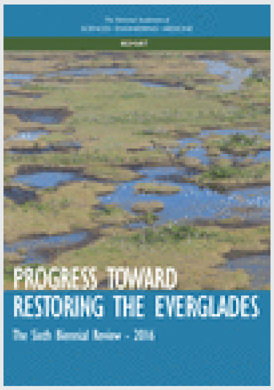

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CONTRIBUTORS

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; National Academies of Sciences, Engineering, and Medicine

PROGRESS TOWARD RESTORING THE EVERGLADES

The Sixth Biennial Review - 2016

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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COMMITTEE ON INDEPENDENT SCIENTIFIC REVIEW OF EVERGLADES RESTORATION PROGRESS

DAVID B. ASHLEY (*Chair*), University of Southern California
MARY JANE ANGELO, University of Florida, Gainesville
WILLIAM G. BOGGESS, Oregon State University, Corvallis
CHARLES T. DRISCOLL, Syracuse University, New York
M. SIOBHAN FENNESSY, Kenyon College, Gambier, Ohio
WILLIAM L. GRAF, University of South Carolina, Columbia
KARL E. HAVENS, University of Florida, Gainesville
WAYNE C. HUBER, Oregon State University, Corvallis
FERNANDO R. MIRALLES-WILHELM, University of Maryland, College Park
DAVID H. MOREAU, University of North Carolina, Chapel Hill
GORDON H. ORIANS, University of Washington, Seattle
DENISE J. REED, The Water Institute of the Gulf, Baton Rouge, Louisiana
JAMES E. SAIERS, Yale University, Connecticut
JEFFREY R. WALTERS, Virginia Polytechnic Institute and State University, Blacksburg

NRC Staff

STEPHANIE E. JOHNSON, Study Director, Water Science and Technology Board
DAVID J. POLICANSKY, Scholar, Board on Environmental Studies and Toxicology
ED DUNNE, Program Officer, Water Science and Technology Board
BRENDAN R. McGOVERN, Senior Program Assistant, Water Science and Technology Board

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Nick Aumen, U.S. Geological Survey
Drew Bartlett, Florida Department of Environment Protection
James Beerens, U.S. Geological Survey
Ingrid Bon, U.S. Army Corps of Engineers
Eric Bush, U.S. Army Corps of Engineers
Cara Campbell, Ecology Party of Florida
Cara Capp, Everglades Coalition
Pat Cauley, Rep. Clawson's Office
David Ceilley, Florida Gulf Coast University
Newton Cook, United Waterfowlers of Florida
Anna Maria Costillo, Arthur R. Marshall Foundation
Chris Costillo, Sierra Club
Dan Crawford, U.S. Army Corps of Engineers
Steve Davis, Everglades Foundation
Tylan Dean, U.S. National Park Service
Don DeAngelis, University of Miami
Deb Drum, Martin County
James Erskine, Miccosukee Tribe of Indians
Shannon Estenoz, U.S. Department of the Interior
Jim Fourqurean, Florida International University
Howie Gonzales, U.S. Army Corps of Engineers
Patti Gorman, South Florida Water Management District
Wendy Graham, University of Florida, Gainesville
Jaime Graulau, U.S. Army Corps of Engineers

Susan Gray, South Florida Water Management District
Jud Harvey, U.S. Army Corps of Engineers
Jennifer Hecker, Conservancy of Southwest Florida
Don Jodrey, U.S. Department of the Interior
Bob Johnson, U.S. National Park Service
Jennifer Leeds, South Florida Water Management District
Tom Lodge, Thomas E. Lodge Ecological Advisors, Inc.
Tom MacVicar, MacVicar Consulting
Ernie Marks, South Florida Water Management District
Jeremy McBryan, South Florida Water Management District
Agnes McLean, U.S. National Park Service
John Mitnik, South Florida Water Management District
Matt Morrison, South Florida Water Management District
Martha Musgrove, Florida Wildlife Federation
Cal Neidrauer, South Florida Water Management District
Jayantha Obeysekera, South Florida Water Management District
Gib Owen, U.S. Army Corps of Engineers
Leonard Pearlstine, U.S. National Park Service
Colin Polsky, Florida Center for Environmental Studies
Bob Progulske, U.S. Fish and Wildlife Service
Gina Ralph, U.S. Army Corps of Engineers
Armando Ramirez, South Florida Water Management District
Nathanial Reed
Lt. Col. Jennifer Reynolds, U.S. Army Corps of Engineers
Stephanie Romanach, U.S. Geological Survey
Colin Saunders, South Florida Water Management District
Dan Scheidt, U.S. Environmental Protection Agency
Dawn Sheriffs, Everglades Foundation
Fred Sklar, South Florida Water Management District
Ed Smith, Florida Department of Environment Protection
Karen Smith, U.S. Army Corps of Engineers
Mike Sukop, Florida International University
Donatto Surratt, U.S. National Park Service
Kim Taplin, U.S. Army Corps of Engineers
Tom Teets, South Florida Water Management District
Abby Tinsley, U.S. Senator Nelson's Office
Jorge Tous, U.S. Army Corps of Engineers
Steve Traxler, U.S. Fish and Wildlife Service
Joel Trexler, Florida International University
Ryan Valdez, National Park Conservation Association
Kate White, U.S. Army Corps of Engineers

Preface

South Florida is blessed with a unique, wonderfully diverse, and geographically extensive, wetland ecosystem reaching from south of Orlando to the Florida Keys. After nearly 150 years of drainage, channelization and flood control actions, this extraordinary natural resource has been dramatically altered and continues to decline. Where water once traveled slowly south toward the Everglades National Park through ridge and slough wetlands, marl prairies and sawgrass plains, it is now often diverted to the ocean or to other uses—less than half ever reaches its historic destination. The quality of the water remaining in the system is compromised by the phosphorus, nitrogen, mercury and other contaminants introduced by urban development, agriculture, and industry. The combination of reduced water flow and degraded water quality impacts has adversely changed land formation and vegetation patterns. Experts recognized over 20 years ago that significant action was needed to preserve and maintain this national wetland resource.

