Progress Toward Restoring the Everglades: The Fifth Biennial Review, 2014

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PROGRESS TOWARD RESTORING THE EVERGLADES

The Fifth Biennial Review - 2014

Committee on Independent Scientific Review of Everglades Restoration Progress

Water Science and Technology Board

Board on Environmental Studies and Toxicology

Division on Earth and Life Studies

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Preface

To much of the public, the Everglades is Marjory Stoneman Douglas's River of Grass—an immense, unique marsh teeming with life, represented and protected in the form of Everglades National Park. As usual, reality is less rosy, and more complicated and interesting, than the ideal. The South Florida ecosystem is vast, stretching more than 200 miles from Orlando to Florida Bay, and Everglades National Park is but a part located at the southern end. It is a diverse and distinctive ecosystem that includes not only marshes, but also the meandering Kissimmee River and associated floodplain and chain of small lakes, the much larger Lake Okeechobee, sawgrass plains, ridge-and-slough wetlands, tree islands, marl prairies, bays, and estuaries. During the 19th and 20th centuries the ecosystem changed as the nation changed. The historical Everglades has been reduced to half of its original size, and what remains is not the pristine ecosystem many imagine it to be, but one that has been highly engineered and otherwise heavily influenced, and is intensely managed by humans. Today the Everglades is not only an iconic natural system, but also the source of water for industry and the millions of residents of South Florida. To address the floods that have occasionally devastated the region, water now moves through a maze of canals, levees, pump stations, and hydraulic control structures, rather than slowly flowing southward in a broad river of grass, and a substantial fraction is diverted from the natural system (see NRC, 2010). The water that remains is polluted by phosphorus and other contaminants originating from agriculture and other human activities. Many components of the natural system are highly degraded, and continue to degrade (see NRC, 2012a).

Recognizing the degradation of the South Florida ecosystem, and the dependence of humans upon a functioning ecosystem, in 1999 the State of Florida and the federal government agreed to a multidecadal, multi-billion-dollar Comprehensive Everglades Restoration Plan (CERP) to protect and restore the remaining Everglades while addressing demands for water supply and flood control. In authorizing the CERP, the U.S. Congress mandated periodic independent reviews of progress toward restoration of the Everglades natural system. The National Research Council's (NRC's) Committee on Independent Scientific Review of Everglades Restoration Progress, or CISRERP, was formed for this purpose in 2004. This report, which is the fifth in a series of biennial evaluations that are expected to continue for the duration of the CERP, reflects the concerted efforts of 14 committee members and 4 NRC staff representing a wide range of scientific and engineering expertise. Our committee met five times over a period of 16 months including three times in Florida and once in Washington, D.C. We reviewed a large volume of written material and heard oral presentations from state, federal, and tribal government personnel, academic researchers, interest groups, and members of the public.

The CERP is a complex, multi-billion-dollar project managed by the U.S. Army Corps of Engineers (USACE) and the South Florida Water Management District (SFWMD) that was projected to require 40 years for completion. With 68 separate project components requiring sophisticated scientific knowledge of the ecosystem and creation of new technologies for water management, the CERP represents a research, planning, implementation, and construction challenge unlike any other. At this writing, the CERP is nearly halfway through its second decade, and in that time the ecosystem has continued to change as the nation and indeed the planet changes. This report presents the committee's consensus view of restoration accomplishments and emerging challenges primarily during the past 2 years but also over the 14 years since the CERP was authorized. In discussing accomplishments, we focus on the progress made on the ground on several CERP projects and supporting non-CERP projects that are producing the first increments of restoration and learning progress to improve the restoration plan through pilot projects and adaptive management. The emerging challenges on which we focus are those posed by the ways in which the ecosystem is changing. The Central Everglades Planning Project is an exciting accomplishment that provides the means to accelerate the pace of restoration in the central Everglades and thus address the ongoing degradation of that part of the ecosystem that was a focus of our last report (NRC, 2012a). However, this critical project can only fulfill its potential if implemented in a timely way and to do so will require finding creative solutions to overcome current constraints related to authorization, funding, and water quality permitting. Climate change and sea-level rise pose enormous challenges to a rainfall-driven system characterized by a low elevational gradient, challenges that could perhaps be set aside for later consideration in 1999, but not in 2014. Rather than compromising restoration, climate change and sea-level rise provide even more incentive for restoring the Everglades ecosystem. Indeed, in this context the CERP can be viewed as a water sustainability plan for both the natural and human environments. Finally, South Florida is now home to a plethora of species that were not present in the pre-drainage ecosystem of the 19th century, and more are arriving every year. These nonnative invasive species pose another important challenge to restoration.

It has been my privilege to serve on this committee with some of the nation's leading experts in biological, hydrologic, and geographic sciences, hydrologic and systems engineering, project administration, law, and policy. I greatly appreciate the time, attention, and thought each committee member invested in understanding the complexity of the Everglades ecosystem and corresponding scope of the CERP. I also appreciate their careful, rigorous analyses, expert judgment, constructive comments and reviews, and the professionalism, collegiality, and good humor with which they conducted their business.

The committee is indebted to many individuals for their contributions of information and resources. Specifically, we appreciate the efforts of the committee's technical liaisons—David Tipple (USACE), Glenn Landers (USACE), Larry Gerry (SFWMD), and Robert Johnson (Department of the Interior)—who responded to numerous information requests and helped the committee utilize the vast resources of agency expertise when needed. Many others educated the committee on the complexities of Everglades restoration through their presentations, field trips, and public comments (see Acknowledgments).

The committee had the good fortune to be assisted by four dedicated and talented NRC staff: Stephanie Johnson, David Policansky, Michael Stoever, and Sarah Brennan. Stephanie Johnson has served as senior project officer for all five CISRERP panels and is a true Everglades expert. Her encyclopedic knowledge and understanding of the science, engineering, and administrative aspects of the CERP, ability to identify and synthesize the complex interrelationships among these aspects, deft management skills, and contacts were critical to the committee's success. NRC scholar David Policansky is also a veteran of all five CISRERP panels and his experience, knowledge, understanding, sage observations, and illuminating questions were instrumental to the committee's deliberations and understanding of the Everglades ecosystem and the CERP. Michael Stoever attended to the complex logistical needs of the committee, provided superb support during and between meetings, and, with assistance from Sarah Brennan, was instrumental in producing the final report. I know I speak for the entire committee in expressing our profound respect and appreciation for the NRC staff's exceptional support and good humor.

This report was reviewed in draft form by individuals chosen for their breadth of perspectives and technical expertise in accordance with the procedures approved by the National Academies' Report Review Committee. The purpose of this independent review was to provide candid and critical comments to assist the institution in ensuring that its published report is scientifically credible and that it meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The reviewer comments and draft manuscript remain confidential to protect the deliberative process. We thank the following reviewers for their helpful suggestions, all of which were considered and many of which were wholly or partly incorporated in the final report: G. Ronnie Best, U.S. Geological Survey (retired); John R. White, Louisiana State University; M. Siobhan Fennessy, Kenyon College; Evelyn Gaiser, Florida International University; Julie Lockwood, Rutgers University; John C. Volin, University of Connecticut; Wendy Graham, University of Florida; Ben Kirtman, University of Miami; and W. Allen Marr, Jr., Geocomp Corporation.

Although these reviewers provided many constructive comments and suggestions, they were not asked to endorse the conclusions and recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by Kenneth W. Potter, University of Wisconsin, Madison, and Bonnie McCay, Rutgers University. Appointed by the NRC, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments received full consideration. Responsibility for the final content of this report rests entirely with the authoring committee and the NRC.

The CERP is a bold, challenging, and complex plan with great potential to provide benefits to the ecosystem and the public, and the small increments of restoration that have been achieved suggest that that potential can be realized. But the time has come for equally bold action in implementing the CERP. Delays in implementation make project costs higher, and the ecosystem degradation that must be addressed larger. The challenges to implementation that exist can be overcome, and in the case of climate change, make implementation more urgent. We offer this report in support of that endeavor.

Jeffrey R. Walters, *Chair*
Committee on Independent Scientific Review
of Everglades Restoration Progress (CISRERP)

Contents

SUMMARY **1**

1 INTRODUCTION **13**

2 THE RESTORATION PLAN IN CONTEXT **21**

3 CENTRAL EVERGLADES PLANNING PROJECT **35**

4 IMPLEMENTATION PROGRESS **71**

5 CLIMATE CHANGE AND SEA-LEVEL RISE: IMPLICATIONS FOR EVERGLADES RESTORATION **131**

6 BIOLOGICAL INVASIONS AND EVERGLADES RESTORATION **169**

7 USE OF SCIENCE IN DECISION MAKING **213**

REFERENCES **229**

ACRONYMS **257**

APPENDICES

A National Research Council Everglades Reports 261

B Additional Major Nonnative Plant and Animal Species in the Everglades 269

C Water Science and Technology Board; Board on Environmental Studies and Toxicology 279

D Biographical Sketches of Committee Members and Staff 281

Summary

The Florida Everglades, one of the world's treasured ecosystems, has been dramatically altered over the past century by an extensive water control infrastructure, designed to increase regional economic productivity through improved flood control, urban water supply, and agricultural production. The remnants of the original Everglades now compete for vital water with urban and agricultural interests and are impaired by contaminated runoff from these two activities. The Comprehensive Everglades Restoration Plan (CERP), a joint effort led by the state and the federal government and launched in 2000, seeks to reverse the decline of the ecosystem. This $13.5 billion project was originally envisioned as a 30- to 40-year effort to achieve ecological restoration by restoring the hydrologic characteristics of the Everglades, where feasible, and to create a water system that serves the needs of both the natural and the human systems of South Florida (Figure S-1).

The National Research Council established the Committee on Independent Scientific Review of Everglades Restoration Progress in 2004 in response to a request from the U.S. Army Corps of Engineers (USACE), with support from the South Florida Water Management District (SFWMD) and the U.S. Department of the Interior, based on Congress's mandate in the Water Resources Development Act of 2000 (WRDA 2000). The committee is charged to submit biennial reports that review the CERP's progress in restoring the natural system. This is the committee's fifth report in a series of biennial evaluations. Each biennial report provides an update on natural system restoration progress over the previous 2 years, describes significant accomplishments (Chapter 4), and addresses important developments in research, monitoring, and assessment that inform restoration decision making (Chapter 7). In each new report, the committee also identifies issues for in-depth evaluation in light of new CERP program developments, policy initiatives, or improvements in scientific knowledge that have implications for restoration progress (see Chapter 1 for the committee's full statement of task). For this 2014 biennial review, the committee examined the Central

FIGURE S-1 The South Florida ecosystem, which shares the same boundaries as the South Florida Water Management District.

SOURCE: © International Mapping Associates

Everglades Planning Project (Chapter 3) and the implications of climate change (Chapter 5) and invasive species (Chapter 6) for Everglades restoration efforts.

OVERALL EVALUATION OF PROGRESS AND CHALLENGES

During the past 2 years, Everglades restoration has been defined by exceptional project planning accomplishments with substantial restoration potential on the one hand; and increasingly frustrating financial, procedural, and policy constraints impeding project implementation on the other. All of this has occurred against the backdrop of modest restoration progress focused along the edges of the Everglades, considerable state efforts to improve water quality, ongoing degradation of the core Everglades, and increasing restoration threats posed by sea-level rise and invasive species.

The Central Everglades Planning Project is an impressive strategy to expedite restoration and avert further degradation of the central Everglades. The Everglades also appears on the threshold of other significant advances in natural system restoration, particularly from several key non-CERP projects. However, project authorization, funding levels, and cost-sharing complexities have impeded the completion of important ongoing restoration projects, and water quality permitting constraints represent serious impediments to near-term implementation of the critical Central Everglades Planning Project. Timely authorization, adequate funding levels, and creative policy and implementation strategies are essential to realize important short-term restoration benefits, but more importantly to expedite implementation of the Central Everglades Planning Project in order to realize its substantial restoration potential.

Climate change provides additional incentives to expedite restoration. The CERP provides important means to help mitigate the impacts of sea-level rise and precipitation and temperature changes by enhancing ecosystem resilience, promoting peat accretion, and reducing saltwater intrusion. Implementation priorities should be revised to focus resources on those projects with the greatest potential to avert ecosystem degradation and provide long-term benefits considering sea-level rise and potential changes in temperature and precipitation. Restoration planners need to examine critical unknowns related to sea-level-rise impacts on the Everglades, assess climate projections as they improve over time, analyze their implications for restoration, and design for flexibility wherever feasible.

Planners must also remain cognizant of the potential impacts of invasive species on the success of the CERP. Additional strategic coordination is needed to prioritize invasive species management and research resources while maintaining an aggressive early detection and rapid response system. The report's major conclusions and recommendations are summarized below.

CENTRAL EVERGLADES PLANNING PROJECT

The Central Everglades Planning Project effort is responsive to the committee's prior recommendations to expedite restoration in the central Everglades via increments of restoration to avert further declines that could take many decades or longer to recover. Overall, the project team did an impressive job under a challenging time frame. The proposed plan seems reasonable and thoughtfully developed with substantial stakeholder input. Implementation of the plan would provide significant benefits to the remnant Everglades ecosystem, including more than 200,000 acre-feet/yr of new water—a sizeable first increment of restoration for the central Everglades that represents approximately two-thirds of the new water to northern Water Conservation Area 3 envisioned in the CERP. A comprehensive adaptive management plan provides an important mechanism to learn from project implementation to improve the operation of the project and the design of future increments of restoration, although additional attention to climate change uncertainties is needed.

If the Central Everglades Planning Project is to avert further ecosystem degradation, CERP planners and policy makers need to expedite project implementation in the face of several hurdles. The best-laid plans will be of little benefit if the project is not implemented in a timely way. Completion of the Chief of Engineers' Report for the Central Everglades Planning Project, congressional authorization, and construction of project dependencies are key near-term steps necessary to move forward. Project funding and water quality permitting constraints currently appear to be the largest barriers to timely project implementation. Creative solutions may be available to significantly expedite restoration, such as finding permit mechanisms to move water that meets water quality criteria into the Everglades prior to completion of the entire Restoration Strategies project. Such approaches will require the agencies to recognize the urgency and to work to find legal and engineering solutions to move increments of water into the Everglades as soon as those increments have been adequately treated to meet water quality standards. Without such solutions, redistribution of existing water may not be feasible until 2035 or beyond, and at the envisioned funding level of $100 million per year, construction would not be completed for approximately four decades—exceedingly long for a system already in significant decline.

Some important lessons were learned from the expedited planning process. Although overall, participants and stakeholders thought the process led to a useful outcome, the 22-month planning time frame was extremely challenging for staff and stakeholders, alike. The process required large numbers of staff and became the central focus of the restoration program. Such attention was deserved for this high-priority initiative, but similar intensive efforts are unlikely to be sustainable for future CERP planning. Furthermore, stakeholders with technical expertise found it difficult to keep up with the pace of model output presented and hence could not adequately evaluate the information provided. Thus, 3 years might be a more reasonable time frame for such a complex effort. Communication within and between agencies was a particular strength of the expedited process; senior decision makers were involved at key decision points and as needed to resolve issues and improve planning efficiency. However, the existing USACE process for evaluating restoration benefits makes it difficult to be transparent about tradeoffs in planning decisions.

The enhanced stakeholder and public engagement process was well executed and should serve as a model for future planning processes. This level of active and inclusive stakeholder engagement had not previously been implemented as part of the CERP, and it provided a means for two-way dialogue between stakeholders and agency staff that substantially influenced the planning outcome. Although the abbreviated time frame led to concerns from participants, overall, the committee commends the efforts to educate and engage the stakeholders and modify the project plan where feasible to address concerns.

RESTORATION PROGRESS

The infrequency of Water Resources Development Acts (WRDAs) has impeded CERP progress over the past 2 years. Seven years have elapsed since the last WRDA was passed, and four Generation 2 CERP projects with approved project plans awaited congressional authorization between 2012 and June 2014 when the Water Resources Reform and Development Act of 2014 (WRRDA 2014) was signed into law. Additionally, two of the previously authorized CERP projects require reauthorization due to cost escalations; thus, prior to WRRDA 2014, only one CERP project—Indian River Lagoon South—was eligible for sizeable (>$25 million) construction funding. With the passage of WRRDA 2014, four additional projects are able to proceed with federal funding, although the Central Everglades Planning Project was not completed in time to be included. Lack of authorizations also had important implications for the cost-share balance, discussed below.

Availability of funding also impeded CERP progress in the past 2 years. State CERP expenditures have declined substantially in recent years, because of reduced SFWMD revenues and the need to fund non-CERP water quality projects to meet a 2012 Consent Order. Even though the state has spent significantly more than the federal government on the CERP since its inception, the state has been precariously close to the mandated 50-50 cost-share requirement because, prior to WRRDA 2014, land acquisition and construction expenditures could only be credited for the four congressionally authorized Generation 1 projects.

Declining state funding for CERP projects over the past 2 years has contributed to cost-sharing challenges, and as of September 2013, the state's "creditable expenditures" exceeded those of the federal government by only $98 million. As a result, the federal government significantly reduced spending in FY 2014 so as not to exceed the 50-50 cost share. Passage of WRRDA 2014 could allow the state to realize approximately $400 million in additional cost-sharing credits for prior spending, thereby easing an impending constraint on federal contributions toward the CERP.

CERP planners need to revisit the Integrated Delivery Schedule with a renewed urgency to advance projects with the greatest potential to avert ongoing ecosystem degradation and those that promise the largest restoration benefits. The current draft Integrated Delivery Schedule has not been updated since 2011, and difficult decisions will need to be made to integrate the four Generation 2 CERP projects and the Central Everglades Planning Project (and related project dependencies) with existing CERP and non-CERP efforts. To expedite Everglades restoration amid limited funding, all authorized projects cannot be advanced equally. Some projects may be more beneficial in light of climate change and sea-level rise and others less so, and these factors should be considered in the prioritization of restoration funding.

The restoration progress made by CERP projects to date remains fairly modest in scope. Ecosystem responses have been detected after phased implementation in the Picayune Strand, Biscayne Bay Coastal Wetlands, and C-111 Spreader Canal projects, although many of these improvements are limited. In some cases, such as Biscayne Bay, the scope of the restoration increment to date is simply so limited in area that ecological responses are equally small. In other cases, such as Picayune Strand, additional time may be needed to achieve full ecosystem responses to the restoration measures in place. Taylor Slough has seen significant hydrologic improvements due to restoration efforts, but the documented benefits to date are primarily derived from the C-111 South Dade Project, a non-CERP project. For all three of these projects, ecological responses would be expected to increase with construction and operation of additional project increments as well as additional time for ecosystem recovery.

Several non-CERP projects have faced bureaucratic and policy issues that hindered implementation progress. Agency disagreements about cost-sharing arrangements and legal requirements affected progress on the Kissimmee River Restoration and the C-111 South Dade project by delaying them for almost 2 years. However, the SFWMD and the USACE have made important progress to resolve these differences and resume construction. Meanwhile, water quality compliance issues and the lack of an operational plan are preventing realization of restoration benefits in the Mod Waters project. Scientific knowledge is adequate for success, and engineering problems in construction and operation appear not to be impeding restoration progress. These non-CERP foundation projects offer large potential restoration benefits once fully implemented. Renewed attention is needed to resolve the remaining bureaucratic challenges to expedite restoration progress and realize the ecological returns from substantial financial investments to date.

STA performance shows signs of improvement under recent management. Long-term sustainable performance, however, will be directly influenced by loading rates. Additional treatment-area and flow-equalization basins in the Restoration Strategies project are likely to further reduce loading rates and outflow concentrations. Continued adaptive management, including implementation of new strategies developed through ongoing research, is needed to meet water quality standards and to sustain performance of these treatment systems.

CLIMATE CHANGE AND SEA-LEVEL RISE: IMPLICATIONS FOR RESTORATION

Climate change provides a strong incentive for accelerating restoration. Current impacts of rising sea levels are a harbinger of future climate change effects on the functioning and structure of the Everglades ecosystem and the ecosystem services on which South Florida depends. Sea-level rise in South Florida is already increasing saltwater intrusion into Everglades freshwater habitats and urban water supplies, and future climate changes are likely to be manifested through changes in the timing, volume, and quality of freshwater; distributions of species; and the extent of wetland habitats. Climate change is also expected to increase agricultural water demands, which when paired with anticipated population growth, highlights the potential regional water supply challenges in South Florida under future scenarios. Everglades restoration enhances the ability of the ecosystem to withstand and adapt to future changes and increases water availability to the ecosystem and to urban and agricultural users. Improvements in Everglades water depths promote higher rates of peat accretion that could help mitigate the effects of sea-level rise and reduce the impacts of saltwater intrusion on urban water supplies.

Although the projections are uncertain, significant changes in precipitation and temperature coupled with increasing sea level have important implications for the CERP. The Everglades landscape is especially sensitive to sea-level rise, and rates of sea-level rise in South Florida are predicted to increase. A scenario of 1.5-degree increase in temperature and a 10 percent decrease in precipitation together with anticipated sea-level rise results in significant changes in coastal ecosystems and insufficient freshwater to sustain the natural and built systems. To decrease uncertainty associated with precipitation projections and clarify future risk, global climate model projections of intra-annual, annual, and interannual variability in precipitation and temperature need to be improved and refined.

These improved climate projections should, in turn, be used by CERP planners as input to drive Everglades hydrologic models suitable for making inferences on year-to-year and seasonal variations in freshwater availability.

Climate change is not adequately considered in the CERP planning process and should be integrated into future ongoing analysis and monitoring. CERP project designs are based on historical hydrology and have not been assessed in the context of future precipitation and evapotranspiration scenarios. Currently, only sea-level rise is considered in CERP planning and usually only as a cursory analysis at the end of the process to assess loss of benefits through 2050 with wetland inundation resulting from sea-level rise. The lack of consideration of the effects of climate change paints an incomplete picture of hydrologic and ecosystem response to the alternatives examined and ignores the potential benefits of the projects to help mitigate the impacts of climate change. Additionally, hydrologic restoration goals are based on the natural systems model, which reflects the past 50 years rather than any likely future. Depending on future climate change, some hydrologic or ecological restoration goals may be unattainable or prove to be not cost-effective. Urban and agricultural water demands unmet under dire climate scenarios highlight the need for additional analysis of water sustainability for the natural and built systems.

CERP planners should consider the implications of sea-level rise and potential hydrologic change in systemwide planning and project prioritization. Likely sea-level-rise projections can be used to evaluate future project benefits, considering uncertainties regarding the potential for accretion in coastal and inland wetlands to mitigate these effects. Sea-level-rise scenarios should also be coupled with hydrologic change scenarios to characterize systemwide response to global change. The outcome of these analyses would inform future systemwide decisions of project prioritization. Re-prioritization should include consideration of both those rendered less important and less effective in light of reduced benefits in the context of climate change and sea-level rise and those projects that become more essential to enhance the ability of the ecosystem and the built environment to adapt to changes and mitigate the effects of changing climate.

Anticipating future changes in temperature, precipitation, and sea-level rise, CERP planners should, where feasible, design for flexibility. Climate change needs to be incorporated into adaptive management planning, at both project-scale and when considering systemwide goals. It is likely that additional water storage will be needed to address anticipated future increases in variability of meteorological conditions. As new knowledge becomes available, it needs to be incorporated into the CERP adaptive management framework so that managers can adjust future restoration efforts appropriately as the nature of changes in climate become more evident. In addition, the current monitoring program should be evaluated to ensure that important effects of climate change will be characterized and quantified.

The committee identified several high-priority research needs related to climate change and Everglades restoration:

- Assess the rates of peat/sediment accretion and subsidence in coastal and inland freshwater wetlands in the context of sea-level rise;
- Improve modeling tools that can be used to assess the effects of projected sea-level rise on groundwater supplies and coastal ecosystem functioning and examine the potential for the CERP to mitigate these effects;
- Improve, refine, and evaluate downscaled climate model projections in the context of South Florida water resources and Everglades restoration;
- Improve the understanding of factors that could help maintain the diverse mosaic of Everglades habitats and increase their resilience amid changes in climate and sea level; and
- With improved climate and sea-level projections, reevaluate the goals for Everglades restoration and develop alternative goals as appropriate.

INVASIVE NONNATIVE SPECIES

Despite excellent progress in developing coordination of the management of invasive species at the operational level, there is a lack of coordination at a strategic level that includes a comprehensive view of all nonnative species in all parts of the greater Everglades. Currently, plants and animals tend to be considered separately. Management and restoration activities need to take account of the entire biotic community and not be partitioned into different taxa. For many invasive species, different agencies take on management activities in different areas, yet individuals of such species move between areas, so that management in one area can impact other areas. These factors argue for the creation of a high-level coordinative entity to oversee policy, management, and budgets related to nonnative species. Prioritization of research needs and control efforts across areas, species, habitats, and agencies would be a major responsibility of this entity. The committee is optimistic that the Comprehensive Invasive Species Strategic Action Framework being developed by the South Florida Ecosystem Task Force will be a major step toward achieving these goals of high-level coordination.

A strategic early detection and rapid response (EDRR) system that addresses all areas, habitats, and species is needed. EDRR is an essential strategy if new invasions of nonnative species in the Everglades are to be eradicated (or at least contained) while it is still feasible and relatively inexpensive to do so. Several EDRR efforts are under way, but the current level of monitoring is insufficient to address the geographic extent and range of nonnative species threats in the Everglades. In general, a rapid response requires quick access to resources, but efforts to eradicate incipient invasions in the Everglades have more often been stymied by the inability to obtain funds from federal, state, or local sources. The costs of additional monitoring and response should be weighed against the likely benefits of finding and acting on early invasions. Additional funding would allow for greater public outreach, expanded operation of the reporting hotline, increased early detection monitoring, and improved capacity for rapid response to facilitate eradication. The committee recognizes that the goal of this recommendation—addressing all areas, habitats, and species—likely is beyond any reasonable expectation of resources, but keeping this goal in mind emphasizes the value of prevention and clarifies the magnitude of the challenge.

There is no systemwide mechanism for prioritizing research on and management of invasive species. Many agencies participating in the Everglades restoration already undertake research activities on certain nonnative species and also implement management activities, but these efforts are limited by insufficient resources and are typically driven by specific agency needs rather than systemwide priorities. Effective prioritization requires a comprehensive understanding of all nonnative species present in the Everglades, their impacts and threats, as well as those of impending or likely new arrivals.

Research is lacking on nonnative species and their impacts to adequately inform prioritization efforts. Many knowledge gaps exist about species considered to be priorities for management. Given the spatial extent of the problem and the threats of future invasions, substantial research is needed to assess the various impacts of nonnative species on ecosystem functioning and native species and to develop or improve control mechanisms. This does not mean comprehensive research on all details of the biology and effects of every nonnative species. Rather, enough basic information should be gathered systematically to determine which species could reasonably be predicted to have considerable ecological impacts. Such knowledge is important in guiding decisions on detailed research on possible impacts and management of particular threats and would help inform priorities for management actions.

If eradication proves impossible, maintenance management and long-term control at acceptable levels should be explicitly recognized as a goal in some cases. Indeed, current practice seems to implicitly recognize this goal. Maintenance management at low densities is sometimes possible by various combinations of biological, chemical, mechanical, and physical controls. In the Everglades, a striking example is the current management of melaleuca (*Melaleuca quinquenervia*), once thought too widespread and dense to be manageable. As a result of sustained intensive research, this species is currently under substantial control in most regions through a combination of mechanical, chemical, and biological control as well as prescribed burns. Maintenance management requires continued, diligent monitoring and flexible, but reliable funding that can be devoted strategically to achieve and maintain long-term control.

At every step of the CERP planning process, full consideration is needed of the implications of restoration activities for nonnative species and their impacts. Until very recently, invasive species have not been considered in CERP project planning and implementation beyond simply removing any invasive species encountered at construction sites. Ideally, hydrologic restoration should favor the reestablishment and expansion of many native wetland species that are better adapted to longer hydroperiods. However, aquatic and flood-tolerant nonnative species may also benefit and replace native species. Removing levees and filling in canals may, in certain circumstances, facilitate the spread of nonnative species by increasing their potential for dispersal. For each CERP project, the potential to increase the spread of invasive species should be examined and the effects on ecosystem functioning assessed. Based on this analysis, strategies and technologies to lessen these impacts should be appropriately considered. Recent CERP guidance and plans to implement national USACE invasive species policy indicate that these considerations are increasingly being incorporated into project planning and implementation, although it is too soon to evaluate this new approach.

Long-term monitoring and research are needed to understand the potential impacts of climate change on Everglades nonnative species management. Climate change has the potential to significantly impact the distributions and abundances of nonnative species in the Everglades and their impacts on the ecosystem as a whole. Thus, research and monitoring to understand long-term changes in nonnative species distribution and behavior and the effectiveness of maintenance control strategies in the context of climate change are needed.

SCIENCE AND DECISION MAKING

Useful long-term systemwide monitoring requires stable funding. If funding cuts result in significant gaps in critical long-term monitoring data, important changes and patterns could be missed, and data collected prior to or after the funding gaps could lose their value. Given the substantial financial investment in Everglades restoration by both the state and the federal government, a dedicated source of funding could provide ongoing long-term systemwide monitoring and assessment that are critical to meeting restoration objectives, ensuring that public resources are spent wisely and adaptive management is supported.

A comprehensive reevaluation of restoration-related monitoring is needed to determine its adequacy considering budget pressures, the extended CERP implementation time frames, and the potential impacts of climate change and

sea-level rise. The dramatic 2011 cuts to Monitoring and Assessment Plan funding create a risk that adequate long-term data will not be available to assess the effects of restoration projects in a systemwide context once they are implemented. This reevalution should clearly articulate the value of the highest priority monitoring to future restoration decision making and the risks of ceasing such monitoring. Also, CERP planners should identify opportunities for improving the efficiency of current monitoring and reducing the frequency of some monitoring in the context of the current slow pace of CERP implementation.

Renewed attention to science coordination is warranted. Scientific research and monitoring programs require coordination and communication to be effective and efficient, but science leadership and coordination appear to have waned over the past few years. For the Science Coordination Group to contribute significantly to better science coordination, it would need to have adequate funding and staff and a clear charge to address critical science needs from a restoration-wide perspective.

1

Introduction

The Florida Everglades, formerly a large and diverse aquatic ecosystem, has been dramatically altered over the past century by an extensive water control infrastructure designed to increase regional economic productivity through improved flood control, urban water supply, and agricultural production (Davis and Ogden, 1994; NRC, 2005). Shaped by the slow flow of water, its vast terrain of sawgrass plains, ridges, sloughs, and tree islands supported a high diversity of plant and animal habitats. This natural landscape also served as a sanctuary for Native Americans. However, large-scale changes to the landscape have diminished the natural resources, and by the mid- to late-20th century, many of the area's defining natural characteristics had been lost. The remnants of the original Everglades (see Figure 1-1 and Box 1-1) now compete for vital water with urban and agricultural interests, and contaminated runoff from these two activities impairs the South Florida ecosystem.

Recognition of past declines in environmental quality, combined with continuing threats to the natural character of the remaining Everglades, led to initiation of large-scale restoration planning in the 1990s and the launch of the Comprehensive Everglades Restoration Plan (CERP) in 2000. This unprecedented project envisioned the expenditure of billions of dollars in a multidecadal effort to achieve ecological restoration by reestablishing the hydrologic characteristics of the Everglades, where feasible, and to create a water system that simultaneously serves the needs of both the natural and the human systems of South Florida. Within the social, economic, and political latticework of the 21st century, restoration of the South Florida ecosystem is now under way and represents one of the most ambitious ecosystem renewal projects ever conceived. This report represents the fifth independent assessment of the CERP's progress by the Committee on Independent Scientific Review of Everglades Restoration Progress (CISRERP) of the National Research Council (NRC).

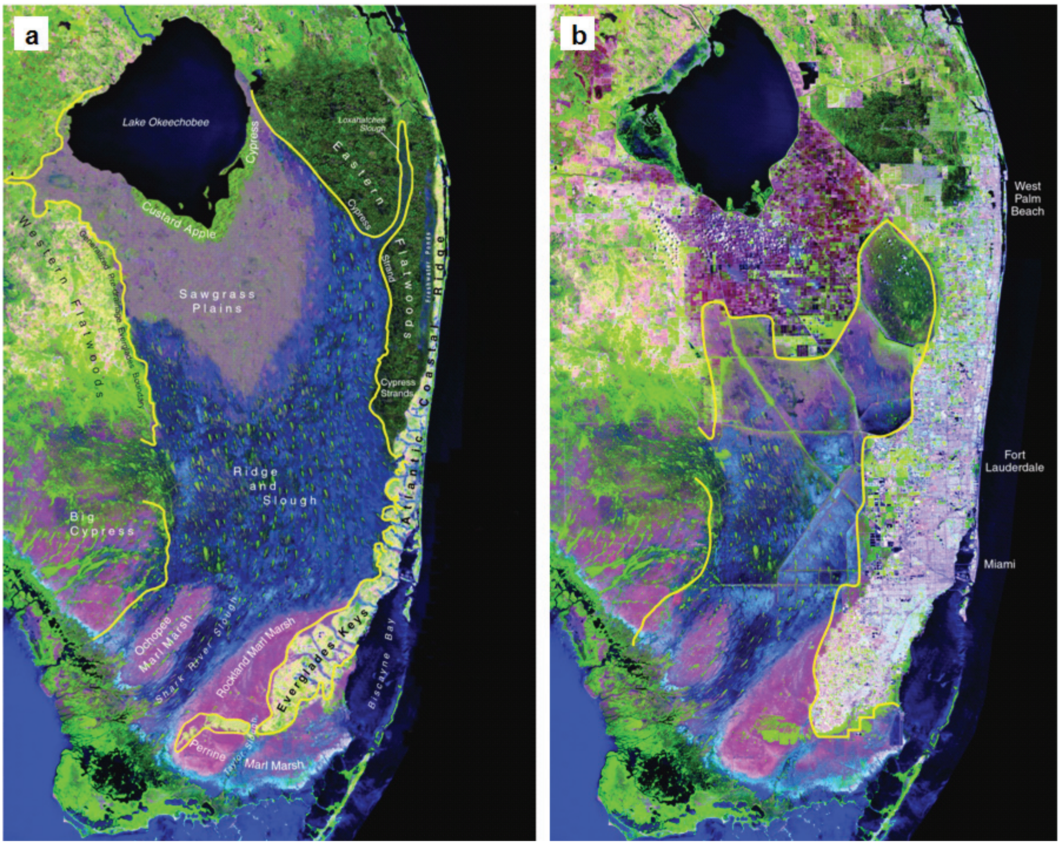

FIGURE 1-1 Reconstructed (a) pre-drainage (circa 1850) and (b) current (1994) satellite images of the Everglades ecosystem.

NOTE: The yellow line in (a) outlines the historical Everglades ecosystem, and the yellow line in (b) outlines the remnant Everglades ecosystem as of 1994.

SOURCE: Courtesy of C. McVoy, J. Obeysekera, and W. Said, South Florida Water Management District. © International Mapping Associates

THE NATIONAL RESEARCH COUNCIL AND EVERGLADES RESTORATION

The NRC has been providing scientific and technical advice related to the Everglades restoration since 1999. The NRC's Committee on the Restoration of the Greater Everglades Ecosystem (CROGEE), which operated from 1999 until 2004, was formed at the request of the South Florida Ecosystem Restoration Task Force (Task Force), an intergovernmental body established to facilitate

BOX 1-1
Geographic Terms

This box defines some key geographic terms used throughout this report.

- The **Everglades,** the **Everglades ecosystem,** or the **remnant Everglades ecosystem** refers to the present areas of sawgrass, marl prairie, and other wetlands and estuaries south of Lake Okeechobee (Figure 1-1b).
- The **original, historical, or pre-drainage Everglades** refers to the areas of sawgrass, marl prairie, and other wetlands and estuaries south of Lake Okeechobee that existed prior to the construction of drainage canals beginning in the late 1800s (Figure 1-1a).
- The **Everglades watershed** is the drainage that encompasses the Everglades ecosystem but also includes the Kissimmee River watershed and other smaller watersheds north of Lake Okeechobee that ultimately supply water to the Everglades ecosystem.
- The **South Florida ecosystem** (also known as the Greater Everglades Ecosystem; see Figure 1-2) extends from the headwaters of the Kissimmee River near Orlando through Lake Okeechobee and the Everglades into Florida Bay and ultimately the Florida Keys. The boundaries of the South Florida ecosystem are determined by the boundaries of the South Florida Water Management District, the southernmost of the state's five water management districts, although they approximately delineate the boundaries of the South Florida watershed. This designation is important and helpful to the restoration effort because, as many publications have made clear, taking a watershed approach to ecosystem restoration is likely to improve the results, especially when the ecosystem under consideration is as water dependent as the Everglades (NRC, 1999, 2004).

The **Water Conservation Areas** (WCAs) include WCA-1 (the Arthur R. Marshall Loxahatchee National Wildlife Refuge), WCA-2A and -2B, -3A, and -3B (see Figure 1-2).

The following represent legally defined geographic terms used in this report:

- The **Everglades Protection Area** is defined in the Everglades Forever Act as comprising WCA-1, -2A, -2B, -3A, and -3B and Everglades National Park.
- The **natural system** is legally defined in the Water Resources Development Act of 2000 (WRDA 2000) as all land and water managed by the federal government or the state within the South Florida ecosystem (see Figure 1-3). "The term 'natural system' includes (i) water conservation areas; (ii) sovereign submerged land; (iii) Everglades National Park; (iv) Biscayne National Park; (v) Big Cypress National Preserve; (vi) other Federal or State (including a political subdivision of a State) land that is designated and managed for conservation purposes; and (vii) any tribal land that is designated and managed for conservation purposes, as approved by the tribe" (WRDA 2000).

Many maps in this report include shorthand designations that use letters and numbers for engineered additions to the South Florida ecosystem. For example, canals are labeled C-#; levees and associated borrow canals as L-#; and structures, such as culverts, locks, pumps, spillways, control gates, and weirs, as S-# or G-#.

FIGURE 1-2 The South Florida ecosystem.

SOURCE: © International Mapping Associates

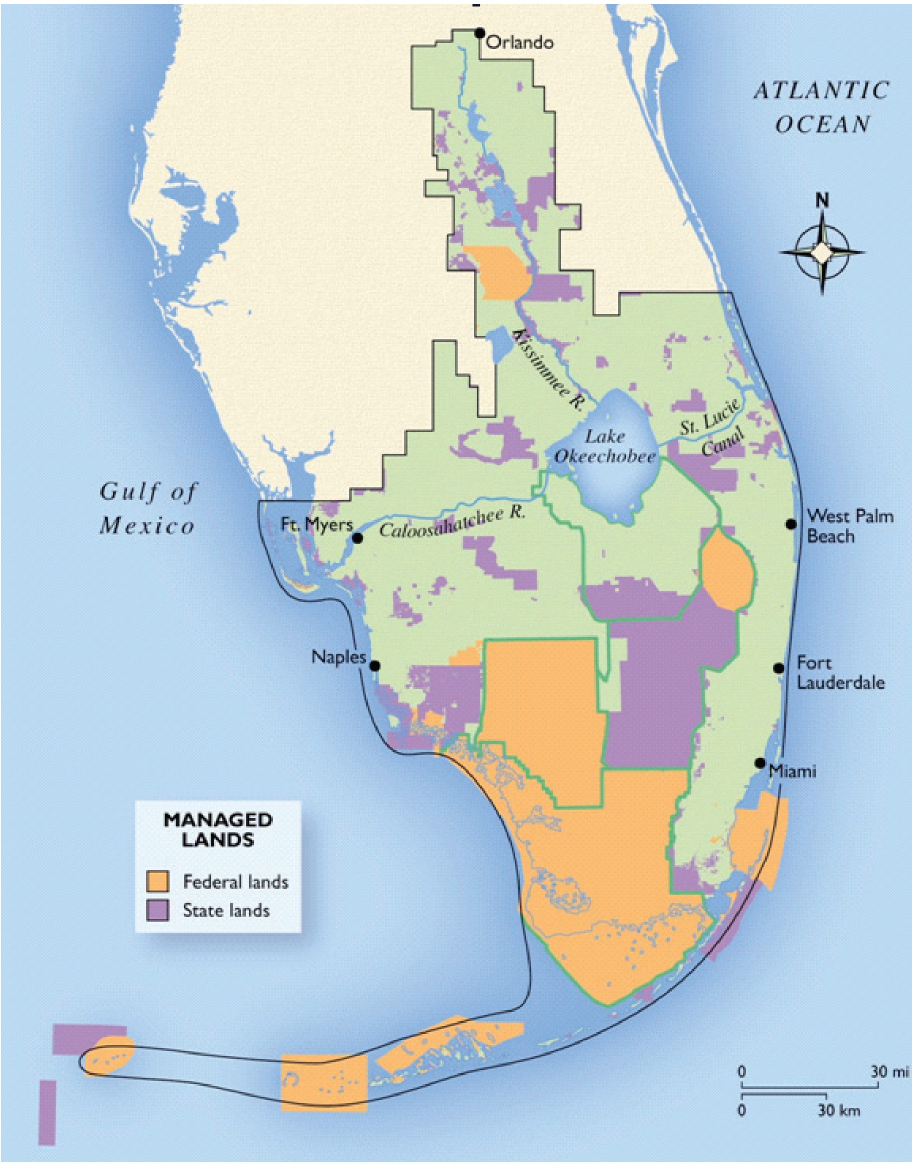

FIGURE 1-3 Land and waters managed by the State of Florida and the federal government as of December 2005 for conservation purposes within the South Florida ecosystem.

SOURCE: Based on data compiled by Florida State University's Florida Natural Areas Inventory (http://www.fnai.org/gisdata.cfm). © International Mapping Associates coordination in the restoration effort, and the committee produced six reports (NRC, 2001, 2002a,b, 2003a,b, 2005). The NRC's Panel to Review the Critical Ecosystem Studies Initiative produced an additional report in 2003 (NRC, 2003c; see Appendix A). The Water Resources Development Act of 2000 (WRDA 2000) mandated that the U.S. Department of the Army, the Department of the Interior, and the State of Florida, in consultation with the Task Force, establish an independent scientific review panel to evaluate progress toward achieving the natural system restoration goals of the CERP. The NRC's CISRERP was therefore established in 2004 under contract with the U.S. Army Corps of Engineers. After publication of each of the first four biennial reviews (NRC, 2007, 2008, 2010, 2012a; see Appendix A for the report summaries), some members rotated off the committee and some new members were added.

The committee is charged to submit biennial reports that address the following items:

1. An assessment of progress in restoring the natural system, which is defined by section 601(a) of WRDA 2000 as all of the land and water managed by the federal government and state within the South Florida ecosystem (see Figure 1-3 and Box 1-1);
2. A discussion of significant accomplishments of the restoration;
3. A discussion and evaluation of specific scientific and engineering issues that may impact progress in achieving the natural system restoration goals of the plan; and
4. An independent review of monitoring and assessment protocols to be used for evaluation of CERP progress (e.g., CERP performance measures, annual assessment reports, assessment strategies, etc.).

Given the broad charge, the complexity of the restoration, and the continually evolving circumstances, the committee did not presume it could cover all issues that affect restoration progress in any single report. This report builds on the past reports by this committee (NRC, 2007, 2008, 2010, 2012a) and emphasizes restoration progress since 2012, high-priority scientific and engineering issues that the committee judged to be relevant to this time frame, and other issues that have impacted the pace of progress. The committee focused particularly on issues for which the "timing was right"—that is, where the committee's advice could be useful relative to the decision-making time frames—and on topics that had not been fully addressed in past NRC Everglades reports. Interested readers should look to past reports by this committee (NRC, 2007, 2008, 2010, 2012a) to find detailed discussions of important topics, such as the human context for the CERP, water quality and quantity challenges and trajectories, Lake Okeechobee, Modified Water Deliveries to Everglades National Park, and incremental adaptive restoration, which are not repeated here.

The committee met five times during the course of this review; received briefings at its public meetings from agencies, organizations, and individuals involved in the restoration, as well as from the public; and took several field trips to sites with restoration activities (see Acknowledgments) to help it evaluate restoration progress. In addition to information received at the meetings, the committee based its assessment of progress on information in relevant CERP and non-CERP restoration documents. The committee's conclusions and recommendations also were informed by a review of relevant scientific literature and the experience and knowledge of the committee members in their fields of expertise. The committee was unable to consider in any detail new materials received after March 2014.

REPORT ORGANIZATION

In Chapter 2, the committee provides an overview of the CERP in the context of other ongoing restoration activities and discusses the restoration goals that guide the overall effort.

In Chapter 3, the committee discusses progress in the Central Everglades Planning Project and presents its evaluation of the effort.

In Chapter 4, the committee analyzes the progress of CERP implementation, including recent developments at Picayune Strand, Biscayne Bay Coastal Wetlands, the C-111 Spreader Canal, and Indian River Lagoon-South and several pilot projects that are under way. Also discussed in the chapter are programmatic progress and issues, including funding, authorization, and sequencing.

In Chapter 5, the committee discusses the implications of climate change for Everglades restoration and recommends planning and research needs to address this issue.

In Chapter 6, the committee examines the impacts of nonnative invasive species on Everglades restoration, discusses current mechanisms to coordinate monitoring and control efforts, and recommends additional steps to improve invasive species control strategies.

In Chapter 7, the committee discusses the contributions and use of science for CERP decision making. The chapter focuses on science coordination, adaptive management, and science support for water quality improvements.

2

The Restoration Plan in Context

This chapter sets the stage for the fifth of this committee's biennial assessments of restoration progress in the South Florida ecosystem. Background for understanding the project is provided through descriptions of the ecosystem decline, restoration goals, the needs of a restored ecosystem, and the specific activities of the restoration project.

BACKGROUND

The Everglades once encompassed about 3 million acres of slow-moving water and associated biota that stretched from Lake Okeechobee in the north to Florida Bay in the south (Figures 1-1a and 2-1a). The conversion of the Everglades wilderness into an area of high agricultural productivity and cities was a dream of 19th-century investors, and projects begun between 1881 and 1894 affected the flow of water in the watershed north of Lake Okeechobee. These early projects included dredging canals in the Kissimmee River Basin and constructing a channel connecting Lake Okeechobee to the Caloosahatchee River and, ultimately, the Gulf of Mexico. By the late 1800s, more than 50,000 acres north and west of the lake had been drained and cleared for agriculture (Grunwald, 2006). In 1907, Governor Napoleon Bonaparte Broward created the Everglades Drainage District to construct a vast array of ditches, canals, dikes, and "improved" channels. By the 1930s, Lake Okeechobee had a second outlet, through the St. Lucie Canal, leading to the Atlantic Ocean, and 440 miles of other canals altered the hydrology of the Everglades (Blake, 1980). After hurricanes in 1926 and 1928 resulted in disastrous flooding from Lake Okeechobee, the U.S. Army Corps of Engineers (USACE) replaced the small berm that bordered the southern edge of the lake with the massive Herbert Hoover Dike, which was eventually expanded in the 1960s to encircle the lake. The hydrologic end product of these drainage activities was the drastic reduction of water storage within the system and an increased susceptibility to drought and desiccation in the southern reaches of the Everglades (NRC, 2005).

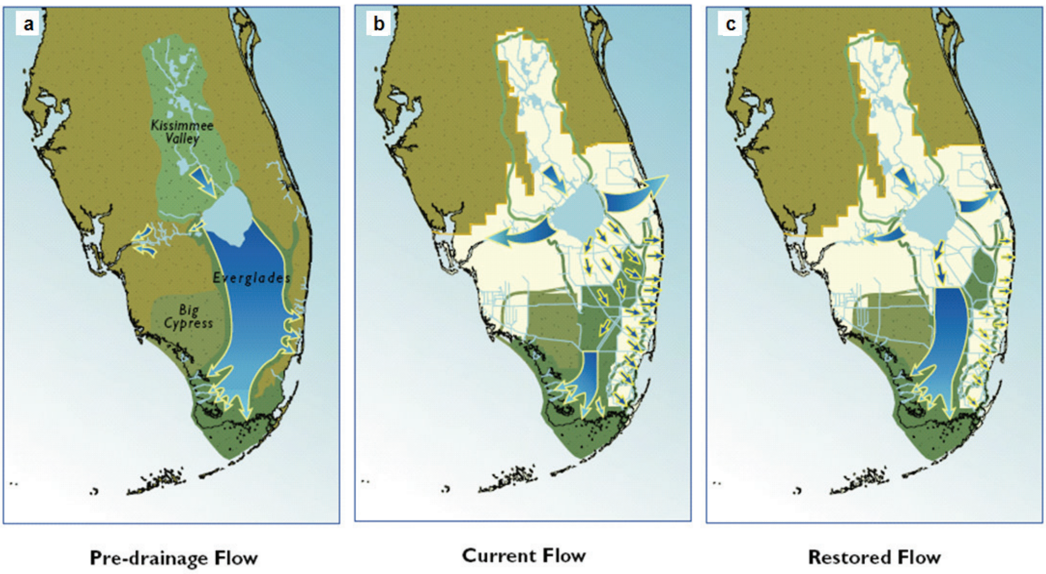

FIGURE 2-1 Water flow in the Everglades under (a) historical conditions, (b) current conditions, and (c) conditions envisioned upon completion of the Comprehensive Everglades Restoration Plan (CERP).

SOURCE: Graphics provided by USACE, Jacksonville District.

After further flooding in 1947 and increasing demands for improved agricultural production and flood control for the expanding population centers on the southeast Florida coast, the U.S. Congress authorized the Central and Southern Florida (C&SF) Project. This project provided flood control and urban and agricultural water supply by straightening 103 miles of the meandering Kissimmee River, expanding the Herbert Hoover Dike, constructing a levee along the eastern boundary of the Everglades to prevent flows into the southeastern urban areas, establishing the 700,000-acre Everglades Agricultural Area (EAA) south of Lake Okeechobee, and creating a series of Water Conservation Areas (WCAs) in the remaining space between the lake and Everglades National Park (Light and Dineen, 1994). The eastern levee isolated about 100,000 acres of the Everglades ecosystem, making it available for development (Lord, 1993). In total, urban and agricultural development have reduced the Everglades to about one-half its pre-drainage size (see Figure 1-1b; Davis and Ogden, 1994) and have contaminated its waters with chemicals such as phosphorus, nitrogen, sulfur, mercury, and pesticides. Associated drainage and flood control structures, including the C&SF Project, have diverted large quantities of water to the coastal areas, thereby reducing the freshwater inflows and natural water storage that defined the ecosystem (see Figure 2-1b).

The profound hydrologic alterations were accompanied by many changes in the biotic communities in the ecosystem, including reductions and changes in the composition, distribution, and abundance of the populations of wading birds. Today, the federal government has listed 67 plant and animal species in South Florida as threatened or endangered, with many more included on state lists. Some distinctive Everglades habitats, such as custard apple forests and peripheral wet prairie, have disappeared altogether, while other habitats are severely reduced in area (Davis and Ogden, 1994; Marshall et al., 2004). Approximately 1 million acres are contaminated with mercury (McPherson and Halley, 1996). Phosphorus from agricultural runoff has impacted water quality in large portions of the Everglades and has been particularly problematic in Lake Okeechobee (Flaig and Reddy, 1995) (see Chapter 4 for a more detailed discussion of phosphorus enrichment in the Everglades). The Caloosahatchee and St. Lucie estuaries, including parts of the Indian River Lagoon, have been greatly altered by high and extremely variable freshwater discharges that bring nutrients and contaminants and disrupt salinity regimes (Doering, 1996; Doering and Chamberlain, 1999).

At least as early as the 1920s, private citizens were calling attention to the degradation of the Florida Everglades (Blake, 1980). However, by the time Marjory Stoneman Douglas's classic book *The Everglades: River of Grass* was published in 1947 (the same year that Everglades National Park was dedicated), the South Florida ecosystem had already been altered extensively. Beginning in the 1970s, prompted by concerns about deteriorating conditions in Everglades National Park and other parts of the South Florida ecosystem, the public, as well as the federal and state governments, directed increased attention to the adverse ecological effects of the flood control and irrigation projects (Kiker et al., 2001; Perry, 2004). By the late 1980s it was clear that various minor corrective measures undertaken to remedy the situation were insufficient. As a result, a powerful political consensus developed among federal agencies, state agencies and commissions, Native American tribes, county governments, and conservation organizations that a large restoration effort was needed in the Everglades (Kiker et al., 2001). This recognition culminated in the Comprehensive Everglades Restoration Plan (CERP), which builds on other ongoing restoration activities of the state and federal governments to create one of the most ambitious and extensive restoration efforts in the nation's history.

RESTORATION GOALS FOR THE EVERGLADES

Several goals have been articulated for the restoration of the South Florida ecosystem, reflecting the various restoration programs. The South Florida Ecosystem

Restoration Task Force (hereafter, simply the Task Force), an intergovernmental body established to facilitate coordination in the restoration effort, has three broad strategic goals: (1) "get the water right," (2) "restore, preserve, and protect natural habitats and species," and (3) "foster compatibility of the built and natural systems" (SFERTF, 2000). These goals encompass, but are not limited to, the CERP. The Task Force works to coordinate and build consensus among the many non-CERP restoration initiatives that support these broad goals.

The goal of the CERP, as stated in the Water Resources Development Act of 2000 (WRDA 2000), is "restoration, preservation, and protection of the South Florida Ecosystem while providing for other water-related needs of the region, including water supply and flood protection." The Programmatic Regulations (33 CFR § 385.3) that guide implementation of the CERP further clarify this goal by defining restoration as "the recovery and protection of the South Florida ecosystem so that it once again achieves and sustains the essential hydrological and biological characteristics that defined the undisturbed South Florida ecosystem." These defining characteristics include a large areal extent of interconnected wetlands, extremely low concentrations of nutrients in freshwater wetlands, sheet flow, healthy and productive estuaries, resilient plant communities, and an abundance of native wetland animals (DOI and USACE, 2005). Although development has permanently reduced the areal extent of the Everglades ecosystem, the CERP hopes to recover many of the Everglades' original characteristics and natural ecosystem processes. At the same time, the CERP is charged to maintain levels of flood protection (as of 2000) and provide for other water-related needs, including water supply, for a rapidly growing human population in South Florida (DOI and USACE, 2005).

Although the CERP contributes to each of the Task Force's three goals, it focuses primarily on restoring the hydrologic features of the undeveloped wetlands remaining in the South Florida ecosystem, on the assumption that improvements in ecological conditions will follow. Originally, "getting the water right" had four components—quality, quantity, timing, and distribution. However, the hydrologic properties of flow, encompassing the concepts of direction, velocity, and discharge, have been recognized as an important component of getting the water right that had previously been overlooked (NRC, 2003c; SCT, 2003). Numerous studies have supported the general approach to getting the water right (Davis and Ogden, 1994; NRC, 2005; SSG, 1993), although it is widely recognized that recovery of the native habitats and species in South Florida may require restoration efforts in addition to getting the water right, such as controlling exotic species and reversing the decline in the spatial extent and compartmentalization of the natural landscape (SFERTF, 2000; SSG, 1993).

The goal of ecosystem restoration can seldom be the exact re-creation of some historical or preexisting state because physical conditions, driving forces, and boundary conditions usually have changed and are not fully recoverable. Rather, restoration is better viewed as the process of assisting the recovery of a degraded ecosystem to the point where it contains sufficient biotic and abiotic resources to continue its functions without further assistance in the form of energy or other resources from humans (NRC, 1996; Society for Ecological Restoration International Science & Policy Working Group, 2004). The term *ecosystem rehabilitation* may be more appropriate when the objective is to improve conditions in a part of the South Florida ecosystem to at least some minimally acceptable level to allow the restoration of the larger ecosystem to advance. However, flood control remains a critical aspect of the CERP design, and artificial storage will be required to replace the lost natural storage in the system (NRC, 2005). For these and other reasons, even when the CERP is complete, it will require large inputs of energy and human effort to operate and maintain pumps, stormwater treatment areas, canals and levees, and reservoirs, and to continue to manage exotic species. Thus, for the foreseeable future, the CERP does not envision ecosystem restoration or rehabilitation that returns the ecosystem to a state where it can "manage itself."

Implicit in the understanding of ecosystem restoration is the recognition that natural systems are self-designing and dynamic, and therefore, it is not possible to know in advance exactly what can or will be achieved. Thus, ecosystem restoration is an enterprise with some scientific uncertainty in methods or outcomes that requires continual testing of assumptions and monitoring and assessment of progress. This report discusses the challenges posed by two major contributors to the dynamic circumstances in which restoration is taking place, climate change (Chapter 5) and nonnative invasive species (Chapter 6). Additional challenges in defining and implementing restoration goals are discussed in the initial National Research Council (NRC) biennial review (NRC, 2007).

What Natural System Restoration Requires

Restoring the South Florida ecosystem to a desired ecological landscape requires reestablishment of the critical processes that sustained its historical functions. Although getting the water right is the oft-stated and immediate goal, the restoration will be considered successful if it restores the distinctive characteristics of the historical ecosystem to the remnant Everglades (DOI and USACE, 2005). Getting the water right is a means to an end, not the end in itself. The hydrologic and ecologic characteristics of the historical Everglades serve as restoration goals for a functional (albeit reduced in size) Everglades ecosystem. The first Committee on Independent Scientific Review of Everglades Restoration Progress review identified five critical components of Everglades restoration (NRC, 2007):

1. Enough water storage capacity combined with operations that allow for appropriate volumes of water to support healthy estuaries and the return of sheet flow through the Everglades ecosystem while meeting other demands for water;
2. Mechanisms for delivering and distributing the water to the natural system in a way that resembles historical flow patterns, affecting volume, depth, velocity, direction, distribution, and timing of flows;
3. Barriers to eastward seepage of water so that higher water levels can be maintained in parts of the Everglades ecosystem without compromising the current levels of flood protection of developed areas as required by the CERP;
4. Methods for securing water quality conditions compatible with restoration goals for a natural system that was inherently extremely nutrient poor, particularly with respect to phosphorus; and
5. Retention, improvement, and expansion of the full range of habitats by preventing further losses of critical wetland and estuarine habitats and by protecting lands that could usefully be part of the restored ecosystem.

If these five critical components of restoration are achieved and the difficult problem of invasive species can be managed (see Chapter 6), then the basic physical, chemical, and biological processes that created the historical Everglades can once again work to create a functional mosaic of biotic communities that resemble what was distinctive about the historical Everglades.

The history of the Everglades likely will make replication of the historical system impossible. Because of the historical changes that have occurred through engineered structures, urban development, introduced species, and other factors, the paths taken by the ecosystem and its components in response to restoration efforts will not retrace the paths taken to reach current conditions. This means that the paths toward restoration will pass through different intermediate conditions from the ones they passed through on their way to the current status. This phenomenon often is referred to as *hysteresis* (e.g., NRC, 2012c; Scheffer et al., 2001; Tett et al., 2007) and is a complicating factor in any estimates of how long restoration efforts are likely to take to achieve their goals (Chapter 4).

Even if the restored system does not exactly replicate the historical system, or reach all of the biological, chemical, and physical targets, the reestablishment of natural processes and dynamics should result in a viable and valuable Everglades ecosystem. The central principle of ecosystem management is to provide for the natural processes that historically shaped an ecosystem, because ecosystems are characterized by the processes that regulate them. If the conditions necessary for those processes to operate are met, then recovery of species and communities is far more likely than if humans attempt to specify and manage every individual constituent and element of the ecological system (NRC, 2007).

RESTORATION ACTIVITIES

Several restoration programs, including the largest of the initiatives, the CERP, are now under way. The CERP often builds upon non-CERP activities (also called "foundation projects"), many of which are essential to the effectiveness of the CERP. The following section provides a brief overview of the CERP and some of the major non-CERP activities.

Comprehensive Everglades Restoration Plan

WRDA 2000 authorized the CERP as the framework for modifying the C&SF Project. Considered a blueprint for the restoration of the South Florida ecosystem, the CERP is led by two organizations with considerable expertise managing the water resources of South Florida—the USACE, which built most of the canals and levees throughout the region, and the South Florida Water Management District (SFWMD), the state agency with primary responsibility for operating and maintaining this complicated water collection and distribution system.

The CERP conceptual plan (USACE and SFWMD, 1999; also called the Yellow Book) proposes major alterations to the C&SF Project in an effort to reverse decades of ecosystem decline. The Yellow Book includes approximately 50 major projects consisting of 68 project components to be constructed at a cost of approximately $13.5 billion (estimated in 2009 dollars; DOI and USACE, 2011; Figure 2-2). Major components of the restoration plan focus on restoring the quantity, quality, timing, and distribution of water for the natural system. The Yellow Book outlines the major CERP components, including the following:

- **Conventional surface-water storage reservoirs.** The Yellow Book includes plans for approximately 1.5 million acre-feet of storage, located north of Lake Okeechobee, in the St. Lucie and Caloosahatchee basins, in the EAA, and in Palm Beach, Broward, and Miami-Dade counties.
- **Aquifer storage and recovery (ASR).** The Yellow Book proposes to provide substantial water storage through ASR, a highly engineered approach that would use a large number of wells built around Lake Okeechobee, in Palm Beach County, and in the Caloosahatchee Basin to store water approximately 1,000 feet belowground; the feasibility of this approach is currently being examined through pilot tests.
- **In-ground reservoirs.** The Yellow Book proposes additional water storage in quarries created by rock mining.

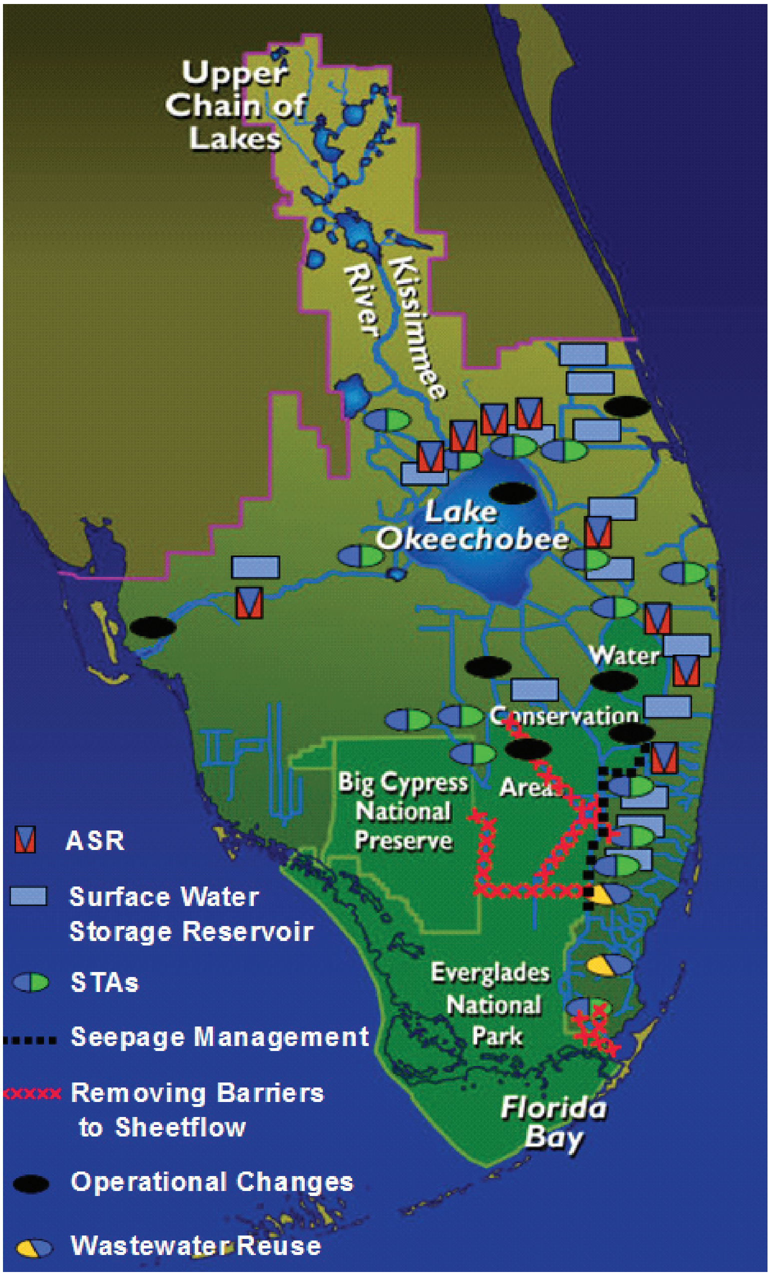

FIGURE 2-2 Major project components of the CERP.

SOURCE: Courtesy of Laura Mahoney, USACE.

- **Stormwater treatment areas (STAs).** The CERP contains plans for additional constructed wetlands that will treat agricultural and urban runoff water before it enters natural wetlands.[1]
- **Seepage management.** The Yellow Book outlines seepage management projects to prevent unwanted loss of water from the natural system through levees and groundwater flow. The approaches include adding impermeable barriers to the levees, installing pumps near levees to redirect lost water back into the Everglades, and holding water levels higher in undeveloped areas between the Everglades and the developed lands to the east.
- **Removing barriers to sheet flow.** The CERP includes plans for removing 240 miles of levees and canals, to reestablish shallow sheet flow of water through the Everglades ecosystem.
- **Rainfall-driven water management.** The Yellow Book includes operational changes in the water delivery schedules to the WCAs and Everglades National Park to mimic more natural patterns of water delivery and flow through the system.
- **Water reuse and conservation.** To address shortfalls in water supply, the Yellow Book proposes two advanced wastewater treatment plants so that the reclaimed water could be discharged to wetlands along Biscayne Bay or used to recharge the Biscayne aquifer.

The largest portion of the budget is devoted to storage and water conservation projects and to acquiring the lands needed for them (see NRC, 2005).

The modifications to the C&SF Project embodied in the CERP were originally expected to take more than three decades to complete (and will likely now take much longer), and to be effective, they require a clear strategy for managing and coordinating restoration efforts. The Everglades Programmatic Regulations (33 CFR Part 385) state that decisions on CERP implementation are made by the USACE and the SFWMD (or any other local project sponsors), in consultation with the Department of the Interior, the Environmental Protection Agency (EPA),

[1] Although some STAs are included among CERP projects, USACE has clarified its policy on federal cost-sharing for water quality features. A memo from the Assistant Secretary of the Army (Civil Works) (USACE, 2007) states: "Before there can be a Federal interest to cost share a WQ [water quality] improvement feature, the State must be in compliance with WQ standards for the current use of the water to be affected and the work proposed must be deemed essential to the Everglades restoration effort. . . . This determination must be based on some finding other than the project is a part of CERP and generally will aid the restoration effort." The memo goes on to state, "the Yellow Book specifically envisioned that the State would be responsible for meeting water quality standards." Therefore, it appears that until the water flowing into the project features meets existing water quality requirements or unless a special exemption is granted for projects deemed "essential to Everglades restoration," the state is responsible for 100 percent of the costs of CERP water quality project features.

the Department of Commerce, the Miccosukee Tribe of Indians of Florida, the Seminole Tribe of Florida, the Florida Department of Environmental Protection, and other federal, state, and local agencies (33 CFR Part 385).

WRDA 2000 endorses the use of an adaptive management framework for the restoration process, and the Programmatic Regulations formally establish an adaptive management program that will "assess responses of the South Florida ecosystem to implementation of the Plan; . . . [and] seek continuous improvement of the Plan based upon new information resulting from changed or unforeseen circumstances, new scientific and technical information, new or updated modeling; information developed through the assessment principles contained in the Plan; and future authorized changes to the Plan." An interagency body called Restoration, Coordination, and Verification (RECOVER) has been established to ensure that sound science is used in the restoration. The RECOVER leadership group oversees the monitoring and assessment program that will evaluate the progress of the CERP toward restoring the natural system and will assess the need for changes to the plan through the adaptive management process.

Major Program-Level CERP-Related Developments Since 2000

Several major program-level developments have occurred since the CERP was launched that have affected the pace and focus of CERP efforts. In 2004, Florida launched Acceler8, a plan to hasten the pace of project implementation that was bogged down by the slow federal planning process (for further discussion of Acceler8, see NRC, 2007). Acceler8 originally included 11 CERP project components and 1 non-CERP project, and although the state was unable to complete all of the original tasks, the program led to increased state investment and expedited project construction time lines for several CERP projects (see Chapter 4).

In 2008, Governor Charlie Crist announced the planned acquisition of 187,000 acres of agricultural land from the U.S. Sugar Corporation to maximize restoration opportunities for the South Florida ecosystem. The SFWMD subsequently launched the River of Grass public planning process to facilitate agency and stakeholder input on future uses of the new lands for restoration. In October 2010, the SFWMD closed on the purchase of 26,800 acres of land for approximately $197 million in cash and retained the option to acquire more than 153,000 additional acres over the next 10 years. Plans for use of the acquired lands have not been finalized at this time.

In 2011, the USACE initiated a pilot program to improve the pace of its project planning. As one of five pilot projects nationwide, the Central Everglades Planning Process was launched in November 2011, with the objective of developing a plan for restoration of the central Everglades that could be delivered for congressional authorization within 2 years. This effort has focused attention on central

Everglades planning at all levels of the CERP partnering agencies and involves extensive stakeholder engagement facilitated by the Task Force (see Chapter 3).

In 2010, EPA issued its court-ordered Amended Determination, which directed the State of Florida to correct deficiencies in meeting the narrative and numeric nutrient criteria in the Everglades Protection Area. In 2012, the State of Florida launched its Restoration Strategies Regional Water Quality Plan, which was approved by EPA and the Court as an alternative means to address the Amended Determination. The State of Florida is currently in the process of constructing approximately 6,500 acres of new STAs and 116,000 acres of flow equalization basins (see Chapter 4). These water quality treatment improvements are designed so that water leaving the STAs will meet a new water quality-based effluent limit (WQBEL) to comply with the 10-ppb total phosphorus water quality criterion for the Everglades Protection Area.

