of opportunities for flexibility in design and operational features of the Restoration Plan components. A systematic review and listing of the opportunities for both design and operational flexibility for major Restoration Plan projects would be useful to identify which projects could be modified in an adaptive assessment process. Results of this inventory could be used in an evaluation of project scheduling and in prioritizing monitoring, experimental, and modeling activities to provide input to the components for which adaptive assessment is likely to have the greatest impact on decisions regarding design and operations.

Much has been written about institutional barriers to adaptive ecosystem management, lamenting the difficulty of maintaining scientifically-based adaptive strategies in an environment of stakeholders, bureaucracies, and political processes (e.g., Holling, 1995; Gunderson, 1999). During the November 2001 workshop much discussion focused on systemic barriers to the Restoration Plan adaptive assessment strategy that need more attention. These include the concern that existing laws could override proposed modifications to water delivery systems and the need for a more thorough policy analysis. There was also concern that current incentive systems in the Army Corps of Engineers and the South Florida Water Management District that reward personnel for completing large projects "on time and under budget" tend to promote inflexibility in decision making. This is not to say that delays and cost overruns are desirable, but to point out that there are no obvious incentives for taking a more precautionary approach to the restoration with more reliance on pilot projects, contingency planning, and non-structural solutions to achieve ecological goals. Others noted that the current organizational strategy does not provide a direct linkage between science and decision making related to water management. Finally, some workshop participants noted that there are no guidelines or "policies" for when to change the plan. This is especially difficult given multiple time lags between implementation of a restoration project and ecosystem responses at different spatial and temporal scales.

Just as flexibility of Restoration Plan design and operation is crucial to adaptive assessment management of the Everglades, societal flexibility and acceptance of scientific uncertainty are essential to the adaptive assessment mix so that modifications of policy that require changes to ecosystem drivers to achieve restoration goals and objectives are understood and accepted. Education and outreach about the scientific issues is central to fostering societal flexibility and acceptance of uncertainty by the public, decision-makers, and legislators. As a result, education is central to the success of the project. Institutional arrangements for transferring science advice to policy-makers and education of the public must be clearly identified in the Monitoring and Assessment Plan. Specific arrangements need to be made to communicate scientific conclusions about the functioning of the ecosystem to the decision-makers in the executive and legislative branches of government. Linkages should be designed to connect the RECOVER Senior Management Team and the Science Coordination Team to the Restoration Plan decision-makers. The key is to have frequent conversations with the decision-makers to inform them of the changing state of knowledge, so that they can make decisions based on current scientific information.

Another important linkage, which does not seem well developed thus far in the Everglades would be between the adaptive assessment process and citizen advisory groups. This linkage has been developed in other restoration efforts such as the Glen Canyon Dam project (NRC, 1996b).

In summary, it is not clear if there is enough flexibility in the Restoration Plan design to provide opportunities to respond to ecosystem response "surprises" or indeed other operational and system changes that will probably arise during implementation of the plan. Most of the flexibility within the Restoration Plan appears to be related to operational features rather than primary construction. To maximize the potential to apply results of increased understanding of the ecosystem, project design should attempt to maximize the range of operational conditions. Monitoring and process studies should focus on hydrologic and ecological features for which improved prediction of response can lead to project modification that will lead to a more successful result.

3
Additional Components of Monitoring

Monitoring to enable adaptive assessment is an important reason to monitor within the Restoration Plan, but it is not the only reason, nor should it be. Local and national interest in progress toward restoration of the Everglades necessitates monitoring those aspects of the system that represent successful restoration in the public eye. That is, it is important to collect monitoring data that can be incorporated into a status report (sometimes called a "report card") that documents progress toward recovery of elements of the ecosystem that are particularly symbolic or highly valued in the public arena. In the Everglades, as in other systems, these elements include endangered species and particularly animals at upper trophic levels. Endangered species figure prominently in another essential type of monitoring, regulatory compliance monitoring. In the Everglades this category includes monitoring of water quality, as well as of endangered species.

THE REPORT CARD

The ultimate success of the Restoration Plan, restoration of the Greater Everglades Ecosystem and conservation/preservation of the natural system, will be realized only through continuing political and financial support in perpetuity. One of the greatest challenges of the restoration will be maintaining public support, and thus political and financial support, during the 30-40 year implementation period. "Report cards" constitute a strategy that has been used successfully to maintain public awareness and support for ecosystem restoration projects (e.g., Heinz Center, 2002; Natural Environment Research Council, 2000; Chesapeake Bay Program, 2002). The primary objective of an ecosystem report card for the Everglades is to inform the public about how the natural system is responding to efforts to return the ecosystem to historical conditions. Several key indicators generally are selected for a report card based on the availability of a long-term record, relevance and comprehensibility to the public, and potential responsiveness to the planned restoration. Evaluation of indicator status with respect to historical conditions is reported periodically to the public in the report. A similar approach is planned during the Restoration Plan.

In 1999, a set of ten report card performance measures (Table 3-1) were selected from the much larger set of Monitoring and Assessment Plan performance measures (Ogden and McLean, 1999). The specific criteria used to select the report card performance measures were that they "(1) measure an element of the natural or human system that the Comprehensive Plan is expected to improve, (2) reflect the overall health of all or a portion of the regional system, and (3) be an element of the regional system that is both highly important and relevant to the public and to decision-makers."

Annual report cards for each measure are planned. Statements at the monitoring and assessment workshop indicated that each report card will provide several types of information. That information is likely to include the final and interim targets for the performance measure, the rationale for selecting the measure, the historical and current condition of the measure, and a grade for the measure. While there may be value in adding additional report card measures to this set that reflect public interest, the importance of maintaining long-term data sets cannot be stressed enough.

TABLE 3-1 Report Card Performance Measures

Performance Measure	Measurement	Grade	Potential non- Restoration Plan related impacts
Lake Okeechobee Phosphorus Levels	Phosphorus concentrations in open water	Red	Release from sediment storage, shoreline development, precipitation patterns, altered lawn chemical application
St. Lucie Oyster Beds	areal extent and health of beds	Red	Disease, predators, harvesting, pollutants, sea-level rise
St. Lucie Phosphorus Levels	Phosphorus loading to the estuary	Red	Release from sediment storage, shoreline development, precipitation patterns, altered lawn chemical application
Lake Okeechobee and East Coast Water Restrictions	years with water-use restrictions	Yellow	Precipitation patterns, development, altered industry types, population increase
Florida Bay Roseate Spoonbills	number of nesting pairs	Yellow	Habitat conditions elsewhere, temperature extremes, precipitation patterns, contaminants (e.g., Hg), fire, hurricanes
Gulf Coast Roseate Spoonbills	number of nesting pairs	Red	Habitat conditions elsewhere, temperature extremes, precipitation patterns, contaminants (e.g., Hg), fire, hurricanes
Tree Islands	number, extent and health	Red	Precipitation patterns, fire, invasive species
Total System Wood Storks	number of nesting pairs	Red	Habitat conditions elsewhere, temperature extremes, precipitation patterns, contaminants (e.g., Hg), fire, hurricanes
Florida Bay Seagrass Beds	Community composition and health	Yellow	Hurricanes, altered herbivory (e.g., increases in manatee or sea turtle populations), development, disease, altered boating patterns, invasive species
Water Lost to Tide	acre feet not captured by the CERP	Red	Precipitation patterns, hurricanes
Tortugas Pink Shrimp	Pounds per vessel per day	Yellow	Precipitation patterns, hurricanes

Note: The grade "red" indicates a seriously degraded condition, "yellow" indicates some degradation or cause for concern, and "green" represents an ecosystem component that is in the target condition or a condition otherwise judged desirable.
Source: Ogden and McLean, 1999.

The value of these report card measures is that they reflect the condition of the ecosystem, are influenced by multiple stressors, and are valued by some portion of the Restoration Plan's stakeholders. They are also useful because they include measures of changes that are irreversible (e.g., extinction of a species) or that reflect the outcome of processes that change very slowly over time (e.g., tree islands). However, it is crucial that the report cards make clear that variations in the performance measures and unexpected results (i.e., lack of response or actual decreases in the report card grade) may be a result of influences other than those produced by the Restoration Plan (Table 3-1). For example, variation in roseate spoonbill populations might result from habitat conditions elsewhere, over winter survival rate or fecundity in previous years (Frederick and Ogden, 2001). Monitoring of the report card measures must be supported by research that establishes the cause-and-effect relationships between the measure and environmental variation as well as variations in these "outside" and Restoration Plan influences. This means that while the report card measures play an essential role in educating the public and informing management decisions, these measures alone are insufficient to capture the ecosystem response to the Restoration Plan. The Monitoring and Assessment Plan must include a much broader list of monitoring variables supported by specific, mechanistic research to allow for restoration of the Everglades using adaptive management.

What is monitored for purposes of reporting progress to the public is to some extent dictated by public interest, and therefore these elements will often lack some of the desirable characteristics of performance measures monitored for adaptive assessment. In particular they may not be especially relevant to the most important predictive models or revealing of critical ecological mechanisms. These features are not essential in a "report card" measure, but it is important to select measures that are somewhat sensitive to the Restoration Plan's design and operation and are associated with relatively low levels of uncertainty, if possible. In addition, some of the measures in Table 3-1 are likely to change only slightly from one report to the next. Monitoring of such slowly changing variables may result in little or no apparent progress for long periods, and thus the reports might appear to be indicative of failure. Reports of variables that change little or not at all also will be of little public interest. For some variables in the report card, annual reporting might be much too frequent (NRC, 2000).

Several other performance measures included in the Monitoring and Assessment Plan, although not part of the "official" status report depicted in Table 3-1, will inevitably serve a "status report " function because of their visibility and interest to the public. Population levels of higher vertebrates, including endangered and threatened species, fall into this category, and their inclusion in the Monitoring and Assessment Plan can be justified on this basis in those cases where links to restoration are tenuous. System-wide measures of this sort, such as alligator populations and numbers of foraging and nesting wading birds, should be viewed primarily as report card measures, and as secondary to system-wide performance measures or indicators more closely linked to ecosystem function in the context of adaptive assessment.

REGULATORY COMPLIANCE MONITORING

Several federal environmental laws apply to the Everglades, for example, the Endangered Species Act, the Clean Water Act, and the National Environmental Policy Act. State laws apply as well. Thus, in addition to focusing on the ecosystem, the Adaptive

Assessment Team must consider information needs at each of the organizational levels of the ecosystem as they develop the Monitoring and Assessment Plan for the Restoration Plan.

The reality of the Endangered Species Act (ESA) means that the Adaptive Assessment Team must consider information needs at the level of individual species, as well as needs related to community structure and ecosystem function. The Everglades system contains significant populations of several endangered species, and some of the monitoring described within Monitoring and Assessment Plan is necessary to comply with the ESA. The Adaptive Assessment Team, by integrating compliance monitoring with other monitoring within Monitoring and Assessment Plan, incorporates compliance monitoring into adaptive assessment to the extent that it is possible. In some cases, it is possible to use monitoring of endangered species to reveal the effectiveness of the Restoration Plan or the nature of critical ecological mechanisms because the declines of these species are closely tied to the functioning of the Everglades ecosystem. Population dynamics of both Cape Sable seaside sparrows (Curnutt et al., 1998; Nott et al., 1998; Walters et al., 2000) and snail kites (Beissinger, 1995) are strongly affected by hydroperiod. Populations of these species are expected to be sensitive to restoration activities, and thus their monitoring can serve an adaptive assessment function, as well as status-report and compliance-monitoring functions. Monitoring of crocodiles may serve all three functions as well due to the impact of salinity in estuaries on hatchlings and juveniles less than 200 g (Mazzotti et al., 1986).

Although impacts of the Restoration Plan on other endangered and threatened species (Florida panther, red-cockaded woodpecker, West Indian manatee) are articulated in the MAP, influences of extraneous factors on these species are sufficiently strong that their population dynamics will likely be rather insensitive to restoration actions. Florida panthers were hunted to near extinction by humans and now suffer from problems inherent to small, isolated populations, among others (NRC, 1995). The dynamics of red-cockaded woodpecker populations are driven by availability of old-growth pines for cavity excavation, and thus will depend more on provisioning of artificial cavities by managers than on restoration efforts (Walters, 1991). Manatee numbers are depressed by mortality resulting from collisions with boats. Performance measures for these species are of little use in adaptive assessment, and are risky as status-report variables. Monitoring of these species is best viewed as strictly compliance monitoring. Wood storks represent an intermediate case; as a key member of the wading bird guild they are expected to respond to restoration and at least be useful as a status-report indicator. Indeed, the number of nesting pairs of wood storks is one of the variables selected for the status report (Table 3-1). But their numbers are more subject to factors extraneous to the restoration than are numbers of Cape Sable seaside sparrows and snail kites, and thus their use in adaptive assessment is more limited.

Strict compliance measures probably should be kept separate from the report card, because what constitutes compliance is likely to change over time. Thus, such measures are likely to drop out of or enter the list of monitored variables over time, which makes them unsuitable as reference baseline indicators or as indicators of restoration progress.

Achieving water quality standards is part of “getting the water right”, and thus monitoring water quality is essential to adaptive assessment, but it is also a regulatory requirement in some cases. Several of the Monitoring and Assessment Plan hydrologic performance measures are specific for phosphorus. However, performance measures for other regulated contaminants such as mercury and organics are not included in the plan.

4

Data Management and Products

QUALITY ASSURANCE/QUALITY CONTROL

The scope and complexity of the monitoring requirements of the Restoration Plan warrant the direction of special attention and resources to the development, implementation and maintenance of a quality assurance/quality control (QA/QC) program. According to a report of the NRC (1996a), "Currently, a great deal of monitoring data is collected in the United States. However, the data are incomplete…of varied quality, and non-standardized in collection protocol." In the case of the Restoration Plan, the potential for these undesirable outcomes is perhaps increased because of multiple or vague monitoring goals or requirements (e.g., testing research hypotheses versus meeting regulatory requirements); involvement of numerous parties in plan development and implementation (federal and state agencies, private sector firms and universities); massive data storage requirements; and the extended "life expectancy" of the project.

As Restoration Plan participants are aware, a successful QA/QC program should consist of various components including planning, implementation, assessment, and reporting. In fact, the Environmental Protection Agency requires that all projects within its regulatory purview develop an approved Quality Assurance Project Plan (QAPP) before project implementation (US EPA, 1998). (This presents a practical dilemma for the Restoration Plan since baseline data have been obtained from numerous sources over a number of years; acquisition of such data continues in the absence of a project-wide QAPP.) Data-quality objectives (DQOs) should be established during the planning stage of the program and used to develop measurable performance criteria. Successful planning will allow managers to identify financial, personnel, and information technology resources needed for implementation, assessment and reporting. Obviously, if this model of a QA/QC program is deemed appropriate for the CERP, considerable effort must be devoted to the development of a QA/QC program. Since monitoring performance indicators and QA/QC performance objectives are intimately related, adding DQOs incrementally to an existing monitoring plan could prove wasteful and inefficient.

As important as it is for the Restoration Plan to develop a comprehensive QAPP, it is just as important that the plan have the flexibility to accommodate the requirements of various aspects of the monitoring program. The actual data and information needs of the Restoration Plan should drive the development of the QAPP as opposed to vice versa. Whereas a rigorous set of EPA or other guidelines might apply well to regulatory required monitoring, a different approach could be applied to monitoring designed for research or hypothesis testing. The QA/QC applied to experimental methods, documentation, etc. might be similar in both cases, but validation in the latter case could extend well beyond statistical accuracy and precision of experimental data. Ultimately, the inferences made from hypothesis-testing data will be evaluated by the scientific peer-review process. This suggests that the QAPP should include methods for both selecting entities to conduct research-based inquiries and evaluating the conclusions reached from these investigations. Even in cases in which routine monitoring data are used to impact management decisions, the quality of these decisions should be scrutinized by the appropriate component of the QAPP.

For example, the Restoration Plan needs to include an objective process for selecting, designing, implementing, and evaluating field experiments and modeling exercises. Consideration should be given to the process of selecting (or certifying) individuals or teams to engage in research projects (competitive solicitations might be one mechanism). There should also be a process for evaluating experimental results, i.e., peer review. Most important, the plan should address how these results will be used in the decision-making process.

DATA AND INFORMATION MANAGEMENT

The Restoration Plan's adaptive management strategy cannot succeed without a well-designed and adequately supported data and information system. Given the complexity and duration of the Restoration Plan, desirable features of such a system include the following:

- clear data and metadata policies and standards;
- policies and procedures for data validation;
- mechanisms to ensure Restoration Plan data integrity and security;
- mechanisms for inter-organizational data and information sharing;
- policies and procedures for public information access and outreach;
- database software and database models to facilitate storage and retrieval;
- tools to facilitate data analysis and learning through shared computing hardware and software resources; and
- human and technological capacity to maintain a growing and increasingly complex store of data and information.