The U.S. Congress authorized the Comprehensive Everglades Restoration Plan (CERP) in 2000 as the multi-decadal, multi-billion-dollar response. The CERP is focused on restoring, preserving, and protecting the South Florida ecosystem while providing for other water-related needs of the region. This massive restoration program, the largest in U.S. history, is jointly administered by the U.S. Army Corp of Engineers (USACE) and the South Florida Water Management District (SFWMD), and is equally funded by federal and Florida monies. As part of the initial authorization, Congress mandated periodic independent reviews of progress toward restoration of the Everglades natural system. The National Academies of Sciences, Engineering, and Medicine's Committee on Independent Scientific Review of Everglades Restoration Progress, or CISRERP, was formed for this purpose in 2004. This report represents the sixth biennial review of CERP progress by this committee.

This sixth iteration of CISRERP includes a mix of science and engineering specialists brought together for their combined expertise in environmental, biological, hydrologic, and geographic sciences; systems engineering; project and program administration; law; economics; and public policy. These experts were selected for their eminence in their fields, as well as their experience with complex, natural systems similar to the Everglades. As committee chair, I am extremely appreciative of the significant time and energy, as well as intellectual capital, committee members devoted to this review; they performed careful, rigorous analyses of program progress and systemic issues. Our committee deliberations were always constructive, collegial, and professional—the positive spirit and good humor contributed to an especially enjoyable collaboration process. This 2016 report is a truly consensus committee product documenting the most critical factors in the successful completion of the CERP program.

The committee wishes to thank many individuals for the information and resources they provided. Specifically, we appreciate the efforts of the committee's technical liaisons—David Tipple (USACE), Glenn Landers (USACE), Rod Braun (SFWMD), and Robert Johnson (DOI)—who responded to numerous information requests and facilitated the committee's access to agency resources and expertise when needed. The committee is also grateful to the numerous individuals who shared their insights and knowledge of Everglades restoration through presentations, field trips, and public comments (see Acknowledgments).

The committee was assisted by five dedicated and very talented National Academies' staff: Stephanie Johnson, David Policansky, Ed Dunne, Brendan McGovern, and Michael Stoever. Stephanie Johnson has served as senior program officer for all six CISRERP panels and is a deep reservoir of Everglades history and knowledge. Her comprehensive understanding of CERP and its component parts, the complex physical system, agency interrelationships, diverse constituencies, and the surrounding political landscape, gave her an unparalleled vantage point in supporting the committee's activities. Stephanie's stewardship of the final report creation process, initial drafting through completion, was exceptional. National Academies of Sciences, Engineering, and Medicine scholar David Policansky is also a veteran of all the CISRERP panels and his experience, insightful observations, and penetrating questions were fundamental to the committee's deliberations. Brendan McGovern, and Michael Stoever before him, most ably supported the logistical needs of the committee. Brendan was also a valued contributor in completing the final report. Representing the entire committee, I wish to express our profound appreciation for the National Academies of Sciences, Engineering, and Medicine staff's exceptional abilities and unswerving support.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the process. We wish to thank the following individuals for their review of this report:

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Ramesh Teegavarapu, Florida Atlantic University, Baco Raton

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the report's conclusions or recommendations, nor did they see the final draft of the report before the release. The review of this report was overseen by Robin McGuire, Lettis Consultants International, Inc., Boulder, CO; and Kenneth Potter, University of Wisconsin, Madison. 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 were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

In this sixth CISRERP review cycle, our committee has the pleasure of reporting the early ecosystem benefits from CERP investments. Another portion of our charge is to illuminate those issues that may impede or diminish the overall success of CERP. In the past, we have highlighted the slow rate of program implementation, focus on the periphery rather than the center, adverse trajectories for natural system components, potential impacts of climate change, and implications of invasive species. We believe our independent reviews have brought an important and timely focus on these critical concerns. Our attention this review is on what we have learned in the 16 years since initial authorization. Everglades restoration has always been an ambitious and complex endeavor; our current review emphasizes how it is also dynamic. Incorporating this new information into future program planning and implementation is crucial to achieving ultimate ecosystem restoration success. We offer this report in the spirit of bringing focus to what has been learned and how it informs future CERP planning.

David Ashley, *Chair*
Committee on Independent Scientific Review of
Everglades Restoration Progress (CISRERP)

Contents

Acronyms

AF	acre-feet
ASR	aquifer storage and recovery
BMAP	Basin Management Action Plan
BMP	best management practice
CEPP	Central Everglades Planning Project
CERP	Comprehensive Everglades Restoration Plan
cfs	cubic feet per second
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
DMSTA	Dynamic Model for Stormwater Treatment Areas
DOI	U.S. Department of the Interior
DPM	Decomp(artmentalization) Physical Model
EAA	Everglades Agricultural Area
EDRR	early detection and rapid response
ELM	Everglades Landscape Model
ENP	Everglades National Park
EPA	U.S. Environmental Protection Agency
ERTP	Everglades Restoration Transition Plan
FDEP	Florida Department of Environmental Protection
FEB	flow equalization basin