Non-CERP Restoration Activities

When Congress authorized the CERP in WRDA 2000, the SFWMD, the USACE, the National Park Service, and the U.S. Fish and Wildlife Service were already implementing several activities intended to restore key aspects of the Everglades ecosystem. These non-CERP initiatives are critical to the overall restoration progress. In fact, the CERP's effectiveness was predicated upon the completion of many of these projects, which include Modified Water Deliveries to Everglades National Park (Mod Waters), C-111 (South Dade), and the Everglades Construction Project (see Box 2-1). Several additional projects are also under way to meet the broad restoration goals for the South Florida ecosystem and associated legislative mandates. They include extensive water quality initiatives, such as the Everglades Construction Project, and programs to establish best management practices (BMPs) to reduce nutrient loading.

SUMMARY

The Everglades ecosystem is one of the world's ecological treasures, but for more than a century the installation of an extensive water control infrastructure has changed the geography of South Florida and facilitated extensive agricultural and urban development. These changes have had profound ancillary effects on regional hydrology, vegetation, and wildlife populations. The CERP, a joint effort led by the state and federal governments and launched in 2000, seeks to reverse the general decline of the ecosystem. Since 2000, the CERP and other major Everglades restoration efforts have adapted to changing budgets, refinements in scientific understanding, and an evolving legal context, particularly as it relates to water quality. The implications on implementation progress are discussed in more detail in Chapter 4.

BOX 2-1
Non-CERP Restoration Activities in South Florida

The following represent the major non-CERP initiatives currently under way in support of the South Florida ecosystem restoration (Figure 2-3).

Kissimmee River Restoration Project

This project, authorized by Congress in 1992, aims to reestablish the historical river-floodplain system at the headwaters of the Everglades watershed and thereby restore biological diversity and functionality. The project plans to backfill 22 miles of the 56-mile C-38 Canal and carve new sections of the river channel to connect channel remnants, thereby restoring over 40 miles of meandering river channel in the Kissimmee River. The project includes a comprehensive evaluation program to track ecological responses to restoration (Jones et al., 2014). See also Chapter 4.

State Water Quality Treatment Projects

The Everglades Forever Act (Fla. Stat. § 373.4592) required the State of Florida to construct stormwater treatment areas (STAs) to reduce the loading of phosphorus into the Arthur R. Marshall Loxahatchee National Wildlife Refuge (LNWR), the WCAs, and Everglades National Park. As part of the state's Everglades Construction Project and long-term plan for meeting the total phosphorus criterion for the Everglades Protection Area of 10 parts per billion (ppb), the SFWMD constructed 57,000 acres of STAs between 1993 and 2012. In 2012, after continued violations of water quality standards, the state and the Environmental Protection Agency agreed upon a new Restoration Strategies Regional Water Quality Plan that has been approved by the U.S. District Court for the Southern District of Florida that requires an additional 6,500 acres of STAs and 116,000 acres of flow equalization basins (see Chapter 4).

Modifications to the C&SF: C-111 (South Dade) Project

This project is designed to improve hydrologic conditions in Taylor Slough and the Rocky Glades of the eastern panhandle of Everglades National Park and to increase freshwater flows to northeast Florida Bay, while maintaining flood protection for urban and agricultural development in south Miami-Dade County. The project plan includes a tieback levee with pumps to capture groundwater seepage to the east, detention areas to increase groundwater levels and thereby enhance flow into Everglades National Park, and backfilling or plugging several canals in the area. A combined operational plan (COP) will integrate the goals of the Mod Waters and C-111 projects and protect the quality of water entering Everglades National Park (DOI and USACE, 2005).

Modified Water Deliveries to Everglades National Park Project (Mod Waters)

This federally funded project, authorized in 1989, is designed to restore more natural hydrologic conditions in Everglades National Park. The project includes levee modifications and installation of a seepage control pump to increase water flow into WCA-3B and northeastern portions of Everglades National Park. It also includes providing flood mitigation to the 8.5-square-mile area (a low-lying but partially developed area on the northeast corner of Everglades National Park) and raising portions of the Tamiami Trail.

continued

BOX 2-3 Continued

Mod Waters is a prerequisite for the first phase of decompartmentalization (i.e., removing some barriers to sheet flow), which is part of the CERP (DOI and USACE, 2005; NRC, 2008). See also Chapter 4.

Northern Everglades and Estuaries Protection Program

In 2007, the Florida legislature expanded the Lake Okeechobee Protection Act (LOPA) to include protection and restoration of the Lake Okeechobee watershed and the Caloosahatchee and St. Lucie estuaries. The legislation, being implemented as the Northern Everglades and Estuaries Protection Program, will focus resources on restoration efforts for Lake Okeechobee and the Caloosahatchee and St. Lucie estuaries. The Lake Okeechobee Watershed Construction Project Phase II Technical Plan, issued

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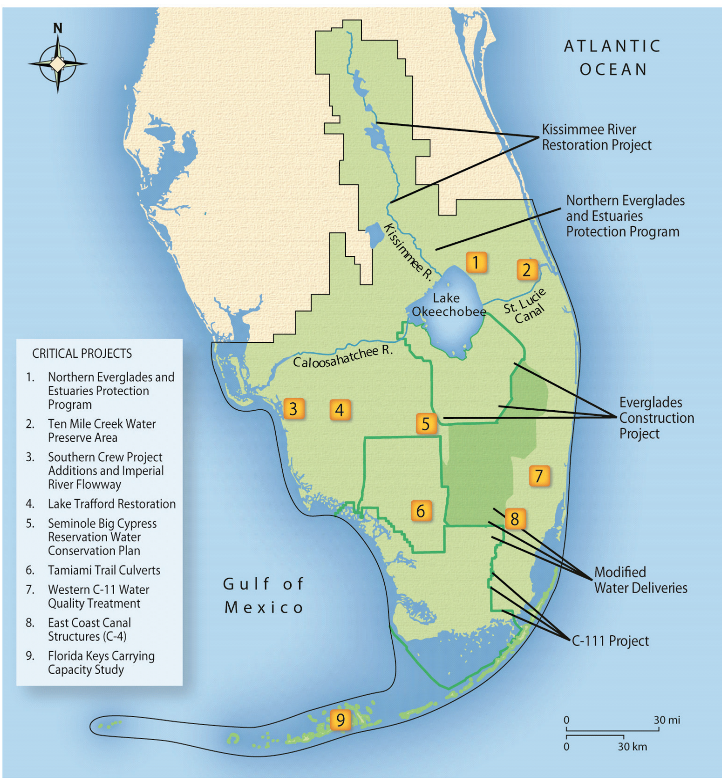

FIGURE 2-3 Locations of major non-CERP initiatives.

SOURCE: © International Mapping Associates

BOX 2-3 Continued

in February 2008 in accordance with LOPA, consolidated the numerous initiatives already under way through Florida's Lake Okeechobee Protection Plan (LOPP) and Lake Okeechobee and Estuary Recovery (LOER) Plan.

Critical Projects

Congress gave programmatic authority for the Everglades and South Florida Ecosystem Restoration Critical Projects in Water Resources Development Act of 1996 (WRDA 1996), with modification in WRDA 1999 and WRDA 2007. These were small projects that could be quickly implemented to provide immediate and substantial restoration benefits such as improved quality of water discharged into WCA-3A and Lake Okeechobee and more natural water flows to estuaries. Examples of the Critical Projects include the Florida Keys Carrying Capacity Study, Lake Okeechobee Water Retention and Phosphorus Removal, Seminole Big Cypress Reservation Water Conservation Plan, Tamiami Trail Culverts, Ten Mile Creek Water Preserve Area, and the Lake Trafford Restoration (DOI and USACE, 2011).

3

Central Everglades Planning Project

Past NRC reports have emphasized the perils of slow restoration progress (NRC, 2008) and documented the declining trajectories of many ecosystem attributes that depend upon restoration of water flows to the central Everglades (NRC, 2012a). NRC (2012a) noted that significant progress has been and continues to be made to reduce phosphorus in the central Everglades through the state's 20-year effort to construct and optimize stormwater treatment areas (STAs) and to encourage best management practices for improved source control. The $880 million Restoration Strategies project, launched in 2012, continues these efforts to attain compliance with water quality criteria in the remnant Everglades (see Chapter 4). However, little progress has been made in restoring flows in the central Everglades because implementation of the Comprehensive Everglades Restoration Plan (CERP) to date has been focused primarily on projects at the edges of the historic Everglades. As a result, declines continue in many of the characteristic features of the Everglades, such as ridge and slough and tree islands, and oxidation of peat alters the slope of the land surface that shapes water flow (as described in detail in NRC, 2012a). The reasons that CERP projects at the periphery of the remnant Everglades have progressed faster than projects in the central Everglades are complex, but include fewer stakeholder conflicts at the periphery of the Everglades and/or strong local stakeholder support for specific efforts. Additionally, the project planning process has been easily stalled by scientific or technical uncertainties, particularly in complex or contentious projects such as the Water Conservation Area 3 (WCA-3) Decompartmentalization and Sheetflow project (Decomp; NRC, 2007). Unresolved water quality issues were also significant barriers in the development of project plans to increase flow to the central Everglades. To address these concerns and expedite restoration of the central Everglades, key federal and state officials launched the Central Everglades Planning Project in October 2011.

The primary purpose of the Central Everglades Planning Project is restoration of more natural patterns of water flows in the central part of the Everglades

(WCA-3 and Everglades National Park). The U.S. Army Corps of Engineers (USACE) described the project purpose:

> to redirect water that is currently discharged to the east and west coast estuaries from Lake Okeechobee and restore water flow to the south, allowing for restoration of natural habitat conditions and water flow in the central Everglades and reconnecting the ecosystem from Lake Okeechobee to Everglades National Park and Florida Bay (76 Federal Register, [December 2, 2011], 75539).

The scope of the project includes *increments* (or components) of a number of CERP projects described in the original restoration plan (USACE and SFWMD, 1999), such as the Everglades Agricultural Area Storage Reservoir, Decomp, seepage management, and rain-driven operations. The Central Everglades Planning Project shifts the planning emphasis from multiple independent project implementation reports (PIRs) to a regional integrated PIR for the first increment of restoration. Thus, the Central Everglades Planning Project is a critical component of the CERP. This chapter reviews the progress made on this effort and prospects for restoration of the central Everglades.

THE EXPEDITED PLANNING PROCESS

The Central Everglades Planning Project was one of five USACE projects chosen to pilot a new expedited planning process. The pilot process aimed to reduce the typical 6-year preauthorization planning time frame to 18-24 months, while still addressing all current legal and programmatic requirements (such as the National Environmental Policy Act [NEPA] and independent external peer review). The process required a shift toward more focused detailed analyses and risk-based project planning prior to authorization—detailed engineering plans would be deferred until after congressional authorization of a project. The process also relied upon frequent engagement of senior leadership (known as vertical team coordination) at key project phases or decision points. The pilot projects are just one component of the USACE planning modernization effort, which includes the "3×3×3 rule" that requires all feasibility studies to be completed within a target of 18 months, but no more than 3 years, at a cost of no more than $3 million, utilizing three levels of vertical team coordination, and a "reasonable" report size (Walsh, 2012). The 3×3×3 rule was applied to all feasibility studies that had not had a feasibility scoping meeting by December 2011. The Central Everglades Planning Project represented an extreme test of the expedited process, considering the complex nature of the project, the extensive stakeholder involvement, and the diverse objectives of various interest groups.

The Central Everglades Planning Project was launched in October 2011 with initial targets of January 2013 to produce a draft PIR and December 2013 for final approval by USACE headquarters (known as the Chief's Report) and submittal to Congress for authorization (K. Taplin, USACE, personal communication, 2012). Staff from the USACE, South Florida Water Management District (SFWMD), Department of the Interior, and other federal, state, local, and tribal governments worked within the project delivery team (PDT) process on all aspects of technical planning. Integration of other stakeholder input occurred through the South Florida Ecosystem Restoration Task Force's (Task Force's) Working Group (see Stakeholder Engagement later in this chapter). The record of opportunities to engage other federal and state agencies and the general public was impressive. During the planning process there were

- 26 meetings of the PDT;
- 5 meetings of the full Task Force at which concepts and updates of the Central Everglades Planning Process were presented;[1]
- 15 public workshops; and
- 12 public meetings as part of the NEPA process,

in addition to numerous briefings for the SFWMD Governing Board, the Water Resources Advisory Committee, and the Task Force's Working Group and Science Coordination Group. Additional "in-progress review" meetings were held at major decision points with the USACE Jacksonville District teams and leadership from USACE regional and headquarters offices.

The process was only slightly behind its original aggressive schedule through the first 15 months of effort, when the late introduction of new water supply issues added approximately 4 months to the process. The draft PIR was publicly released in August 2013. A longer-than-anticipated review process and unresolved policy issues further delayed the schedule. On May 23, 2014, the USACE Civil Works Review Board approved release of the final Central Everglades Planning Project PIR (contingent upon some revisions and concurrence by the SFWMD) for state, agency, and administration review, and a Chief of Engineers' Report is anticipated in summer 2014 (delayed approximately 8 months from the original target). The report was not finished in time to be included in the Water Resources Reform and Development Act (WRRDA) of 2014, which was signed into law on June 10, 2014, authorizing 34 projects for which USACE Chief's Reports were complete. This section summarizes the development of the Central Everglades Planning Project plan and key unresolved issues.

[1] See www.sfrestore.org/tf_minutes.html.

Development of Alternatives

Alternative plans were formulated based on four spatially discrete subregions of the planning area. The subregions, divided by color-referenced boundaries shown in Figure 3-1 and listed here from north to south, are also characterized by their functions:

A. **North of the Red Line** represents the location of storage and treatment to reduce phosphorus loads and includes the Everglades Agricultural Area, Lake Okeechobee, and surrounding areas;

B. **South of the Red Line** is the area characterized by management measures for distribution and conveyance of water in northern WCA-3A;

C. The **Green and Blue Lines** represent the areas in southern WCA-3 and into Everglades National Park that are characterized by management measures for distribution and conveyance of water; and

D. The **Yellow Line** represents the location along the Lower East Coast Protective Area, which is the location of seepage management options to protect the lower east coast urban areas from flooding.

The PDT and stakeholders via the public workshops formulated management alternatives for each of the areas, starting from the north and working toward the south. The PDT used a variety of analysis tools, including spreadsheet-style screening models, an inverse model, and preliminary cost-effectiveness analyses, to identify the most promising management options and optimize the combinations of management measures within each region. In some areas, such as North of the Red Line (storage and treatment), a single option emerged as best. South of the Red Line (distribution and conveyance), two basic options emerged, while four suites of options were considered worthy of further analysis in the Blue/Green Line (distribution and conveyance in WCA-3) and Yellow Line (seepage management) areas (see Table 3-1). Some of the variation in proposed seepage management measures (Yellow Line) was determined by the upstream flow conditions created by the management options in the Blue/Green Line scenarios. The management options were formulated into four alternatives (Alt-1, Alt-2, Alt-3, and Alt-4) for further modeling analysis and evaluation. Detailed descriptions of the rationale behind the formulation of these four alternatives are documented in the draft PIR (USACE and SFWMD, 2013b).

Evaluation of Alternatives and Subsequent Refinements

Alternatives were evaluated using a variety of techniques, including hydrologic and ecological modeling to assess systemwide performance and detailed

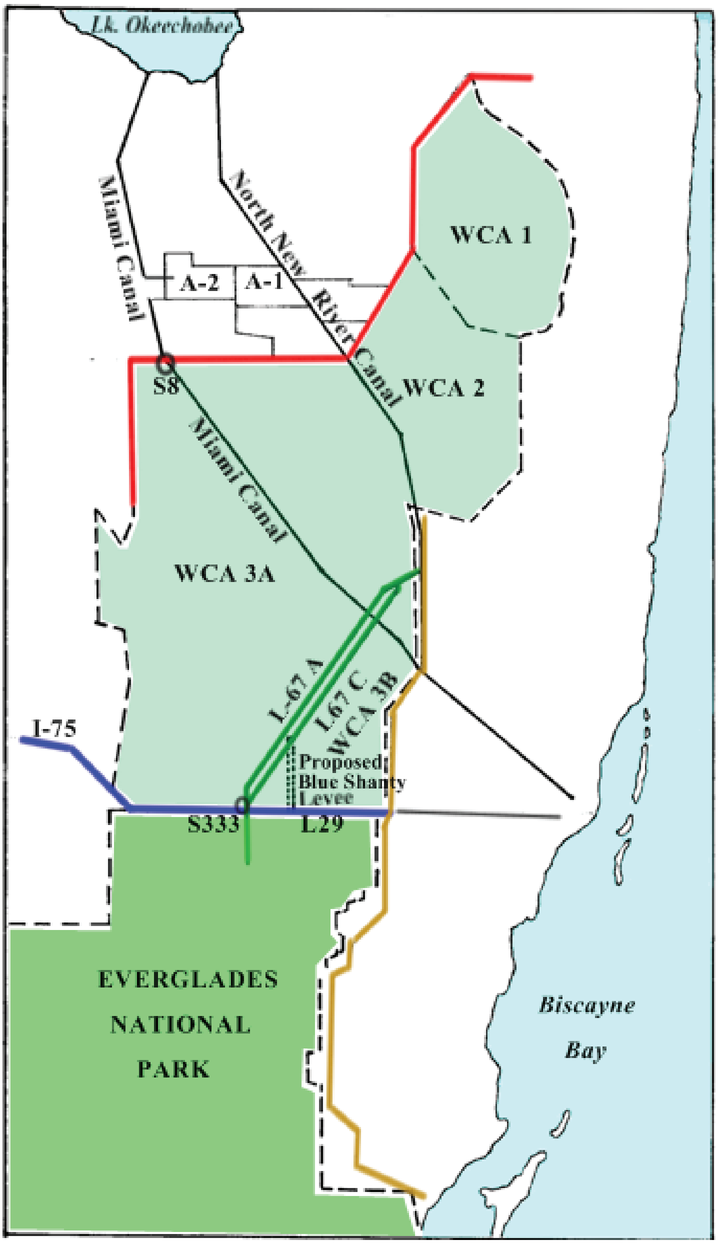

FIGURE 3-1 Subregions of the Central Everglades Planning Project Study Area.

SOURCE: Adapted from USACE and SFWMD (2013b).

TABLE 3-1 Summary of the Major Features of the Four Alternatives

Zone	Features	Alt-1	Alt-2	Alt-3	Alt-4
North of Red Line	Storage/treatment	28,000-acre FEB (A-2) Lake Okeechobee Operation Refinements			
South of Red Line	Conveyance	Diversion of L-6 flows and L-5 canal improvements, removal of ~3 miles of the L-4 levee, G404 and S-8 pump station modifications			
	Spreader	Spreader canal ~3 mi west of S-8 (3,000 cfs)	Spreader canal ~3 mi west of S-8 (3,000 cfs), ~3 mi east of S-8 (800 cfs), and ~1.5 mi east of G-206 (400 cfs)		
	Backfill	Backfill Miami Canal from 1.5 mi south of S-8 to I-75	Backfill Miami Canal from S-8 to I-75		
Blue/Green Line	L-67A Structures	One 750-cfs gated structure	One 750-cfs and two 500-cfs gated structures	Four 500-cfs gated structures	Three 500-cfs gated structures
	Blue Shanty Levee with degrade of L-29 and L-67C in flowway	No	No	No	Yes
	6000-ft gaps in L-67C	1	3	4	1
	Pumps and gravity structures	NA	One 500-cfs gravity structure out of WCA-3B	Two 500-cfs pumps out of WCA-3B	NA
Yellow Line	S-356 pump	increase to 1,000 cfs			
	Seepage barriers S-335 to S-334	NA	Full depth	Full depth	NA
	Seepage barriers south of Tamiami Trail, along L-31N	NA	2-mile partial-depth seepage barrier	5-mile partial-depth seepage barrier	
	L-31N pumps	Two 250-cfs pumps	One 250-cfs pump	NA	NA

ecological and physical responses in specific subareas. Systemwide evaluation was based on multiple criteria as prescribed in the USACE's Planning Guidance (USACE, 2000), including

- Effectiveness—the extent to which an alternative plan alleviates the specified problems and achieves specified opportunities;
- Acceptability—the workability and viability of alternatives with respect to acceptance by state and local entities and the public and compatibility with existing laws, regulations, and public policies;
- Completeness—the extent to which a given alternative provides and accounts for all necessary investments or other actions to ensure the realization of the planned effects; and
- Efficiency—the extent to which the alternative maximizes environmental benefits compared to costs, both overall and by individual project increments.

The effectiveness of each alternative was evaluated with a diverse set of performance measures—hydrologic surrogates for physical, chemical, and biological indicators of restoration progress. The study region was divided into 17 spatially distinct zones—two for the northern estuaries, six in the WCAs, three in Everglades National Park, and six in Florida Bay—each with specified performance measures that would be assessed relative to specific restoration objectives.[2] Some of the performance measures, such as statistics of high and low flows in the northern estuaries and salinity in Florida Bay, were unique to particular zones, while other performance measures (e.g., ridge and slough inundation duration and sheet flow, drought intensity [a hydrologic surrogate for soil oxidation]) were common to several zones. Hydrologic models were used to evaluate the effectiveness of alternatives according to how well the targets for each performance measure were met, on a scale of 0 to 100. Zero represented a fully degraded ecosystem, and 100 represented full achievement of the restoration target.

To assess the efficiency of the project alternatives, "habitat units" associated with each alternative were calculated. First, a habitat suitability index (HSI; scaled from 0 to 1) was calculated for each of the 17 zones, based on an average of the performance measure values. The benefits model included an option to differentially weight the performance measures when calculating the HSI, but that option was not used, and all performance measures were assigned equal

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[2] There were two performance measures for each of the northern estuaries, five for each zone in the WCAs and Everglades National Park, and one for each Florida Bay zone. In several cases, performance measures included submetrics that were then averaged to produce a single performance measure score.

weights. The overall habitat units associated with each alternative were calculated by multiplying the area of each zone by the HSI and adding the habitat units across the 17 zones. Habitat units generated by an alternative were then compared against a "future without the project" (FWO) scenario to calculate the "habitat unit lift" provided by that alternative (see Table 3-2). Habitat unit contributions were also annualized by incorporating estimates of the time it would take to realize the benefits.

After analysis and evaluation of the benefits of the four alternatives, several refinements were made to the alternatives. Analysis of the additional spreader and backfill features south of the Red Line in Alternatives 2, 3, and 4 (see Table 3-1) showed no additional environmental benefit, despite $130,000 additional cost (observed differences in benefits in southern WCA-3 were assumed to be dependent on other features). Thus, Alternatives 2, 3, and 4 were modified by using the conveyance features south of the Red Line of Alt-1, and an "M" was added to their labels.

The cost-effectiveness of alternatives, measured by the average cost per habitat unit lift, is shown in Figure 3-2. Alt-1 generated slightly more habitat units than Alt-2 and at a much lower cost. Alt-4 produced higher numbers of habitat units than any of the alternatives at a unit cost only $3 higher than Alt-1. When Alt-2, -3, and -4 were modified to include only the Alt-1 conveyance features south of the Red Line, Alt-1 and Alt-4M were judged to be cost-effective. Alt-4M became the most cost-effective option because it contributed substantially greater habitat units at the lowest cost per habitat unit.

In addition to the efficiency criterion, Alt-1 and Alt-4 also scored as high as or higher than Alt-2 and Alt-3 on USACE planning criteria of effectiveness, acceptability, and completeness. Acceptability was judged on the basis of documented concerns expressed by stakeholders (summarized in USACE and SFWMD, 2013b). Completeness was evaluated primarily by noting project

TABLE 3-2 Systemwide Habitat Units for Future Without Project Condition and Four Alternatives

	FWO	Alt-1	Alt-2	Alt-3	Alt-4
Habitat units	683,582	982,513	977,306	1,001,360	1,023,642
Habitat unit lift	NA	298,931	293,724	317,778	340,060
Estimated cost (billion $)[a]	NA	1.93	2.24	2.35	2.22

[a] Not including interest during construction.

SOURCE: USACE and SFWMD (2013b).

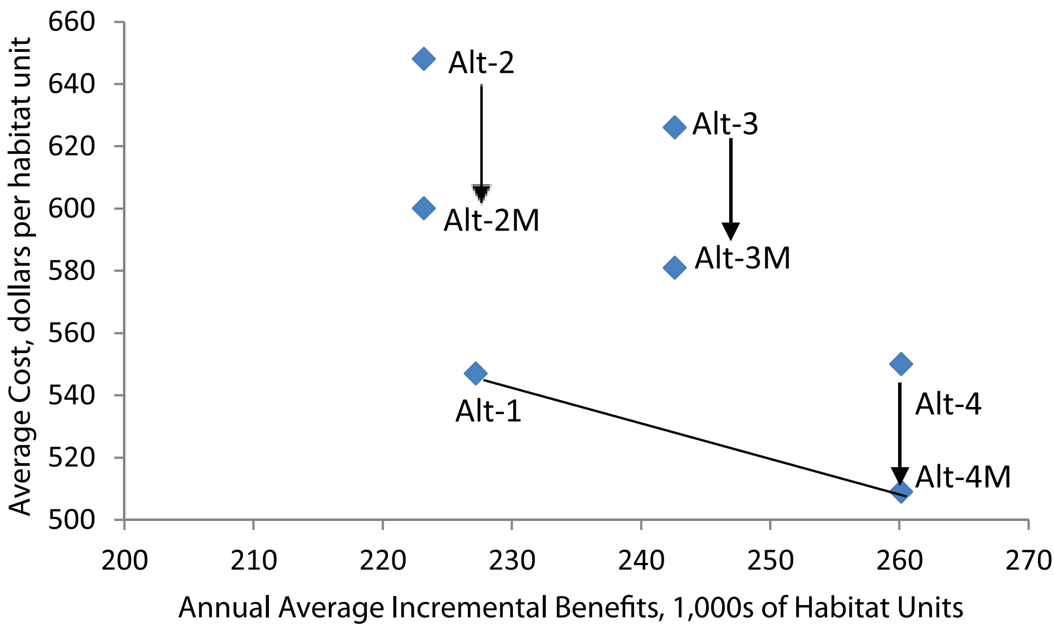

FIGURE 3-2 Cost-effectiveness of alternatives. Each alternative is located on the longitudinal axis by the increment of average annual habitat units and on the vertical axis by the average annual cost per average annual habitat unit.

SOURCE: Data from USACE and SFWMD (2013b).

dependencies of the Central Everglades Planning Project on other CERP and non-CERP projects (discussed in more detail later in this chapter).

Subsequent operational refinements were made to Alt-4M to increase confidence in satisfaction of the Savings Clause.[3] The result, Alt-4R, was presented to the SFWMD Governing Board in February 2013 as the initial version of the Tentatively Selected Plan. In a presentation during the Governing Board meeting, it was noted that next steps included a "sequencing strategy, saving clause/ project assurances analysis, draft preliminary operating manual, adaptive man-

[3] The Savings Clause is a provision of WRDA 2000 related to CERP implementation that is designed to ensure that an existing legal source of water (e.g., agricultural or urban water supply, water supply for Everglades National Park, water supply for fish and wildlife) is not eliminated or transferred until a replacement source of water of comparable quantity and quality—as was available on the date of enactment of WRDA 2000—is available and that levels of flood protection existing as of 2000 are not reduced.

agement plan, and a monitoring plan" (Minutes of Governing Board Meeting, Feb. 13, 2013[4]). Issues regarding the Saving Clause and project assurances, cost sharing, and water quality issues were still unresolved when the board met on March 14, 2013, but the time required to resolve the issues was estimated to be 6-8 weeks. By the time the Governing Board met in April 2013, a new concern was added that had not been included in the original purpose of the project—the omission of "other project benefits to meet the additional water supply needs especially for the Lower East Coast and agricultural users" (Minutes of Board Meeting, April 11, 2013).

Alt-4R was subsequently refined to increase confidence in satisfaction of the Savings Clause and to increase public water supply deliveries. Addressing these issues to the satisfaction of stakeholders added about 4 months to the schedule before a draft of the PIR (USACE and SFWMD, 2013b) was published in August 2013. The further "refined" version of Alt-4R, referred to as Alt-4R2, was selected as the Tentatively Selected Plan in the Draft PIR (Figure 3-3). None of the refinements to Alt-4R involved changes to the major structural features shown in Table 3-1. Instead, Alt-4R2 included updates and changes to operating policies for Lake Okeechobee and the CERP Indian River Lagoon-South and Broward Water Preserve Areas projects, all within the limits of existing rules. Those changes provided an additional 12 million gallons per day (MGD) for municipal and industrial users in Lower East Coast Service Area 2 (Broward County) and 5 MGD to Lower East Coast Service Area 3 (Miami-Dade County).

The refinements made to Alt-4M to formulate the Tentatively Selected Plan came with a reduction in environmental benefits as measured by aggregate habitat units (see Table 3-3). There was a net decrease of 54,371 habitat units between Alt-4M and Alt-4R2, a decrease of 16 percent. Most of that loss was attributable to Savings Clause modifications from Alt-4M to Alt-4R, with the largest decreases in southern Everglades National Park, western Florida Bay, and east central Florida Bay. In further modifications from Alt-4R to Alt-4R2, it is unclear how the increase in water supply (not included in the original statement of purpose for the project; 76 Federal Register [December 2, 2011], 75539) impacted the overall benefits, because operational changes were made to provide more water than otherwise could have been provided to the natural system.

Unresolved Issues

After release of the PIR, the agencies conducted required reviews and worked to address several issues that were not fully resolved in the planning process,

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[4] See http://www.sfwmd.gov/portal/page/portal/xweb about us/gb application/ for all SFWMD Governing Board meeting minutes.

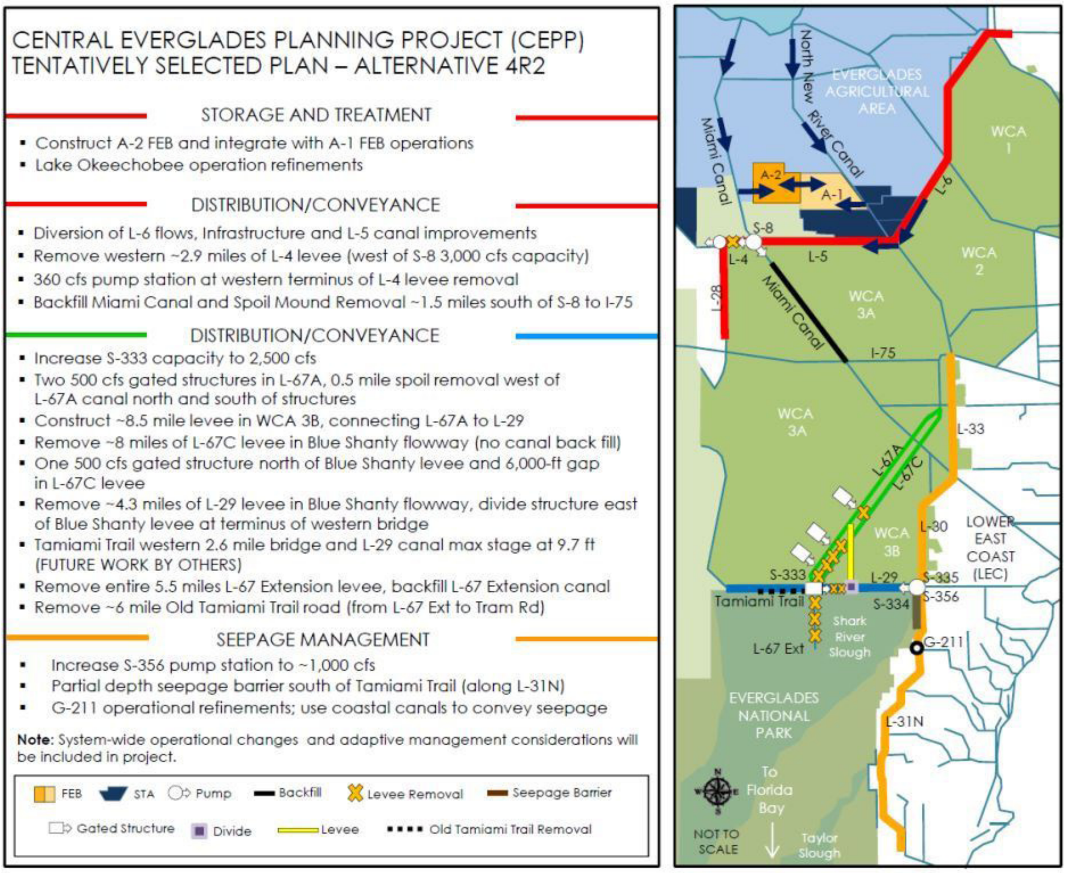

FIGURE 3-3 The Central Everglades Planning Project Tentatively Selected Plan, Alt-4R2.

SOURCE: USACE and SFWMD (2013b).

including phased implementation, revised systemwide operations, water quality, and impacts on threatened and endangered species. Some of these issues were resolved and others were deferred to more detailed post-authorization planning, engineering, and design. Among the most significant issues are

- Effects of water levels on threatened and endangered species; and
- Water quality, including effects of increased flows once the Central Everglades Planning Project is implemented.

TABLE 3-3 Habitat Unit Contributions of Alternatives and Changes Due to Refinements to Alternative 4

		Contributed HUs			Changes to Contributed HUs in Refinements to Alt-4		
Region	Future Without	Alt-4	Alt-4R	Alt-4R2	Alt-4 to Alt-4R	Alt-4R to Alt-4R2	Alt-4 to Alt-4R2
Caloosahatchee Estuary	34,070	4,968	4,968	4,968	0	0	0
St. Lucie Estuary	2,399	2,399	2,699	5,848	300	3,149	3,449
Total northern estuaries	36,469	7,367	7,667	10,816	300	3,149	3,449
Northeast WCA-3A	29,634	66,677	62,972	61,738	−3,705	−1,234	−4,939
WCA-3A Miami Canal	27,373	29,719	27,373	27,373	−2,346	0	−2,346
Northwest WCA-3A	30,266	23,228	23,932	23,932	704	0	704
Central WCA-3A	105,669	4,117	4,117	5,490	0	1,373	1,373
Southern WCA-3A	68,423	0	0	0	0	0	0
WCA-3B	48,842	5,998	9,426	10,283	3,428	857	4,285
Northern ENP	55,054	47,547	43,793	43,793	−3,754	0	−3,754
Southern ENP	126,454	62,034	42,946	42,946	−19,088	0	−19,088
Southeast ENP	81,062	2,702	4,054	2,702	1,352	−1,352	0
Total Greater Everglades	572,777	242,022	218,613	218,257	−23,409	−356	−23,765
Florida Bay West	20,534	31,590	18,954	20,534	−12,636	1,580	−11,056
Florida Bay Central	8,205	9,025	5,743	6,564	−3,282	821	−2,461
Florida Bay South	14,659	20,523	12,705	13,682	−7,818	977	−6,841
Florida Bay East Central	20,225	26,381	13,191	14,070	−13,190	879	−12,311
Florida Bay North Bay	2,028	887	506	633	−381	127	−254
Florida Bay East	8,685	2,265	1,133	1,133	−1,132	0	−1,132
Total Florida Bay	74,336	90,671	52,232	56,616	−38,439	4,384	−34,055
Total All Regions	683,582	340,060	278,512	285,689	−61,548	7,177	−54,371

Note: Shadings represent the areas of largest habitat unit declines between Alt-4 and Alt-4R2.

SOURCE: Data from USACE and SFWMD (2013b).

The U.S. Fish and Wildlife Service (FWS) issued a Biological Opinion for the Central Everglades Planning Project in December 2013 (revised in April 2014) in which it came to the preliminary conclusion that "the proposed project is not likely to jeopardize the continued existence" of the Cape Sable seaside sparrow, snail kite, and wood stork and "is not likely to adversely modify critical habitat, where designated" (FWS, 2014). The Biological Opinion concluded that the project would provide some benefits to all three species, but the FWS was not able to predict the overall impacts to the three species because of the many uncertainties related to project design, operations, and the time line for project implementation. For the sparrow, which has a relatively narrow range of hydrologic conditions that provide suitable habitat, the FWS noted that projected adverse effects on one subpopulation (E) could outweigh the small benefits projected for subpopulation A. The single large subpopulation (B), which comprises roughly 80 percent of the total population, is projected to be relatively unaffected by the Central Everglades Planning Project (FWS, 2014). Providing suitable habitat for sparrows and avoiding adverse effects on their population promise to be ongoing challenges during implementation of the project. FWS (2014) concluded that incidental take of all three species is likely but did not authorize incidental take. This means that further consultation will be necessary as specific project details are finalized and increments of the project are implemented.

Storage and treatment measures included in the Central Everglades Tentatively Selected Plan are designed to keep phosphorus levels in compliance with water quality-based effluent limits (WQBEL)[5] for the STAs while allowing additional flows of approximately 210,000 acre-feet per year (AF/yr). However, this plan builds upon existing projects now under construction by the SFWMD to bring current flows into compliance with the WQBEL, and there is some uncertainty about the time line of meeting these water quality objectives (see also Chapter 4). Also, there is uncertainty about how implementation of the Central Everglades Planning Project will affect compliance with water quality criteria downstream in Everglades National Park. The methodology within Appendix A of the 1991 Settlement Agreement that determines compliance with state phosphorus standards is a flow-weighted mean phosphorus limit that was developed based on the observed relationship between water flow and phosphorus concentrations entering the park. Both the quantity and the spatial pattern of flow will be modified by implementation of the Central Everglades Planning Project. The Draft PIR (USACE and SFWMD, 2013b) stated:

> Over the long-term, distributing the flow over the northern WCA-3A marsh, reducing short-circuiting down the canals to Everglades National Park, adding more flow from the lake that is treated to the WQBEL, and distributing these flows over the marsh should result in improvements by lowering the flow weighted mean total phosphorus concentration entering the Park.

[5] The WQBEL is a numeric discharge limit used to regulate permitted discharges from the STAs so as not to exceed a long-term geometric mean of 10 µg/L within the Everglades Protection Area. This numeric value is now translated into a flow-weighted mean (FWM) TP concentration and applied to each STA discharge points, which now must meet the following: *(1) the STAs are in compliance with WQBEL when the TP concentration of STA discharge point does not exceed an annual FWM of 13 µg/L in more than 3 out of 5 years, and (2) annual FWM of 19 µg/L in any water year* (Leeds, 2014). See Chapter 4 for more details on STA performance.

The Everglades Technical Oversight Committee established by the 1991 Settlement Agreement has been charged with reviewing the applicability of the current version of Appendix A to the restored ecosystem and whether changes are necessary in the context of the increased inflows to Northeast Shark River Slough.

Neither of these issues is likely to be resolved with confidence in the near future. The ongoing Restoration Strategies project to bring concentrations in existing outflows from STAs into compliance with WQBELs is not estimated to be fully constructed until 2024, although the Central Flowpath projects, which would receive inflow from the Central Everglades Planning Project FEB, are expected to be completed by 2016[6] (see Chapter 4). The 2012 Consent Order allows for up to a 5-year period for determining compliance with the WQBEL after construction is completed. SFWMD staff have stated that the STAs are currently permitted as a package, and therefore, the entire system must meet the WQBEL before existing flows can be redistributed or additional flows can be initiated (E. Barnett, SFWMD, personal communication, 2013)—potentially 2029 or later.[7] Although water quality models have predicted compliance sufficiently well to justify expenditures for corrective actions, actual post-construction water quality will be a determining factor in how to proceed at that time. After an extensive review period, the USACE Civil Works Review Board considered the remaining unresolved issues and unanimously approved moving forward with the project. As discussed previously, the Chief of Engineers has initiated the concluding administrative steps of preparing a final project report and recommendation to Congress.

ASSESSMENT OF THE CENTRAL EVERGLADES PLANNING PROJECT

This section includes the committee's assessment of the Tentatively Selected Plan, efficiency analyses used to select the plan, and the implementation plan. The committee also assesses the adaptive management plan, the expedited process, and stakeholder engagement.

The Plan

If implemented in a timely manner, the Tentatively Selected Plan for the Central Everglades Planning Project would make substantial improvements toward

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[6] The 2014 South Florida Environmental Report (Leeds, 2014) reports that the Restoration Strategies project features are anticipated to be completed for the Central Flowpath by July 2016, for the Eastern Flowpath by December 2018, and for the Western Flowpath by December 2024.

[7] After release of the report in prepublication form, it was pointed out that this sentence could be read to imply that SFWMD is responsible for assessing permit compliance. FDEP, with oversight from EPA, will interpret permit and Consent Order compliance, including any water quality issues that may affect flow redistribution.

the goal of restoring the Everglades. It would make significant improvements to the storage capacity and treatment performance of existing STAs by means of a new 56,000-AF flow equalization basin. When combined with adjustments to the regulation schedule in Lake Okeechobee operations, the flow equalization basin will allow an additional 210,000 AF/yr of water to be treated by the STAs and delivered to the remnant Everglades ecosystem that would otherwise be discharged through the Caloosahatchee River and St. Lucie Canal. This represents a 21 percent increase over existing flows (Figure 3-4) and approximately two-thirds of the new water envisioned by the CERP to be delivered along the northern end of the WCAs.

The Central Everglades Planning Project will also shift the distribution of water in the southern part of the system toward historical patterns, increasing flows into Northeast Shark River Slough and reducing flows into Western Shark River Slough. Excessively wet conditions in southwestern WCA-3A and adja-

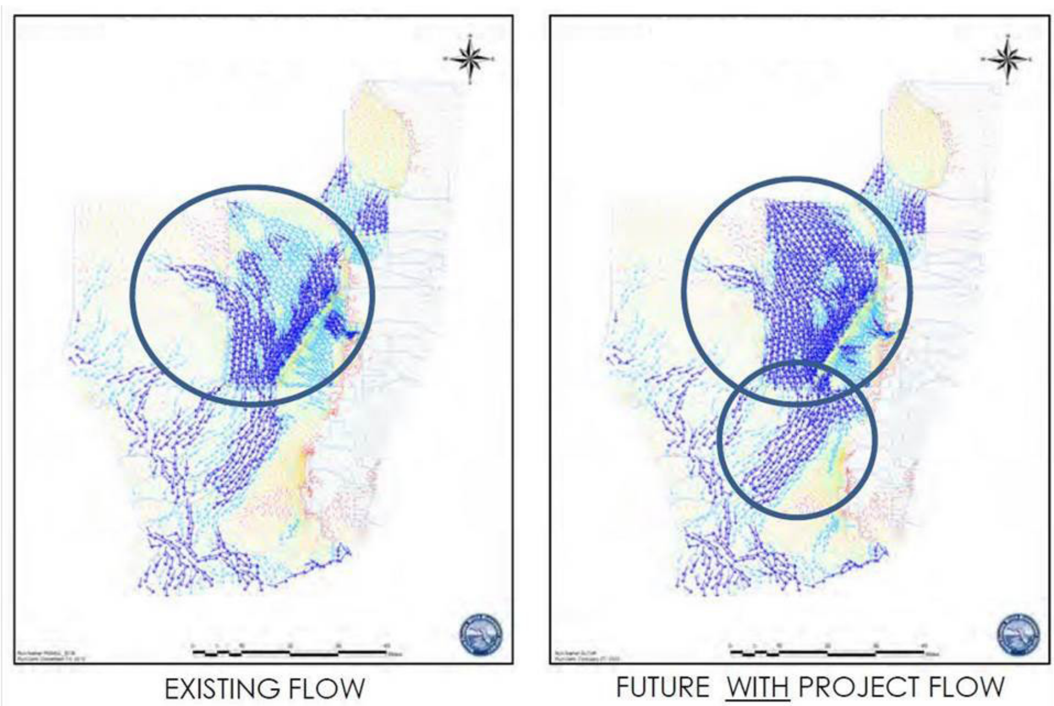

FIGURE 3-4 Central Everglades Planning Project existing and future flows. The graphics represent the average annual overland flow from 1965 to 2005. The direction of the arrows represents the movement of water across the landscape, and the colors represent the relative volume of water flow, with dark blue being the highest and red being the lowest.

SOURCE: USACE and SFWMD (2013b).

cent portions of Everglades National Park and excessively dry conditions in the eastern portion of the park have contributed greatly to ecosystem degradation in those areas (NRC, 2012a).

Systemwide, the plan improves ecosystem conditions (as measured in habitat units) by more than 40 percent over the future without the project, and in none of the 17 geographic areas would the condition be made worse overall. Northern estuaries would improve by 30 percent, the Greater Everglades (consisting of the WCAs and Everglades National Park) by 38 percent, and Florida Bay by 76 percent. Northwestern portions of the WCA-3 that have been subject to frequent dryouts would be rehydrated (USACE and SFWMD, 2013b). Northeast Shark River Slough on average would receive an additional 250,000 AF/yr of overland flow compared with the future without the project (D. Crawford, USACE, personal communication, 2014); however, an additional 500,000 to 700,000 AF/yr may be necessary to bring Florida Bay to full restoration. Ecological and hydrologic connectivity of the WCAs and Everglades National Park would be enhanced by partially degrading the L-67C and L-29 levees, and protective water depths in the eastern parts of WCA-3B would be maintained by the Blue Shanty Levee (USACE and SFWMD, 2013b).

Although improvements to estuaries of the Caloosahatchee River and St. Lucie Canal were not primary objectives of the Central Everglades Planning Project, water quality in those estuaries would be enhanced to some degree by diversion of flows to the Everglades. Damaging high-flow events (>2,800 cfs) in the Caloosahatchee would be reduced by 14 percent when compared with the future without condition; high-flow events (> 2,000 cfs) in the St. Lucie would be reduced by 34 percent. Low-flow events below desirable rates would be reduced by 15 percent in the Caloosahatchee and 29 percent in the St. Lucie (USACE and SFWMD, 2013b). Water available for existing users would be maintained, and a modest increase of 17 MGD would be added for urban, industrial, and agricultural water supply along the lower east coast.

In summary, the proposed plan offers significant benefits that should make important strides toward reversing ongoing declines in the remnant Everglades ecosystem and enhancing the condition of Everglades landscapes and species. The project is one of the first CERP efforts to have successfully integrated water flow restoration with water quality restoration. Overall, the plan is an impressive response to the need to accelerate the pace of restoration of the central Everglades.

Efficiency Analysis

The use of habitat units for quantifying environmental restoration benefits (discussed previously in this chapter) is included in Appendix E of the USACE planning guidance (USACE, 2000). That document, however, does not provide guidance as to how habitat units are to be estimated for complex multifunction, multispecies projects such as the Everglades. The habitat unit approach evolved out of the Habitat Evaluation Procedure (FWS, 1980) that was developed and formally adopted for evaluation of effects on habitats of a single species. The CERP applies the metric as an area-weighted performance measure, but there are inherent flaws in its application to the optimization of environmental benefits in such highly complex environments. First, it involves simple addition of changes to very dissimilar environmental effects. For example, area-weighted performance measures for changes in high- and low-flow patterns in estuaries are added to area-weighted measures for changes to ridge-and-slough topography when there is no obvious common effect between the two ecological settings. Second, all performance measures are judged to be equally important, weighted only by the size of zones to which they are applicable.

This second issue has proved especially problematic for integrating restoration with recovery of threatened and endangered species, such as the Cape Sable seaside sparrow and the snail kite. For example, take two areas: Zone A with 100 acres of critical habitat for an endangered species, and Zone B with 1,000 acres of relatively abundant habitat not used by this species. If an alternative improves the condition of Zone A by 50 percent and Zone B by 25 percent and the average cost of improvements are the same, the 50-habitat-unit lift generated in Zone A represents only one-fifth of the 250-habitat-unit increase in Zone B. If tradeoffs are necessary to achieve optimal environmental benefits under a financial or water-budget constraint, investments to improve Zone B would be far more highly valued than the same investment to improve critical habitat for the endangered species in Zone A. Comparisons of highly aggregated sums of habitat units across disparate environmental settings thus can obscure the implicit tradeoffs that are being made between underlying ecosystem values. Critics have argued that application of habitat suitability analysis to multiple species is inappropriate, and in the context of the Central Everglades Planning Project, it was applied to very different physical and biological processes that not only impact multiple species but also a vast array of other environmental benefits. Indeed Alt-4R2 is projected to have negative impacts on endangered bird species in some locations (FWS, 2014) as was discussed previously. Protection of endangered species will ultimately require additional detailed analysis beyond the simple, habitat unit approach used to calculate environmental benefits, possibly resulting in some future modifications to project design.

The quest for a single benefit metric by which to compare alternatives is as old as benefit-cost analysis, but, so far, a fully satisfactory answer remains elusive. Promising advances have been made in the field of evaluating ecosystem services, but much work remains before a comprehensive model could be applied to the wide array of complex, interactive physical, chemical, and biological processes that make up the Everglades ecosystem. A recent report on an ecosystem services approach to damages resulting from the Deepwater Horizon oil spill in the Gulf of Mexico outlines a model for analysis based on fundamental concepts of microeconomics and discusses obstacles to its implementation (NRC, 2013). Prior research and monitoring of the Everglades makes it a better understood system than the impacted area of the Gulf. However, the lack of well-defined ecosystem service production/response functions that relate specific increases in ecosystem services in the Everglades to specific project attributes (i.e., how much "lift" is achieved by the project for each of the identified ecosystem services) remains an important obstacle. Another obstacle to implementation common to both cases is the lack of a set of well-defined, relative values for the diverse array of ecosystem services, many of which remain difficult to assess in monetary terms. Evaluation of all services need not be in monetary terms, but, if tradeoffs are necessary for optimization under constrained budgets, there must be a well-defined set of preferences (or weights) among different kinds of services.

There were no such well-defined preferences for the Central Everglades Planning Project process,[8] and it was not made clear what substitution of services were being made as alternatives were being formulated, evaluated, modified, and refined. In the absence of a well-defined set of preferences or weights for diverse environmental benefits, a display of marginal differences of performance measures in the evaluation of effectiveness across the alternatives would be useful. Such a display enhances transparency and understanding of the inherent tradeoffs associated with alternative plans. Section 5 of the Draft PIR and supporting appendices (USACE and SFWMD, 2013b) provide considerable detail of environmental impacts of the final array of alternatives and the Tentatively Selected Plan. What are not clearly shown and summarized in those displays are the principal tradeoffs among alternatives as measured by performance measures and related ecosystem effects that were made in moving from Alternative 4 to the Tentatively Selected Plan. Changes (reductions) to aggregated habitat lifts were reported by zone, but changes to the performance measures underlying aggregated measures are not made clear. Those would be informative additions to the evaluation.

Implementation Plan

The strategy for implementing the Tentatively Selected Plan received considerable attention in the planning process. Initial development of an implementation plan focused on recognizing constraints and dependencies, basic

[8] The Central Everglades Planning Project attempted an evaluation of ecosystem services, but data were lacking to support a comprehensive analysis (K. Whittmann, USACE, personal communication, 2013), and the results were not published in the August 2013 draft PIR.

sequencing of project features, reasonable estimates for cost and schedule, and appropriate contingencies for the current level of design detail. The stated goal was to realize restoration benefits as soon as practicable, while still adhering to all water quality and other permitting requirements. The project team analyzed variations of the implementation plan, ranging from a scenario with largely unconstrained resources as a best-case to a more likely scenario governed by moderate annual expenditures. The best case could provide full restoration benefits 6 years after the Restoration Strategies water quality projects are permitted. A more realistic schedule considering $100 million/year funding would have those same benefits available by approximately 2053. To better understand these timing differences, the committee looked further into the governing constraints, sequencing of project components, and implementation uncertainties. Constraints and dependencies fell generally into four categories: physical (including planning and design), operational (hydrology), operational (permitting and compliance), and fiscal/funding (Table 3-4).

The dependencies, principles, and geography led to a simple, conceptual organization of the Tentatively Selected Plan into three component projects, each with a separate project partnership agreement (PPA): PPA North, encompassing spreading and backfill projects in northern WCA-3A; PPA South, representing distribution and sheet flow features in southern WCA-3A and Everglades National Park; and PPA New Water, representing the new storage and seepage management features (see Box 3-1). The relationship between the implementation constraints and the three PPAs is also shown in Table 3-4.

From a construction/implementation point of view, the three PPAs were configured to be independent from one another; the operational dependencies were confined within each PPA. Sequencing of the three PPAs could thus be in any order or even concurrent. However, funding realities are likely to limit the potential to significantly overlap the PPAs. PPA North alone yielded approximately 17 percent of total project benefits at 33 percent of the total cost, with the greatest benefit contribution to WCA-3A (Figure 3-5). PPA South alone provided about 21 percent of the total benefits at 22 percent of the total cost, with Everglades National Park followed by Florida Bay as the greatest beneficiaries. PPA New Water alone produced negligible benefits, but when PPA New Water followed the other two, its total contribution was approximately 62 percent of total project benefits at 45 percent of total cost. Figure 3-5 summarizes how the project phases contribute individually and together to each of the five regions.

This benefits distribution analysis seems to show that moving forward with PPA South first may have a slight edge in yielding early benefits, but the results are essentially equivalent. Thus, the sequencing of PPAs should be a future interagency decision that considers both existing constraints and potential for delivering the most early benefits, particularly to regions in decline that require

TABLE 3-4 Central Everglades Planning Project Implementation Plan Constraints and Dependencies

Constraint, Dependency, or Principle	Rationale	PPA Constrained: PPA North	PPA Constrained: PPA South	PPA Constrained: PPA New Water
Physical, design and planning				
Availability of borrow material	Timing the availability of fill for Miami Canal backfilling and the Blue Shanty Levee minimizes costs	X	X	
Adaptive management plan	Allowing steps and timing to test concepts will improve future success			
Operational (hydrology)				
A-1 FEB state restoration strategies	Required prior to implementation of northern WCA-3A distribution features to ensure adequate water quality of inflows	X		X
C-358 and S-357N features	Construction of these seepage management features in Mod Waters is necessary to provide seepage mitigation before increasing flows into Northeast Shark River Slough		X	X
S-356 Operation Plan	Operation of the existing S-356 pump station is required to provide seepage management before increasing flows into Northeast Shark River Slough		X	X
C-111 South Dade	Completion of the detention areas required prior to significantly increasing flows to Northeast Shark River Slough to provide seepage management		X	X
BCWPA C-11 Impoundment	Required prior to increasing flow through S-333 or implementation of WCA-3B inflow structures along the L-67A & C levees		X	X
Tamiami Trail Next Steps bridging and road raising	Required prior to increasing capacities of S-333 and S-356 and implementation of WCA-3B inflow structures along the L-67A levee, gaps in L-67C levee and Blue Shanty flowway		X	X
C-44 Reservoir (IRL-S) and connection to C-23 Canal	Required prior to redirecting the maximum amount of water from Lake Okeechobee south to meet environmental performance			X
Modification of the Lake Okeechobee regulation schedule	Changes to the 2008 LORS needed prior to full utilization of the A-2 FEB in order to achieve the complete ecological benefits			X
Outlet capacity of WCA-3A	Additional outlet capacity from WCA-3A must be provided before new project water from Lake Okeechobee is released into the system			X

continued

TABLE 3-4 Continued

Constraint, Dependency, or Principle	Rationale	PPA Constrained: PPA North	PPA South	PPA New Water
Operational (permitting and compliance)				
Restoration Strategies Permit Compliance	All features of the state's Restoration Strategies must be completed and meet state water quality standards prior to initiating construction of most CEPP project features	X	X	X
Water Quality Compliance in Everglades National Park	Appendix A water quality compliance issues need to be addressed for new project water entering Everglades National Park		X	X
Compliance with state water quality standards	Must first determine that feature will not violate state water quality standards, discharge limits, or permit conditions and it will not adversely affect flora and fauna in the area	X	X	X
Fiscal/Funding				
Funding availability	Pace of construction will be dependent on funding stream	X	X	X
State-federal cost-share balance	Total federal creditable expenditures cannot exceed state's	X	X	X

SOURCES: Based on information from Bush (2013); Barnett, SFWMD, and Hobbie, USACE, personal communication, 2013; E. Bush, USACE, personal communication, 2013.

long times to recover (NRC, 2012a). For the purposes of further analysis, the draft Implementation Plan utilized the PPA North ➔ PPA South ➔ PPA New Water sequence as a base.

Building on this base sequence and allowing for a small amount of overlap between PPA phases, the project team produced a Central Everglades project implementation schedule including recognized constraints and considering a nominal $100 million/year funding level. This scenario estimated 19 years from construction start to completion and was viewed as a realistic time line (although it lacked risk-based schedule contingencies). As an extreme, best-case scenario, executing all three PPAs concurrently with no resource constraints produced a total construction duration of 6 years (E. Bush, personal communication, 2014).

The initiation of construction of the Central Everglades Planning Project will be contingent upon numerous project dependencies (see Table 3-4), including improvements in water quality. The draft PIR includes the statement that "all features of the State's Restoration Strategies must be completed and meet state water quality standards prior to initiating construction of most CEPP project features"

BOX 3-1
Proposed Groupings of Central Everglades Project Features

PPA North

- L-6 Diversion
- S-8 Pump Modifications
- L-4 Levee Degrade and Pump Station
- L-5 Canal Improvements
- Miami Canal Backfill

PPA South

- L-67A Structure 1 North
- One L-67C Gap
- Increase S-356
- Increase S-333
- L-29 Divide Structure
- L-67A Structures 2 and 3 South
- L-67A Spoil Mound Removal
- Remove L-67C Levee Segment
- Remove L-67 Extension Levee (no backfill)
- 8.5-Mile Blue Shanty Levee
- Remove L-29 Levee Segment
- Backfill L-67 Canal Extension
- Remove Old Tamiami Trail[a]

PPA New Water

- Seepage Barrier L-31N
- A-2 FEB

[a]Removal of Old Tamiami Trail can be completed at any time during implementation, but must precede backfilling of L-67 Extension Canal.

Source: E. Bush, USACE, personal communication, 2014.

(USACE and SFWMD, 2013b). Any project construction would require certification by the state that the project would not lead to a violation of state water quality standards. However, it does not necessarily follow that construction of *most* Central Everglades Planning Project components must be deferred until *all* components of the Restoration Strategies are implemented. For example, construction of the A-2 FEB and improved seepage management would only improve water quality and could provide a means to expedite overall construction in the face of other constraints. Combining the large contingencies resulting from funding with the stated implementation and permitting constraints driven by the Restoration Strategies project leads to a rather alarming picture of potential restoration prog-

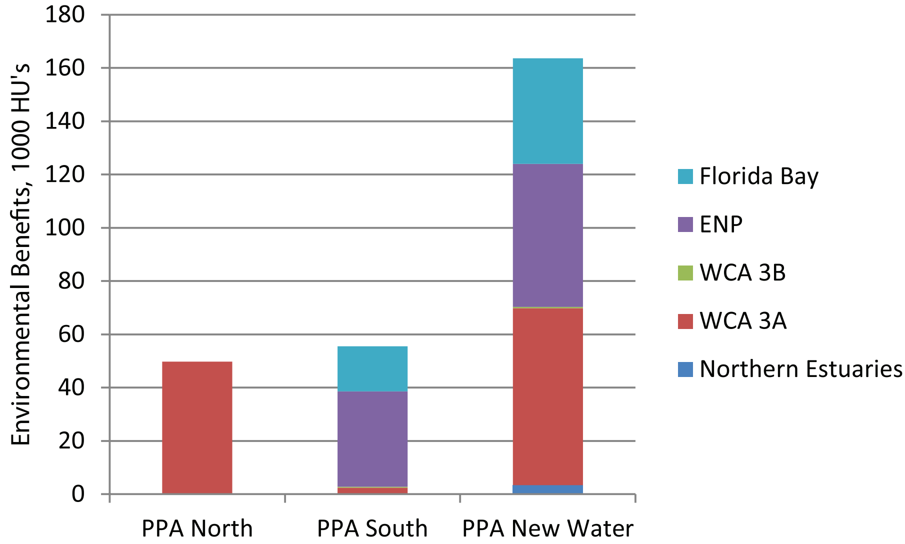

FIGURE 3-5 PPA contribution to Central Everglades Planning Project benefits by region. PPA New Water benefits are dependent upon the completion of both PPA North and PPA South.

SOURCE: Based on information from E. Bush, USACE, personal communication, 2014.

ress. Figure 3-6 shows the serial effect of constraints, permitting, construction phasing, and contingency addition to the scheduled availability of project benefits—a scenario in which the first new water benefits occur approximately four decades into the future with funding of approximately $100 million/year in constant dollars. Allocating schedule contingency from Appendix B in USACE and SFWMD (2013a) proportionally to each PPA, the first benefits based on existing water could be about 21 years from now, assuming that Central Everglades Planning Project construction is not initiated until all of the Restoration Strategies projects have been permitted. At three decades into the future, realized benefits could still only be 38 percent or less of the full Central Everglades Planning Project. Different funding streams could produce different scenarios, and more recent updates to the cost engineering appendix of the PIR present even longer possible time frames.[9]

[9] Since the August draft PIR was released, the Cost Engineering Appendix B has been revised using a project duration of 329 months with a contingency of 89 months, for a total of 34.8 years at an 80 percent confidence level. This updated estimate reflects a scenario of $100 million/year, not adjusted for inflation (Amro Habib, USACE, personal communication, 2014). In contrast, the August draft PIR presented a schedule duration of 186 months with a contingency of 107 months, for a total of 24.4 years at an 80 percent confidence level (USACE and SFWMD, 2013a).

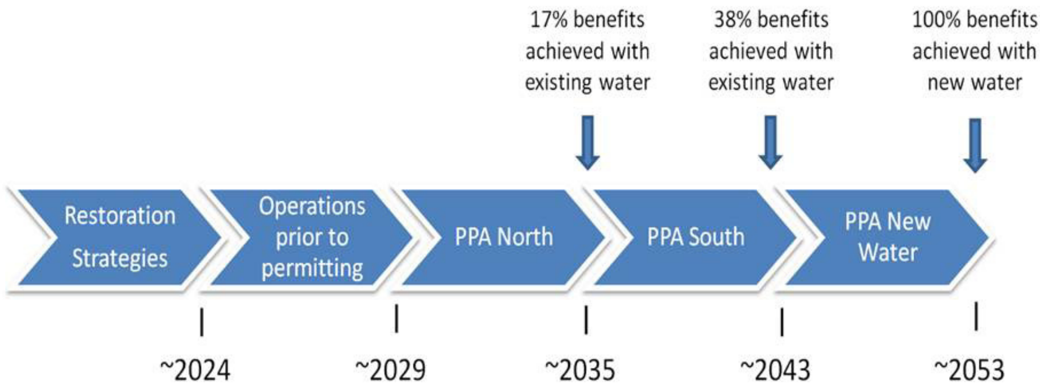

FIGURE 3-6 Schedule implications of serial phasing of state water quality construction, operations, and permitting of all STAs (as a unit), and Central Everglades project partnership agreement (PPA) construction. The years shown reflect the risk-based schedule according to USACE and SFWMD (2013b, Appendix B) of 186 months with an additional 107 months of schedule contingency (at 80 percent confidence), based on a $100 million/year constant dollar funding scenario. The 293-month total construction time (including contingencies) was apportioned to the three PPAs according to time lines presented in a draft constrained implementation schedule (E. Bush, USACE, personal communication, 2014).

The committee judges that this is an unreasonable and undesirable result. To avert continued ecosystem declines in the central Everglades, including some that would require decades to centuries to recover (NRC, 2012a), the Corps and SFWMD need to look for creative implementation strategies to reduce existing constraints. To take advantage of the likelihood that the Central Flowpath (STA-2 and -3/4) achieves compliance with the WQBEL much earlier than the remainder of the STAs (see Chapter 4), the agencies should investigate design, implementation, and permitting alternatives that would enable the Central Everglades Planning Project to move forward as quickly as possible with WQBEL-compliant discharges, This will require a thorough evaluation of the risks, costs, and benefits of such actions to the entire South Florida ecosystem and collaboration among multiple agencies and stakeholders. Additionally, an increased and consistent funding profile would have a major impact on achieving Central Everglades restoration goals sooner.

Adaptive Management and Monitoring

The Central Everglades adaptive management plan (USACE and SFWMD, 2013b) was developed to identify key areas where restoration efforts would benefit from monitoring and assessment and outline how proposed and existing monitoring could be used to adapt project implementation to reduce uncertainties and improve restoration outcomes. Additionally, the plan was to document the monitoring necessary to meet project-specific regulatory and permit objectives. It is intended to serve as a guide on the use of monitoring data to maximize restoration benefits while reducing costs and to inform project design and implementation to improve performance. Hence, the adaptive management plan represents a highly ambitious balancing act, given the multiple objectives and the scope of the Central Everglades Planning Project.

The Central Everglades Planning Project adaptive management team identified key project uncertainties, defined as planning questions "regarding the best actions to achieve desired goals and objectives within constraints, which cannot be fully answered with available data or modeling." These uncertainties reflect scientific understanding of the anticipated restoration responses to management actions rather than administrative and funding uncertainties surrounding scheduling and implementation. Based on criteria developed from RECOVER (2011a), the team screened and prioritized uncertainties, selecting only those uncertainties that

1. Are directly related to Central Everglades Planning Project goals, objectives, or constraints;
2. Are focused at the project scale;
3. Are not already well understood;
4. Have at least one measurable attribute that can provide information to resolve the uncertainty; and
5. Have adaptive management options (i.e., the ability to be addressed through adjustments to restoration plans).

The uncertainties identified were further prioritized according to three additional criteria:

1. The risk of not achieving restoration goals if the uncertainty is not resolved,
2. The level of knowledge about the uncertainty, and
3. The relevance or level of confidence that the uncertainty could be resolved.

Uncertainties that scored high on risk and relevance and low on knowledge were ranked higher than those with low risk and relevance and high knowledge. The highest priority uncertainties resulting from this process are listed in Box 3-2.

For each uncertainty listed in Box 3-2, the adaptive management plan includes information on the drivers of uncertainty, CERP- and project-level targets for ecosystem attributes related to the uncertainty, and a plan for monitoring

BOX 3-2
Central Everglades Planning Project Uncertainties

The following uncertainties were identified in Annex D of the Central Everglades Planning Project PIR (USACE and SFWMD, 2013b):

CEPP-wide: How will CEPP influence the introduction and growth of nonnative and native nuisance species within the project area, and will the species influence the predicted landscape and performance of CEPP?

Lake Okeechobee: Will CEPP's operational refinements for Lake Okeechobee affect its littoral and nearshore vegetation coverage?

Flow Equalization Basins (FEBs): How can the operation of the FEBs be optimized to maximize flows to the Everglades while serving the needs of Lake Okeechobee and the northern Everglades?

Northern Everglades, St Lucie Estuary: Do reductions in high flows result in measurable increases in submerged aquatic vegetation (SAV) coverage in the estuary? To what extent will the reduction in the frequency and magnitude of high flows to the estuary stabilize conditions sufficiently to improve benthic habitat in the south fork of the estuary? To what extent will the reduction of frequency and magnitude of high flows to the estuary help reestablish historic oyster beds on the south fork of the estuary?

Northern Everglades, Caloosahatchee Estuary: Do reductions in high flows result in measurable increases in SAV coverage and oyster acreage and health in the estuary? Will the reduction in low-flow violations in the estuary help reestablish persistent *Vallisneria* beds in the upper estuary?

Greater Everglades: Are flow velocities, direction, volumes, and depth improvements from CEPP sufficient to reestablish historic ridge-and-slough landscapes? Can CEPP create hydrology favorable for tree island elevation requirements? Are inundation and hydroperiod sufficient to reduce current high rates of soil oxidation and peat fires?

the attributes to track progress toward the targets. The plan also discusses the time frame in which changes in the attributes will be measurable, and identifies triggers or thresholds that would give early warning that project performance is deviating from restoration goals. Management options are proposed that could then be chosen based on monitoring results. The adaptive management plan relies on data from hydrometeorological, ecological, water quality, and nuisance and exotic vegetation monitoring and, as such, is tightly connected to monitoring activities associated with project implementation within and beyond the Central Everglades Planning Project. Although new monitoring activities are proposed, the adaptive management plan also relies heavily on data from existing monitor-

How much will CEPP improve alligator relative density and body condition in northern WCA-3A and -3B and northeast Shark River Slough? How much will hydrologic restoration and vegetation management result in increases in prey densities? How much will hydrologic restoration and vegetation management result in increases in wading bird foraging conditions and increased nest number and success of wood storks and roseate spoonbills?

Greater Everglades/Lower East Coast: Will the full suite of CEPP TSP structures be required in WCA-3B to create the Blue Shanty Flowway?

Everglades National Park (ENP)/Southern Coastal Systems: Will there be downstream biogeochemical effects associated with modifying inflows and hydrologic conditions in ENP, including effects on nutrient movement, availability, and ecological responses? Will increased flows to northeastern Shark River Slough yield natural distribution of waters toward the southeastern Everglades and northeast Florida Bay without operation of the SFWMD Canal System east of L-30, L-31N, and L-31W? Will CEPP improve flows to Florida Bay and the lower southwest coast, resulting in more natural salinity patterns, and will responses be consistent with the expectations from the CEPP scenario model predictions? Will predicted CEPP flows mitigate saltwater intrusion and associated coastal wetland vegetation, soil stability, and nutrient retention or release? If salinity is affected by overland flow increases through ENP to Florida Bay, how much benefit is generated for SAV, prey, coastal wading birds, and crocodiles, and can operations be adjusted to improve estuarine performance in Florida Bay?

Lower East Coast: Will the constructed and operational features of CEPP maintain flood risk management level of service east of the L-30, L-31N, L-31W and C-111 without reducing quantity or quality of groundwater in water supply well fields compared to existing conditions? Will the constructed and operational features of CEPP reduce surface and/or groundwater base flows and wetland/groundwater recharge to the east of the L-30 and L-31N in areas such as the Pennsuco Wetlands, south Miami-Dade wetlands, and Biscayne Bay?

SOURCE: USACE and SFWMD (2013b).

ing and ongoing research (such as the Science Plan for the Everglades Stormwater Treatment Areas [SFWMD, 2013d] discussed in Chapter 7).