The Restoration Plan Project Management Plan for Data Management (USACE and SFWMD, 2002a) calls for a program-wide phased approach to management and acquisition of data, including activities to "identify, standardize, organize, document, serve and preserve program data." This document is mainly concerned with identifying relevant standards for Restoration Plan data. Some federal data and metadata standards are identified for GIS, Computer Aided Design and Drafting, and survey data. The plan calls for an "enterprise Geographic Information System (GIS)" consisting of a central repository of spatial data gathered and used by multiple organizations based on agreed-upon standards. The plan also calls for establishment of a Data Clearinghouse, a Data Oversight Committee, and a program to bring existing data into the Restoration Plan's common spatial framework. In summary, the plan partially addresses items 1-4 above. Technical and logistical details of data management (items 5-7) are to be addressed in the next phase of data management activities.

Section 10 of the Project Management Plan for Data Management specifically addresses RECOVER data, but only in very general terms that hint at but do not provide substantive solutions to the large technical and institutional challenges to implementing an effective data and information management system for adaptive assessment in the Restoration Plan. Data relevant to the Restoration Plan's adaptive assessment will be gathered at thousands of locations by perhaps hundreds of organizations and individuals. These include physical, biological and socioeconomic data gathered over many scales using a wide array of methods. Adaptive assessment depends on integrating these data across space and time for exploration, visualization, statistical and simulation modeling, and performance monitoring.

At this stage, Restoration Plan data and information activities are largely at the conceptual stage. However, based on the material produced to date, two general concerns arise:

- Substantive work on data and information management appears to be lagging well behind other aspects of the Restoration Plan in general and the MAP in particular. It seems that inadequate attention and resources are being committed to this component of the Restoration Plan.
- Many if not most data relevant to the Restoration Plan's adaptive assessment will be collected for other purposes by non-Restoration Plan personnel. The Restoration Plan strategy for data and information management strategy should consider moving beyond centralized databases, rigid standards, and data clearinghouses.

The Restoration Plan could exert leadership by creating mechanisms and providing funding for promoting confederation of databases that are controlled and maintained locally by participating organizations and individuals. Mechanisms include development and/or dissemination of tools that promote good data management practices and shared data and metadata syntax and semantics. For example, Jones et al. (2001) described a network-enabled database framework for research ecologists that allows individual scientists to customize metadata to meet their needs while also promoting the use of standards such as the U.S. Ecological Metadata Standard and National Biological Information Infrastructure's Biological Data Profile.

SYNTHESIS OF DATA

Finally, synthesis of monitoring data and preparation of adaptive-assessment reports should be a prominent feature of the MAP. While development of these portions of the MAP is still in its infancy, as these sections of the plan begin to be formulated the following questions should be addressed: How often should formal reviews of the Restoration Plan performance be conducted? Are there ecosystem responses that will trigger a formal review in addition to scheduled reviews? Is sufficient time for data analysis and synthesis built into the assessment process? How will independent peer-review of the data collection and synthesis be conducted? Who will insure that monitoring results be incorporated into the implementation and operation of the Restoration Plan, and how will that be accomplished? These issues are critical to successfully incorporating adaptive assessment into the Restoration Plan to insure that the MAP does not become "data rich and information poor," a problem common to many monitoring and assessment projects.

5

Conclusions and Recommendations

Conclusion: The Comprehensive Everglades Restoration Plan (Restoration Plan) Monitoring and Assessment Plan (MAP) is grounded in current scientific theory and practice of adaptive management. The least developed aspects of the planned adaptive management are feedback mechanisms to connect monitoring to planning and management.

Recommendations:

- Adaptive management must not simply mean "flexibility in decision making under uncertainty." When considering a variety of possible strategies, actions should be taken that are informative, reversible, and less uncertain or at least robust to uncertainties.
- Institutional mechanisms should be created and sustained to ensure that scientific information is available and accessible to the decision-making process.
- Opportunities for flexibility in design should be identified and operational features of the Restoration plan components should be assessed to help prioritize monitoring and assessment activities.

Conclusion: Restoration goals, objectives, and targets for the Everglades are inadequately defined and are not reconciled with the large-scale forces of change in south Florida.

Recommendations:

- Targets should be set as soon as possible that define the extent of compatibility between the built and natural systems and that address possible conflicts between ecological restoration and other policies, statutes, and social demands.
- Research and monitoring must continue to better conceptualize and describe current conditions in the Greater Everglades Ecosystem. Continued support and coordination of hydrologic and ecological monitoring and coordination among them are important components of monitoring and assessment. Integrated modeling is the best method for extrapolating findings over large areas and long periods.

- Since the Everglades can never be fully restored, probable conflicts among desired targets must be identified, necessary compromises must be acknowledged, and the scope of the MAP must contemplate this line of inquiry continuing for the duration of the restoration (so emergent conflicts can be resolved appropriately).

Conclusion: Adaptive management requires an effective process for learning from management actions. The primary reliance on passive adaptive management planned for the restoration may be the only feasible approach given the large time and space scales of the project and constraints such as those imposed by endangered species. Passive adaptive management uses science to formulate predictive models, makes policy according to the models, and revises the models as data become available. But monitoring is done without controls, replication, and randomization, and thus it lacks statistically valid experimental design, and therefore cannot be used to infer cause and effect. Policy effects are not distinguishable from other human forces or from natural processes.

Recommendation:

The MAP should be augmented with active adaptive management wherever possible to enable conclusions about cause and effect to be made. As soon as possible, additional expertise in sampling design and analysis of environmental data should be engaged. Opportunities should be identified for active adaptive management that compares alternative policies by means of deliberate experiments. The experiments should use controls, paired comparisons, replication, and randomization. s

Conclusion: The MAP needs a rigorous quality assurance/quality control (QA/QC) program to ensure that monitoring data are of high quality and utility.

Recommendation:

To ensure the quality of RECOVER environmental data and related data products, a QA/QC program with clearly defined roles and responsibilities should be established. The current Restoration Plan Program Management Plan for Data Management calls for such a function, but it appears that there has been little substantive progress in this important area. The National Institute of Standards and Technology or other similar organization should be consulted to provide guidance as a QA/QC plan is developed.

Conclusion: Including combinations of ecological performance measures and environmental variables hypothesized to impact those measures is critical for the MAP given the adaptive management approach being implemented.

Recommendations:

- More ecosystem-level, system-wide performance measures or indicators (such as defined by NRC, 2000) should be identified and set. For example, more use could be made of the nine broad targets developed by the Restudy Adaptive Assessment Team (AAT). Other possibilities include land cover and land use measures, an Index of Biotic Integrity and system-wide diversity measures.
- Monitoring of invasive species, mercury, and other contaminants needs to be added.
- Hydrologic performance measures useful in designing the Restoration Plan need to be modified to better serve adaptive management. New aggregated performance measures will be especially critical.

Conclusion: Region-wide monitoring of ecosystem drivers as discussed in Chapter 2 is essential to reducing the uncertainties associated with the Restoration Plan but these drivers appear to have received comparatively little attention by the Monitoring and Assessment Plan.

Recommendations:

- To understand better the potential effects of restoration decisions in the Greater Everglades Ecosystem and the Restoration Plan, the external human and environmental drivers of the system, such as human population growth, water demand, and long-term climate, should be monitored and their contributions to ecosystem response should also be assessed through experimentation as well as modeling. Many of them already are monitored by local, state, and federal agencies and so the main challenge will be to coordinate an integrated modeling, monitoring, and experimentation effort that makes good use of such data.
- Given the expected long time scales of ecosystem response (as well as the extended implementation time scales), models of hydrologic processes and ecological responses, adaptable to new situations and new stressors, will remain a primary design and evaluation tool for projects and monitoring programs. External drivers for these models should be varied over a range of scenarios to assess the "robustness" of the Restoration Plan to future changes.

Conclusion: Effective adaptive management requires an explicit feedback mechanism for learning from management actions. Scientists developing the monitoring and assessment plan need an explicit understanding of what information management needs and how monitoring results will be used.

Recommendations:

- To create a basis for scheduling and sequencing projects in the Restoration Plan, an assessment of the design and operational flexibility of the 68 proposed major projects could be used in prioritizing monitoring, experimental, and modeling activities. Therefore, it should be determined which project components have the greatest impact on decisions, and hence on monitoring activities. In other words, the relative ease with which projects could be modified in an adaptive management process should be assessed. Therefore, monitoring and process studies should include hydrologic and ecological features for which improved prediction of response can lead to project modification that will improve the restoration outcome.

- Formal linkages should be established to connect the RECOVER Senior Management Team and the Science Coordination Team to the Restoration Plan decision-makers to keep them informed of the changing state of knowledge, so that they can make decisions based on current scientific information.

Conclusion: In addition to serving adaptive management, the monitoring program must also serve compliance monitoring and report card functions.

Recommendations:

- The strategy of integrating, but differentiating, performance measures used for adaptive management, compliance monitoring, and the report card is a worthy one. The MAP should determine on a continuing basis the most effective ways of communicating and explaining scientific information to the decision makers and various stakeholders related to the restoration of the Everglades using adaptive management.
- System-wide performance measures sensitive to restoration activity and associated with low uncertainty should be included in the report card. It is appropriate to use visible measures of interest to the public, such as abundance of endangered species, in the report card but these will not be sufficient to show positive progress toward restoration.
- It is appropriate to include compliance monitoring in the adaptive management framework when the performance measures involved will be affected by the Restoration Plan. However, in other cases performance measures will be driven by other factors (e.g., populations of some endangered species), and monitoring of these should be clearly labeled as compliance in nature.

Conclusion: The overall design and funding of the Restoration Plan obviously requires adequate and continued support of long-term monitoring and scientific studies throughout the restoration. At this time funding of monitoring activities appears secure and ample. Still, funding is never unlimited, and it is therefore critical that Adaptive Assessment Team develop strategies for prioritizing monitoring needs of all kinds. This includes prioritizing the importance of the various ecological indicators. The Adaptive Assessment Team has done an excellent job of winnowing a large number of possible indicators and monitoring objectives down to a much smaller, but still substantial, subset.

Recommendation:

The Adaptive Assessment Team should prioritize within this subset of monitoring objectives, and consider the relative utility of elements of the subset in meeting the several monitoring objectives (i.e., adaptive assessment, report card, and regulatory compliance).

References

Adaptive Assessment Team (AAT). 2001. RECOVER Adaptive Assessment Operating Procedures White Paper. Draft dated November 14, 2001.

Alsdorf, D. E., J. M. Melack, T. Dunne, L. A. K. Mertes, L. L. Hess, and L. C. Smith. 2000. Interferometric radar measurements of water level changes on the Amazon floodplain. Nature 404: 174-177.

Appelbaum, S. 2002. Presentation to the South Florida Ecosystem Restoration Task Force. March 21, 2002, Washington, D.C.

Bales, J. D., J. M. Fulford, and E. Swain. 1997. Review of Selected Features of the Natural Systems Model, and Suggestions for Application in South Florida. U.S. Geological Survey, Water Resources Investigations Report 97-4039. Raleigh, North Carolina.

Beissinger, S. R. 1995. Modeling extinction in periodic environments: Everglades water levels and snail kite population viability. Ecological Applications 5: 618-631.

Blake, N. M. 1980. Land into Water—Water into Land: A History of Water Management in Florida. Tallahassee: University Presses of Florida.

Bradshaw, A. D. 1996. Underlying principles of restoration. Canadian Journal of Fisheries and Aquatic Science. 53(suppl. 1):3-9.

Cairns, J. 1988. Increasing diversity by restoring damaged ecosystems. Pp. 333-343 in Biodiversity. E. O. Wilson, ed. Washington, D.C.: National Academy Press.

Chesapeake Bay Program. 2002. The State of the Chesapeake Bay: A Report to the Citizens of the Bay Region. Chesapeake Bay Program, Annapolis, Maryland.

Curnutt, J. L., J. Comiskey, M. P. Nott, and L. J. Gross. 2000. Landscape-based spatially explicit species index models for Everglades restoration. Ecological Applications. 10(6):1849-1860.

Curnutt, J. L., A. L. Mayer, T. M. Brooks, L. Manne, O. L. Bass, Jr., D. M. Fleming, M. P. Nott, and S. L. Pimm. 1998. Population dynamics of the endangered Cape Sable Seaside Sparrow. Animal Conservation 1: 11-21.

Davis, S. M., and J. C. Ogden. 1994. Toward ecosystem restoration. In: Everglades: The Ecosystem and Its Restoration. Eds. S. M. Davis and J. C. Ogden. Delray Beach, Fla.: St. Lucie Press.

Davis, S. M., L. H. Gunderson, W. A. Park, J. R. Richardson, and J. E. Mattson. 1994. Landscape dimension, composition, and function in a changing Everglades ecosystem. In Everglades: The Ecosystem and Its Restoration. Delray Beach, Fla.: St. Lucie Press.

DeAngelis, D. L., L. J. Gross, E. J. Comiskey, W. M. Mooij, and M. P. Nott. 2003. The use of models for a multi-scaled ecological monitoring system. In Monitoring Ecosystems: Interdisciplinary Approaches to Ecological Monitoring of Ecosystem Initiatives, David E. Busch and Joel C. Trexler, eds. Washington, D.C.: Island Press.

Doren R. F., K. Rutchey, and R. Welch. 1999. The Everglades: A perspective on the requirements and applications for vegetation map and database products. Photogrammetric Engineering And Remote Sensing. 65 (2): 155-161.

Douglas, M. S. 1947. The Everglades: River of Grass. 50th Anniversary Edition. Sarasota, Fla.: Pineapple Press, Inc.

Frederick, P. and J. Ogden. 2001. Presentation to the Committee on Restoration of the Greater Everglades Ecosystem.

Galloway, D., R. Jones, and S. E. Ingebritsen, eds. 1999. Land Subsidence in the United States. U.S. Geological Survey Circular 1182. Online: http://water.usgs.gov/pubs/circ/circ1182/.

Gleason, P. J. and P. Stone. 1994. Age, Origin, and Landscape Evolution of the Everglades Peatland. Pp. 149-197 in Everglades: The Ecosystem and Its Restoration, S. M. Davis and J. C. Ogden, eds. Delray Beach, Fla.: St. Lucie Press.

Gribbons, B., and J. Herman. 1997. True and quai-experimental designs. Practical Assessment, Research, & Evaluation 5(14).

Gunderson, L. 1999. Resilience, flexibility and adaptive management—antidotes for spurious certitude? Conservation Ecology 3(1):7.

Harwell, M. A., V. Myers; T. Young, A. Bartuska, N. Gassman, J. H. Gentile, C. C. Harwell, S. Appelbaum, J. Barko, B. Causey, C. Johnson, A. McLean, R. Smola, P. Templet, and S. Tosini. 1999. A framework for an ecosystem integrity report card. Bioscience 49(7):543-556.

Heinz Center. 2002. The State of the Nation's Ecosystems: Measuring the Lands, Waters, and Living Resources of the United States. The H. John Heinz III Center for Science, Economics, and the Environment, Washington, D.C. and Edinburgh: U.K.: Cambridge University Press,

Holling, C. S. 1978. Adaptive Environmental Assessment and Management. London: John Wiley and Sons.

Holling, C. S. 1995. What barriers? What bridges? In Barriers and Bridges to the Renewal of Ecosystems and Institutions, L. Gunderson, C. S. Holling, and S. Light, eds. New York: Columbia University Press.

Holling, C. S., L. H. Gunderson, and C. J. Walters. 1994. The structure and dynamics of the Everglades system: Guidelines for ecosystem restoration. Pp. 741-756 in Everglades: The Ecosystem and Its Restoration, S. M. Davis and J. C. Ogden, eds. Delray Beach, Fla.: St. Lucie Press.

Jones, M. B., C. Berkley, J. Bojilova and M. Schildhauer. 2001. Managing scientific metadata. IEEE Internet Computing 5(5): 59-68.

Karr, R. J., and E. W. Chu. 1999. Restoring Life in Running Waters: Better Biological Monitoring. Washington, D.C.: Island Press.

Kasischke, E. and L. Bourgeau-Chavez. 1997. Monitoring South Florida wetlands using ERS-1 SAR imagery. Photogrammetric Engineering and Remote Sensing, 63(3): 281-291.

Lefsky, M. A., W. B. Cohen, and T. A. Spies. 2001. An evaluation of remote sensing products for forest inventory, monitoring, and mapping of Douglas-fir forests in western Oregon. Can. J. of Forest Research 31(1):78-87.

Lewis, J. A. 1948. Soils, Geology and Water Control in the Everglades Region. Gainesville, FL: University of Florida Agricultural Experiment Station.

Light, S. S., and K. Blann. 2001 (unpublished manuscript). Implications of Kissimee River Restoration. Unpublished manuscript prepared for the Committee on Restoration of the Greater Everglades Ecosystem.

Light, S. S., L. H. Gunderson, and C. S. Holling. 1995. The Everglades: Evolution of water management in a turbulent ecosystem. In Barriers and Bridges to the Renewal of Ecosystems and Institutions, L. H. Gunderson, C. S., and S. S. Light, eds. New York: Columbia University Press.

Light, S., and J. W. Dineen. 1994. Water control in the Everglades: A historical perspective. In Everglades: The Ecosystem and Its Restoration. S. M. Davis and J. C. Ogden, eds. St. Lucie Press: Delray Beach, Fl.