FHA	Federal Highway Administration
FWM	flow-weighted mean
FWS	U.S. Fish and Wildlife Service
FY	fiscal year
GDM	General Design Memorandum
HHD	Herbert Hoover Dike
IDS	Integrated Delivery Schedule
IOP	Interim Operational Plan
IRL-S	Indian River Lagoon-South
JEM	Joint Ecosystem Modeling
kAF	thousand acre-feet
LILA	Loxahatchee Impoundment Landscape Assessment
LNWR	Loxahatchee National Wildlife Refuge
LOPA	Lake Okeechobee Protection Act
LORS	Lake Okeechobee Regulation Schedule
MAF	million acre-feet
MBTA	Migratory Bird Treaty Act
MGD	million gallons per day
MOM	Management Options Matrix
NAVD	North American Vertical Datum
NESRS	Northeast Shark River Slough
NGVD	National Geodetic Vertical Datum
NRC	National Research Council
NSM	Natural System Model
NSRSM	Natural System Regional Simulation Model
ppb	parts per billion
psu	practical salinity units
RECOVER	REstoration, COordination, and VERification
RESOPS	Reservoir Sizing and Operations Screening
RPA	Reasonable and Prudent Alternative
RSM	Regional Simulation Model

RSMWQ	Regional Simulation Model Water Quality engine
SERES	Synthesis of Everglades Research and Ecosystem Services
SFERTF	South Florida Ecosystem Restoration Task Force
SFWMD	South Florida Water Management District
SFWMM	South Florida Water Management Model
STA	stormwater treatment area
TBD	to be determined
TMDL	total maximum daily load
TP	total phosphorus
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
WADEM	Wader Distribution Evaluation Modeling
WCA	Water Conservation Area
WPA	Water Preserve Area
WQBEL	water quality-based effluent limit
WRDA	Water Resources Development Act
WRRDA	Water Resources Reform and Development Act
WSE	Water Supply and Environment
WY	water year

Summary

Over the past century, the Everglades, one of the world's treasured ecosystems, has been dramatically altered by drainage and water management infrastructure that was intended to improve flood control, urban water supply, and agricultural production. The remnants of the original Everglades now compete for 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 launched by the state and the federal government in 2000, seeks to reverse the decline of the ecosystem. The $16.4 billion project was originally envisioned as a 30- to 40-year effort to achieve ecological restoration by reestablishing the natural 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.

The National Academies of Sciences, Engineering, and Medicine 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 (DOI), 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 ecosystem. This is the committee's sixth report. Each report provides an update on natural system restoration progress over the previous 2 years, describes substantive accomplishments (Chapter 3), and addresses important developments in research, monitoring and assessment that inform restoration decision making (Chapters 3 and 5). In each new report, the committee also identifies issues for in-depth evaluation considering 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 the 2016 review, the committee examined the implications

of knowledge gained and changes in widely accepted scientific understanding regarding pre-drainage hydrology, climate change, and the feasibility of water storage since the CERP was developed (Chapter 4). The committee examined how this information can be used in forward-looking systemwide analyses, consistent with an adaptive management framework, to improve the effectiveness of the restoration program (Chapter 5).

OVERALL EVALUATION OF PROGRESS AND CHALLENGES

Sixteen years into the CERP, there are some demonstrable ecosystem improvements from initial program investments. Additional major restoration enhancements are within reach as two CERP projects are nearing completion, four more are ongoing (see Figure S-1), and three major non-CERP projects with large-scale restoration benefits should be complete and operational in the next 5 years. Planning for the next potential projects is advancing.

Amidst this important progress in CERP implementation, some serious concerns remain. Although the funding outlook has improved over the past 2 years, the funding pace remains slower and the project costs greater than originally envisioned for the CERP, leading to prospects of program completion well beyond 2060. Additionally, there has been insufficient attention to refining long-term systemwide goals and objectives and the need to adapt the CERP to radically changing system and planning constraints. It now is known that the natural system was historically much wetter than previously assumed, bringing into question some of the hydrologic goals embedded in the restoration plan. Sea level rise will reduce the footprint of the system, temperature and evaporative water losses are expected to increase, rainfall may become more variable, and more storage would likely be needed to accommodate future changes in the quantity and intensity of runoff. At the same time, over 1 million acre-feet (AF) of the originally envisioned storage has been lost due to design changes, new understanding of project feasibility, and changes to Lake Okeechobee's operating schedule.

All of these factors underscore the critical need for forward-looking, systemwide analysis to examine restoration outcomes and revisit CERP goals and objectives in light of recent and potential future changes. Forward-looking analysis, in conjunction with program-level adaptive management and long-overdue updated systemwide restoration plan evaluations (termed "CERP updates"), will ensure that the CERP is based on the latest scientific and engineering knowledge, considers long-term ecosystem needs, addresses potential restoration conflicts, and is robust to changing conditions. Such efforts need not impede ongoing or planned construction progress, and they will better inform current and future project and systemwide planning efforts. It is only through such rigorous pro-