The Central Everglades Planning Project team has developed the most structured, complex, and comprehensive adaptive management plan within the CERP to date. Because it has been developed in tandem with the Central Everglades Planning Project process, rather than retrospectively, it exhibits greater integration, relevance, and coordination with implementation of the restoration plan. Thus, monitoring data derived from the plan are more likely to be useful for determining ecological responses to project implementation and the ability to meet restoration goals. Although the adaptive management plan is intended to provide flexibility and robustness in the face of unexpected or surprising events (i.e., unknown uncertainties) within a highly dynamic system, aside from operational changes, much of the flexibility would be derived from future increments of restoration in the central Everglades, rather than within the project itself.

Although the plan addresses system dynamics and variability, it does not appear to take into account the strong likelihood of nonstationary processes (i.e., system dynamics in which the trend and variability change through time). This is particularly pertinent to the effects of climate change, for instance, where not only the average temperature and precipitation are projected to change, but temperatures and precipitation are projected to exhibit greater variance (Hansen et al., 2012) (see Chapter 5). Nonstationary systems and processes are notoriously difficult to monitor and manage because they turn what are assumed to be stationary baseline conditions, against which restoration responses are compared, into a moving target. For the Central Everglades Planning Project, and indeed much of the CERP, sea-level rise, climate change, and the introduction of new invasive species are perhaps the most prominent threats on the horizon that could impede the ability to measure restoration relative to starting conditions. These are also highly uncertain in their timing and projected effects on the system. In this context, flexibility to address these potentially disruptive uncertainties should be explicitly built into adaptive management and monitoring recommendations, and they should be made more explicit and expanded upon in the adaptive management plan.

Stakeholder Engagement

CERP stakeholders range across a diverse set of actors including, but not limited to, federal, state, and district agencies, tribes, environmental nongovernmental organizations and community groups, recreation groups, agricultural entities, and individual members of the general public. This is, in great part, due to the multiobjective and multifaceted nature of restoration in this region that cuts across social, economic, ecological, and hydrologic concerns over a broad landscape. The types of stakeholder engagement elicited during CERP project planning has typically focused on engaging other federal, state, local, and tribal government agencies as part of the project development team process. Under the Federal Advisory Committee Act (FACA), representatives from nongovernmental organizations, recreation groups, and agricultural interests are typically unable to actively and collaboratively participate in CERP project planning. Public participation in these meetings is typically limited to brief (2- to 3-minute) comments with no mechanism for discussion. Recognizing that greater acceptance is likely when stakeholders and the public are afforded opportunities to actively participate in the planning process, the USACE and the SFWMD worked with the FACA-exempt Task Force to facilitate enhanced stakeholder engagement for the Central Everglades Planning Project.

Building on experiences gained through previous stakeholder processes, such as the state's non-CERP River of Grass planning effort, the Task Force's Working Group, the Science Coordination Group, and the SFWMD's Water Resources Advisory Commission, moderated a total of 16 public workshops—many that were day-long or longer—that emphasized enhanced public and stakeholder engagement (Figure 3-7). This provided opportunities for two-way dialogue at a more detailed level and accommodated input from a broader representation of stakeholders and the public on the scope of the study; the

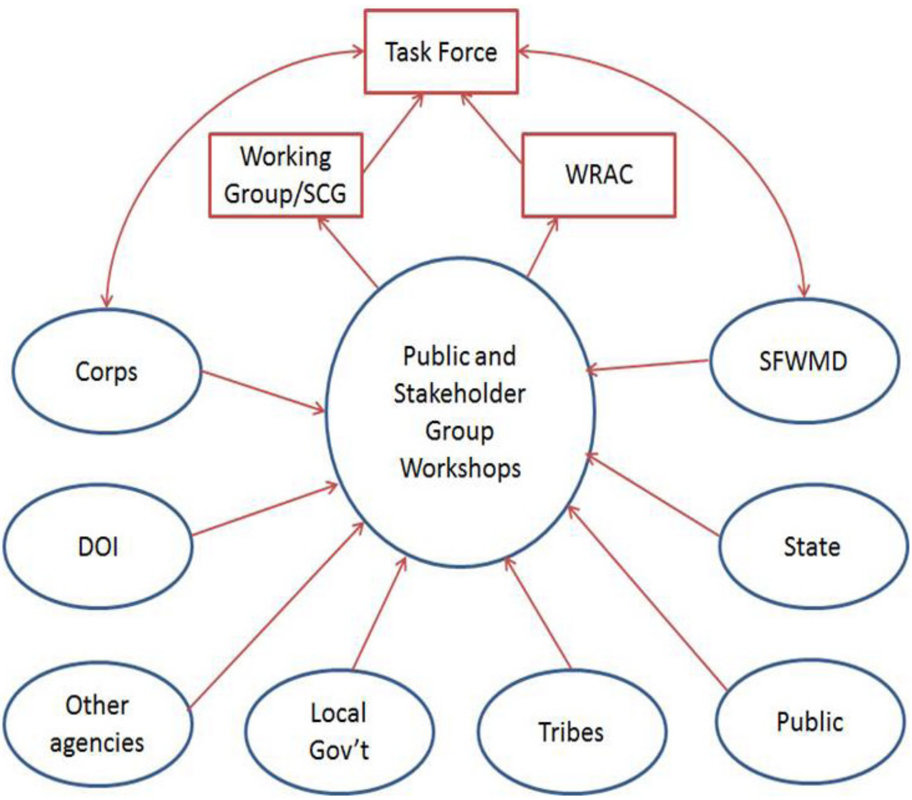

FIGURE 3-7 Public and stakeholder group workshops, showing feedback mechanism to the Corps and the SFWMD.

SOURCE: http://www.sfrestore.org/wg/wgminutes/2011meetings/11172011/Draft_Protocol.pdf.

development of goals, targets, and alternatives; and plan selection. One example of active input from stakeholders and the public was the use of configuration development exercises to elicit input on specific restoration strategies and implementation sequencing. Although not aiming for consensus, the results of the configuration development exercises allowed the Task Force to provide informed input to the Corps and the SFWMD during planning. Feedback from participants on the effectiveness of the enhanced public and stakeholder participation process, and the outcomes that have arisen from it, has been mixed. Feedback has been overwhelmingly positive about the extent to which the Corps and the SFWMD have reached out to a broad range of stakeholder and public entities to provide information and seek feedback, particularly with the recreation community. The configuration development exercises were regarded as valuable in soliciting input on some project components as they challenged participants to offer justified preferences for plans. This exercise ultimately influenced the recommendations, largely due to participation and feedback from the recreation community. Other aspects of the enhanced public and stakeholder participation process that were regarded as positive include a greater degree of two-way dialogue not seen in other planning endeavors in the CERP, the adoption of mechanisms to provide feedback and to change plans through more active and inclusive engagement, greater effort to explain the plan to broader stakeholder and public groups, and a more transparent planning process involving a more engaged community.

Opinion on the mechanism for feedback into the planning process (i.e., the process of using stakeholder comments, concerns, and suggestions to make changes) was mixed. Some stakeholders point to the change in alternatives based on concerns raised by the recreation community as evidence of a genuine feedback mechanism. However, others assert that the process by which feedback would be used to change plans lacked transparency from the outset, that input was accepted and acted upon on the basis of convenience and ease of implementation, and that disparate views across the broader stakeholder body were not addressed. It was the view of one stakeholder that most of the attention and discussion arising during workshops focused on the northern portions of the central Everglades because that is where most stakeholder and public interest lay; however, this led to incomplete or superficial consideration of the southern areas of the central Everglades and seepage issues.

Criticism has also been raised about the time frame of the Central Everglades Planning Project. Although a broad representation of stakeholders and the public was generally well informed by the process, those with knowledge of the CERP and the hydrologic models used in CERP planning had insufficient time and information to keep up with the dissemination of model output generated by the modeling team. Hence, stakeholders were limited in their understanding of the modeling results to what the agencies presented, rather than being able to gain insights from their own analysis of the data.

Numerous challenges arose during the enhanced public and stakeholder engagement process. First, to comply with FACA, multiple duplicate meetings were necessary, causing meeting fatigue. The numerous day-long, information-rich public workshops created a very intense process that was challenging to keep up with. And although the process of stakeholder engagement was regarded as an improvement over previous planning efforts, disappointment was expressed that some key stakeholders did not actively participate in the process, because they were either absent or reticent.

On balance, this committee judges that the enhanced stakeholder and public engagement process was well executed and inclusive. Although the expedited time frame was likely too fast to ensure rigorous consideration of all components of such a complex project, this committee commends the efforts to structure stakeholder and public engagement to allow more active participation than in previous planning processes. The limitations incurred by an expedited planning time frame aside, the efforts to educate stakeholders and the public and to elicit comments, criticisms, and modifications to the Central Everglades Planning Project have been exemplary and should serve as a model for future planning processes.

The Process

Despite some delays in the schedule, the Central Everglades Planning Project team produced a public version of a decision document within approximately 22 months and is anticipated to have a Chief's Report in a total of 34 months. Although there has been no formal survey of participants and stakeholders, it appears that the project was well administered, stakeholders were generally pleased with the opportunity to participate in the process directly, and it produced a useful product. Brief slippage in the schedule came in part because of extra time required to develop confidence that the project could satisfy the Savings Clause and provide project assurances as required in the authorizing legislation, but another contributing factor in the delay was the tardy insertion of concerns about additional public water supply that were not part of the early scoping process. That is a reality for all planning processes. It is not uncommon for some stakeholders to become engaged in a planning process after scoping has been completed or after initial plans have been formulated and evaluated. At that point, they are better informed as to what has or has not been included in the alternatives. Although it is unfortunate that all interests are not always at the table at the beginning of a process, concerns of late-arriving stakeholder groups can be dismissed only at the risk of further delay in the review process. Only time will tell as to whether all interests were sufficiently satisfied by addressing the stated need for additional water supply. The expedited process focused more narrowly on environmental restoration than the broader goals of the 1999 Restudy (and WRDA 2000) and as a result, the Central Everglades Planning Project may not enjoy the broad support of the original CERP. The project also encountered some delays while unresolved issues were addressed during the review process, particularly for policy issues associated with the FWS Biological Opinion (FWS, 2014). Collectively, these delays meant that the project was not authorized in WRRDA 2014, which proved to be a significant disappointment for the staff and stakeholders who had committed extensive time and energy to the project for more than 2 years. Whether this delay proves to be significant to restoration progress remains to be seen. If the Central Everglades Planning Project can be authorized through a future Water Resources Development Act (or some other mechanism) within approximately the next 3-5 years, the impacts of this delay are likely to be small, because numerous project dependencies need to be constructed before the Central Everglades construction can proceed. However, further authorization delays could lead to missed opportunities to expedite restoration progress with the greatest benefits for the natural system.

The original target of 18 months to complete the planning process for such a complex project proved to be overly ambitious. The staffing levels and intensity were greater than anticipated, leading to total planning costs that were similar to the prior 6-year planning model (M. Morrison, SFWMD, personal communication, 2013). Those involved in managing the expedited process suggested that a 3-year time frame might be a better, more achievable goal. The agencies supported the aggressive schedule and committed key personnel for the duration of the study. However, not all agencies were able to make the same resource commitments, and some agencies—particularly local governments—found it challenging to keep up with the expedited process.

Communication within and between agencies, especially vertically into senior management, was a particular strength of the expedited process. Leadership was informed quickly of issues that required resolution and was involved in developing solutions. This strategy significantly improved the efficiency of the planning process compared with the prior USACE planning model.

It was recognized throughout the early alternatives analyses and plan selection that the level of site-specific information available and the features' design details were less than the normal, non-expedited planning process, posing possibly greater project risks. Probabilistic cost models at an 80 percent confidence level yielded a construction cost contingency of 44 percent. Using escalation adjustments and calculating on a constant-dollar basis, the estimated total project cost was $1.9 billion (including $571 million for contingency; E. Bush, USACE, personal communication, 2014). Similarly, the total project duration at an 80 percent confidence level was originally reported as 293 months (including a contingency of 107 months) (USACE and SFWMD, 2013b).[10] A sensitivity analysis provided a means of ranking the larger contributors to project risk, and the uncertainty in the "funding profile" was the biggest contributor to both cost and duration variation. Several feature design uncertainties also contributed to the cost risk, but no other variables compared to funding as a driver of schedule risk. This dominance of the funding uncertainty is particularly noteworthy in light of the less-complete design and site data levels, and it reinforces the validity of the expedited, more conceptual design planning process.

Although the number of unique alternatives specified in the expedited process appears to be less than a typical USACE 6-year process, there were effectively a large number of possibilities that were pared down through a rational, defensible process. The four alternatives with the major variations described earlier were actually a much larger number of possible combinations. Dividing up the large geographic area into regions based on functional characteristics (e.g., storage, conveyance) was an effective way of reducing the number of combinations and communicating both within and external to the team. Overall, the planning organization, backed by the extensive technical modeling, gives strong support to the conclusion that the range of alternatives evaluated was reasonable and appropriate for this planning process. Given the time constraints, however, there was limited ability to cycle back to earlier alternatives once assumptions or options for a geographic area were defined. Simplistically, the expedited process was a more linear approach than the typical process and provided less opportunity for iteration. In the committee's judgment, however, the weaknesses of the expedited process did not materially diminish the quality of the final plan.

Some important analyses, however, were overlooked in the expedited planning process. Beyond a cursory examination of the effects of sea-level-rise scenarios on project benefits due to land loss, there was a distinct lack of consideration of the potential effects of climate change on restoration benefits under each alternative. This is due, in part, to the expedited time frame driving the project that limited such an in-depth analysis and the uncertainty inherent in quantifying these effects with an acceptable degree of accuracy. However, the lack of consideration of the effects of climate change paints an incomplete picture of hydrologic and ecosystem response to the alternatives examined. Explicit consideration of how the performance measures are affected by increased temperature, changes in precipitation (and increased variability in temperature

[10] Since the August draft PIR was released, the Cost Engineering Appendix has been revised to include an even-longer total project duration of 329 months with a contingency of 89 months, for a total of 34.8 years at an 80 percent confidence level. This updated estimate reflects a scenario of $100 million/year, not adjusted for inflation (Amro Habib, USACE, personal communication, 2014).

and precipitation), and sea-level rise would likely lead to revised habitat unit estimates. Additionally, such an analysis would have enabled the quantification of specific benefits associated with mitigating the impacts of climate change, which might have elucidated additional alternatives pertinent to performance measures explicitly related to climate change impacts, such as salinity envelopes, slough vegetation, and extreme high and low water depths in the Greater Everglades. Future planning efforts will need to consider the impacts of climate change on performance measures and restoration goals more broadly, despite the uncertainty associated with temperature and, particularly, precipitation projections (see Chapter 5). Scenario planning (Peterson et al., 2003; Polasky et al., 2011), currently adopted by the National Park Service (NPS, 2013), provides a structured framework for decision making under alternative futures in the face of uncertainty in climate change projections and should be considered in future planning efforts. A more complete analysis of the impacts of climate change and quantification of the benefits associated with mitigating these could potentially lead to increased public and political support for the Central Everglades Planning Project.

CONCLUSIONS AND RECOMMENDATIONS

The Central Everglades Planning Project effort is responsive to the need to expedite restoration in the central Everglades via increments of restoration to avert further declines that could take many decades or longer to recover. Overall, the project team did an impressive job under a challenging time frame. The proposed plan seems reasonable and thoughtfully developed with substantial stakeholder input. Implementation of the plan would provide significant benefits to the remnant Everglades ecosystem, including more than 200,000 AF/yr of new water—a sizeable first increment of restoration for the central Everglades that represents approximately two-thirds of the new water to northern WCA-3 envisioned in the CERP. A comprehensive adaptive management plan provides an important mechanism to learn from project implementation to improve the operation of the project and the design of future increments of restoration, although additional attention to climate change uncertainties is needed.

If the Central Everglades Planning Project is to avert further ecosystem degradation, CERP planners and policy makers need to expedite project implementation in the face of several hurdles. The best-laid plans will be of little benefit if the project is not implemented in a timely way. Completion of the Chief's Report for the Central Everglades Planning Project, congressional authorization, and construction of project dependencies are key near-term steps necessary to move forward. Project funding and water quality permitting constraints currently appear to be the largest barriers to timely project implementation.

Creative solutions may be available to significantly expedite restoration, such as finding permit mechanisms to move water that meets water quality criteria into the Everglades prior to completion of the entire Restoration Strategies project. Such approaches will require the agencies to recognize the urgency and to work to find legal and engineering solutions to move increments of water into the Everglades as soon as those increments have been adequately treated to meet water quality standards. Without such solutions, redistribution of existing water may not be feasible until 2035 or beyond and at the envisioned funding level of $100 million per year, construction would not be completed for approximately four decades—exceedingly long for a system already in significant decline.

Some important lessons were learned from the expedited planning process. Although overall, participants and stakeholders thought the process led to a useful outcome, the 22-month time frame to produce the PIR was extremely challenging for staff and stakeholders, alike. The process required large numbers of staff and became the central focus of the restoration program. Such attention was deserved for this high-priority initiative, but similar intensive efforts are unlikely to be sustainable for future CERP planning. Furthermore, stakeholders with technical expertise found it difficult to keep up with the pace of model output presented and hence could not adequately evaluate the information provided. Thus, 3 years might be a more reasonable time frame for such a complex effort. Communication within and between agencies was a particular strength of the expedited process; senior decision makers were involved at key decision points and as needed to resolve issues and improve planning efficiency. However, the existing Corps process for evaluating restoration benefits makes it difficult to be transparent about tradeoffs in planning decisions.

The enhanced stakeholder and public engagement process was well executed and should serve as a model for future planning processes. This level of active and inclusive stakeholder engagement had not previously been implemented as part of the CERP, and it provided a means for two-way dialogue between stakeholders and agency staff that substantially influenced the planning outcome. Although the abbreviated time frame led to concerns from participants, overall, the committee commends the efforts to educate and engage the stakeholders and modify the project plan where feasible to address concerns.

4

Implementation Progress

This committee is charged with the task of discussing significant accomplishments of the restoration and assessing "the progress toward achieving the natural system restoration goals of the Comprehensive Everglades Restoration Plan [CERP]" (see Chapter 1). In this chapter, the committee updates the National Research Council's (NRC's) previous assessments of CERP and related non-CERP restoration projects (NRC, 2007, 2008, 2010, 2012a). This chapter also addresses programmatic and implementation progress as well as analyzes any natural system benefits resulting from the progress to date.

PROGRAMMATIC PROGRESS

To assess programmatic progress the committee reviewed a set of primary issues that strongly influence the progress of the CERP toward its overall goals of ecosystem restoration. These issues, described in the following sections, relate to authorization, funding, and scheduling.

Project Authorization

Once project planning is complete, CERP projects with costs exceeding $25 million[1] must be individually authorized by Congress.[2] Water Resources Development Acts (WRDAs) have served as the mechanism to congressionally

[1] Programmatic authority for smaller projects (less than $25 million each) was subject to a total limit of $206 million (Water Resources Development Act of 2000 [WRDA 2000]).

[2] WRDA 2000 included authorizations for 10 initial Everglades restoration projects (pending congressional approval of the project implementation reports [PIRs]), and an adaptive management and monitoring program. WDRA 2000 stipulated that the initial project authorizations are subject to Section 902 of WRDA 1986, thereby requiring reauthorization if project costs increase by more than 20 percent of the original authorized cost (exclusive of inflation). As a result of the Section 902 limits or other major project changes, all 10 conditionally authorized projects now require reauthorization (S. Appelbaum, USACE, personal communication, 2012).

authorize U.S. Army Corps of Engineers (USACE) projects, and the CERP planning process was developed with the assumption that WRDAs would be passed every 2 years. This, however, has not occurred. In the 13 years after the CERP was launched in WRDA 2000, Congress passed only WRDA 2007, which authorized Indian River Lagoon-South, Picayune Strand Restoration, and the Site 1 Impoundment projects. Additionally, the Melaleuca Eradication Project was authorized under programmatic authority. These four projects are considered Generation 1 projects (see Table 4-1; Figure 4-1), and for the past 7 years, they have been the only projects that could receive federal appropriations to support construction.

In May 2014, Congress passed the Water Resources Reform and Development Act (WRRDA), which authorized four additional projects (C-43 Reservoir, C-111 Spreader Canal, Biscayne Bay Coastal Wetlands, Broward County Water Preserve Areas), termed Generation 2 projects. With the passage of WRRDA 2014, the federal government will be able to maintain progress on several state-expedited projects now under way (e.g., C-111 Spreader Canal, Biscayne Bay Coastal Wetlands) and initiate construction on two other new projects.

The expedited planning process for the Central Everglades Planning Project was originally targeted for completion in December 2013 in anticipation of it being included in a 2013 authorization. Delays in the planning process, however, pushed it beyond closure on WRRDA 2014 (see Chapter 3). Slippage in the completion schedule for the Central Everglades Project beyond closure for WRRDA 2014 delays authorization of that project to the next WRDA (or other authorization mechanism). As discussed in Chapter 3, the implications of such delays on restoration progress should be relatively minor if the next WRDA is passed in the next 3-5 years.

Funding

Funding for restoration of the South Florida ecosystem comes from a variety of federal and state sources.[3] A combination of several factors has contributed to deceleration in the rate of spending for restoration of the Everglades over

[3] Federal agencies include the USACE, four Department of the Interior agencies (National Park Service, U.S. Fish and Wildlife Service, Bureau of Indian Affairs, and U.S. Geological Survey), two Department of Agriculture agencies (Natural Resources Conservation Service and Agricultural Research Service), National Oceanic Atmospheric Administration, and U.S. Environmental Protection Agency. The South Florida Water Management District (SWFMD) is the nonfederal partner for CERP and several non-CERP cost-shared projects, and the State of Florida directs monies from state appropriations and several trust funds into SFWMD accounts. Two trust funds have been particularly important to CERP projects—Florida Forever and Save Our Everglades. Other Florida agencies that contribute include the Departments of Agriculture, Environmental Protection, and Transportation, and the Fish and Wildlife Conservation Commission.

TABLE 4-1 CERP or CERP-Related Project Implementation Status as of May 2014

Project or Component Name	Yellow Book (1999) Estimated Completion Date	IDS (Aug. 2011) Estimated Completion Date	PIR (or PPDR) Status	Authorization Status	Planning/ Design	Construction Status; Installation and Testing Status for Pilots
PILOT PROJECTS						
Hillsboro ASR Pilot (Fig. 4-1, No. 1)	2002	Not specified	PPDR Final Oct. 2004	Authorized in WRDA 1999	Completed	Completed, 2013
Kissimmee ASR Pilot (Fig. 4-1, No. 2)	2001	Not specified	PPDR Final Oct. 2004	Authorized in WRDA 1999	Completed	Completed, 2013
Regional ASR Study	NA	Not specified	NA	NA	Completed	Ongoing
LPA Seepage Management Pilot (Fig. 4-1, No. 3)	NA	Not specified	NA	NA	Completed	Completed
C-111 Spreader Canal Design Test (Fig. 4-1, No. 9)	NA	2011	NA	Programmatic authority WRDA 2000	Completed	Testing completed
Decomp Physical Model (Fig. 4-1, No. 4)	NA	2014	NA	Programmatic authority WRDA 2000	Completed	Ongoing

continued

TABLE 4-1 Continued

Project or Component Name	Yellow Book (1999) Estimated Completion Date	IDS (Aug. 2011) Estimated Completion Date	PIR (or PPDR) Status	Authorization Status	Planning/ Design	Construction Status; Installation and Testing Status for Pilots
RESTORATION PROJECTS—Generation 1						
Picayune Strand Restoration (Fig. 4-1, No. 5)	2005	Merritt: 2012 Faka-Union: 2014 Miller: 2016	Submitted to Congress in 2005	Construction authorized in WRDA 2007 *Reauthorization required because of cost increases*	Completed	Prairie Canal completed in 2007 Merritt, Faka Union ongoing pending Sec. 902 limits
Site 1 Impoundment* (Fig. 4-1, No. 6)	2007		Submitted to Congress in 2006	Construction Authorized in WRDA 2007	Completed	
• Phase 1		2013				Ongoing
• Phase 2		TBD		*Phase 2 requires reauthorization*		Not begun
Indian River Lagoon-South (Fig. 4-1, No. 7)		Not specified	Submitted to Congress in 2004	Construction authorized in WRDA 2007		
• C-44 Reservoir/STA*	2007	2018			Completed	Ongoing
Melaleuca Eradication and Other Exotic Plants (Fig. 4-1, No. 7)	2011	2012	Final June 2010	Programmatic authority WRDA 2000	Completed	Construction completed 2013 Operations ongoin.

RESTORATION PROJECTS—Generation 2						
C-111 Spreader Canal* • Western Project (PIR #1) (Fig. 4-1, No. 9)	2008	2012	Approved by USACE Chief of Eng. in Jan. 2012	Construction authorized in WRRDA 2014	Completed	Ongoing; expedited by FL
Biscayne Bay Coastal Wetlands (Phase 1) (Fig. 4-1, No. 10)	2018	2016	Approved by USACE Chief of Eng. in May 2012	Construction authorized in WRRDA 2014	Completed	Ongoing; expedited by FL
C-43 Basin Storage: West Basin Storage Reservoir (Fig. 4-1, No. 11)	2012	TBD	Approved by USACE Chief of Eng. in Jan. 2011	Construction authorized in WRRDA 2014	Ongoing	Not begun
Broward County WPAs (Fig. 4-1, No. 12)			Approved by USACE Chief of Eng. in May 2012	Construction authorized in WRRDA 2014		
• C-9 Impoundment*	2007	Not specified			Ongoing	Not begun
• Western C-11 Diversion Impoundment*	2008	2018			Ongoing	Not begun
• WCA-3A & -3B Levee Seepage Management*	2008	2022			Ongoing	Not begun
RESTORATION PROJECTS—Generation 3						
Central Everglades Planning Project (Fig. 4-1, Nos. 13 and 14)	NA	NA	Draft PIR Aug. 2013	Not authorized	Ongoing	Not begun
Loxahatchee River Watershed (Fig. 4-1, No. 15)	Not specified	Not specified	In development	Not authorized	Ongoing	Ongoing; expedited by FL

* Projects that were conditionally authorized in WRDA 2000, subject to approval of the PIR.

NOTES: Projects in Table 4-1 reflect those CERP projects or pilot projects deemed by the committee to be relevant to CERP progress. This table does not include non-CERP foundation projects. Gray shading of project names reflects projects being expedited and/or carried out entirely with state funding as of 2014. Gray shading of construction cells indicates past or present aspects of projects that were expedited with state funding. NA = not applicable; TBD = to be determined.

SOURCE: www.evergladesplan.org.

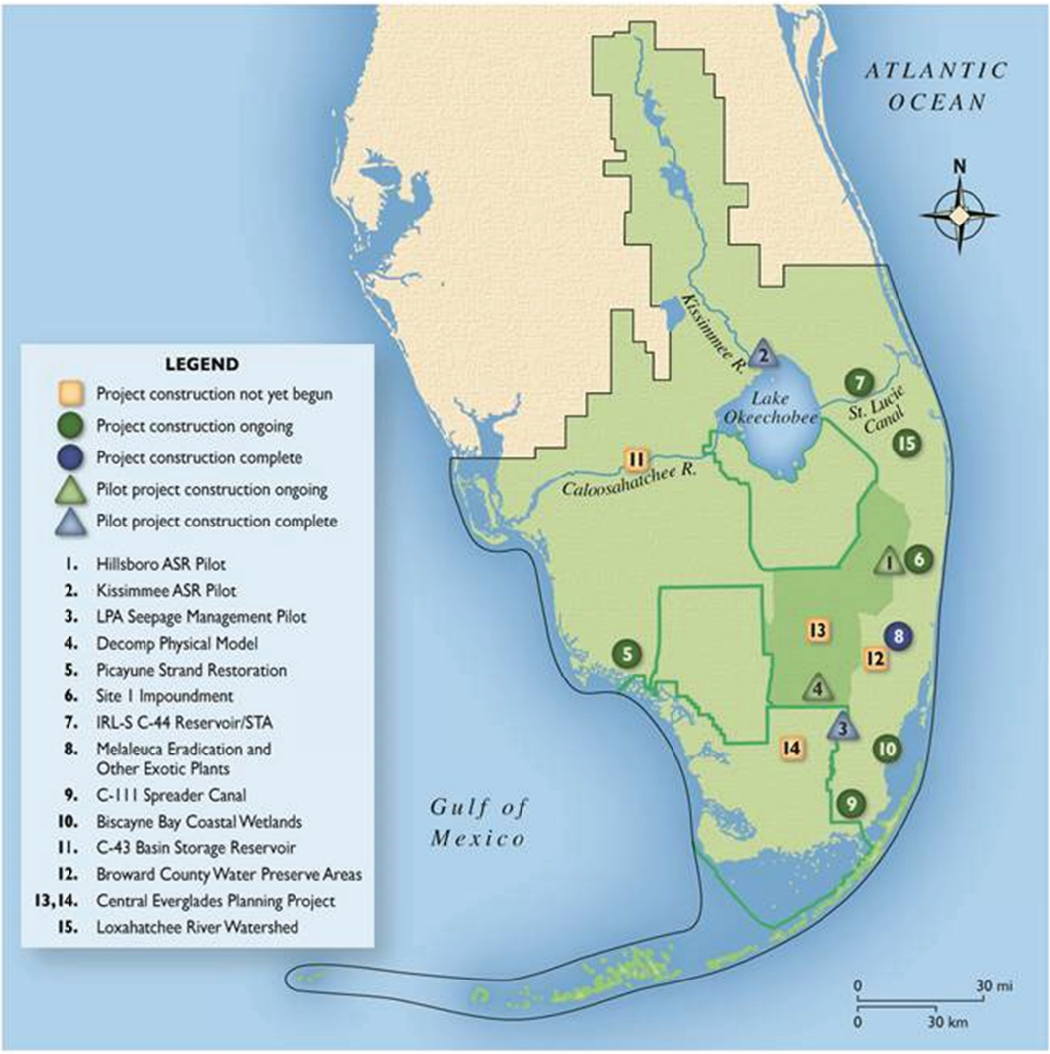

FIGURE 4-1 Locations of CERP and CERP-related projects and pilots listed in Table 4-1. Projects under active construction are noted with a green circle.

SOURCE: © International Mapping Associates

the past 3 to 4 years. Reductions in budgets for restoration by federal and state agencies, court mandates requiring the SFWMD to make additional water quality improvements, delays in congressional authorizations of additional projects, and rules governing cost sharing have all had an impact. Those trends and potential bottlenecks are explored in more detail in subsequent sections.

CERP Spending

Figures reported by the South Florida Ecosystem Restoration Task Force (Task Force) indicate that federal and state governments have spent $4.25 billion on CERP projects since passage of WRDA 2000 through FY 2013 (SFERTF, 2014). Spending by the State of Florida, including the SFWMD, has substantially outpaced federal spending—about $3.23 spent toward the CERP by the state for every dollar spent by the federal government. Rates of CERP spending have been highly variable, as shown in Figure 4-2. Florida's spending grew at a fast pace through FY 2007, remained high in FY 2008, and rapidly declined afterward. Federal spending on the CERP accelerated after passage of WRDA 2007, peaking in FY 2010, and declining since then.

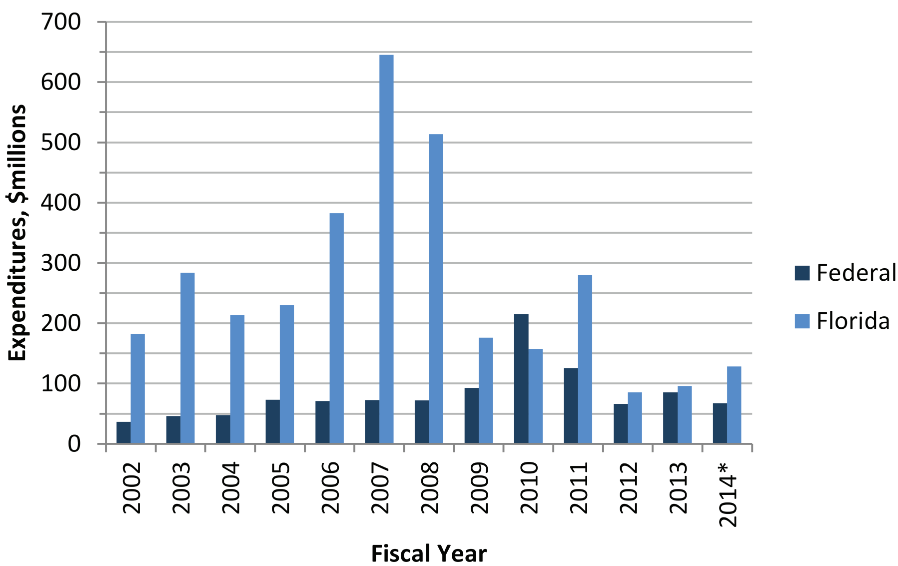

FIGURE 4-2 Spending on CERP projects by federal and state governments.
NOTE:* Requested.

SOURCE: SFERTF (2014).

All South Florida Ecosystem Restoration Spending

The economic downturn and related fiscal constraints at both national and state levels have slowed the rate of spending on most ecosystem restoration projects in South Florida, not just the CERP. Some items that have been included in the Task Force's cross-cut budget may be indirectly related to restoration, but those entries do not alter the general decline in expenditures since 2010, as shown in Figure 4-3. Reported federal expenditures in FY 2013 were only 47 percent of FY 2010 values, and Florida's spending on restoration in FY 2013 was only 41 percent of its FY 2010 numbers. If planned expenditures for FY 2014 are realized, they would represent a slight upturn from prior years at both the federal and state levels. Among the larger items included in federal non-CERP expenditures over the 5-year period FY 2010 to FY 2014 are $470 million by the Natural Resources Conservation Service for agricultural programs; $149 million by the National Park Service for Everglades National Park management; and over $100 million for Kissimmee River Restoration.

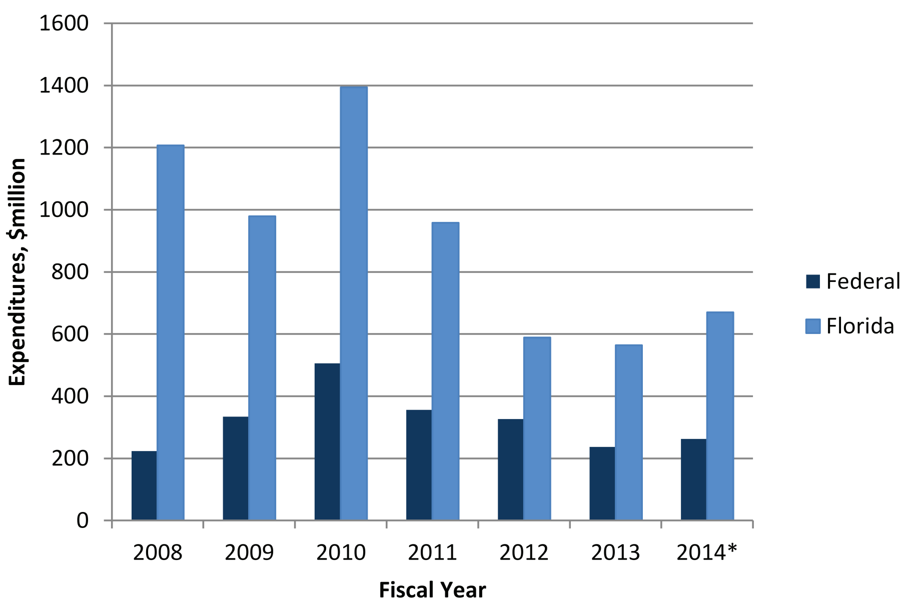

FIGURE 4-3 Federal and state spending related to South Florida ecosystem restoration activities, including CERP and non-CERP projects and related expenditures.
NOTE:* Requested.

SOURCE: SFERTF (2014).

Of particular concern, South Florida ecosystem restoration is losing ground in USACE Civil Works construction budgets. As shown in Table 4-2, funding requested by the USACE for South Florida ecosystem restoration is about 48 percent of what it was 3 years earlier. The Corps' construction budget has declined, and the South Florida ecosystem restoration share of that budget is declining.

SFWMD Financial Resources

The SFWMD's capacity to undertake new CERP projects and possibly complete authorized projects is hampered by its obligations to fund the Restoration Strategies, an $880 million project mandated under a consent order to remedy phosphorus exceedances in the Everglades Protection Area (see Chapter 2; also discussed later in this chapter). Expenditures of that magnitude are in competition with financial demands for the SFWMD's ongoing operations, for other non-CERP construction projects, and for completion of previously authorized CERP projects.

If revenues are not enhanced, the SFWMD will be challenged to keep up cost sharing as the nonfederal partner for CERP and some non-CERP projects and to continue funding other restoration projects and programs. Annual SFWMD revenues dropped sharply over the period FY 2008 through FY 2013 as shown in Figure 4-4 from just over $900 million to $346 million. The largest portion of the loss in revenue was due to a decline in ad valorem taxes, down from $549 million in FY 2008 to $268 million in FY 2013 (Figure 4-4). Intergovernmental revenue (state appropriations and trust fund transfers) also declined, from $286 million in FY 2008 to $37 million in FY 2013.

Furthermore, in recent years, revenues have been supplemented with significant funding from reserve fund balances: $228 million in FY 2013 and $299 million in FY 2014 (SFWMD, 2013c, 2014). The SFWMD had accrued large fund balances (approaching $900 million in FY 2009). Those funds were being held in reserve to address future spending needs, and since 2009, the SFWMD has

TABLE 4-2 Budget Requests for the U.S. Corps of Engineers Civil Works Program

Requested Budgets	FY 2011	FY 2012	FY 2013	FY 2014
All construction, $ million	1,690	1,480	1,471	1,350
South Florida Ecosystem Restoration, $ million	180	163	153	88
Percent of total	10.7	11.0	10.3	6.5

Note: These totals are different from appropriated budgets.

SOURCE: Data from USACE (2010, 2011b, 2012a, 2013c).

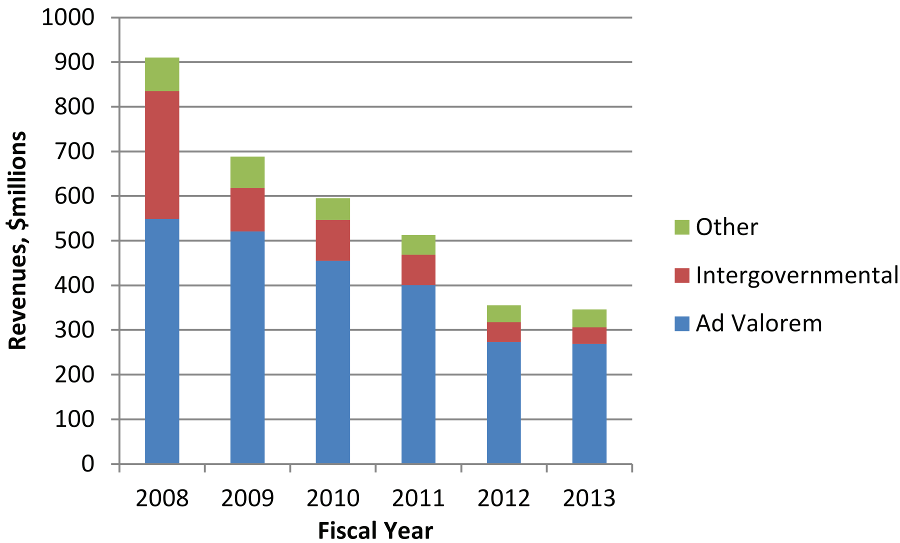

FIGURE 4-4 SFWMD revenues for FY 2008 through FY 2013. In addition to revenues, the SFWMD drew upon fund balances, which are not reflected here.

SOURCES: SFWMD (2008, 2009b, 2010, 2011b, 2012a, 2013e).

been drawing on this balance to cover capital outlay and other expenses. By the end of FY 2013, the fund balance was down to $448 million, and, as shown in Figure 4-5, the FY 2014 budget projects that by FY 2018, the fund balance will be only $37 million. Thus, unless other sources of revenue increase in the next few years, there will be very limited funds available for new projects.

As SFWMD revenues have declined, so have expenditures, as shown in Figure 4-6. Capital outlay was at $379 million in 2008, but by 2012 had been reduced to only $67 million. In FY 2013, capital outlay decreased to $48 million, with $21 million going to the CERP. The FY 2014 to FY 2018 Capital Improvements Plan is based on a 5-year projection of $1,146 million in revenues to fund items included in the plan; $770 million or 67 percent would be spent for Everglades Restoration. Of this, $171 million is programmed for Generation 1 projects (Picayune Strand and Indian River Lagoon-South's C-44 Reservoir and stormwater treatment area [STA]) and $348 million for the Restoration Strategies project and other water quality-related non-CERP projects. An additional $30 million is budgeted for the Loxahatchee Watershed project (Generation 3), and $176 million is for debt service (Table 4-3; Heater and Maytok, 2014).

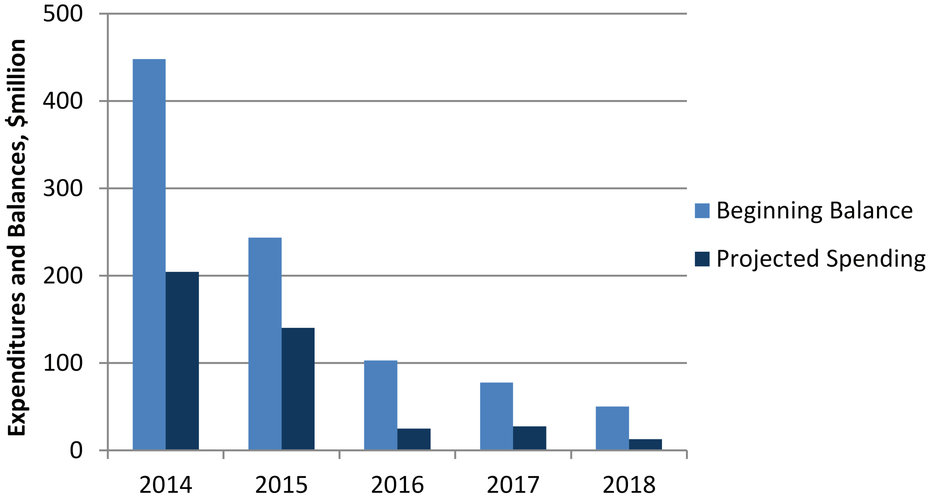

FIGURE 4-5 Drawdown of SFWMD reserve fund balances.

SOURCE: SFWMD (2013b).

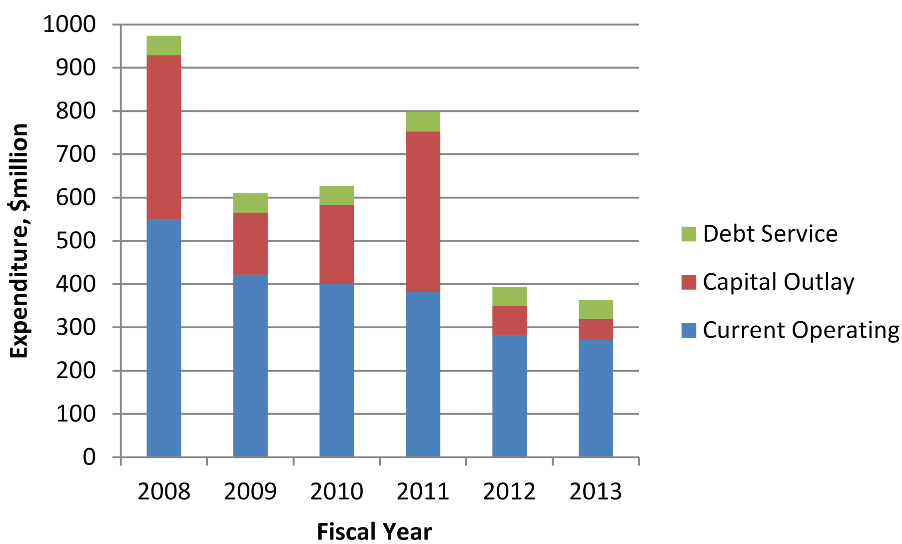

FIGURE 4-6 Overall SFWMD expenditures, including but not limited to South Florida ecosystem restoration, FY 2008 through FY 2012.

SOURCES: SFWMD (2008, 2009b, 2010, 2011b, 2012a, 2013e).

TABLE 4-3 FY 2014 to FY 2017 SFWMD Capital Improvements Plan Expenditures for Everglades Restoration

EXPENDITURES	Total
East Flowway	$ 2,000,000$
C-44 Reservoir and STA	156,439,234
Picayune Strand	14,601,218
C-111 South Contract	9,000,000
LTP EAA STA Compartment B Design Construction & Build Outs	1,345,536
Loxahatchee Watershed	29,812,479
MECCA FEB	19,836,468
A-1 FEB	67,824,964
STA-1W Expansion #1	161,793,068
STA-1W Expansion #2	21,554,370
L-8 Divide	5,042,000
G-716	5,309,000
S-5AS	3,032,000
Source Control	18,066,834
Science Plan	44,342,154
Debt Service - 2006 COPs	175,802,909
Future Restoration Projects (SOETF)	34,135,727
TOTAL	**769,937,961**

SOURCE: Heater and Maytok (2014).

For FY 2014, the SFWMD budgeted approximately $45 million for authorized CERP projects, including $29 million for the C-44 Reservoir and $16 million for Picayune Strand (SFWMD, 2014b).

Cost-Sharing Implications

Effects of 50-50 state-federal cost-sharing rules as outlined in WRDA 2000 and detailed in the 2009 Master Agreement have become a matter of significant concern. Management of expenditures to satisfy cost-sharing rules has always been a challenge, but it has become more challenging over the past 2 years with reduced budgets, mandated expenditures for other projects, and limited project authorizations. Even though the SFWMD has far outspent federal agencies on CERP projects from land acquisition and expedited construction efforts (Figure 4-2), cost-sharing rules dictate that the SFWMD can only apply its storehouse of potential credits toward the 50-50 cost-sharing requirement on those projects that have been authorized by Congress, have signed project partnership agreements, and have received federal appropriations. Non-planning-related SFWMD expenditures on yet-to-be authorized CERP projects cannot be officially credited toward the 50-50 cost-sharing requirement until those projects are authorized and funds have been appropriated. Cost-sharing agreements are restrictive with respect to how credits can be used and how the federal-nonfederal balance must be maintained. The 50 percent proportionate share owed by the local sponsor (i.e., the SFWMD) must be brought into balance annually across the CERP program. Several options are provided for eliminating an imbalance, including delaying construction schedules or requiring cash payments from the local sponsor.[4]

As discussed previously, until late May 2014, only four projects had been authorized. As of September 30, 2013, $1.88 billion had been spent on those four projects: $891 million by the federal government and $989 million by the SFWMD, leaving the state with only $98 million in excess creditable expenditures above the minimum required 50-50 balance.

In the past few years, the CERP strategy to address this pending cost-sharing issue has been to reduce federal spending where feasible, particularly for non-construction-related activities. As of September 2013, the federal government could spend no more than $49 million more than the state on the CERP through September 2014 without necessitating additional expenditures by the state. Recent federal Everglades restoration funding through the federal Consolidated Appropriations Act of January 2014 was reduced to $46 million, down from prior discussions of $80 million, because the USACE indicated it could not spend the money (Scott, 2014) due to a combination of policy, authorization, and cost-sharing issues (Tipple, USACE, personal communication, 2014).

WRRDA 2014, therefore, is an important achievement for Everglades restoration progress because it temporarily alleviates cost-sharing constraints that have restricted federal spending over the past few years. The four Generation 2 project authorizations represent a critical step to enable the SFWMD to realize an estimated $382 million in accumulated credits from its prior spending on land acquisition and construction (G. Rogers, SFWMD personal communication, 2014), allowing federal appropriations to continue in the near future.

Project Scheduling and Prioritization

The CERP project construction schedule for the next decade is outlined in the Integrated Delivery Schedule (IDS; Figure 4-7). The IDS was developed in consultation with the Task Force and reflects the priorities of the CERP partners as well as sequencing constraints and other project implementation issues. Between 2008 and 2011, the IDS was revised several times per year (typically

[4] See Master Agreement at http://www.evergladesplan.org/pm/pm_docs/master_agreement/081309_master_agreement_cerp.pdf.

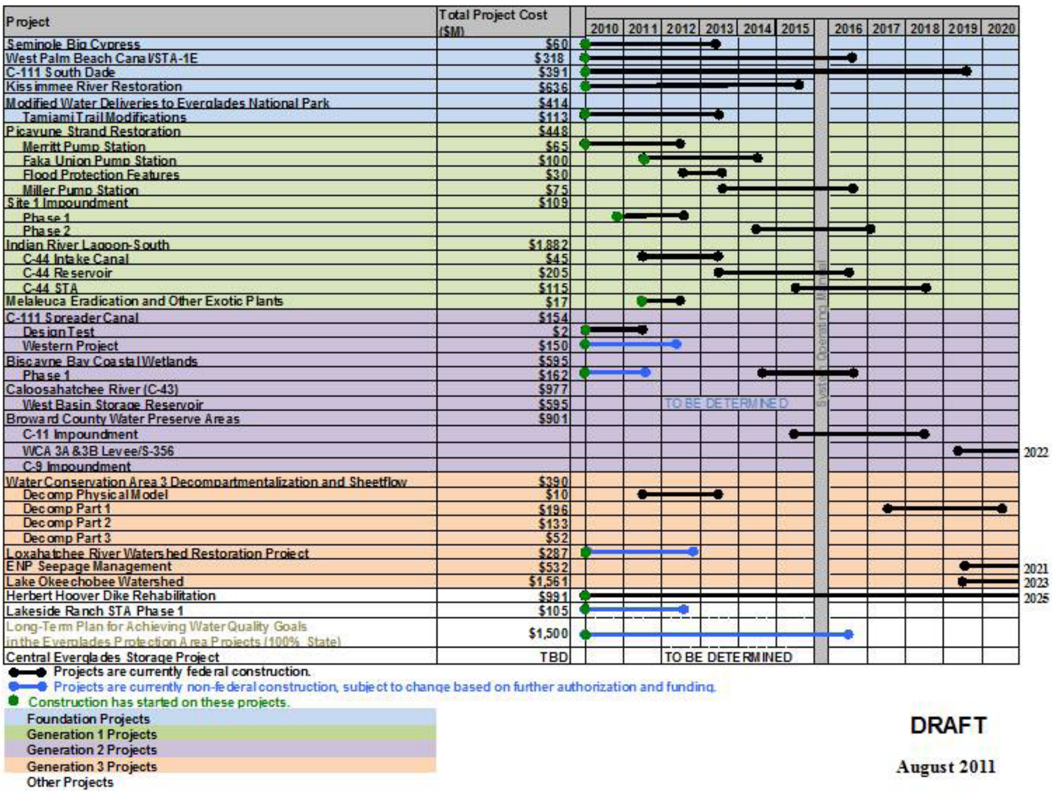

FIGURE 4-7 Integrated Delivery Schedule, August 2011 draft.
NOTE: Project costs cited represent October 2008 price levels and have been adjusted for inflation based on construction start and finish dates for each contract.

SOURCE: K. Tippett, USACE, personal communication, 2011.

in draft) to reflect changing budgets and other developments that affect project schedules, but with intense staff efforts devoted toward the development of Central Everglades Planning Project, the IDS has not been revised since August 2011 draft (Figure 4-7). The IDS now is badly out of date.

Several factors will affect the next update of the IDS, including state and federal CERP and non-CERP appropriations and the recent congressional authorizations for the Generation 2 projects (Table 4-1). Much uncertainty remains over how new authorizations and lack of authorization for the Central Everglades Planning Project will affect the overall implementation schedule. For example, should early authorized projects (Generation 1) be funded before later authorized projects (Generation 2)? What is the priority of non-CERP projects, such as the Modified Water Deliveries, Kissimmee River Restoration, C-111-South Dade, or Tamiami Trail Next Steps projects, relative to the CERP Generation 1 and 2 projects? How can the Central Everglades Planning Project be expedited in the schedule? Some planners have expressed a strong desire to finish what was started in Generation 1 projects to show progress to the public and Congress. However, expediting key non-CERP projects could provide large benefits and complete important project dependencies for the Central Everglades Planning Project, which was specifically intended to halt ecosystem declines and expedite improvements in the condition of the remnant Everglades. Now that the four Generation 2 projects are authorized in WRRDA 2014, they will be competing for extremely limited funding under current fiscal pressures. With recent federal CERP expenditures of approximately $80 million/year (see Figure 4-2) and projected state spending of approximately $40 million/year on authorized CERP projects, the pace of progress on these projects will be slow if available funding is spread equally across all projects (see Table 4-4).

The current budget situation necessitates clear priorities for spending. As the state works to complete the Restoration Strategies project to address current water quality issues, federal funds and available state funds should be targeted toward CERP and non-CERP projects that will quickly avert current ecosystem declines and/or promise the largest potential restoration benefits, considering future climate change and sea-level-rise impacts. Until this point, CERP prioritization efforts have not explicitly considered the ecosystem condition and future benefits. Previously, with more-plentiful construction funding and few authorized projects, such difficult decisions were not necessary. But today's grim budgetary landscape requires a new CERP prioritization framework to avert ongoing ecosystem degradation and make the best use of currently available funding.

RESTORATION PROGRESS

In the following section the committee focuses on benefits emerging from the implementation of CERP restoration projects as well as from non-CERP foundation projects. The committee's previous report (NRC, 2012a) contains more extensive descriptions of the projects, and progress up to March 2012, while only progress over the last 2 years is described here. The South Florida Environmental Report (SFWMD, 2013a) and the 2012 Integrated Financial Plan (SFERTF, 2012) also provide detailed information about implementation and restoration progress. The 2014 System Status Report (RECOVER, 2014a; see Chapter 7) provides additional information on changing ecosystem conditions and discusses linkages to early project construction.

TABLE 4-4 Status of Project Expenditures and Estimated Funding Needs (in Millions) for Generations 1, 2, and 3 and Key Non-CERP Projects as of December 2013

Project Name	Total Estimated Costs	State Funding to Date	Federal Funding to Date	Estimated Funding Remaining for Completion
NON-CERP FOUNDATION PROJECTS				
Kissimmee River Restoration Project	780	345	315	120
C-111 South Dade Project	290	115	120	55
Modified Water Deliveries to Everglades National Park Project[a]	418	0.2	399	19
Restoration Strategies[a]	880	60	0	820
Non-CERP totals	**2,368**	**520**	**834**	**1,014**
1st GENERATION CERP PROJECTS				
Picayune Strand Restoration	618	162	317	139
Indian River Lagoon-South (Phase 1)	1,450	365	55	1,030
Site 1 Impoundment (Phase 1)	85	8	68	9
Melaleuca Eradication Project and Other Exotic Plants	25[b]	0.212	4.3	20.5[b]
2nd GENERATION CERP PROJECTS				
C-43 West Basin Storage Reservoir	570	90	35	445
Broward County WPAs	870	260	60	550
C-111 West Spreader Canal	85	64	12	9
Biscayne Bay Coastal Wetlands (Phase 1)	125	42	12	71
3rd GENERATION CERP PROJECTS				
Central Everglades Planning Project	1,750	4	31	1,715
Loxahatchee River Watershed Restoration	TBD	163	5	TBD
CERP Totals	**5,578+**	**1,158**	**599**	**3,989+**

NOTES:
[a] Not a 50-50 cost-shared project.
[b] Includes operations and maintenance funding for mass rearing, release, and field monitoring of biocontrol agents.

SOURCE: T. Morgan, SFWMD, and H. Gonzales, USACE, personal communication, 2013; M. Collis, USACE, personal communication, 2014; R. Johnson, DOI, personal communication, 2014; L. Gerry, SFWMD, personal communication, 2014.

Reportable restoration progress as a result of CERP and non-CERP projects occurs in three sequential steps: completion of project construction, physical system response (e.g., as a return of more natural hydrologic conditions or sheet flow), and changes in the biological system, including changes to individual species or ecosystem components. The physical and ecological responses are often assessed by monitoring-project-specific and systemwide performance measures (see RECOVER, 2007) and comparing the results to target values.

Construction for smaller projects takes place in a single phase, whereas more-complex projects have multiple phases, each of which can be assessed in terms of progress. Once construction is complete, most projects have their first effects by introducing new quantities of water, direction of flow, hydroperiods that are longer or shorter, or adjusted rates of change. The return of freshwater to some landscapes and saltwater to others may be an objective, and the return of sheet flow instead of highly concentrated confined flows is often essential to encouraging recovery of Everglades landscapes. Observations of restored hydrologic conditions are therefore the initial indicator of success for restoration projects.

The return of hydrologic conditions more similar to pre-drainage conditions sets the stage for the critical next step in observable restoration whereby plant and animal communities develop that are more similar to pre-drainage communities and less like those disrupted by water control infrastructure. After many months to several years, these changes can become a matter of quantitative record if there is routine monitoring using formal performance parameters. Continuous monitoring in the post-project period is essential in judging the success of the project, and the period of monitoring must be long enough to discern whether changes in performance measures are linked to the project rather than to other influences or to normal variability.

Most projects require several years to make the transition from the beginning of construction to the quantitative observation of desired ecological changes. However, this time frame, often of a few years to a decade, is fast relative to the several decades of disruption that have created the altered ecosystem that is the subject of Everglades restoration.

In the following sections, restoration progress is highlighted in four Generation 1, projects, two Generation 2 projects, and one Generation 3 project, for which construction has begun. Progress in three pilot projects and three non-CERP foundation projects is also discussed. The analysis that follows covers only those projects with substantial new developments or information on natural system restoration progress since the committee's last report (NRC, 2012a). A summary of all implementation progress as of May 2014, including developments in planning and authorization, is provided in Table 4-1. The location of the various projects is shown in Figure 4-1.

Generation 1 CERP Projects

Generation 1 projects are those authorized by Congress in WRDA 2007 (Picayune Strand Restoration, Site 1 Impoundment, and Indian River Lagoon-South) or by program authority (Melaleuca Eradication). Until June 2014, these were the only projects eligible for federal funding, while other projects awaited authorization.

Picayune Strand

The Picayune Strand, the first CERP project under construction, focuses on an area in southwest Florida substantially disrupted by a real estate development project that introduced 260 miles of roadway and 48 miles of major canals and drained 55,000 acres of wetlands before being abandoned (Figure 4-1, No. 5). The roads and drainage disrupted sheet flow into Ten Thousand Islands National Wildlife Refuge and altered regional groundwater flows in surrounding natural areas. The reduction of freshwater wetlands adversely affected habitat. These disruptions were especially important because Picayune Strand is surrounded by and contiguous with several other protected areas. Picayune Strand is particularly important as a habitat for white-tailed deer and feral hogs that serve as prey for the endangered Florida panther (USACE, 2011d; but see also Chapter 6 for a discussion of feral hogs as a troublesome invasive species). As of May 2014, the total anticipated cost of the project was $618 million (M. Collis, USACE, personal communication, 2014).

There has been considerable progress in constructing the Picayune Strand Restoration Project, with approximately $480 million expended to date on the project by the state and federal governments. The project components are summarized in Table 4-5 and the progress made to date in canal plugging, road removal, construction of pump stations, and other project elements (Figure 4-8). In late summer 2014, the USACE anticipates completing the Merritt Canal phase, which included construction of a pump station with associated spreader canal and levees, the plugging of 9 miles of canals, and removal of 95 miles of roads. Construction is currently under way on the Faka Union and Miller Canal project portions (see Table 4-5) (USACE, 2014c).

Despite this important progress, the Picayune Strand Restoration faces the prospect of halting construction because the costs of the project are expected to exceed the Section 902 limits.[5] Thus, the USACE is required to submit a limited reevaluation report to Congress for authorization (T. Morgan, SFWMD, personal communication, 2013). The timeliness of congressional reauthorization will determine when the project can be completed. There are no scientific or engineering impediments to project completion.

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[5] WRDA 2007 authorized the project with a budget of $375.3 million, and Section 902 of WRDA 1986 requires that projects seek reauthorization if costs increase more than 20 percent above the original authorized costs (exclusive of inflation).

TABLE 4-5 Phases and Progress of the Picayune Strand Project

	Lead Agency	Road Removal (mi)	Canals to Be Plugged (mi)	Other	Project Phase Status
Prairie Canal	State expedited project	65	7	Invasive vegetation removed, 17 culverts constructed, >13,000 acres of habitat enhanced	Completed in 2007
Merritt Canal	Federal	95	9	Remove invasive vegetation; construct Merritt pump station, ~14,000 acres of enhanced habitat	Construction began in 2010; anticipated completion in summer 2014
Faka Union Canal	Federal	100	0	Construct Faka Union pump station	Construction began in 2011; anticipated completion in 2015
Miller Canal	Federal	47	13	Construct Miller Canal pump station and spreader canal	Construction began in late 2013; to be completed in 2017
Southwestern protection and manatee mitigation features	State	0	0	Construct 9-mile levee for flood protection of adjacent lands and excavate manatee refugium to mitigate loss	Construction to begin in 2016, pending authorization of increased project cost
Canal plugging and road removal	State	86	16.5	Remove roads north of tie-back levee, plug Faka Union and east-west canals	Construction to begin in 2017; canal plugging must follow completion of manatee mitigation and southwestern protection features

SOURCE: L. Gerry, SFWMD, personal communication, 2013, 2014; USACE (2014c); M. Collis, USACE, personal communication, 2014.

Because one phase of the Picayune Strand Restoration Project (Prairie Canal) was completed in 2007, there has been sufficient time to collect and assess environmental data to determine what natural system benefits associated with the completed work have been observed. In a general observation, USACE (2014c) reports a resurgence of foraging wading birds (Figure 4-9) and native flora that have been absent for many decades. In areas where canals have been plugged, roads removed, and invasive plant species removed, freshwater wetlands have returned (Figures 4-9 and 4-10). Researchers have also reported detailed—but preliminary—results from multiyear monitoring efforts (Box 4-1). The most recent data are for late 2011, with the assessments completed in late 2013 focused

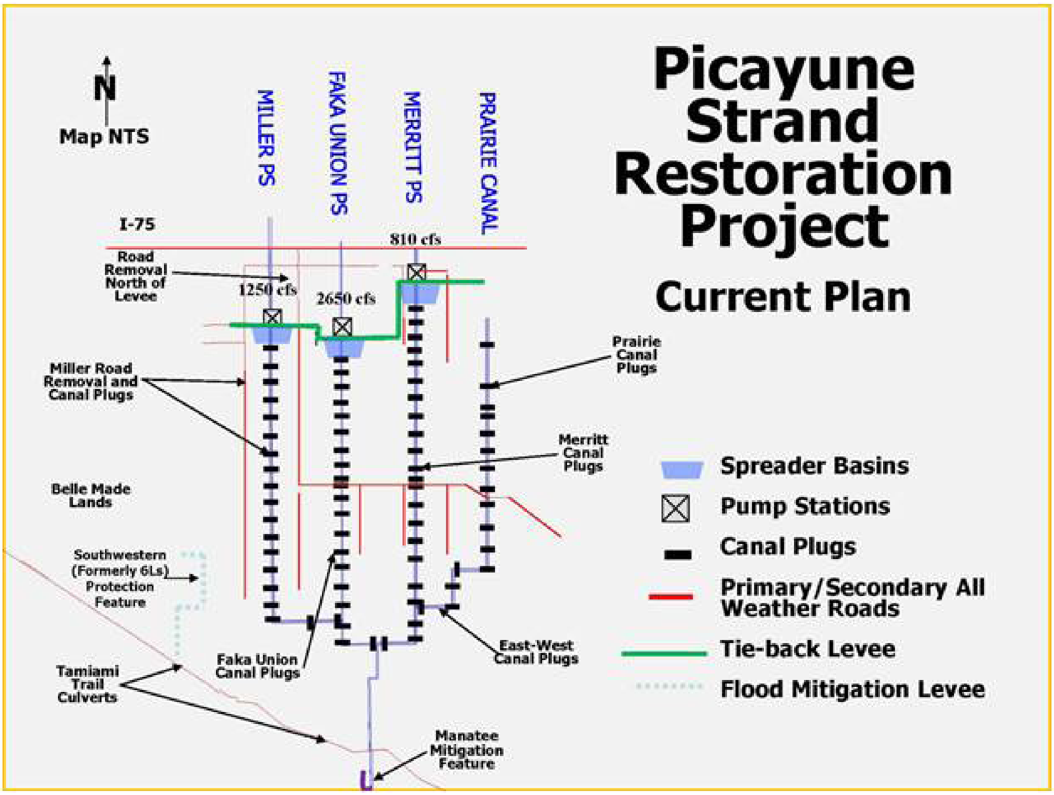

FIGURE 4-8 Picayune Strand Restoration features.

SOURCE: L. Gerry, SFWMD, personal communication, 2014.

on the Prairie Canal area, which had 4 years of post-project monitoring data (USACE, 2014c; RECOVER, 2014b).

These monitoring data show that the restoration of the Prairie Canal area is having clear positive effects on the area by adjusting water levels and hydroperiods toward pre-drainage conditions, although neighboring canals not yet filled by the project continue to affect the area hydrology. The data also show, however, that some biological components of the restored system are not yet experiencing major changes. There are two likely reasons. First, more time may be needed for the complex fauna and flora communities to adjust to new steady-state conditions. Everglades ecosystems may have a reaction time during which changes in controlling factors must work their way through the complexities of

FIGURE 4-9 Freshwater wetland in the Picayune Strand restoration area showing wading birds.

SOURCE: USACE (2014c).

FIGURE 4-10 Freshwater wetland in an area that was once a canal in the Picayune Strand restoration area.

SOURCE: USACE (2014c).

BOX 4-1
Analysis of Monitoring Results from 2007 to 2011 at Picayune Strand

The following outlines the natural system responses to the Prairie Canal features of the CERP Picayune Strand project:

Water levels: Water-level data from observation wells measured from 1987 to 2012 demonstrate the effects of plugging Prairie Canal. Although water-level fluctuations in the area have a complex history related to the management of the Picayune Strand area, prior to the Prairie Canal component of the restoration, water levels were 5-6 feet lower than the reference area in Fakahatchee Strand Preserve State Park. In the period after the completion of the Prairie Canal component of the restoration project, water levels have become similar to a relatively undisturbed reference area during the wet period of the year, but are still about 3.5 feet lower than the reference during dry periods. This shortcoming is probably related to the fact that the canal immediately to the west of the Prairie Canal is not yet fully plugged, so it affects its neighbor's water levels.

Hydroperiods: The number of days per year that water is at or above ground level (called the hydroperiod), has lengthened in the restored area despite droughts in 2007 and 2012.

Plant communities: Comparisons between 25 vegetation transects in the Prairie Canal restoration area with 11 transects in a relatively undisturbed reference area show that the restoration has so far resulted in little change in dominant tree species. In the restored area, cypress and pop ash growth rates are slower, and pine growth rates are faster than in reference areas. There have been no changes in densities of cabbage palm, considered a nuisance species in the Picayune area. Cypress plots in the restoration area also are developing plant assemblages that increasingly include wetland species, showing that the hydrologic restoration is supporting a more wetland-like community.

Aquatic macroinvertebrates: The restored areas had enough water to support aquatic macroinvertebrates, and 45 percent of the aquatic species in the restored areas were also found in the reference areas.

Fishes: Fish populations were generally similar between restored and reference sites, except that two indicator species, Everglades pygmy sunfish (*Elassoma evergladei*) and warmouth (*Lepomis gulosus*), were found only at reference sites.

Tree frogs: Indigenous species such as green and squirrel tree frogs were dominant at reference sites, whereas the exotic Cuban tree frogs were dominant in restoration areas.

Water quality: Decades of water quality data are available, and they reveal no areas of concern. Post-restoration data reflect no change and no water quality decline.

SOURCE: RECOVER (2014b).

the system which therefore does not respond immediately. Second, the restoration of the Prairie Canal area is still affected by its neighboring Merritt Canal area that was not yet restored during the 2007-2011 analysis period.

Site 1 Impoundment

The Site 1 impoundment project (also known as the Fran Reich Preserve; No. 6 on Figure 4-1) is in Palm Beach County at the junction of the southern tip of the Loxahatchee National Wildlife Refuge (LNWR, also known as Water Conservation Area 1 [WCA-1]) with the Hillsboro Canal. The project was originally cast as a single-phase effort to modify local hydrologic conditions so that more water could be stored to alleviate demands on water in LNWR. Without the project, during wet periods, runoff from LNWR is shunted to the ocean, while during dry periods, water is taken from the refuge to meet user demands elsewhere. With the Site 1 impoundment, water can be better managed to supply natural system demands within the LNWR. Project components included construction of a reservoir to store 13,300 acre-feet (AF) of water, a pump station, gated discharge culvert, spillway, and seepage control canal to retain more flows within the LNWR (USACE, 2013g; Figure 4-11). In 2009 the project was divided into two phases.

Construction of Phase 1 is under way, including the L-40 levee enhancements and seepage management measures, and is scheduled for completion by 2015 (L. Gerry, SFWMD, personal communication, 2014). Once these features are completed, designers anticipate a reduction in seepage loss from LNWR, but no natural system benefits can be reported at this time. Phase 2 of the project awaits congressional reauthorization necessitated by increased costs (NRC, 2012a).

Indian River Lagoon-South

The Indian River Lagoon and St. Lucie Estuary are biologically diverse estuaries located on the east side of the Florida Peninsula, whose ecosystems have been altered by polluted runoff from farmlands and urban areas and surges of freshwater (USACE, 2013d). These changes have reduced the abundances of many native species. The Indian River Lagoon-South project (Figure 4-1, No. 7) is designed to reverse this damage through improved water management, including the 56,000-AF C-44 storage reservoir, three additional reservoirs with a total of 97,000 AF of storage, four new stormwater treatment areas (STAs), dredging of the St. Lucie River to remove 7.9 million cubic yards of muck, and restoring 53,000 acres of wetlands, among other features (Figure 4-12). The project is anticipated to cost $1.45 billion (see Table 4-5).