Lindblom, C. 1968. The Policy-Making Process. Englewood Cliffs, N.J.: Prentice Hall.

Lord, L. A. 1993. Guide to Florida Environmental Issues and Information. Winter Park, FL: Florida Conservation Foundation.

Mazzotti, F. J., B. Bohnsack, M. P. McMahon, and J. R. Wilcox. 1986. Field and laboratory observations on the effects of high temperature and salinity on hatchling *Crocodylus acutus*. Herpetologica 42:191-196.

McPherson, B. F., and R. Halley. 1996. The South Florida Environment: U.S. Geological Survey Circular 11134.

National Research Council (NRC). 1994. Review of EPA's Environmental Monitoring and Assessment Program. Washington, D.C.: National Academies Press.

National Research Council (NRC). 1995. Science and the Endangered Species Act. Washington, D.C.: National Academies Press.

National Research Council (NRC). 1996a. Science and the Endangered Species Act. Washington, D.C.: National Academies Press.

National Research Council (NRC). 1996b. River Resource Management in the Grand Canyon. Washington, D.C.: National Academies Press.

National Research Council (NRC). 1999. Our Common Journey: A Transition Toward Sustainability. Washington, D.C.: National Academies Press.

National Research Council (NRC). 2000. Ecological Indicators for the Nation. Washington, D.C.: National Academies Press.

National Research Council (NRC). 2001. Aquifer Storage and Recovery in the Comprehensive Everglades Restoration Plan: A Critique of the Pilot Projects and Related Plans for ASR in the Lake Okeechobee and Western Hillsboro Areas. Washington, D.C.: National Academies Press.

National Research Council (NRC). 2003. Science and the Greater Everglades Ecosystem Restoration: An Assessment of the Critical Ecosystem Studies Initiative. Washington, D.C.: National Academies Press.

Natural Environment Research Council. 2000. Accounting for Nature: Assessing Habitats in the U.K. Countryside. Natural Environment Research Council, Centre for Ecology and Hydrology, Department of the Environment, Transport, and the Regions, London.

Nott, M. P., O. L. Bass, Jr., D. M. Fleming, S. E. Killeffer, N. Fraley, L. Manne, J. L. Curnutt, T. M. Brooks, R. Powell, and S. L. Pimm. 1998. Water levels, rapid vegetation changes, and the endangered Cape Sable Seaside Sparrow. Animal Conservation 1: 23-32.

Ogden, J. C., S. M. Davis, D. Rudnick, and L. Gulick. 1997. Natural Systems Team report to the Southern Everglades Restoration Alliance. West Palm Beach, Fla.: South Florida Water Management District.

Ogden J. C., and A. McLean. 1999. Baseline Report for the Comprehensive Everglades Restoration Plan. Online. Available on www.evergladesplan.org/docs/baseline_rpt_99_rev0101.pdf.

Pianka, E. R. 1978. Evolutionary Ecology. 2nd edition. New York: Harper and Row.

Restudy Alternative Evaluation Team (AET). 1998. Defining Restoration - I: A Restudy Alternative Evaluation Team White Paper. November 16, 1998. Available on http://www.sfrestore.org/-crogee/ra8/defining.html.

Rutchey, K., and L. Vilchek. 1999. Air photointerpretation and satellite imagery analysis techniques for mapping cattail coverage in a Northern Everglades impoundment. Photogrammetric Engineering And Remote Sensing. 65 (2): 185-192.

Solecki, W. D., J. Long, C. C. Harwell, V. Myers, E. Zubrow, T. Ankerson, C. Deren, C. Feanny, R. Hamann, L. Hornung, and G. Snyder. 1999. Human-environment interaction in South Florida's Everglades region: Systems of ecological degradation and restoration. Urban Ecosystems 3(3-4): 305-343.

South Florida Ecosystem Restoration Task Force (SFERTF). 1998. An Integrated Plan for South Florida Ecosystem Restoration and Sustainability: Success in the Making. The Working Group of the South Florida Ecosystem Restoration Task Force.

South Florida Ecosystem Restoration Task Force (SFERTF). 2000. Coordinating Success: Strategy for Restoration of the South Florida Ecosystem. Available on www.sfrestore.org/documents/-isp/index.htm.

Stewart-Oaten, A., and J. R. Bence. 2001. Temporal and spatial variation in environmental impact assessment. Ecological Monographs (71) 2:305-340.

Trustees. 1881. Articles of Agreement with Hamilton Disston for the Reclamation of the Overflowed Lands in the Valley of Lake Okeechobee and Kissimmee River. In: Minutes of the Trustees, Feb. 26, 1881 Meeting. Vol. II (1904). Tallahassee, FL: Trustees of the Internal Improvement Fund.

Tarboton, K., D. Loucks, S. Davis, and J. Obeysekera.. 2003. Habitat Suitability Indices for Evaluating Water Management Alternatives. Technical Report. West Palm Beach, Fla.: South Florida Water Management District.

U. S. Army Corps of Engineers (USACE). 2002. Final Environmental Impact Statement, Interim Operational Plan for Protection of the Cape Sable Seaside Sparrow.

U.S. Army Corps of Engineers (USACE) and South Florida Water Management District (SFWMD). 1999. Central and Southern Florida Comprehensive Review Study. Section 9, Recommended Comprehensive Plan in the Final Integrated Feasibility Report and Programmatic Environmental Impact Statement. Online. April 1999.

U.S. Army Corps of Engineers (USACE) and South Florida Water Management District (SFWMD). 2001a. Monitoring and Assessment Plan of the Comprehensive Everglades Restoration Plan. March 29, 2001. Jacksonville, Fla.

U.S. Army Corps of Engineers (USACE) and South Florida Water Management District (SFWMD). 2001b. CERP Environmental and Economic Equity Program Management Plan. Online. http://www.cerpzone.org/pm/progr_eee_plan.cfm. Accessed: September 17, 2001.

U.S. Army Corps of Engineers (USACE) and South Florida Water Management District (SFWMD). 2002a. Central and South Florida Project Comprehensive Everglades

Restoration Plan Project Management Plan Data Management. February 26, 2002. Jacksonville, Florida.

U.S. Army Corps of Engineers (USACE) and South Florida Water Management District (SFWMD). 2002b. The Comprehensive Everglades Restoration Plan: Development and Study Goals. Available online http://www.evergladesplan.org/about/rest_plan_02.cfm. Accessed: February 2003.

U.S. Environmental Protection Agency (US EPA). 1998. EPA Guidance for Quality Assurance Project Plans. EPA QA/G5. EPA/600/R-98/018.

Walters, C. 1997. Challenges in adaptive management of riparian and coastal ecosystems. Conservation Ecology 1(2):1-21.

Walters, C. J., and C. S. Holling. 1990. Large-scale management experiments and learning by doing. Ecology 71(6):2060-2068.

Walters, J. R. 1991. Application of ecological principles to the management of endangered species: The case of the red-cockaded woodpecker. Annual Review of Ecology and Systematics 22: 505-523.

Walters, J. R., S. R. Beissinger, J. W. Fitzpatrick, R. Greenberg, J. D. Nichols, H. R. Pulliam, and D. W. Winkler. 2000. The AOU Conservation Committee review of the biology, status, and management of Cape Sable Seaside Sparrows: Final report. The Auk 117: 1093-1115.

Appendix A

COMMITTEE ON RESTORATION
OF THE GREATER EVERGLADES ECOSYSTEM

Adaptive Assessment and Monitoring Workshop

South Florida Water Management District
Fort Myers Service Center
Ft. Myers, Florida
November 28, 2001

Agenda

Wednesday, November 28, 2001

8:00 AM	Welcome and Introductions of CROGEE and AAT

Adaptive Assessment Strategies

8:15 AM	Statement of workshop objectives (Frank Davis, session chair)
8:30 AM	Relationship between construction projects and monitoring – Topic #2
9:00 AM	Impact of ecological response on construction projects – Topic #3
9:30 AM	Use of monitoring information to alter management – Topic # 1
10:15 AM	Break
10:30 AM	Reality of applying adaptive assessment – Topic # 4
11:30 AM	Public comments, and wrap up of morning session
12:00 Noon	Lunch break

Monitoring Plan Strategies

1:00 PM	Statement of afternoon workshop objectives and format (Scott Nixon, session chair)
1:15 PM	Proposed ecological performance measures – Topic #6
1:45 PM	Measurement of stressors and impact on restoration goals – Topic #5
2:15 PM	Design of monitoring program - Topic #7
2:45 PM	Break
3:15 PM	Performance measure prioritization strategies – Topic #9
4:00 PM	Integration of monitoring approaches – Topic #8
5:00 PM	Public comments, and wrap up of evening session
5:30 PM	Adjourn open session

Attendees:

John Adams, University of Minnesota, CROGEE
Nick Aumen, ENP
Jean Bahr, University of Wisconsin, CROGEE Chair
Andy Barienbrock
Tomma Barnes, SFWMD
Mike Bauer, Audubon
G. Ronnie Best, USGS
Jim Beever, FWC
Matt Bixler, CSWF
Linda Blum, University of Virginia, CROGEE
Bruce Boler, EPA
Stephan Brady, FWS
Patrick Brezonik, University of Minnesota, CROGEE
Ralf Brooks, FWF
Bill Brown, Arthur D. Little, Inc.
Brad Brown, NOAA
Michael Byrne
John Cassini, SWFRPC
David W. Ceilley, The Conservancy of SW Florida
Frank Davis, University of California, Santa Barbara, CROGEE
Steve Davis, SFWMD
Bill Dobson, Miami-Dade County
Elizabeth Donley
Bob Doren, SFERTF
Kim Dryden
Aaron C. Eller, Jr., FWS
David Erne, Booz Allen Hamilton
Chris Farrell
Matt Giles, SFWMD
Chad Gillis, Naples Daily News
Brian Griffin, Council of Civic Associations
Betty Grizzle, U.S. Fish & Wildlife Service
Layne Hamilton, FWS
Bill Hammond, Florida Gulf Coast University
Richard Harvey, EPA
Bobbie Lee Hasty, Sierra Club
Ann Hauck, Council of Civic Associations
Pam Hayford, News-Press
John Hobbie, Marine Biological Laboratories
Wayne Huber, Oregon State University, CROGEE
Stephen Humphrey, Florida State University, CROGEE
Patricia Jones Kershaw, National Research Council

Jim Krakowski, FWS
Bonnie Kranzer, SFWMD
Jerry Krenz, SFWMD
Elmar Kurzbach, USACE
Linda Lindstrom, SFWMD
Will Logan, National Research Council
D. Pete Loucks, Cornell University, CROGEE
Kathy Malone, Council of Civic Associations
John Marshall, Art Marshall Foundation
Frank Mazzotti, University of Florida
Scott Nixon, University of Rhode Island,
CROGEE Vice Chair
John Ogden, SFWMD
Peter Ortner, NOAA
Keith Overton, USGS
Stephen Parker, National Research Council
Eduardo Patino, USGS
Sue Perry, Everglades National Park
Bill Perry, Everglades National Park
Ellen Peterson
David Policansky, National Research Council
Ken Potter, University of Wisconsin, CROGEE
Larry Robinson, Florida A&M University,
CROGEE
David Rudnick, SFWMD
Brian Scherf, Florida Bidoversity Project
Susanne Schlotzhauer, BEM Systems, Inc.
Carol Senne, SFWMD
Larry Shannon
James Tate, U.S. Dept. of Interior
Kris Thoemke, International College
Robert Timmeney, Project Phoenix
Greg Tolley, SWFRPC
Arturo Torres, USGS
Steve Trexler, Florida International University
Kelly Unger, USACE
John Vecchioli, CROGEE
Jeffrey Walters, Virginia Polytechnic Institute
and State University, CROGEE
Naiming Wang, SFWMD

Appendix B

WATER SCIENCE AND TECHNOLOGY BOARD

RICHARD G. LUTHY, *Chair,* Stanford University, Stanford, California
JOAN B. ROSE, *Vice Chair,* Michigan State University, East Lansing
RICHELLE M. ALLEN-KING, Washington State University, Pullman
GREGORY B. BAECHER, University of Maryland, College Park
KENNETH R. BRADBURY, Wisconsin Geological and Natural History Survey, Madison
JAMES CROOK, Water Reuse Consultant, Norwell, Massachusetts
EFI FOUFOULA-GEORGIOU, University of Minnesota, Minneapolis
PETER GLEICK, Pacific Institute for Studies in Development, Environment, and Security, Oakland, California
JOHN LETEY, JR., University of California, Riverside
DIANE M. MCKNIGHT, University of Colorado, Boulder
CHRISTINE L. MOE, Emory University, Atlanta, Georgia
ROBERT PERCIASEPE, National Audubon Society, Washington, D.C.
RUTHERFORD H. PLATT, University of Massachusetts, Amherst
JERALD L. SCHNOOR, University of Iowa, Iowa City
LEONARD SHABMAN, Resources for the Future, Washington, D.C.
R. RHODES TRUSSELL, Montgomery Watson, Pasadena, California

Staff

STEPHEN D. PARKER, Director
LAURA J. EHLERS, Senior Staff Officer
JEFFREY W. JACOBS, Senior Staff Officer
WILLIAM S. LOGAN, Senior Staff Officer
LAUREN ALEXANDER, Staff Officer
MARK C. GIBSON, Staff Officer
STEPHANIE E. JOHNSON, Staff Officer
M. JEANNE AQUILINO, Administrative Associate
ELLEN A. DE GUZMAN, Research Associate
PATRICIA JONES KERSHAW, Study/Research Associate
ANITA A. HALL, Administrative Assistant
JON Q. SANDERS, Senior Project Assistant

BOARD ON ENVIRONMENTAL STUDIES AND TOXICOLOGY

Appendix C
Biographical Sketches of Members of the Committee on Restoration of the Greater Everglades Ecosystem

JEAN M. BAHR, CHAIR, is professor in the Department of Geology and Geophysics at the University of Wisconsin-Madison where she has been a faculty member since 1987. She served as chair of the Water Resources Management Program, UW Institute for Environmental Studies, from 1995-99 and she is also a member of the Geological Engineering Program faculty. Her current research focuses on the interactions between physical and chemical processes that control mass transport in ground water. She earned a B.A in geology from Yale University and M.S. and Ph.D. degrees in applied earth sciences (hydrogeology) from Stanford University. She has served as a member of the National Research Council's Board on Radioactive Waste Management and several of its committees. She is a National Associate of the National Academies.

SCOTT W. NIXON, VICE-CHAIR, is professor of oceanography at the University of Rhode Island. He currently teaches both graduate and undergraduate classes in oceanography and ecology. His current research interests include coastal ecology, with emphasis on estuaries, lagoons, and wetlands. He is a member of the NRC's Ocean Studies Board and has severed on several of its committees. Dr. Nixon received a B.A. in biology from the University of Delaware and a Ph.D. in botany/ecology from the University of North Carolina-Chapel Hill.

JOHN S. ADAMS is professor and chair of the Department of Geography at the University of Minnesota. He researches issues relating to North American cities, urban housing markets and housing policy, and regional economic development in the United States and the former Soviet Union. He has been a National Science Foundation Research Fellow at the Institute of Urban and Regional Development, University of California at Berkeley, and economic geographer in residence at the Bank of America World Headquarters in San Francisco. He was senior Fulbright Lecturer at the Institute for Raumordnung at the Economic University in Vienna and was on the geography faculty of Moscow State University. He has taught at Pennsylvania State University, the University of Washington, and the U.S. Military Academy at West Point. His most recent book, Minneapolis-St. Paul: People, Place, and Public Life, looks at the region's growth and at what factors may affect the metropolitan area's future. Adams holds two degree in economics and a doctorate in urban geography from the University of Minnesota.

BARBARA L. BEDFORD is a Senior Research Associate at Cornell University. She joined the Department of Natural Resources in 1989, having served as the Associate Director of Cornell University's Ecosystems Research Center since 1980. Her research focuses on wetland plant diversity, what controls it, how human actions affect it, and how to manage it. She and her students work primarily in fens, bogs, riparian wetlands, and Great Lakes wetlands. Current projects include: (a) relationship of groundwater hydrology and chemistry to nutrient availability, plant productivity, and plant species diversity; (b) inter-relationships among nutrient availability, plant tissue chemistry, and plant species diversity; (c) landscape control of wetland biogeochemistry and hydrology; (d) effects of removing cattails on fen species composition and diversity; and plant species diversity in phosphorus-poor wetlands. She teaches courses in Wetland Ecology and Management and Landscape Analysis. She served on the NRC Committee on Review of Scientific Research Programs at the Smithsonian Institution, and the Committee on Wetlands Characterization. She received a B.A. from Marquette University in 1968, and her M.S. and Ph.D. from the University of Wisconsin at Madison in 1977 and 1980, respectively.

LINDA K. BLUM is research associate professor in the Department of Environmental Sciences at the University of Virginia. Her current research projects include study of mechanisms controlling bacterial community abundance, productivity, and structure in tidal marsh creeks; impacts of microbial processes on water quality; organic matter accretion in salt marsh sediments; and rhizosphere effects on organic matter decay in anaerobic sediments. Dr. Blum earned a B.S. and M.S. in forestry from Michigan Technological University and a Ph.D. in soil science from Cornell University. She chaired the NRC committee that recently completed a study of the Critical Ecosystem Studies Initiative.