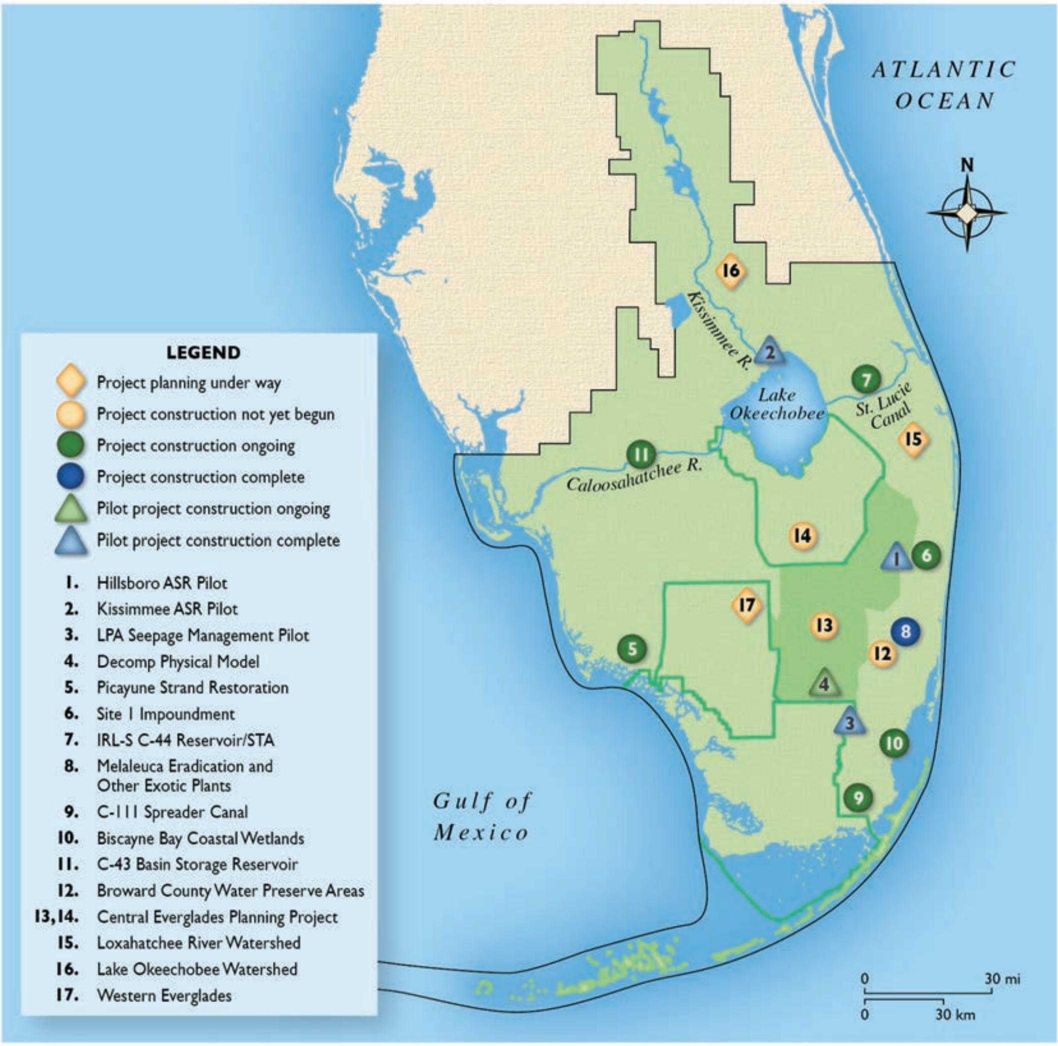

FIGURE S-1 Locations and status of early CERP projects and CERP or CERP-related pilot projects. The CERP includes approximately 41 projects, 6 pilot projects, and 6 plans and studies originally intended to be implemented over 30-40 years. See Chapter 3 for more information on CERP implementation progress.

SOURCE: © International Mapping Associates.

gram evaluations combined with well-designed system performance monitoring and modeling that decision makers and the public can be assured that the best restoration investments are being pursued. The report's major conclusions and recommendations are summarized below.

RESTORATION PROGRESS

Chapter 3 addresses programmatic and implementation progress, and discusses the ecosystem benefits resulting from the progress to date.

Completed components of CERP projects are beginning to show ecosystem benefits. Several CERP project increments that have been completed or are nearing completion are beginning to yield measurable results, especially in terms of creating hydrologic conditions that are increasingly similar to predrainage flows. For example, portions of Picayune Strand are experiencing higher groundwater levels even though the project is not yet complete, and vegetation is becoming more similar to reference conditions. The Biscayne Bay Coastal Wetlands project has enhanced wetland inundation for more than 1,600 acres of the project area, although nearshore salinity values remained above the project targets. The documented hydrologic improvements from the CERP to date, however, involve a small proportion of the overall CERP footprint and are located on the periphery of the remnant Everglades.

Major non-CERP projects are nearing completion, with documented early benefits and anticipated large-scale ecosystem restoration outcomes in the heart of the remnant Everglades once fully implemented. After resolving procedural impediments that led to delays noted in the committee's last biennial report (NRC, 2014), there is substantial progress under way on the Modified Water Deliveries (Mod Waters), C-111 South Dade, and Kissimmee River Restoration Projects, which are all anticipated to be completed in the next 5 years. Emergency deviations allowed additional water to flow under the Mod Waters 1-mile bridge in the spring of 2016, bringing enhanced benefits to Everglades National Park while reducing high water in Water Conservation Area 3A. Continued attention to completing the few remaining project components and developing operational plans will help to avoid further delays in the delivery of these large-scale restoration benefits that the CERP will build upon. Rigorous monitoring is essential to document the ecosystem responses to these projects, to communicate restoration progress to decision makers and the public and to inform future restoration projects.

Water quality in the remnant Everglades continues to improve through enhancements in stormwater treatment area (STA) management and operation, but water quality entering Lake Okeechobee and in the lake and its outflows remains in a degraded state. South of the lake, STAs are currently removing approximately 80 percent of phosphorus from their inflows, and in water year 2015 the flow-weighted mean outflow concentration for all STAs (17 parts per billion [ppb] total phosphorus) was the lowest achieved over 21 years of operation. Although the target of 13 ppb total phosphorus has not yet been achieved, some STAs are approaching that goal. Improvements to STA operations are anticipated to continue as progress is made on Restoration Strategies projects and targeted research efforts. Continued progress on the quality of STA outflows is an essential prerequisite to additional and redistributed CERP flows in the central Everglades. In contrast, there is no long-term downward trend in phosphorus loading to Lake Okeechobee, despite implementation of projects that have reduced phosphorus export from agricultural land parcels and certain sub-basins. In the lake itself, phosphorus concentrations at over 100 ppb are more than double what they were in the early 1980s, and concentrations of nitrogen also are high. As a result, outflows from the lake continue to contribute nutrient pollution to the estuaries, as evidenced by the algal blooms of 2016, and make it more difficult to reach CERP goals for those areas. Additionally, if high phosphorus loads into Lake Okeechobee are not reduced through more stringent nutrient management in the watershed, larger CERP STAs may be necessary for future projects that move lake water south.