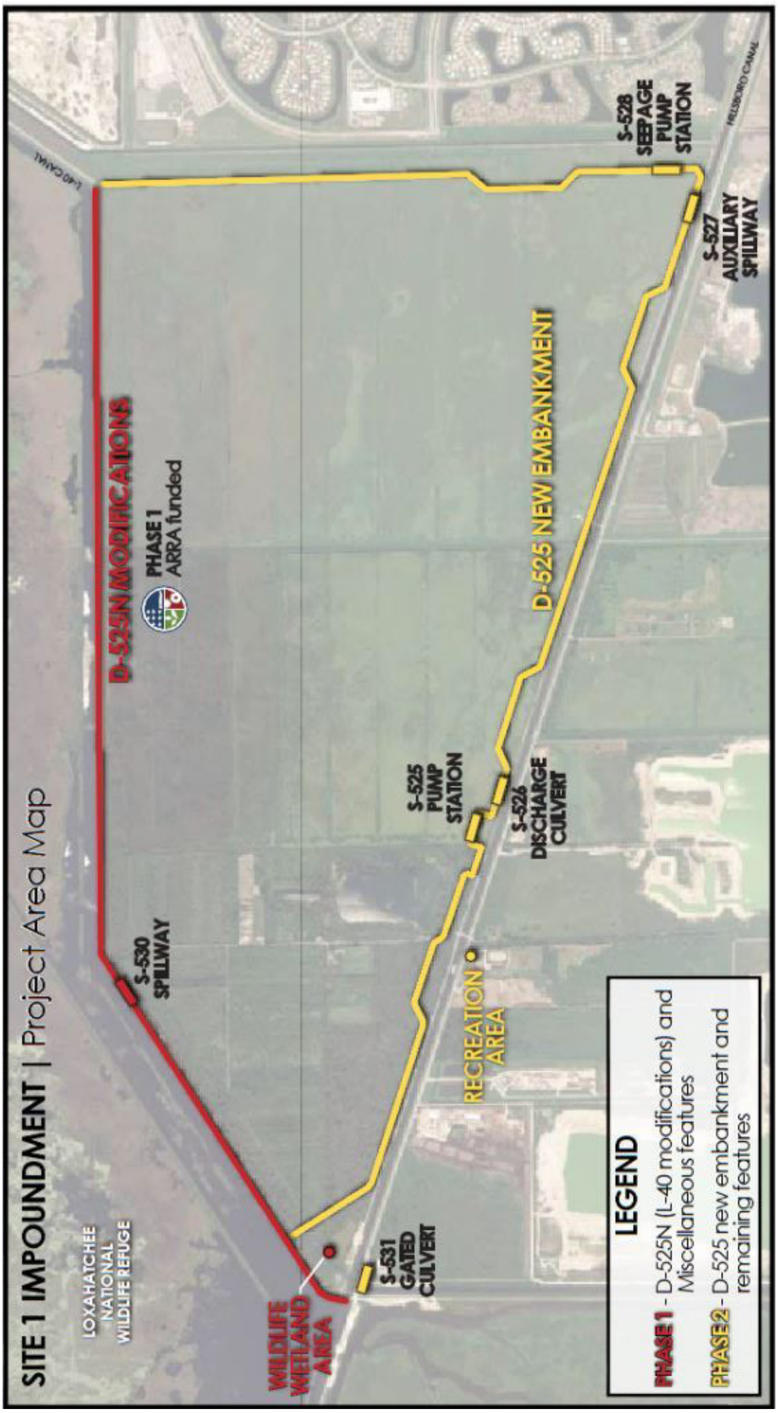

FIGURE 4-11 Phase 1 and 2 project elements of the Site 1 impoundment.

SOURCE: USACE (2013g).

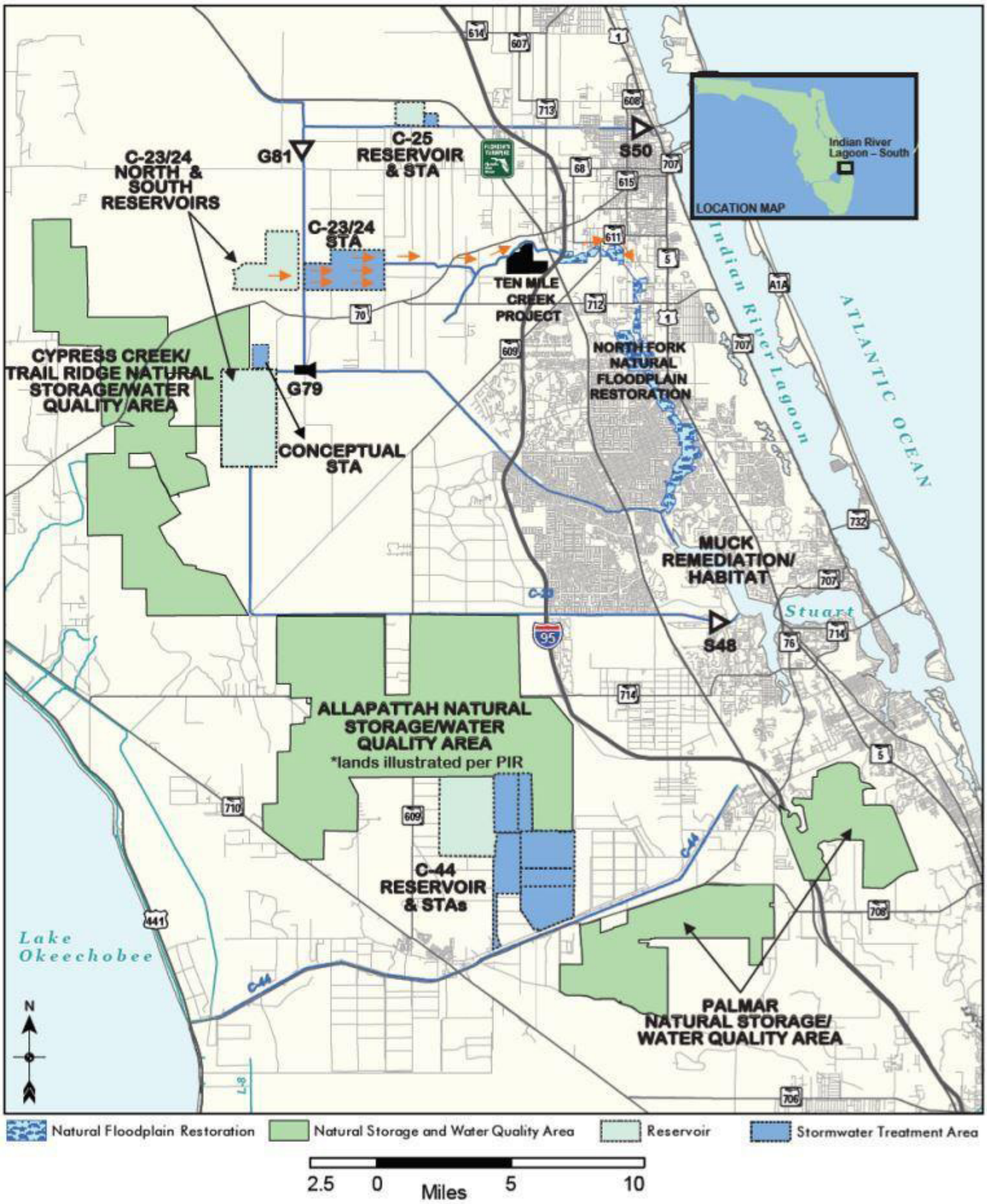

FIGURE 4-12 Components of the Indian River Lagoon-South restoration project.

SOURCE: USACE (2013d).

The Indian River Lagoon restoration project is just beginning. Preliminary work for the C-44 reservoir and associated 6,300-acre STA is under way, including an intake canal, access roads, culvert removal, and other improvements that are anticipated to be completed in summer 2014 (L. Gerry, SFWMD, personal communication, 2014). C-44 reservoir and STA construction is expected to begin in 2015, with an estimated completion date of 2020 for the C-44 reservoir and 2018 for the STA (H. Gonzales, USACE, personal communication, 2014). Additionally, operational changes have been made using existing water control structures to rehydrate the Allapattah Natural Storage Area (L. Gerry, SFWMD, personal communication, 2013). However, it is too soon to expect substantial restoration from this project based on the work completed to date.

Melaleuca Eradication and Other Exotic Plants

The Melaleuca Eradication and Other Exotic Plants Project is a CERP effort to address the potential threat to restoration posed by nonnative invasive plant species (see Chapter 6). Four invasive species that are particularly problematic are the focus of major ongoing management efforts: Melaleuca (*Melaleuca quinquenervia*), Brazilian pepper (*Schinus terebinthifolius*), Australian pine (*Casuarina* spp.), and Old World climbing fern (*Lygodium microphyllum*). A crucial part of this work is centered at the U.S. Department of Agriculture's Invasive Plant Research Laboratory in Davie, Florida, where specific biological control agents—mostly insects—are developed. With CERP funds, USDA has constructed a 2,700-ft^2 annex to the present laboratory to facilitate additional mass rearing (Figure 4-1, No. 8). The $4.5 million annex was completed in August 2013 and has been transferred to the local sponsor (USACE, 2014b; T. Morgan, SFWMD, personal communication, 2013). The project includes CERP operations and maintenance funding (estimated at $660,000/year) for mass rearing, release, and field monitoring of biocontrol agents to manage the spread of invasive nonnative plant species in the Everglades and South Florida (USACE and SFWMD, 2010). This project enables a more aggressive approach to biological control of invasive plants in the Everglades restoration area. It is too soon to document specific natural system benefits resulting from this CERP investment, although the expanded facility has increased the rearing capacity by 3- to 10-fold (P. Tipping, USDA, personal communication, 2014). Invasive species control in the Everglades is discussed in more detail in Chapter 6.

Generation 2 CERP Projects

Four second-generation CERP projects were authorized in June 2014 as part of WRRDA 2014 (Table 4-1). Although they had received no federal funding for construction at the time of authoring this report, in two cases—Biscayne Bay Coastal Wetlands and the C-111 Spreader Canal projects—the State of Florida has expedited construction in advance of federal authorization.

Biscayne Bay Coastal Wetlands

The Biscayne Bay Coastal Wetlands are along the southeastern edge of the Florida Peninsula; the Miami-Dade County area at the western edge of Biscayne Bay is a unit of the national park system (Figure 4-1, No. 10, and Figure 4-13). The installation of canals has cut off a section of the wetlands from their source of freshwater sheet flows resulting in a loss of wetland ecosystems and causing an increase in salinity along the margin of the bay. The project seeks to reverse these effects on 11,300 acres of the total 22,500 acres of wetlands by installing pump stations, spreader canals, culverts, and canal plugs.

The project is in two phases: Phase 1 is a stand-alone project encompassing three geographic areas (Deering Estates Flowway, Cutler Wetlands, and L-31 Flowway), and Phase 2, which is not yet specifically planned. The three components of the Deering Estates Flowway—a spur canal extension, spreader canal, and pump station—were completed and became operational in December 2012; the two culverts in the L-31E canal designed to divert flows into coastal wetlands were finished in June 2010. The work on Cutler Wetlands has not yet begun. To date, $54 million has been expended on the $125 million Phase 1 project (T. Morgan, SFWMD, personal communication, 2013), although the project increments implemented so far have been rather small in the context of the original project objectives.

The Biscayne Bay Coastal Wetlands Project has begun to show some ecosystem restoration results (Figure 4-14). Deering Estates Flowway, which includes 170 acres of degraded freshwater wetlands that transition to tidal wetland (USACE and SFWMD, 2012a), has been in operation for only a few months, so data are preliminary and may show more about short-term variability than long-term trends. Since the completion of the Deering Estates work, water flows have elevated seasonable water surfaces by about 2.7 feet in wetland areas. There have been some observed improvements of reduced salinity in the coastal wetlands and in the establishment of more natural salinity gradients (from freshwater in the wetlands to saline water in the bay). Although salinity of surface water in the nearshore responds to freshwater infusions from the new S-700 pump station, there are many other potential control mechanisms on salinity that must be sorted out with the aid of longer monitoring records. Vegetation communities were surveyed in 2009, and will be resurveyed in 2015 (RECOVER, 2014a). The L-31E culverts have diverted approximately 3 percent of the canal flow in water years 2012 and 2013 into the adjacent coastal wetlands. Routine maintenance inspections

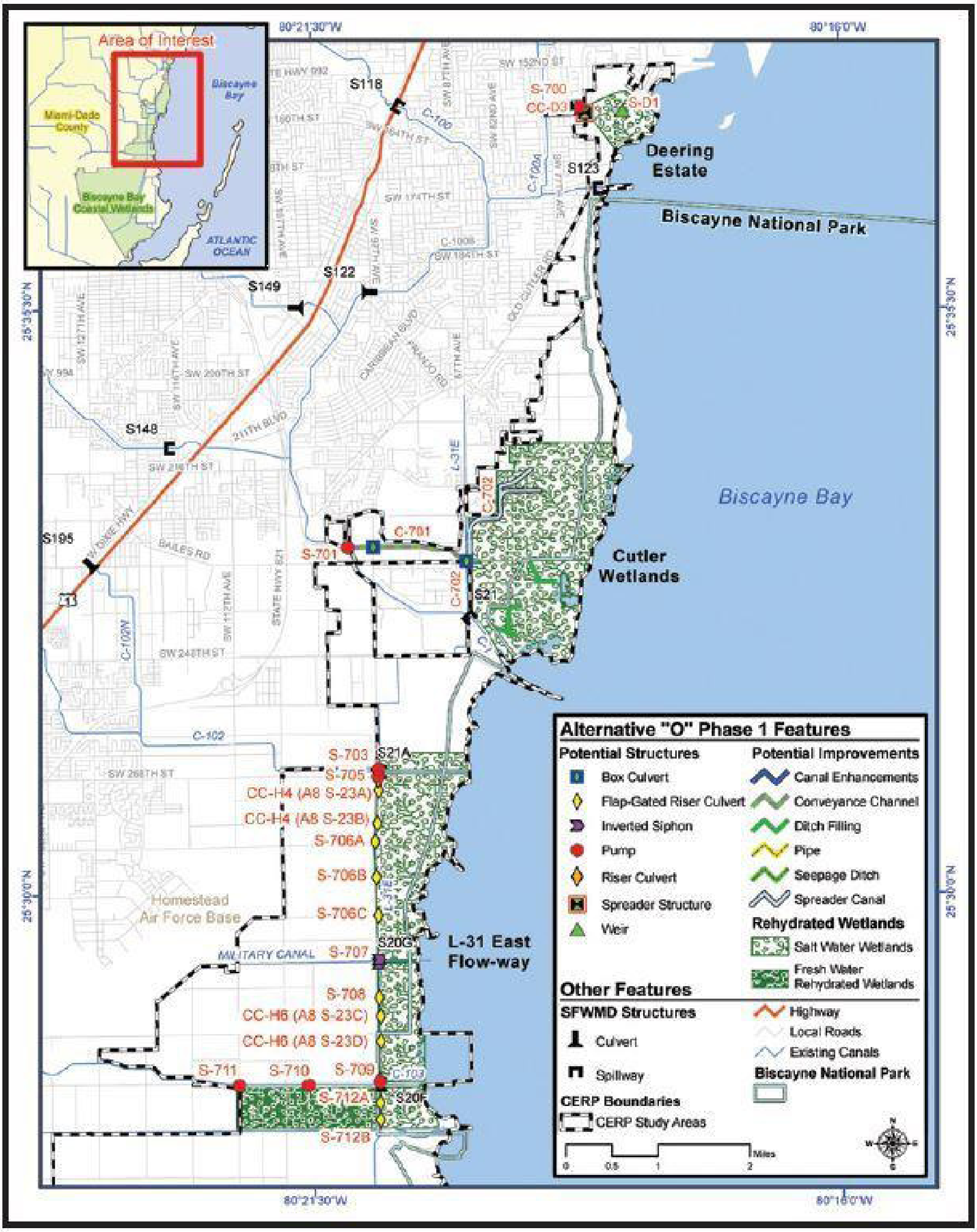

FIGURE 4-13 Biscayne Bay Coastal Wetlands project area in southeast Florida.

SOURCE: USACE (2014a).

FIGURE 4-14 Pump house and planted wetland vegetation at Deering Estate Flowway, Biscayne Bay Coastal Wetlands. The hydrated surface with wetland vegetation replaces a dry surface without wetland vegetation.

SOURCE: Courtesy of the Deering Estate at Cutler and Brian F. Call Photography.

established that accumulation of aquatic vegetation, sediment, and silt hindered the performance of the L-31E culverts. The SFWMD removed accumulated downstream sediment, realigned downstream sumps and pipe inverts, and installed floating debris barriers across the mouth of each culvert inlet channel. This task was completed in August 2012 and has shown local improvements to the system.

Monitoring data for nearshore salinity show no trends related to completion of the L-31E feature. Vegetation communities are, however, showing some adjustment in the post-project period with a minor decrease in areal coverage of red mangrove overall and an increase in sawgrass on the estuarine side of the L-31E levee (RECOVER, 2014a). These minor or negligible results are consistent with the low volume of diverted flows in 2012-2013.

C-111 Spreader Canal

The C-111 canal (Figure 4-1, No. 9) is the southernmost canal for the entire Central and Southern Florida Project. Designed to provide drainage and an outlet for confined flood flows, the C-111 also eliminated sheet flow from the Southern Glades and drained water from Taylor Slough in Everglades National Park. The C-111 Spreader Canal project promises increased flow volumes in Taylor Slough through seepage control, return of sheet flow to wetlands, and improved salinity regimes in western Florida Bay. The project complements the ongoing C-111 South Dade Project (see Box 2-1), which has related project objectives. The

C-111 Spreader Canal project is structured in two phases, with the first phase (Western Project) to include two pumping stations, a 560-acre detention basin (the Frog Pond), along with various canal modifications for the Aerojet, L-31, and C-110 canals (Figure 4-15). The C-111 Spreader Canal Western Project is critical to the restoration of Taylor Slough in Everglades National Park and Florida Bay and was largely completed in February 2012 as described in NRC (2012a) and USACE (2013b) and is now operational.

Some quantitative assessments of project effects on natural system hydrology are available. For example, during the wet season of its first year in operation, from June through mid-November, the project moved an average of 811 AF per day (a total of about 140,000 AF) from the C-111 canal and transferred it

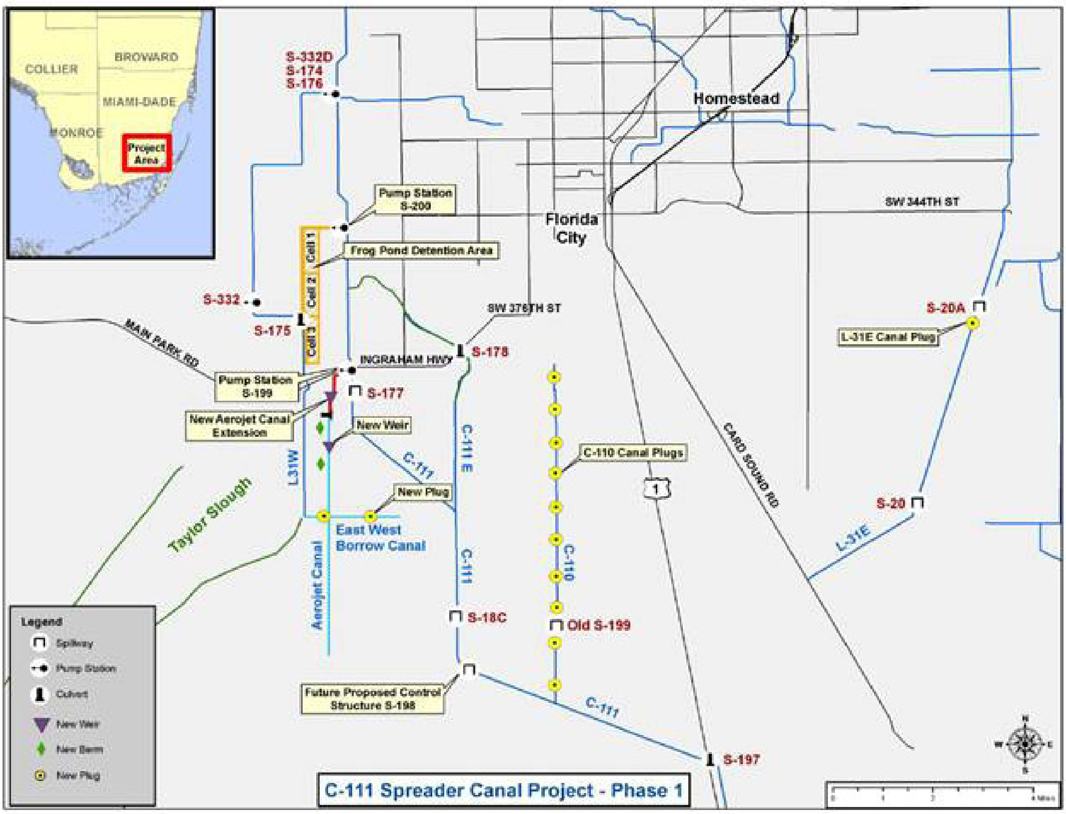

FIGURE 4-15 Project design features for C-111 Spreader Canal Western Project.

SOURCE: SFWMD (2013a).

to the Taylor Slough area of Everglades National Park (Audubon Florida, 2014). Taylor Slough now carries more water than prior to the completion of the C-111 Spreader Canal project. Taylor Slough now is wet 10 months out of the year rather than 3 months per year before the restoration efforts (Fleshler, 2014).

Recent research published in the refereed literature establishes some hydrologic improvements from the C-111 project. Kotun and Renshaw (2013) examined hydrologic data for the C-111 canal and for Taylor Slough and found that specific improvements were observed in the Taylor Slough hydrology between 2000 and 2010 when C-111 South Dade projects were in operation. Water surface level was maintained in the canal at heights above the surrounding terrain for 6 months each year, contributing to a hydrologic seepage barrier effect. Their data showed that a groundwater mound developed under the canal as expected, an approach to keep water in the slough and prevent its migration eastward. They also found that the hydroperiod in the Rocky Glades near Taylor Slough had been lengthened 90 days.

Ecosystem benefits are difficult to assign to a single restoration project. An important complication in interpreting the changes is that it is difficult to separate and identify benefits from the C-111 Spreader Canal project from the benefits of the closely related C-111 South Dade project. The C-111 South Dade detention areas, also designed to rehydrate Taylor Slough, were completed in 2009, and improvements in flows in Taylor Slough are likely to be connected to that project. Benefits from the ongoing C-111 Spreader Canal project are likely to be smaller but result in some additional flow in Taylor Slough (R. Johnson, NPS, personal communication, 2014).

Generation 3 Projects

Third-generation projects are near-term priorities, but they do not yet have a USACE-headquarters-approved PIR. Until congressionally authorized, implementation of these projects could only occur if expedited with state funding. Restoration efforts are under way on one third-generation CERP project—Loxahatchee River Watershed Restoration.

Loxahatchee River Watershed Restoration

The Loxahatchee River Watershed Restoration Project is a CERP project that has been expedited by SFWMD investment (Figure 4-1, No. 15; USACE and SFWMD, 2013c). The purpose of the project, located in the southern headwaters of the Loxahatchee River and north of LNWR (WCA-1), is to rehydrate several thousand acres of wetland habitat that has been desiccated by artificial drainage, provide restoration flows to the Northwest Fork Loxahatchee River, and address saltwater intrusion. Although development of the PIR is still ongoing, the SFWMD has expedited installation of culverts and control structures leading to Loxahatchee Slough (Flowway 1) to raise water levels and lengthen periods of inundation, measures that affect about 5,000 acres (Figure 4-16). As of 2013, Martin County, a local sponsor partner, was implementing invasive species control efforts and construction of water control structures in the Cypress Creek (Flowway 3).[6] Other partners in addition to SFWMD include Palm Beach County, the Loxahatchee River District, Florida Department of Environmental Protection, and the Florida Park Service. The river is a federally designated Wild and Scenic River, one of only two in Florida. Restoration related to the Loxahatchee River Watershed includes attempts to improve downstream areas all the way to the ocean, including the construction of 5.8 acres of new oyster habitat and refined operations of control structure S-46. Since 2011, releases of water to the northwest fork of the Loxahatchee River have reduced periods of low flows, attenuated high flows in the southwest fork, and reduced damaging high variability in salinity at the river mouth. The initial restoration steps under the Loxahatchee River Watershed CERP Project have not yet led to significant effects on the overall watershed behavior (Loxahatchee River District, 2013).

CERP Pilot Projects

Pilot projects are limited efforts designed to provide scientific or engineering knowledge that can be applied to improve major projects that result in natural system benefits. Additionally, pilot projects may inform larger projects to make them more timely and cost-effective. Pilot projects provide the opportunity to experiment with methods and approaches without the large expense of fully developed restoration projects. Below, we briefly review the Aquifer Storage and Recovery, Decomp Physical Model, and Seepage Management pilot projects.

Aquifer Storage and Recovery

Everglades restoration relies on increasing freshwater storage. In the CERP, aquifer storage and recovery (ASR) was proposed as the largest contributor to new storage, with more than 300 ASR wells providing up to 1.7 billion gallons of freshwater storage per day (or 500,000 AF/yr; USACE and SFWMD, 1999). Implementation of ASR in the Everglades would involve pumping excess surface water into the Floridan Aquifer system and recovering this stored water during dry periods to sustain freshwater flows (Figure 4-17). ASR is an established

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[6] See http://xportal.sfwmd.gov/paa_dad/docs/F1077773745/32_Loxahatchee%20Storage%20-%20Barnett.pdf.

FIGURE 4-16 Restoration progress in the Loxahatchee Watershed from 2002 (top) to 2013 (bottom), showing the transition from upland species to more wetland species due to increased periods of inundation.

SOURCE: Palm Beach County Environmental Resources Management.

technology, but it had not been widely tested in South Florida. Therefore, the CERP ASR Pilot Project was conducted to address uncertainties and concerns regarding the efficacy and feasibility of ASR, particularly given the high costs of its implementation at the scale proposed by the CERP. The final report summarizing the findings of this 14-year pilot project was released in December 2013 (USACE and SFWMD, 2013a).

The CERP ASR Pilot Project focused on construction, operation, and monitoring of two facilities. The Kissimmee River ASR was built along the Kissimmee River, near its confluence with Lake Okeechobee, while the Hillsboro ASR was constructed along the Hillsboro Canal in southern Palm Beach County (Figure 4-1). The objectives of these pilot studies were to (1) assess ASR feasibility at two locations distinguished on the basis of surface-water chemistry, hydrogeologic conditions, and surface-water distribution configurations; (2) evaluate technical and regulatory compliance issues stemming from ASR operation; and (3) quantify operation costs. The final technical data report describes, in considerable detail, the various elements of these pilots, including planning and

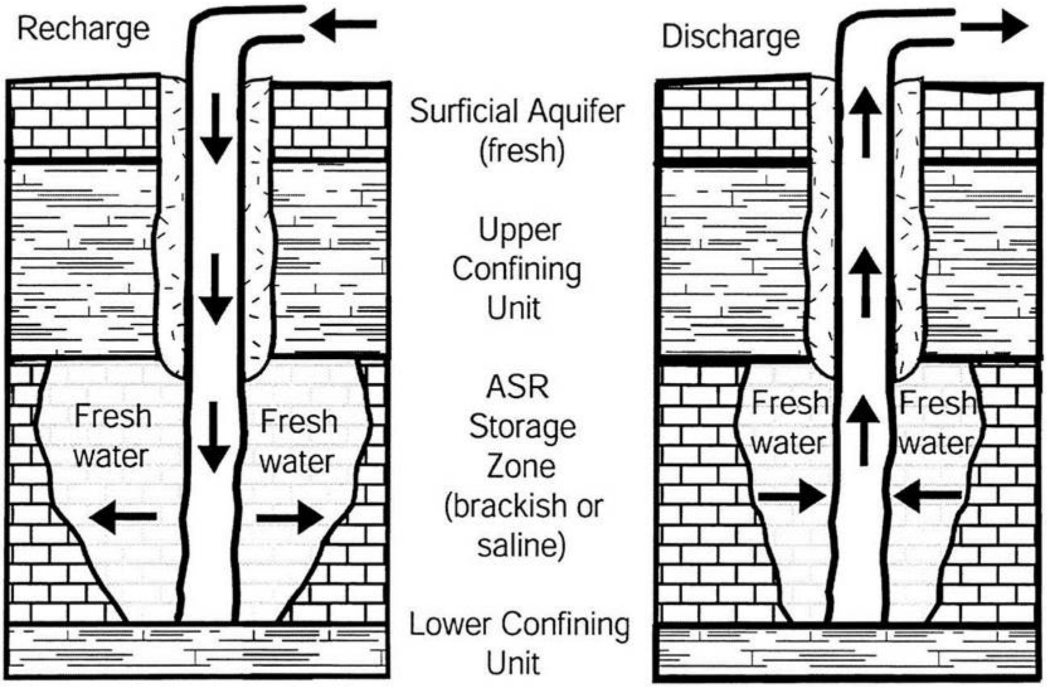

FIGURE 4-17 Schematic diagram of the recharge and recovery phases of ASR for a typical South Florida system.

SOURCE: NRC (2001).

permitting, system design and construction, groundwater hydrogeology, regulatory compliance, surface-water and groundwater quality testing, and ASR system costs (USACE and SFWMD, 2013c).

Both ASR pilot systems were operated for multiple recharge-storage-recovery cycles, with each cycle increasing in length and thus volume of water stored. More than 1 billion gallons of water were stored for a 1-year period during the fourth cycle test of the Kissimmee River ASR pilot, making this test one of the largest single-well recharge events conducted in Florida.

Findings from the pilot projects are generally encouraging from the standpoint of operational efficacy, and most problems that emerged during cycle testing were resolved. Recoveries of stored freshwater were approximately 100 percent for the four cycle tests at Kissimmee River, but were lower (21 to 85 percent) during the three cycle tests of the Hillsboro ASR pilot, owing to mixing with brackish formation water. Water quality analyses revealed that the recharge waters at both facilities were in compliance with respect to all primary constituents except total coliforms. Total coliforms were detected in both the Kissimmee River and Hillsboro ASR wells in excess of the 4-CFU/100 mL criterion, suggesting that the ultraviolet disinfection systems used to treat the surface water prior to injection were insufficiently effective. Analysis of groundwater collected from storage-zone monitoring wells indicated that arsenic concentrations exceeded the 10-μg/L criterion at both facilities. Arsenic concentrations peaked during the first cycle test, but, at both facilities, fell to permissible levels prior to the onset of the next cycle test. Measurements of pressure made within the ASR wells during freshwater recharge remained below 70 psi, which is less than the pressure necessary to induce hydraulic fracturing.

The final construction costs differed significantly between the two ASR pilot projects. The costs of the surface facility, ASR well, and monitoring wells at Kissimmee River equaled $7.9 million, while the costs of these components at the Hillsboro ASR facility equaled $4.3 million. Operational costs ranged from $104 per million gallons of water during the recovery phase at the Hillsboro facility to $401 per million gallons of water during the recharge phase at the Kissimmee River facility. Labor and electric power represented the greatest portion of operational costs. The lessons learned through implementation of these pilot projects should improve planning, design, and operational efficiency which, in turn, should lower costs as more ASR systems are deployed.

Several issues deserving attention were identified through analysis of the ASR pilots. For example, improved approaches must be adopted to disinfect recharge water, and the supervisory control and data acquisition system requires further refinement. Aside from these sorts of existing issues, additional challenges will be encountered as new ASR facilities are constructed and operated on sites that differ with respect to water quality, geological properties, and hydrologic conditions. Nevertheless, these pilot studies have provided evidence that ASR is a technically feasible approach for increasing freshwater storage in the Everglades, and the report provides cost data that allow planners to compare ASR against other available storage alternatives (NRC, 2005).

A report on the regional effects of multiple ASR wells in the Everglades is anticipated in 2014. This regional-study report is likely to address several outstanding issues that are needed to evaluate the feasibility and appropriateness of large-scale implementation of ASR within South Florida. These issues include, but are not limited to, overall costs for construction, operation, and monitoring; systemwide energy demands associated with the conveyance and treatment of large volumes of water; and the potential effects of large-scale ASR operations on regional groundwater flow patterns, water supply, and water quality.

Decomp Physical Model

The Decomp Physical Model (DPM) is a large-scale field experiment intended to inform project planning decisions by reducing uncertainty about the ecological effects of various options for restoring sheet flow to the ridge-and-slough landscape. The experiment involves measuring biophysical responses to canal and levee modifications and is intended to address the following questions:

- **Sheet flow questions**: To what extent do entrainment, transport, and settling of sediments differ in ridge-and-slough habitats under high- and low-flow conditions? Does high flow cause changes in water chemistry and consequently changes in sediment and periphyton metabolism and organic matter decomposition?
- **Canal backfill questions**: Will canal backfill treatments act as sediment traps, reducing overland transport of sediment? Will high flows entrain nutrient-rich canal sediments and carry them into the water column downstream? To what extent are these functions altered by the various canal backfill options, including partial and full backfills?

The DPM experiment is being conducted between L-67A and L-67C, in an area near the border of WCA-3A and WCA-3B known as the "the pocket" (Figure 4-18). In preparation for the experiment, 10 gated culverts on the L-67A canal (S-152, shown in Figure 4-18) were built. A 3,000-ft gap in the L-67C levee and three backfill treatments in the adjacent canal were completed in October 2013. The canal was left completely open for the northernmost treatment, while the center and southernmost treatments have partial and complete backfills, respectively.

A pulse-flow experiment was initiated on November 5, 2013, by opening the 10 gated culverts that make up S-152. This allowed water from the L-67A canal to enter the marsh and flow in a southerly direction toward the 3,000-ft gap in the L-67 levee and portions of the adjacent canal that remain open or have been partially or completed backfilled. Analysis of initial results from a dye-tracer release suggests that surface-water velocities within the slough increased several-fold, exceeding 3 cm/s in some locations (Figure 4-19). These hydrologic changes are, in turn, expected to affect sediment entrainment, transport, and deposition, which are processes believed to be instrumental in the maintenance and formation of Everglades ridge-and-slough topography. The pulse flow was maintained for 2 months, and two additional pulses are planned in 2014 and 2015 (F. Sklar, SFWMD, personal communication, 2014).

An extensive suite of measurements are being made during the experiment to characterize the spatiotemporal variability in surface-water depth and velocity,

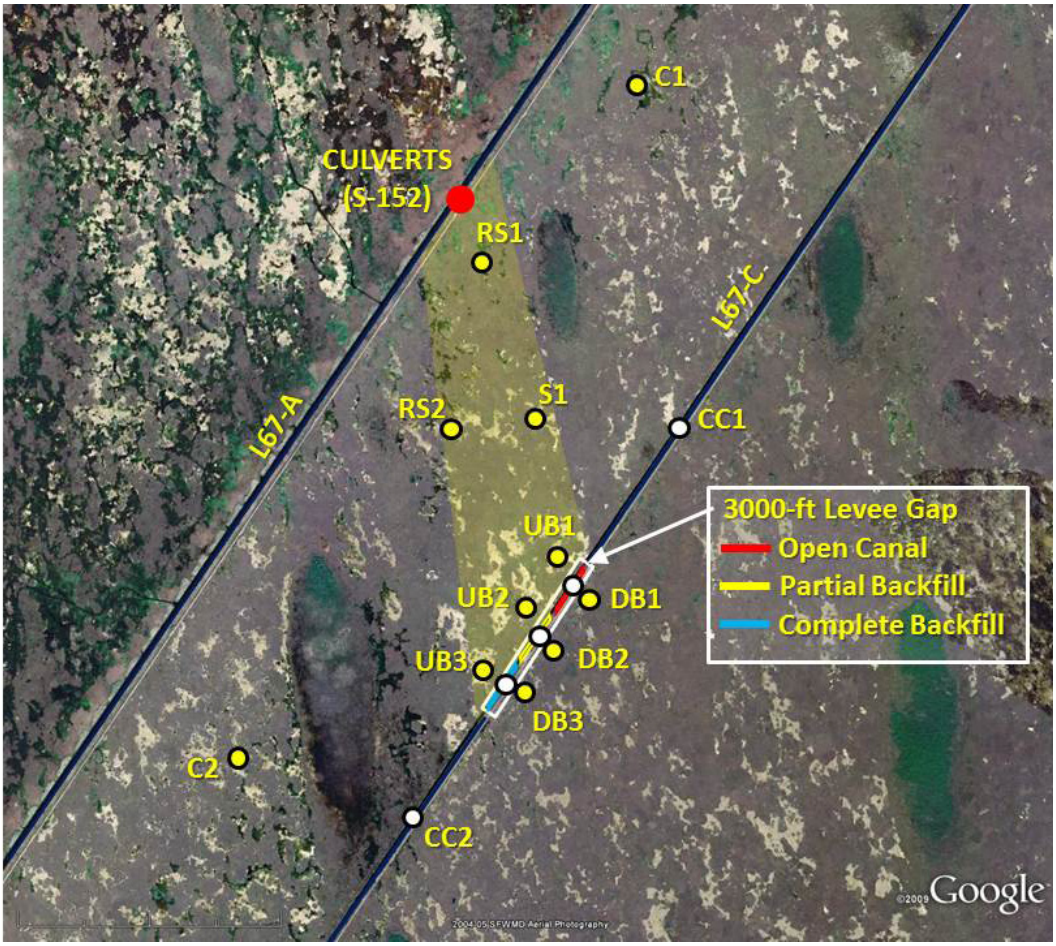

FIGURE 4-18 Map of the Decomp Physical Model located in "the pocket" between L-67A and L-67C.

SOURCE: Sklar (2013).

sediment transport in the marsh, sediment accumulation and entrainment rates in the L-67C canal, surface-water chemistry, and suspended-sediment composition. Observations of fish, macroinvertebrate, and amphibian density are also being taken in coordination with measurements of vegetation structure. The physicochemical and ecological measurements being made during the experiment will be compared with baseline data that have been collected since 2010, prior to the beginning of DPM construction. Analysis of the data will require

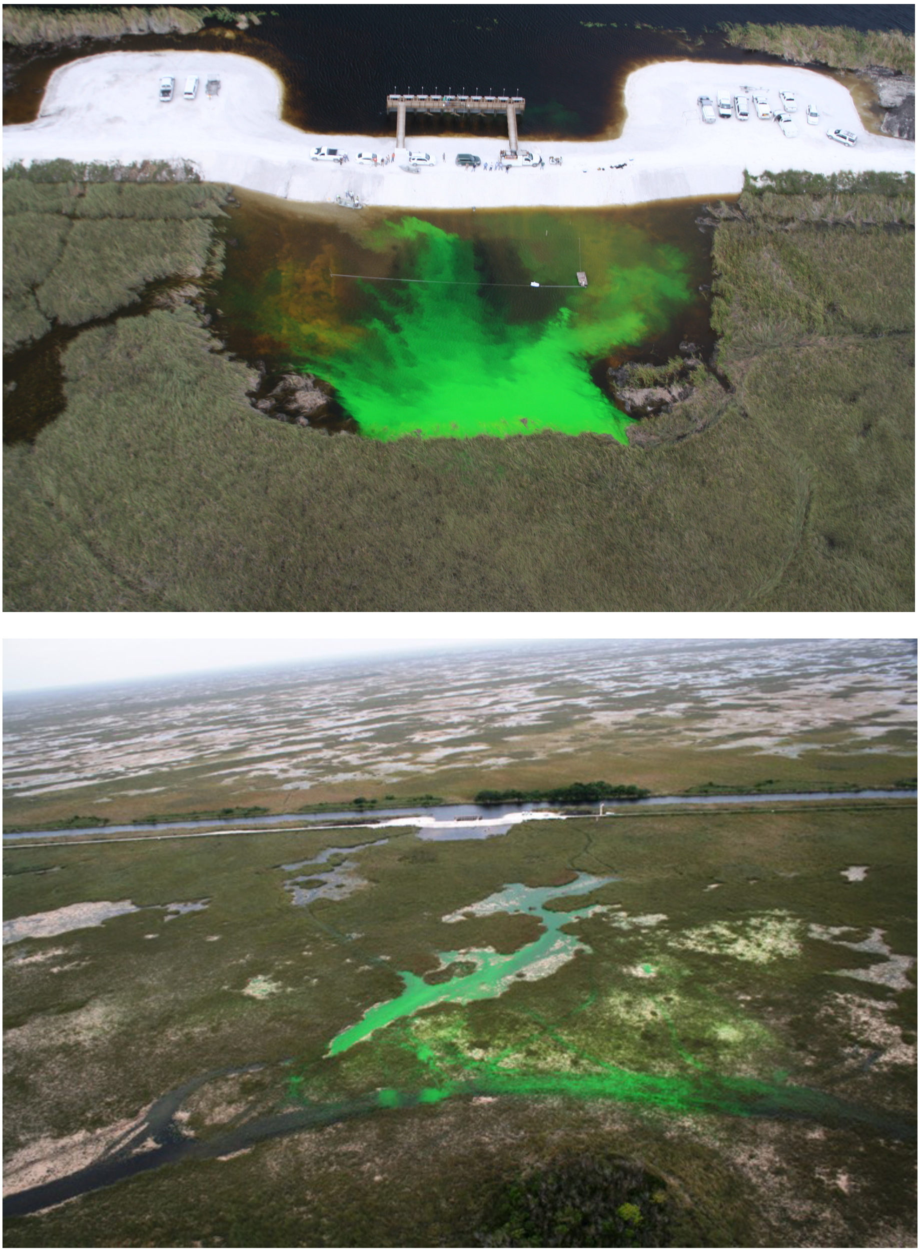

FIGURE 4-19 Distribution of fluorescein dye within the ridge and slough at 1 hour (top) and 1,300 hours (bottom) after its release into the open water at a point adjacent to S-152.

SOURCE: F. Sklar, SFWMD, personal communication, 2014.

several months, but the project scientists should begin reporting preliminary results in spring 2014.

Seepage Management

Seepage, when used in context of the CERP, generally refers to groundwater movement. Seepage management involves regulating the exchange of groundwater between compartmentalized areas of the Everglades that are separated from one another by canals and levees. Groundwater and surface-water reservoirs of the Everglades are hydraulically connected. Therefore, management of groundwater seepage affects surface-water hydropatterns, and conversely, manipulation of surface-water levels in canals and impoundments through operation of control structures affects the magnitude and direction of groundwater seepage.

Seepage management has focused most intensively on the north-south boundary separating the remnant Everglades from isolated pockets of agricultural land and large urban areas that have sprawled inland from the Atlantic Coast. Plans to manage seepage across this boundary have not escaped controversy. Restoration relies on holding water within the Everglades and thus lowering groundwater seepage compared with current levels. However, too much seepage control would lower the hydraulic heads within the region's drinking-water well fields, making them susceptible to saltwater intrusion. Others express concern that restricting seepage from the Everglades would reduce freshwater flows to Biscayne Bay. Thus, understanding seepage management strategies is critical to meeting these multiple objectives as well as the Savings Clause in WRDA 2000, which mandated that the CERP not impact existing water supplies.

The most progress on understanding seepage management can be traced to a non-CERP project that is being privately funded by the Limestone Products Association in exchange for wetland mitigation credits. This pilot project centers around the construction of a 2-mile-long seepage barrier. The barrier extends south of Tamiami Trail between the north-south trending L-31 Levee and L-31N Canal (Figure 4-20). The hydrology of this area is dominated by the L-31N Canal, which cuts through the exceedingly permeable bedrock of the Miami Limestone Formation and into the top layers of the Fort Thompson Formation. During the wet season in particular, the L-31N Canal diverts groundwater, drawn primarily from the northeastern portion of Everglades National Park, to the C-111 basin in south Miami-Dade County. The seepage barrier is intended to reduce this groundwater discharge to the L-31N Canal, thereby increasing water levels and promoting greater sheet flow in northeast Shark River Slough.

The 2-mile seepage barrier was completed on time in July 2012, only 5 months after excavation began. Construction of the barrier was an impressive

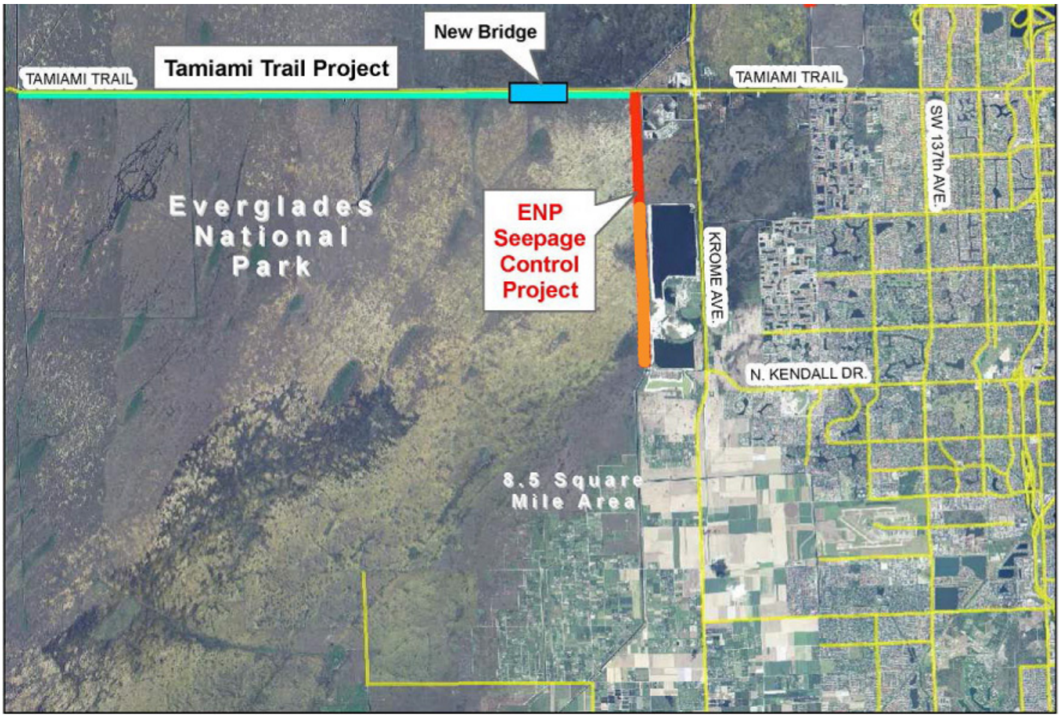

FIGURE 4-20 Position of the 2-mile-long, 35-foot-deep seepage barrier (shown in red), west of the L-31N Canal. The orange line represents a possible 3-mile extension of the project.

SOURCE: MacVicar (2014).

technological feat and involved excavating a 32-inch-wide trench to a depth of 35 feet below ground surface using a bedrock trenching machine that resembled a giant chain saw.[7] The trench was filled with a concrete-bentonite slurry formulated specifically for this application.

The performance of the L-31N seepage barrier is being evaluated through an ongoing monitoring program including automated measurements of hydraulic head in six pairs of groundwater monitoring wells. The four, northernmost pairs consist of wells on the upgradient and downgradient sides of the seepage barrier. The two, southernmost pairs of monitoring wells are positioned at control sites beyond the terminus of the seepage barrier. The groundwater measurements are

[7] See http://www.l31nseepage.org/.

supplemented by stage and velocity measurements made at five locations along the L-31N Canal. Measurements of changes in discharge along the canal are used to estimate groundwater seepage into L-31N.

Hydrologic conditions have been monitored for 20 months since completion of the construction of the seepage barrier. The hydrologic measurements reveal that groundwater hydraulic heads have responded to installation of the seepage barrier. Moreover, the data demonstrate that the subsurface barrier is lowering rates of groundwater seepage from Everglades National Park into the L-31N Canal (Figure 4-21). The observed reductions in seepage approximate those predicted by a groundwater flow model developed to inform the design of this pilot project. Based in part on these encouraging observations of seepage reduction, Everglades National Park is supporting a proposal for a 3-mile southward extension of the seepage barrier that is currently under review by the Lake Belt Committee (Figure 4-20; R. Johnson, NPS, personal communication, 2014).

The LPA seepage management pilot provides a good example of incremental adaptive restoration, by providing tangible increments of restoration while

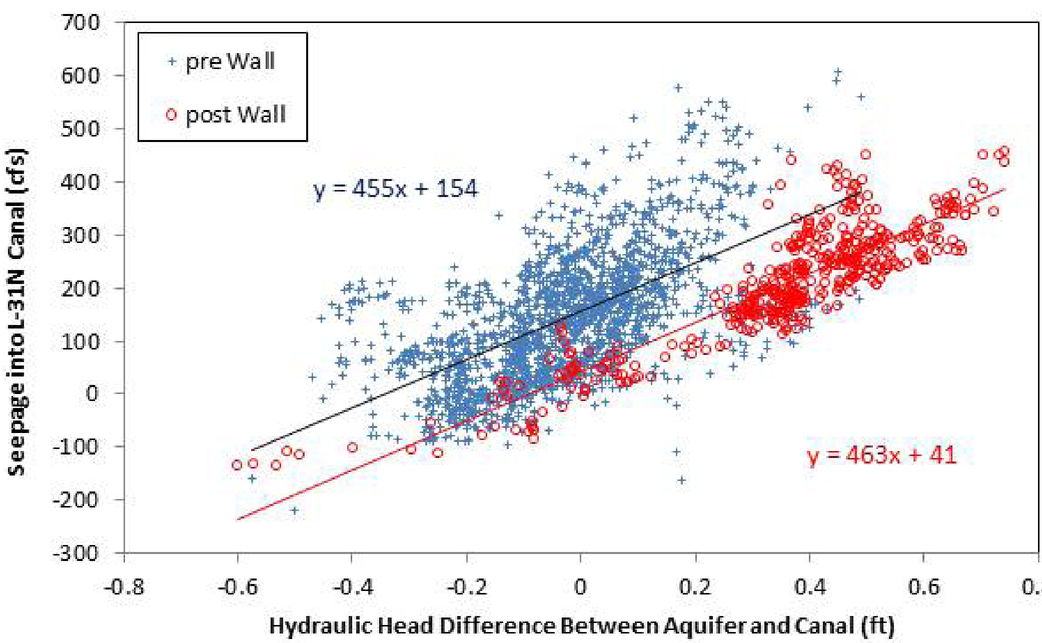

FIGURE 4-21 Reduction in groundwater seepage into L-31N Canal due to presence of seepage barrier.

SOURCE: MacVicar (2013).

working to resolve questions that prevent implementation of the full-scale project (NRC, 2007). The project also appears to offer the potential for substantial seepage management at little to no CERP cost.

Non-CERP Projects

CERP projects are not the only restoration efforts ongoing in the Everglades region. Several non-CERP projects are critical to the overall success of the restoration program, and their progress directly affects CERP restoration progress. Four important non-CERP efforts with new information on their restoration progress are reviewed in this section: the Modified Water Deliveries Project, the Everglades Restoration Transition Plan, the Kissimmee River Restoration Project, and the Seminole Big Cypress Water Conservation Plan. Progress on the C-111 South Dade project was discussed previously in the context of the related CERP C-111 Spreader Canal project.

Modified Water Deliveries and the Tamiami Trail Bridge

Congress provided legislative authority in 1989 for the creation of a project to improve water flows into Everglades National Park, where Everglades microtopography and vegetation were in decline as a result of lack of sufficient inflows. In 1992 the General Design Memorandum for the Modified Water Deliveries to Everglades National Park Project (Mod Waters; USACE, 1992) envisioned several features to increase the flow of water from WCA-3 into Everglades National Park to accommodate flows up to 4,000 cubic feet per second (cfs). The memorandum also provided mitigation of the effects of those flows for the 8.5-square mile area (an area of private development and residences), and the establishment of conveyance and seepage control measures (NPS, 2012; USACE, 2011c). Proposed plans to reach these original project goals have varied over time (for more details on the complex history of the Mod Waters project, see NRC, 2008), but there now appears to be general agreement on the steps necessary to complete the Mod Waters project.

As of December 2013, significant portions of the Mod Waters project have been completed. Protection for the 8.5-square-mile area is substantially complete, and many of the planned conveyance and seepage control features have been constructed (USACE, 2013a), including installation of the S-355A and B gated structures in the L-29 levee, S-333 modifications, four of nine planned miles of reduction for the L-67 Extension levee, installation of the S-356 pump station, and raising the Tigertail Camp (a tribal residential area). A central feature of the Mod Waters project—improved conveyance across the Tamiami Trail—is now partly complete with the construction of the 1-mile eastern bridge (Figure 4-22) and the completion of raising the roadbed to accommodate higher canal stages.

The completion in March 2013 of the 1-mile bridge is a major step in restoration of the hydrology and ecology of Shark River Slough in Everglades National Park. The bridge and the raising of the remainder of the roadbed allows for increased elevations in the L-29 canal, immediately north of Tamiami Trail. These higher levels provide an increased head (height differential between the canal surface in WCA-3B and Shark River Slough in Everglades National Park) that results in peak flows of 1,848 cfs into the park, an increase of 47 percent over

FIGURE 4-22 The newly constructed 1-Mile Tamiami Trail bridge, showing conveyance area beneath the newly elevated highway.

SOURCE: R. Johnson, NPS, personal communciation, 2014.

pre-bridge conditions, although still well below the original goal of 4,000 cfs (NPS, 2012). The Next Steps project, directed by the National Park Service, has completed an environmental impact statement with a plan to support up to a total of 5.5 miles of additional bridging. The Park Service is presently working on planning and design for the next bridge, about 2.6 miles long (DOI, 2013). In August 2013, Governor Scott announced a commitment of $90 million in state funds for a 2.6-mile bridge to match federal funding to reach the total cost of $180 million (Scott, 2013).

There are several unfinished features of Mod Waters and unresolved issues, however, that must be addressed before the project can be operated to deliver ecosystem benefits. Some features in the protection of the 8.5-square-mile area remain unfinished, and land acquisition and easement issues must be resolved to complete the project. Additionally, an operations plan must be developed, and operation of the project is dependent upon completion of an unfinished contract of the C-111 South Dade project, which has been stalled over cost-sharing disagreements. Finally, water quality concerns regarding compliance under Appendix A of the Consent Decree must be resolved before more water will be supplied to Everglades National Park (T. Morgan, SFWMD, personal communication, 2013). Completing the Mod Waters project and overcoming these final constraints deserves high priority to expedite restoration benefits from substantial prior restoration investments at relatively low additional cost (approximately $19 million; see Table 4-4).

Everglades Restoration Transition Plan

Water control for WCA-3 influences surrounding lands, including Everglades National Park and Big Cypress National Preserve, as well as the distribution of water within the 921-square-mile Water Conservation Area. Longstanding challenges include balancing the right quantities of water and timing of flows to habitats hosting the endangered Cape Sable seaside sparrow and other areas providing food and nesting space for the endangered snail kite (Figure 4-23) and wading bird species. Additionally, tree islands and ridge and slough topography in the WCA-3 were being degraded by water levels that were too high in some places and too low in others. An interim operating plan (IOP) was ineffective in dealing with the various demands on water management, and in October 2012, the plan was replaced by the Everglades Restoration Transition Plan (ERTP) (USACE, 2012c).

The ERTP was designed to provide a flexible multispecies approach to water operations associated with WCA-3 by balancing the various demands for specific water levels in specific places at designated times of the year. It establishes targets for wet-season high water levels, recession rates, dry-season low water levels, and ascension rates (Figure 4-24), and calls for increased operational flexibility

FIGURE 4-23 Snail kite, an endangered species likely to be benefited by the Everglades Restoration Transition Plan.

SOURCE: http://www.saj.usace.army.mil/SharedMedia/saj/2012/Nov/1/121022-A-CE999-001.JPG.

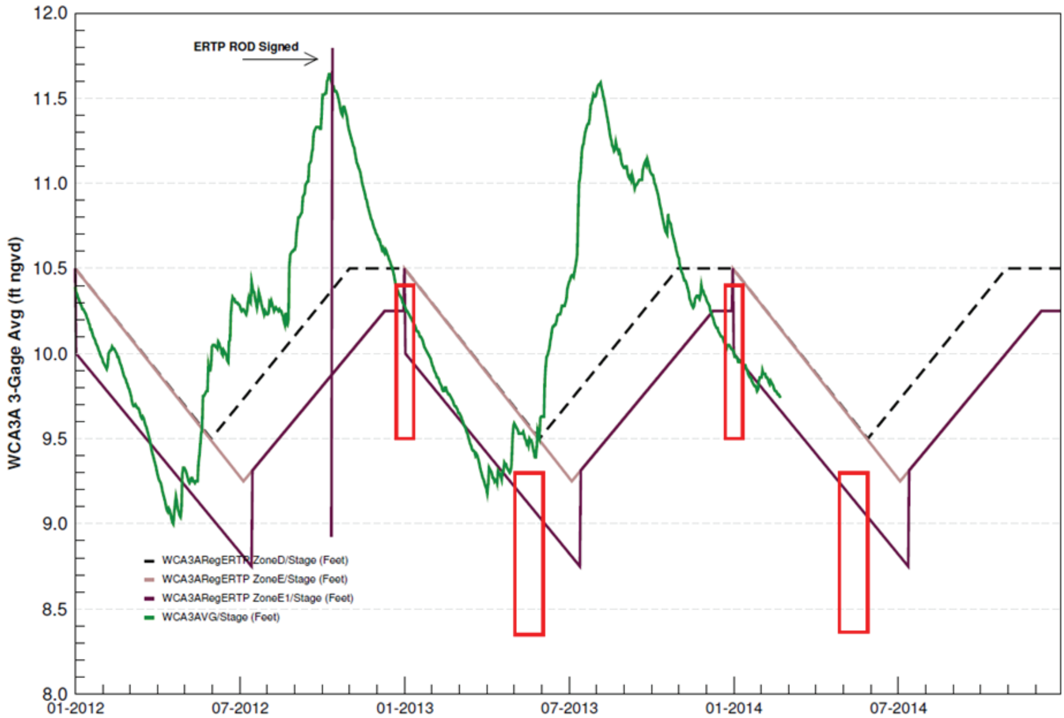

FIGURE 4-24 ERTP targets versus observed performance, 2012-2013. The slanting horizontal boxes delineate operational regulation zones, and the vertical red boxes represent desired water levels for snail kites, apple snails, and wading birds at key points in the annual water cycle. The green line represents actual water levels. The system operated under the interim operational plan (IOP) during January to October 2012 and ERTP thereafter, although the figure plots ERTP targets throughout.

SOURCE: R. Johnson, NPS, personal communication, 2014.

in order to meet these objectives. The plan lowered wet season regulation stages by 0.25 feet and dry season stages by 0.5 feet (USACE, 2012b), reducing stages in northern and central WCA-3A relative to the IOP schedule. Under the new arrangements, there will be no mandatory seasonal closure of the S-12C gate to allow more water to flow southward into Everglades National Park in cases of unusually high water in Southern WCA-3A (USACE, 2011a).

In the first year of ERTP operation, the dry season recession rate and the wet season ascension rate were both somewhat faster than the target rate, and both wet- and dry-season high water levels were higher than target levels, just as they had been the previous year under the IOP (Figure 4-24). Deviations from targets were actually larger in the first year of operation under ERTP, which water managers attributed to a wet season that began early and was unusually wet, along with a dry season (November 2012 to March 2013) with significantly less rainfall than average (USACE, 2013b). Deviations in dry- and wet-season water levels were sufficient to exceed levels of incidental take of endangered species specified in the Biological Opinion of the ERTP (FWS, 2010). The threshold deviation in short-term recession rate was also exceeded several times in water year (WY) 2013, due to below-average rainfall in the first 3 months of 2013 (USACE, 2013a).

The ERTP has a number of ecological targets and performance measures for individual species and ecological components (USACE, 2011a) derived from the multispecies management strategy (FWS, 2010). The difficulties experienced in meeting overall ERTP performance targets are reflected in failure to meet many of these more specific targets (Table 4-6). In the spirit of adaptive management, water managers have assessed the causes of performance failures and made adjustments designed to improve performance in future years. However, under the ERTP, the WCAs are to be managed to provide flood control and water supply, as well as

TABLE 4-6 ERTP Performance Targets for Endangered Species and Other Ecological Components of Special Concern

Measure	2011	2012	2013
Cape Sable Seaside Sparrow			
>60 days dry conditions subpopulation A	Yes	Yes	No
Water level subpopulation A < 7 ft by 12/31	Yes	Yes	Yes
Hydroperiod 90-210 days for six subpopulations	—	—	2 Yes, 6 No
Snail Kite			
9.8-10.3 ft WCA-3A by 12/31	Yes	Yes	Yes
8.8-9.3 ft WCA-3A from 5/1 to 6/1	Yes	No	No
Apple Snails			
Recession of 1 ft at rate of 0.05 ft per week	No	Yes	Yes
Ascension rates < 0.25 ft per week February-September	Yes, 8/8 months	Yes, 8/8 months	Yes, 7/8 months
Tree Islands			
Peak < 10.8 ft WCA-3A	Yes	No	No
< 60 days above 10.8 ft WCA-3A	Yes	Yes	No

NOTES: "Yes" indicates achievement of target, "No" indicates failure to achieve target, and "—" indicates not measured.

SOURCE: USACE (2013a).

to provide viable wetland habitat (USACE, 2011a). Thus, in many cases, failure to meet a particular target is attributed to excessive or deficient rainfall at particular times (USACE, 2013a), which imposes constraints related to flood control and water supply on operations that impact the flexibility required to achieve ecological goals. Also, the potential of ERTP to produce ecological benefits will be limited until the Modified Waters Delivery Project is fully operational. Still, the ERTP is providing opportunities for learning, and its ecological goals represent informed management of the natural system for multiple species. It provides the means to simultaneously address the needs of multiple species within the current constraints imposed on water management and by the current condition of the natural system. One cannot, however, expect the ERTP to produce significant changes in those conditions, such as a shift in the distribution of water from western to northeastern Shark River Slough or more flow into Everglades National Park and Florida Bay, that the CERP is designed to achieve.

State Water Quality Treatment Projects

As part of its Long-Term Plan for Achieving Water Quality Goals, the state has completed construction of STA Compartments B and C, and now has approximately 57,000 acres of STAs that are permitted to operate (Figure 4-25). Meanwhile, enhancements to maintain or improve the performance of existing STAs continue, such as regrading some cells to address hydraulic short-circuiting and converting or reestablishing vegetation as needed (Andreotta et al., 2014).

STA Performance. The STA performance, compliance, and optimization are summarized in the annual South Florida Environmental Reports (Andreotta et al., 2014; Ivanoff et al., 2013). Additionally, NRC (2010) summarizes key issues and challenges regarding STA performance. This section reviews recent STA performance in light of long-term goals.

During WY 2012 (May 1, 2011, to April 30, 2012), a relatively dry year with low hydraulic loading rates, the six STAs reduced inflow total phosphorus (TP) flow-weighted mean concentrations from 111 to 19 μg/L (Table 4-7; Ivanoff et al., 2013). With the exception of STA-5 and STA-6, all other STAs produced outflow TP concentrations of <25 μg/L.[8] During the wet WY 2013, STAs received a higher average hydraulic loading rate and produced outflow

[8] Both STA-5 and STA-6 receive highly phosphorus-enriched waters from the C-139 basin and these STAs are subjected to frequent drying conditions as a result of inconsistent water availability. Unlike other STAs, STA-5 and STA-6 are dominated by cells with emergent vegetation. These issues have been addressed by adding additional treatment area and combining both STAs. In addition, submerged aquatic vegetation cells were added to STA-5/6, which significantly improved the outflow TP concentrations (see Table 4-8).

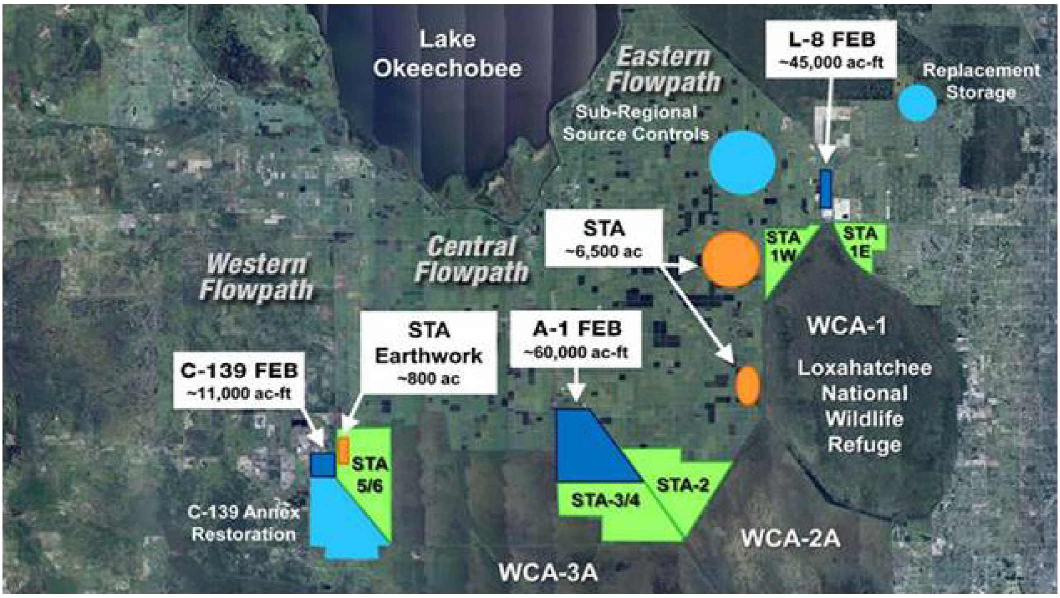

FIGURE 4-25 Location of the Everglades stormwater treatment areas (STAs): STA-1E, STA-1W, STA-2, STA-3/4, and STA-5/6 and the planned locations for additional STAs, STA earthwork, and flow equalization basins (FEBs) associated with the Restoration Strategies plan.

SOURCE: http://www.sfwmd.gov/portal/page/portal/xrepository/sfwmd_repository_jpg/map_restoration_strategies.jpg.

TABLE 4-7 STA Performance During WY 2012 (May 1, 2011, to April 30, 2012)

STAs	Hydraulic Loading Rate (cm/day)	Inflow TP (μg/L)	Outflow TP (μg/L)	TP Inflow Load Rate (g/m^2 per year)	TP Retained Load Rate (g/m^2 per year)	% TP Removal Efficiency
STA-1E	1.4	109	21	0.56	0.46	83
STA-1W	1.2	143	22	0.63	0.54	85
STA-2	2.6	87	12	0.82	0.69	84
STA-3/4	1.4	109	19	0.54	0.44	82
STA-5	0.6	156	32	0.37	0.30	82
STA-6	1.7	126	75	0.78	0.53	68
All STAs	1.4	111	19	0.58	0.48	83

SOURCE: Data from Ivanoff et al. (2013).

flow-weighted TP concentrations ranging from 14 to 36 μg/L (Table 4-8). High outflow TP in STA-1E and STA-1W was due to high phosphorus loading rate, approximately two times higher than in STA-2 and STA-3/4. Overall, WY 2013 data show positive signs that STAs are performing well with an average outflow TP concentration of 21 μg/L.

Compared with the period of record (Table 4-9), the past 2 years, including both wet and dry conditions, demonstrate substantial improvement in STA performance for most of the STAs when TP loading was maintained at <1 g P/m^2 per year. Long-term data during the period of record show a direct relationship between outflow TP concentrations and inflow TP concentrations (Table 4-9), suggesting that maintaining low inflow TP levels may be needed to achieve low outflow TP levels, although other biotic and abiotic factors also play important roles. Overall, during the period of record, STAs have experienced variable loadings, extreme weather conditions, and internal management of vegetation. STA-2 and STA3/4 are the best-performing STAs over the period of record, due to

TABLE 4-8 STA Performance During WY 2013 (May 1, 2012 to April 30, 2013)

STAs	Hydraulic Loading Rate (cm/day)	Inflow TP (μg/L)	Outflow TP (μg/L)	TP Inflow Load Rate (g/m^2/year)	TP Retained Load Rate (g/m^2/year)	% TP Removal Efficiency
STA-1E	2.6	207	26	2.0	1.7	87
STA-1W	2.1	245	36	1.9	1.6	83
STA-2	2.6	106	22	1.0	0.8	78
STA-3/4	2.5	105	14	0.9	0.8	86
STA-5/6	0.6	131	17	0.3	0.3	90
All STAs	2.1	138	21	1.1	0.9	84

SOURCE: Data from Andreotta et al. (2014).

TABLE 4-9 Performance of STAs over the Entire Period of Record of Each STA's Operation

STAs	Start Date [Years in operation]	Inflow TP μg/L (SD)	Outflow TP μg/L (SD)	TP Inflow Load (mt)	TP Retained Load (mt)	% TP Removal Efficiency
STA-1E	2004 [9]	179 (54)	52 (115)	173	125	72
STA-1W	1993 [20]	175 (56)	50 (31)	739	522	71
STA-2	1999 [14]	103 (38)	22 (9)	392	302	77
STA-3/4	2003 [10]	113 (29)	17 (4)	584	493	84
STA-5/6	1999 [16]	179 (59)	74 (40)	436	286	66
All STAs	1994-2012	140 (25)	37 (13)	2,323	1,727	74

SOURCE: Data from Andreotta et al. (2014).

long-term low TP loading rates (<1.0 g P/m^2 per year) (Table 4-9). Rehabilitation of STA-1W in 2007, combined with low loading rates in WY 2012, appears to have improved its performance in WY 2012 and 2013 compared with the period of record. It is expected that implementation of additional treatment area and flow equalization basins (see Restoration Strategies in the next section) is likely to reduce STA loading rates and therefore improve the outflow TP concentrations. However, sustained performance of STAs depends on the effectiveness of these restoration strategies and consistent hydraulic and TP loading to the STAs.