PATRICK L. BREZONIK is professor of environmental engineering and director of the Water Resources Research Center at the University of Minnesota. Prior to his appointment at the University of Minnesota in the mid-1980s, Dr. Brezonik was professor of water chemistry and environmental science at the University of Florida. His research interests focus on biogeochemical processes in aquatic systems, with special emphasis on the impacts of human activity on water quality and element cycles in lakes. He has served as a member of the National Research Council's Water Science and Technology Board and as a member of several of its committees. He earned a B.S. in chemistry from Marquette University and a M.S. and Ph.D. in water chemistry from the University of Wisconsin-Madison.

FRANK W. DAVIS is a Professor at the University of California Santa Barbara (USCB) with appointments in the Donald Bren School of Environmental Science and Management and the Department of Geography. He received his B.A. in biology from Williams College and a Ph.D. from the Department of Geography and Environmental Engineering at The Johns Hopkins University. He joined the Department of Geography at UCSB in 1983, and established the UCSB Biogeography Lab in 1991. His research focuses on the ecology and management of California chaparral and oak woodlands, landscape ecology, regional conservation planning, and spatial decision support systems. He was Deputy Director of the National Center for Ecological Analysis and Synthesis between 1995 and 1998, and currently directs the Sierra

Nevada Network for Education and Research Page. Dr. Davis has been a member of three prior NRC committees.

WILLIAM L. GRAF is Education Foundation University Professor and Professor of Geography at the University of South Carolina. His specialties include fluvial geomorphology and hydrology, as well as policy for public land and water. His research and teaching have focused on river-channel change, human impacts on river processes, morphology, and ecology, along with contaminant transport and storage in river systems. In the arena of public policy, he has emphasized the interaction of science and decision making, and the resolution of conflicts among economic development, historical preservation, and environmental restoration for rivers. He has authored or edited 7 books, written more than 120 scientific papers, book chapters, and reports, and given more than 90 public presentations. He is past President of the Association of American Geographers and has been an officer in the Geological Society of America. President Clinton appointed him to the Presidential Commission on American Heritage Rivers. His NRC service includes past membership on the Water Science and Technology Board and present membership on the Board on Earth Sciences and Resources. He chaired the NRC Committee on Research Priorities in Geography at the U.S. Geological Survey and the Committee on Watershed Management, and was a member of several other NRC committees. He is a National Associate of the National Academies. His Ph.D. is from the University of Wisconsin, Madison.

WAYNE C. HUBER is professor and head of the Department of Civil, Construction, and Environmental Engineering at Oregon State University. Prior to moving to Oregon State in 1991, he served 23 years on the faculty of the Department of Environmental Engineering Sciences at the University of Florida where he engaged in several studies involving the hydrology and water quality of south Florida regions. His technical interests are principally in the areas of surface hydrology, stormwater management, nonpoint source pollution, and transport processes related to water quality. He is one of the original authors of the Environmental Protection Agency's Storm Water Management Model (SWMM) and continues to maintain the model for the EPA. Dr. Huber holds a B.S. in engineering from the California Institute of Technology and an M.S. and Ph.D. in civil engineering from the Massachusetts Institute of Technology.

STEPHEN R. HUMPHREY is dean of the College of Natural Resources and Environment at the University of Florida where he also serves as affiliate professor of Latin American studies, wildlife ecology, and zoology. He also has been the curator in ecology for the Florida Museum of Natural History since 1980. Dr. Humphrey has authored and co-authored numerous articles and books on the effects of urbanization on wildlife. He holds B.A. in biology from Earlham College in Richmond, Indiana and a Ph.D. in zoology from Oklahoma State University. He is former chair of the Environmental Regulatory Commission of the Florida Department of Environmental Regulation and a member of the Florida Panther Technical Advisory Council of the Florida Game Commission.

DANIEL P. LOUCKS is professor of civil and environmental engineering at Cornell University. His research, teaching, and consulting interests are in the application of economics, engineering, and systems theory to problems involving environmental and water resources development and management. Dr. Loucks has taught at a number of universities in the United States and abroad and has worked for the World Bank, and the International Institute for

Applied Systems Analysis. He also served as a consultant to a variety of government and international organizations concerned with resource development and management. He is a member of the National Academy of Engineering and has served on several National Research Council committees.

KENNETH W. POTTER is professor of civil and environmental engineering at the University of Wisconsin-Madison. His expertise is in hydrology and water resources, including hydrologic modeling, estimation of hydrologic risk, estimation of hydrologic budgets, watershed monitoring and assessment, and aquatic ecosystem restoration. He received his B.S. in geology from Louisiana State University and his Ph.D. in geography and environmental engineering from The Johns Hopkins University. He has served as a member of the NRC's Water Science and Technology Board and several of its committees.

KENNETH H. RECKHOW is a professor of water resources at Duke University and is the director of the Water Resources Research Institute at North Carolina State University. Dr. Reckhow's research interests focus on the development, evaluation, and application of models for the management of water quality. In particular, he is interested in the effect of uncertainty on model specification, parameter estimation, and model applications. Recent work has expanded this theme to consider the effect of scientific uncertainties on water quality decision making. He recently chaired the NRC Committee to Assess the Scientific Basis of the Total Maximum Daily Load Approach to Water Pollution Reduction. He was also a member of the NRC Committee to Improve the U.S. Geological Survey National Water Quality Assessment Program. Dr. Reckhow received a B.S. in engineering physics from Cornell University and an M.S. and Ph.D. in environmental science and engineering from Harvard University.

LARRY ROBINSON is director of the Environmental Sciences Institute at Florida A&M University where he is also a professor. At Florida A&M University he has led efforts to establish B.S. and Ph.D. programs in environmental science in 1998 and 1999, respectively. His research interests include environmental chemistry and the application of nuclear methods to detect trace elements in environmental matrices and environmental policy and management. Previously he was group leader of a neutron activation analysis laboratory at Oak Ridge National Laboratory (ORNL). At ORNL he served on the National Laboratory Diversity Council and was President of the Oak Ridge Branch of the NAACP. Dr. Robinson earned a B.S. in chemistry, summa cum laude, from Memphis State University and a Ph.D. in nuclear chemistry from Washington University in St. Louis, Missouri.

REBECCA R. SHARITZ is professor of botany at the University of Georgia and senior scientist at the Savannah River Ecology Laboratory in Aiken, South Carolina, where she has been the Head of the Division of Wetlands Ecology. Her research focuses on ecological processes in wetlands, including factors affecting the structure and function of bottomland hardwood and swamp forest ecosystems, responses of wetland communities to environmental disturbances, and effects of land management practices on nearby wetland systems. Dr. Sharitz has served on several NRC committees. She received a B.S. in biology from Roanoke College and a Ph.D. in botany and plant ecology from the University of North Carolina.

HENRY J. VAUX, JR. is professor of resource economics at the University of California, Riverside. He currently serves as Associate Vice President - Agricultural and Natural Resource

Programs for the University of California system. He previously served as Director of the University of California Water Resource Center. His principal research interests are the economics of water use and water quality. Prior to joining the University of California he worked at the Office of Management and Budget and served on the staff of the National Water Commission. He received a Ph.D. in economics from the University of Michigan in 1973. He recently served as chair of the Water Science and Technology Board, has served on many NRC committees, and is a National Associate of the National Academies.

JOHN VECCHIOLI retired as a hydrologist with the U.S. Geological Survey's Water Resources Division in Tallahassee, Florida and as chief of the Florida District Program. Previously, he was responsible for quality assurance of all technical aspects of ground water programs in Florida. His research interests have included study of hydraulic and geochemical aspects of waste injection in Florida and of artificial recharge in Long Island, N.Y. He has also done research on ground water-surface water interactions in New Jersey and Florida. Mr. Vecchioli received his B.S. and M.S. in geology from Rutgers University. Mr. Vecchioli previously served on the NRC's Committee on Ground Water Recharge.

JEFFREY R. WALTERS is Bailey Professor of Biology at Virginia Polytechnic Institute and State University, a position he has held since 1994. His professional experience includes assistant, associate, and full professorships at North Carolina State University from 1980 until 1994. Dr. Walters has done extensive research and published many articles on the red-cockaded woodpeckers in North Carolina and Florida and he chaired an American Ornithologists Union Conservation Committee Review that looked at the biology, status, and management of the Cape Sable Seaside Sparrow, a bird native to the Everglades. He is a fellow of the American Ornithologist Union, a member of Sigma Xi, American Society of Naturalists, Animal Behavior Society, Audubon Society, Cooper Ornithological Society, Ecological Society of America, Phi Beta Kappa, and many other scientific organizations. His research interests are in cooperative breeding in birds; reproductive biology of precocial birds; primate intragroup social behavior; evolution of cooperative breeding in birds; ecological basis of sensitivity to habitat fragmentation; kinship effects on behavior; and parental behavior on precocial birds. He holds a B.A. from West Virginia University and a Ph.D. from the University of Chicago.

Appendix D

ACRONYM LIST

AAT	Adaptive Assessment Team
AET	Alternative Plan Evaluation Team of the Central and South Florida Restudy
ATLSS	Across Trophic Level System Simulation
CERP	Comprehensive Everglades Restoration Plan
CROGEE	Committee on Restoration of the Greater Everglades Ecosystem
CSFP	Central and South Florida Project
DQO	Data Quality Objectives
ELM	Everglades Landscape Model
ENP	Everglades National Park
ESA	Endangered Species Act
FPAR	Fraction of Photosynthetically Active Radiation
GEE	Greater Everglades Ecosystem
IBI	Index of Biotic Integrity
LAI	Leaf Area Index
MAP	Monitoring and Assessment Plan
MODIS	Moderate Resolution Imaging Spectrometer
NDVI	Normalized Difference Vegetation Index
NRC	National Research Council
NSM	Natural Systems Model
QA/QC	Quality Assurance/Quality Control
QAPP	Quality Assurance Project Plan
RECOVER	Restoration Coordination and Verification Team
SFERTF	South Florida Ecosystem Restoration Task Force
SFWMD	South Florida Water Management District
USFWS	U.S. Fish and Wildlife Service

Appendix E
Monitoring and Assessment Plan

MARCH 29, 2001

MONITORING AND ASSESSMENT PLAN

COMPREHENSIVE EVERGLADES RESTORATION PLAN

CENTRAL & SOUTHERN FLORIDA PROJECT

COMPREHENSIVE EVERGLADES RESTORATION PLAN

U.S. Army Corps of Engineers
Jacksonville District

South Florida
Water Management District

Comprehensive Everglades Restoration Plan
Monitoring and Assessment Plan

Table of Contents

I. Introduction and Background

The Comprehensive Everglades Restoration Plan (CERP) monitoring and assessment plan is a product of an interagency, interdisciplinary team known as Restoration Coordination and Verification (RECOVER). The Adaptive Assessment Team (AAT) of RECOVER has the lead responsibility for creating the monitoring and assessment plan, and for conducting an on-going review of how well it is working. In addition, the AAT has the responsibility to use the information that is provided by the monitoring program to assess system responses, as a basis for recommending improvements in the restoration plan where needed. Overall, the RECOVER Leadership Group holds accountability for the CERP monitoring and assessment program within RECOVER.

(1) Purpose of the Monitoring and Assessment Plan

The primary purpose of this monitoring and assessment plan is to identify and describe the performance measures and parameters of the natural and human systems in south Florida that should be measured in order to determine the success of the CERP. The goal is to create a single, integrated, system-wide monitoring and assessment program that will be used and supported by all participating agencies as the means for tracking and measuring the success of the Comprehensive Plan. This document identifies the specific set of physical and biological performance measures that should be monitored, the geographic regions where these measures should be monitored, and the improvements in these measures that should occur during and following the implementation of the Comprehensive Plan. Collectively these measures will serve as indicators of the overall health of natural and human systems in south Florida, relative to the objectives of CERP. This monitoring and assessment program is required as a basis for determining whether CERP achieves these objectives (i.e., the recovery of healthy and sustainable ecosystems throughout south Florida and an improved environment for people), and to support an adaptive assessment process for refining and improving the design and operation of CERP throughout its implementation.

This is a system-wide monitoring and assessment program, designed solely for assessing how well CERP meets the system-wide objectives of ecosystem restoration and water supply. Each CERP project will develop a separate, local monitoring plan to assess the success of the individual project. To ensure that measures and targets selected by the project teams are consistent with system-wide measures, each project team should review this system-wide plan.

As a prerequisite to the implementation of the CERP monitoring and assessment plan, RECOVER is preparing four additional planning documents that will substantially expand upon the summaries provided below. These are:

1) an integrated and standardized system-wide sampling design and data management protocol for the monitoring plan (subsection 4);
2) an adaptive assessment strategy explaining how the AAT will use the monitoring data to conduct annual assessments of system-wide responses (subsection 6);

3) a detailed monitoring plan implementation strategy (subsection 7); and
4) a research needs document in support of the monitoring and assessment plan (Section IV).

In addition to these four planning documents, RECOVER prepares (and revises annually) a Program Management Plan. This management plan describes the tasks and responsibilities for all South Florida Water Management District and U.S. Army Corps of Engineers activities pertaining to RECOVER for a three-year planning period. The RECOVER management plan includes a budget for all monitoring and assessment tasks.

The CERP monitoring and assessment plan is organized into five sections. Section I, the Introduction and Background, provides a broad overview of the purpose of the monitoring plan, how it was created, and how it should be applied. Section II contains the narrative descriptions and flow diagrams for the set of nine conceptual ecological models that provide the technical foundation for most of the natural system performance measures that have been incorporated into the monitoring plan. Section III contains the technical documentation sheets for each of the CERP performance measures that make up the monitoring plan. This section includes a description of the process used to develop and screen the biologic, hydrologic, and water quality performance measures comprising the CERP monitoring and assessment plan. These documentation sheets identify the specific parameters of the natural and human systems that are to be monitored, the geographic region where each is to be monitored, and the restoration targets for each. Section IV is a summary of the uncertainties associated with the hypotheses in the ecological conceptual models and a recommendation for research needs in support of CERP. The research listing identifies studies needed to reduce uncertainties in the model hypotheses in order to improve the ability of RECOVER teams to predict and interpret system responses. Section V is a set of spreadsheets, to be revised annually, for purposes of tracking the status of each element in the monitoring plan.[1] Additional information on the content of each section is provided in the introductory paragraphs for each of the subsequent sections. Specific monitoring protocols, i.e., how the elements should be monitored individually and collectively, will be determined through consultation with the agency(s) or organizations responsible for implementing the data management program and the elements of the monitoring plan as well as outside consultants.

The content and adequacy of the CERP monitoring and assessment plan will be regularly reviewed by the AAT and the full RECOVER team, by all participating agencies, and by independent reviewers. Changes in the monitoring and assessment plan will be approved by the AAT. During the initial reviews of the monitoring plan the number and focus of the performance measures may be revised, due to on-going efforts to maximize the efficiency and coverage of the monitoring effort, while at the same time attempting to settle on the smallest number of measures necessary to track system-wide responses to CERP. As part of this initial review, the AAT will continue to examine the biological performance measures that are contained in this draft. The objective of this continuing review is to insure that the biological measures have been carefully selected and designed to effectively track responses by the components of the key restoration hypotheses

[1] Note that this section is not included in this review draft of the monitoring and assessment plan.

contained in the conceptual ecological models. However, once the initial monitoring and assessment plan is reviewed and approved, it is not expected that large-scale changes will occur or would be desirable.

(2) What are Monitoring and Assessment?

Monitoring and assessment are critical components in the CERP adaptive assessment protocol and as such, merit clear definitions. Monitoring is the systematic process of collecting and storing data related to particular natural and human systems at some specified locations and times. Assessment is the process whereby monitoring data are interpreted in the context of particular questions and issues, such as tracking progress towards certain restoration objectives. Assessment also includes the development of statistical relationships from the monitoring data, other model development and application, and cause-effect research linked directly to the objectives of the restoration program. Monitoring can be used to document the status and trends of elements within the ecosystem over a range of temporal and spatial scales, and provide feedback that can be used to assess whether the predicted results are being achieved. It also provides information that can be used to help refine or modify actions to ensure that the targets for the project are being met.

When applied to natural ecosystems where maintenance in their current condition is desired, monitoring can be used to evaluate whether there are aspects of the ecosystem that are varying beyond what would be expected under the influence of natural processes. When monitoring is applied to disturbed ecosystems that are being restored, monitoring can be used to evaluate whether the ecosystem is moving in the desired direction. Monitoring can also determine when the ecosystem has moved within the bounds of what is defined as the restored condition.

It is important to be aware that rates of change, and thus the time required to document them, are often very different depending on the element being measured. Site history, landscape setting, the kind, degree, and direction of change, the potential rates of change for each parameter, and the level of applied effort in restoration projects can all affect rates of change. Restoration of some disturbed ecosystems can only be considered in geologic time frames because of the degree of disturbance that has occurred on these sites. In addition, other aspects of the South Florida ecosystem, including both restoration and development activities, will inevitably be changing at the same time, further complicating the ability to assess the success of the individual restoration components. It is essential that these differences in rates of change be factored into the assessments of environmental responses.