Reports on CERP progress need to clearly describe ecosystem benefits by documenting changes in key indicators relative to expectations, goals, and baseline and/or reference conditions. Timely and effective reporting of CERP ecosystem benefits to decision makers and the public is critical to ensure accountability for governmental entities that provide funding and for generating continued public support. So far CERP reporting has emphasized construction progress, but clear ecosystem changes are now evident for some projects and ecosystem benefits from other projects are likely in the near future. Therefore, additional attention is needed toward assessing and reporting CERP natural system restoration progress. Reports of CERP progress should describe the ecosystem effects predicted to result from the project relative to baseline and/or reference conditions and the time frame over which they are likely to unfold. Explaining the expected time frame for ecosystem effects is important because although some ecosystem responses (e.g., hydrologic changes) are typically rapid, others (e.g., changes in vegetation structure) may unfold slowly. To avoid creating unrealistic expectations, funders, the public, and managers need to appreciate and understand why some important ecosystem benefits may only become apparent long after project implementation. Also, understanding ecosystem responses relative to expectations is necessary to support adaptive management and determine the need for subsequent management actions if benefits fall far short of project objectives. CERP reports of restoration progress should also describe and explain the key indicators that need to be monitored to document the predicted changes. This step could help communicate to decision makers the value of carefully chosen indicators and a well-designed monitoring plan that uses resources efficiently to address the needs of assessment and adaptive management efforts. Finally, the performance of individual projects should be linked to a holistic assessment of progress toward systemwide restoration objectives to support systemwide adaptive management (see Chapter 5) and to clearly communicate overall progress.

Although the outlook for CERP funding has shown modest improvements since the all-time low in 2012, outlays of funds continue to fall short of what is needed to complete the CERP within the next 50 years. Increased CERP funding would expedite project implementation and the delivery of restoration benefits and ameliorate ongoing ecosystem declines. Recent Water Resources Reform and Development Act legislation, new project partnership agreements, and a more stable source of state funds have alleviated constraints on federal spending that had been caused by state-federal 50-50 cost-sharing requirements for the CERP. Although construction is under way on six CERP projects, the pace of progress is dependent on funding. Sixteen years into the restoration (roughly half the original timeline of the CERP), only 16 to 18 percent of estimated total cost has been funded. Thus, substantial additional investment is needed to complete the project as envisioned.

Conflicts between restoration objectives and the needs of protected species are issues that require programmatic solutions. The creation of new wetlands and alterations in hydrology in Everglades restoration creates potential conflicts between broad restoration goals and the specific needs of protected species. The frequent nesting of stilts and snail kites in the STAs affects operations of most flow-ways and a large percentage of individual STA treatment cells. Protecting stilts and kites potentially conflicts with restoration goals related to water quality, although the effect on overall STA performance has not yet been quantified. Documenting the reduction in STA performance due to protection of nesting birds is critical to determining the importance of this conflict. In addition, restoration activities that produce net benefits for a species at the system scale can often create negative local impacts on that species. Thus, conflicts emerge between the needs of these species and the needs of restoration, as has occurred repeatedly and will likely continue to occur with Cape Sable seaside sparrows. These conflicts merit forward-looking programmatic solutions, so they do not repeatedly cause restoration delays. The USACE has proposed that a Comprehensive Conservation Plan be developed that includes identification of potential future habitat for this subspecies considering predicted flows associated with Everglades restoration projects. This approach has the potential to produce a much-needed long-term solution for the sparrow conflict that integrates systemwide sparrow conservation with the multi-species benefits provided by the restoration. As such, it could provide a model for addressing similar issues with other species. In the case of the conflict over management of the STAs, the agencies could explore options under the Migratory Bird Treaty Act, such as special use permits or memoranda of understanding, that would provide the flexibility necessary to optimize STA performance.

KNOWLEDGE GAINED SINCE 1999 AND IMPLICATIONS FOR THE CERP

In Chapter 4, the committee examines major changes that have occurred since 1999 that are likely to affect the construction of the CERP as initially envisioned and the potential for achieving the original objectives. The committee also recommends steps to address these major developments.

Knowledge gained regarding the pre-drainage system, climate change, and sea level rise suggests that a reexamination of the CERP restoration goals—including both ecology and hydrology—is in order, together with a realistic assessment of what can be achieved. It is now widely accepted that the Everglades ecosystem was much wetter historically than previously thought. As a result, re-creating historic hydrology will require more new water and have different ecological outcomes than envisioned in the CERP. This information raises new issues and opportunities that should be considered in the context of future CERP design options, including the potential for improved conditions and likely risks associated with higher flows in the southern Everglades. Restoring pre-drainage features while preserving post-drainage features that are viewed as desirable, for example the presence of marl prairies inhabited by Cape Sable seaside sparrows, will be especially challenging. Even if the restored system cannot replicate the pre-drainage system or attain all of the physical, chemical, and biological goals, improved ecosystem functioning is anticipated from partial attainment of objectives for historical water depth, and benefits from incremental restoration steps may be significant. Revised goals should also reflect the dynamic nature of the system and developing constraints imposed by climate change and sea level rise. Climate change has the potential for marked effects on the structure and functioning of the Everglades, increasing the need for CERP benefits that are robust in the face of climate change uncertainties or outcomes that help mitigate the effects of changing climate and sea level rise.