Restoration Strategies. In 2012, the State of Florida announced its Restoration Strategies Regional Water Quality Plan to ensure that sufficient treatment is provided for the approximately 1.4 million AF/yr currently flowing into the Everglades Protection Area to meet the legally required water quality standard. The plan was proposed as an alternative to the approach set forth by the U.S. Environmental Protection Agency in its 2010 Amended Determination. The plan includes six projects that create approximately 6,500 acres of new STAs and 116,000 AF total capacity in three new flow equalization basins (FEBs), which are intended to moderate inflows into existing STAs and thereby improve their treatment performance (Figure 4-25). The Restoration Strategies plan also includes some earthwork in STA-5/6 as well as additional source controls to reduce nutrient loads on the STAs.[9] The Restoration Strategies plan was formally launched in September 2012, and the SFWMD FY 2014 budget includes nearly \$102 million toward the \$880 million plan. The state anticipates that the entire plan will not be constructed and fully implemented until 2024, but the A-1 FEB in the central flow path could come online as soon as 2016 (Leeds, 2014). The SFWMD plans to initiate construction of the A-1 FEB in June 2014 and already has construction of the L-8 FEB under way.[10] The plan's focus on providing significant additional flow equalization and water quality treatment is a significant development with important implications for restoration of both water quality and flow in the central Everglades (see Chapter 3).

As described in Chapter 3, water from the STAs cannot be redistributed in the Central Everglades Planning Project unless it meets the water quality-based effluent limitation (WQBEL) set forth in the National Pollutant Discharge Elimination System (NPDES) permit currently in effect.[11] The NPDES permit covers discharges

[9] See http://www.sfwmd.gov/portal/page/portal/xweb protecting and restoring/restoration strategies#projects.

[10] See http://www.sfwmd.gov/portal/page/portal/xrepository/sfwmd_repository_pdf/restoration_strategies_update_2013_nov.pdf.

[11] After release of the report in prepublication form, it was pointed out that this sentence was not clear about which agencies are responsible for permit compliance decisions. As noted in Chapter 3, FDEP, with oversight from EPA, is the permitting authority that would interpret compliance associated with the redistribution of water.

from all STAs. However, as described above, the STAs currently operate at very different levels of efficacy. Certain STAs, such as STA-2 and STA-3/4 (Figure 4-25) in the central flow path, are the best performing and consistently have outputs that are approaching the limitations prescribed by the WQBEL in the NPDES permit (not to exceed an annual flow-weighted mean (FWM) of 13 μg/L total phosphorus in more than 3 out of 5 years, and an annual FWM of 19 μg/L in any water year). Other STAs are not performing as well and it could take more time and work to bring the discharges from these STAs into compliance with NPDES permit requirements. While the committee recognizes the need to comply with all applicable law, including federally approved water quality standards and the WQBEL set forth in the NPDES permit, the agencies may be unnecessarily constraining themselves (and restoration progress) by concluding that *all* STA discharges must comply with the WQBEL before *any* water from *any* STA can be released to the Everglades. As discussed in Chapter 3, the agencies should consider permitting mechanisms and, if necessary, design and implementation alternatives that would allow discharge and redistribution of water from a flow path that meets the WQBEL rather than postponing the redistribution of WQBEL-compliant discharge until all STAs are WQBEL-compliant. If a revision to the NPDES permit is necessary to authorize each STA (or subsets of the STAs, by flow path) to discharge as soon as the WQBEL requirements are met, the agencies should take the necessary steps to revise the permit to expedite restoration in the central Everglades and avert ongoing ecosystem declines caused by a reduced flow (NRC, 2012a).

Kissimmee River Restoration

The Kissimmee River drains the northern extremity of the entire Everglades watershed, rising from lakes in the vicinity of Orlando, and flowing south to empty into Lake Okeechobee. The Central and Southern Florida Project caused widespread changes in the hydrology, geomorphology, and ecology of the Kissimmee River. The previously meandering, 103-mile-long channel was replaced by an artificial channel 55 miles long, control gates and pumps were installed, and much of the floodplain was drained (USACE, 2012b). Unforeseen consequences included a wholesale change in the bed and banks of the river from sandy conditions to organic-rich fine materials with an accompanying loss of native fishes. The replacement of freshwater wetlands with drained pasture lands on the floodplain resulted in the loss of habitat for numerous waterfowl and wading birds. Seventy-five percent of the historically active floodplain was disconnected from the river; waterfowl populations declined by 90 percent (Blake, 1980). Additionally, the river became a major source of phosphorus for Lake Okeechobee, derived from drainage from agricultural lands.

FIGURE 4-26 Photos showing the natural historic Kissimmee River and floodplain in 1954 prior to channelization of the river (left), and the same view after canal filling and river restoration (right). The filled channel is circled in the right-hand figure.

SOURCE: T. Morgan, SFWMD, personal communication, 2013.

Two restoration projects were designed to reverse these impacts. The Kissimmee Headwaters Revitalization Project refined operations in the headwaters of the basin by canal refinements, construction of supplemental levees, and improved management of control gates that regulated the outflow of the four primary lakes in the region, and was completed in 2012. The more extensive Kissimmee River Restoration Project was congressionally authorized in 1992 and sought to replace the straight constructed channel with a 40-mile meandering one more similar to the original geomorphology, backfilling of 22 miles of canal, recarving 10 miles of river, and removing control structures that segmented the lower reaches of the river (Figure 4-26). The first phase of its construction began in 1999, with a 2001 completion date. Two additional phases of the project were completed in 2007 and 2009 (Jones et al., 2014). The final project phase began in 2012 but was recently delayed and is now expected to be completed in 2019.

Of all the projects described in this chapter, the Kissimmee River restoration is probably the most advanced in demonstrating substantial restoration of the natural system, and the long-term monitoring of restoration progress is a useful example for many CERP projects. Jones et al. (2014) and USACE (2012b) report recent insights on the project's hydrologic and ecological benefits since the committee's last report:

- The project has met the target of connecting the floodplain to the channel 180 days during WY 2013 at four of the five observation sites.
- Wetland plants are thriving in the floodplain (see Figure 4-27), including pickerelweed, arrowhead, Carolina willow, and buttonbush.
- Dissolved oxygen has met the targets for mean concentrations in the 2012-2013 year, and the dissolved oxygen concentration target of 2.0 mg/L was met almost 90 percent of the time.
- The total phosphorus load into Lake Okeechobee remained virtually unchanged.
- Native largemouth bass and various native sunfishes now make up 63 percent of the fish community; prior to restoration, they represented only 38 percent.
- Organic deposits on the river bottom decreased by 71 percent, reestablishing sand bars and providing new habitat for shorebirds and invertebrates, including native clams.

FIGURE 4-27 A functional wetland restored to an area that once was a pasture on the floodplain of the Kissimmee River.

SOURCE: Lawrence Glenn, SFWMD.

- Eight shorebird species, absent before restoration, have returned to the river and floodplain, including breeding black-necked stilts.
- The 3-year running average for wading bird abundance was above the target of 30.6 birds per square kilometer, although the target was missed during WY 2013.
- Waterfowl abundance was more than double the target WY 2012 and WY 2013.

The Kissimmee River restoration has made substantial construction progress that has already resulted in measureable natural system benefits, and even more benefits are anticipated once final control structures are finished and changes to the water control schedule are implemented. Several project features that remain to be completed include additional canal filling, removal of S-65C, and construction of the S-69 weir. The agreement on a water control schedule for the headwaters areas will also institute a more natural flow regime in the river with additional natural system benefits.

Restoration progress on the Kissimmee River restoration (and the C-111 South Dade project) had been delayed for about 2 years by cost-sharing issues between the SFWMD and the USACE. However, in April 2014 the agencies reached agreement on the issues that separated them, and construction is now set to move forward (USACE, 2014). These issues and their resolution continue a record of solving management issues through interagency negotiation that requires time (and delays), but that allows the project to eventually move forward with full support of both partners.

Seminole Big Cypress Reservation Water Conservation Plan Critical Project

The Seminole Big Cypress Reservation Water Conservation Plan Critical Project (Big Cypress Project, authorized by the 1996 WRDA) is a non-CERP project focused on the Seminole Big Cypress Reservation located near the northwest corner of WCA-3A. The project was intended to address water quality issues in agricultural runoff on the reservation, enhance water storage, and thereby improve conditions for native vegetation on the reservation (USACE and SFWMD, 2013d). The project included construction of new water storage areas designed to capture stormwater discharges, a series of culverts and canals, and 24 pump stations. The Big Cypress Project addresses the quality of water flowing eastward from the Seminole Reservation into the Everglades ecosystem in WCA-3A and the Miccosukee lands (USACE, 2012d; Figure 4-28). The project also provides additional water to rehydrate wetlands in the northern portion of the Big Cypress National Preserve.

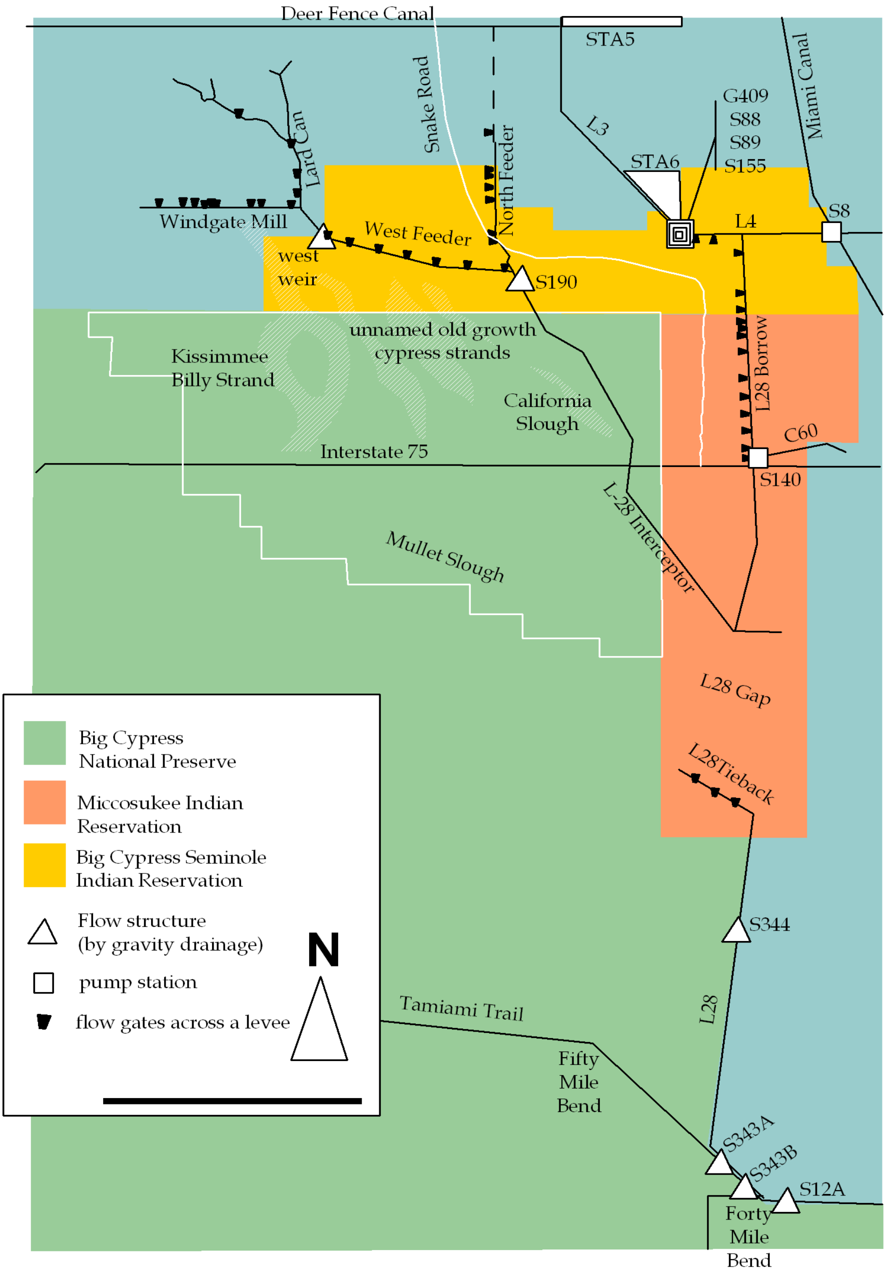

FIGURE 4-28 The Western Glades and the L-28 levee system at the northwest corner of WCA-3A.

SOURCE: Florida Gulf Coast University, http://www.fgcu.edu/bcw/Restore/History/History_L28.htm.

Construction of the Phase 1 conveyance canal system was completed in 2003. Phase 2 of this project has been divided into four basins north of the West Feeder Canal (Figure 4-28). In 2008 the USACE completed construction of the largest basin, Basin 1, which was transferred to the tribe for operations and maintenance in 2010. The basin has failed to perform as designed, which necessitated design modifications for the other three basins (SFERTF, 2012). Construction of Basin 4 was completed in 2013, and Basin 2 is currently under construction (USACE, 2014d). After tribal frustrations over the poor performance of Basin 1, federal, state, and tribal leaders held multiple meetings in 2013 in efforts to resolve these technical issues, and that process is ongoing.

CONCLUSIONS AND RECOMMENDATIONS

The infrequency of Water Resources Development Acts (WRDAs) has impeded CERP progress over the past 2 years. Seven years have elapsed since the last WRDA was passed, and four Generation 2 CERP projects with approved project plans awaited congressional authorization between 2012 and June 2014 when WRRDA 2014 was signed into law. Additionally, two of the previously authorized CERP projects require reauthorization due to cost escalations; thus, prior to WRRDA 2014, only one CERP project—Indian River Lagoon-South—was eligible for sizeable (>$25 million) construction funding. With the passage of WRRDA 2014, four additional projects are able to proceed with federal funding, although the Central Everglades Planning Project was not completed in time to be included. Lack of authorizations also had important implications for the cost-sharing balance, discussed below.

Availability of funding also impeded CERP progress in the past 2 years. State CERP expenditures have declined substantially in recent years, because of reduced SFWMD revenues and the need to fund non-CERP water quality projects to meet a 2012 Consent Order. Even though the state has spent significantly more than the federal government on the CERP since its inception, the state has been precariously close to the mandated 50-50 cost-sharing requirement because, prior to WRRDA 2014, land acquisition and construction expenditures could only be credited for the four congressionally authorized Generation 1 projects. Declining state funding for CERP projects over the past 2 years has contributed to cost-sharing challenges, and as of September 2013, the state's "creditable expenditures" exceeded those of the federal government by only $98 million. As a result, the federal government significantly reduced spending in FY 2014 so as not to exceed the 50-50 cost share. Passage of WRRDA 2014 could allow the state to realize approximately $400 million in additional cost-sharing credits for prior spending, thereby easing an impending constraint on federal contributions toward the CERP.

CERP planners need to revisit the Integrated Delivery Schedule with a renewed urgency to advance projects with the greatest potential to avert ongoing ecosystem degradation and those that promise the largest restoration benefits. The current draft Integrated Delivery Schedule has not been updated since 2011, and difficult decisions will need to be made to integrate the four Generation 2 CERP projects and the Central Everglades Planning Project (and related project dependencies) with existing CERP and non-CERP efforts. To expedite Everglades restoration amid limited funding, all authorized projects cannot be advanced equally. Some projects may be more beneficial in light of climate change and sea-level rise and others less so, and these factors should be considered in the prioritization of restoration funding.

The restoration progress made by CERP projects to date remains fairly modest in scope. Ecosystem responses have been detected after phased implementation in the Picayune Strand, Biscayne Bay Coastal Wetlands, and C-111 Spreader Canal projects, although many of these improvements are limited. In some cases, such as Biscayne Bay, the scope of the restoration increment to date is simply so limited in area that ecological responses are equally small. In other cases, such as Picayune Strand, additional time may be needed to achieve full ecosystem responses to the restoration measures in place. Taylor Slough has seen significant hydrologic improvements due to restoration efforts, but the documented benefits to date are primarily derived from the C-111 South Dade Project, a non-CERP project. For all three of these projects, ecological responses would be expected to increase with construction and operation of additional project increments as well as additional time for ecosystem recovery.

Several non-CERP projects have faced bureaucratic and policy issues that hindered implementation progress. Agency disagreements about cost-sharing arrangements and legal requirements affected progress on the Kissimmee River Restoration and the C-111 South Dade project by delaying them for almost 2 years. However, the SFWMD and the USACE have made important progress to resolve these differences, and resume construction. Meanwhile, water quality compliance issues and the lack of an operational plan are preventing realization of restoration benefits in the Mod Waters project. Scientific knowledge is adequate for success, and engineering problems in construction and operation appear not to be impeding restoration progress. These non-CERP foundation projects offer large potential restoration benefits once fully implemented. Renewed attention is needed to resolve the remaining bureaucratic challenges to expedite restoration progress and realize the ecological returns from substantial financial investments to date.

STA performance shows signs of improvement under recent management. Long-term sustainable performance, however, will be directly influenced by loading rates. Additional treatment area and flow equalization basins in the

Restoration Strategies project are likely to further reduce loading rates and outflow concentrations. Continued adaptive management, including implementation of new strategies developed through ongoing research, is needed to meet water quality standards and maintain sustained performance of these treatment systems.

5

Climate Change and Sea-Level Rise: Implications for Everglades Restoration

Climate change is a major threat to the persistence and functioning of ecosystems globally, including wetlands (IPCC, 2013; NCADAC, 2014; NRC, 2014). Warmer climates accompanied by changes in precipitation patterns and increases in atmospheric carbon dioxide concentrations will affect wetland ecosystem functioning through changes in hydrologic conditions, biogeochemistry, and primary productivity, and alter linkages with the built environment. Increases in temperatures also will accelerate the rate of global sea-level rise, with median projected global increases of 17 to 29 inches by 2100 for two scenarios (IPCC, 2013; Figure 5-1). In this chapter the committee reviews the latest climate change and sea-level-rise projections and discusses their implications for the Everglades and restoration planning.

CLIMATE AND SEA-LEVEL CHANGE IN FLORIDA OVER THE PAST CENTURY

Global change effects on land surface temperature and precipitation are manifested most clearly and strongly at northern latitudes, but in other regions, patterns of global change are more complex and can be masked by other factors. This is particularly true of the southeastern United States, which has generally shown decreasing rather than increasing trends in land surface temperature in the second half of the 20th century (DeGaetano and Allen, 2002; Portmann et al., 2009; Trenberth et al., 2007). In Florida, Obeysekera et al. (2011b) investigated trends in air temperature and precipitation at 32 meteorological stations (1950-2008) and observed no consistent trends in either air temperature or precipitation.

There are several components of precipitation in South Florida that contribute to the complexity and variability of rainfall, including tropical cyclones and less intense tropical storms, which can be a substantial and variable contributor of precipitation. Adding to the complexity in precipitation patterns, sea surface temperatures undergo slow oscillations between relative warm and cold conditions (the Atlantic Multidecadal Oscillation [AMO] and the Pacific Decadal

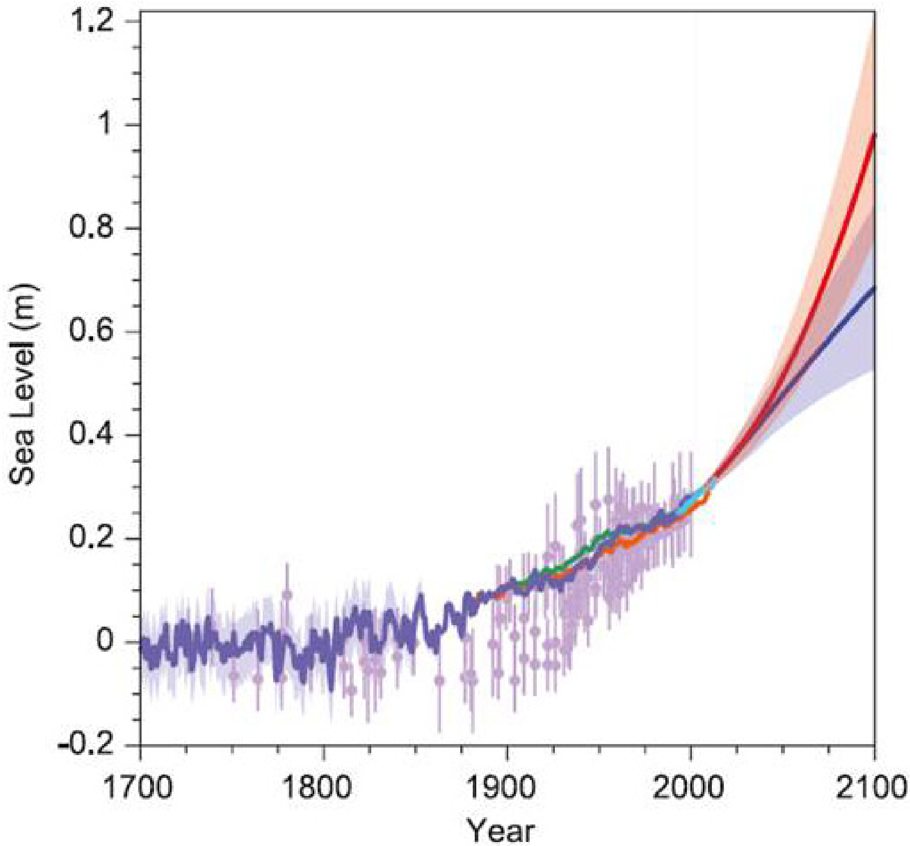

FIGURE 5-1 Projected global rise in sea level for two emission scenarios in comparison with historical records. Historical and paleorecords from salt marshes are shown in purple. The green, blue, and red lines between 1900 and 2010 represent yearly average global mean sea level reconstructed from tide gages using three different methods, while the light blue line represents satellite altimetry data. The future projections show median estimates and likely ranges for future sea-level rise for a low-emissions scenario (RCP2.6; blue) and a high-emissions scenario (RCP8.5; red). The Intergovernmental Panel on Climate Change did not assess the likelihood of the specific scenarios, but they should not be assumed to be equally probable.

SOURCE: IPCC (2013).

Oscillation [PDO]), which have been shown to influence precipitation quantity, distribution, and interannual variability in South Florida (Enfield et al., 2011; Moses et al., 2013; Shin and Lee, 2011). For example, for periods of two to three decades, the AMO follows a warm-water phase of the North Atlantic, which is characterized by more hurricanes and precipitation in South Florida, and then shifts to a cold-water phase with fewer hurricanes and less rainfall (Enfield et al., 2001; Kelly, 2004) although the PDO can interfere in ways that increase or decrease these changes. The AMO has been in the warm-water phase since the mid-1990s and will likely shift to the cold-water phase in the future, likely decreasing precipitation inputs irrespective of the effects of greenhouse gases. These oscillations may mask long-term trends in precipitation in Florida.

In contrast to temperature and precipitation, there is little uncertainty about trends in sea level. Currently, sea level is rising almost an order of magnitude faster than the long-term rate of 0.35 mm/yr that prevailed for the past 4,000 years (Scholl and Stuiver, 1967; Scholl et al., 1969; Wanless et al., 1994). Using long-term measurements at Key West, NOAA[1] calculated the average sea-level rise to be 8.8 inches (22 cm) over the past century (or 2.2 mm/yr). This value is more than 30 percent higher than the global average of 6.7 inches (17 cm) for the 20th century (Figure 5-1) and is consistent with relatively rapid rates observed along the Atlantic and Gulf coasts of North America (IPCC, 2013).

CLIMATE AND SEA-LEVEL PROJECTIONS FOR SOUTH FLORIDA

Given that the Comprehensive Everglades Restoration Plan (CERP) is a multi-decadal restoration effort, it is important to understand how anticipated changes in climate and sea level could impact restoration outcomes.

Climate Projections

Accurate projection of climate change and its effects is a major challenge under the best of circumstances, but these challenges are amplified in the complex meteorological environment and landscape of South Florida. Climate change projections are derived through a complex, multistep process from general circulation models (GCMs), which are large numerical models that simulate land-ocean-atmosphere exchanges of energy, water, and other characteristics within and across coarse grid cells. Dozens of different GCMs are used in climate projections, which are driven by storylines that integrate economic, demographic, and technological drivers to estimate potential future human-caused emissions and land cover change.

[1] See http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8724580.

There are several sources of uncertainty in projecting global climate changes (Hawkins and Sutton, 2009; Kirtman et al., 2011), including uncertainty in initial conditions, external forcings that drive model scenarios (e.g., changes in future carbon dioxide emissions), and model uncertainty. The relative contribution of these categories of uncertainty shift with the timescale of projections. For South Florida, there are a number of specific issues that add to uncertainty of GCM projections of changing temperature and precipitation. Peninsular Florida's proximity to the warm ocean and flat terrain create additional uncertainty in GCM projections. South Florida is also positioned along a discontinuity in rainfall projections. Although the position of this discontinuity is uncertain, the Intergovernmental Panel on Climate Change (IPCC) AR4 simulations suggest that eastern North America will experience increases in precipitation, while for the Caribbean there will be a marked decrease in precipitation (Enfield et al., 2011).

GCMs generally produce outputs on a relatively coarse grid scale (hundreds of kilometers), which limits local-scale assessments of climate change. Two broad downscaling approaches are used to translate coarse-scale GCM output to local-scale conditions. Statistical downscaling uses empirical relationships between past grid-based or station-based meteorological observations and comparable values from GCM hindcast simulations and relies on these relationships to tune future GCM projections of climate output (e.g., surface air temperature, precipitation) to local-scale grid or site conditions. In contrast, dynamical downscaling uses GCM meteorological output as input to a mesoscale climate model to simulate potential future climate regionally or locally. Although investigations have shown that both statistical and dynamically downscaled data are able to reproduce historical temperature and precipitation patterns for Florida, there are biases in these relationships which challenge the accuracy of future downscaled projections. For example, Obeysekera et al. (2011a) showed that various GCMs typically underpredict historical wet-season precipitation in central and southern Florida and do not represent the extremes in observed events. This bias stems from an inability in the models to depict sea-breeze-driven convective thunderstorms. There is considerable variability in projections across different GCMs and under different future scenarios (Figure 5-2). However, ensembles of GCMs that show similar results provide more confidence in outputs. More consistent patterns are evident for changes in temperature than precipitation.

Obeysekera et al. (in press) summarized the general range of GCM downscaled climate change projections for South Florida for 2060 (Table 5-1). Results suggest that South Florida will experience modest increases in temperature (Figure 5-3, top). Precipitation projections are variable for different GCMs (Figure 5-2) and more uncertain than temperature projections (Figure 5-3, bottom). Projections generally indicate increased precipitation in the fall and early winter and decreases in late winter through early summer. Moreover, precipitation is

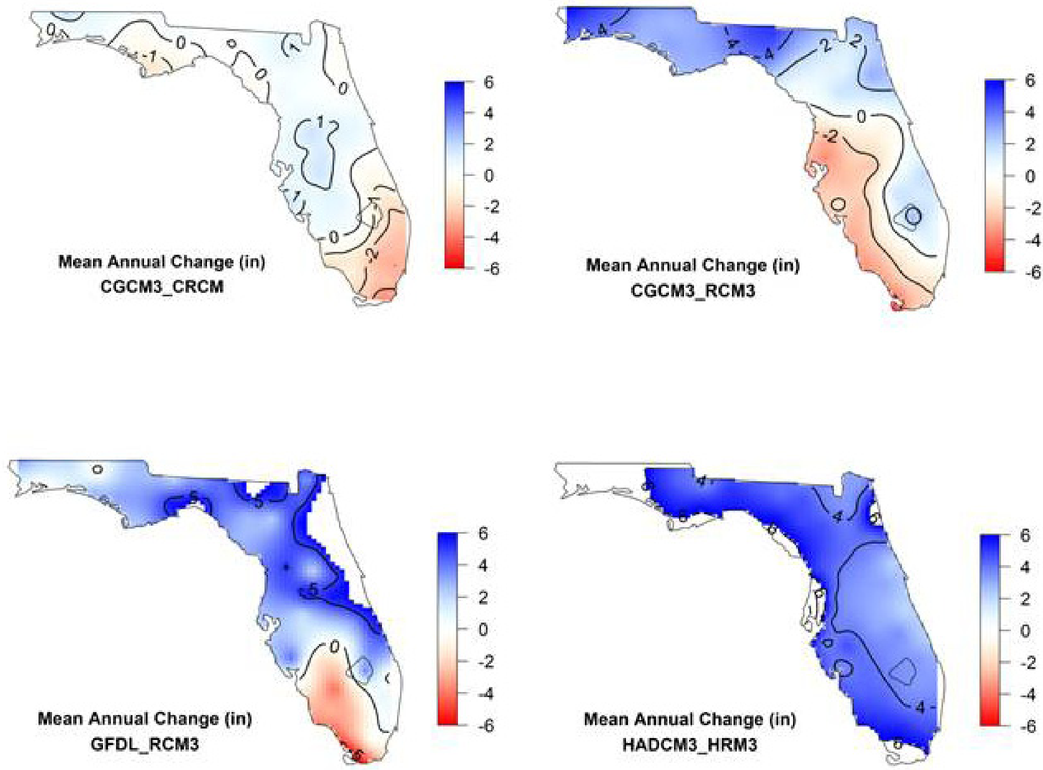

FIGURE 5-2 Spatial patterns of specific downscaled GCM projections of precipitation change for Florida.

SOURCE: J. Obeysekera, SFWMD, personal communication, 2014.

TABLE 5-1 Summary of Climate Change Projections for South Florida for 2060

Variable	GCMs	Statistically Downscaled	Dynamically Downscaled
Average temperature (°C)	1 to 1.5	1 to 2	1.8 to 2.1
Precipitation	−10% to +10%	−5% to +5%	−76 to +50 mm (−3 to +2 inches)
Reference crop evapotranspiration (in.)			76 to 15 mm (3 to 6 inches)

SOURCE: Data from Obeysekera et al. (in press).

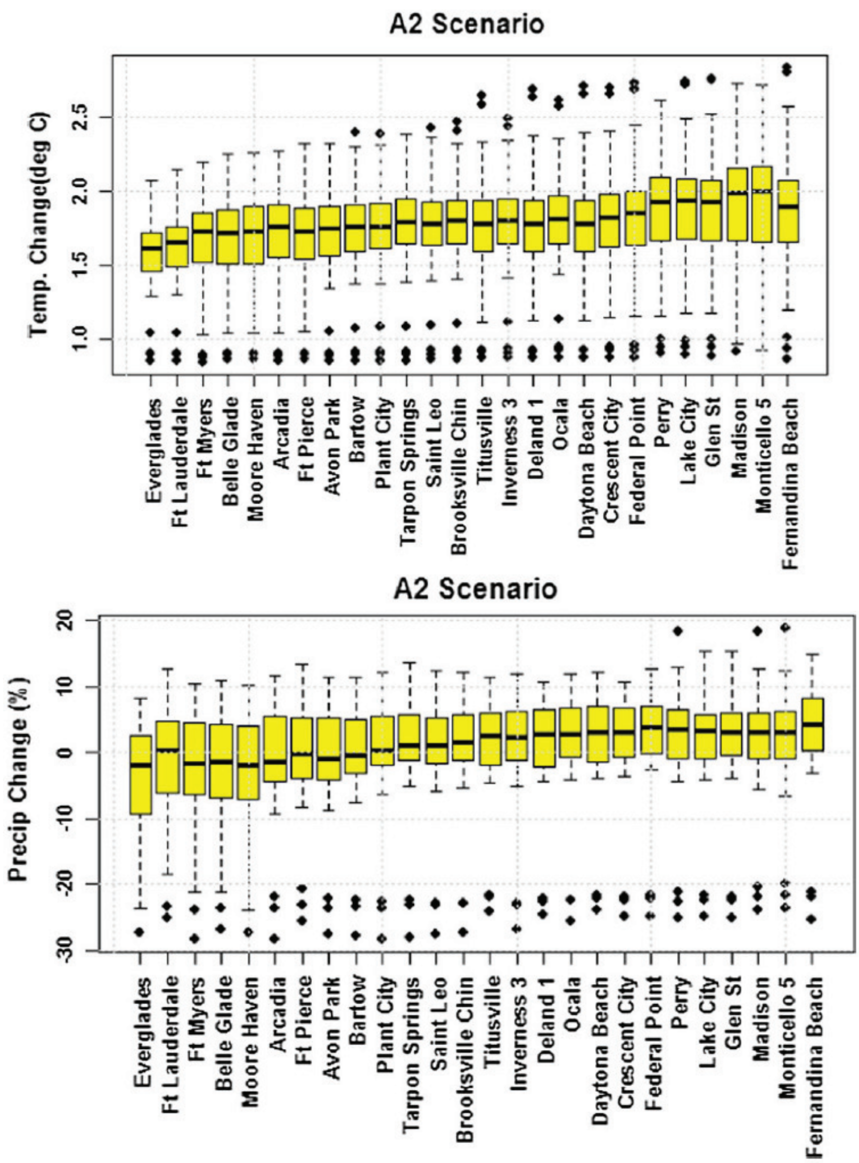

FIGURE 5-3 Box and whisker plots showing magnitude and variability of different downscaled GCM-projected changes in (top) temperature and (bottom) precipitation from 1970-1999 to 2041-2070 for meteorological stations in Florida under the IPCC A2 scenario sorted by latitude (after Obeysekera et al., 2014). GCM data are from the World Climate Research Programme [WCRP] Coupled Model Intercomparison Project 3 [CMIP3] multimodel dataset. Note that the A2 scenario depicts a world of independently operating, self-reliant nations, with continuously increasing population, and regionally oriented economic development.

more likely to decrease with latitude through the Florida peninsula (Figures 5-2 and 5-3, bottom). Statistically downscaled projections for the Everglades also show increases in annual temperature and decreases in annual precipitation (Obeysekera et al., in press). As a result of this considerable uncertainty, rather than evaluating specific projections, Obeysekera et al. (in press) developed scenarios to probe the hydrologic response of the Everglades to hypothetical changes in temperature, precipitation, and sea-level rise based on the results of GCM projections (discussed below in Implications for Everglades Hydrology).

Potential changes in tropical cyclone activity also have important implications for the CERP. Although there is no evidence that climate change has altered hurricane activity to date (Bender et al., 2010), the number of intense (category 4 and 5) hurricanes is projected to increase over the next century, while the total number of hurricanes is expected to decrease (Bender et al., 2010; Enfield et al., 2011). These projections are sensitive to the particular GCM models that are used in the downscaling experiments, and hence should be interpreted cautiously.

Sea-Level Rise

Sea-level rise is already impacting South Florida. Sea level is certain to continue to rise, although the rate of the increase depends on global factors such as future greenhouse gas emissions, thermal expansion of the ocean, and the extent of melting from glaciers and ice sheets (IPCC, 2013). The vulnerability of the Everglades to sea-level rise will depend on local factors, including isostatic uplift rates, which are generally low in South Florida[2] (Adams et al., 2010), and accretion rates of peat and inorganic sediments (discussed later in this chapter).

The IPCC (2013) recently increased its estimates of global sea-level rise (IPCC, 2007a) by 60 percent based on improved process models depicting thermal expansion of the ocean, ice-sheet dynamics, and glacial melting. Model simulations of future sea-level rise were run under four different scenarios for greenhouse gas emissions called representative concentration pathways (RCPs). The models project a likely rise in global sea level between 11 and 24 inches by 2100 under the low-emissions scenario (RCP2.6, which requires technology for CO_2 capture that does not exist today) and a likely increase between 21 and 38 inches under a regime of continued high emissions (RCP8.5) (Figure 5-1). The IPCC did not assess the likelihood of the RCP scenarios themselves, but these scenarios should not be considered equally probable. Although the IPCC remains

[2] South Florida rests on a relatively stable tectonic platform, located too far south to be affected by glacial isostatic adjustment. However, Adams et al. (2010) suggested that Florida's land surface may be rising isostatically, driven by dissolution of the limestone bedrock. Their predicted uplift rate of 0.047 mm/yr for northern Florida would be equivalent to a total rise of only 0.38 cm by 2100.

confident in these scenario-specific projections, some degree of uncertainty remains with regard to (1) the climate models that are used to simulate thermal expansion of the ocean; (2) modeling ice-sheet dynamics; and (3) modeling the timing and magnitude of ice-sheet collapse. The stability of the Greenland and Antarctic ice sheets has been a major element of uncertainty (IPCC, 2013), and recent research in West Antarctica has reported more rapid rates of glacial melting than previously anticipated (Rignot et al., 2014).

Following USACE guidance (USACE, 2011e), which was based on NRC (1987), the USACE Jacksonville District Office developed projections for sea-level rise in South Florida at low, intermediate, and high scenarios through 2100. These local sea-level rise projections range from 4 to 26 inches in South Florida over the next 50 years and between 9 and 78 inches over the next century (Figures 5-4 and 5-5; USACE and SFWMD, 2013b). As previously discussed in the context of Florida's observed sea-level rise, ocean circulation patterns can cause local sea-level changes to differ from global changes, creating more uncertainty in local sea-level-rise projections compared with global projections. Thus, it is reasonable that the local USACE projections fully encompass and, at the upper projections, exceed

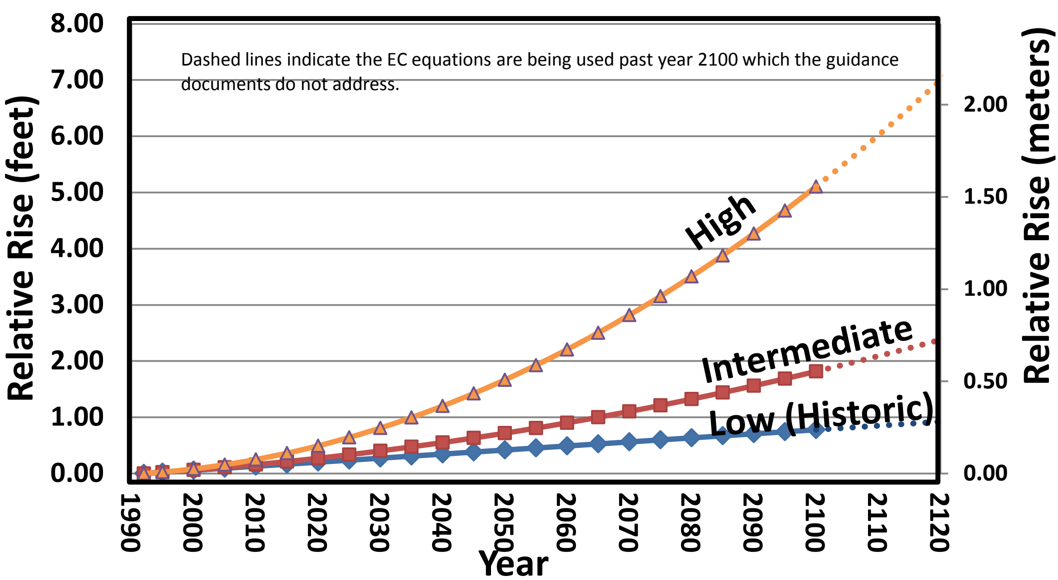

FIGURE 5-4 Sea-level rise scenarios for Key West, Florida, based on USACE sea-level rise guidance EC 1165-2-212.

SOURCE: USACE and SFWMD (2013b).

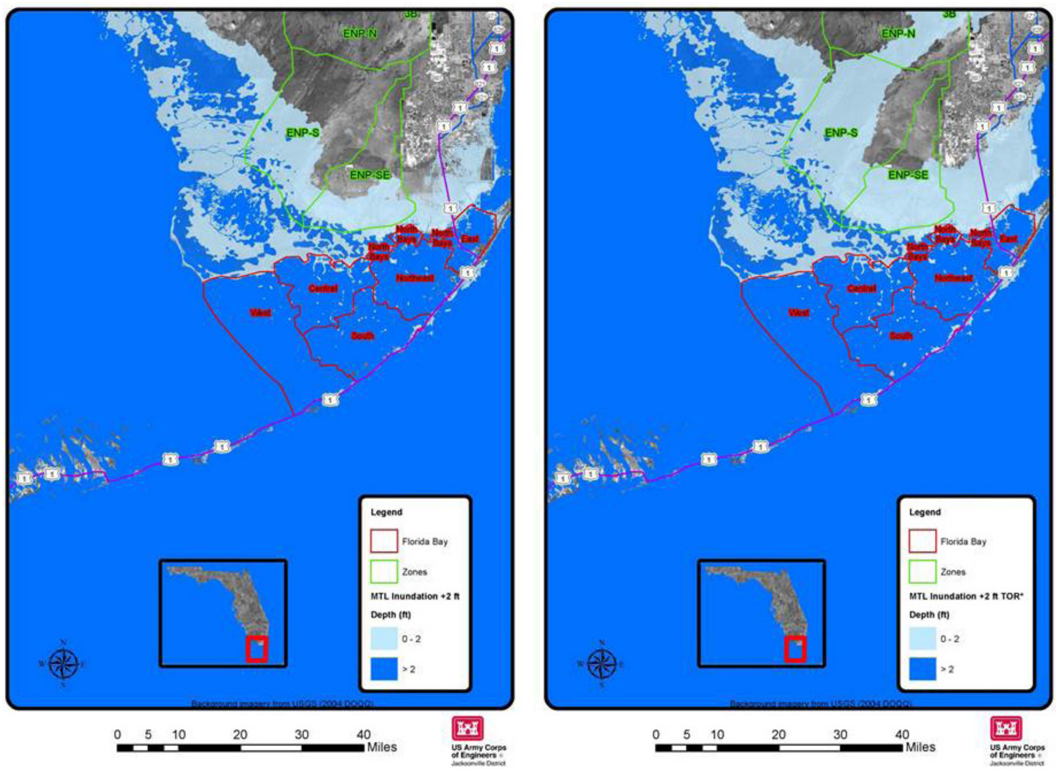

FIGURE 5-5 Predicted land loss in Everglades National Park based on 2 feet of sea-level rise (the intermediate scenario for 2100 in Figure 5-4), (a) assuming existing topography and (b) assuming complete loss of peat soils, which leads to substantially greater land loss. Neither scenario considers new peat accretion.

SOURCE: USACE and SFWMD (2013b).

the most recent global sea-level rise projections of the IPCC (2013; 11-38 inches by 2100; see Figure 5-1) and NRC (2012b; 20-55 inches by 2100).[3]

IMPLICATIONS FOR THE EVERGLADES

The impacts of climate change on the Everglades will depend upon the magnitude and rate of change in the physical environment (e.g., sea-level rise,

[3] NRC (2012b) global sea-level rise estimates exceeded those of the IPCC (2013) because the NRC assumed higher rates of loss from ice sheets and used a different extrapolation procedure based on Meier et al. (2007).

temperature) and the ecosystem's capacity to resist and/or be resilient to these stressors. A warmer climate in South Florida accompanied by changes in precipitation patterns will affect hydrologic regimes, biogeochemical cycling, community composition and productivity, and, hence, wetland ecosystem structure and function. Accelerated sea-level rise will likely submerge many areas, thereby increasing the salinity of freshwater wetlands, altering biotic communities and productivity, and changing the rates and decomposition pathways of organic matter (Weston et al., 2006, 2011). Alterations to natural disturbance regimes, such as fire or intense hurricanes, could also have significant ecosystem effects. These issues were explored in a recent workshop on the ecological effects of climate change in the Everglades.[4] In this section, the committee describes the implications of climate change and sea-level rise on Everglades hydrology, landscapes, water quality, and biota.

Implications for Everglades Hydrology

The hydrologic responses to future climate conditions are particularly challenging to characterize and quantify in the rainfall-driven South Florida ecosystem. In addition to the uncertainties in climate projections discussed in the preceding section, South Florida water management operations may also change in response to changing climate. For example, the water level in coastal canals could be maximized to buffer the coastal groundwater system against saltwater intrusion (Obeysekera et al., 2011a). Future increases in the population of Florida will increase the demand for water resources for urban areas, and under changing climate conditions, water demand is likely to change.

As a result of these important but uncertain drivers, projections of changes in hydrologic conditions in response to a changing climate are highly uncertain. From this perspective, Obeysekera et al. (2014) conducted a preliminary ("screening level") assessment to help understand the sensitivity of the water system to climate change drivers and the potential implications for water resources and management in South Florida. Using the South Florida Water Management Model, Obeysekera et al. (2014) evaluated the hydrologic outcomes of a series of hypothetical scenarios:

1. 2010 Baseline (2010 water demands and land use corresponding to and simulated with 1965-2005 rainfall and evapotranspiration);
2. 2010 Baseline with a 10 percent decrease in rainfall;
3. 2010 Baseline with a 10 percent increase in rainfall;

[4] See http://www.ces.fau.edu/climate_change/ecology-february-2013/.

4. 2010 Baseline with a 1.5°C increase in temperature and a 1.5-ft increase in sea level with increases in coastal canal maintenance levels;

5. 2010 Baseline with 10 percent decrease in rainfall, 1.5°C increase in temperature, and a 1.5-ft increase in sea level with increases in coastal canal levels;

6. 2010 Baseline with 10 percent decrease in rainfall, 1.5°C increase in temperature, and a 1.5-ft increase in sea level with no increases in coastal canal levels; and

7. 2010 Baseline with 10 percent increase in rainfall, 1.5°C increase in temperature, and a 1.5-ft increase in sea level with increases in coastal canal levels.

These hypothetical climate scenarios are reasonable changes that might be anticipated based on statistically downscaled GCM projections for South Florida for 2060 (Table 5-1). The analysis, however, was highly simplified, because seasonal and extreme interannual variations in precipitation were not considered. Instead, changes in precipitation were applied uniformly across the year, based on 1965-2005 historical climate data, even though global climate models have projected increasing precipitation extremes over many regions (Kharin et al., 2007; O'Gorman and Schneider, 2009; Sun et al., 2007).

Results of this analysis show that water discharge and demand are sensitive to hypothetical climate change projections. The hypothetical 10 percent increases in precipitation results in increases in water stage and discharge throughout the South Florida ecosystem (Figure 5-6). The scenarios of increases in temperature (i.e., evapotranspiration) and decreases in rainfall are projected to increase water demand and decrease runoff, which results in particularly acute water shortages (Figure 5-6). Simulations show up to 1.7-ft decreases in the stage of Lake Okeechobee with increasing temperature only (Scenario 4), and simulations of 10 percent decrease in rainfall combined with increasing temperature (Scenario 7) resulted in up to 6-ft decreases in lake stage (Table 5-2; Obeysekera et al., 2014). This direst scenario resulted in unmet agricultural water supply demand of 40 to 58 percent (up from 7 to 8 percent in the 2010 base), highlighting the potential water supply pressures under future scenarios. Such decreases in precipitation would impact both surface-water and groundwater levels, reducing freshwater flows to estuaries and increasing the extent of saline intrusion of coastal wetlands and aquifers (Saha et al., 2011).

This analysis suggests that for conditions that are likely occur in the future, water quantity challenges could become a critical issue in South Florida. Under scenarios of increased precipitation, the CERP as currently designed could produce desired hydrologic outcomes, but scenarios of decreased precipitation or increased temperature (or both) result in large decreases in flow that would undermine restoration as currently planned.

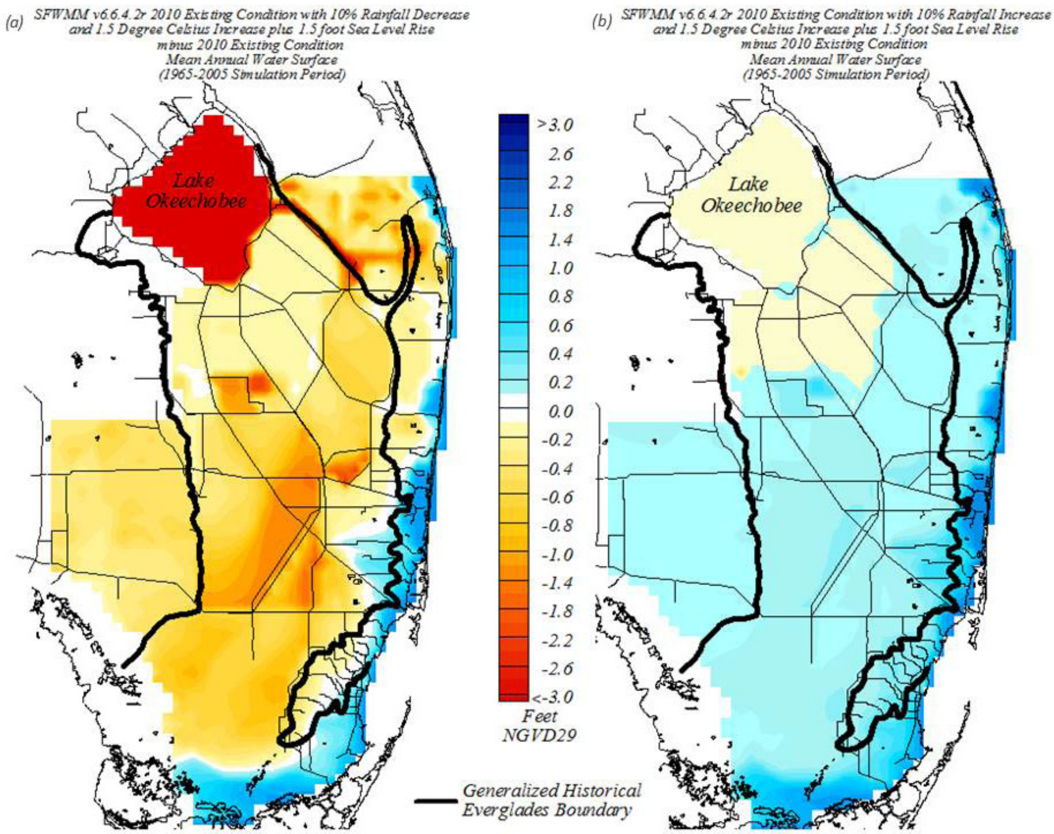

FIGURE 5-6 Hypothetical simulations showing mean annual changes in water stage for (a) 2010 baseline with 10 percent decrease in rainfall, 1.5°C increase in temperature, and 1.5-ft increase in sea level with increases in coastal canal levels (Scenario 5) and (b) 2010 baseline with a 10 percent increase in rainfall, 1.5°C increase in temperature, and 1.5-ft increase in sea level (Scenario 7).

SOURCE: J. Obeysekera, SFWMD, personal communication, 2014.

Implications for Everglades Landscapes

The Everglades landscape is especially sensitive to rising sea level because it has low topographic relief of porous limestone bedrock and is in close proximity to the ocean. The topography of the Everglades is shaped by two components: a dynamic surficial layer of wetland soil and the stable floor of the underlying bedrock basin (Gleason and Stone, 1994; Parker and Cooke, 1944; Petuch and Roberts, 2007). The bedrock rises less than 10 ft above mean sea level around

TABLE 5-2 Changes in Hydrologic Conditions Relative to 2010 Baseline with Three Climate Change Scenarios

	Scenario 4: No change Precip., +1.5°C, 1.5-ft SLR	Scenario 5: 10% Decrease Precip., +1.5°C, 1.5-ft SLR	Scenario 7: 10% Increase Precip., +1.5°C, 1.5-ft SLR
Lake Okeechobee stage	Up to 1.7-ft decrease	Up to 6-ft decrease	Minimal change
Structural inflow to WCA-3	−247 million m^3/yr (−15%)	−704 million m^3/yr (-43%)	+245 million m^3/yr (+15%)
Structural inflow to Everglades National Park	−337 million m^3/yr (−24%)	−820 million m^3/yr (−58%)	+314 million m^3/yr (+22%)

NOTE: SLR = sea-level rise; WCA = Water Conservation Area.

SOURCE: Adapted from Obeysekera et al. (in press), Havens and Steinman (2013).

Lake Okeechobee, while the bedrock underlying the Shark River Slough rises less than 3.3 ft above mean sea level (Parker and Cooke, 1944). Everglades freshwater wetland soils, consisting mostly of organic-rich peat, are generally less than 3.3 ft deep across large portions of the central and southern Everglades, with thicker peats in some areas (e.g., northeastern Water Conservation Area 3 [WCA-3], localized depressions) (Richardson, 2008; Scheidt and Kalla, 2007). Freshwater peat provides essential structure and slope that influence the direction and velocity of water flow in the Everglades as the peat itself is shaped by the distribution and velocity of water across the landscape. These peat soils also support the ridge-and-slough landscape and many tree islands (Box 5-1). Soils within coastal wetlands (e.g., salt marshes, mangroves) contain substantial organic matter along with varying amounts of inorganic sediment washed in by tides, waves, or storm surges and trapped by plant structures (Castañeda-Moya et al., 2013; Krauss et al., 2013).

Freshwater peat in the Everglades represents a dynamic surface that will continue to change in the future through accretion and/or subsidence. Peat accumulates when plant materials are only partially decomposed prior to burial and compaction. Net accretion requires submerged, anaerobic conditions that allow the accumulation of plant material to outpace decomposition and compaction (see NRC, 2012a, for more detail on freshwater peat accretion rates). However, peat is highly susceptible to subsidence under dry conditions. When the water table falls, pore space collapses and oxygen penetrates more deeply into the peat profile, driving more rapid decomposition (NRC, 2012a). A future scenario of decreases or no change in precipitation coupled with increased temperature and evapotranspiration would reduce hydroperiods, accelerating rates of peat decomposition. Fire regimes are also likely to shift under such conditions. While

BOX 5-1
Potential Effects of Reduced Water Inflows on the Ridge-and-Slough Landscape

In the central and southern Everglades, the ridge-and-slough landscape consists of linear ridges that alternate with deeper sloughs; these patterns generally run north-south, parallel to pre-drainage flows (Gaiser et al., 2012). The ridges have characteristically short hydroperiods dominated by sawgrass, while the sloughs have longer hydroperiods dominated by water lilies (McVoy et al., 2011). Tree islands are among the highest and driest habitats in the Everglades (Wetzel et al., 2011), and irregularly punctuate the ridge-and-slough habitat matrix. These islands are floristically diverse, provide critical habitat for many wildlife species, and are sites where nutrients are concentrated (Ross et al., 2006; Wetzel et al., 2011) and sequestered by the dominant tree species (Lejeune et al., 2004).

Flow patterns that initially built and maintained these features, through controls on peat formation and sediment movement (Brandt et al., 2000), have been highly modified, with a resultant compression of the once variable topography (Sklar et al., 2001). Drainage and compartmentalization of the Everglades have led to peat subsidence and conversion to marl prairie habitat on the wet prairie ridges (Davis et al., 2005b), and degradation of tree island communities (NRC, 2012a). Compositional shifts away from tree dominance on the islands have disrupted their capacity to concentrate and store nutrients, with attendant release/leakage of nutrients into adjacent oligotrophic habitats and displacement of sawgrass assemblages by cattails (Wetzel et al., 2009). Without appropriate hydrologic restoration, the future of these features is in jeopardy because water surface levels are currently inadequate to move sediment from slough to ridge (Larsen et al., 2009). Continued disruption of flows, and potentially more severe water deficits with climate change, will drive further deterioration of habitat heterogeneity and increased homogenization of vegetation. In the face of climate change, implementing hydrologic restoration in the central Everglades (see Chapter 3) would help protect the remaining features of this iconic, patterned landscape that provides critical habitat in support of Everglades diversity.

low-intensity surface fires generally have only ephemeral impacts on Everglades vegetation, highly intense fires can result in large losses of inland peat over a short period (Loveless, 1959; Sklar et al., 2001). With existing water management, a scenario of reduced future precipitation would therefore increase rates of freshwater peat loss, further altering the slope and microtopography of the landscape and impacting water depth and flow (Nungesser et al., 2014; see Box 5-1). However, increased precipitation in South Florida would increase mean water depths in the freshwater Everglades wetlands (Figure 5-6), reducing microbial decomposition rates (DeBusk and Reddy, 1998) and thereby promoting peat accretion.

Rates of coastal peat and inorganic sediment accretion or subsidence will directly influence the rate of coastal wetland retreat and other impacts of sea-level rise on the Everglades landscape. Most coastal wetlands possess a limited capacity to keep pace with rising sea level through accretion of organic matter and storm-derived sediment. In coastal wetlands, accretion and subsidence rates vary widely among different depositional settings and with the extent of human impacts (Cahoon and Lynch, 1997; Kirwan and Megonigal, 2013). Sediment cores indicate that the average accretion rate in mangroves is about 1 mm/yr over millennial timescales, with a range of 1-3 mm/yr from Florida and adjacent regions (McKee et al., 2007; Parkinson et al., 1994). More rapid accretion rates are possible over shorter time intervals—accretion rates of 6 mm/yr over several years and even higher rates associated with single storm events have been reported (see Box 5-2). However, the implications of these short-term, local elevation changes in the context of sea-level rise remain poorly understood (Kirwan and Megonigal, 2013). Continual monitoring of surface elevations is, therefore, needed over extended time periods to determine the response of wetland deposits to rising sea level.

BOX 5-2
Climate and Sea-Level Rise Effects on Mangrove Swamps

Mangrove swamps occupy the marine-terrestrial interface and are therefore among the "first responders" to sea-level rise. These communities typically have distinct spatial zonation patterns, which are governed by gradients in salinity and soil conditions (Chen and Twilley, 1999; Egler, 1952). Marine forces are clearly important, but the timing and quantity of freshwater flows from the upper parts of the watershed also influence salinity levels. This interplay can influence water budgets and ecosystem productivity, as elevated salinities during the dry season lead to decreased evapotranspiration and carbon assimilation rates (Barr et al., 2014). Thus, mangrove community distribution on the landscape is shaped bidirectionally through the interplay between freshwater flows and tidal regimes (Davis et al., 2005a), making them excellent indicators of climate change because they are highly vulnerable to marine forces and hydrologic changes in the watershed.

With increasing sea-level rise and water management practices during the 20th century, mangroves have been declining in coverage on the southern Everglades landscape (Wanless et al., 2000), despite inland migration in many areas. A readily visible indicator of this migration is the inland shift in the upper edge of the mangrove/marl prairie ecotone, also known as the "white zone" (Ross et al., 2002; Figure 5-7). These shifts often coincide with displacement and sometimes concurrent inland movement of adjacent freshwater sawgrass communities (Ross et al., 2000) and appear to be facilitated in some cases by fire (Smith et al., 2013). With rising seas, potentially drier conditions that heighten the likelihood of fire at the mangrove-marsh ecotone and increased salinity levels in the estuaries are likely to continue.

continued

BOX 5-2 Continued

The seaward fringes of the mangrove landscape are maintained, in part, through peat accretion, which occurs at the upper end of their tidal range (Scholl, 1964). The ability of mangroves to keep pace with sea-level rise and persist in situ is also uncertain because accretion rates are highly variable and dependent not only on sufficient freshwater inflows to prevent oxidation of existing peat but also factors that control productivity of the vegetation and rates of organic matter inputs that drive accretion rates. In a recent review of mangrove adjustments to sea-level rise across the globe, Krauss et al. (2013) reported soil surface elevation changes ranging from –3.7 to 6.2 mm/yr over several years. Accretion rates as high as 20.8 mm/yr were reported, although subsurface subsidence reduced the total surface elevation change. Storm events were generally responsible for the upper limit of this range. Smoak et al. (2013) reported accretion rates of 5.9 and 6.5 mm/yr in Everglades mangrove forests produced by a single storm-surge deposit, whereas long-term rates (averaged over a 130-year period) of 2.5 to 3.6 mm/yr were measured at the same sites. After Hurricane Wilma, Casteñeda-Moya et al. (2010) reported 5 to 450 mm of sediment deposition in the Shark River mangrove forests—up to 17 times greater than average annual accretion rates of approximately 3 mm/yr. Although storm surges can provide sizeable deposits of inorganic sediment, part of this elevation gain will subsequently be lost through compaction and erosion (Whelan et al., 2009). The challenge for interpreting these short-term accretion rates is to determine their implications for accretion rates over multidecadal timescales or longer in the context of projections of sea-level rise.

In some areas, these systems can keep pace with *current* rates of sea-level rise, but in other places where accretion rates are low, saltwater encroaches and the swamps succumb to the sea (Lodge, 2010). Continued acceleration of sea-level rise will increase their vulnerability, as elevated salinity levels limit productivity and can lead to peat collapse (Chambers et al., 2013a,b). The mangrove zone in Taylor Slough, for example, is highly threatened due to low productivity and, hence, low accretion rates (Gaiser et al., 2006). Future rates of sea-level rise that are sufficiently rapid to impede inland migration may threaten their persistence in the broader landscape.

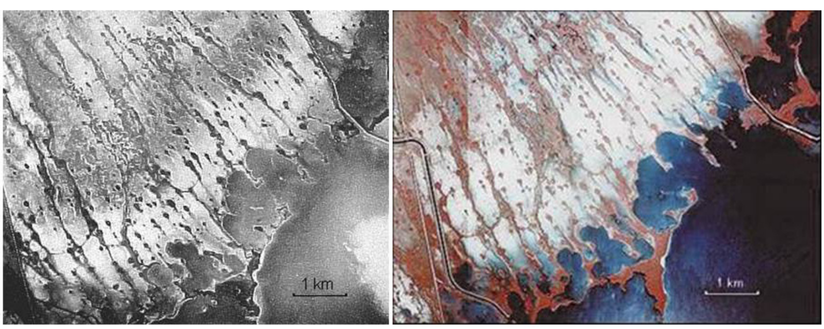

FIGURE 5-7 Images of the coastal gradient from 1940 (left) and 1994 (right) between U.S. Highway 1 and Card Sound Road, illustrating shifts in the "white zone."

SOURCE: Ross et al. (2000).

The USACE scenarios for Key West, Florida (Figure 5-4) describe rates of sea-level rise that increase from historic rates of 2.24 mm/yr to between 8 and 27 mm/yr under low and high scenarios by the end of the 21st century (G. Landers, USACE, personal communication, 2014). Thus, it remains highly questionable whether accretion rates in coastal wetlands will be sufficient to prevent inundation and retreating shorelines in the future or to what extent accretion could at least mitigate the impacts. Assessing current accretion rates in both the coastal and freshwater wetlands of the Everglades and understanding the factors that contribute to their variability are high priorities for research. Efforts are currently under way in the Everglades to monitor changes in surface elevation across a network of control points using customized elevation gauges to assess accretion rates in the context of sea-level rise (Box 5-3).

The phenomenon of "peat collapse" in coastal wetlands (Cahoon et al., 2003; Day et al., 2011; DeLaune et al., 1994) poses significant concerns for Everglades management and restoration in the face of climate change. Peat collapse has been used to describe the conversion of coastal marshes to open water as well as sudden land subsidence in salt marshes and mangroves (Figure 5-10). The peat deterioration can release a large amount of sequestered carbon (as carbon dioxide and methane) and nutrients, such as phosphorus, stored in the soil profile (Bouillon et al., 2008; Nichols et al., 2007). An important suspected mechanism for peat collapse is increasing saltwater intrusion from sea-level rise and tropical storm surges and associated high sulfate concentrations that alter microbial organic matter decomposition pathways and rates (Chambers et al., 2014; Erickson et al., 2007; Weston et al., 2006). However, additional agents for lowering peat surface elevations could include mechanical damage to the vegetation or peat skeleton by high winds or storm surges (e.g., Doyle et al., 1995; Kirwan and Guntenspergen, 2010; Smith et al., 1994, 2009), nitrogen inputs that enhance microbial decomposition of root structures (Deegan et al., 2012; McKee et al., 2007), and loss of groundwater inputs (Whelan et al., 2005).

Implications for Water Quality

Changes in climate can alter linkages between coupled hydrologic and biogeochemical cycles that are critical to the functioning and persistence of wetland ecosystems (Reddy and Delaune, 2008; Reddy et al., 2010; Rivera-Monroy et al., 2007). Shifts in the frequency, timing, and intensity of rainfall events can affect the transport of sediments, nutrients, and other constituents from wetlands to downstream aquatic ecosystems. Perturbations in hydroperiod and hydrologic and pollutant loading rates can significantly affect vegetation, algae, microbial and animal communities in native and constructed wetlands

BOX 5-3
Measuring Peat Accretion and Subsidence

Wetlands have a dynamic land surface that continually rises and falls through the interplay of physical, chemical, and biological processes. Key questions remain as to what extent rates of peat and sediment accretion can keep pace with the rapid rise in sea level projected for the 21st century.

Two different approaches have been used to measure accretion and subsidence rates over contrasting timescales. The traditional method is based on the analysis of sediment cores that can be dated into discrete time slices of 0-50 years by ^{137}Cs, 0-150 years by ^{210}Pb, and 500-40,000 years by ^{14}C. Accretion rates can then be calculated by dividing the length of each section by its total age, although much finer age resolution is often possible for a ^{210}Pb chronology. The alternative method directly measures shorter-term changes in surface elevation by means of custom gauges (e.g., the sediment-erosion table-marker horizon [SET]-MH system of Cahoon et al., 1995; Webb et al., 2013; Figures 5-8 and 5-9). Although the different approaches are complementary, they

FIGURE 5-8 A sediment elevation table (SET) used to measure changes in the elevation of the soil surface in a mangrove forest in Everglades National Park.

SOURCE: U.S. Geological Survey, http://fl.biology.usgs.gov/Science_Feature_Archive/2010/monitoring_enp/monitoring_enp_gallery.html.

provide different measures of accretion rates that are specific to a discrete timescale. Any comparison of accretion rates needs to consider the general tendency for these rates to decline over longer time spans because of the continual loss of pore waters (by compression) and organic matter (by decomposition). These processes are most rapid in the upper portion of a sedimentary profile (e.g., Bemer, 1980; Glaser et al., 2012), and therefore, caution should be exercised in extrapolating short-term rates to longer timescales.

FIGURE 5-9 Measurement of soil accretion using the marker horizon method in Everglades National Park. In this method, researchers place a layer of feldspar clay (visible as a white layer) on the surface of the marsh and later return to measure the soil that has accumulated. The marker horizon method is often used in conjunction with a sediment elevation table (SET) to measure total soil accretion or erosion.

SOURCE: U.S. Geological Survey, http://fl.biology.usgs.gov/Science_Feature_Archive/2010/monitoring_enp/monitoring_enp_gallery.html.

FIGURE 5-10 Peat collapse at northern Cape Sable, Everglades National Park.

SOURCE: Wanless and Vlaswinkel (2005).

(stormwater treatment areas), and associated biogeochemical processes that ultimately have significant effects on water quality. Reduced precipitation and increased evapotranspiration will decrease the water content of wetland soils. Dry conditions promote the oxidation of soil organic matter, which results in the mineralization of associated chemical elements (Holden et al., 2004; Reddy et al., 2006). Also, oxidation of sulfides can occur, which can decrease soil pH and facilitate the mobilization of phosphorus bound to calcium carbonate (Reddy and DeLaune, 2008). When these dry areas are rehydrated, dissolved and particulate forms of carbon, phosphorus, nitrogen, sulfur, and mercury are released, increasing nutrient and contaminant loads to downstream habitats (Bates et al., 2000; Strober et al., 1995). Increases in wet-dry cycles accelerate biogeochemical cycling, and element availability and loss, which could lead to exceedences of Everglades nutrient criteria.

Climate-change-induced temperature increases influence several biogeochemical processes of wetlands and water quality. For example, increased temperature can increase primary productivity, organic matter decomposition, nutrient regeneration, and greenhouse gas emissions, and alter the composition and diversity of biotic communities (Carney et al., 2007; Watts et al., 2010). An increase in rates of these biogeochemical processes is likely to increase overall export of nutrients, dissolved organic matter, and associated contaminants and impact downstream water bodies (Qualls and Richardson, 2003; Reddy et al., 1999).

Sea-level rise that exceeds the rate of vertical soil and sediment accretion causes increased salinity stress in freshwater wetland communities and shifts ecosystems from freshwater to brackish (Koch et al., 2012; Saha et al., 2011; discussed in the next section). Increased sulfate inputs can potentially increase organic carbon mineralization and carbon dioxide emissions while decreasing methane emissions (Chambers et al., 2011, 2013a,b, 2014; Weston et al., 2011). These biogeochemical changes can increase the release of bioavailable nutrients (e.g., nitrogen, phosphorus), ultimately degrading water quality (Chambers et al., 2013a, 2014). In coastal phosphorus-limited wetlands, additional inputs of phosphorus from storm surge deposits can actually enhance the productivity of mangrove forests (Castañeda-Moya et al., 2010).

Implications for Everglades Biota

The effects of climate change and human-driven alterations of freshwater flows are already unfolding in the Everglades (Gaiser et al., 2012). Increased rates of sea-level rise have decreased the areal extent of several Everglades habitats, changed the distributions of many species, and driven inland migration of coastal vegetation (Box 5-2; Willard and Bernhardt, 2011). The *rate* and *nature* of future change remain unclear, however, because of uncertainty in downscaled climate change forecasts for the Everglades (discussed previously in this chapter), and the poor understanding of the capacity of ecological systems to respond to these impacts. Additionally, the multiple, interacting factors (e.g., increases in temperature, sea-level rise, changes in the quantity and distribution of precipitation, increases in atmospheric carbon dioxide and associated responses in biogeochemistry and ecology) are likely to generate complex effects that are difficult to fully predict.

Changes in precipitation, temperature, sea-level rise, and atmospheric carbon dioxide, in conjunction with anthropogenic alterations to hydrology, will collectively dictate the future environmental templates to which species respond. In climate change scenarios where sea-level rise is marked, temperature is elevated, and precipitation is reduced (Figure 5-6a), shortening of hydroperiods should occur, with concomitant shifts toward less flood-tolerant vegetation and peat decomposition. The past century of Everglades water management offers numerous lessons about the adverse ecological impacts of reduced water flows (see Box 5-1 for one example). In scenarios with increasing rainfall (Figure 5-6b), freshwater flows can continue to maintain the diverse array of habitats in the Everglades and abate saltwater intrusion of coastal wetlands, essentially holding the sea at bay (Gaiser et al., 2012, Saha et al., 2012).