In the context of RECOVER, monitoring has been defined in an adaptive assessment strategy (An Adaptive Assessment Strategy for the Comprehensive Everglades Restoration Plan; AAT, 2000) as having four objectives:

1) Establish base-line variability for each of the performance measures;
2) Determine the status and trends among the performance measures;

3) Detect unexpected responses for components or measures of the ecosystem that have not been specifically identified as CERP performance measures; and
4) Cause-and-effect scientific investigations designed to increase ecosystem understanding, particularly if restoration implementation yields unanticipated results.

Addressing these objectives will allow the determination of how CERP is affecting the physical, biological, and chemical components of the system, and to increase scientific understanding of how the system works. Knowledge of how the system is changing in response to CERP restoration actions combined with investigations of cause-and-effect relationships will contribute to the refinement of CERP projects to ensure that targets are being met. It is recognized that this monitoring plan does not include all of the measures necessary to document the long-term “restoration” of all systems in south Florida (e.g., some upland systems in undeveloped and developed landscapes), but it will provide a minimal set of measures for those systems directly affected by CERP.

(3) What Should Be Monitored?

In General

The main point of environmental monitoring is to detect change or lack of change over time, and to provide information sufficient to understand the causes of these patterns so that appropriate actions can be taken to manage the ecosystem for a desired condition. Part of the challenge in designing and sustaining a successful monitoring program is to select a limited set of parameters that adequately convey whether the ecosystem is or is not changing, in what direction it is changing, whether these changes are natural or a result of human actions, and if the latter, whether the changes improve or adversely affect the ecosystem in some significant way.

Prior to determining whether a change in condition or state has occurred, it is necessary to establish the initial or baseline conditions. Baseline information provides the benchmark against which the progress of the restoration plan can be measured, and to understand the ranges of natural variability necessary to confirm when change has actually occurred. While some regions of the Everglades ecosystem have well established monitoring programs, other areas have little or no baseline data. Plugging the gaps in baseline conditions is one of the critical components of the monitoring and assessment plan.

There are different approaches that can be used for selecting the best suite of monitoring parameters. One can select parameters that are considered to be the major stressors or processes that control the context within which an ecosystem operates. With this approach it is assumed that as long as the major processes are operating appropriately, the ecosystem is functioning appropriately.

Alternately, parameters such as individual species or groups of species that are considered to be indicators of the processes operating within the ecosystem can be selected. This approach assumes that unless all of the significant processes are operating appropriately, these indicators could not exist in this ecosystem at normal population levels.

This mix of constraints on the ability to detect either desirable change resulting from restoration or undesirable change in an ecosystem argues for monitoring a mix of both basic processes and integrators. This and the ever-present possibility of unanticipated ecosystem changes also argue for the use of as many monitoring parameters as are "feasible" from as broad a spectrum of ecosystem parameters as possible. In practical terms, "feasible" means that there are good assurances that the parameters can be measured and understood over sufficient time periods to determine the long-term affects of management or a restoration program.

The performance measures in this monitoring plan are planning and assessment tools that were approved (and in most cases also developed) by the CERP planning teams to identify the objectives for the restoration plan. Each performance measure identifies one or more components of the natural and human systems in south Florida that CERP has been designed to improve. The performance measures may be used in evaluation of proposed changes (primarily where simulation models exist) and as field indicators that the appropriate change has occurred.

These performance measures have, for the most part, been selected through two CERP planning processes; 1) the C&SF Project Comprehensive Review Study's (Restudy) Alternative Evaluation Team (AET) and 2) the RECOVER Regional Evaluation, Adaptive Assessment, and Water Quality teams.

Restudy/AET process

Between 1996 – 1999, during the Restudy feasibility phase of CERP, an interdisciplinary, interagency team of biologists, ecologists, and other resource specialists (AET) developed a set of performance measures as the basis for designing and evaluating alternative restoration plans. Each performance measure was implicitly linked to one or more planning objectives, and consisted of a measurable indicator and target. Because a key tenet of south Florida ecosystem restoration is that hydrologic restoration is a necessary starting point for ecological restoration, the performance measures created by the AET were largely indicators of hydrologic characteristics, consistent with what is known or hypothesized about the optimum hydrologic patterns for a number of characteristic plant and animal communities in the historic Everglades.

These performance measures described hydrological parameters, data format and hydrological targets originally used by the AET to evaluate hydrologic simulation of alternative plans. Refined versions of these hydrologic performance measures are included in this monitoring plan for their value in setting hydrological targets for CERP, and for evaluating how well CERP implementation corrects the hydrological problems in the natural and human systems.

Conceptual Model process

The Restudy included an Applied Science Strategy that will now be used to link science and management during all phases of CERP. An essential step in this strategy has been the creation and refinement of a set of nine conceptual ecological models, each for a different physiographic region of south Florida. The models link stressors on the ecosystem to ecological attributes that are considered to be indicators of ecosystem health. Each of these linkages represents a working hypothesis based upon current knowledge of the ecosystem.

The overall Restudy strategy was to use the conceptual models as a basis for reducing the total number of performance measures from an almost infinite number of potential measures in the natural and human systems of south Florida to a manageable number of major key indicators of environmental conditions. The models allowed for the selection of a parsimonious set of performance measures directly based on the stressors and attributes in each model. These measures collectively describe the physical and biological conditions that will be used to define a successfully restored natural system.

The rationale for having performance measures and targets for each stressor is that the stressors are known or hypothesized to be the immediate sources of the ecological problems in each landscape. A successful restoration program must eliminate the unnatural stresssors acting on the natural systems. A performance measure describes the stressor and how that stressor should be measured, and how that stressor must change in order to neutralize its adverse effects. The hydrological performance measures for the natural system that were developed by the AET were for the most part derived from the hydrological stressors in these models.

Performance measures have also been developed for each attribute in the conceptual models. The attributes have been identified as the biological or ecological elements that are the best indicators of responses in the natural systems to the adverse effects of the stressors. The hypotheses used to construct the conceptual models link each attribute to the stressor(s) that are most responsible for change in that attribute. If the hypotheses are correct, neutralizing the adverse affects of the stressor will result in a predictable positive response by the attribute. The performance measure developed for each attribute identifies the element(s) of that attribute that should respond, how the element(s) should be measured, and how the element(s) should change once the effects of the stressor are removed.

The conceptual models also were used to identify uncertainties in knowledge in the linkages among the stressors and attributes. These uncertainties identify where additional research is needed to ensure the success of CERP and is discussed in Section IV.

Development of Water Quality Performance Measures

A number of the performance measures developed during the Restudy/AET process specifically focused on water quality. Water quality is identified as a stressor in several of the conceptual models. The linkages between water quality, hydrology and biology are complex and led to the decision to create a team that focuses on water quality as part of the RECOVER process. Refinement of water quality performance measures for RECOVER were conducted through the application of water quality and landscape models, empirical analyses, and results of on-going research.

Selection of performance measures for this plan

Over 900 performance measures and indicators resulted from the above processes. The monitoring and assessment plan must be sustainable for perhaps five decades or longer if it is to be successful in guiding CERP throughout its implementation and subsequent operation. The high cost of monitoring a large number of parameters over a large area and a long period of time is a major reason that many monitoring plans in support of adaptive assessment and management have failed to be sustainable. Therefore, it is crucial to identify a minimum set of performance measures that will indicate whether CERP is achieving ecological recovery of the greater Everglades ecosystem and is meeting its water supply and flood protection objectives.

Determining this minimum set of parameters from the many performance measures that were proposed was one of the tasks of the AAT's Editorial Team. This task was accomplished by organizing the submitted performance measures into broad categories, and reviewing the performance measures in each category to determine where overlapping measures could be combined. Measures were combined when two or more had similar locations, parameters or targets (see Section III for details). The result is a list of ~150 performance measures (~60 biological and soils, ~20 hydrological and ~70 water quality) with identification of the information they provide to assess system-wide CERP performance.

The refinement of the performance measures is an on-going process. It is essential that the monitoring and assessment plan address the key restoration hypotheses, and that it focus on a sustainable number of performance measures. Long-term monitoring and assessment efforts fail if they are too large, too complicated, too expensive, or if the results can not be interpreted within the context of the key hypotheses. The next steps in the evolution of this monitoring and assessment plan is for the Adaptive Assessment team to re-exam the current set of recommended measures in the context of their linkages as outlined in the conceptual models. As part of this review, the measures will be grouped into logical, hypothesis-based packages as a basis for designing a more efficient system-wide monitoring protocol. The selection of these key hypotheses provides the focus for the monitoring and assessment program and for setting hypothesis-driven priorities in on-going and future natural systems research. The ultimate success of the CERP adaptive assessment program will depend on the acquisition of new information from an integrated program of modeling, monitoring and hypothesis-driven research. The general framework for this approach is further outlined in Section III of this monitoring and assessment plan.

(4) Monitoring Plan Design Strategy: Monitoring design considerations

Along with the identification of essential parameters to monitor, a monitoring network must be logistically economical, provide quantitative data, apply a standardized monitoring and data management protocol, and ensure that data analysis is done in ways insure that trends can be correctly recognized and tracked over time with confidence. There are a number of different approaches that can be taken in the design of a monitoring network that meets these design objectives. Although decisions regarding the details of the design protocol have yet to be determined, certain guiding considerations are provided here.

Field monitoring and laboratory methods must be standardized. All participating investigators in the monitoring and assessment program must use agreed-upon methods for collecting and managing monitoring data. Any changes in methods during the implementation of the monitoring and assessment plan will be documented.

A spatial framework for the monitoring network and its component performance measures needs to be defined. Selection of performance measures can best be done within this framework because: 1) the spatial scale of sampling will financially constrain the number of parameters that can be measured; 2) consideration of spatial domains that are consistent with the conceptual models will promote consideration of the interactions of performance measures and the need for grouping measures, rather than assessing measures independently; and 3) consideration of gradients will add realism to the conceptual model approach – the habitats included in the conceptual models are not isolated entities, but rather exist as part of a continuum across the landscape. Common performance measures of several habitats and how they change temporally across habitat ecotones needs to be assessed.

RECOVER should consider documenting changes across three important gradients that will be changed during the restoration: hydrologic, nutrient, and salinity gradients.

- Hydrologic gradients – restoration will change the spatial distribution of hydropatterns and associated plant and animal communities. Gradients from uplands through deeply inundated wetlands may shift over substantial distances.
- Nutrient gradients – must be able to detect effectiveness of water quality improvements in and near impacted zones, which generally are gradients oriented by discharge sources. Indirect hydrological effects on natural nutrient gradients must also be assessed (e.g. within mangrove zone).
- Salinity gradients – changing water quantity, distribution, and timing will cause changes in the location of salinity gradients and the salinity patterns along those gradients. This will yield biological responses that can best be assessed by sampling along these gradients.

Several monitoring design options are available. These options are not mutually exclusive, but each should be carefully assessed as to their advantages and disadvantages prior to selecting a design. Transects are an excellent approach toward assessing changes along gradients. These gradients are the most likely locations where ecological change will occur; transects maximize the ability to detect this change. A randomized design (like the EPA EMAP) or stratified randomized design is capable of spatially integrating broad-scale changes for the entire landscape area . This design is desirable if a broad spatial integration is the highest priority. A network of fixed stations that are based on existing monitoring networks can provide a larger data time series for comparison with post-restoration conditions (e.g. hydrological and water quality). Sites of special interest will provide information relative to unique species or communities and how they are affected by restoration (e.g. within selected reference or indicator areas).

If a transect design is chosen, sampling along gradients can either be completely randomized or stratified random sampling (depending on steepness of gradient or on habitat type); sample sites can be fixed for some parameters (with randomized initial selection) such as for ground water wells or individual trees. Likewise, if the focus is on indicator regions, sampling within these regions can be randomized or transect based (assuming these regions span recognizable gradients). See Appendix A for Indicator region maps.

Existing monitoring networks or sites (especially hydrologic and water quality sites) may be incorporated into the CERP monitoring program, to the maximum extent possible and consistent with the purposes of the existing programs. While there is a need to utilize historical data to assess long-term change, the CERP network should not be based on the existing network if this design is not appropriate for future needs.

A network of "indicator regions" created by the AET, and refined by the RECOVER Regional Evaluation Team, should be considered in the spatial design of the monitoring plan. Indicator regions are select groupings of cells (2-mile x 2-mile grid) within the Natural System Model and the South Florida Water Management Model. Each of the indicator regions was chosen on the basis of having relatively uniform hydrologic and vegetation characteristics. The indicator regions were used in simulation modeling to average model output over multiple similar cells as a way of reducing analytical uncertainties associated with single cell comparisons. The current set of indicator regions may provide preferred locations for a network of monitoring stations throughout the CERP restoration area. See Appendix A for indicator region maps.

Monitoring and research spatial design should be integrated. It is not efficient to have separate designs for hydrologic, water quality, and biological networks – these should be part of an integrated monitoring system to the extent possible. Because of the importance of this integration, it may be necessary to change the existing hydrologic and water quality network or the indicator region selections. Large-scale integration should be explored using aerial photography and remote sensing.

(5) How are monitoring data managed and analyzed?

The scientific and technical information generated from the system-wide monitoring and assessment program must be organized and analyzed in such a fashion to allow RECOVER to effectively evaluate CERP performance and system responses and to produce an annual assessment report describing and interpreting the responses. Development of appropriate database systems, data analysis protocols and outputs, and a data driven web interface are key to the successful implementation of the adaptive assessment process.

The design of the CERP monitoring data management and analysis system will be based on knowledge gained from the successful data management systems currently being used in several on-going regional monitoring programs in south Florida, including the Kissimmee River restoration program and the Lake Okeechobee ecological data-bases.

The data management and analysis system used to organize and archive data and reports generated from the system-wide monitoring program will be part of a centralized CERP shared data and information network infrastructure. This system will be designed and developed so that it integrates with other database components of the infrastructure. With guidance and direction from the AAT, the monitoring data management system will be evaluated, designed, developed, tested and implemented within the CERP Data Management Program. Additionally, appropriate user web-based interface tools to display and analyze the monitoring data will be designed and developed.

A separate program-level management and analysis plan for all CERP-related data will include the information technology necessary to collect, store and retrieve and analyze the data. The data management plan will describe the scope, schedule and costs associated with design, procurement, installation and configuration of the hardware, software, network, security and data communication lines that comprise the shared data and information network. The appropriate protocol and procedures for tracking and storing all documents, data and records needs to be established in the plan as well.

The data management and analysis system will be designed to facilitate electronic storage and retrieval of environmental data and reports as well as provide access to other information (modeling, socio-economic, costs and schedules, etc.) that may be needed to assess CERP performance. The system will be equally accessible to the SFWMD, the USACE and other participating agencies, and will consist of database servers and a web site that will allow a multitude of data types and relevant documents to be easily accessed and shared. The infrastructure and software will be designed to eliminate the potential for security and firewall breaches that could threaten the integrity of the system and the information it contains. The web site will also be used to post information and data for review by other agencies, stakeholder groups and the public.

The monitoring program database will contain all environmental (hydrologic, water quality, and biological) monitoring spatial and time series data tables that will be used to assess the effects of implementing CERP. The database will store documents, imagery and other tables (such as those that describe methods, conceptual models, performance measures, costs, etc.) that are needed to interpret or enhance understanding of the environmental data. Development of the database hinges on continued evolution of the conceptual models and listing of associated performance measures and monitoring needs to guide the process.

System development will also require acquisition/capture from multiple sources (CERP projects, external agencies, SFWMD, etc.) and inventory of all existing (and future) data that may be relevant to the performance measures. Types of data to be captured and archived in the system include: metadata, geospatial, time series, operations, engineering/construction designs, and technical reports/relevant research. Geospatial data includes, but is not limited to, surveys, maps, aerial photography, aerial imagery, and modeling coverages (biological, water quality and hydrological). There is a considerable amount of time series data generated from a number of on-going monitoring and research programs that will also need to be incorporated into the system.

To effectively manage these data and ensure that they can be easily stored, accessed and retrieved, and transferred by all authorized users, a set of standards, processes, procedures and tools will be established. The standards and procedures will address such topics as geospatial metadata, data projections, horizontal/vertical datums, file formats, compression techniques, file coding and file naming conventions for all data to be stored on the shared data and information network. A document management and control system/process will be developed and implemented to assist with organizing and tracking program documents and reports.

A quality assessment/quality control (QA/QC) process will be established to ensure that data generated from the monitoring program are checked for the proper integrity before being archived into the shared database.

The database system will be maintained, updated, quality assured and expanded to meet the needs of the adaptive assessment process, as necessary, and to accommodate continuous acquisition, storage, analysis and publishing of data. The system will require periodic hardware and software upgrades, along with possible purchase of additional disk space and memory.

A key component in a successful data management system is data analysis. The management system must produce data reports that present the monitoring data in formats that clearly support the Adaptive Assessment team in its task of interpreting system responses in the context of restoration targets. For this to happen, the raw monitoring data for each of the performance measures must be analyzed according to a protocol that is consistent with the guiding hypotheses and the restoration targets. The Adaptive Assessment team will have a lead role in determining the requirements for the design for data analysis for each of the performance measures, and for determining the required formats for the data reports.