New information, project designs, and revised lake management rules have reduced the storage capacity envisioned originally in the CERP by over 1 million AF compared to the 1999 plan, which could have serious ecological consequences in both the northern estuaries and the Everglades ecosystem if this shortfall is not addressed. Major reductions in storage capacity are associated with the replacement of the EAA and L-8 Reservoir footprints with flow equalization basins (FEBs), the largely reduced capacity of regional aquifer storage and recovery (ASR), the uncertain feasibility of the Lake Belt reservoirs, and the implementation of a new Lake Okeechobee regulation schedule. The amount of storage capacity provided by planned and authorized CERP projects to date plus the Central Everglades Planning Project (386,000 AF) is less than the 564,000 AF lost by the lower 2008 Lake Okeechobee regulation schedule. Additionally, based on the conclusions of the ASR Regional Study, estimated feasible ASR storage has been reduced by approximately 60 percent, reducing its maximum outflow capacity to a level comparable to a single large CERP reservoir and reducing CERP benefits provided in multi-year droughts. Recent scenario analyses show how loss of storage reduces restoration performance in the northern estuaries in terms of mean annual flood control releases and months with low flow, with additional impacts to restoration benefits in the remnant Everglades ecosystem and Florida Bay. Further analysis is warranted to examine the implications of various levels of storage on CERP outcomes. It is possible that updated storage designs may be distributed and operated more effectively than originally envisioned, but sufficient information is not publicly available to predict the hydrologic and ecological effects of various changes in storage on the expected systemwide benefits of the CERP. Meanwhile, climate change scenario analyses suggest an increased need for water storage under both reduced and increased precipitation scenarios to mitigate future ecosystem and water supply impacts.

Considerable uncertainty exists regarding future Lake Okeechobee regulation, available water storage beyond Lake Okeechobee, and the impacts of a changing climate. This uncertainty should not be ignored; rather, it should be addressed and incorporated into CERP planning. To address scientific and planning uncertainties associated with climate change and water storage, there is a critical need to analyze these factors and their interacting effects in CERP planning efforts. A systemwide screening analysis of feasible, yet-to-be-implemented CERP storage alternatives is needed to evaluate modeled restoration outcomes with various levels of storage. This screening could also identify the most cost-effective combinations of storage alternatives, which could be examined in more detail in individual project planning efforts. Assessments of hydrologic responses to changes in precipitation (including quantity, intensity, distribution, and changes in seasonality) under anticipated increases in temperature and evapotranspiration should be conducted on the most promising alternatives to demonstrate the outcomes of the CERP in the face of climate change and sea level rise with variable quantities and locations of storage.

The process to revise the Lake Okeechobee regulation schedule should be initiated as soon as possible in parallel with the Herbert Hoover Dike modifications to inform near-term project planning involving water storage north and south of the lake. The large impacts on water storage with just modest changes in the lake regulation schedule suggest that Lake Okeechobee is a central factor in future considerations of water storage. Decisions made on the future regulation schedule will affect storage needs both north and south of the lake and overall restoration outcomes and costs. A planning process, with substantial public engagement, would need to evaluate different regulation schedule options and their differential benefits for the lake, the northern estuaries, and the remnant Everglades as well as related economic and water supply impacts. Expediting the revision to the lake regulation schedule would also ensure that the process is complete (including a required dam safety risk assessment) so that the new schedule can be put into place as soon as the Herbert Hoover Dike repairs are determined to be sufficient to sustain higher water levels, thereby expediting ecological benefits to the northern estuaries. Once other storage elements are constructed, the lake schedule will likely need to be revisited to optimize its operations considering the additional storage features.

LOOKING FORWARD

When the CERP was launched in 2000, adaptive management was embraced as a means of incorporating new information into the plan and addressing unforseen issues related to the plan, and the CERP was widely viewed as a leader in adaptive management. Since that time, a framework for CERP adaptive management has been developed, and a structure for implementation at a project-level adopted, but the original vision of adaptive management at the program level remains unfulfilled. In Chapter 5, the committee outlines steps that need to be taken for the CERP program to continue to lead in adaptive management and, more importantly, to ensure restoration success by incorporating new knowledge and changing circumstances into the restoration plan at the systemwide scale.

The CERP has made limited progress in articulating restoration objectives that are sufficiently quantitative to support effective planning, implementation, and assessment. An effort is now needed to develop quantitative restoration goals that capture new science and address potential conflicts in restoration. When authorized, the CERP goals were broad narrative statements on restoring the South Florida ecosystem and ensuring that the water needs of the region were met. Reaching these goals requires that realistic, quantitative objectives be developed and applied to project- and program-level restoration, which in turn requires consideration of the inherent tradeoffs that must be made in any complex ecosystem restoration program (as discussed in Chapter 4). Work has stalled on improving the quantitative interim goals, which were not adopted because of the substantial assumptions that were made in their development. Developing quantitative objectives is an essential component of adaptive management, and once established, these objectives should be periodically revisited to ensure they are still desirable and achievable given new knowledge and modeling capability and major changes that affect future systemwide operations under the CERP.

The CERP Program-Level Adaptive Management Plan is an important first step in identifying critical uncertainties affecting restoration progress, but it requires an implementation plan and sufficient resources to be effective. The plan asks highly relevant questions about the CERP that are related to questions of storage, design and implementation, and climate change. Many of the questions can and should be addressed now through new research and modeling in addition to ongoing monitoring. Monitoring alone cannot address the challenges and tradeoffs required for decision making and management at the program level. The CERP Program-Level Adaptive Management Plan concludes that a failure to address the Priority 1, mission-critical uncertainties will paralyze progress toward meeting CERP restoration goals and that many of these uncertainties need to be addressed immediately, but no actions have been taken to implement the plan. To expedite implementation of the Program-Level Adaptive Management Plan, an implementation strategy to address the Priority 1 uncertainties is needed that identifies tasks, timelines, resources, and staffing required, and the highest priorities if sufficient funding is not available for the ideal implementation plan.