Changes in the composition and structure of Everglades communities are expected as species respond to changing climate. Species exposed to a warmer and perhaps drier Everglades subject to sea-level rise are likely to shift in distribution across the landscape in accordance with their climatic envelopes. For example, where salt marsh assemblages interface with mangroves, the northern edge of the mangrove distribution is controlled by the lack of cold tolerance. With increasing temperatures, mangroves are likely to advance northward with the freeze line (Cavanaugh et al., 2014), perhaps at the expense of transitional, brackish marsh assemblages (Stevens et al., 2006). Species with broad physiological tolerances will be the slowest to respond to increases in temperature, whereas those with narrow physiological ranges will be impacted more immediately. Drier conditions in the Everglades are also likely to reduce the densities of aquatic species that rely upon refugia during the dry season (e.g., fish and invertebrates; Catano et al., 2014), with consequent negative impacts to wading birds and other species that depend upon this prey base. With continued environmental changes, species eventually reach tipping points, beyond which they will either shift spatially on the landscape or gradually decline in abundance.

Low-lying coastal wetlands are sentinels of climate change impacts (Brinson et al., 1995; Scavia et al., 2002). They may be initially capable of coping by adjusting physiologically or vertically through biophysical processes to escape submergence (Cherry et al., 2009; McKee and Cherry, 2009; Morris et al., 2002). Where coastal species cannot keep pace with sea-level rise through vertical adjustment, their distributions contract at the seaward edge, and upslope expansion of species distributions must occur or their populations will gradually decline and disappear from the landscape (Brinson et al., 1995; Craft et al., 2009; Donnelly and Bertness, 2001; Williams et al., 1999). Thus, upgradient freshwater wetlands may be gradually converted to brackish marshes and finally to salt marshes in response to increased salinity. The rate and direction of response will be determined by both stress tolerance at their seaward edge and competitive ability at the inland edge of their distributions (Crain et al., 2004; Ervin and Wetzel, 2002; Kim et al., 2011). Among the biogeochemical processes affected by saltwater intrusion are increased sulfate inputs, which can increase the potential for sulfide toxicity to plants. Bidirectional compression could result if species are increasingly limited by environmental stress at the lower or upper ends of their distributions, leading to coastal "squeezing" (Shirley and Battaglia, 2006, 2008).

Increased hurricane intensity (Bender et al., 2010; Blake et al., 2011) could also have important implications for Everglades biota. Intensified storms would drive changes in light and water availability to plants (Bianchette et al., 2009; Guntenspergen et al., 1995) and increase storm surges and associated wrack deposition (Blake et al., 2011; Tate and Battaglia, 2013), salt burning (Cahoon, 2006; Lam et al., 2011), and wind-driven damage to forest canopies (Lam et al., 2011; Rodgers et al., 2009).

A poorly understood but potentially important aspect of global change is the fertilization effects of increases in atmospheric carbon dioxide concentrations on wetland vegetation (Rasse et al., 2005). This process can enhance primary productivity and peat accretion (Erickson et al., 2013; Krauss et al., 2013) and lead to heightened sequestration of carbon, nitrogen, phosphorus, and mercury. Carbon dioxide fertilization effects could ameliorate several of the adverse consequences of climate change. Some plants, for example, reduce the size of pores that allow CO_2 to enter leaves for photosynthesis, while still increasing carbon assimilation. This adjustment leads to reduced evapotranspiration (de Boer et al., 2011) and increased water-use efficiency (Li et al., 2010), potentially offsetting some effects of rising temperature. However, this trend is unlikely to increase indefinitely because the responses of individual plant species will be bounded by their genetic capacity to adapt structurally to future atmospheric carbon dioxide levels (Lammertsma et al., 2011). Shifts in plant community composition are also expected because CO_2 fertilization can influence the timing of life-cycle events (e.g., flowering) (Springer and Ward, 2007), germination patterns (Mohan et al., 2004), and salinity tolerance of plants (Rozema et al., 1991). Grasses and sedges with a photosynthetic pathway that can better utilize increased CO_2 and photosynthesize faster (e.g., sawgrass) may increase in abundance over similar species that use alternative pathways (Drake et al., 1996; Pearlstine et al., 2010). The effects of elevated CO_2 are complicated, however, by temperature and precipitation regimes (Bjorkman et al., 1974; Raven, 2001) and may be relatively short-lived in some species as they plateau in their responses due to nutrient limitations (Reich et al., 2006). An improved quantitative understanding of carbon dioxide fertilization effects on wetland and marine ecosystems of South Florida would help refine predictions of the impacts of changing climate.

IMPLICATIONS FOR THE CERP AS ORIGINALLY DEVELOPED

Rising sea level and changes in evapotranspiration and precipitation could have significant effects on the success of the CERP.

Implications of Sea-Level Rise

Sea-level rise is already impacting shallow coastal marsh habitats (Figure 5-7), altering the salinities of surface waters and groundwaters, and changing the structural and operational requirements of coastal water management infrastructure (see Figure 5-11). To consider how future sea-level rise might affect the CERP, the committee considered three projects or areas targeted for CERP restoration: Picayune Strand, Biscayne Bay Coastal Wetlands, and Florida Bay. Each illustrates a different aspect of how sea-level rise may affect restoration.

Picayune Strand

In the Picayune Strand area in southwest Florida, drainage for a failed housing development caused the broad-scale conversion of freshwater wetland forests and marshes to communities dominated by species better adapted to drier conditions. The canal system increased the incidence of wildfires and oxidation of peat, led to proliferation of invasive species, and caused some inland expansion of mangroves (Chuirazzi and Duever, 2008). The objective of the Picayune Strand CERP project is to plug canals, rehydrate the area, and restore freshwater wetland habitat (see Chapter 4). The potential effects of sea-level rise stem from the fact that the project is a low-lying freshwater wetland, with ground surface elevations ranging from 3 to 10 ft NAVD, with several sloughs 0.5-2 ft lower in elevation (USACE, 2013e). The groundwater table can be as low as 2 ft (0.6 m) above sea level (Chuirazzi et al., 2012). USACE (2013e) determined that with 2 ft of sea-level rise (approximately the USACE intermediate local sea-level rise scenario in 2100), 9 percent of the project area would be inundated. Thus, the Picayune Strand project is likely to be minimally impacted by intermediate sea-level rise projections, but the extent to which project goals are affected remains unknown.

Shoreward portions of the soils in Picayune Strand will become increasingly impacted by saline intrusions with sea-level rise. As sea level rises, the groundwater salinity gradient would move inshore along with associated plant and thus animal communities. These effects have not yet been assessed (USACE, 2013e), although they could be determined using a coupled surface-water-flow variable-density groundwater model (e.g., Langevin et al., 2005). However, elevated groundwater stages resulting from the project will likely reduce the rate of salinity intrusion (compared with a future scenario without the project). The Picayune Strand project is therefore likely to delay ecological transitions from native freshwater wetland vegetation (e.g., cypress forest, sawgrass marshes) to brackish marshes and enhance the resilience capacity of coastal wetlands to cope with sea-level rise.

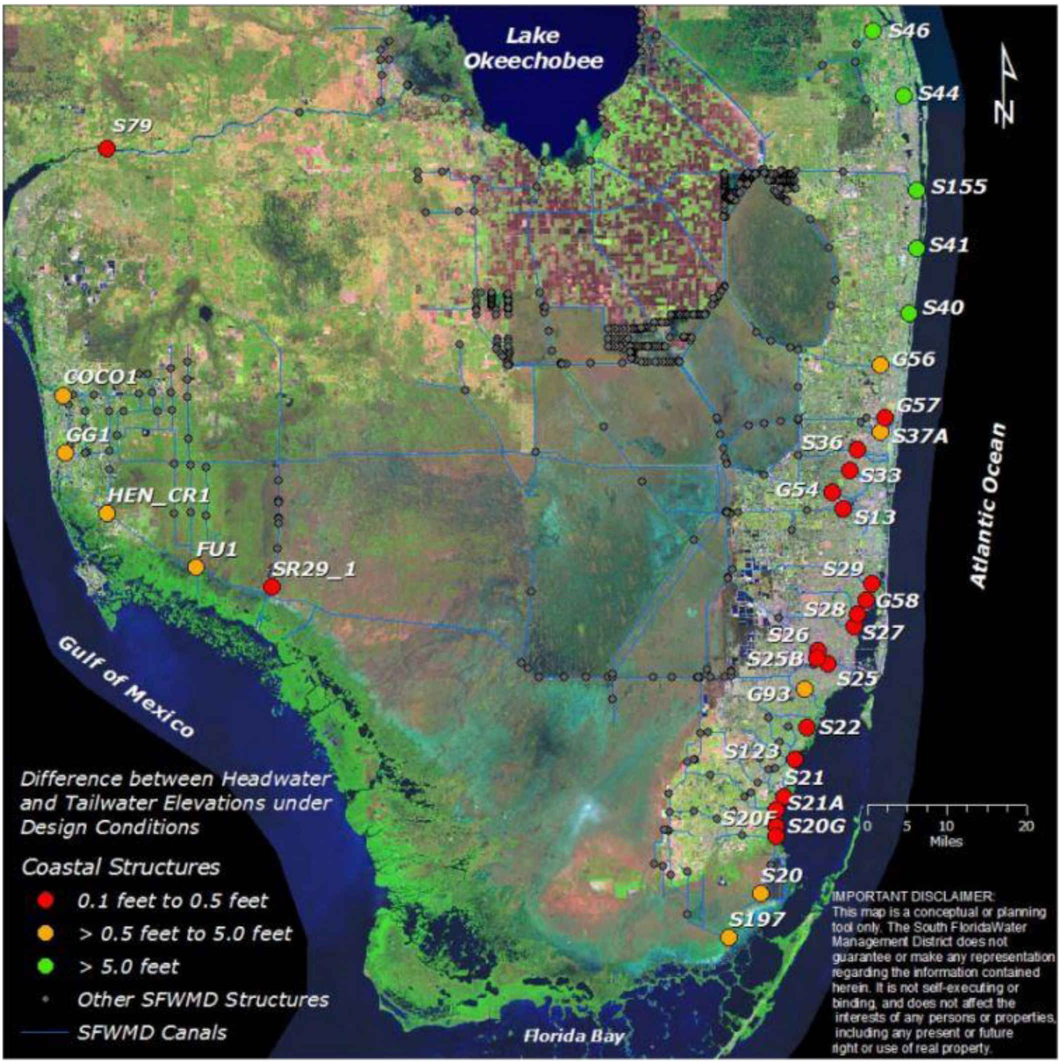

FIGURE 5-11 Vulnerability of SFWMD coastal structures to sea-level rise. High-vulnerability structures are red, medium-vulnerability structures are orange, and low-vulnerability structures are green. Those that are vulnerable to sea-level rise may require the addition of pump stations in place of gravity-driven control structures.

SOURCE: SFWMD (2009a).

Biscayne Bay Coastal Wetlands, Phase 1

The Biscayne Bay Coastal Wetlands Phase 1 project is designed to rehydrate coastal wetlands impacted by canal drainage and thereby improve salinity distributions in nearshore regions of Biscayne Bay (see Chapter 4). The impacts of various sea-level-rise scenarios on project benefits are shown in Table 5-3. At 2 ft of sea-level rise (the high scenario for 50 years and intermediate scenario for 100 years), less than 50 percent of the overall project benefits to freshwater and saltwater benefits are projected, although 88 percent of the nearshore salinity benefits remain (USACE and SFWMD, 2012b). On the basis of these analyses, planners concluded that project benefits over the 50-year planning horizon were sufficient to recommend the project, noting that the project would "delay future degradation of coastal wetland habitat caused by increased sea level conditions by redirecting freshwater flows into critical habitat" (USACE and SFWMD, 2012b). However, at the highest levels of sea-level rise considered over a 100-year time frame, all of the project benefits are lost (Table 5-3). USACE and SFWMD (2012b) state:

> The effects of SLR on project benefits that occur after the 50-year project lifespan should be treated the same as benefits that occur after the project lifespan. In other words, effects that occur after the 50 year project lifespan should not be considered for plan selection or determination of project viability.

While consistency of planning constraints seems reasonable, the project highlights the limitations of 50-year planning horizons in the context of climate change.

Compared to the Picayune Strand Project, which represents a large area that is likely to gradually transition from freshwater to brackish wetlands, the Biscayne Bay Coastal Wetlands, Phase 1 project represents a narrow strip of coastal wetlands that are restricted from migrating landward by the L-31E levee and existing development (Figure 4-13). Thus, unlike Picayune Strand, all project benefits are likely to be lost at extreme levels of sea-level rise, and significant benefits are lost at likely levels of sea-level rise over the 21st century (2 ft; Table 5-3). However, these findings represent rather simplistic analysis of increments of sea-level rise overlain upon geographic information system maps, with no modeling of salinity changes expected in groundwater or nearshore areas of Biscayne Bay. Assessing the value of the project in the context of sea-level rise necessitates a rigorous analysis of existing ecosystem conditions and trends, the impacts of various sea-level-rise scenarios on project performance measures, and the extent to which the project could mitigate the impacts of sea-level rise.

TABLE 5-3 Projected Reduction in Biscayne Bay Coastal Wetlands Benefits by Component and Ecozone Under Several Sea-Level-Rise Scenarios

Estimated Percent Benefit Reduction at 3" of SLR	Percent Reduction in Freshwater Wetland Benefits	Percent Reduction in Saltwater Wetland Benefits	Percent Reduction in Nearshore Salinity Benefits
Estimated Percent Reduction in Benefits with 3" of SLR *			
Deering	0%	2%	0%
Cutler	0%	2%	0%
L-31E	0%	10%	0%
Estimated Percent Reduction in Benefits with 7" of SLR *			
Deering	0%	4%	0%
Cutler	0%	4%	0%
L-31E	0%	20%	0%
Estimated Percent Reduction in Benefits with 9" of SLR *			
Deering	0%	5%	0%
Cutler	0%	5%	0%
L-31E	0%	30%	0%
Estimated Percent Reduction in Benefits with 24" of SLR			
Deering	100%	10%	0%
Cutler	100%	10%	0%
L-31E	50%	100%	25%
Estimated Percent Reduction in Benefits with at 68" of SLR			
Deering	100%	100%	100%
Cutler	100%	100%	100%
L-31E	100%	100%	100%

* Reduction in benefits for SLR less than 1 ft were estimated by interpolating between the estimated losses at 0 ft of SLR and 1 ft of SLR.

SOURCE: USACE and SFWMD (2012b).

Florida Bay

Florida Bay provides a large-scale example of the implications of sea-level rise for restoration. Florida Bay is a unique estuarine system with salinity determined by evaporation and precipitation as well as freshwater inputs. Water management changes in the South Florida ecosystem over the past 60 years have reduced freshwater inflows to the bay such that it can be seasonally hypersaline in the middle parts of the bay (Figure 5-12; Kelble et al., 2007; Nuttle et al.,

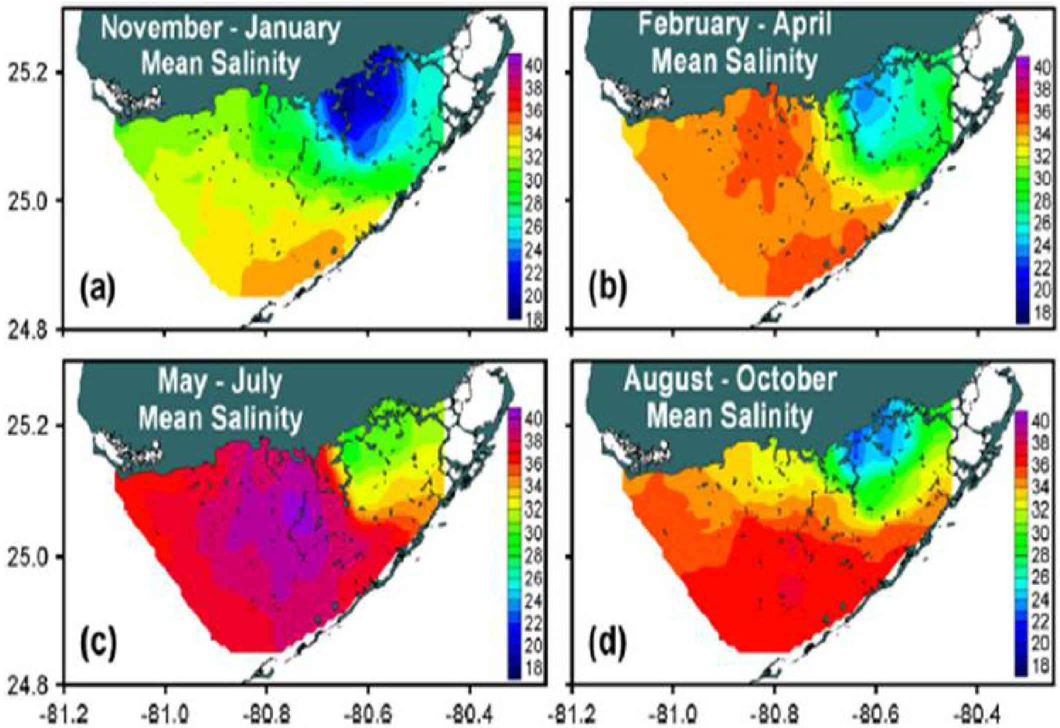

FIGURE 5-12 Mean salinity distributions in Florida Bay, showing conditions of hypersalinity (c).

SOURCE: Kelble et al. (2007).

2000). In 1987, a widespread collapse of seagrasses occurred, which is generally attributed to hypersalinity (Deis, 2011).

In general, the large-scale increases in sea level will cause Florida Bay to become deeper and incorporate portions of the southern Everglades. Increases in sea level of 2 ft (roughly the intermediate USACE local sea-level rise projection for 2100) would change the average depth of Florida Bay from 3 to 5 ft, presumably causing a significant change in salinity (e.g., Monismith et al., 2002). Sea-level rise could increase salinities throughout much of present-day Florida Bay during the wet season but could decrease occurrences of hypersalinity in central and northern Florida Bay through dilution. Any potential increase in salinity is of concern to the restoration, given that one of the objectives of the CERP is to reduce salinities in Florida Bay through increased freshwater inflow to more closely mimic pre-drainage hydrology. However, the effect of sea-level rise on Florida Bay salinity is significant enough that restoration goals will need to be revisited under various sea-level-rise scenarios.

To fully evaluate effects of sea-level rise on the conditions and restoration of Florida Bay, a fully three-dimensional (3-D) circulation model of the bay, such as that described by Zheng and Weisberg (2012), is needed, albeit one coupled with a regional hydrologic model. Given the importance of precipitation and surface flows to Florida Bay, ideally such a model would also include a regional atmospheric model (e.g., Maxwell et al., 2011). Neither existing empirical models of salinity in Florida Bay (FATHOM) nor 2-D models properly depict the physics associated with sea-level rise (see also NRC, 2002a).

Water Budget Implications

Although future climate conditions are uncertain, the seven hypothetical scenarios presented previously in the chapter (see Implications for Everglades Hydrology; Obeysekera et al., 2014) highlight the range of challenges that Everglades restoration could face. Increases in rainfall represent the best-case scenario for the ecosystem, with increases in water flow (Table 5-2, Figure 5-6b). The combination of increased coupled evapotranspiration, decreased precipitation, and rising sea level over future decades represents the worst-case scenario among those modeled. Under this scenario, water levels would decline throughout the system (Figure 5-6a) and unmet water supply demands from agriculture and urban population centers would intensify existing conflicts over water supply. Declining groundwater levels combined with sea-level rise would further exacerbate saltwater intrusion, compromising urban water supplies (Figure 5-13) and impacting coastal ecosystems. Although no modeling has been done to quantify the effects of the CERP as currently planned under such a scenario, it is possible that the benefits of the CERP would be surpassed by the negative impacts of reduced precipitation and increased evapotranspiration. However, the scenario of potential future decreases in flow associated with decreases in precipitation and increased evapotranspiration amplify the urgency to accelerate projects that increase storage and move more water southward to enhance the resilience of the ecosystem under future conditions.

Given the competing demands of water supply, environmental restoration, and flood control, it is clear that providing as much flexibility as possible to water managers will be critical to the success of the CERP. In many systems, flexibility of operation is achieved through water storage (e.g., reservoirs, aquifer storage). For example, in the western United States, large reservoirs such as Lake Mead or Lake Shasta buffer water supplies against interannual variations in precipitation as well as reducing high flows so as to prevent floods. In South Florida, existing

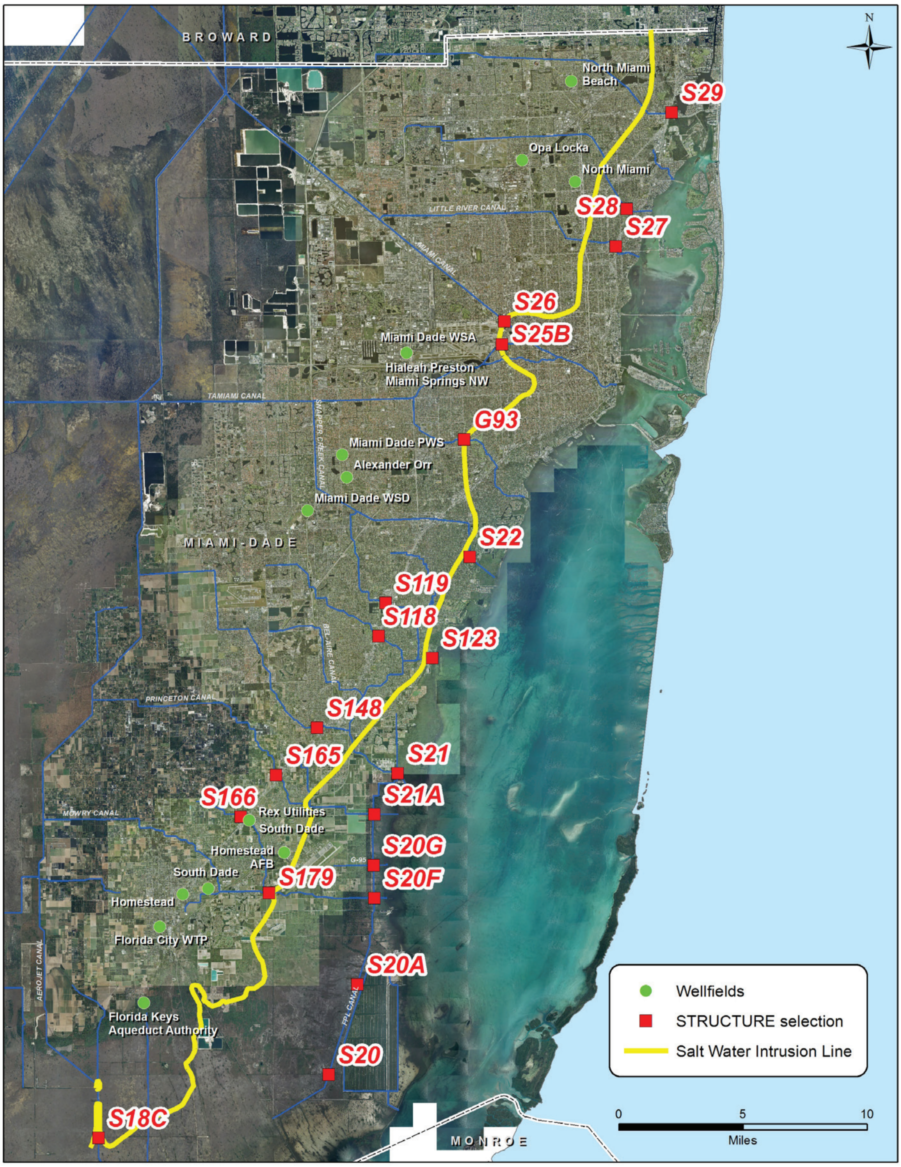

FIGURE 5-13 Saltwater intrusion interface in Miami-Dade County, and proximity to water supply well fields.

SOURCE: J. Obeysekera, SFWMD, personal communication, 2014.

operational flexibility is achieved by operation of the extensive network of channels and structures and through storage in Lake Okeechobee, although the lake is highly constrained by ecological and dam safety considerations. The CERP, if fully constructed, would add substantial storage via aquifer storage and recovery and several large reservoirs, but it is unknown whether this storage would be sufficient to sustain the ecosystem under the worst-case climate scenarios.

In the face of possible changes in hydrologic conditions and sea-level rise, increasing water storage to provide more reliable flow to the Everglades as well as to water users could provide useful operational flexibility. For example, maximizing the ability to capture and store water in surface-water reservoirs during wet periods that would otherwise be discharged through the northern estuaries would also provide water for environmental and human uses during dry periods and increase groundwater recharge to mitigate salinity intrusion into South Florida aquifers.

Implications on CERP Goals

As discussed in Chapter 2, the CERP generally aims to restore the "essential hydrological and biological characteristics that defined the undisturbed South Florida ecosystem" (33 CFR § 385.3). The Natural Systems Model has played an important role in shaping restoration goals. However, under the worst-case scenarios of climate change and sea-level rise in the Everglades, some CERP goals may not be attainable, and others may need to be revisited considering substantially changed conditions under sea-level rise (e.g., Florida Bay). Although the CERP, as finalized in 2000, did not incorporate climate change effects on restoration outcomes, there is broad recognition in the research and management communities of the multiple facets of climate change and their impacts (Aumen et al., in press). Estimates of sea-level rise and downscaled climate projections and their ecological impacts will continue to be refined with future research and incorporated into management planning. Restoration planners will need to continuously revisit whether pre-drainage hydrologic and ecological targets still provide useful restoration goals, and to develop alternative goals in light of what is feasible and sustainable under future conditions. Meanwhile, changes in temperature and precipitation could reduce regional water availability, necessitating additional attention to water sustainability for built and natural systems to address potential water supply challenges unforeseen when the CERP was originally developed.

Literature on climate change is replete with studies of probable and possible impacts of climate change on water resources in various geographic regions. Work of that kind in South Florida is impressive. Although there are many recommendations to incorporate effects of climate change in water resource planning, far fewer in-depth studies that suggest how that can be accomplished are available than the assessments of impacts of climate change. Among the more complete publications addressing adaptation is in the context of water management in California, especially the *Climate Change Handbook for Regional Water Planning* (CDM, 2011) developed for the California Department of Water Resources, USACE, EPA, and Resources Legacy Fund and the *2009 California Climate Adaptation Strategy* (California Natural Resources Agency, 2009). Hanak and Lund (2012) and the National Research Council (NRC, 2012c) discussed progress toward incorporating climate change in managing California's water resources.

Those documents describe an array of management options to adapt to climate change. Broad categories such as aggressive pursuit of water use efficiency, enhancement and restoration of ecosystems, increased storage, improved conveyance and transfers, management of land use, and optimization of system operations are followed by more detailed measures. Many of those actions have already been taken in South Florida, some of which are directly targeted by CERP and non-CERP projects. Miami-Dade, West Palm Beach, and other urban areas have adopted progressive increasing block-rate pricing and other conservation measures to manage demand for public water supplies. Much of the degradation of the Everglades and demands on its services are due to external forces. Although development of a comprehensive strategy to adapt to climate change in South Florida is beyond the scope of the CERP, a more complete strategy for restoration of the Everglades and adaptation to climate change would need to address management of demand and supply for water and related land resources within and external to the Everglades ecosystem. Ongoing research through the 5-year South Florida Water, Sustainability, and Climate Project[5] led by Florida International University and funded by the National Science Foundation may help inform such planning.

PLANNING TO ADDRESS CLIMATE CHANGE

CERP planners are just beginning to address climate change impacts. USACE project planning guidance (USACE, 2011e) specifically includes a method for estimating sea-level rise in project design, and the USACE requires analysis of three sea-level rise scenarios for all Civil Works projects (discussed earlier for Biscayne Bay Coastal Wetlands and Picayune Strand). To date, however, such analysis has been limited to the project level, where sea-level rise is used to design coastal structures and adjust project benefits through simple analyses of land lost due to inundation under different sea-level rise scenarios (Figure 5-14). Early analyses primarily examined changes in benefits over 50 years (USACE

[5] See http://sfwsc.fiu.edu/.

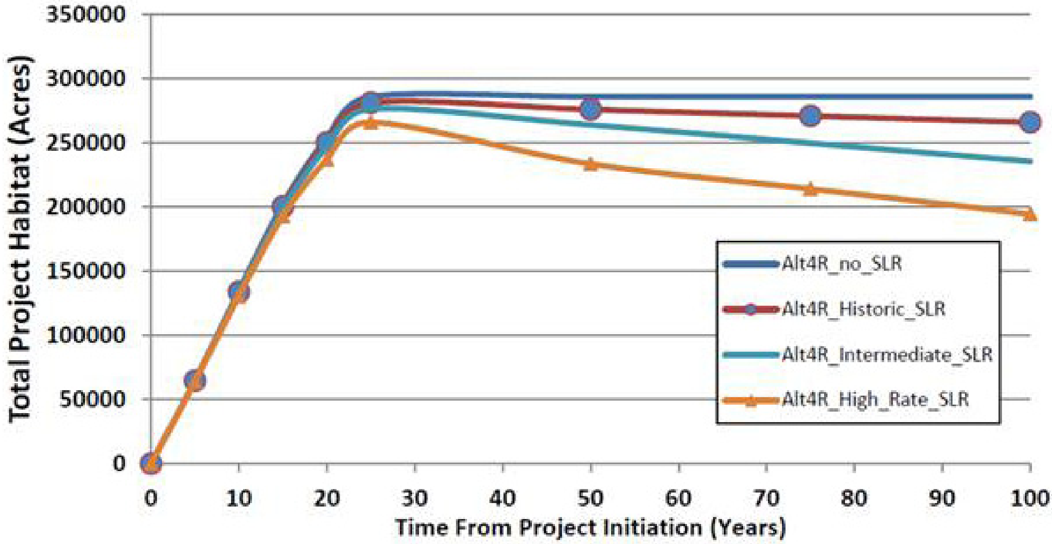

FIGURE 5-14 Projected impact of sea-level rise on overall habitat improvements (in habitat units) provided by the Central Everglades Planning Project under different scenarios (see also Chapter 3 and Figure 5-4). The analysis considers the reduction in overall project-derived benefits due to seawater inundation of freshwater wetlands in the project area.

SOURCE: USACE and SFWMD (2013b).

and SFWMD, 2012b), but more recent analyses considered changes in benefits over 100 years—a more useful time horizon in the context of climate change, sea-level rise, and restoration investments of the magnitude of the CERP (USACE, 2013e; USACE and SFWMD, 2013b). To the best of the committee's knowledge, models capable of computing salinity fields in surface waters and groundwater have not been used in the CERP to assess the effects of sea-level rise on salinities. Nonetheless, suitable models (e.g., Langevin et al., 2005) currently exist that could be coupled to surface-water models.

The USACE-required sea-level-rise analyses typically are performed at the end of the planning process, after the desired project alternative has been selected. However, CERP project planning would benefit from broader incorporation of climate and sea-level-rise scenarios during project development. Despite uncertainty associated with climate projections, more rigorous scenario planning (NPS, 2013; Peterson et al., 2003; Polasky et al., 2011) provides a framework for project-level decision making. Such planning would consider the effects of climate change on performance measures for various alternatives, quantify the specific benefits associated with mitigating the impacts of climate change, and identify the costs and benefits of additional flexibility to address climate change uncertainties (see also Chapter 3).

System-Level Considerations

NRC (2008) emphasized that in light of climate change, restoration efforts "are even more essential to improve the condition of the South Florida ecosystem and strengthen its resiliency as it faces additional stresses in the future." However, this perspective does not imply that restoration should continue unchanged. To date, as far as the committee is aware, CERP planners have not made any major adjustments at the systemwide level in light of climate change and sea-level rise. Accurate precipitation or temperature projections are not available that can serve as a basis for major changes in the CERP because of uncertainty associated with future storylines driving greenhouse gas emissions and land cover, GCM simulations, and regional downscaling. However, sea-level-rise projections are available that should form the basis for project prioritization, considering project benefits in the context of sea-level-rise and the potential for the CERP to delay or mitigate sea-level-rise impacts. Existing scheduling and prioritization as reflected in the Integrated Delivery Schedule are largely driven by project authorizations (see Chapter 4), but wise expenditures of funds necessitates periodic reassessment of the priority of previously authorized projects in light of improved understanding of future conditions.

Considering the uncertain projections of future precipitation and temperature, systemwide analysis across an array of future scenarios is critical. Current hydrologic and ecosystem modeling for the CERP is based solely on historical hydrology and does not address potential effects of long-term changes in temperature, precipitation, evapotranspiration, and sea-level rise. Additional Everglades climate-sensitivity analyses are needed to anticipate challenges, identify potential contingencies and system flexibilities to mitigate climate-related changes, and target additional research efforts toward critical uncertainties. The recent scenario analysis by Obeysekera et al. (2014) provides a useful first step, although the scenarios selected were purposefully simplistic. More recently, Swain et al. (2014) used a hydrodynamics model to examine the effects of changes in sea level and precipitation on freshwater flows, surface-water salinity, and inundation within Everglades National Park and coastal areas to the east. Additional modeling of this kind is needed to analyze the sensitivity of the South Florida ecosystem to seasonal and long-term precipitation and temperature variability to enhance the understanding of possible climate impacts. This modeling should be used to examine the possible effects of climate change on Everglades hydrology and ecology with and without the implementation of CERP. Scenario-based modeling could also be used to explore the impacts of specific projects to identify which projects are most resilient to climate change and/or which projects mitigate the impacts of climate change under a range of scenarios. These model simulations should be refined as new data become available that reduce uncertainties in model forcings and hence model predictions.

Modeling Tools

CERP planning in the context of sea-level rise and climate change may require the development of new modeling tools or the improvement and application of existing tools. Improved salinity modeling tools are needed, such as 3-D circulation models for the major estuaries coupled to regional hydrologic models, as discussed previously in this chapter. Understanding salinity intrusion in coastal wetlands and aquifers used for urban water supply requires a surface-water flow model coupled with a variable-density groundwater flow model (e.g., Tides and Inflows in the Mangroves of the Everglades [TIME] v. 2.0). The TIME model domain includes the terrestrial areas of Everglades National Park, its coastal mangrove zones to the south and east of the park, and the northern edge of Florida Bay, but it does not include Biscayne Bay. Currently, the model is being refined for assessing sea-level rise and restoration alternatives in Everglades National Park (Bahm and Fennema, 2013). For variable density modeling of saltwater intrusion, the SFWMD uses a coupled MODFLOW/SEAWAT model (Harbaugh et al., 2000; Langevin et al., 2003; Restrepo and Montoya, 2008).

Sea-level rise will lead to landward shifts of the interface between fresh groundwater and saltwater, thereby increasing the potential of saltwater intrusion (Figure 5-13). Sea-level rise will also increase groundwater levels, as the aquifer system responds to new conditions along its seaward boundary. This water-table adjustment will be greatest along the coast, but will propagate inland. Because groundwater and surface-water systems are tightly connected in South Florida, rising water tables will alter the rates and volumes at which excess water can be conveyed through canals and natural waterways of the Everglades. The ability to forecast these sea-level-induced changes in groundwater flow and groundwater/surface-water interactions is requisite to informing the design and operation of water control infrastructure under the CERP.

IMPORTANCE OF EVERGLADES RESTORATION IN CONTEXT OF CLIMATE CHANGE

Systems such as the Everglades that are highly vulnerable to the impacts of climate change are likely to benefit from management strategies that incorporate maximizing ecological resilience (or the capacity to respond to environmental changes) as a goal (Millar et al., 2007; Tompkins and Adger, 2004). The ability of these systems to respond to the impacts of climate change depends upon their capacity to rebound from disturbance as well as to respond to chronic and gradual environmental changes (Gunderson, 2000). Long-term persistence of ecological functioning depends upon maintenance of adequate source populations in the landscape. For example, unimpaired coastal wetland ecosystems can respond to sea-level rise through a combination of biological (e.g., organic-matter accumulation) and physical processes (e.g., sediment accretion from storm surges). Where rate of environmental change exceeds the capacity for species to remain in place, lateral migration, regulated by dispersal, and availability of suitable habitat, is necessary. In the Everglades, restoration of hydrologic regimes will support such processes, helping to perpetuate diversity, ecosystem functioning, and fluidity of the landscape as climate envelopes of species shift (Manning et al., 2009).

In the face of climate change, Everglades restoration will increase the resilience of the ecosystem and the water management system and decrease their vulnerability. From the perspective of water resources management, the CERP may offer substantial benefits. In particular, increasing surface-water flows through water conservation areas and into Everglades National Park may help mitigate the sea-level-rise-induced salinization of the aquifers that provide water supply for Dade, Broward, and adjoining counties. This issue would benefit from modeling to better characterize and quantify the scope of potential benefits.

CONCLUSIONS AND RECOMMENDATIONS

Climate change provides a strong incentive for accelerating restoration. Current impacts of rising sea levels are a harbinger of future climate change effects on the functioning and structure of the Everglades ecosystem and the ecosystem services on which South Florida depends. Sea-level rise in South Florida is already increasing saltwater intrusion into Everglades freshwater habitats and urban water supplies, and future climate changes are likely to be manifested through changes in the timing, volume, and quality of freshwaters; distributions of species; and the extent of wetland habitats. Climate change is also expected to increase agricultural water demands, which when paired with anticipated population growth, highlights the potential regional water supply challenges in South Florida under future scenarios. Everglades restoration enhances the ability of the ecosystem to withstand and adapt to future changes, and increases water availability to the ecosystem and to urban and agricultural users. Improvements in Everglades water depths promote higher rates of peat accretion that could help mitigate the effects of sea-level rise and reduce the impacts of saltwater intrusion on urban water supplies.

Although the projections are uncertain, significant changes in precipitation and temperature coupled with increasing sea level have important implications for the CERP. The Everglades landscape is especially sensitive to sea-level rise, and rates of sea-level rise in South Florida are predicted to increase. A scenario of 1.5-degree increase in temperature and a 10 percent decrease in precipitation together with anticipated sea-level rise results in significant changes in coastal ecosystems and insufficient freshwater to sustain the natural and built systems. To decrease uncertainty associated with precipitation projections and clarify future risk, global climate model projections of intra-annual, annual, and interannual variability in precipitation and temperature need to be improved and refined. These improved climate projections should, in turn, be used by CERP planners as input to drive Everglades hydrologic models suitable for making inferences on year-to-year and seasonal variations in freshwater availability.

Climate change is not adequately considered in the CERP planning process and should be integrated into future ongoing analysis and monitoring. CERP projects are designed based on historical hydrology and have not been assessed in the context of future precipitation and evapotranspiration scenarios. Currently, only sea-level rise is considered in CERP planning and usually only as a cursory analysis at the end of the process to assess loss of benefits through 2050 with wetland inundation resulting from sea-level rise. The lack of consideration of the effects of climate change paints an incomplete picture of hydrologic and ecosystem response to the alternatives examined and ignores the potential benefits of the projects to help mitigate the impacts of climate change. Additionally, hydrologic restoration goals are based on the natural systems model, which reflects the past 50 years rather than any likely future. Depending on future climate change, some hydrologic or ecological restoration goals may be unattainable or prove to be not cost-effective. Urban and agricultural water demands unmet under dire climate scenarios highlight the need for additional analysis of water sustainability for the natural and built systems.

CERP planners should consider the implications of sea-level rise and potential hydrologic changes in systemwide planning and project prioritization. Likely sea-level-rise projections can be used to evaluate future project benefits, considering uncertainties regarding the potential for accretion in coastal and inland wetlands to mitigate these effects. Sea-level-rise scenarios should also be coupled with hydrologic change scenarios to characterize systemwide response to global change. The outcome of these analyses would inform future systemwide decisions of project prioritization. Re-prioritization should include consideration of both those rendered less important and effective in light of reduced benefits in the context of climate change and sea-level rise and those projects that become more essential to enhance the ability of the ecosystem and the built environment to adapt to changes and mitigate the effects of changing climate.

Anticipating future changes in temperature, precipitation, and sea-level rise, CERP planners should, where feasible, design for flexibility. Climate change needs to be incorporated into adaptive management planning, at the project scale as well as when considering systemwide goals. It is likely that additional water storage will be needed to address anticipated future increases in variability of meteorological conditions. As new knowledge becomes available, it needs to be incorporated into the CERP adaptive management framework so that managers can adjust future restoration efforts appropriately as the nature of changes in climate become more evident. In addition, the current monitoring program should be evaluated to ensure that important effects of climate change will be characterized and quantified.

The committee identified several high-priority research needs related to climate change and Everglades restoration:

- Assess the rates of peat/sediment accretion and subsidence in coastal and inland freshwater wetlands in the context of sea-level rise;
- Improve modeling tools that can be used to assess the effects of projected sea-level rise on groundwater supplies and coastal ecosystem functioning, and examine the potential for the CERP to mitigate these effects;
- Improve, refine, and evaluate downscaled climate model projections in the context of South Florida water resources and Everglades restoration;
- Improve the understanding of factors that could help maintain the diverse mosaic of Everglades habitats and increase their resilience amid changes in climate and sea level; and
- With improved climate and sea-level projections, reevaluate the goals for Everglades restoration and develop alternate goals as appropriate.

6

Biological Invasions and Everglades Restoration

Invasions by nonnative species can threaten Everglades restoration, displacing native species and transforming large expanses into ecosystems that differ radically from their historical structure, functioning, and provision of ecosystem services. Melaleuca (Australian paperbark, *Melaleuca quinquenervia*), Brazilian pepper (*Schinus terebinthifolius*), Australian pine (*Casuarina* spp.), and Old World climbing fern (*Lygodium microphyllum*) together infest hundreds of thousands of acres of the Everglades region and foster frequent, hot fires that destroy native plants in the "River of Grass" and tree islands, facilitating dominance by exotic vegetation (Schmitz et al., 1997). The Burmese python has quickly become the top carnivore in the Everglades food web, eating not only alligators but virtually all vertebrates it can reach. Its invasion of the Everglades has coincided with ~90 percent declines in populations of bobcats, raccoons, and opossums and a 100 percent decline of rabbits (Dorcas et al., 2012).

The extent to which invasions hinder restoration depends on how restoration is defined. As noted in Chapter 2, different agencies define "restoration" differently, as is revealed in the specific goals. The South Florida Ecosystem Restoration Task Force (Task Force) describes three goals for Everglades restoration, of which the second is "Restore, preserve, and protect natural habitats and species" (SFERTF, 2000). The Comprehensive Everglades Restoration Plan (CERP) defines the goal of Everglades restoration as "restoration, preservation, and protection of the South Florida Ecosystem while providing for other water-related needs of the region, including water supply and flood protection." The Programmatic Regulations that guide implementation of the CERP state that the desired hydrologic and biological characteristics include resilient plant communities and an abundance of native wetland animals (DOI and USACE, 2005). Substantial establishment by nonnative species is certainly incompatible with the Task Force goal, and establishment of at least some highly aggressive nonnative species is incompatible with the CERP goal. A senior DOI official succinctly summarized the problem: "an Everglades landscape teeming with exotic species is not a restored Everglades" (S. Estenoz, DOI, personal communication, 2013).

This chapter details the status and trends of nonnative species invasions of the Everglades ecosystem, discusses some of the challenges for managing these nonnative species in the context of Everglades restoration, and suggests ways of addressing these challenges.

EVERGLADES INVASIVE SPECIES AND THEIR IMPACTS

Invasive species are increasingly common around the globe, and the impacts of nonnative species are quite variable because they depend upon characteristics of the species itself and the ecosystem it invades. Ecological changes induced by these invaders range from no immediately discernible impacts to dramatic effects limited to particular native species or specific groups of them, to broad-scale habitat transformation with attendant changes in ecosystem structure and functioning. This section reviews the effects of invasive species in the Everglades.

Some biological invasions affect particular native species or specific groups of them. For instance, the newly invading redbay ambrosia beetle (*Xyleborus glabratus*; Figure 6-1) attacks a native plant species, swamp bay (*Persea palustris*), infecting trees with the deadly laurel wilt fungus (*Raffaelea* sp.) (Fraedrich et al.,

FIGURE 6-1 Laurel wilt damage to swampbay trees on an Everglades tree island (left), which is caused by the laurel wilt fungus carried by the nonnative redbay ambrosia beetle (right). Note the scale: the adult insect is less than 3 mm long.

SOURCES: Photographs courtesy E. Allen, SFWMD (left) and J. A. MacGowan, Mississippi Entomological Museum (right).

2008; Rodgers et al., 2014a). Ecological impacts may spread beyond swamp bay to species that depend on it for food, habitat, or other services (Chupp and Battaglia, 2014; Kendra et al., 2013). Other trees in the laurel family (Lauraceae), such as avocado, are also at risk (Mayfield et al., 2008; FDACS, 2012).

Other biological invasions affect ecosystem processes (such as fire regimes or nutrient or hydrologic cycles) or ecosystem structure, so they automatically affect many native species. For instance, melaleuca and Old World climbing fern both greatly affect the fire regime in parts of the Everglades. The altered fire regime then adversely affects marshes, sawgrass prairies, and tree islands, with follow-on effects on species that may occupy these habitats, such as epiphytes and various rare plants (Serbesoff-King, 2003).

Further complicating both understanding and management of nonnative species is the fact that they can interact synergistically with one another to exacerbate impacts, a phenomenon known as invasional meltdown (Simberloff and Von Holle, 1999). For example, nonnative fig trees were present for a century in South Florida as ornamentals, restricted largely to residential areas and not an invasive problem in the Everglades until the 1990s. This restriction was caused by the fact that each fig species can be pollinated only by a particular fig wasp species, and the nonnative fig species present in Florida lacked their fig wasps. However, beginning in the 1980s, the nonnative fig wasps of three of these fig species arrived (by unknown means) in Florida, and at least one of the figs, *Ficus microcarpa*, is now an invasive pest in parts of the Everglades (Kauffman et al., 1991).

The case of the figs and fig wasps also exemplifies another complication in assessing invasion threats and prioritizing management activities—many introduced species that ultimately become widespread, highly damaging invaders can remain restricted and innocuous for an extended period, even for decades, before spreading across the landscape (Crooks, 2011). In South Florida, Brazilian pepper was introduced at least as early as the 1880s but did not explode across the region until the 1950s (Ewel, 1986). Melaleuca was similarly present long before it became a major vegetation element (Ewel, 1986). For Brazilian pepper and melaleuca, the reason for the lag between introduction and widespread invasion is not known with certainty. The rather sudden explosion of Brazilian pepper in the 1950s might even have resulted from hybridization between two separate earlier introductions that differed genetically (Mukherjee et al., 2012). However, whether the reasons for a lag and its termination are known (as with the fig) or not (as with Brazilian pepper and melaleuca), the frequency of such invasion lags cannot be doubted (Crooks, 2011). These lags, in turn, challenge attempts to classify a newly discovered introduction as likely innocuous or potentially threatening.

Invasion of nonnative species is often accompanied by structural, functional, and biogeochemical changes in the community. Invasion by melaleuca has transformed prairies of sawgrass and muhly grass into forests almost wholly composed of melaleuca (Bodle et al., 1994), while Australian pine (*Casuarina* spp.) dominates formerly treeless beaches (Schmitz et al., 1997). Invasion by these plants affects the native animal community; for example, Australian pine interferes with nesting of endangered sea turtles (Wheeler et al., 2011). Similarly, spread of the Burmese python (*Python bivittatus*) threatens the entire food chain, challenging even the American alligator for the apex position. This top predator is spreading quickly, leading to dramatic declines in mammal populations (Dorcas et al., 2012), and native bird populations may also be at risk (Dove et al., 2011). Table 6-1 highlights several potential impacts of invasive species on CERP performance measures in the Greater Everglades region.

Following their removal, some of those changes linger, leaving legacies of unknown longevity and impacts. For example, substantial remains of melaleuca trees persist on tree islands and other areas in the Everglades where trees were girdled and died in place (Figure 6-2). Such legacies may negatively influence subsequent regeneration of native species and/or facilitate reinvasion of nonnative species (D'Antonio and Meyerson, 2002). Areas with seedbanks of per-

TABLE 6-1 Examples of Potential Invasive Species Threats to CERP Performance Measures

Performance Measure	Invasive Species/Guild	Potential Threat or Risk
American Alligator Distribution, Size, Nesting and Condition	Argentine black and white tegu Nile Monitor Burmese python	Reduced reproduction due to egg and hatchling predation Direct competition for food resources Direct predation by pythons
American Crocodile – Juvenile Growth and Survival	Argentine black and white tegu Nile monitor Burmese python	Reduced reproduction due to egg and hatchling predation Direct competition for food resources Direct predation by pythons
Marl Prairie Cape Sable Seaside Sparrow Habitat	Melaleuca Australian pine	Degradation nesting habitat due to changes in plant community structure and fire regimes
Prey-Based Freshwater Fish Density Performance Measure	Nonindigenous freshwater fish	Reduced native small dish density due to predation or competitive interactions
Ridge and Slough Community Sustainability	Melaleuca Australian pine Old World climbing fern Brazilian pepper	Alteration of plant community structure, microtopography, and fire regimes
Wet Prairie	Melaleuca Australian pine	Displacement of native plant community Alteration of fire regimes Loss of wildlife habitat

SOURCE: RECOVER (2014a).

FIGURE 6-2 Stands of melaleuca in the Everglades, after control efforts using ground-based herbicide application.

SOURCE: Photograph courtesy of D. Policansky, National Research Council.

sistent, viable propagules of nonnative species are particularly vulnerable to reinvasion. Unfortunately, very little is known about these legacies and potential impacts on restoration success in the Everglades. Sites where nonnative species have been removed may remain altered by their legacies and require additional rehabilitation to achieve long-term restoration goals.

In many cases, the effects of invaders are currently unknown. For example, nonnative fishes are quite abundant in certain areas, exceeding 6 percent at 12 sites in Everglades National Park (RECOVER, 2014a). Yet no studies have documented and quantified their effects on native fish species or on various

CERP performance measures (e.g., freshwater fish density, wading birds nesting and foraging).[1] Once established, removal of nonnative fishes is "problematic," although options may exist to prevent future introductions or limit their spread (RECOVER, 2014a).

In this section, some of the more significant Everglades invaders are discussed, focusing on some of the most damaging ones or ones with unknown potential to be damaging, to illustrate the types of impacts that can occur. The types of treatments that have been used to manage them and the efficacy of available treatments are summarized. Appendix B contains descriptions of other invasive species in the Everglades, and extensive lists of invasive plants and animals are provided in the 2014 System Status Report (RECOVER, 2014a).

Invasive Plants

Many nonnative plants are pervasive pests in the Everglades (reviewed in Junk et al., 2006). There are approximately 250 nonnative plant species in aquatic, wetland, and terrestrial habitats of the Everglades, constituting 16 percent of the flora (Long, 1984). Currently, 75 species are listed as priorities for control by the South Florida Water Management District (SFWMD), with a particular emphasis on species able to displace natives and transform ecosystem structure and functioning (Rodgers et al., 2014a). Of the 75 priority species, 12 are considered particularly high priority because they are believed to threaten the success of the mission of the SFWMD (Rodgers et al., 2014a), and four of these are systemwide priorities, described in detail in the sections that follow. Table 6-2 summarizes the status and trends of all 12 high-priority species, along with two others that have been targeted for early detection and rapid response (EDRR). Appendix B provides some additional details of invasion history and impacts of these and other invasive species.

Melaleuca

Melaleuca is a highly invasive tree native to Australia, New Guinea, and New Caledonia. It readily establishes in sawgrass prairies and tree islands (Davis et al., 2005b), converting these communities into low-diversity forests with highly altered structure and functioning (Schmitz et al. 1997, Serbesoff-King, 2003). Melaleuca can drive changes in soil chemistry, depth to the water table, nutrient cycling, and perhaps most importantly, fire regime. Native sawgrass communities are adapted to frequent, low-intensity fires, but when melaleuca-dominated areas burn, the fires are much more intense as the essential oils in

[1] See http://www.evergladesplan.org/pm/recover/perf_ge.aspx.

TABLE 6-2 High-Priority Invasive Plants in the South Florida Water Management District

Species	Areal Extent	Ecological Impacts	Treatment Availability	Systemwide Trends
Melaleuca	10,035 canopy acres in ECISMA, systemwide	Displaces native vegetation, alters plant community structure, changes soil chemistry, alters fire regime	Integrated mechanical, herbicide, biocontrol—effective with continued maintenance management	36% decrease since 2010-2012
Brazilian pepper	22,145 canopy acres in ECISMA, systemwide	Displaces native vegetation, reports of allelopathy (chemicals produced by plant affect other vegetation), alters fire regimes	Mechanical, herbicide, prescribed burning (in low-density areas); expensive to manage successfully	16% increase since 2010-2012
Old World climbing fern	5,927 canopy acres in ECISMA, systemwide	Displaces native vegetation, alters fire regime	Mechanical; herbicide effective but affects nontarget species; biocontrol efforts promising	69% increase since 2010-2012
Australian pine	1,869 canopy acres in ECISMA, systemwide	Alters habitat for nesting sea turtles and small mammals; limits regeneration of native species	Mechanical and herbicide methods effective but require repeat; biocontrol agents under development	Spatial distribution constant; 94% increase in canopy acres since 2010-2012
Water hyacinth	Acreage unknown; significant infestations in Kissimmee Basin and Lake Okeechobee	Displaces native aquatic species; clogs waterways	Herbicide, biocontrol	Unknown; monitored in public waters; treated as needed and resources allow
Hydrilla	Acreage unknown; significant infestations in Kissimmee Basin and Lake Okeechobee	Displaces native aquatic species; clogs waterways	Herbicide effective but recent detection of resistance; mechanical harvesting	Unknown; monitored in public waters; treated as needed and as resources allow
Air potato	Acreage unknown	Shades and displaces native species	Herbicide; biocontrol partially effective; other agents under development	Unknown
Shoebutton ardisia	Acreage unknown; high densities in southern Everglades and eastern part of ENP	Shades and displaces native species in a wide range of habitats	Mechanical cutting followed by herbicide	Unknown; difficult to detect aerially

continued

TABLE 6-2 Continued

Species	Areal Extent	Ecological Impacts	Treatment Availability	Systemwide Trends
Torpedograss	9,000 acres in marshes of Lake Okeechobee	Displaces native species; readily invades disturbed areas	Herbicide; no biocontrol agents approved	Unknown; no systemwide monitoring
Downy rose myrtle	Unknown coverage; mostly coastal counties	Displaces native species	Mechanical cutting, herbicide; biocontrol agent under testing and development	Unknown; difficult to assess aerially
Cogongrass	6,900 acres in the SFWMD	Displaces native species in wide range of habitats; alters fire regimes and nutrient cycling	Herbicide, mechanical, prescribed fire; no biocontrol agents approved	Unknown, appears to have spread recently
Water lettuce	Acreage unknown; significant infestations in Kissimmee Basin and Lake Okeechobee.	Displaces native aquatic species; clogs waterways	Repeat application of herbicide; biocontrol agents ineffective	Unknown; monitored in public waters; treated as needed and as resources allow
Tropical American water grass	Restricted mainly to Lake Okeechobee	Displaces native aquatic species	Herbicide	Unknown; some expansion on Lake Okeechobee marsh
Black mangrove	Limited and contained distribution	Not fully understood; threat to diversity and function of native mangroves	Mechanical	EDRR reduced occurrence, likely to eradicate
Mile-a-minute	Limited and contained distribution	Shades out and blankets native vegetation	Herbicide	EDRR reduced occurrence, eradication may be possible

NOTE: The acreage numbers presented here are compiled from multiple sources, some with sampling over the entire South Florida Water Management District, which, at 4,662,000 ha, is much larger than the 728,000-ha Everglades Cooperative Invasive Species Management Area (ECISMA), representing all state and federal conservation lands within the Everglades Protection Area, Miccosukee and Seminole lands, Broward County, Palm Beach County, and Miami-Dade County. Sampling methods and time frames of measurement may also differ.
EDRR = early detection and rapid response; ENP = Everglades National Park.

SOURCE: Rodgers et al. (2014a,b); R. Johnson, NPS, personal communication, 2014.

the foliage become explosive, killing nearby sawgrass and many other native members of the community (Center et al., 2012). Melaleuca seeds are liberated by fire, and millions of seeds are released during the high-intensity fires. Thus, melaleuca is a habitat transformer (Gordon, 1998). Rodgers et al. (2014b) report that melaleuca infested over 40,000 acres of the Everglades Cooperative Invasive Species Management Area (ECISMA; which consists of all state and federal conservation lands within the Everglades Protection Area, Miccosukee and Seminole lands, Broward County, Palm Beach County, and Miami-Dade County) in 2010-2012, including more than 10,000 canopy acres.[2]

Melaleuca has been treated in many areas with mechanical removal, herbicide (Silvers et al., 2007), and most recently with several biocontrol agents—natural enemies of melaleuca imported from its native range (Franks et al., 2006). These insects reduce its seed production, growth, and density, and increase its susceptibility to fire and herbicides, leading to greater native species diversity in some targeted areas (Rayamajhi et al., 2009). Control efforts have been quite successful, and abundance of melaleuca has been dramatically reduced to maintenance control levels in many areas of the Everglades (Figure 6-3; Center et al., 2012; Rodgers et al., 2013), although not systemwide to date. With combined control efforts, there was an estimated 36 percent decrease in canopy acres in the ECISMA between 2010 and 2012 (Rodgers et al., 2014a). Untreated plants can flower within a year of establishment, replenishing the seed bank, which enables melaleuca to reinvade treated areas readily. Although biocontrol efforts have slowed the rate of new invasions, frequent monitoring and retreatment are necessary to achieve maintenance control of this species.

Brazilian Pepper

Brazilian pepper is highly invasive and widely distributed in the Everglades (Ewe and Sternberg, 2002) with the highest spatial coverage of nonnative plant species (see Figure 6-2). The growth form of Brazilian pepper is quite plastic, and it can occur as a shrub, small tree, or even vine depending on environmental conditions (Spector and Putz, 2006). On tree islands and other areas where it dominates the canopy, understories support few if any native species (Rodgers et al., 2013). It is highly fecund, producing thousands of seeds each year (Ewel et al., 1982). Its rapid growth rates, vigorous sprouting capacity, and reported ability to produce chemicals that inhibit other plant species (Morgan and Overholt, 2005) enhance its capacity to displace native species and become dominant.

[2] Canopy acres represent the area of ground covered by foliage of a particular invasive species. Infested area is defined as the acreage encompassed after drawing a line around the perimeter of the areas of infestation (the canopy cover of the plants) excluding areas not infested (Price, 2009).

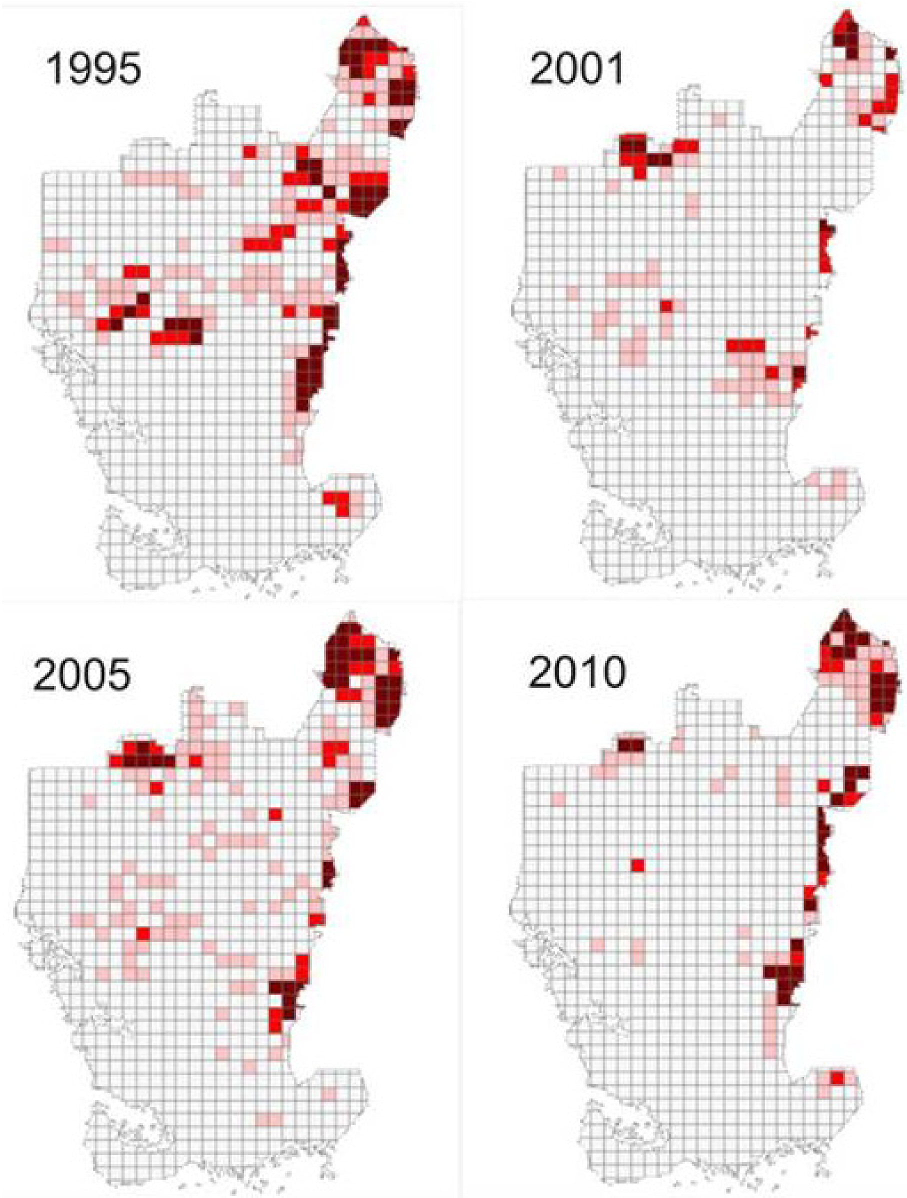

FIGURE 6-3 Areas with melaleuca infestations, 1995-2010. Darker shades indicate denser coverage of melaleuca.

SOURCE: J. Eckles, Florida Fish and Wildlife Conservation Commission, and L. Rodgers, SFWMD, personal communication, 2013.

If allowed to continue to spread across the Everglades, Brazillian pepper could significantly affect CERP performance measures, such as ridge-and-slough sustainability (RECOVER, 2014a).

Fire can be used to manage low densities of Brazilian pepper. However, in high-density stands, fire has much less impact, and Brazilian pepper can drive a fire suppression feedback that leads to further invasion (Stevens and Beckage, 2009). Brazilian pepper is particularly difficult to control in nutrient-rich conditions. For example, the Hole-in-the-Donut within Everglades National Park had perhaps the most expansive infestation of Brazilian pepper. This area was heavily disturbed and had elevated soil nutrient availability from previous farming practices (Li and Norland, 2001). Restoration required removing the soil substrate, which had been highly modified by rock plowing (Ewel, 2013), down to the bedrock to promote reestablishment of native vegetation (Smith et al., 2011). Mechanical removal and herbicides can also control this species to some degree. In the Picayune Strand CERP project, massive mortality of Brazilian pepper occurred followed flooding of plot PC26 (RECOVER, 2014b). Biological control agents have been tested, but to date, none have been released. Currently, a gall-producing potential biocontrol agent is under testing and development. Brazilian pepper is not under maintenance control and is still spreading. This species infested 74,225 acres in the ECISMA area and there was an estimated 16 percent increase in canopy acres during the period 2010-2012 (Rodgers et al., 2014a).

Australian Pine

Three species of Australian *Casuarina* are highly invasive in the Everglades. *Casuarina equiseitfolia* is the most common and widely distributed of the three and threatens coastal areas and beaches because it tolerates arid conditions and saline soils with limited fertility. It is limited by long hydroperiods, occurring mostly on better drained soils and in some short-hydroperiod sawgrass habitats. *C. glauca* and *C. cunninghamiana* are often found on disturbed sites in upland habitats adjacent to coastal communities. Left unchecked, *C. equisetifolia* can dramatically alter the structure and functioning of many coastal areas of the Everglades. For example, the root structures and fallen "needles" of the Australian pine on invaded beaches inhibit nesting by loggerhead and green sea turtles (Wheeler et al., 2011). Also, the heavy litter layer that develops under dense Australian pine canopies can impede regeneration of other plant species.

Mechanical removal has proven difficult because these species have tremendous sprouting capacity. Controlled burning is not effective (Doren and Jones, 1997), and herbicide applications are expensive. An effective biological control agent is being sought (Wheeler et al., 2011); recent discovery that Australian pine species are hybridizing in the Everglades may further complicate this search. Australian pine is currently relatively low in abundance compared with melaleuca and Brazilian pepper (Figure 6-4). Australian pine is considered to be at maintenance control levels in most areas of the Everglades (Rodgers et al., 2013). During 2010-2012, Australian pine infested 10,325 acres in the ECISMA area. Although its spatial distribution has remained relatively constant, there was an estimated 94 percent increase in canopy acres during this period (Rodgers et al., 2014a). This dramatic increase in abundance indicates that monitoring and control remain warranted.

Old World Climbing Fern

Old World climbing fern is native to Africa, southeast Asia, and Australia and is highly invasive in the Everglades (Volin et al., 2004). Its tiny, numerous spores disperse readily, and it poses a great risk to upland, marsh, and coastal habitats alike. Rapid growth where light is not limiting, as in canopy gaps (Lynch et al., 2011), and its twining growth form enable it to cover whole forest stands rapidly (Figure 6-5). Once established vertically in the stand, it alters the fire regime by extending "flame ladders" into the canopy not normally exposed during low-intensity ground fires. Burning fern mats can be dislodged and carried long distances to ignite new outbreaks. Between 1995 and 2010, Old World climbing fern expanded from 1 percent to 10 percent of the ECISMA (F. Laroche, SFWMD, personal communication, 2013). Figure 6-6 shows a lower rate of continued expansion between 2003 and 2013.

Successful chemical control requires contact of the herbicide with all foliar surfaces, and repeated applications of herbicide are often necessary. Because the fern is most commonly found twining around other species, herbicide application may have undesirable effects on surrounding nontarget native species (Hutchinson and Langeland, 2012). Several biocontrol agents have been introduced, and others are still in development. The most successful one to date has been the brown *Lygodium* moth (*Neomusotima conspurcatalis*), which was introduced in 2008 and is now established in the field. Its larvae can radically reduce coverage of the fern. Despite these control efforts, this highly aggressive invader remains widespread and is not currently under maintenance control (Figure 6-5; Rodgers et al., 2013). Old World climbing fern infested 24,619 canopy acres in the ECISMA during 2010-2012 and has increased 69 percent in canopy cover since that period (Rodgers et al., 2014a).

Invasive Animals

At least 192 nonnative animal species are established in the Greater Ever-

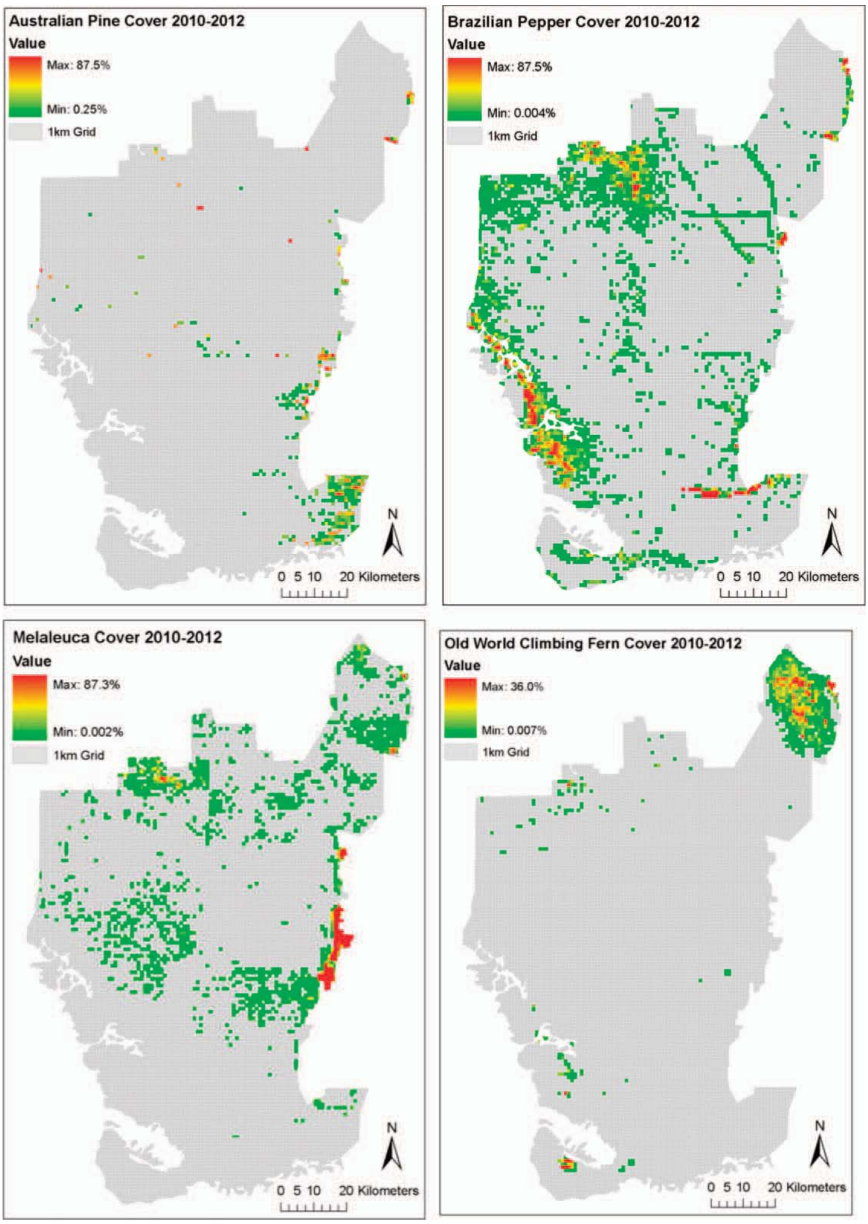

FIGURE 6-4 Aerial extent of melaleuca, Brazilian pepper, Australian pine, and *Lygodium* in the Everglades. The colors represent the percentage of mapped polygons within the grid cell containing the species.

SOURCE: Rodgers et al. (2014b).

FIGURE 6-5 Old World climbing fern completely blanketing a tree island in the Arthur R. Marshall Loxahatchee Wildlife Refuge.