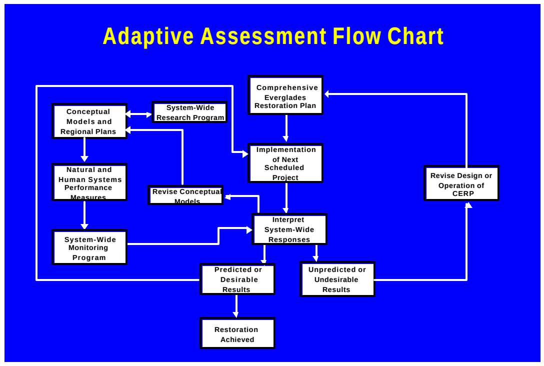
(6) How are monitoring data used to assess CERP performance?

The monitoring data will be analyzed, and used to support an adaptive assessment protocol that has been established in CERP as a means for tracking the results of CERP, and for improving its design and operation whenever unexpected and/or undesirable responses occur. The assessment will follow the protocol developed by the AAT (AAT 2000; Figure X). The actual responses that occur in the natural and human systems during and following the implementation of CERP will be compared to the trends and targets that have been established for each performance measure. These comparisons will serve as a basis for determining how successfully the CERP projects, individually and collectively, are moving these systems towards the plan's overall goals. It will be the combined responses from the full set of performance measures that will determine the overall success of CERP.

The CERP monitoring program is designed to track the responses by each of the restoration plan's performance measures. Empirical data from the monitoring program is fed into the CERP data management system. This data management system will convert the field data into formats that can be used by the RECOVER teams to interpret system responses to the CERP projects. Data management will include synthesis and analysis of the monitoring data, in order to create the data reports that will best support the assessment process.

Data analysis is an essential prerequisite to the task of interpreting system responses. Raw monitoring data must be converted into formats and reports that reveal the status and trends, patterns of variability, and probable responses to the effects of CERP, for each of the performance measures.

The AAT has the lead responsibility for reviewing and interpreting the analyzed outputs from the monitoring data, and for integrating new knowledge of the natural systems into the assessment process, as a basis for tracking the success of CERP. A protocol will be developed that not only examines monitoring data for each of the individual performance measures, but also integrates these into an overall assessment of system health/integrity. The AAT will issue annually a report on the performance of CERP. These reports will identify where ecosystem responses to CERP are on track to meet the goals of the plan, and/or where undesirable responses are being detected. Where undesirable responses occur, or may be anticipated based on initial interpretations of monitoring and research data, the annual reports will suggest whether the causes of these responses are due to some structural or operational component of the restoration plan or are external to the plan. The Comprehensive Plan Refinement Team of RECOVER will use these AAT reports as a basis for coordinating efforts to recommend solutions to any problems in CERP's performance.



(7) Implementation of the Plan

The CERP Monitoring and Assessment Plan will be the tool by which the RECOVER team will assess the performance of CERP.   By necessity, the development of such an important plan is an iterative process. This is to ensure the technical soundness of the plan, the concurrence of the SFWMD and USACE, and the full participation of the other state, federal, and local partners, as well as the non-governmental organizations (NGOs) that are critical to the success of CERP.

The primary consideration of the Monitoring and Assessment Plan is the selection of key indicators that will describe the response of the ecosystem, as well as water supply and flood control, as CERP is implemented. The ecosystem performance measures were derived from a number of sources, including numeric hydrological and landscape models, and ecological conceptual models. Concerted efforts were made, and continue to be made, to include the best scientific and technical expertise in the development of the plan.

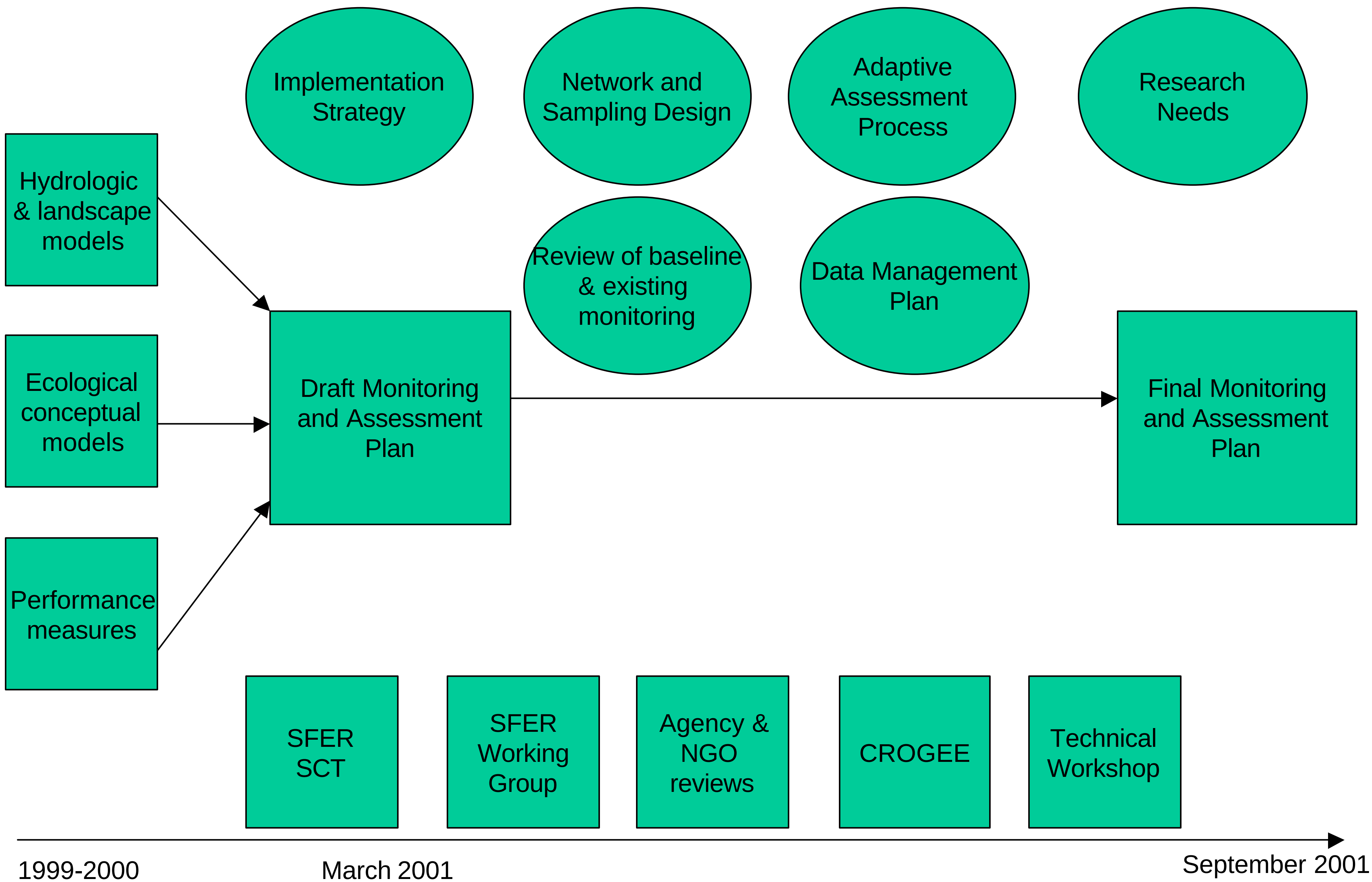
Another factor to consider in the development of the Monitoring and Assessment Plan is to ensure that it is sustainable over the life of CERP. This takes into consideration the complexity of the ecosystem, as well as the resource and funding needs, to carry forward a program over the next 20 to 30 years. Therefore, the Adaptive Assessment Team will continue to refine the plan during the first few years of implementation.

The March 20th draft Monitoring and Assessment Plan includes the revised ecological conceptual models, the proposed suite of performance measures, a preliminary outline of critical research areas, and the performance measure documentation sheets. Additional supporting documents are required to complete this plan. These include the implementation strategy, the monitoring network and sampling design, the adaptive assessment process, and the supporting research requirements. In addition, the AAT is conducting a review of current and baseline monitoring efforts as they pertain to the performance measures, and a review of other large-scale ecological restoration programs to learn how they developed and implemented their own monitoring and assessment process.

Over the next six months, the supporting documents will be developed and incorporated into the Plan (Fig 1). During this time, the Plan is also being distributed to a number of groups and agencies to solicit review comments. A technical workshop will also be held to present the final Plan and address any remaining issues. It is anticipated that the final Monitoring and Assessment Plan will be available by September 2000, with initial implementation of the plan occurring immediately thereafter.

Implementation of the monitoring and assessment activities is envisioned to be a phased effort, with the initial focus on filling the gaps in essential baseline data. The first year will also focus on optimizing the monitoring network and sampling design with the goal of incorporating those existing monitoring efforts that are consistent with the intent of the Plan. The final schedule will consider the time necessary for equipment purchase and installation, database development and set up, and quality assurance/quality control procedures. Initiation of monitoring at specific sites or regions will be coordinated with implementation of the various CERP components.

Figure 1: Monitoring and Assessment Plan Implementation Process



The CERP monitoring program consists of approximately 150 different biological, hydrological and water quality parameters. No single agency can or should have responsibility for conducting the full suite of monitoring tasks. Although lead responsibility for funding and implementing this monitoring program is held by the USACE and the SFWMD, the success of this program will depend on a long-term participation by a number of different south Florida resource agencies. Following are suggested guidelines for some of the tactical steps required to implement the CERP monitoring program. Some of these steps are, by necessity, sequential but many may be conducted simultaneously.

Selection of Performance Measures

- Determine the parameters of the natural and human systems in south Florida to be monitored, those which will best measure the success of CERP.

Peer Review of Plan

- Conduct an internal review of the monitoring plan within the SFWMD and USACE.
- Provide for external peer review of the monitoring plan (SCT, CROGEE).
- Introduce the monitoring plan to the south Florida agencies through the agency representatives on RECOVER, and through the South Florida Ecosystem Restoration Working Group.
- Facilitate agency reviews of the monitoring plan.

Monitoring Network Spatial and Temporal Design

- Review and evaluate regional monitoring programs for other large restoration efforts for their extent, operational protocols, data management processes, and funding basis relative to long-term needs of CERP (LTR program, EMAP, Kissimmee River, etc.).
- Bring in experts on monitoring network development and design methods, as well as on evaluating and determining monitoring methods and protocols for each performance measure.
- Identify the elements of the CERP monitoring program that are currently being monitored by one or more agencies, and incorporate, to the extent practical, these existing monitoring networks and infrastructure to achieve the objectives of adaptive assessment, while still meeting individual agency needs.
- Lay out and optimize the network at spatial scales and over time periods that are consistent with the scales of the implementation schedule for CERP and the expected system responses.

Monitoring Network Implementation Flexibility

- Design and implement the monitoring program with monitoring stations being phased in over the next one to three years.
- Where appropriate, refine and redirect existing environmental monitoring to better focus on needs of CERP.
- Identify monitoring gaps.
- Create a monitoring schedule, based on a prioritization process that focuses first on integrating existing monitoring programs and on new baselines (where none exist) that need to be established prior to implementation of the restoration program.

Capture and Inventory Historical Data for Performance Measures

- Conduct an inventory/analysis of existing historical performance measure data and determine a process for acquiring the data, evaluating its quality and organizing it for archival in the CERP data management system.

Assign Monitoring Responsibilities

- Assess the type and extent of external agency involvement in the implementation of monitoring tasks and determine which agency will be responsible for monitoring what performance measures and where.
- Assign to an appropriate entity, the responsibility for general oversight of the day-to-day operations and maintenance of the overall system.

Establish Standard Operating Procedures

- Develop protocols and standard operation procedures for data collection (i.e. sampling methods for each performance measure), instrumentation, data processing, lab analysis, quality control and assurance, flow and load calculation methods, and reporting format/schedule.
- Work with CERP Data Management Program team to establish a set of standards, process procedures and tools to effectively quality assure/quality control data and ensure it can be easily stored, accessed and retrieved, and transferred. Such standards and procedures include those for data validation and formatting criteria, station naming conventions, and metadata requirements (e.g., site registration, GPS coordinates, vertical datum, etc.) for the performance measures.

Integrate Program with Research and Projects

- Integrate RECOVER monitoring and assessment program with other research and modeling efforts and develop linkages between the RECOVER monitoring and project-specific monitoring.

Procurement Strategy

- Develop a SFWMD/USACE procurement strategy for monitoring services and resources that includes identification of outsourcing opportunities and possible M/WBE vendors and contractors
- Pre-qualify expertise of contractors.
- Develop standard scopes of work for MOUs, MOAs, contracts etc. with agencies and laboratories that will be collecting and analyzing data for the system-wide monitoring network.
- Outline a prioritization schedule for procuring required monitoring system instrumentation (telemetry, CR10s, autosamplers, etc.) and other capital needs as each phase of monitoring is implemented.

Review and Assess Effectiveness of Monitoring Program

- Conduct annual reviews of the monitoring program to determine the effectiveness of the program for measuring system responses and supporting an adaptive assessment process. The plan will be periodically fine tuned on a scientifically informed basis, including refining and enhancing performance measures to optimize the network, as needed.

- The AAT will prepare an annual adaptive assessment report on system responses, and will identify where CERP refinement may be needed.

(8) Uncertainties in system responses

In the development and selection of performance measures and the resultant monitoring and assessment plan, there are varying degrees of certainty regarding the expected system response as we construct and operate the various CERP projects. Performance measures derived from predictive models that have been calibrated and verified with empirical data, or through cause-and-effect experimentation, provide the most certainty as to their accuracy. However, this type of in-depth analysis and documentation of ecological processes is not routine or uniform across the ecosystem. Many of the performance measures are based on indirect, correlative approaches or best professional judgement. Therefore, it is anticipated that unexpected or "negative" responses may occur as we move through the CERP program.

To illustrate, each conceptual model for CERP links ecosystem stressors to attributes via a series of causal pathways. The linkages between stressors and attributes are the basis for predicted responses of the attributes to changes in the stressors. The linkages represent the present state of scientific knowledge of the ecosystem regarding causal effects of the hydrologic and water quality stressors on the attributes. The level of certainty in each linkage may vary from published causal relationships and models, to ongoing research and unpublished data, to research in comparable ecosystems, to field observations, to best professional judgement. Because large, complex ecosystems such as the Everglades may never be wholly understood or predictable based on research and modeling, the causal linkages represent working hypotheses with varying levels of certainty.

The levels of certainty in the conceptual ecological model linkages affect our ability to interpret ecological changes that are detected through the monitoring and assessment plan. Interpreting an ecosystem change during the implementation of CERP requires an understanding of the causal relationships of the ecological indicators to hydrology, water quality and other stressors that may be outside the influence of CERP. This will be particularly true when unexpected ecological responses occur. Understanding why unexpected responses occur will be fundamental to the role of adaptive assessment in guiding CERP throughout its implementation.

Assessment of the varying levels of certainty in the conceptual model linkages indicates strengths and weaknesses in the restoration expectations of CERP and in our ability to interpret ecological changes toward, or away from, those expectations. Low levels of certainty in the linkages identify highest-priority areas of research necessary to support and supplement the monitoring and assessment plan. Thus the conceptual models, and the levels of certainty in their linkages, yield a strategy for prioritized research and modeling, described in Section IV, that is driven by the adaptive assessment process.

The implementation of the monitoring and assessment plan will, over time, additionally help to raise the levels of certainties of CERP-related effects on the south Florida ecosystem.

(9) Perspectives on Successful Restoration

This section does not attempt to specifically answer the question of what is successful restoration. Rather it raises several key issues and identifies the key discussions that must occur on a continuing basis during the implementation of CERP, if a broad consensus regarding a collective vision of a successful restoration program is to be maintained and strengthened. To a large extent, the question of "what is successful restoration?" should strongly influence the decisions of "what should be monitored?".

The question of what is, or is not, successful restoration, is a complex issue, one that continues to be discussed by both scientists and the broader public. It is acknowledged that there currently is a range of definitions of "success" for CERP. The range of views on this question simply illustrates that there are many legitimate criteria that have been proposed for use in characterizing healthy, "restored" natural and human systems. Depending on which criteria are preferred, and there are different views on how the priorities should be set, there are different elements of these systems that can serve as indicators of successful restoration. Continuing discussion of these questions will result in the addition of new performance measures and in improvements to the existing set of measures.

CERP contains both natural system and human system goals. The performance measures and monitoring plan address an array of system-wide biological, ecological, water quality, water distribution, and depth and flow, water supply and flood protection objectives. Broadly stated, the success of CERP will have been achieved when the objectives described by the full suite of performance measures have been reached.

In the natural system, it is widely acknowledged that ultimate success should be determined through measures of ecological and biological responses. Hydrological and water quality objectives are essential precursors to the realization of the overall natural system restoration goals. How closely CERP must achieve these precursor objectives in order to meet its ecological objectives remains uncertain, in a system that is so greatly altered spatially, and where pre-drainage hydrological and ecological linkages are incompletely known.