A systemwide analysis of the potential future state of the Everglades ecosystem, with and without CERP and other restoration projects, should be conducted in conjunction with a CERP Update, which is long overdue. The regular 5-year CERP Updates called for in the Programmatic Regulations to evaluate the restoration plan considering new scientific, technical, and planning information have not been routinely conducted. A holistic, forward-looking analysis of the possible future state of the ecosystem is needed in the light of new knowledge gained over the past 16 years. This analysis should consider various scenarios for climate change and sea level rise and explore the ecosystem implications of various options for future CERP implementation. By exploring alternative future scenarios, considering uncertainties in climate or funding to support implementation, decision makers and stakeholders will be better informed of the implications of near- and long-term decisions. The halfway point in the original CERP timetable is an appropriate time for such analysis and evaluation of the future condition of the ecosystem. Challenges identified by this analysis may illuminate the need for modifications, either in future project planning efforts or in the restoration goals and objectives themselves. Although some might consider that illuminating such issues makes a complex stakeholder interaction even more difficult, failing to confront these problems in a science-based, objective manner can lead to even less desirable circumstances, including unrealistic expectations, litigation, and reduced public or congressional support. The analysis and evaluation process conducted as part of the CERP Update will enable the CERP agencies to ensure restoration expectations are clear and can be achieved and to determine if further modifications of the CERP, as allowed for in the Programmatic Regulations, are needed.

Developed and developing tools exist that can support forward-looking analyses of the CERP for project and systemwide analyses. Tools and strategies are available to explore future climate change and sea-level rise scenarios, examine the robustness of the CERP to these potential futures, and enhance decision making under uncertainty. These approaches can illuminate opportunities to adapt the restoration plan to changing precipitation, hydrology, and sea level rise and mitigate the impacts of climate change. The capability for ecological modeling has advanced in recent years, to the point that models can be used to project systemwide effects of restoration activities for a variety of ecological performance measures. Ecological models link the response of species and habitats to underlying hydrologic models at local or systemwide scales, and allow alternatives to be evaluated based on projected ecological outcomes. Ecological models are now being used along with hydrologic models in planning and assessments related to restoration—a major advance. Ecological models may be especially useful in evaluating tradeoffs between restoration goals and targets. In contrast, development and application of water quality models in the CERP continues to lag behind the use of hydrologic and now ecological models. Robust and well-tested water quality models are important tools to inform restoration strategies, particularly those that involve new water flows or redistribution of existing flows, and continued attention is needed to develop these models. The development of a robust Everglades water quality model is a key need moving forward. Improved water quality modeling tools also should lead to further refinement of ecological models, since Everglades habitat, species distribution, and ecological functioning are closely linked to water quality. As modeling advances toward an integrated set of tools to evaluate hydrologic, water quality and ecosystem response to changes, there is a need for comprehensive sensitivity and uncertainty analysis of these linked models to inform and guide assessment and planning decisions.

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 sixth independent assessment of the CERP's progress by the Committee on Independent Scientific Review of Everglades Restoration Progress (CISRERP) of the National Academies of Sciences, Engineering, and Medicine.

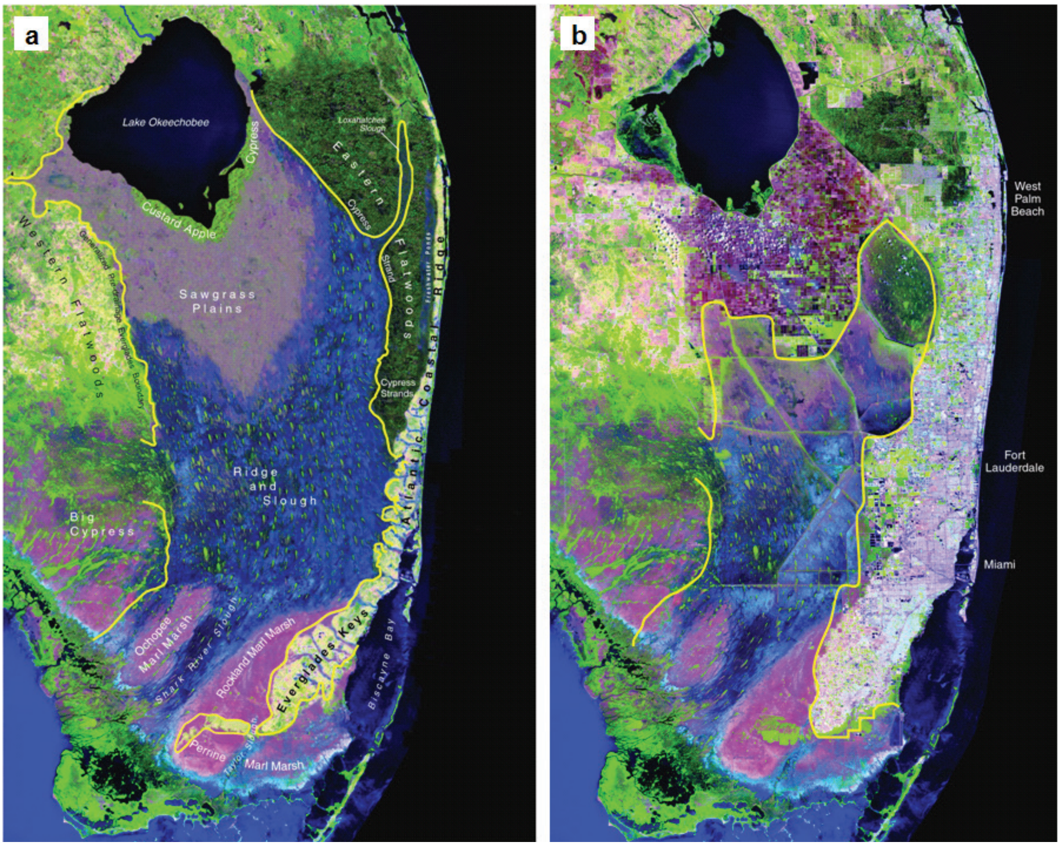

FIGURE 1-1 Reconstructed (a) pre-drainage (circa 1850) and (b) current (1994) satellite images of the Everglades ecosystem.