SOURCE: Photo courtesy of Tony Pernas, National Park Service.

glades. Particularly noteworthy species are discussed below, with information on these and other species listed as high priority for management (Rodgers et al., 2014a) given in Table 6-3. These and several other noteworthy animal invaders are detailed in Appendix B. Those that have drawn particular attention (some of which have been the focus of specific management efforts) tend to be either large, flashy predators such as the Burmese python or Nile monitor (*Varanus niloticus*) or insect species, such as the redbay ambrosia beetle, that attack or

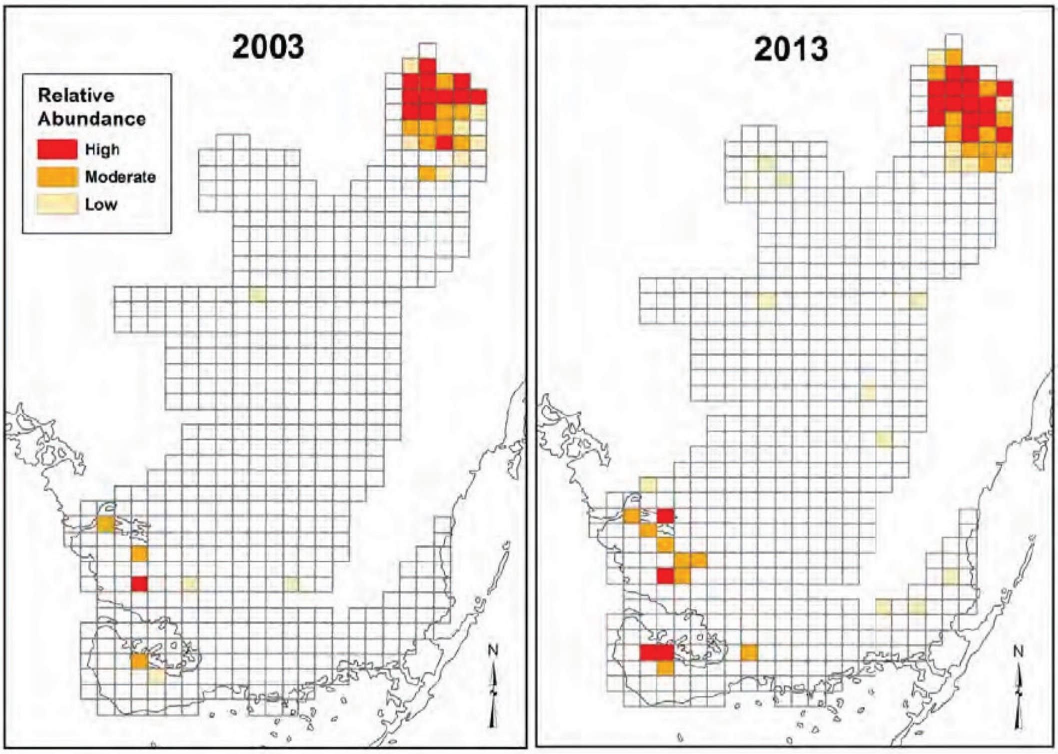

FIGURE 6-6 The spread of Old World climbing fern between 2003 and 2011. Darker shades indicate more dense coverage.

SOURCE: RECOVER (2014a).

spread pathogens to plant species of special concern. Even for these nonnative animal species, the impact on Everglades species and ecosystems cannot be determined quantitatively without intensive research.

Whereas certain plant species (e.g., Brazilian pepper, melaleuca) overgrow vast areas, so that at least some aspects of their impact are readily evident, animal impacts are generally not as obvious. Even if one sees a Burmese python eating an alligator or a Mexican bromeliad weevil (*Metamasius callizona*) eating a bromeliad, the impact on the population of the prey or host species can be determined only by substantial research. The great majority of established nonnative species have not been studied in detail in the Everglades. Therefore, great caution is warranted in determining which nonnative species pose threats

TABLE 6-3 Noteworthy Invasive Animals in South Florida

Species	Areal Extent	Ecological Impact	Treatment Availability	Trends	Priority Status[a]
Burmese python	Spreading northward beyond Alligator Alley	Depresses populations of many prey species	Licensed hunting, extremely limited success	Unknown, population likely increasing within range	Priority
Argentine black and white tegu	Established and spreading in Dade	Attacks many prey species; population impact unknown	Traps	Population increasing within range	Priority
Nile monitor	Several areas of South Florida	Likely predator but impacts unknown	Snares, traps, hunting	Unknown	Priority
Spectacled caiman	Dade and Broward	Likely predator but impacts unknown	Hunting	Unknown	Priority
Wild hog	Throughout region	Greatly disturbs vegetation by rooting; may prey on accessible eggs and animals	Hunting and trapping, but limited because valued game animal	Unknown	Priority
Feral house cat	Throughout region	Attacks many prey species, including birds, mammals, reptiles, and amphibians	Trapping, but limited because cannot use lethal means	Unknown	
Lionfish	Entire Atlantic and Gulf coasts of Florida	Attacks and locally eliminates reef fish	Spearing on single corals; no regional management methods	Rapidly increasing abundance	
Redbay ambrosia beetle	Throughout region	Vectors laurel wilt, which devastates redbay and swamp bay	None	Unknown	Priority
Gambian pouched rat	Grassy Key	Unknown	Trapping, but unable to eradicate because cannot trap on private property	Stable	Priority
Northern African python	Small region of Dade County	Unknown	Intense hunting	Unknown	Priority
Oustalet's chameleon	Small region of Dade County	Unknown	Intense hunting	Unknown	Priority
Veiled chameleon	Lee and Dade	Unknown	Hunting	Unknown	Priority

continued

TABLE 6-3 Continued

Species	Areal Extent	Ecological Impact	Treatment Availability	Trends	Priority Status[a]
Cuban tree frog	Throughout region	Unknown	None	Unknown	Priority
Cane toad	Throughout region	Unknown	None	Unknown	
Purple swamp hen	Entire region except possibly west coast	Aggressive and eats eggs and young of waterfowl	None	Unknown	Priority
Asian swamp eel	Miami and Tampa regions; Everglades National Park	Unknown	Electrofishing or toxicants possible in isolated areas	Unknown, but common	Priority
Mayan cichlid	Southern part of region	Unknown	Electrofishing or toxicants possible in isolated areas	Unknown	
Pike killifish	Much of region	Unknown	Electrofishing or toxicants possible in isolated areas	Unknown	
Black acara	Southern part of region	Unknown	Electrofishing or toxicants possible in isolated areas	Unknown	
Island apple snail	Throughout region	Believed to outcompete native apple snail; may aid snail kite	None	Unknown	Priority
Giant African land snail	Miami	Eats wide variety of cultivated and natural vegetation; economic damage	Hand collecting; poison	Slated for eradication	Priority
Mexican bromeliad weevil	Throughout region	Attacks native bromeliads; threatens populations of two species	None	Unknown	Priority
Rugose spiraling whitefly	Dade County and Florida Keys	Attacks many plant species; population impact unknown	None	Unknown	

[a]Included in a list of species prioritized for SFWMD management in Rodgers et al. (2014a).
SOURCE: Rodgers et al. (2013, 2014a).

and in predicting the nature and extent of those threats, particularly given the subtlety and frequent delay of invasive impacts.

Several animal invaders that have attracted the most attention are presented below; these are but a small fraction of recorded nonnative animals in South Florida. In most cases, research has not been sufficiently extensive and detailed to confirm the extent of the threats they pose, but in each case, existing observations and data suggest impact is likely great. Appendix B details the history and potential impacts of several other notable invasive animals.

Burmese Python

The Burmese python is established in wide areas of the Everglades (Figures 6-7 and 6-8), although the population size, believed to be large, can be at best estimated only with very wide confidence limits. It is believed that even skilled herpetologists can detect at most 1 percent of those in areas they search,

FIGURE 6-7 A Burmese python in Everglades National Park.

SOURCE: Photograph courtesy of Catherine Puckett, U.S. Geological Survey.

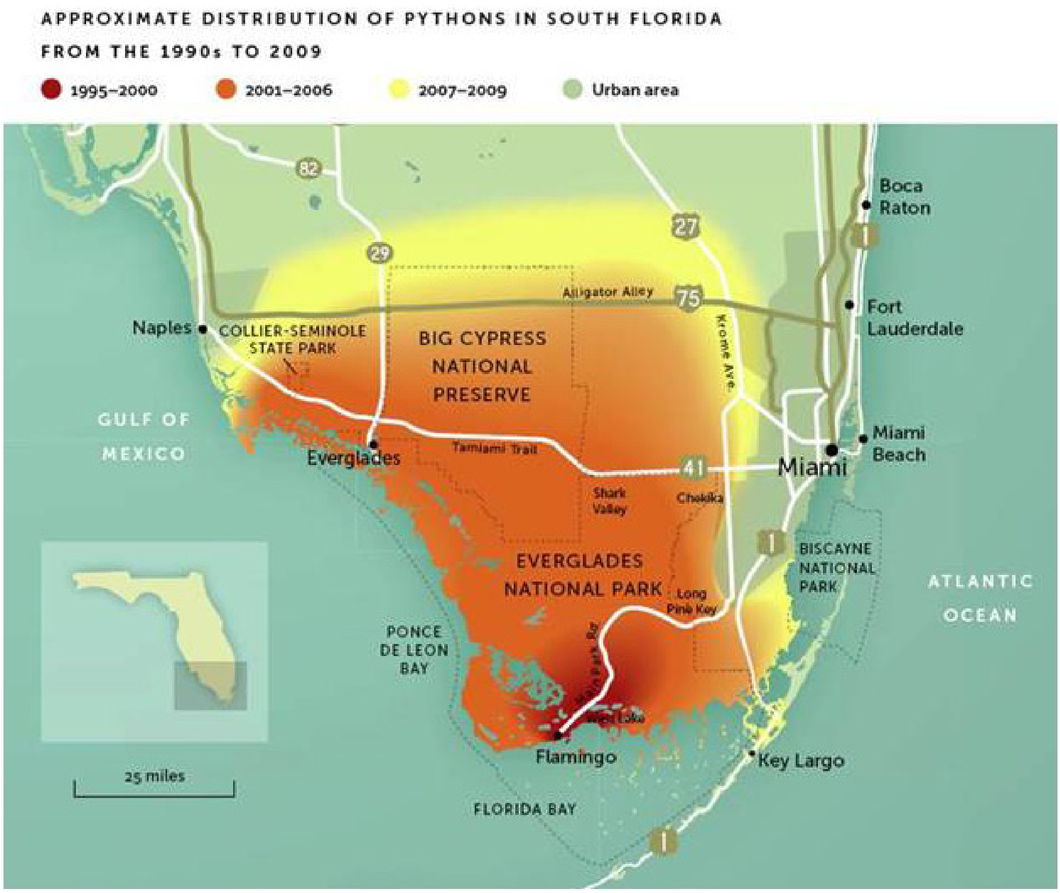

FIGURE 6-8 Approximate distribution of Burmese pythons in South Florida from the 1990s to 2010, indicating rapid spread throughout the area.

SOURCE: Dorcas and Willson (2011).

and that the population in South Florida is in the tens of thousands (Dorcas and Willson, 2013). By virtue of its massive size and position as top carnivore in the food web, the python has attracted enormous attention in South Florida. A precipitous decline in populations of many mammal species in the Everglades was correlated with the arrival and spread of the Burmese python (Dorcas et al., 2012), although population declines of nonprey species suggest other factors may also have played roles (F. Mazzotti, University of Florida, personal communication, 2013). The Burmese python likely affects several CERP performance measures, such as juvenile crocodile survivorship, various aspects of alligator population status, and wading bird survivorship (Dorcas and Willson, 2011).

The Burmese python is monitored along several defined routes that cover a small fraction of the Everglades, as well as less systematically by reptile enthusiasts (Rodgers et al., 2014a); however, no estimate of population size is possible with existing data. Development of an attractant and means of detection are recognized as critical needs, but limited resources have hamstrung control efforts (Rodgers et al., 2013). Contracted research to develop an attractant possibly based on pheromones was terminated by the contractor (F. J. Mazzotti, University of Florida, personal communication, 2013). Because this is a promising avenue for control, delays in this research are crippling. A promising trial using highly trained dogs for detection (Romagosa et al., 2011) also has not been followed up. The tremendous amount of press received by this invasion has led to many unorthodox proposals for management, such as enlisting consultants from the Irula tribe, a small group from southern India who traditionally hunt snakes. The Florida Fish and Wildlife Conservation Commission (FWC) has a permit program to allow trained hunters to capture Burmese pythons and other nonnative reptiles.[3]

Argentine Black and White Tegu (Tupinambis merianae)

This predaceous lizard (Figure 6-9), which can reach 4 feet in length, recently became established and is spreading from a small area in Dade County. It poses a threat of unknown magnitude to ground-nesting birds and reptiles (Rodgers et al., 2013). It also is established in Hillsborough and Polk counties in Florida, and has reproduced in Miami-Dade County (Florida Fish and Wildlife Conservation Commission, 2012; Pernas et al., 2012). They were first noticed in Everglades National Park in 2009 (Tony Pernas, NPS, personal communication, 2014), and their presence in the wild is likely due to releases of unwanted pets. ECISMA has coordinated a monitoring effort but lacks resources for an adequate rapid response team (Rodgers et al., 2014a). As is often the case with nonnative animals, no reliable information is available on the number of individuals in the wild. According to the Florida Fish and Wildlife Conservation Commission (2012), the current approach to reducing tegu numbers in the wild is targeted trapping and removal, and additional trapping efforts are under way to contain the invasion east of Everglades National Park (R. Johnson, DOI, personal communication, 2014).

[3] See http://myfwc.com/license/wildlife/nonnative-species/python-permit-program/.

FIGURE 6-9 Argentine black-and-white tegu.

SOURCE: Photograph courtesy of David Policansky, National Research Council.

Wild Hog (Sus scrofa)

Wild hogs (Figure 6-10) are damaging invaders worldwide, inflicting many kinds of ecological and economic damage to varying degrees in different locations (Barrios-Garcia and Ballari, 2012). Furthermore, they can interact with other introduced species, such as mutalistic mycorrhizal fungi and invasive plants, to generate invasional meltdowns—that is, much greater impacts than each species could have produced on its own (Nuñez et al., 2013). Wild hogs are

FIGURE 6-10 A wild hog in the Everglades.

SOURCE: National Aeronautics and Space Administration.

in all of Florida's 67 counties, but information on local numbers and distribution is difficult to obtain. Their impact is apparent in the Everglades, with large areas disturbed by their rooting. Some hog control, mainly by trapping and hunting through contracts given to trappers, is undertaken on particular SFWMD lands, but there is no high-level coordination of such activities, and this is recognized as a need (Rodgers et al., 2013, 2014a). Aggressive hog control is controversial because hogs are a valued game species; the contribution of hunting to control of hog populations is unstudied. Hogs are also a major prey item for the endangered Florida panther (Maehr et al., 1990), and improved habitat for this prey species has been offered as one benefit from the Picayune Strand restoration project (see Chapter 4). These conflicting views on the desirability of hog control greatly complicate an effective management response.

Feral House Cat (Felis catus)

Feral house cats are damaging invaders worldwide, killing approximately 2 billion birds and 12 billion mammals annually in the United States alone (Loss et al., 2013). Their impact in Florida is similarly substantial (Feral Cat Issue Team, 2003), and they are a major predator of birds and mammals (and perhaps other animals as well) in the Everglades, although the committee knows of no specific estimate. Feral cats trapped in the Everglades may be neutered and released, but they are not killed, as cat control generally is viewed through the lens of animal welfare rather than as a conservation issue. Despite the damage feral cats can cause, they are frequently overlooked in lists of priority invasive species (e.g., RECOVER, 2014a; Rodgers et al., 2014a).

Asian Swamp Eel (Monopterus albus complex)

Asian swamp eels are large, carnivorous eels first reported in the wild in Florida in 1997 (Kline et al., 2013). They appear to have been introduced more than once, and because they have some degree of salinity tolerance, apparently variable across populations, swamp eels have the ability to invade estuaries as well as freshwater. They are opportunistic predators and get quite large (up to at least 4 feet; see Figure 6-11), and they also tolerate desiccation, pollution, and low temperatures (Schofield and Nico, 2009). Therefore they have the potential to be invasive as well as to affect ecosystem structure. Relatively little is known about their distribution in South Florida.

FIGURE 6-11 Wood stork with swamp eel, which it ate; at Royal Palm, Everglades National Park, 2013.

SOURCE: Photograph courtesy of Theron Mays.

Lionfish (Pterois volitans and P. miles)

Lionfish, native to the Indo-Pacific region, are now widely distributed in the Caribbean and southeastern United States. They are highly predaceous, greatly lower the population density of their prey, and outcompete native reef fish (Albins and Hixon, 2008, 2011). Lionfish also invade estuaries, including that of the Loxahatchee River (Jud and Layman, 2012), and a preliminary study shows a major impact on estuarine invertebrates (Layman et al., 2014). In addition, their venomous spines can cause extremely painful injuries to people who come in contact with them. Lionfish are numerous in coral regions of South Florida (e.g., Florida Keys, Biscayne Bay). They are currently managed in South Florida on a coral-head-by-coral-head basis as opposed to a regionwide basis, and the public is encouraged to capture them by angling or spearfishing and to use them as food. There is no evidence that this approach has hindered their spread or lowered their density, except perhaps locally.[4] They appear to be rapidly increasing in abundance and impact (Ruttenberg et al., 2012).

Island Apple Snail (Pomacea insularum)

The island apple snail is much larger than the native apple snail, *P. paludosa*, which is the main food of the endangered Everglades snail kite (*Rostrhamus sociabilis*). Evidence strongly suggests that the island apple snail outcompetes the native apple snail (Barnes et al., 2008), and also that the snail kite has lower net energy balance when feeding on the island apple snail (Cattau et al., 2010). However, Pias et al. (2012) report some initial behavioral adaptations by the kite to the island apple snail. The island apple snail consumes a wide range of aquatic plants as well as other food sources and is capable of completely defoliating lush ecosystems (RECOVER, 2014a). In a single cell of STA-1E, a major increase in the population of this snail in 2013 devastated submerged vegetation. The event was correlated with large increases of total phosphorus in outflow concentrations, such that the cell had to be taken offline for rehabilitation (Figure 6-12; L. Gerry, SFWMD, personal communication, 2014). RECOVER (2014a) reported that as of 2012, the island apple snail was well established in the northwestern littoral zone of Lake Okeechobee and spreading southward. There is little coordination of monitoring and little research on impacts and possible control measures (Rodgers et al., 2014a).

[4] See http://www.reef.org/lionfish.

FIGURE 6-12 Island apple snail with egg cluster (left). Egg clusters of nonnative apple snails in STA-1E, showing the extreme density of clusters and reproductive potential of this species. Native apple snails have white eggs.

SOURCE: Photograph courtesy of Delia Ivanoff, SFWMD.

Redbay Ambrosia Beetle (Xyleborus glabratus)

The redbay ambrosia beetle (Figure 6-1) and its associated fungus, laurel wilt (*Raffaelea lauricola*), have spread widely throughout the southeastern United States since 2002 (Fraedrich et al., 2008; Kendra et al., 2013), including to parts of the Everglades by 2010 (Rodgers et al., 2014a). It attacks some native (e.g., swamp bay, redbay) and nonnative (e.g., avocado) members of the laurel family and may also affect species that are restricted to feeding on such species, including the Palamedes swallowtail butterfly (*Papilio palamedes*) (Lederhouse et al., 1992). The fungal disease threatens tree island habitat where redbay is a dominant species. There is also great potential for loss of cultural resources because redbay is used extensively by local tribes. There is coordinated monitoring of the recent dramatic spread of the disease (see Figure 6-13) but little research on impacts on native species (other than redbay) in the Everglades or on management methods.

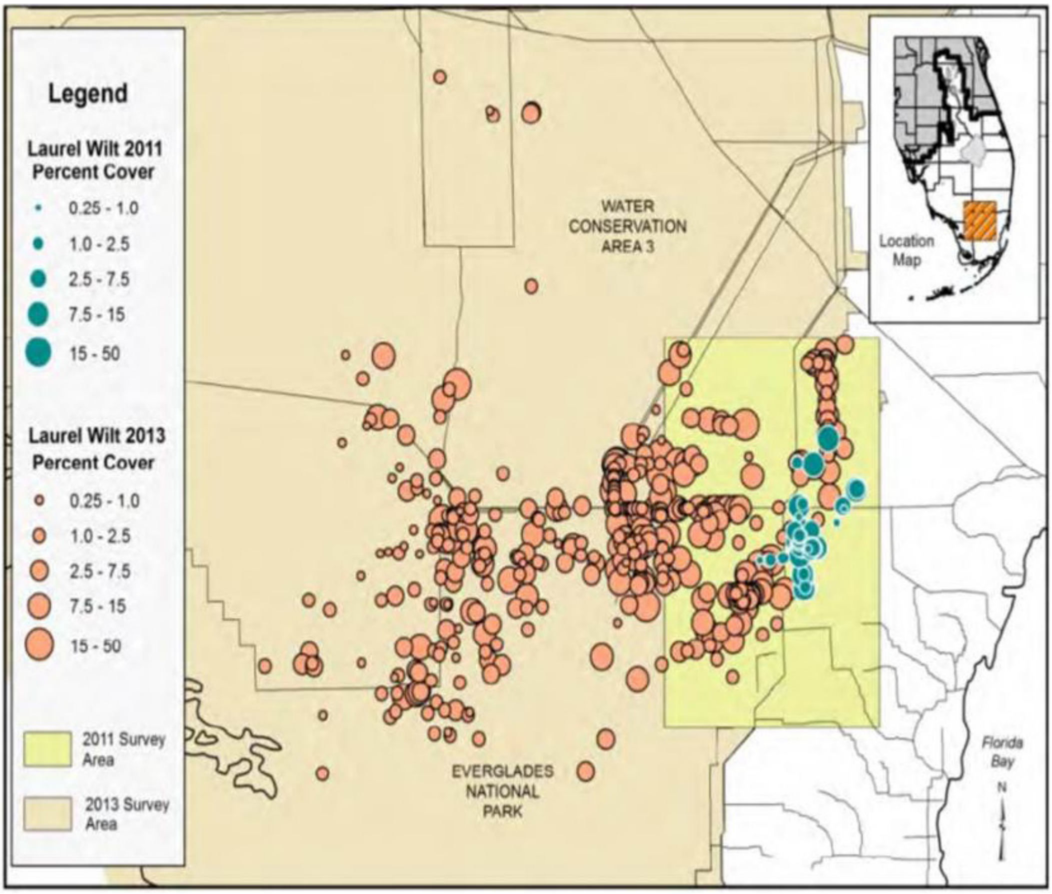

FIGURE 6-13 Distribution and abundance of laurel wilt-infected swamp bays in the central Everglades in 2011 and 2013.

SOURCE: RECOVER (2014a).

MANAGING INVASIVE SPECIES IN THE EVERGLADES

Management approaches differ for species at different stages of the invasion process. Biological invasions typically begin with the arrival of a small number of individuals (propagules) that establish a population that grows slowly at first. After this initial period, which varies in length depending on the species and environmental conditions, population numbers increase rapidly until some environmental limit is reached (e.g., fewer and fewer habitats are available as more and more are occupied) and population growth slows, eventually leveling off. The resulting sigmoid curve (Figure 6-14) can be used to determine management costs and strategies.

Although eradication often is possible with early detection of new arrivals, most of the species listed as priorities (Tables 6-2 and 6-3) are in advanced stages of invasion. Eradication in such cases is always more expensive and difficult and may not even be possible with current technology. In cases where eradication is highly unlikely, containment and long-term management are the pragmatic strategies. Thus, continued presence of some nonnative species on the landscape is a reality in the modern Everglades. The following sections outline efforts in South Florida with regard to prevention, early detection and rapid response, eradication, and maintenance management (including containment and long-term management).

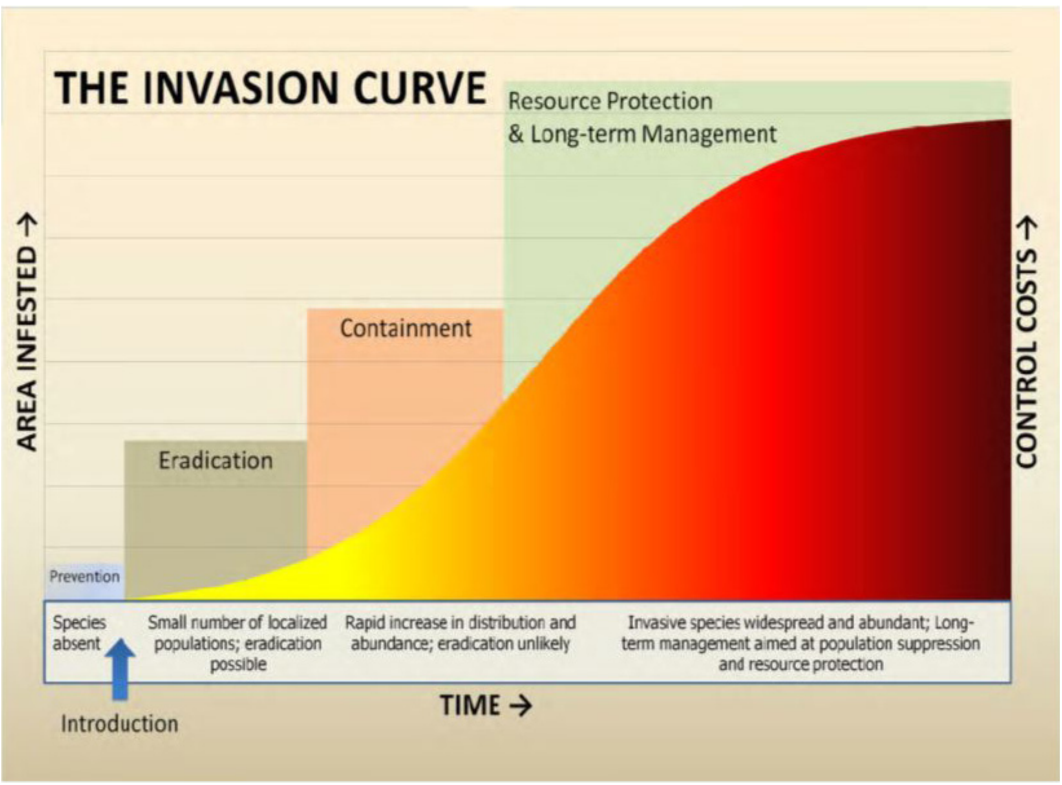

FIGURE 6-14 The invasive species invasion curve.

SOURCE: South Florida Ecosystem Restoration Task Force, 2013.

Prevention

A number of state and federal laws are designed to prevent the introduction of potentially invasive nonnative species into the United States. Two primary federal laws restrict the import of certain nonnative species into the United States: (1) the Lacey Act (18 U.S.C. § 42 and 16 U.S.C. §§ 3371 et seq.) and (2) the Plant Protection Act (7 U.S.C. §§ 7701 et seq.).

The Lacey Act prohibits the importation of certain specified fish and wildlife that the Department of the Interior (DOI) designates as injurious to humans, agriculture, wildlife, and "wildlife resources" of the United States. The law has limited effect in that the only species that can be listed as injurious are certain classes of animals. In practice, the Lacey Act has been applied only in a reactive way (Fowler et al., 2007). For example, the DOI's list of injurious species includes only ones that have already become a problem. The DOI does not list species that may, but have not yet, become problematic. To date, only about 239 species have been included on the list. Several of the invasive animal species in the Everglades are on the DOI list of injurious species. For example, the list currently includes four species of constrictors (Burmese python, northern African python, southern African python, and yellow anaconda). The DOI has proposed listing four additional species of constrictors. Many animal species that are considered to be invasive in the Everglades, including the Argentine black and white tegu, are not included on the list. Because the list is limited in scope and because it contains only species that have already become problematic, the Lacey Act as currently implemented is not particularly useful at ensuring that new, potentially invasive species releases are prevented in the Everglades.

Under the Lacey Act, states are permitted to adopt and enforce laws related to invasive animals, provided such laws are not inconsistent with federal law. Florida law prohibits the importation for sale or use or release within Florida of any wildlife not native to Florida unless specifically authorized by the FWC. However, by regulation, the Commission has limited this prohibition only to the import, sale, possession, or transport of any live specimens that it lists as "conditional non-native species." In recent years, the FWC has listed the Burmese python, reticulated python, northern African python, southern African python, scrub python, amethystine python, green anaconda, and Nile monitor as "conditional non-native species," and thus, the prohibition now applies to each of these reptile species. The FWC regulations also encourage persons possessing unwanted nonnative species, such as pet pythons, to turn over the animals to the FWC by providing amnesty.

The Plant Protection Act authorizes the U.S. Department of Agriculture (USDA) to prohibit or restrict the importation and interstate movement of certain organisms that USDA determines to be plant pests or noxious weeds. The

Act imposes significant restrictions on species listed as “noxious weeds.” USDA can list species as noxious weeds if the species can directly or indirectly injure agriculture or the natural resources of the United States, public health, or the environment. As with the Lacey Act, species typically are listed as noxious weeds only after they have become a problem. Many of the invasive plant species in the Everglades are listed as noxious weeds, including melaleuca, hydrilla, water hyacinth, and feathered mosquito fern. In addition, the Plant Protection Act regulates the interstate movement of noxious weeds and authorizes emergency action within states that are not taking adequate measure to eradicate the plant pest or noxious weed. Under the Act, the USDA has broad authority to declare quarantine and take remedial action to prevent the introduction of new, or not widely distributed, plant pests or noxious weeds. In contrast to the Lacey Act, the Plant Protection Act preempts state laws that are in conflict with or are more stringent than the federal law except where a state can demonstrate a special need for additional restrictions.

The Florida Division of Plant Industry (DPI) in the Department of Agricultural and Consumer Affairs (DACS) does maintain its own list of noxious weeds, which includes species on the federal list, as well as additional species that are invasive in Florida but are not on the federal list. Similar to the Plant Protection Act, Florida law prohibits the introduction, possession, and movement of noxious weed unless permitted by DPI for limited purposes, such as research. Most of the invasive plants in the Everglades, including Brazilian pepper, air potato, Australian pine, Old World climbing fern, cogongrass, water lettuce, skunk vine, and downy rose myrtle, are on the Florida list (Florida Administrative Code Annotated, Rule 5B-57.007). As with the federal noxious weed list, DPI typically lists species only after they have become a problem.

Early Detection and Rapid Response

Eradication is far more likely and less costly early in the sigmoid invasion curve (Figure 6-14), but this requires early detection associated with a rapid response mechanism. Thus, investments in early monitoring can yield great economic benefits by finding invasions while relatively inexpensive eradication or containment efforts are still feasible. Of course, monitoring has costs, so the likely benefit of finding and acting early on invasions needs to be weighed against the cost of a given degree of monitoring. Estimating these costs and benefits involves many unknowns, but the principle is clear (Epanchin-Niell et al., 2012).

In the Everglades, wild red rice (*Oryza rufipogon*) was detected and eradicated before it could spread (Westbrooks and Eplee, 2011). Another success of early detection and rapid response (EDRR) is the sacred ibis (*Threskiornis* *aethiopicus*), a large African bird first discovered breeding in the Everglades in 2005 after many escapes from captivity (Herring and Gawlik, 2008). This species, which is known to prey on eggs and young of several bird species in aquatic habitats (Lefeuvre, 2013), appears to have been eliminated from the Everglades before it could disperse widely (Rodgers et al., 2013). The quick effort to eradicate exotic black mangrove (*Lumnitzera racemosa*) before it could spread from a site near Fairchild Tropical Botanical Garden also appears to be nearing success (Rodgers et al., 2013). These examples show that, if an invader is detected before it is widespread and if action is quick, eradication is sometimes possible.

The Everglades Cooperative Invasive Species Management Area (ECISMA; discussed later in this chapter), which coordinates nonnative species management in South Florida, has developed an EDRR system for the Everglades (ECISMA, 2009). Such systems have proven to be possible and cost-effective elsewhere (Westbrooks and Eplee, 2011). Several detection programs have been established in the Everglades—largely through ECISMA—including a public hotline and website (1-888-IVE-GOT-1; www.ivegot1.org) operated by FWC for reporting nonnative animals (no analog exists yet for plants). The hotline was used successfully to alert ECISMA agencies to Argentine black and white tegus in residential areas of Dade County in time to remove them through targeted trapping. Also, more than 30 tegus that had been abandoned in an outdoor breeding facility in Panama City were discovered and removed after a hotline report (J. Ketterlin-Eckles, FWC, personal communication, 2013).

Another ongoing ECISMA EDRR effort is the Everglades Invasive Reptile and Amphibian Monitoring Program (EIRAMP), implemented by a team from the University of Florida with support from FWC and the SFWMD. Under this program, regular monthly monitoring is conducted on 20 routes (Rodgers et al., 2014a). However, the degree of monitoring is insufficient, and the system does not assign specific responsibilities for monitoring for many sorts of species. EIRAMP's routine monitoring routes are located along just a few roads and trails (see Figure 6-15), a minuscule percentage of available area, and not all reptiles and amphibians would be likely to occupy such habitats. Members of the EIRAMP team are also contracted for a certain number of follow-up visits to address hotline and website reports of reptiles and amphibians.

FWC has also mounted a Python Patrol program, started by the Nature Conservancy and now operated by FWC, to limit the spread of pythons into new areas. The program trains land managers to capture and remove large constrictors and also provides outreach to people who frequent natural areas, such as hunters, local law enforcement agents, and state agency workers. These persons are trained to identify and report pythons, as well as other nonnative animals. Python Patrol trainees may also respond to hotline and website reports. This program has resulted in the removal of the first Burmese python in Picayune

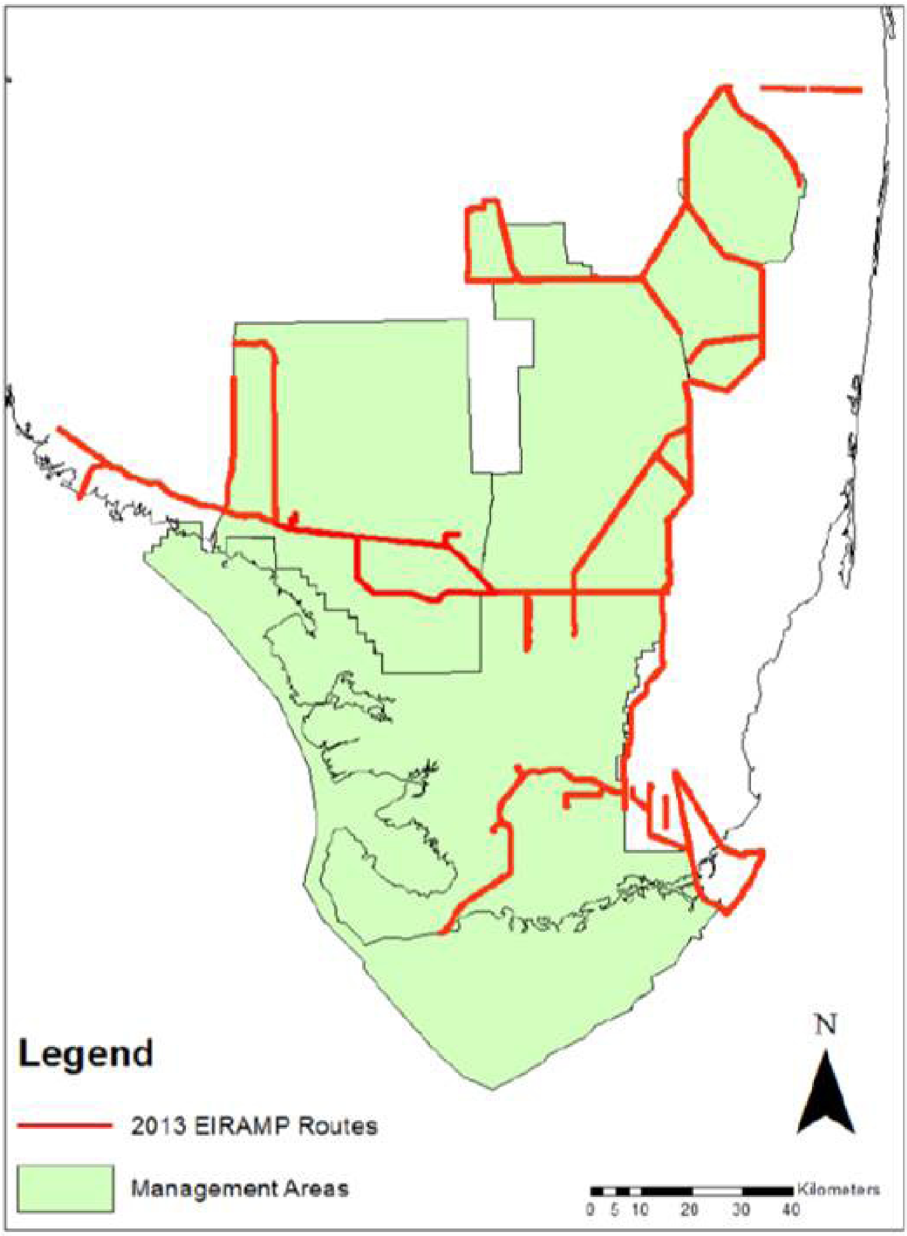

FIGURE 6-15 Everglades Invasive Reptile and Amphibian Monitoring Program (EIRAMP) routes.

SOURCE: RECOVER (2014a).

Strand after it was reported on the hotline, and responders trained under the Python Patrol Program were able to find and remove the snake. So far, over 400 persons have received capture training and over 1,400 have received training on detecting invasive animals.

ECISMA relies heavily on the Early Detection and Distribution Mapping System (EDDMapS), a web-based mapping system and clearinghouse founded in 2005 by the Center for Invasive Species and Ecosystem Health at the University of Georgia. EDDMapS accepts reports of nonnative species from the public at large and forwards the information to South Florida invasive species managers to determine the accuracy of the species determination. Panther chameleons (*Furcifer pardalis*) were located and possibly eradicated from a Broward county property after a report of the chameleons on EDDMapS. After surveys, FWC and the University of Florida were able to remove more individuals from the surrounding community, and continuing surveys have detected no panther chameleons recently (J. Ketterlin-Eckles, FWC, personal communication, 2013).

It is unclear for certain types of species who decides what, if any, response to a verified hotline, website, or EDDMapS report is required and what entity should implement the response. In general, a rapid response requires quick access to resources, which was generated by FWC for exotic black mangrove. Other invasive species that were detected early and for which adequate resources were mobilized quickly were the sacred ibis (now thought to be eradicated in the Everglades) and the northern African rock python (currently contained to a limited area). However, efforts to eradicate incipient invasions in the Everglades have more often been stymied by the inability to obtain funds from federal, state, or local sources. For example, the Argentine black and white tegu was confined to a very small area when first discovered in Dade County in 2009. A plea for quick action (Pernas et al., 2012), which would have yielded a high probability of successful eradication, went unheeded because none of the agencies queried could provide the necessary resources. This lizard is now almost surely too widespread for eradication with currently available technologies.

Eradication

Time is of the essence for eradicating invasive species. Although eradication was once viewed as impossible or unlikely in most cases (Simberloff, 2003), technologies have improved greatly over the last few decades, particularly for terrestrial vertebrates (Genovesi, 2011). In general, aquatic species, insects, and plants have proven more difficult to eradicate than terrestrial species, especially vertebrates. Nevertheless, there have been successful eradications of all classes of organisms, especially in instances where the invasion was detected early enough that the nonnative species had not spread widely. As noted in the previous section, several spatially restricted invaders have been eradicated in the Everglades region, including plants. No widespread invader in the Everglades has been targeted for eradication. However, invasions frequently pass through a stage in which there are several spatially separated populations of a nonnative species. In such a circumstance, it is often strategically desirable to eradicate small, discrete populations in the hope of containing the invasion in a smaller area and perhaps ultimately eradicating it (Moody and Mack, 1988). Nationally, this strategy has been used successfully in a high-profile massive attempt to stem the spread of the Asian long-horned beetle (*Anaplophora glabripennis*). In the Everglades area, the strategy has been pursued with isolated populations of the Argentine black and white tegu in residential areas.

Several invasions that became very widespread have nevertheless been eradicated, such as a pasture weed (*Kochia scoparia*) in western Australia. In the United States, a 50-year campaign to eradicate the parasitic plant witchweed (*Striga asiatica*) from 400,000 acres of North and South Carolina is nearing success (Simberloff, 2013a). However, in both instances, the locations of the invasive individuals were well known and the invaders were agricultural pests, so the high cost of the effort (particularly for witchweed) could be borne as an agricultural expense. In the Everglades, some locations of many widespread invaders are poorly known, and the cost of an invasion campaign against widespread invaders would likely be prohibitive, at least with current technology.

As described previously in this section (see Prevention), a number of federal and state laws are designed to reduce the introduction of potentially invasive nonnative species into the United States. Once an invasive species is established, however, federal statutes are of limited utility. Because large areas of the Everglades are owned or managed by federal, state, or tribal governments, however, these public land owners and managers typically have specific legal authority to address invasive species concerns on their land. For example, the National Park Service Management Policies (NPS, 2006) authorizes the destruction of species detrimental to Park Service resources on Park Service lands. In addition, Presidential Executive Order 13112 directs federal agencies to take actions to control invasive species, and the U.S. Army Corps of Engineers (USACE) is currently working to develop a strategy to comply with this mandate.

When invasive species management depends on removing plants or animals that may be on private land and may have the ability to spread to public lands, it may be necessary to access private lands to remove invasive plants or animals. In some circumstances, private landowners are willing to provide access and permission to remove the invasive species. When private landowners are not willing to provide access and permission, however, there is limited legal authority for government officials to control invasive species on private property. In certain extreme circumstances, state or federal agencies may be able to access private property to remove invasive species that pose significant risks. For example, the State of Florida has destroyed citrus trees on private land when citrus canker threatened a major economic interest in the state. However, in that case, specific legislation authorized the state action and the state paid compensation to private landowners whose trees were destroyed. It is not clear under what circumstances and to what extent statutes such as the Plant Protection Act would allow similar actions to be taken to private land to protect the natural resources of the Everglades without running afoul of constitutional protections against illegal search and seizure and taking of property without just compensation. The Gambian pouched rat on Grassy Key persists only because it is on six private properties whose owners do not permit access to federal or state officials (Witmer et al., 2010a). As long as this rat is present, there is the possibility that it will spread to other areas of South Florida.

Maintenance Management

If eradication fails or is not attempted, several technologies can be used to maintain invasive populations at low levels. Traditional approaches to such maintenance management are

1. Physical control, such as pulling invasive weeds or catching snakes by hand;
2. Mechanical control, entailing the use of machines;
3. Chemical control, using pesticides and herbicides; and
4, Biological control, importing natural enemies, such as predators and parasites, from the native region of the targeted pest.

Each of these approaches has been successful in some cases, and each has failed in other cases (Simberloff, 2009, 2014). The important point is that technologies have evolved in all of these methods (e.g., Clout and Williams, 2009; DiTomaso, 2011; Van Driesche et al., 2008). All have been used in the Everglades. For instance, several invasive plants, such as melaleuca and Australian pine, have been targeted by specially adapted land-clearing machines (Anonymous, 2005). Herbicides, both aerially dispersed and delivered by hand sprayers, have been also been used (Laroche and McKim, 2004). The USDA's Invasive Plant Research Laboratory in Davie, Florida, seeks and tests biological agents, mostly insects, to attack major invasive plants in the Everglades, and in 2013 the USDA completed construction of a mass rearing facility as an annex to the laboratory as part of the CERP (see Chapter 4). Melaleuca is one of several key invasive plants in the Everglades that have been substantially reduced by biocontrol agents (Figures 6-2 and 6-16). Other methods of maintenance management are used less frequently

FIGURE 6-16 Melaeuca treatment via mechanical and chemical methods (left) and biological control by means of the melaleuca snout beetle (*Oxyops vitiosa*).

SOURCE: Photograph courtesy of Tony Pernas, National Park Service, and Stephen Ausmus, Department of Agriculture.

but have provided significant control of particular invaders. In the Everglades, for example, prescribed fire applied to stands of melaleuca seedlings has contributed to developing a successful maintenance management program.

New approaches to maintenance management have occasionally provided control of previously refractory invaders, including the use of pheromones and genetic manipulation (Simberloff, 2014). Invasive species whose control seems hopeless today, as that of melaleuca did 20 years ago, may someday be managed well by methods resulting from ongoing research. The melaleuca management program, which evolved over 20 years and includes biological, chemical, and mechanical control (Figure 6-16) as well as prescribed burns, is an example of a program that developed gradually from several lines of research and is now showing substantial success (Figure 6-3).

COORDINATION AND ORGANIZATION

The management of nonnative species in South Florida is distributed across many federal, state, and local agencies and programs. Federal agencies that have at least some jurisdiction over nonnative species include the FWS, the National Marine Fisheries Service, the NPS, the USDA Animal and Plant Health Inspection Service and Agricultural Research Service, the U.S. Forest Service, the USACE, and the U.S. Customs and Border Patrol. State agencies include the FWC, the SFWMD, the Florida Department of Agriculture and Consumer Services, and the Florida Department of Transportation. Miami-Dade County and the Miccosukee and Seminole Indian tribes also have strong interests and management roles, as do a variety of nongovernmental and academic organizations.

Although official communication channels exist among many of these organizations and many individuals associated with them communicate as well, they do not all share the same legislative and regulatory mandates, they have differing budgetary and other constraints, and they have differing degrees of technical expertise. Two notable attempts have been or are being made to coordinate efforts and resources for managing nonnative species.

Everglades Cooperative Invasive Species Management Area

Federal, state, and local governments have been collaborating to address Everglades nonnative species issues since the Everglades Forever Act was passed in 1993, and the establishment of the ECISMA in 2008 formalized the collaboration and expanded the partners involved. Like other CISMAs, ECISMA is a formal partnership composed of federal, state, and local government agencies, tribes, individuals, and various interested groups that manage invasive species in the Everglades region (see Box 6-1).

ECISMA has fostered an increasing amount of coordination at the operational level. Among ECISMA's stated goals are to

- Formalize areas of coordination and cooperation among agencies;
- Define specific geographic areas and prioritize species for Everglades restoration; and
- Integrate coordination, control, and management of invasive species at regional, multijurisdictional levels.

ECISMA has improved coordination of the implementation of invasive species management. Its website provides access to a great deal of pertinent information, such as distribution maps (EDDMapS) of invasive plants and animals. ECISMA has also had some notable successes with EDRR, as discussed previously in this chapter. However, ECISMA does not coordinate and cross-calibrate sampling methods.

However, there does not appear to be a formal process to determine system-wide priorities—which nonnative species are managed to what extent, what monitoring is performed, and what monitoring or other observations trigger a management response. Currently, nonnative species management appears largely driven by the objectives of individual agencies, with limited leveraging of funding across agencies to address the needs of multiple agencies. How system-wide prioritization for management, coordination of management activities, and funding sources are determined remains obscure. This committee could not iden-

BOX 6-1
ECISMA Partners

The Everglades Cooperative Invasive Species Management Area (ECISMA) coordinates nonnative species management in South Florida through a formal agreement under the Florida Invasive Species Partnership. The ECISMA partners include

Signatories

- Florida Fish and Wildlife Conservation Commission
- South Florida Water Management District
- U.S. Army Corps of Engineers
- U.S. Fish and Wildlife Service
- U.S. National Park Service
- Miami-Dade County

Cooperators

- Auburn University
- Broward County
- Friends of Everglades CISMA, Inc.
- The Everglades Foundation
- Fairchild Tropical Botanic Garden
- Florida Department of Agriculture and Consumer Affairs
- Florida Department of Transportation
- Florida Power and Light
- Miccosukee Tribe of Indians of Florida
- National Oceanic and Atmospheric Administration
- Seminole Tribe of Florida
- The Nature Conservancy
- University of Florida
- University of Georgia—Center for Invasive Species and Ecosystem Health
- USDA Agricultural Research Service
- USDA Wildlife Services
- U.S. Geological Survey

tify an algorithm or formal process by which nonnative species are prioritized for management action or particular resources are allocated to nonnative species management activities. Nor could the committee identify how a specific agency comes to bear responsibility for dealing with particular nonnative species.

For instance, ECISMA lists 14 plant species and 16 animal species as the highest priority for management. What process led to these designations? What process led to specification of management activities targeting these species and entities charged with carrying them out? For plants, there is no doubt that several of the targeted species have great impacts, although it is not obvious that other species do not have equally great impacts. Two of the 14 priority plant species are not yet widespread and are perceived as eradicable. Nonnative animals have been a management focus for a much shorter period than nonnative plants (Rodgers et al., 2013), and it is even less clear how the 16 priority animal species were chosen. Some priority species are already believed to have a substantial impact, although others with suspected major impacts (e.g., feral housecat) are unlisted. Other priority species are not currently having major effects and are still geographically restricted and believed to be feasible targets for eradication, even though possible management methods tend to be poorly developed or unknown (Table 6-3).

Comprehensive Invasive Species Strategic Framework

The second coordinative effort recognizes and responds to a problem with policy and management of biological invasions to date: namely, the absence of sufficient coordination, particularly at the strategic level. DOI's Office of Everglades Restoration Initiatives, in coordination with the Task Force, is currently supporting development of a Comprehensive Invasive Species Strategic Action Framework that includes greatly enhanced high-level coordination and a crosscut budget.[5] In December 2012, the Task Force established a working group to conduct a comprehensive review of the coordination and nature of efforts to combat invasive species in the Everglades. As of December 2013 a strategic planning exercise was under way by the working group to fashion the Strategic Action Framework. Efforts to devise a governance structure to address the current gap in strategic and funding coordination could be particularly useful. This activity is in its early stages, but it appears to be directed at a concern expressed to this committee by many individuals—the lack of high-level coordination in developing priorities for budgets and actions across agencies to address invasive species.

INVASIVE NONNATIVE SPECIES IN THE CONTEXT OF RESTORATION GOALS

The catchphrase "get the water right" governing planning for Everglades restoration assumes that restoring a semblance of the pre-development water flow to the region will lead to restoration of ecosystems and species. This dictum has dominated aquatic and wetland restoration since its inception and has been termed the "field of dreams" hypothesis (Palmer et al., 1997). As discussed in this chapter, many empirical examples of nonnative species invasions show that this is not necessarily the case (Palmer et al., 2014). It is possible that getting

[5] See http://www.sfrestore.org/ies.html.

the water right will, for certain nonnative species, at least help to lower their populations and impacts, but for others, attempts to get the water right may actually exacerbate impacts and even foster further invasions (Ogden et al., 2005; RECOVER, 2014a).

Recently, the USACE and SFWMD issued guidance to incorporate invasive species management into CERP project planning and implementation. CERP Guidance Memorandum 062.00 (USACE and SFWMD, 2012d) required invasive species management to be incorporated into all phases of CERP projects and an invasive and nuisance species management plan to be developed as part of the project implementation report (PIR) process. To date, plans have been developed for C-111 Spreader Canal, Biscayne Bay Coastal Wetlands, and the Central Everglades Planning Project (USACE and SFWMD, 2011, 2012a, 2013a), although only the Central Everglades Planning Project addresses both plants and animals (RECOVER, 2014a). Several projects that were developed prior to the guidance memorandum have now developed vegetation management plans. At a national level, a December 2013 draft *Program Management Plan for the Invasive Species Leadership Team* (USACE, 2013f) provides a detailed vision for management of invasives at all stages of project planning and implementation, including considerations of design features to reduce the likelihood of enhancing the spread of invasives. The document provides a strategic plan for educating USACE staff and implementing new regulations, including Executive Order 13112 (1999), which directed federal agencies "to prevent the introduction of invasive species and provide for their control and to minimize the economic, ecological, and human health impacts that invasive species cause," as well as the 2009 USACE Invasive Species Policy Memorandum (Temple, 2009). If fully implemented, these documents could help address major concerns of invasive species management associated with CERP project planning and implementation, and the committee looks forward to evaluating their results.

Despite the enormous impacts of some nonnative species, invasive species management has so far not been a major focus of the CERP, beyond treating invasive plants that spread during construction. Communities composed of mixtures of nonnative species with varying remains of native assemblages are commonplace in the Everglades landscape. There is great urgency to detect and eliminate new arrivals and manage those that have spread beyond the point where eradication is still feasible. However, funding and manpower are limiting and effective control techniques (e.g., biocontrol agents) for many nonnatives are still in the development stage (see Tables 6-2 and 6-3). Prioritization decisions leave some areas unmanaged and some nonnative species uncontrolled because the particular system is not ecologically or economically feasible to restore or because some nonnative species have not been shown to have substantial harmful ecological impacts or possess seemingly desirable characteristics. Thus, many parts of the greater Everglades landscape, particularly remote areas with poor access, remain invaded by multiple nonnative species and will remain so for the foreseeable future.

Thus, although restoration to a semblance of the way the Everglades looked and functioned a century ago may, with sufficient effort, be possible for certain areas, such a goal is impractical for other sites. The spatial extent of the problem highlights the importance of understanding the effects on ecological functions as well as potential ecosystem services of these altered assemblages to the overall ecosystem. Although it is highly likely that the functioning is different and services are reduced compared with uninvaded, native communities, some research in this system has shown that certain nonnative species can provide benefits (e.g., exotic apple snails as a potentially important food for native snail kites [NPS, 2013]), even if they are simultaneously detrimental in other respects.

The need to prioritize management resources and decipher how vast sections of the "invaded" Everglades are functioning, however, should not obscure the ideal goal of a functioning Everglades with its full complement of native species. CERP partners will have to decide on the restoration goals for specific areas of the Everglades, recognizing that hydrological restoration alone will not necessarily achieve ecological restoration goals (Clewell and Aronson, 2013). Discussions on this issue will need to consider that areas left unmanaged for invasive species because full restoration is not a goal can serve as sources of seeds, spores, and other propagules and thereby threaten other areas being managed for more ambitious restoration goals.

In addition, as described earlier in the chapter, interactions between nonnative and native species and between different nonnative species often are complicated, and one invasion may exacerbate the spread of another (as exemplified by the case of the invasive figs and their fig wasp pollinators).

CLIMATE CHANGE AND INVASIVE SPECIES

With global warming, sea-level rise, and the water management activities associated with them, distributions and abundances of nonnative species are expected to shift across the landscape. New species will likely invade, while distributions of some existing species will contract and others expand (Hellmann et al., 2008). These changes will be driven in part by shifting climatic envelopes, but also by changes in species interactions (Simberloff, 2012).

As discussed in Chapter 5, global climate change models developed at coarse scales for the Everglades vary with respect to projected temperature and precipitation regime changes, as well as rate of sea-level rise (Obeysekera et al., 2011a). Responses of nonnative species to these scenarios, as well as the anticipated changes in hydrologic regimes with restoration activities, present an area of great uncertainty that has received relatively little attention. Given the ever-growing number of nonnative species in the system, a multitude of species-specific response patterns and interactions with native flora and fauna is likely as the effects of these environmental changes unfold (Junk et al., 2006).

One possible climate change scenario includes increased temperatures and potential evapotranspiration, along with reduced precipitation, resulting in reduced water supplies to the entire system. Human-caused changes to the Everglades ecosystem have already shortened hydroperiods, in some cases favoring the spread of many nonnative plant and animal species (Jones and Doren, 1997; Olmstead and Loope, 1984). Further shortening of hydroperiods under some climate change scenarios may promote their continued expansion (Davis et al., 2005b). In addition, many of the species introduced into the Everglades are native to tropical habitats and are thus likely to expand with warmer conditions at the expense of resident native flora and fauna that are better adapted to temperate and subtropical climates. For instance, Trexler et al. (2000) suggest that the densities and range of several nonnative fish species in the Everglades currently are limited by occasional low temperatures or severity of droughts. A changed climate could relax some of those limiting constraints.

Biological control agents have been introduced to counter many invasive nonnative species in the Everglades. These species themselves are generally nonnative as they have been selected and introduced from the home range of the target species. As with other nonnative species, there is great uncertainty with respect to effects of climate change on these agents. As temperature and rainfall patterns change, geographic distributions of the agents and their targets are likely to change as well. Such changes could promote increased contact between agents and nontarget species. Further, the effectiveness of these agents could be affected by changing environmental conditions and shifts in timing of the plants' or animals' life-cycle events (Parmesan, 2006; Simberloff, 2012). Agents that are currently effective may become less useful and potentially problematic if they become spatially or temporally decoupled from their targets.

CONCLUSIONS AND RECOMMENDATIONS

Despite excellent progress in developing coordination of the management of invasive species at the operational level, most notably through ECISMA, there is a lack of coordination at a strategic level that includes a comprehensive view of all nonnative species in all parts of the Greater Everglades. Currently, plants and animals tend to be considered separately. Management and restoration activities need to take account of the entire biotic community and not be partitioned into different taxa. This indeed is consistent with the vision for Everglades restoration. However, it can be difficult to take such a view at a project level. Further, for many invasive species, different agencies take on management activities in different areas, yet individuals of such species move between areas, so that management in one area can impact other areas. These factors argue for the creation of a high-level coordinative entity to oversee policy, management, and budgets related to nonnative species. Prioritization of research needs and control efforts across areas, species, habitats, and agencies would be a major responsibility of this entity. The committee is optimistic that the Comprehensive Invasive Species Strategic Action Framework being developed by the Task Force will be a major step toward achieving these goals of high-level coordination.

A strategic early detection and rapid response (EDRR) system that addresses all areas, habitats, and species is needed. EDRR is an essential strategy if new invasions of nonnative species in the Everglades are to be eradicated (or at least contained) while it is still feasible and relatively inexpensive to do so. Currently several EDRR efforts are under way, but the current level of monitoring is insufficient to address the geographic extent and range of nonnative species threats in the Everglades. In general, a rapid response requires quick access to resources, but efforts to eradicate incipient invasions in the Everglades have more often been limited by the inability to obtain funds from federal, state, or local sources. The costs of additional monitoring and response should be weighed against the likely benefits of finding and acting on early invasions. Additional funding would allow for greater public outreach, expanded operation of the reporting hotline, increased early detection monitoring, and improved capacity for rapid response to facilitate eradication. The committee recognizes that the goal of this recommendation—addressing all areas, habitats, and species—likely is beyond any reasonable expectation of resources, but keeping this goal in mind emphasizes the value of prevention and clarifies the magnitude of the challenge.

There is no systemwide mechanism for prioritizing research on and management of invasive species. Many agencies participating in the Everglades restoration already undertake research activities on certain nonnative species and also undertake management activities, but these efforts are limited by insufficient resources and are typically driven by specific agency needs rather than systemwide priorities. Effective prioritization requires a comprehensive understanding of all nonnative species present in the Everglades, their impacts and threats, as well as those of impending or likely new arrivals.

Research is lacking on nonnative species and their impacts to inform prioritization efforts adequately. Tables 6-2 and 6-3 highlight some of the many gaps in knowledge about species considered to be priorities for management. Given the spatial extent of the problem and the threats of future invasions, substantial research is needed to assess the various impacts of nonnative species on ecosystem functioning and native species and to develop or improve control mechanisms. This does not mean comprehensive research of all details of the biology and effects of every nonnative species. Rather, enough basic information should be gathered systematically to determine which species could reasonably be predicted to have considerable ecological impacts. Such knowledge is important in guiding decisions on detailed research on possible impacts and management of particular threats and would help inform priorities for management actions.

If eradication proves impossible, maintenance management and long-term control at acceptable levels should be explicitly recognized as a goal in some cases. Indeed, current practice seems implicitly to recognize this goal. Maintenance management at low densities is sometimes possible by various combinations of biological, chemical, mechanical, and physical controls. In the Everglades, a striking example is the current management of melaleuca, once thought too widespread and dense to be manageable. As a result of sustained intensive research, this species is currently under substantial control in most regions through a combination of mechanical, chemical, and biological control as well as prescribed burns. Maintenance management requires continued, diligent monitoring and flexible, but reliable funding that can be devoted strategically to achieve and maintain long-term control.

At every step of the CERP planning process, full consideration is needed of the implications of restoration activities for introduced species and their impacts. Until very recently, invasive species have not been considered in CERP project planning and implementation beyond simply removing any invasive species encountered at construction sites. Ideally, hydrologic restoration should favor the reestablishment and expansion of many native wetland species that are better adapted to longer hydroperiods. However, aquatic and flood-tolerant nonnative species may also benefit and replace native species. Removing levees and filling in canals may, in certain circumstances, facilitate the spread of nonnative species by increasing their potential for dispersal. For each CERP project, the potential to increase the spread of invasive species should be examined and the effects on ecosystem functioning assessed. Based on this analysis, strategies and technologies to lessen these impacts should be appropriately considered. Recent CERP guidance and plans to implement national USACE invasive species policy indicate that these considerations are increasingly being incorporated into project planning and implementation, although it is too soon to evaluate this new approach.

Long-term monitoring and research are needed to understand the potential impacts of climate change on Everglades nonnative species management. Climate change has the potential to significantly impact the distributions and abundances of nonnative species in the Everglades and their impacts on the ecosystem as a whole. Thus, research and monitoring to understand long-term changes in nonnative species distribution and behavior and the effectiveness of maintenance control strategies in the context of climate change are needed.

7

Use of Science in Decision Making

Given the enormous scope and complexity of the restoration effort, strategic, high-quality, responsive, and sustained science and adaptive management are needed to ensure the effectiveness of the impressive Comprehensive Everglades Restoration Plan (CERP) engineering efforts under way. In this chapter, the committee reviews scientific support for Everglades restoration from several perspectives. This chapter builds upon prior reviews of this topic by the National Research Council (NRC, 2007, 2008, 2010, 2012a). First, science coordination and management are discussed, with particular emphasis on what is needed for an effective, sustainable systemwide monitoring program. Next, progress on the implementation of adaptive management is discussed. Finally, the recently released *2014 Draft System Status Report* (RECOVER, 2014a) and the *Science Plan for Everglades Stormwater Treatment Areas* (SFWMD, 2013d) are reviewed, because they represent important contributions to the adaptive management process.

SCIENCE COORDINATION AND MANAGEMENT

A comprehensive program of scientific research and systemwide monitoring helps ensure that the substantial investment in Everglades restoration is being directed effectively. Moreover, the concept of adaptive management depends on monitoring data to assess whether restoration goals and targets are being met and on lessons learned through scientific research to improve restoration outcomes. Because of the complex nature of the Everglades ecosystem and the numerous federal, state, and tribal government agencies and stakeholders involved with multiple perspectives and objectives, science governance is a challenge. To have a robust effective science and monitoring program for this complex restoration program, a number of features are required, including stable funding and effective science coordination and communication. The committee judges that research support for Everglades decision making is robust; therefore, this section focuses on monitoring and coordination.

The Need for Robust Science and Monitoring Programs

Substantial federal and state resources have been and continue to be invested in Everglades restoration. To ensure that these resources are being used wisely to achieve restoration objectives, a robust science and monitoring program is essential. Scientific research provides knowledge and tools that assist decision makers. Monitoring involves the collection of data necessary to evaluate the success of various restoration projects. Long-term data that describe the conditions, variability, trends, and patterns related to resources and processes in the Everglades are fundamental to understanding whether and how projects, once implemented, change conditions. Systemwide, long-term perspectives are all the more important in the context of climate change, given that "baseline" (pre-project) conditions are not anticipated to be stationary through time (see Chapter 5). Comprehensive ongoing monitoring and assessment are also critical to adaptive management.

The importance of comprehensive monitoring and assessment to the success of Everglades restoration has been recognized from the beginning by CERP partners and by prior NRC committees (NRC, 2003a, 2007). Under RECOVER, a systemwide Monitoring and Assessment Plan (MAP) was developed as "a single integrated, system-wide monitoring and assessment plan that will be used and supported by all participating agencies and tribal governments as the means of tracking and measuring the performance of the CERP."[1] The most recent is the 2009 MAP (RECOVER, 2009), which is a revised version of MAP 2004 (RECOVER, 2004). The RECOVER program is responsible for linking science with CERP systemwide planning, evaluation, and assessment, and one key RECOVER responsibility is to "ensure that a system-wide perspective is maintained through the restoration process" (RECOVER, 2012a). The RECOVER program uses scientific information developed pursuant to implementation of the MAP to assess the performance of the CERP.

Beginning with a dedicated workshop in November 2001, the NRC has reviewed the development of MAP and the selection of appropriate and practical performance measures by RECOVER (NRC, 2003, 2007, 2008, 2010). As noted in NRC (2008), performance measures of both ecosystem condition and critical ecosystem stressors (e.g., estuarine salinity, soil and water phosphorus concentrations, hydropatterns) have been developed, which allows assessment of cause-effect relationships. This is a great strength of the performance measure system, because an understanding of ecosystem dynamics is crucial for implementing an adaptive management approach. The MAP and its performance measures were reviewed extensively in NRC (2008), which concluded that "[t]he number of performance measures is not inherently problematic" but noted that

[1] http://www.evergladesplan.org/pm/recover/recover_map_part2.aspx.

"the set of performance measures should be reviewed regularly to determine whether . . . adequate data collection for each could be sustained over the course of the restoration."

Previous NRC reports (2003a, 2007, 2010) have judged that the RECOVER MAP is a reasonable plan for monitoring and assessing systemwide conditions in the Everglades. The team that developed the MAP seems to have taken a holistic view and does not appear to have been overly influenced by parochial interests. The MAP does not narrowly focus on specific projects, specific geographic areas, or specific resources, but instead takes a systemwide approach. However, there are several shortcomings with the MAP. From the beginning, the MAP was intended to fill critical gaps in systemwide monitoring, rather than to control and fund all restoration-related monitoring for the Everglades. The challenge with this approach is that no entity oversees the entire monitoring effort or manages monitoring priorities across a diverse array of agencies and institutions. Thus, it would be helpful to have a process to evaluate and revise the MAP over time as agencies' funding changes.

A recurring, comprehensive review process would also help the MAP adapt as new information becomes available and as ecosystem conditions change due to climate change or other anthropogenic or natural circumstances. Given the extremely long time lines currently being projected for completion of the Central Everglades Planning Project (see Chapter 3) and the very real likelihood that climate change and sea-level rise will cause significant changes to the South Florida ecosystem during this time (see Chapter 5), the MAP should be revisited to evaluate whether it is still appropriate. Key long-term monitoring to understand the shifting ecological baselines in the context of climate change may currently be overlooked, while other monitoring may be too frequent in the context of the slow pace of CERP implementation.

The Need for Stable Funding

The most significant shortcoming with the MAP, however, is not necessarily with the plan itself, but with the implementation of the plan, because of substantial funding cuts that have occurred in the past few years and the overall funding structure. A dedicated, stable, and reliable funding source is essential to obtain the long-term systemwide monitoring data necessary to evaluate the success of restoration efforts. Such funding is necessary to conduct monitoring for long enough to provide a scientifically sound understanding of the conditions, trends, and patterns for each parameter of concern.

NRC (2012a) addressed the recent budgetary cuts and their impact on monitoring and assessment. In that report, the committee concluded that the large and sudden cuts to the RECOVER MAP pose a risk to systemwide assessment, which is important to the success of Everglades restoration. The cost of the RECOVER-funded monitoring through the MAP increased from about $0.7 million in fiscal year (FY) 2000 to about $10 million in FY 2007, and MAP funding has declined roughly 60 percent since 2007, with a sharp cut of 48 percent in FY 2012 (NRC, 2012a). The funding level has remained flat throughout 2013. These cuts were amplified by cuts in many other agencies' monitoring budgets. Agency staff voiced concerns that the monitoring cuts reduced the capacity to understand systemwide ecosystem responses and to explain why changes may have occurred.

Although the CERP is struggling with many budget uncertainties, the committee remains convinced of the vital importance of systemwide monitoring to the success of Everglades restoration. Without a sufficient monitoring program, the CERP cannot be accountable to federal or state sponsors and cannot support its adaptive management program. The committee recognizes the realities of changed economic conditions, budgets cuts, and shifting priorities and thus understands that funding cuts sometimes are unavoidable. But the long-term costs of monitoring cuts are often overlooked. If funding cuts result in significant gaps in critical long-term monitoring data, important changes and patterns could be missed, and data collected prior to or after the gaps created by funding cuts could lose their value. Therefore, to ensure that existing monitoring is cost-effective and provides adequate support for CERP planning, adaptive management, and public communication, a comprehensive review of all monitoring programs that were considered in the original design of the MAP is needed, considering recent and projected reductions. The major MAP budget reductions for FY 2012 were implemented very quickly (NRC, 2012a), and time was not available to reconsider the essential components of a monitoring program, particularly in light of the slow pace of CERP implementation in a changing climate, or to consider the shifting budgets of other agency monitoring programs.

The existing monitoring funding structure with its 50-50 state-federal cost-sharing requirement (see Chapter 4) appears to be especially vulnerable to changing economic and political conditions. The structure of the cost share is such that if the state experiences cutbacks that result in funding cuts to the MAP, the federal government may be constrained from making up the differences to fund the MAP because such funding will heighten imbalances in the overall cost share. A different funding structure that not only provides a more reliable, consistent long-term source of support could go a long way in ensuring continuity in long-term monitoring. Although there may be a wide range of possible mechanisms for providing long-term stable funding for ecosystem-wide monitoring and assessment, one approach could be dedicated funding provided to one federal agency without being tied to the 50-50 cost-sharing requirements of the current system.

The Need for Effective Coordination and Communication

Scientific research and monitoring programs require coordination and communication to be effective and efficient. Currently, there is no single entity that is responsible for coordinating scientific study and scientific monitoring related to restoration. Numerous federal and state agencies, as well as other entities such as tribes, local governments, nongovernmental organizations, and universities carry out research projects and monitoring related to restoration. In fact, in the last few years, at least 50 scientific studies have been conducted in the Everglades. Many of these studies are either agency specific or project specific. In other words, each agency carries out studies to support its own responsibilities and objectives. For example, the National Park Service, the U.S. Geological Survey, and the South Florida Water Management District (SFWMD) each conduct research related to its agency missions and objectives. These research efforts may focus on specific resources or specific geographic locations or may have systemwide applications.