A more pragmatic question is to ask how many, and which, of the total number of performance measures must be achieved before the plan is considered successful? And how closely to the desired objective that have been established for each measure does the plan's performance need to come? These questions over time will become more easily answered as understandings and agreements of what actually constitutes a healthy, "restored" natural system improve. The combined effects of continuing research coupled with improvements in public understandings of the natural systems of south Florida will inevitably lead to a growing consensus regarding the qualities of healthy natural and human environments. The current Comprehensive Everglades Restoration Plan, according to modeling, is predicted to return the natural system to a hydrological and ecological condition that is well within the boundaries of a “restored system” as defined by the performance measures used during the Central and Southern Florida Restudy. CERP is predicted also to largely meet its water supply objectives. The role of the monitoring plan and the adaptive assessment process are to increase the chances that these predictions are correct, while at the same time “raising the bar” for the overall objectives of CERP.

(10) Adaptive Assessment Team Editorial Team Members

The following people served as members of the ad hoc editorial team that drafted the CERP system-wide monitoring and assessment plan. For additional information on the monitoring and assessment plan, contact either of the AAT co-chairs, Laura Brandt (laura_brandt@fws.gov) or Susan Gray (sgray@sfwmd.gov), or the SFWMD’s RECOVER Program Manager, John Ogden (jogden@sfwmd.gov).

Tomma Barnes, South Florida Water Management District
Laura Brandt, U.S. Fish & Wildlife Service
Cheryl Buckingham, U.S. Army Corps of Engineers
Steve Davis, South Florida Water Management District
Juan Diaz-Carreras, South Florida Water Management District
Mike Duever, South Florida Water Management District
Susan Gray, South Florida Water Management District
Eric Hughes, U.S. Environmental Protection Agency
Linda Lindstrom, South Florida Water Management District
Agnes McLean, South Florida Water Management District
Brenda Mills, South Florida Water Management District
John Ogden, South Florida Water Management District
Joe Walsh, Florida Fish & Wildlife Conservation Commission

III. PERFORMANCE MEASURES AND DOCUMENTATION SHEETS

This section provides the recommended set of performance measures that form the foundation for the RECOVER monitoring and assessment program. It presents a technical documentation sheet for each recommended performance measure and identifies the categories of information that can be gained by monitoring each parameter. Each documentation sheet describes the parameter of the natural or human systems to be measured, in what geographic regions it is to be measured, and the restoration target. The details of how each parameter is to be measured, how the overall monitoring plan will be designed, (including further review of all of the performance measures to identify the most efficient, informative and cost-effective set of measures to support this regional monitoring program), and how the results of the monitoring will be evaluated will be developed by the AAT over the next few months from the general guidelines outlined in the Introduction

(1) Selection of Performance Measures

The current list of 156 CERP performance measures was developed from three categories of measures (Biological and Soils; Hydrologic; Water Quality) through a series of steps conducted by the AET and, more recently, by several teams of RECOVER. These steps were:

1) AET created a set of approximately 900 hydrological and water quality performance measures (with restoration targets) and performance indicators (without targets) used to evaluate alternative plans during the C&SF Restudy process.
2) AAT created additional biological performance measures based on the biological attributes in the nine conceptual ecological models.
3) RET removed all performance measures/indicators from the original AET list that lacked restoration targets (all indictors) or were not used by the AET during the Restudy plan evaluations.
4) The RET then organized the resulting set of hydrological performance measures into categories, screened and synthesized them within each category to create a new set of performance measures.
5) WQT developed a revised set of water quality performance for each region.
6) A technical documentation sheet for each performance measure was submitted to the AAT, RET or WQT.
7) AAT organized the biological and soil performance measures into broad categories, screened, and synthesized the measures within each category to create a list of 56 biological and 5 soil CERP performance measures.
8) WQT organized the water quality performance measures, screened and synthesized the measures to create a list of approximately 73 water quality CERP performance measures.
9) AAT and WQT teams categorized all performance measures according to the kinds of information that the monitoring data from each will provide to the assessment process.

10) The measures created by the AAT, RET and WQT were combined into a "final" list of approximately 156 CERP performance measures. Additional information on the screening and categorization criteria are provided below.

(2) Categorization of Performance Measures

Most monitoring plans fail because they try to do too much, exceed their resources, and in the end, fail to do enough. It was recognized that, even though the list of potential ecological performance measures had been limited to only a few hundred as compared to the almost infinite list of possible measures, it would still be impossible to monitor all of them everywhere. Therefore, a screening procedure was developed to review the submitted performance measures for the information that could be gained from them and their value to the monitoring plan.

The submitted performance measures were organized into the broad categories of:

- Biological-Animal including endangered species, keystone species, exotics, communities, and productivity, which were evaluated by the AAT.
- Biological-Plants including communities, invasive exotic and native species, and productivity, which were evaluated by the AAT.
- Soils, which were evaluated by the AAT.
- Water Quality, which were evaluated by the WQT
- Hydrologic including water supply, flood control, and natural system regimes, which were evaluated by the RET.

(3) Evaluation of Biological and Soil Performance Measures

Once the biological and soil performance measures were appropriately grouped, they were further evaluated to determine if any could be combined where the same performance measure was listed from multiple conceptual models, or where two or more were measuring the same components of the system, or could be monitored using similar procedures. This process helped to reduce the number of performance measures and provided a group of consolidated performance measures that could be evaluated for inclusion in the monitoring and assessment plan.

This grouping process condensed the number of biological and soils performance measures to a number still too large for a long term, sustainable monitoring plan. Therefore, a series of screening criteria were used to determine if the consolidated performance measures were suitable for inclusion in the CERP monitoring and assessment plan. In developing the criteria the AAT Editorial Team relied heavily on the list of general criteria developed by The National Research Council for ecological indicators for the nation (National Research Council 2000, *Ecological Indicators For The Nation*. National Academy Press, Washington, DC). In that document, they state, in part that "the challenge is deciding which rates of change to watch, and to determine which of the changes observed represent significant departures from expected natural variability." The AAT Editorial Team derived from the NRC list seven areas that should be considered in evaluating CERP performance measures. These fall generally into the four phases (Conceptual Relevance; Feasibility of Implementation; Response Variability; Interpretation and Utility) for indicator evaluation developed by the Environmental Protection Agency to assist with their Environmental Monitoring and Assessment Program (Jackson, Laura E., Janis C. Kurtz, William S. Fisher. 2000. *Evaluation Guidelines for Ecological Indicators*. U.S. Environmental Protection Agency Office of Research and Development, Research Triangle Park, NC).

Conceptual Relevance

Conceptual Model Basis. Is a performance measure based on one or more of the CERP conceptual models? (This criterion does not apply to performance measures for agricultural and urban water supply, flood control, and water quality which are not based on conceptual models at this time.)

General Importance. Does a performance measure provide information about one or more of the following: multiple ecological attributes, multiple conceptual models, important ecological processes, and major environmental changes?

Avoidance of duplication. Do two or more performance measures indicate the same environmental change or ecological response?

Interpretation and Utility

Well-defined Targets. Is the restoration target for the performance measure clearly identified in the conceptual model(s) as an expected response to changes in hydrology and/or water quality due to the implementation of CERP?

Response Variability

Temporal and Spatial Scales. COMMENT: I'm not sure what the previous sentence means. Seems like the next two sentences cover the ground adequately. "Can the performance measure detect changes at appropriate temporal and spatial scales without being overwhelmed by variability?" Does the suite of selected performance measures cover a wide range of appropriate temporal and spatial scales?

Reliability. Has the successful previous use of a performance measure demonstrated its reliability as an indicator of environmental changes that are relevant to CERP? Regarding statistical properties, has the performance measure been shown to serve its intended purpose? "Is the indicator sensitive enough to detect important changes but not so sensitive that signals are masked by natural variability?" A new performance measure that is needed to track an ecological response, but that has yet to be fully developed and tested, may be identified as a research priority in support of the monitoring plan.

Feasibility of Implementation

Cost-effectiveness. The above criteria determine the value of the information yielded by a performance measure, without regard to cost-effectiveness. If that information is found to be essential, can it be obtained for less cost in another way?

Evaluations to date have focused primarily on the assessment of Conceptual Relevance and Interpretation and Utility. Each performance measure was subjected to a screening process using the following criteria:

- Is the performance measure expected to change DIRECTLY in relation to CERP (is there a clear linkage between the performance measure and the predicted changes from implementing CERP).

- Is the performance measure in a conceptual model (applicable to biological and soil performance measures only)

- Does the performance measure have a clearly defined target?

Any performance measure not meeting all of the above criteria was not considered for inclusion in the monitoring plan. The remaining biological and soils performance measures were then evaluated for their ability to provide information on the following:

- Is it an indicator of an important ecological process? (Processes were considered things such as food webs, energy transfer, etc.).

- Is it an indicator of important ecological structure? (Including being an indicator for things such as fragmentation, compartmentalization, succession, disturbance)

- Is it a clear indicator of major environmental change? (Hydrology, Fire, Water Quality, Exotics).

Animal performance measures were further reviewed using:

- Is the indicator a State or Federally listed Threatened or Endangered Species?

- Does it have high aesthetic value, high public appreciation/ symbol of the Everglades?

- Does it have important recreational value (fishing, boating, bird-watching, etc.)?

- Does it have important commercial value (fisheries)?

The result of this process are presented in TableIII-1

Table III-1 - Biological Performance Measures

Category	Unique ID	Performance Measure	Conceptual Models that contain the Attribute	Ecological Process	Ecological Structure	Environmental Change	Temporal Scale	Threatened, Endangered, or SSC	High Aesthetic value	Important recreational Value	Important Commercial Value
Soil	S01	accretion - negative shoreline organic berm LOK	Lake Okeechobee		X	X					
Soil	S02	shoreline habitat - Indian River Lagoon	St Lucie Estuary	X	X	X		X		X	X
Soil	S03	Wetland soil accretion in greater Everglades	Ridge/Slough, Mangrove Estuarine Transition, Marl Prairie, Big Cypress	X		X					
Soil	S04	St Lucie Estuary Muck Removal	St Lucie Estuary	X	X	X					X
Soil	S05	MTZ Soil Nutrient Dynamics	Mangrove Transition Zone	X		X					
Animal	A01	Snail Kite Nesting	Lake Okeechobee				M	X			
Animal	A02	Wading Bird Nesting	Florida Bay, Lake Okeechobee, Mangrove Estuarine Transition, Big Cypress, Ridge & Slough	X	X	X	M	X	X	X	
Animal	A03	Wintering Waterfowl population estimates	Mangrove Estuarine Transition		X	X	M		X		
Animal	A04	Juvenile crocodile growth, survival, and condition	Biscayne Bay, Mangrove Estuarine Transition		X	X	M	X			
Animal	A05	Deer numbers and distribution	Big Cypress		X	X	M		X	X	
Animal	A06	Crocodile distribution and relative abundance	Biscayne Bay, Mangrove Estuarine Transition		X	X	M	X	X		
Animal	A08	Manatee Number and distribution	Caloosahatchee and Biscayne Bay		X	X	L	X	X	X	
Animal	A09	Manatee Mortality	Caloosahatchee and Biscayne Bay				L		X		
Animal	A10	Alligator Abundance, distribution, and size classes	Marl Prairie, Big Cypress, Lake Okeechobee, Mangrove Estuarine Transition, Ridge & Slough	X	X	X	M		X	X	X
Animal	A11	Alligator nesting effort and success	Marl Prairie, Big Cypress, Lake Okeechobee, Mangrove Estuarine Transition, Ridge & Slough	X	X	X	L				X
Animal	A12	Alligator condition	Marl Prairie, Big Cypress, Lake Okeechobee, Mangrove Estuarine Transition, Ridge & Slough	X		X	M				
Animal	A13	Alligator hole distribution and occupancy	Marl Prairie, Ridge & Slough	X	X	X	M				
Animal	A14	Wading bird feeding aggregations	Lake Okeechobee, Marl Prairie	X		X	M		X		
Animal	A15	Dolphin Health Profile ???	Biscayne Bay	X			L		X	X	
Animal	A16	Juvenile Pink Shrimp Density	Florida Bay, Biscayne Bay			X	M				
Animal	A17	Pink Shrimp Catch Rates	Florida Bay, Biscayne Bay			X	M			X	X
Animal	A18	Abnormal Fish Prevalence	Biscayne Bay, Florida Bay??								
Animal	A19	Estuarine Aquatic Fauna; Macroinvertibrates	Florida Bay, Biscayne Bay, Caloosahatchee Estuary, St. Lucie Estuary	X	X	X	M				
Animal	A20	Estuarine Fish Community	Florida Bay, Mangrove Estuarine Transition, Biscayne Bay, Caloosahatchee Estuary, St. Lucie Estuary	X	X	X	M			X	
Animal	A21	Wetland Aquatic Fauna	Ridge & Sough, Marl Prairie, Mangrove Estuarine Transition, Big Cypress, Lake Okeechobee	X	X	X	S			X	X
Animal	A22	Lake Okeechobee Fisheries Monitoring	Lake Okeechobee	X	X	X	M			X	X
Animal	A24	Cape Sable Seaside Sparrow	Marl Prairie		X	X	M	X			
Animal	A25	Oyster Distribution, Abundance and Condition	St Lucie Estuary, Caloosahatchee		X	X	M			X	X
								NOT APPLICABLE for PLANTS			
Plants	P01	Cattail extent	Ridge and Slough	X		X	L				
Plants	P02	Coastal Lakes and Basins Submerged Aquatic Vegetation	Mangrove Estuary Model				M				
Plants	P03	Community composition of cypress forests	Big Cypress	X	X	X	M				
Plants	P04	Community composition of hammocks	Big Cypress	X	X	X	M				
Plants	P05	Community composition of herbaceous wetlands	Big Cypress	X	X	X	M				
Plants	P06	Community composition of mesic pineland	Big Cypress	X	X	X	M				
Plants	P07	Diverse littoral zone native plant community	Lake Okeechobee		X	X	L				
Plants	P08	Forested Wetland Plant Communities	Big Cypress	X	X	X	M				
Plants	P09	Manatee Habitat	Caloosahatchee Estuary and Biscayne Bay		X	X	M				
Plants	P10	Mangrove presence, distribution, health, relative abundance	Caloosahatchee Estuary	X	X	X	M				
Plants	P11	Marl Prairie Vegetation Mosaic	Marl Prairie	X	X	X	M				
Plants	P12	Panther habitat	Big Cypress		X	X	M				

Plants	P13	Periphyton	Ridge & Slough	X	X	X	M				
Plants	P14	Periphyton mat cover, organic-inorganic production, and marl accretion	Marl Prairie	X	X	X	M				
Plants	P15	Phytoplankton primary productivity in Lake Okeechobee	Lake Okeechobee	X	X	X	L				
Plants	P16	Plant community gradients	Big Cypress	X	X	X	M				
Plants	P17	Plant community mosaic	Big Cypress	X	X	X	M				
Plants	P18	Plant vegetation dynamics	Mangrove Estuarine Transition	X	X	X	L				
Plants	P19	Sawgrass and slough spatial coverage and orientation	Ridge and Slough	X	X	X	L				
Plants	P20	Sea Grasses Abundance - Caloosahatchee	Caloosahatchee Estuary	X	X	X	M				
Plants	P21	Seagrasses Biscayne Bay	Biscayne Bay				M				
Plants	P22	Seagrasses Florida Bay	Florida Bay	X	X	X	M				
Plants	P23	Spatial extent of continuous bulrush stands	Lake Okeechobee		X	X	L				
Plants	P24	Spatial extent of invasive exotic plants in Lake Okeechobee	Lake Okeechobee		X		L				
Plants	P25	Submerged aquatic vegetation St Lucie Estuary	St. Lucie Estuary	X	X	X	M				
Plants	P26	Submerged Aquatic Vegetation Coastal Lake	Mangrove Estuarine Transition	X		X	M				
Plants	P27	Submerged Aquatic Vegetation Lake Okeechobee	Lake Okeechobee	X	X	X	M				
Plants	P28	Tree island structure and function	Ridge and Slough	X	X	X	M				
Plants	P29	Upland/Wetland Mosaic for Indian River Lagoon	St Lucie Estuary	X	X	X	M				
Plants	P30	Wetland community composition	Big Cypress	X	X	X	M				
Plants	P31	Oyster Habitat	St Lucie Estuary		X	X	M				

(3) Evaluation of Hydrologic Performance Measures

The second broad category of performance measures are specific to the hydrology of the natural and human systems in south Florida. For the natural system two categories of hydrological performance measures have been created by the RET. One set is based on pre-drainage hydrological patterns predicted by the Natural System Model. This set uses these pre-drainage hydropatterns as targets for restoration. A key tenet of south Florida ecosystem restoration is that hydrologic restoration is a necessary starting point for ecological restoration. The second category of hydrological performance measures are those that define desirable characteristics of wetland systems, which differ from pre-drainage conditions. The measures in this second category are influenced by regional management constraints (e.g., Lake Okeechobee lake levels) or reflect more modern views of desirable ecosystem conditions (e.g., estuarine salinty patterns that may differ from pre-drainage conditions). COMMENT: I thought non-NSM targets were always a result of management constraints (e.g., Biscayne Bay, Caloosahatchee River, WCAs and Lake Okeechobee).

Both categories of natural system hydrological measures are derived from the hydrological stressors contained in the conceptual ecological models. Originally these stressor-based performance measures were developed by the AET to set a number of hydrologic targets for restoration that could be simulated by computer models as a basis for evaluating alternative plans during the Restudy. A highly modified set of hydrological performance measures is finding application in the CERP monitoring plan. The hydrologic performance measures are included in this monitoring plan for their value in setting hydrological restoration and water supply targets for CERP, which when compared to actual field measurements will allow us to assess how well CERP corrects the hydrologic problems in the natural and human systems.

The hydrologic performance measures listed in Table III-2 represent the current set of performance measures necessary to assess changes in the stressors resulting from CERP actions. They define hydropatterns for the different Everglades ecosystems, e.g., ridge and slough, marl prairie, the range of water flows to sustain estuaries and bays, and the ability to meet the water supply and flood protection needs of the human systems. Because all of the proposed hydrological performance measures have their origin either as stressors in the conceptual ecological models or are based on water supply policy or law, no screening or ranking of these measures by the RET was necessary. All are included in the monitoring plan because CERP is designed to correct the problems caused by all of the hydrological stressors

Table III-2 Hydrologic Performance Measures

Category	Unique ID	Performance Measure
Hydrologic	H1	Lake Okeechobee Extremes in Low Lake Stages
Hydrologic	H2	Lake Okeechobee Extremes in High Lake Stages
Hydrologic	H3	Spring Recession for Lake Okeechobee
Hydrologic	H4	St. Lucie Estuary Salinity Envelope
Hydrologic	H5	Lake Worth Salinity Envelope
Hydrologic	H6	Salinity Envelope for Caloosahatchee Estuary
Hydrologic	H7	Average Inundation Duration for Greater Everglades
Hydrologic	H8	Number of Dry Events in Greater Everglades
Hydrologic	H9	Duration of Water Level Deviation from NSM in Greater Everglades
Hydrologic	H10	Extreme Low Water Levels in Ridge and Slough Ecosystems
Hydrologic	H11	Extreme High Water Levels in Ridge and Slough Ecosystems
Hydrologic	H12	Seasonal Amplitude and Interannual Variability of Water Levels in Greater Everglades
Hydrologic	H13	Seasonal and Annual Overland Flow Volume in Greater Everglades
Hydrologic	H14	Tree Island Hydrologic Impacts
Hydrologic	H15	Model Lands/C-111 Hydrologic Performance Measure Suite
Hydrologic	H16	Surface Water Discharges to Biscayne Bay
Hydrologic	H17	Florida Bay - Surface Water Flows
Hydrologic	H18	Lake Okeechobee Service Area - Frequency of Water Restrictions
Hydrologic	H19	Frequency of Water Restrictions for the Lower East Coast Service Area
Hydrologic	H20	Potential for High Water Levels in South Miami-Dade Agricultural Area
Hydrologic	H21	Prevent Salt Water Intrusion of the Biscayne Aquifer: Meet Minimum Flow and Level criteria for Biscayne Aquifer
Hydrologic	H22	Prevent Salt Water Intrusion of Biscayne Aquifer in South Miami-Dade County
Hydrologic	H23	Continuity: Water Surface Elevations across Barriers
Hydrologic	H24	Sheetflow: Volume of Water Across Transects in the WCAs and Everglades National Park

(4) Evaluation of Water Quality Performance Measure Documentation Sheets

For the water quality component of the monitoring and assessment plan, the list of AET performance measures was expanded to over 70 performance measures by members of the RECOVER WQT. Measures were developed on a region-by-region basis to capture the unique conditions of each of the main physiographic regions in South Florida. As a consequence, there are multiple performance measures for what appears to be the same water quality parameter; however, each one has a restoration target unique to a specific region. The WQT discussed, agreed upon and went through an evaluation process to assess and better understand the informational quality/applicability of each of the water quality performance measures. However, this process was somewhat different from that conducted for the biological performance measures, in that the evaluations were made based upon a unique set of criteria that the WQT felt was more applicable to water quality. Each measure was initially screened as to whether it:

- Would likely change in response to the implementation of CERP components.
- Would be a regional indicator of CERP performance (vs. a project-level measure).
- Had a clearly defined restoration target.

If the performance measure did not meet all three criteria, it was not considered for inclusion in the monitoring plan. The set of water quality performance measures remaining for each of the geographical regions from this initial screening underwent further evaluation by the team using the following criteria:

- Is the proposed performance measure a strong indicator of the health of the ecosystem or a major stress?
- Does the performance measure have a strong regulatory basis?
- Is the performance measure easy to use or implement?
- Does the performance measure provide information not provided by other performance measures being recommended for the geographical region?
- Does the performance measure have a relatively strong degree of predictability (i.e. can you easily distinguish changes resulting from CERP from those contributed by other factors, and is there a mechanism available to predict future performance of the performance measure?)
- Does the performance measure have a relatively low measurement uncertainty?

The results of this evaluation are displayed in Table III-3.

Table III-3 Water Quality Performance Measures									
				EVALUATION CRITERIA					
Category	**Unique ID**	**Performance Measures by Region (North to South)**	**Conceptual Model**	Stong Indicator of Ecosystem Health or a Major Stress	Strong Regulatory Basis	Easy to use or implement	Not duplicative of other performance measures	Relatively strong degree of predictability	Relatively low measurement uncertainty
		Lower Kissimmee River Basin							
Water Quality	**WQ1**	TP Load Reduction at and downstream from S-65D		X	X	X	X	X	X
Water Quality	**WQ2**	Trace Metals (Mercury) at Highway 78 bridge		X		X	X		X
		Lake Okeechobee							
Water Quality	**WQ3**	Phosphorus Loads	Lake Okeechobee	X	X	X	X		X
Water Quality	**WQ4**	Pelagic zone total phosphorus	Lake Okeechobee	X	X	X	X	X	X
Water Quality	**WQ5**	Net P assimilative capacity	Lake Okeechobee	X	X	X	X		X
Water Quality	**WQ6**	Water Clarity	Lake Okeechobee	X	X	X	X	X	X
Water Quality	**WQ7**	Pelagic zone algal bloom frequency based on chlorophyll a concentrations	Lake Okeechobee	X	X	X	X	X	X
Water Quality	**WQ8**	Pelagic zone TN to TP ratio	Lake Okeechobee	X		X	X	X	X
Water Quality	**WQ9**	Sediment Porewater Phosphorus (P)		X			X	X	X
Water Quality	**WQ10**	Pelagic Zone Diatom; Cyanobacteria ratio		X		X	X		X
Water Quality	**WQ11**	Pelagic zone nutrient limitation status				X			
		Lake Okeechobee ASR							
Water Quality	**WQ12**	Increase in Methly Mercury in surface waters in response to ASR activity related to increase in Sulfur		X	X	X	X		
Water Quality	**WQ13**	Increase in Cl and salinity in L.O. in response to ASR Activity		X	X	X	X		X
		Everglades Agric. Area/STAs							
Water Quality	**WQ14**	WCA Inflow Phosphorus Concentrations		X	X	X	X	X	X
Water Quality	**WQ15**	WCA Inflow Phosphorus Loads		X	X	X	X	X	X
Water Quality	**WQ16**	STA Bypass Loads			X	X	X	X	X
Water Quality	**WQ17**	Total Load Reductions in STAs & Reservoirs		X	X	X	X	X	X
Water Quality	**WQ2**	Trace Metals (Mercury)		X	X	X	X		X
		Caloosahatchee River and Estuary							
Water Quality	**WQ18**	Biochemical Oxygen Demand	Caloosahatchee Estuary	X	X	X	X	X	X
Water Quality	**WQ19**	Total Phosphorus	Caloosahatchee Estuary	X	X	X	X	X	X
Water Quality	**WQ20**	Dissolved Oxygen	Caloosahatchee Estuary	X	X	X	X	X	X
Water Quality	**WQ21**	Chlorophyl *a*	Caloosahatchee Estuary	X	X	X	X		X
Water Quality	**WQ22**	Total Nitrogen	Caloosahatchee Estuary	X		X	X		X
Water Quality	**WQ23**	Toxicity-Heavy Metals	Caloosahatchee Estuary			X			
Water Quality	**WQ24**	Total and fecal coliforms	Caloosahatchee Estuary		X	X	X		
Water Quality	**WQ25**	Organics (Pesticides)	Caloosahatchee Estuary	X	X	X	X	X	X
		Caloosahatchee Basin/ASR							
Water Quality	**WQ12**	Increase in Methlyl Mercury in in surface waters in response to ASR activity related to increase in Sulfate		X	X	X	X		
Water Quality	**WQ13**	Increase in Cl and salinity in river in response to ASR activity		X	X	X	X		X
		St. Lucie Estuary and Indian River Lagoon							
Water Quality	**WQ25**	Organcis (Pesticides)	SLE&IRL	X	X	X	X	X	X
Water Quality	**WQ26**	(TN Loads) - Reduce N Loads to estuary	SLE&IRL	X		X	X	X	X
Water Quality	**WQ27**	(TP Loads) -Reduce P Loads to estuary	SLE&IRL	X		X	X	X	X
Water Quality	**WQ28**	P Load to the IRL from C-25 and C-1 canals	SLE&IRL	X		X	X		X
Water Quality	**WQ29**	N Load to the IRL from C-25 and C-1 canals	SLE&IRL	X	X	X	X		X
Water Quality	**WQ30**	Phytoplankton/Chlorophyll a	SLE&IRL	X		X			X
Water Quality	**WQ31**	Flow and TP loads to Lake Okeechobee		X	X	X	X		X

		Lake Worth Lagoon							
Water Quality	**WQ32**	TSS Loads		X		X	X		X
Water Quality	**WQ33**	P Loads		X		X	X		X
Water Quality	**WQ34**	N Loads		X		X	X		X
		Lower East Coast (North of Biscayne Bay)							
Water Quality	**WQ35**	N Loads and Concentrations in waters delivered to tide through G56 (Hillsboro Basin)		X	X	X	X	X	X
Water Quality	**WQ36**	P Loads and Concentrations in waters delivered to tide through G56 (Hillsboro Basin)		X	X	X	X	X	X
Water Quality	**WQ37**	P Loads and Concentrations in waters delivered to Loxahatchee Refuge (WCA-1)		X	X	X	X	X	X
Water Quality	**WQ38**	P Loads and Concentrations in waters delivered to WCA3 from C11 Basin		X	X	X	X	X	X
		Lower East Coast ASR							
Water Quality	**WQ12**	Increase in Methlyl Mercury in in surface waters in response to ASR activity related to increase in Sulfate		X	X	X	X		
Water Quality	**WQ13**	Increase in Cl and salinity in river in response to ASR activity		X	X	X	X		X
		Greater Everglades - WCAs, ENP, eastern Big Cypress, Holey Land, Rotenberger, Model Lands/C-111 Basin							
Water Quality	**WQ25**	Organics (Pesticides)	ER&S	X	X	X	X		X
Water Quality	**WQ2**	Trace Metals (Mercury)	ER&S	X	X	X	X		X
Water Quality	**WQ39**	Wetland Soil Phosphorus concentration	ER&S	X	X	X	X	X	X
Water Quality	**WQ40**	Wetland Surface Water Phosphorus Mass/Area Loading	ER&S	X	X	X	X	X	X
Water Quality	**WQ41**	Wetland Surface Water Phosphorus Concentration (includes WCA 3)	ER&S	X	X	X	X	X	X
Water Quality	**WQ42**	Wetland Surface Water Phosphorus Mass Loading (includes WCA 3)	ER&S	X	X	X	X	X	X
Water Quality	**WQ43**	Sulfate - surface water; sulfide/sulfate-porewater		X	X	X	X		X
Water Quality	**WQ44**	Conductivity		X	X	X	X	X	X
Water Quality	**WQ45**	Total Organic Carbaon		X		X	X		X
		Miccosukee Reservation							
Water Quality	**WQ46**	Total Phosphorus Concentration		X	X	X	X	X	X
Water Quality	**WQ47**	Total Phosphorus Load		X	X	X	X	X	X
		Big Cypress Seminole Reservation							
Water Quality	**WQ48**	Quality of surface water entering reservation		X	X	X	X	X	X
Water Quality	**WQ49**	Quality of surface water leaving reservation		X	X	X	X	X	X
		Lower West Coast-Lake Trafford							
Water Quality	**WQ50**	Dissolved Oxygen		X	X	X	X	X	X
Water Quality	**WQ51**	Trophic State Index		X		X	X		X
		Lower West Coast- Southern Golden Gates Estates							
Water Quality	**WQ52**	Hardness Concentration		X		X	X	X	X
Water Quality	**WQ53**	Phosphorus Concentrations		X	X	X	X	X	X
		Big Cypress Basin							
Water Quality	**WQ54**	Mean wet season phosphorus concentration in SE and NE Big Cypress relative to 10 year POR	Big Cypress Regional	X	X	X	X		X
Water Quality	**WQ2**	Trace Metals (Mercury)	Big Cypress Regional	X		X	X		X
Water Quality	**WQ25**	Organics (Pesticides)	Big Cypress Regional	X		X	X		X
		Everglades National Park							
Water Quality	**WQ55**	Flow-weighted mean TP concentrations entering Shark River Slough		X	X	X	X	X	X
Water Quality	**WQ56**	Frequency of Shark River TP inflow samples exceeding 10 ppb within a given 12-month period.		X	X	X	X	X	X
Water Quality	**WQ57**	Mean TP concentration at Shark River Slough marsh stations		X	X	X		X	X
Water Quality	**WQ58**	Flow-weighted mean TP concentrations entering Taylor Slough/Coastal Basins		X	X	X	X	X	X
Water Quality	**WQ59**	Frequency of Taylor Slough TP inflow samples exceeding 10 ppb within a given 12-month period.		X	X	X	X	X	X

Water Quality	**WQ60**	Mean TP concentration at Taylor Slough/Coastal Basin marsh stations		X	X	X		X	X
		Biscayne Bay							
Water Quality	**WQ61**	Sediment Chemistry and Toxicity	Biscayne Bay	X	X	X	X		X
Water Quality	**WQ62**	Water Transparency	Biscayne Bay	X	X	X	X		X
Water Quality	**WQ63**	Total Coliform	Biscayne Bay	X	X	X	X		X
Water Quality	**WQ64**	Ammonia	Biscayne Bay	X	X	X	X	X	X
Water Quality	**WQ65**	Total Nitrogen	Biscayne Bay	X	X	X	X	X	X
Water Quality	**WQ66**	Total Phosphorus	Biscayne Bay	X	X	X	X	X	X
Water Quality	**WQ67**	Nox	Biscayne Bay	X	X	X	X	X	X
		Model Lands/C-111 Basin							
Water Quality	**WQ68**	Mean TP concentration of inflow points to the South Dade Wetlands		X	X	X	X	X	X
		Florida Bay							
Water Quality	**WQ69**	Toxics	Florida Bay	X	X	X	X		X
Water Quality	**WQ70**	Algal Blooms	Florida Bay	X		X	X		X
Water Quality	**WQ71**	Nutrients	Florida Bay	X		X	X		X
Water Quality	**WQ72**	Nutrient Loads	Florida Bay	X		X	X	X	X
Water Quality	**WQ73**	Light	Florida Bay	X		X	X		X
	Note:								
	WQ1	Summary Sheet for Lower Kiss. River TP Load Reduction							
	WQ2	Summary Sheet for Trace Metals							
	WQ12	Summary Sheet for ASR - Methyl Mercury							
	WQ13	Summary Sheet for ASR - Cl and Salinity							
	WQ25	Summary Sheet for (Organics) Pesticides							
	WQ54	Summary Sheet for Big Cypress Mean Wet Season TP Concentration							

(5) Documentation Sheets

The documentation sheets presented here are for the set of 156 performance measures listed in Tables III-1 to 3. Each documentation sheet describes the performance measure, in what geographic regions it is to be measured, the restoration target, and a general description of the monitoring protocol. If the original sheets were combined or edited it is noted in the editing comments.

(6) Further Refinements of What to Monitor

The 156 performance measures listed here linked with the key hypotheses in the conceptual models provide the basis for the monitoring and assessment plan. One of the next steps is to review the performance measures in the context of their linkages and uncertainties within the conceptual models and refine the monitoring and assessment plan to ensure that it addresses the key restoration hypotheses and focuses on a sustainable number of performance measures. The approach that will be used will examine the performance measures in an integrated hierarchical framework to ensure that the resulting plan will be holistic and include indicators at a range of temporal and spatial scales. The conceptual models will be further refined to focus on the most critical over-riding restoration hypotheses for each physiographic region. The models will be examined for logical groupings of performance measures, linkages, and key questions that will provide the essential information for the adaptive assessment process. The groupings within each model will be evaluated for their importance related to the success of CERP and the resulting groupings from each model will be reviewed together to ensure a system-wide perspective. It is anticipated that this process will be completed in the next 3-4 months.