After the U.S. Government Accountability Office (GAO, 2003) recommended improved science coordination, the South Florida Ecosystem Restoration Task Force's (Task Force's) Science Coordination Group (SCG) developed the *2006 Plan for Coordinating Science* (SFERTF, 2006), last updated in 2010 (SFERTF, 2010). The Department of the Interior released its *Science Plan in Support of Ecosystem Restoration, Preservation, and Protection in South Florida* in 2005 (DOI, 2005). However, these plans are now dated, and no longer serve to facilitate scientific coordination.

The SCG was specifically formed to coordinate the scientific aspects of restoration to support the efforts of the Task Force. SCG members include both scientists and senior managers from federal and state agencies, tribes, and local governments. The purpose of including both scientists and senior managers in the SCG is to "enhance the integration of science and management" (SCG, 2003). The SCG is charged with coordinating the scientific aspects of restoration in general and thus is not limited to CERP projects or monitoring. Despite the broad science coordination charge to the SCG, the group's success in providing coordination and oversight of science has been limited. Ideally, an organization such as the SCG, broadly tasked with science coordination, would keep track of ongoing scientific studies, identify gaps and redundancies, identify scientific needs, and direct staff and financial resources to fill significant information gaps. It does not appear that the SCG has played a significant role since 2006 in evaluating the state of the science to identify gaps or overlaps. It is not entirely clear why the SCG has not played a more significant role. The SCG's lack of dedicated funding and lack of authority to direct financial resources to pay for needed science certainly is part of the limitation. For the SCG to significantly contribute to better science coordination, it would need to have adequate funding and staff and a clear charge to address critical science needs from a restoration-wide perspective.

The history of the SCG suggests that its role and priorities have shifted over time. These shifts may be contributing to the perceived diminution of science coordination or may be the result of other actions such as cuts to science budgets or personnel changes. In any event, a review of the role of the SCG over the past 10 years may provide some insight that could inform efforts to improve science coordination and communication.[2] In the first few years after its formation in 2003, the SCG appears to have been intensely focused on developing its comprehensive *Plan for Coordinating Science* and developing systemwide indicators. Both were original efforts that required intense staff and SCG member engagement and creative work. In 2007-2008, the SCG continued working on a science coordination plan and systemwide indicators while beginning to tackle some challenging questions in focused meetings or workshops (e.g., identifying ecosystem features or areas with the largest rates of decline, potential impacts of climate change). In 2009-2011, the SCG shifted its focus to new initiatives related to climate change, invasive species, and new science. Although these efforts were intended to be original syntheses to assist the Task Force in identifying next steps, the actual impact of these efforts is not clear. During this time, the SCG also held a workshop on science and decision making, which was well received. Since 2011, the SCG meetings have discussed the Central Everglades Planning Project and MAP budget issues. Although there was discussion of a workshop to reevaluate the monitoring plan,[3] such a workshop has not yet occurred. It also appears that during the past few years, the number of SCG meetings has tapered off and the meetings have been focused more on providing restoration updates, rather than unique SCG initiatives. The extent to which recent budget cuts and the recent intense focus on the Central Everglades Planning Project has diverted attention from science coordination is unclear. In any event, it seems clear to the committee that the SCG could and should reengage in its mission of science coordination and leadership. An important task for the SCG would be a comprehensive reevaluation of restoration-related monitoring in light of current budget impacts, the extended CERP implementation time frames, and

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[2] Meeting agendas and minutes for the SCG can be found at http://www.sfrestore.org/scg_minutes.html.

[3] See http://www.sfrestore.org/wg/wgminutes/2013meetings/013113/minutes_092013.pdf.

climate change. This reevaluation should clearly articulate the value of the highest priority monitoring needs and the risks of ceasing such monitoring to future restoration decision making. One important component of carrying out these recommendations would be for the SCG to hold regular meetings focused on science coordination planning and for the SCG to host occasional workshops on important science-related issues.

Another issue that has been raised with regard to science governance is the challenge of communication between scientists and upper-level managers and policy makers. A communication structure that facilitates communication between scientists and upper-level management is fundamental to sound decision making. Managers need a mechanism to communicate information needs to researchers to meet policy objectives. Researchers also need a mechanism that enables them to communicate science needs and results of research and monitoring to upper-level management. One process that could be put into place is a regular meeting between senior science staff and upper-level managers to discuss the status of ongoing science and how it relates to decisions being made at high levels. It does not appear that this type of meeting between scientists and high-level managers occurs with any regularity. If the SCG revisited the comprehensive 2006 Plan for Coordinating Science, the SCG could facilitate discussions between policy makers and scientists to identify additional pressing science needs.

ADAPTIVE MANAGEMENT

In the context of the CERP, adaptive management is defined as "a structured management approach for addressing uncertainties by testing hypotheses, linking science to decision making, and adjusting implementation as necessary to improve the probability of restoration success" (USACE and SFWMD, 2011b). A major characteristic of adaptive management is a feedback mechanism for refining project planning and implementation based on new information gained from monitoring results, thus reducing uncertainties that may prevent a project from proceeding or achieving its intended outcomes. Adaptive management has been a core component of the CERP since the year 2000 and remains an active and continually evolving area of planning. Previous NRC reports have provided detailed reviews and evaluations of the adaptive management principles and frameworks developed for the CERP in terms of their ability to meet adaptive management goals and assess restoration outcomes (NRC, 2008, 2010). In this section the committee reviews the progress made in activities to support adaptive management within the CERP since 2010. A more detailed review of adaptive management progress in the context of the Central Everglades Planning Project is provided in Chapter 3.

In the CERP Monitoring and Assessment Plan (RECOVER, 2004, 2006a, 2009) monitoring and research needs are identified for measuring ecosystem responses to CERP implementation, but the first authorized CERP projects did not include formal adaptive management plans. Although the Water Resources Development Act of 2000 acknowledged the adaptive management foundations of the CERP, the 2003 Programmatic Regulations (33 CFR Part 385) required development of an adaptive management program by CERP-implementing agencies, and the *2006 Comprehensive Everglades Restoration Plan Adaptive Management Strategy* (RECOVER, 2006b) laid a framework for adaptive management, it was not until 2009 that the U.S. Army Corps of Engineers (USACE) required adaptive management plans for all USACE ecosystem restoration projects (Convertino et al., 2012; LoSchiavo et al., 2013). Since 2009, formal adaptive management plans have been developed or revised for four CERP projects (Table 7-1): Decompartmentalization of Water Conservation Area 3 (WCA-3), the Biscayne Bay Coastal Wetlands project, Broward County Water Preserve Area, and Central Everglades Planning Project (USACE and SFWMD, 2011c, 2012c,e, 2013b). The C-111 Spreader Canal also has a monitoring and assessment plan (USACE and SFWMD, 2011d) that contains many components of an adaptive management plan despite lack of formalization and approval as an adaptive management plan (Table 7-1). These plans contain various levels of complexity, dictated in part by the scope of the project and the suite of desired ecosystem responses with project implementation. Additionally, adaptive management options are limited if they are not integrated into the project design from the outset—the initial phases of the CERP did not explicitly integrate adaptive management into project implementation plans because it was not mandated. Hence, since 2009, adaptive management plans have become more integrated and sophisticated with time as guidance has been developed and refined, with the Central Everglades Planning Project adaptive management plan being the most complex and sophisticated to date (see Chapter 3).

Two notable sets of guidelines have recently been finalized with the aim of providing an explicit framework for developing consistent adaptive management plans for CERP projects: the Adaptive Management Integration Guide (RECOVER, 2010), and the CERP Guidance Memorandum 56 (USACE and SFWMD, 2011b). The CERP Guidance Memorandum 56 is the first guide to merge the various adaptive management documents with other guidance memoranda for development of project implementation reports (PIRs). It specifically focuses on areas of intersection in adaptive management guidance across the CERP 6-step planning process, the Adaptive Management Integration Guide, the USACE Planning Guidance Notebook (USACE, 2000), engineering circulars and regulations, and USACE Headquarters guidance memoranda. These two

TABLE 7-1 Time Line of Inclusion of Adaptive Management Plans in Active CERP Projects

CERP Project	Current USACE Life-Cycle Phase (year authorized)	Adaptive Management Plan	Adaptive Management Features
Aquifer Storage and Recovery	Pilot projects implemented (2000 authorization)	No[a]	Testing pilot projects and sensitivity modeling
Indian River Lagoon-South	Construction (2007 authorization)	No	
Picayune Strand	Construction (2007 authorization)	No	Monitoring and assessment plan with recommendations to use adaptive management
Site 1 Impoundment	Construction (2007 authorization)	No	
Melaleuca eradication	Implementation (2007 authorization)	No[a]	Adaptive management implementation strategy and some monitoring
2009 USACE HQ policy requiring adaptive management for ecosystem restoration projects; 2011 CERP Adaptive Management Integration Guide and 2011 CERP Memorandum Guide 56 released			
C-111 Spreader Canal	Pilot project and Planning Chief's report (2011), operations	No[a]	Design and operational tests, project phasing
Decompartmentalization of WCA-3	Pilot project constructed (2013)	Yes	Decomp Physical Model adaptive management field test
Biscayne Bay Coastal Wetlands	Planning Chief's report (2012)	Yes	Post-construction management options matrix and linked monitoring
Broward County Water Preserve Areas	Planning Chief's report (2012), design	Yes	Operational options linked to nutrient and ecological monitoring, and design improvements
Central Everglades Planning Project	Planning	Yes	Design tests, project phasing, post-construction contingency options, and operations linked to monitoring

[a] Indicates that the project had some components of adaptive management even though it did not have a formal adaptive management plan.
NOTE: Projects are listed chronologically by when they were authorized for construction or when the planning chief's report was approved for Congress.

SOURCE: Modified from LoSchiavo et al. (2013).

guides are the products of years of effort to develop a coherent, generalized, and comprehensive structure for adaptive management planning for CERP projects in response to repeated recommendations and mandates, and as such they represent significant progress toward adaptive management planning.

Recommendations to develop decision analysis tools to support the adaptive management process have been a focus of two previous NRC reports (NRC, 2010, 2012a). Formal decision frameworks to integrate scientific information from monitoring activities, stakeholder values, and costs, while addressing risk and uncertainty, are crucial to providing transparent decision support to weigh multiple objectives in highly complex and uncertain multiagent systems such as the CERP. The development of multicriteria decision analysis tools to supplement adaptive management for the CERP was under way during the prior committee's review (NRC, 2012a). The year 2012 marked the Phase 1 completion of a Bayesian network decision analysis tool intended to "provide managers with a framework for evaluating and assessing multiple restoration objectives (performance measures, constraints, costs, risk/uncertainty, and social values) in order to understand how implementation of a program and/or project and its adaptive management plan(s) should change based on a given state of information" (Convertino et al., 2012, 2013). In a proof-of-concept case study, the tool was applied to management alternatives related to the decompartmentalization of WCA-3. The decision support tool characterizes linkages between the project objectives, conceptual and predictive models, the direct and indirect effects of project alternatives on project objectives, stakeholder values to weight objectives, and the uncertainty associated with achieving competing objectives. A distinctive feature of this tool is a global sensitivity analysis that allows for assessment of the value of information each parameter in the decision tool contributes to the decision. In this way the decision support tool can inform the monitoring activities that can optimally reduce uncertainties while minimizing costs induced in redirecting or increasing data acquisition efforts in the context of meeting restoration objectives. If funding for the project is continued, this tool will be improved in Phase 2 by broadening the stakeholder involvement and including greater depth and breadth in spatial and ecological parameters and expanded in Phase 3 to the larger ecosystem under the CERP (Convertino et al., 2012).

2014 SYSTEM STATUS REPORT

RECOVER System Status Reports (SSRs) provide periodic assessments of monitoring data throughout the South Florida ecosystem to support adaptive management and improve CERP planning and implementation. The 2014 Draft SSR (RECOVER, 2014a), the fifth in the series, was released in late March

2014, and represents a synthesis of 5 years of monitoring data and scientific research since the last comprehensive SSR was released in 2009. The document is "intended to convey key scientific information to water managers, budget directors, decision-makers, and the public about the status of the Everglades ecosystem to support restoration and water management decisions" (RECOVER, 2014a).

The 2014 Draft SSR, like its predecessors, is a comprehensive document. The committee's review addresses the degree to which it provides information to support adaptive management, and because the document became available late in the committee process, the committee focused on Chapters 1 (Key Findings) and 4 (Systemwide Science). In brief, the committee concludes that the SSR is well written and provides good information, including syntheses and recommendations, that are helpful to management decisions about Everglades restoration. Some specific comments are provided as examples below.

The Key Findings (Chapter 1) of the 2014 Draft SSR set the stage by reporting recent hydrologic and climate conditions affecting the region between 2009 and 2013, compared with historical averages. Overall, it provides a succinct summary of major findings with regard to status and trends, projects and operations, and new science covering scales from project level to systemwide. A strength of the document is its synthesis of a huge array of monitoring data and recent research into science-based recommendations for management. Rather than simply reporting observed trends, the 2014 Draft SSR explains and documents the causal mechanisms and provides recommendations for continued ecological improvements. For example, on the basis of new research findings on oyster survival in the St. Lucie Estuary, the SSR documents the adverse effects of back-to-back dry years and proposes salinity targets that could be used in the operational plans for the Indian River Lagoon-South project. Research also determined that oyster restoration in the St. Lucie Estuary is limited by suitable substrate rather than the supply of larvae, and the SSR recommends substrate enhancement just prior to spawning to improve restoration outcomes. Similar synthesis of findings and recommendations are provided for the Greater Everglades, Lake Okeechobee, and Florida Bay.

The 2014 Draft SSR also documents ecosystem improvements that can be quantitatively linked to CERP and non-CERP projects:

- Hydrology improved due to the operational part of the Deering Estate Biscayne Bay Coastal Wetlands expedited project;
- Picayune Strand showed higher water levels near the filled Prairie Canal (1 to 2 feet higher) and vegetation is starting to show signs of improvement and moving closer to reference conditions;

- Hydroperiods were 50 days longer (on an annual average basis) along the centraleastern edge of Everglades National Park as a result of the C-111 South Dade project; and
- Roseate spoonbill nesting improved, most likely due to favorable climatic conditions and better real-time environmental coordination with water management operational decisions.

The SSR does not overstate the ecological project responses (citing these as "demonstrations of small restoration successes") and points to steps necessary to increase observable improvements in the Biscayne Bay Coastal Wetlands and Picayne Strand projects. The document also highlights the continuing ecosystem declines and "the need for and value of authorizing, constructing, and operating more CERP restoration projects to achieve systemwide hydrologic (water quantity, quality, timing, and distribution) and ecological (flora, fauna, and landscape) goals and objectives."

In Chapter 4, Systemwide Science, the draft SSR reflects a subject-matter focus that is quite similar to the focus of this NRC report, with extensive information and discussion of climate change and invasive species, including a substantial appendix devoted to invasive species. The draft SSR includes discussions of the implications for restoration of changing climate and rising sea level, and its discussions and analyses of invasive species include regional and systemwide status and trends. The 2014 SSR also provides a comprehensive review of recent research and data on the role of fire in the Everglades (described as "one of the first attempts to reconcile the historical data set of fire history in ENP [Everglades National Park] and BCNP [Big Cypress National Preserve] with the current management") and the implications for fire management. These summaries represent important and useful synthesis efforts, building on other recent science synthesis reports (RECOVER, 2011b; SERES Project Team, 2010; WG and SCG, 2010) summarized in NRC (2012a).

The committee concludes that the Draft 2014 SSR reflects a comprehensive, scientifically up-to-date and sound approach and execution. It is well organized and illustrated, and for such a large document, it is easy to read. The document is very clear and explicit in connecting the information presented with the needs of managers as they make restoration decisions concerning project design, construction, implementation, and operation. One area that could receive additional attention is at the intersection between water quality and hydrology, including recognition where conflicts exist between near-term restoration goals.

REVIEW OF THE SCIENCE PLAN FOR EVERGLADES STORMWATER TREATMENT AREAS

The SFWMD in collaboration with the U.S. Environmental Protection Agency and the Florida Department of Environmental Protection developed the *Science Plan for the Everglades Stormwater Treatment Areas* (STAs; SFWMD, 2013d) to investigate critical factors that regulate the sustainable removal of phosphorus by STAs. The science plan is intended to support a $50 million water quality research program over the next 10 years. The science plan identified several key questions (Box 7-1) that need to be addressed to improve the understanding of various physical, chemical, and biological factors regulating the total phosphorus concentration in STA outflows and research and monitoring efforts to address them. Examples of proposed research include studies on the effects of inflow phosphorus concentrations and loads, uptake of phosphorus by vegetation, microbial activity in soils and the water column, and the stability of accreted phosphorus in soil compartments. The SFWMD plans to use the results of these investigations to improve the design and operations of STAs to achieve compliance with the total phosphorus water quality-based effluent limit (WQBEL).[4] Thus, the primary objective of this Science Plan is to improve understanding of the external and internal drivers that regulate the performance of STAs at low phosphorus concentration.

Overall, the Science Plan is comprehensive and well developed to meet general operational goals of the STAs. Additional comments and suggestions regarding the six key research questions are provided in Box 7-1. There are also many interesting and useful science subquestions identified, but their usefulness in developing improved STA management strategies needs additional consideration. One overarching concern is the single-minded focus on phosphorus cycling in the Science Plan, to the detriment of important analyses of the role of other macroelements (carbon, nitrogen, and sulfur) on the regulation of total phosphorus in STA outflows. It is critical to recognize the importance of coupled biogeochemical cycles of these macroelements in regulating sustained performance of STAs. Additionally, the Science Plan does not include any discussion on the influence of extreme events such as hurricanes and severe droughts. Currently, 60 percent of the STA treatment is in submerged aquatic vegetation, which has been shown to be more prone to disturbances from extreme events.

[4] The WQBEL is a numeric discharge limit used to regulate permitted discharges from the STAs so as not to exceed a long-term geometric mean of 10 μg/L within the Everglades Protection Area. This numeric value is now translated into a flow-weighted mean (FWM) total phosphorus (TP) concentration and applied to each STA discharge points, which now must meet the following: (1) the STAs are in compliance with WQBEL when the TP concentration of STA discharge point does not exceed an annual FWM of 13 μg/L in more than three out of five years, and (2) annual FWM of 19 μg/L in any water year (Leeds, 2014).

BOX 7-1
Reflections on Key Questions from the *Science Plan for the Everglades Stormwater Treatment Areas*

Key Question 1: ***How can the flow equalization basins (FEBs) be designed and operated to moderate and optimize phosphorus concentrations, phosphorus loading rates, and hydraulic loading rates entering the STAs, possibly in combination with water treatment technologies, and/or inflow canal dredging/lining?***

The Restoration Strategies program relies heavily on FEBs to improve the operation of STAs. Depending on water depth and residence time, FEBs can function both as sources and sinks for nutrients, especially phosphorus. The FEBs may also respond differently to low flows and high flows. The proposed research and monitoring plan will provide new data that will be useful for implementing appropriate adaptive management plans to support the design and operation of FEBs for maximum effectiveness. Properly managed FEBs will potentially reduce inflow total phosphorus concentrations, thus reducing loads to STAs.

Key Question 2: ***How can internal loading of phosphorus to the water column be reduced or controlled, especially in the lower reaches of the treatment trains?***

Microbial, periphyton, and vegetation communities are the major ecosystem biotic components that respond to and exert reciprocal control on abiotic drivers and in doing so generate biogeochemical cycles that may influence STA outflow total phosphorus (TP) concentrations. For effective management of STAs, it is critical to understand the internal biogeochemical dynamics of biotic and abiotic transformations in water, soils, and periphyton that regulate low TP levels as proposed in the Science Plan.

For the past two decades, state and federal agencies and universities have accumulated a wealth of data on internal dynamics of microorganisms, periphyton, and vegetation (SAV and EAV) in the Everglades Protection Area (WCAs and Everglades National Park) and their role in regulating low TP concentrations (10 µg TP/L) in surface waters (see Reddy et al., 2011, for a compilation of review papers). Although STAs are operated at much higher flow rates and TP loading rates than the rates encountered in the Everglades, contrasting these two ecosystems (STAs and the Everglades Protection Area) can provide insights to develop strategies to manage STA outflows for low TP concentrations.

Key Question 3: ***What measures can be taken to enhance vegetation-based treatment in STAs and FEBs?***

The role of biotic communities in assimilating phosphorus from the soil and water column is well known. In addition to assimilating phosphorus into their tissues, these

CONCLUSIONS AND RECOMMENDATIONS

Useful long-term systemwide monitoring requires stable funding. If funding cuts result in significant gaps in critical long-term monitoring data, important changes and patterns could be missed, and data collected before or after the biotic communities will also alter the micro- and macroenvironment in the water column and soils and influence phosphorus retention and release. Several studies are proposed in the Science Plan to understand the role of vegetation to reduce phosphorus concentration of the water column, with primary focus on phosphorus assimilation and storage in the vegetation. However, additional attention to nutrient balance (macro- and micronutrients) and abiotic and biotic reactions that may be more important in regulating phosphorus retention is merited.

Key Question 4: ***How can the biogeochemical and/or physical mechanisms be managed to further reduce soluble reactive, particulate and dissolved organic phosphorus concentrations at the outflow?***

Very little is known on transformations of particulate phosphorus (PP) and dissolved organic phosphorus (DOP) within various treatment cells. The challenge for STA optimization is to develop innovative management strategies to reduce internal production of PP and DOP. The Science Plan identifies various technologies to reduce PP and DOP, and some of these technologies are currently being tested. Although this practical approach is important and useful, it is equally important to conduct some studies that will determine the role of physical, chemical, and biological processes, vegetation types, and hydraulic loading rates on internal production of PP and DOP. This information will provide support to determine the type of technologies needed reduce outflow PP and DOP.

Key Question 5: ***What operational and/or design refinements could be implemented at existing STAs and future features (i.e., STA expansions, flow equalization basins) to improve and sustain treatment performance?***

The Science Plan identifies the importance of some operational and/or design refinements to STA to improve treatment performance. Examples of some operational/design refinements may include: managing high flows and low flows by taking advantage of FEBs and altering hydraulic retention times in treatment cells; sediment management in inflows and outflows; minimizing short-circuiting and improving flow distribution; inducing downward flow in STAs to reduce upward flux of phosphorus. These strategies may provide some operational flexibility to improve the overall performance of STAs to reduce TP levels in outflow.

Key Question 6: ***What is the influence of wildlife and fisheries on the reduction of phosphorus in the STAs?***

Wildlife (birds, fish, alligators, macro-crustaceans, mollusks, and others) can be a significant factor in phosphorus loading to STAs, especially in treatment cells near outflows. It is important to determine direct and indirect effects of wildlife of the extent of phosphorus loading and its ultimate impact on outflow TP concentrations.

funding gaps could lose their value. Given the substantial financial investment in Everglades restoration by both the state and the federal governments, a dedicated source of funding could provide ongoing long-term systemwide monitoring and assessment that is critical to meeting restoration objectives, ensuring that public resources are spent wisely, and adaptively managing restoration efforts.

A comprehensive reevaluation of restoration-related monitoring is needed to determine its adequacy considering budget pressures, the extended CERP implementation time frames, and the potential impacts of climate change and sea-level rise. The dramatic 2011 cuts to MAP funding create a risk that adequate long-term data will not be available to assess the effects of restoration projects in a systemwide context once they are implemented. This reevalution should clearly articulate the value of the highest priority monitoring to future restoration decision making and the risks of ceasing such monitoring. Also, CERP planners should identify opportunities for improving the efficiency of current monitoring and reducing the frequency of some monitoring in the context of the current slow pace of CERP implementation.

Renewed attention to science coordination is warranted. Scientific research and monitoring programs require coordination and communication to be effective and efficient, but science leadership and coordination appear to have waned over the past few years. For the SCG to significantly contribute to better science coordination, the SCG would need to have adequate funding and staff and a clear charge to address critical science needs from a restoration-wide perspective.

In recent years, project-level adaptive management plans have become more sophisticated and better integrated with project planning as guidance has been developed and refined. After calls for adaptive management since 2000, significant progress has been made toward adaptive management planning at multiple scales. The Central Everglades Planning Project adaptive management plan is the most complex and sophisticated to date.

The 2014 System Status Report is an effective synthesis of recent monitoring and research and provides valuable science-based guidance to restoration decision makers. Its key findings summarize ecosystem status and trends, monitoring related to implemented CERP and non-CERP projects, and new science relevant at local and systemwide scales. A particular strength of the document is its explanations of ecosystem trends and their causal mechanisms that lead to recommendations for possible changes in project design or operations to improve restoration outcomes.

Implementation of the Restoration Strategies Science Plan to develop strategies to meet STA discharge criteria is a high priority for Everglades restoration. The Science Plan and associated $50 million research program is an important contribution that should improve STA management and effectiveness. However, the single-minded focus on phosphorus in the Science Plan may overlook the influence of other macroelements such as carbon, nitrogen, and sulfur on sustained STA performance.

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Acronyms

AF	acre-feet
AMO	Atlantic Multidecadal Oscillation
ARS	Agricultural Research Service
ASR	aquifer storage and recovery
BCNP	Big Cypress National Preserve
BCWPA	Broward County Water Preserve Areas
BIA	Bureau of Indian Affairs
BMP	best management practice
CEPP	Central Everglades Planning Project
CERP	Comprehensive Everglades Restoration Plan
CESI	Critical Ecosystem Studies Initiative
CFU	colony-forming unit
CISRERP	Committee on Independent Scientific Review of Everglades Restoration Progress
COP	combined operational plan
CROGEE	Committee on the Restoration of the Greater Everglades Ecosystem
C&SF	Central and Southern Florida
DACS	Florida Department of Agriculture and Consumer Services
DOI	U.S. Department of the Interior
DOP	dissolved organic phosphorus
DPI	Florida Department of Plant Industry
DPM	Decomp Physical Model
EAA	Everglades Agricultural Area
EAV	emergent aquatic vegetation
ECISMA	Everglades Cooperative Invasive Species Management Act

EDDMapS	Early Detection and Distribution Management System
EDRR	early detection and rapid response
EIRAMP	Everglades Invasive Reptile and Amphibian Monitoring Program
ENP	Everglades National Park
EPA	U.S. Environmental Protection Agency
ERTP	Everglades Restoration Transition Plan
FACA	Federal Advisory Committee Act
FEB	flow equalization basin
FWC	Florida Fish and Wildlife Conservation Commission
FWM	flow-weighted mean
FWO	future without the project
FWS	U.S. Fish and Wildlife Service
FY	fiscal year
GCM	general circulation model
GIS	geographic information system
HASR	Hillsboro Aquifer Storage and Recovery
HSI	habitat suitability index
IDS	Integrated Delivery Schedule
IOP	Interim Operational Plan
IPCC	Intergovernmental Panel on Climate Change
IPR	in-progress review
IRL-S	Indian River Lagoon-South
KRASR	Kissimmee River Aquifer Storage and Recovery
LNWR	Loxahatchee National Wildlife Refuge
LOER	Lake Okeechobee and Estuary Recovery
LOPA	Lake Okeechobee Protection Act
LOPP	Lake Okeechobee Protection Plan
LORS	Lake Okeechobee Regulation Schedule
LPA	Limestone Products Association
MAP	monitoring and assessment plan
MCDA	Multi Criteria Decision Analysis
MGD	million gallons per day
NAVD	North American Vertical Datum

NCRS	Natural Resources Conservation Service
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPS	National Park Service
NRC	National Research Council
OERI	Office of Everglades Restoration Initiatives
PDT	project delivery team
PIRs	project implementation reports
PP	particulate phosphorus
PPA	project partnership agreement
ppb	parts per billion
PPDR	Pilot Project Design Report
RCP	Representative Concentration Pathway
RECOVER	Restoration, Coordination, and Verification
SAV	submerged aquatic vegetation
SCG	Science Coordination Group
SFERTF	South Florida Ecosystem Restoration Task Force
SFWMD	South Florida Water Management District
SFWMM	South Florida Water Management Model
SSR	System Status Report
STA	Stormwater Treatment Area
TIME	Tides and Inflows in the Mangroves of the Everglades
TP	total phosphorus
TSP	Tentatively Selected Plan
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WCA	Water Conservation Area
WQ	Water Quality
WQBEL	water quality-based effluent limit
WRDA	Water Resources Development Act
WRRDA	Water Resources Reform and Development Act
WY	water year

Appendix A

National Research Council Everglades Reports

Progress Toward Restoring the Everglades: The Fourth Biennial Review, 2012 *(2012)*

This report is the fourth biennial evaluation of progress being made in the Comprehensive Everglades Restoration Plan (CERP), a multi-billion-dollar effort to restore historical water flows to the Everglades and return the ecosystem closer to its natural state. The report finds that 12 years into the Comprehensive Everglades Restoration Project, little progress has been made in restoring the core of the remaining Everglades ecosystem; instead, most project construction so far has occurred along its periphery. To reverse ongoing ecosystem declines, it will be necessary to expedite restoration projects that target the central Everglades, and to improve both the quality and quantity of the water in the ecosystem. The new Central Everglades Planning Project offers an innovative approach to this challenge, although additional analyses are needed at the interface of water quality and water quantity to maximize restoration benefits within existing legal constraints.

Progress Toward Restoring the Everglades: The Third Biennial Review, 2010 *(2010)*

This report is the third biennial evaluation of progress being made in the Comprehensive Everglades Restoration Plan (CERP), a multi-billion-dollar effort to restore historical water flows to the Everglades and return the ecosystem closer to its natural state. The report finds that while natural system restoration progress from CERP remains slow, in the past 2 years, there have been noteworthy improvements in the pace of implementation and in the relationship between the federal and state partners. Continued public support and political commitment to long-term funding will be needed for the restoration plan to be completed. The science program continues to address important issues, but more transparent mechanisms for integrating science into decision making are needed. Despite such progress, several important challenges related to water quality and water quantity have become increasingly clear, highlighting the difficulty of achieving restoration goals simultaneously for all ecosystem components. Achieving these goals will be enormously costly and will take decades at least. Rigorous scientific analyses of potential conflicts among the hydrologic requirements of Everglades landscape features and species, and the tradeoffs between water quality and quantity, considering timescales of reversibility, are needed to inform future prioritization and funding decisions. Understanding and communicating these tradeoffs to stakeholders are critical.

Progress Toward Restoring the Everglades: The Second Biennial Review, 2008 *(2008)*

This report is the second biennial evaluation of progress being made in the Comprehensive Everglades Restoration Plan (CERP), a multi-billion-dollar effort to restore historical water flows to the Everglades and return the ecosystem closer to its natural state. Launched in 2000 by the U.S. Army Corps of Engineers and the South Florida Water Management District, the CERP is a multiorganization planning process that includes approximately 50 major projects to be completed over the next several decades. The report concludes that budgeting, planning, and procedural matters are hindering a federal and state effort to restore the Florida Everglades ecosystem, which is making only scant progress toward achieving its goals. Good science has been developed to support restoration efforts, but future progress is likely to be limited by the availability of funding and current authorization mechanisms. Despite the accomplishments that lay the foundation for CERP construction, no CERP projects have been completed to date. To begin reversing decades of decline, managers should address complex planning issues and move forward with projects that have the most potential to restore the natural ecosystem.

Progress Toward Restoring the Everglades: The First Biennial Review, 2006 *(2007)*

This report is the first in a congressionally mandated series of biennial evaluations of the progress being made by the CERP, a multi-billion-dollar effort to restore historical water flows to the Everglades and return the ecosystem closer to its natural state, before it was transformed by drainage and by urban and agricultural development. The report finds that progress has been made in developing the scientific basis and management structures needed to support a massive effort to restore the Florida Everglades ecosystem. However, some important projects have been delayed due to several factors including budgetary restrictions and a project planning process that can be stalled by unresolved scientific uncertainties. The report outlines an alternative approach that can help the initiative move forward even as it resolves remaining scientific uncertainties. The report calls for a boost in the rate of federal spending if the restoration of Everglades National Park and other projects are to be completed on schedule.

Re-engineering Water Storage in the Everglades: Risks and Opportunities *(2005)*

Human settlements and flood control structures have significantly reduced the Everglades, which once encompassed more than 3 million acres of slow-moving water enriched by a diverse biota. The CERP was formulated in 1999 with the goal of restoring the original hydrologic conditions of the remaining Everglades. A major feature of this plan is providing enough storage capacity to meet human and ecological needs. This report reviews and evaluates not only storage options included in the plan, but also other options not considered in the plan. Along with providing hydrologic and ecological analyses of the size, location, and functioning of water storage components, the report also discusses and makes recommendations on related critical factors, such as timing of land acquisition, intermediate states of restoration, and tradeoffs among competing goals and ecosystem objectives.

The CERP imposes some constraints on sequencing of its components. The report concludes that two criteria are most important in deciding how to sequence components of such a restoration project: (1) protecting against additional habitat loss by acquiring or protecting critical lands in and around the Everglades and (2) providing ecological benefits as early as possible.

There is a considerable range in the degree to which various proposed storage components involve complex design and construction measures, rely on active controls and frequent equipment maintenance, and require fossil fuels or other energy sources for operation. The report recommends that, to the extent possible, the CERP should develop storage components that have fewer of those requirements, and are thus less vulnerable to failure and more likely to be sustainable in the long term.

Further, as new information becomes available and as the effectiveness and feasibility of various restoration components become clearer, some of the earlier adaptation and compromises might need to be revisited. The report recommends that methods be developed to allow tradeoffs to be assessed over broad spatial and long temporal scales, especially for the entire ecosystem, and gives an example of what an overall performance indicator for the Everglades system might look like.

Adaptive Monitoring and Assessment for the Comprehensive Everglades Restoration Plan *(2003)*

A key premise of the CERP is that restoring the historical hydrologic regime in the remaining wetlands will reverse declines in many native species and biological communities. Given the uncertainties that will attend future responses of Everglades ecosystems to restored water regimes, a research, monitoring, and adaptive management program is planned. This report assessed the extent to which the restoration effort's "monitoring and assessment plan" included the following elements crucial to any adaptive management scheme: (1) clear restoration goals and targets, (2) a sound baseline description and conceptualization of the system, (3) an effective process for learning from management actions, and (4) feedback mechanisms for improving management based on the learning process.

The report concludes that monitoring needs must be prioritized, because many goals and targets that have been agreed to may not be achievable or internally consistent. Priorities could be established based on the degree of flexibility or reversibility of a component and its potential impact on future management decisions. Such a prioritization should be used for scheduling and sequencing of projects, for example. Monitoring that meets multiple objectives (e.g., adaptive management, regulatory compliance, and a "report card") should be given priority.

Ecosystem-level, systemwide indicators should be developed, such as land-cover and land-use measures, an index of biotic integrity, and diversity measures. Regionwide monitoring of human and environmental drivers of the ecosystem, especially population growth, land-use change, water demand, and sea-level rise are recommended. Monitoring, modeling, and research should be well integrated, especially with respect to defining the restoration reference state and using "active" adaptive management.

Does Water Flow Influence Everglades Landscape Patterns? *(2003)*

A commonly stated goal of the CERP is to "get the water right." This has largely meant restoring the timing and duration of water levels and the water quality in the Everglades. Water flow (speed, discharge, direction) has been considered mainly in the coastal and estuarine system, but not elsewhere. Should the restoration plan be setting targets for flows in other parts of the Everglades as well?

There are legitimate reasons why flow velocities and discharges have thus far not received greater emphasis in the plan. These include a relative lack of field information and poor resolution of numerical models for flows. There are, however, compelling reasons to believe that flow has important influences in the central Everglades ecosystem. The most important reason is the existence of major, ecologically important landforms—parallel ridges, sloughs, and "tree islands"—are aligned with present and inferred past flow directions. There are difficulties in interpreting this evidence, however, as it is essentially circumstantial and not quantitative.

Alternative mechanisms by which flow may influence this landscape can to some extent be evaluated from short-term research on underlying bedrock topography, detailed surface topographic mapping, and accumulation rates of suspended organic matter. Nonetheless, more extensive and long-term research will also be necessary, beginning with the development of alternative conceptual models of the formation and maintenance of the landscape to guide a research program. Research on maintenance rather than evolution of the landscape should have higher priority because of its direct impact on restoration. Monitoring should be designed for the full range of flow conditions, including extreme events.

Overall, flows approximating historical discharges, velocities, timing, and distribution should be considered in restoration design, but quantitative flow-related performance measures are not appropriate until there is a better scientific understanding of the underlying science. At present, neither a minimum nor a maximum flow to preserve the landscape can be established.

Florida Bay Research Programs and Their Relation to the Comprehensive Everglades Restoration Plan (2002)

This report of the Committee on Restoration of the Greater Everglades Ecosystem (CROGEE) evaluated Florida Bay studies and restoration activities that potentially affect the success of the CERP. Florida Bay is a large, shallow marine system immediately south of the Everglades, bounded by the Florida Keys and the Gulf of Mexico. Some of the water draining from the Everglades flows directly into northeast Florida Bay. Other freshwater drainage reaches the bay indirectly from the northwest.

For several decades until the late 1980s, clear water and dense seagrass meadows characterized most of Florida Bay. However, beginning around 1987, the seagrass beds began dying in the western and central bay. It is often assumed that increased flows to restore freshwater Everglades habitats will also help restoration of Florida Bay. However, the CERP may actually result in higher salinities in central Florida Bay than exist presently, and thus exacerbate the ecological problems. Further, some percentage of the proposed increase in fresh surface-water flow discharging northwest of the bay will eventually reach the central bay, where its dissolved organic nitrogen may lead to algal blooms. Complicating the analysis of such issues is the lack of an operational bay circulation model.

The report notes the importance of additional research in the following areas: estimates of groundwater discharge to the bay; full characterization and quantification of surface runoff in major basins; transport and total loads of nitrogen and phosphorous from freshwater sources, especially in their organic forms; effects on nutrient fluxes of decreasing freshwater flows into the northeastern bay, and of increasing flows northwest of the bay; and the development of an operational Florida Bay circulation model to support a bay water quality model and facilitate analysis of CERP effects on the bay.

Science and the Greater Everglades Ecosystem Restoration: An Assessment of the Critical Ecosystems Study Initiative *(2003)*

The Everglades represents a unique ecological treasure, and a diverse group of organizations is currently working to reverse the effects of nearly a century of wetland drainage and impoundment. The path to restoration will not be easy, but sound scientific information will increase the reliability of the restoration, help enable solutions for unanticipated problems, and potentially reduce long-term costs. The investment in scientific research relevant to restoration, however, decreased substantially within some agencies, including one major Department of the Interior (DOI) science program, the Critical Ecosystem Studies Initiative (CESI). In response to concerns regarding declining levels of funding for scientific research and the adequacy of science-based support for restoration decision making, the U.S. Congress instructed the DOI to commission the National Academy of Sciences to review the scientific component of the CESI and provide recommendations for program management, strategic planning, and information dissemination.

Although improvements should be made, this report notes that the CESI has contributed useful science in support of the DOI's resource stewardship interests and restoration responsibilities in South Florida. It recommends that the fundamental objectives of the CESI research program remain intact, with continued commitment to ecosystem research. Several improvements in CESI management are suggested, including broadening the distribution of requests for proposals and improving review standards for proposals and research products. The report asserts that funding for CESI science has been inconsistent and as of 2002 was less than that needed to support the DOI's interests in and responsibilities for restoration. The development of a mechanism for comprehensive restoration-wide science coordination and synthesis is recommended to enable improved integration of scientific findings into restoration planning.

Regional Issues in Aquifer Storage and Recovery for Everglades Restoration: A Review of the ASR Regional Study Project Management Plan of the Comprehensive Everglades Restoration Plan *(2002)*

The report reviews a comprehensive research plan on Everglades restoration drafted by federal and Florida officials that assesses a central feature of the restoration: a proposal to drill more than 300 wells funneling up to 1.7 billion gallons of water a day into underground aquifers, where it would be stored and then pumped back to the surface to replenish the Everglades during dry periods. The report says that the research plan goes a long way to providing information needed to settle remaining technical questions and clearly responds to suggestions offered by scientists in Florida and in a previous report by the NRC.

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 *(2001)*

Aquifer storage and recovery (ASR) is a major component in the CERP, which was developed by the U.S. Army Corps of Engineers (USACE) and the South Florida Water Management District (SFWMD). The plan would use the upper Floridian aquifer to store large quantities of surface water and shallow groundwater during wet periods for recovery during droughts.

ASR may limit evaporation losses and permit recovery of large volumes of water during multiyear droughts. However, the proposed scale is unprecedented and little subsurface information has been compiled. Key unknowns include impacts on existing aquifer uses, suitability of source waters for recharge, and environmental and/or human health impacts due to water quality changes during subsurface storage.

To address these issues, the USACE and SFWMD proposed aquifer storage recharge pilot projects in two key areas. The CROGEE charge was to examine a draft of their plans from a perspective of adaptive management. The report concludes that regional hydrogeologic assessment should include development of a regional-scale groundwater flow model, extensive well drilling and water quality sampling, and a multiobjective approach to ASR facility siting. It also recommends that water quality studies include laboratory and field bioassays and ecotoxicological studies, studies to characterize organic carbon of the source water and anticipate its effects on subsurface biogeochemical processes, and laboratory studies. Finally, it recommends that pilot projects be part of adaptive assessment.

Appendix B

Additional Major Nonnative Plant and Animal Species in the Everglades

This appendix provides additional information about the occurrence and threats posed by invasive plants and animals in the Everglades, as well as available management strategies.

PLANTS

Water Hyacinth (*Eichhornia crassipes*)

South American water hyacinth is one of the world's worst invasive species (Mitchell, 1976). It can double its biomass in 6 days (Mitchell, 1976) and has average annual biomass production of up to 250 tons of dry weight per hectare (Spencer and Bowes, 1986). In the Everglades, water hyacinth readily invades wetlands, freshwater lakes, and other open-water habitats, where it effectively outcompetes other floating species, and its dense mats shade out submerged aquatic vegetation. This highly aggressive species is treated using a combination of herbicide and biocontrol agents, including the latest release in 2010, the water hyacinth plant hopper (*Megamelus scutellaris*). Some biocontrol agents have reduced biomass (> 50 percent) and seed production. Other potential agents are undergoing trials and are in development. However, chemical control, primarily with 2,4-D, is currently the main factor in controlling water hyacinth (Schardt, 1997).

Hydrilla (*Hydrilla verticillata*)

This Asian species, introduced in Florida in the 1950s, is a submerged aquatic that has become a widespread invader. It can displace aquatic species, affecting the composition and functioning of communities. Heavy infestations clog waterways, interfering with recreation and navigation. It is readily dispersed by boat traffic and has greatly expanded its distribution in recent years. Herbicide application is the main form of management, but recently detected resistance to the most commonly used herbicide, fluridone, leads to concerns that it will cease to be effective (Puri et al., 2007). Mechanical harvesting is sometimes used for particularly dense infestations.

Air Potato (*Dioscorea bulbifera*)

Air potato is an Asian vine. It was introduced to the United States as an ornamental, but in many areas of the world (e.g., Africa) its starchy bulbils are used as a food (Ewe et al., 2006). In its introduced range, it spreads vegetatively through dispersal of its bulbils (Rodgers et al., 2013), and it can quickly blanket an area, shading out native vegetation. Chemical control has been used in the past. Recently, a foliage-consuming beetle from China (*Lilioceris cheni*), released as a biocontrol agent, has been successfully established in the field and is imposing substantial defoliation. A second beetle from China (*L. egeria*) is under testing and shows promise for its bulbil consumption (Center et al., 2013).

Shoebutton Ardisia (*Ardisia elliptica*)

This ornamental shrub was introduced from Southeast Asia to Florida in the early 1900s (Gordon and Thomas, 1997). It is bird-dispersed, which facilitated its escape into surrounding natural areas (Ewe et al., 2006), including tree islands, hammocks, and short-hydroperiod wetlands that it readily invades in the Everglades. Highly shade-tolerant, this shrub creates thickets that cast dense shade, excluding regeneration of other species. It is difficult to detect and control. Cutting, followed by herbicide application to the stumps, has been used effectively in some invasions. However, where the population is exceptionally dense, a two-step process of shredding and herbicide application has been the most effective (Rodgers et al., 2013).

Torpedograss (*Panicum repens*)

This invasive exotic grass is native to Africa and Eurasia and has invaded a broad range of wetland and successional habitats in Florida. Despite its widespread distribution in South Florida, it is not known to reproduce via seeds but spreads rapidly and aggressively via vegetative means. It readily displaces native species and (along with *Melaleuca*) has expanded rapidly into the marshes around Lake Okeechobee (Ogden et al., 2005). If not controlled, torpedograss is likely to impact CERP performance measures in Lake Okeechobee, such as increased native fish recruitment or the recovery of native vegetation (RECOVER, 2014a). Control efforts are largely through aerial and ground-level herbicide application. Because it is a grass and the Everglades system has many native grass species, this species is not likely to be a target for biocontrol development (Rodgers et al., 2014a).

Downy Rose Myrtle (*Rhodomyrtus tomentosa*)

This Asian shrub was introduced as an ornamental and has now spread into pine flatwoods and some cypress stands, where it can displace native species. It occurs in many counties of central and South Florida, particularly along the coast. The extent of its infestation is unclear, however, and on-the-ground surveys/observations are required to detect it unambiguously. Herbicide application and shredding have been the most effective methods for controlling it. A potential biocontrol agent is currently under testing and development (Rodgers et al., 2014a).

Cogongrass (*Imperata cylindrica*)

Cogongrass is native to southeastern Asia and is a highly aggressive, widespread exotic grass in the southeastern United States (Evans et al., 2007). It has a deep, dense rhizomatous mat (Byrd and Bryson, 1999), allowing it to resprout readily, even after fire. The chemical residue it exudes into the soil can hinder establishment of some species (Koger and Bryson, 2004), and it can alter fire regimes (Lippincott, 2000). This species negatively affects native biodiversity and is one of the few that has been definitively shown to result in native species extirpations, particularly of low-stature forbs in pine savannas of the southeastern United States (Brewer, 2008). Its coverage is estimated at ~1 million acres in Florida (Miller, 2007), including pine flatwood and freshwater marsh communities. Control efforts include mechanical removal (often repeated), herbicide application, and repeated prescribed fire. No biocontrol agents have been identified (Rodgers et al., 2014a), and it is an unlikely candidate for that program because of its close phylogenetic relationships with many native species in the Everglades (P. Tipping, USDA, personal communication, 2013).

Water Lettuce (*Pistia stratiotes*)

Water lettuce is a native of temperate to tropical regions of South America. Its status in Florida is uncertain; it may be another “native invader” (Evans, 2013). In any event, it is a highly invasive floating macrophyte that has invaded many open-water and wetland habitats in the Everglades (Rodgers et al., 2014a). This species can take advantage of elevated nutrients and quickly expand its distribution (along with *Eichhornia*) (Ogden et al., 2005), clogging waterways and shading out submerged aquatic species. Herbicide application is the most effective control method, and it has been used quite successfully in many canals in South Florida. Biocontrol agents released to control this species have had minimal impact on its abundance.

Tropical American Water Grass (*Luziola subintegra*)

This nonnative aquatic grass species was first reported in 2007 from Lake Okeechobee. Plants with aquatic and terrestrial morphologies were documented. Preliminary observations suggest that this species could become a highly aggressive invader capable of displacing native species and altering structure and function of these aquatic habitats. Herbicide application has been used to control this species.

Black Mangrove *(Lumnitzera racemosa)*

This nonnative mangrove was planted in Fairchild Tropical Botanic Garden in 1966-1971 (14 plants) and an infestation was discovered in nearby Miami-Dade County in 2008 (Possley, no date). It is listed as a priority species and focused eradication efforts are under way and expected to be successful (Possley, no date).

Mile-a-Minute *(Mikania micrantha)*

This invasive vine is also known as climbing hempweed, Chinese creeper, and bittervine. It has recently been detected in the Redlands area of Miami-Dade County. It is fast-growing and potentially invasive; it is listed as a priority species. Because of its currently limited distribution efforts are focused on containment and eradication.[1]

Skunk Vine (*Paederia foetida*)

This Asian vine was introduced to the United States in the late 1800s as a potential fiber plant. It has a woody root stock and can produce trailing aboveground vines that extend ~10 m in length. It is widely distributed in Florida. It can reproduce vegetatively and via seed that is dispersed by frugivorous birds. It can invade a wide range of habitats where it can displace native species and

[1] See http://www.freshfromflorida.com/Divisions-Offices/Plant-Industry/Pests-Diseases/Mikania-Micrantha-Mile-a-minute.

blanket stands of trees (University of Florida, Institute of Food and Agricultural Sciences Extension).

Climbing Cassia (*Senna pendula*)

This evergreen South American shrub is an ornamental widely cultivated in Florida. It has escaped into the wild and is naturalized in South Florida. Some of its characteristics suggest that it may become highly invasive, as it is known to invade hammocks and cypress strands (Richard and Ramey, 2007). Further, it is a legume, and therefore its capacity for nitrogen fixation should be considered when evaluating its potential invasiveness.

Feathered Mosquitofern (*Azolla pinnata*)

Feathered mosquitofern is an aquatic floating fern that is establishing in canals and some open-water habitat in South Florida (Pemberton and Bodle, 2009). This species is native to parts of Africa, Asia, and Australia, but recent molecular evidence suggests that the subspecies invading the Everglades is of Australian origin, suggesting that biocontrol efforts that focus on Australian insects may be fruitful (Madeira et al., 2013). Earlier research indicates that the native herbivorous weevil *Stenopelmus rufinasus*, which uses native *Azolla* spp., has been found in association with *A. pinnata* and is a potential "native" biocontrol agent (Pemberton and Bodle, 2009) that has not, to our knowledge, been investigated further. Currently, herbicide application is used for control.

ANIMALS

Gambian Pouched Rat (*Cricetomys gambianus*)

Gambian pouched rats are established on Grassy Key in the Florida Keys, despite a long-term eradication effort. Although they are currently restricted to Grassy Key, the concern is that they could be inadvertently or deliberately carried to mainland South Florida. They are difficult to trap (Witmer et al., 2010b), as witness the persistence of the Grassy Key population. As they are the largest muroid rodent in the world, their impact in the Everglades could be enormous, although there is no substantial research on the magnitude of this threat should they become established. They also carry monkeypox. The Florida Fish and Wildlife Conservation Commission (FWC) and U.S. Department of Agriculture plan to continue trapping on Grassy Key to the extent that funding permits (Rodgers et al., 2014a), though they are hindered by the fact that they cannot gain access to six private properties (Witmer et al., 2010a).

Northern African Python (*Python sebae*)

The northern African python is apparently still established in Dade County—two individuals were captured and a third was photographed in March 2013 (C. Romagosa, Auburn University, perconal communication, 2013). Were they to become widespread, their impacts might be similar to those of the Burmese python. Other than monitoring, there is no long-term management plan at this time.

Oustalet's Chameleon (*Furcifer oustaleti*)

A population of this large chameleon was discovered in rural Dade County in 2011; FWC removed a large number of them, and an interagency team is periodically monitoring the population (Rodgers et al., 2013). It is unclear what observation would trigger management activity or further research.

Veiled Chameleon *(Chamaeleo calyptratus)*

This large chameleon is native to the Middle East. A breeding population was discovered in Lee County in 2002, and recently, another population was discovered in an agricultural area in south Miami-Dade County less than 4 miles from the boundary of Everglades National Park (Rodgers et al., 2014a). Their presence is suspected to have resulted from "intentional releases by reptile enthusiasts" (Rodgers et al., 2014a).

Spectacled Caiman *(Caiman crocodilus)*

This crocodilian is native to southern Mexico and southward to Argentina. It can attain 8 feet in its native habitat but usually is less than 6 feet long in Florida, where its distribution results from escapes or releases from the pet trade (Florida Fish and Wildlife Conservation Commission, 2014). Breeding populations have been reported from Miami-Dade and Broward counties; its northern expansion is limited by occasional freezes (Florida Fish and Wildlife Conservation Commission, 2014). Control methods include egg collection and hunting.

Nile Monitor *(Varanus niloticus)*

This large predatory lizard, native to Africa, is said to be adaptable and intelligent (Bennett, 1998). It is a generalist feeder, and impacts on South Florida's fauna are unknown, although it has a high potential for predation and competition (Rodgers et al., 2014a). It is established in several South Florida locations, and control methods—currently applied in piecemeal fashion—include snares, traps, and hunting (Rodgers et al., 2014a). It is monitored in Palm Beach County (Rodgers et al., 2014a).

Cuban Tree Frog (*Osteopilus septentrionalis*)

This tree frog is ubiquitous and common throughout the Everglades, and there is substantial evidence that it depresses native tree frog populations (Rodgers et al., 2014a; Smith, 2005; Wyatt and Forys, 2004). In the Picayune Strand Restoration Project, the Cuban tree frog colonized and dominates the restored areas, rather than native tree frogs that are found in the reference sites (RECOVER, 2014b). Predicted climate change is likely to be favorable for the Cuban tree frog (Rödder and Weinsheimer, 2009). The Everglades Invasive Reptile and Amphibian Monitoring Program records Cuban tree frogs on its routes (Rodgers et al., 2014a), but there is no coordination or management effort for this tree frog, and basic research on its impacts and possible control methods is needed (Rodgers et al., 2014a).

Cane Toad (*Rhinella marina*, formerly *Bufo marinus*)

Despite the fact that the cane toad is a legendary invader with major impacts in Australia and elsewhere (Lever, 2001), there does not appear to be concern over its possible impacts in the Everglades. They are uncommon in the heart of the Everglades but very common in suburban areas (C. Romagosa, Auburn University, personal communication, 2013). There has been no substantial study of status or impacts throughout the Everglades, despite the fact that Punzo and Lindstrom (2001) found that ingestion of its eggs causes massive mortality among several native Everglades vertebrates.

Purple Swamp Hen (*Porphyrio porphyrio*)

This species established in the Everglades ca. 1996 and has spread widely from an initial location in Pembroke Pines despite sustained efforts (which terminated in 2009) to limit the population (Rodgers et al., 2013). This is a highly aggressive, territorial species that is omnivorous, feeding on, among other things, eggs and young of waterfowl. There is no current coordinated monitoring or control effort (Rodgers et al., 2014a).

Asian Swamp Eel (*Monopterus albus*)

This is a large, generalized predator that has now spread substantially into the Everglades (Rodgers et al., 2014a). It appears to be expanding northward and is commonly found in some canals (Kline et al., 2013). There is no coordinated monitoring or management (Rodgers et al., 2014a).

Mayan Cichlid (*Cichlasoma urophthalmus*)

This fish became abundant in the estuarine zone of northern Florida Bay, and density of native fishes varies inversely with density of the Mayan cichlid (Trexler et al., 2000). It has now become intermittently abundant even in the northern reaches of Everglades National Park (Trexler et al., 2000). Observational data show interference competition with and predation on several native fish species (Trexler et al., 2000), although no research has linked the Mayan cichlid to population-level impacts on native species. The Mayan cichlid and other introduced fish potentially affect various CERP performance measures, such as regional population sizes of fishes, crayfish, grass shrimp, and amphibians.

Pike Killifish (*Belonesox belizanus*)

The pike killifish persisted in small populations in canals east of the Everglades for over 20 years before dramatically spreading across much of the Everglades, where its density fluctuates greatly locally (Trexler et al., 2000). There is no definitive evidence of impact or lack of impact on any native species.

Black Acara (*Cichlasoma bimaculatum*)

Black acara populations fluctuate locally and the species is common in solution holes (Trexler et al., 2000). There is no evidence of impact on native species.

Giant African Land Snail *(Lissachatina fulica)*

This snail, slated for eradication, was discovered in Miami in 2011. It eats a wide variety of vegetation, including agricultural, horticultural, and native species (Rodgers et al., 2014a). In addition, it is an intermediate host of rat lungworm, which can infect humans and cause meningitis (Rodgers et al., 2014a). A prior infestation occurred in 1966; eradication took 10 years and cost $1 million. Eradication in this case again seems likely (Rodgers et al., 2014).

Mexican Bromeliad Weevil (*Metamasius callizona*)

This species, introduced in the late 1980s, attacks bromeliads, including species of conservation concern. It has spread widely in the Everglades. There is no coordinated regional monitoring because of lack of funding. A parasitic fly was approved for release as a biological control but has not established a population. Research is ongoing by University of Florida scientists on a biological control agent (Rodgers et al., 2014a).

Rugose Spiraling Whitefly (*Aleurodicus rugioperculatus*)

First discovered in South Florida in 2009 and rapidly spreading throughout the region, this whitefly attacks and kills many host plants, both native and non-native, and achieves massive densities (Stocks and Hodges, 2012). There is no research on its ecological impact. A parasitic fly was approved for release as a biological control but has not established a population (Rodgers et al., 2014a). Research on biological or chemical control methods is under way at the University of Florida.

Appendix C

Water Science and Technology Board; Board on Environmental Studies and Toxicology

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Appendix D

Biographical Sketches of Committee Members and Staff

Jeff Walters, *Chair*, is the Harold Bailey Professor of Biology at Virginia Tech, 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 endemic to the Everglades. His research interests are in the behavioral ecology, population biology, and conservation of birds, and his recent work has focused on cooperative breeding, dispersal behavior, and endangered species issues. Dr. Walters served in two panels of the Sustainable Ecosystems Institute that addressed issues with endangered birds in the Everglades restoration in addition to previously serving as a member of the NRC's Committee on Restoration of the Greater Everglades Ecosystem and the first and fourth Committees on Independent Scientific Review of Everglades Restoration Progress. He holds a B.A. from West Virginia University and a Ph.D. from the University of Chicago.

Mary Jane Angelo is professor of law at the University of Florida's Levin College of Law and Director of the Environmental and Land Use Law Program. Her research areas focus on environmental law, water law, administrative law, biotechnology law, dispute resolution, pesticides law, law and science, and legal ethics. Prior to joining the faculty, Ms. Angelo served as an attorney in the U.S. Environmental Protection Agency's Office of General Counsel and as senior assistant general counsel for the St. Johns River Water Management District. She received her B.S. in biological sciences from Rutgers University and her M.S. and J.D. from the University of Florida.

David B. Ashley is professor of civil engineering at the University of Nevada, Las Vegas (UNLV). Dr. Ashley also served as the eighth president at the school from 2006 to 2009. Prior to joining UNLV, President Ashley served as executive vice chancellor and provost at the University of California, Merced, and held the Shaffer-George Chair in Engineering. He has also served as dean of engineering at The Ohio State University and has held civil engineering faculty positions at the University of California, Berkeley, the University of Texas at Austin, and the Massachusetts Institute of Technology. Dr. Ashley's principal research and teaching activities are in the area of construction project planning, focusing primarily on risk analysis and management of large-scale, complex projects. His recent studies have addressed innovative project financing and new project procurement approaches. He has served on several NRC committees, including the Committee on Assessing the Results of External Independent Reviews for U.S. Department of Energy Projects. Dr. Ashley received a B.S. in civil engineering and an M.S. in civil engineering–project management from the Massachusetts Institute of Technology, an M.S. in engineering–economic systems, and a Ph.D. in civil engineering–constructing, engineering, and management from Stanford University.

Loretta L. Battaglia is an associate professor of plant biology at Southern Illinois University, Carbondale. Her research interests focus on the dynamics of wetland plant communities and the ecological processes that link them with the surrounding landscape. Specifically, her research is focused on the effects of climate change and large-scale phenomena, such as exotic species invasions, on community structure and function, as well as development of restoration targets for coastal wetlands undergoing rapid climate change. She received her B.S. in zoology and her M.S. in biological sciences from the University of Louisiana, Monroe, and her Ph.D. in ecology from the University of Georgia.

William G. Boggess is professor and executive associate dean of the College of Agricultural Sciences at Oregon State University (OSU). Prior to joining OSU, Dr. Boggess spent 16 years on the faculty at the University of Florida in the Food and Resource Economics Department. His research interests include interactions between agriculture and the environment (e.g., water allocation, groundwater contamination, surface-water pollution, sustainable systems); economic dimensions and indicators of ecosystem health; and applications of real options to environmental and natural resources. Dr. Boggess previously served on the Oregon Governor's Council of Economic Advisors and the Board of Directors of the American Agricultural Economics Association, and he currently serves on the Board of the Oregon Environmental Council. He served on the State of Oregon Environment Report Science Panel and has been active in the design and assessment of the Oregon Conservation Reserve Enhancement Program. Dr. Boggess served as a member of the National Research Council Committee on the Use of Treated Municipal Wastewater Effluents and Sludge in the Production of Crops for Human Consumption, and on the second, third, and fourth Committees on Independent Scientific Review of Everglades Restoration Progress serving as chair of the fourth committee. He received his Ph.D. from Iowa State University in 1979.

Charles T. Driscoll (NAE) is university professor in the Department of Civil and Environmental Engineering at Syracuse University where he also serves as the director of the Center for Environmental Systems Engineering. His teaching and research interests are in the area of environmental chemistry, biogeochemistry, and environmental quality modeling. A principal research focus has been the response of forest, aquatic, and coastal ecosystems to disturbance, including air pollution, land-use change, climate change, and elevated inputs of nutrients and mercury. Dr. Driscoll is currently a principal investigator of the National Science Foundation's Long Term Ecological Research Network's project at the Hubbard Brook Experimental Forest in New Hampshire. He is a member of the National Academy of Engineering and was a member of the National Research Council's (NRC's) Panel on Process of Lake Acidification, the Committees on Air Quality Management in the U.S. and the Collaborative Large-Scale Engineering Analysis Network for Environmental Research (CLEANER), and the second, third, and fourth Committees on Independent Scientific Review of Everglades Restoration Progress. He is a member of the NRC Board on Environmental Studies and Toxicology. Dr. Driscoll received his B.S. in civil engineering from the University of Maine and his M.S. and Ph.D. in environmental engineering from Cornell University.

Paul H. Glaser is a research professor in the Department of Earth Sciences at the University of Minnesota (Twin Cities campus) with appointments to the Graduate Faculty in Earth Sciences and Conservation Biology. He is a fellow of the Geological Society of America and a member-at-large of the Geology and Geography Section of the American Association for the Advancement of Science. His current research interests are focused on wetland-groundwater interactions in peatlands with special reference to carbon cycling and greenhouse gases. However, his research interests are cross-disciplinary, spanning the fields of wetland ecology, hydrology, biogeochemistry, and paleoecology. Dr. Glaser earned his Ph.D. from the University of Minnesota in 1978.

William L. Graf is Foundation University Distinguished Professor, Emeritus, at the University of South Carolina. His expertise is in fluvial geomorphology and hydrology, as well as policy for public land and water. Dr. Graf's 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. His present work emphasizes the downstream effects of dams on rivers. 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. Dr. Graf has served as a member of the National Research Council's (NRC's) Water Science and Technology Board and Board on Earth Sciences and Resources, the Panel to Review the Critical Ecosystem Studies Initiative, the Committee on Restoration of the Greater Everglades Ecosystem, and the first three Committees on Independent Scientific Review of Everglades Restoration Progress, serving as chair of the second committee. He is chair of the NRC's Geographical Sciences Committee. He is also a national associate of the National Academies and an American Association for the Advancement of Science fellow. Dr. Graf earned a certificate of water resources management and his Ph.D. from the University of Wisconsin, Madison.

Stephen G. Monismith is chair of the Civil and Environmental Engineering Department and Obayashi Professor in the School of Engineering at Stanford University. His research in environmental and geophysical fluid dynamics is focused on the application of fluid mechanics principles to the analysis of flow processes operating in rivers, lakes, estuaries, and the oceans. Flows that involve physical-biological interactions are of particular interest to him. Dr. Monismith has previous National Research Council experience, having served on the Panel to Review California's Draft Bay Delta Conservation Plan and the Committee on Sustainable Water and Environmental Management in the California Bay-Delta. He earned his B.A., M.S., and Ph.D. degrees from the University of California, Berkeley.

David H. Moreau is research professor, Department of City and Regional Planning, at the University of North Carolina at Chapel Hill. He recently completed a term as chair of the Curriculum for the Environment and Ecology. His research interests include analysis, planning, financing, and evaluation of water resource, water quality, and related environmental programs. Dr. Moreau is engaged in water resources planning at the local, state, and national levels. He has served on several National Research Council committees, including the Committee on New Orleans Regional Hurricane Protection Projects Review, the Committee on the Mississippi River and Hypoxia in the Gulf of Mexico, and the second, third, and fourth Committees on Independent Scientific Review of Everglades Restoration Progress. Dr. Moreau recently completed 19 years as a member and 16 years as chairman of the North Carolina Environmental Management Commission, the state's regulatory commission for water quality, air quality, and water allocation. For his service to North Carolina he was awarded the Order of the Long Leaf Pine, the highest civilian award offered by the state. He received his B.S. and M.S. from Mississippi State University and North Carolina State University, respectively, and his Ph.D. degree from Harvard University.

K. Ramesh Reddy is graduate research professor and chair of the Department of Soil and Water Science at the University of Florida. His research areas include biogeochemistry, soil and water quality, ecological indicators, and restoration of wetlands and aquatic systems. Dr. Reddy investigates biogeochemical cycling of macronutrients in natural ecosystems, including wetlands, shallow lakes, estuaries, and constructed wetlands, as related to soil and water quality, carbon sequestration, and greenhouse gas emissions. He served as a member of the U.S. National Committee for Soil Sciences in the National Academy's Policy and Global Affairs Division. He served on the U.S. Environmental Protection Agency's Science Advisory Board Panel. Dr. Reddy served as a member of the second and third Committees on Independent Scientific Review of Everglades Restoration Progress. Dr. Reddy earned his Ph.D. in agronomy and soil science from Louisiana State University.

Helen Regan is an associate professor of biology at the University of California, Riverside. Her research areas span quantitative conservation ecology and probabilistic risk assessment. Dr. Regan has applied population models, uncertainty analyses, and decision-making techniques to address a variety of conservation and wildlife management issues. She focuses on methodological issues of these techniques, the practicalities of their application and their interpretation for management. Projects include ecological risk assessment of chemical contaminants, population viability of species impacted by a range threats, monitoring of multiple species habitat conservation plans, population-level effects of habitat fragmentation, and fire and disease on plants in fire-prone ecosystems. Current research includes examination of the impact of uncertainty on potential adaptation strategies for threatened species impacted by climate change. She currently serves on the Standards and Petitions Subcommittee of the International Union for the Conservation of Nature Species Survival Commission and on the scientific advisory committee for the Australian Centre of Excellence for Risk Analysis. Dr. Regan received her B.S. from LaTrobe University and her Ph.D. from the University of New England in Armidale, both in Australia.

James E. Saiers is professor of hydrology, associate dean of Academic Affairs, and professor of chemical engineering at the Yale School of Forestry and Environmental Studies. Dr. Saiers studies the circulation of water and the movement of waterborne chemicals in surface and subsurface environments. One element of his research centers on quantifying the effects that interactions between hydrologic and geochemical processes have on the migration of contaminants in groundwater. Another focus is on the dynamics of surface-water and groundwater flow in wetlands and the response of fluid flow characteristics to changes in climate and water management practices. His work couples field observations and laboratory-scale experimentation with mathematical modeling. He earned his B.S. in geology from the Indiana University of Pennsylvania and his M.S. and Ph.D. degrees in environmental sciences from the University of Virginia.

Daniel Simberloff (NAS) is the Nancy Gore Hunger Professor of Environmental Science in the Department of Ecology and Evolutionary Biology at the University of Tennessee, Knoxville. His research centers on ecology, statistical ecology, biogeography, evolution, and conservation biology, and addresses plants, insects, birds, and mammals. Specifically, his research focuses on invasion biology, community composition and structure, and community morphological structure. He maintains an extensive world-wide field research program focused on issues of biological invasions and global change and is a leading innovator in the application of statistical methods to large ecological data sets. Dr. Simberloff is a member of the National Academy of Sciences and is the recipient of numerous awards, including the Ecological Society of America's Eminent Ecologist Award and the Ramon Margalef Award for Ecology. He has served on multiple National Research Council (NRC) committees and was a member of the NRC Board on Life Sciences. He received his A.B. and Ph.D. from Harvard University.

STAFF

Stephanie E. Johnson, study director, is a senior program officer with the Water Science and Technology Board. Since joining the National Research Council in 2002, she has worked on a wide range of water-related studies, on topics such as desalination, wastewater reuse, contaminant source remediation, coal and uranium mining, coastal risk reduction, and ecosystem restoration. She has served as study director for 15 committees, including the Panel to Review the Critical Ecosystem Studies Initiative and all five Committees on Independent Scientific Review of Everglades Restoration Progress. Dr. Johnson received her B.A. from Vanderbilt University in chemistry and geology, and her M.S. and Ph.D. in environmental sciences from the University of Virginia.

David J. Policansky is a scholar of the Board on Environmental Studies and Toxicology. He earned a Ph.D. in biology from the University of Oregon. Dr. Policansky has directed approximately 35 National Research Council studies, and his areas of expertise include genetics; evolution; ecology, including fishery biology; natural resource management; and the use of science in policy making.

Michael J. Stoever is a research associate with the Water Science and Technology Board. He has worked on a number of studies including Desalination: A National Perspective, the Water Implications of Biofuels Production in the United States, and the Committee on Louisiana Coastal Protection and Restoration. He has also worked on National Research Council studies on the National Flood Insurance Program, the effect of water withdrawals on the St. Johns River, and Chesapeake Bay restoration. Mr. Stoever received his B.A. in political science from The Richard Stockton College of New Jersey in Pomona.

Sarah E. Brennan is a senior program assistant with the Water Science and Technology Board (WSTB). Since joining the NRC in 2010, she has worked on six projects including Everglades restoration progress, U.S. Army Corps of Engineers' water resources, and water and environmental management in the California bay delta. Before joining WSTB, Ms. Brennan was a Peace Corps Volunteer in Ghana, West Africa. She Received her B.S. in international development from Susquehanna University.