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.

THE NATIONAL ACADEMIES AND EVERGLADES RESTORATION

The National Academies has been providing scientific and technical advice related to the Everglades restoration since 1999. The Academies' 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 (hereafter, simply the Task Force), an intergovernmental

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

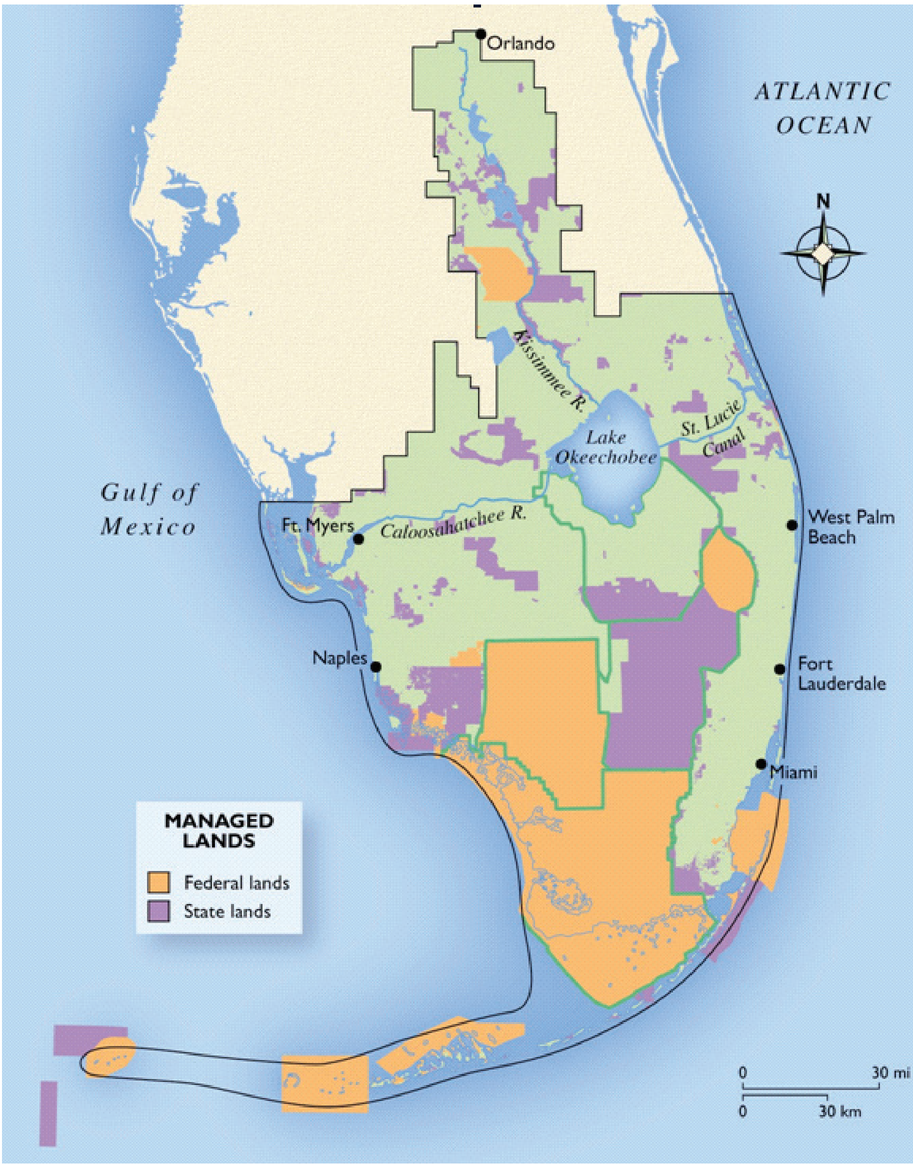

FIGURE 1-3 Land and waters managed by the State of Florida and the federal government as of December 2005 for conservation purposes within the South Florida ecosystem.

SOURCE: Based on data compiled by Florida State University's Florida Natural Areas Inventory (http://www.fnai.org/gisdata.cfm). © International Mapping Associates body established to facilitate coordination in the restoration effort, and the committee produced six reports (NRC, 2001, 2002a,b, 2003a,b, 2005). The Academies' 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 National Academies' CISRERP was therefore established in 2004 under contract with the U.S. Army Corps of Engineers. After publication of each of the first five biennial reviews (NRC, 2007, 2008, 2010, 2012, 2014; 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 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, 2012, 2014) and emphasizes restoration progress since 2014, 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 National Academies' Everglades reports. Interested readers should look to past reports by this committee to find detailed discussions of important topics, such as climate change (NRC, 2014), invasive species (NRC, 2014), the human context for the CERP (NRC, 2010), water quality and quantity challenges and trajectories (NRC, 2010, 2012), Lake Okeechobee (NRC, 2008), Modified Water Deliveries to Everglades National Park (NRC, 2008), and incremental adaptive restoration (NRC, 2007), which are not repeated here. Past reports have also discussed various aspects of the CERP monitoring and assessment plan (NRC, 2004, 2008, 2010, 2012, 2014); in this report the committee addresses new developments in monitoring, assessment, and adaptive management, as well as lessons learned.

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 August 2016.

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 analyzes the progress of CERP implementation, including recent developments on authorized projects and two pilot projects, as well as major non-CERP projects with important implications for the CERP. Also discussed in the chapter are programmatic progress and issues, including funding, sequencing, and strategies for addressing conflicting restoration objectives.

In Chapter 4, the committee discusses three major areas where knowledge has been gained since the launch of the CERP that have substantial implications for systemwide CERP outcomes. Much has been learned in the areas of predrainage hydrology, climate change and sea level rise, and the feasibility of CERP storage alternatives that influences the future benefits of the CERP as originally designed.

In Chapter 5, steps to incorporate knowledge gained (Chapter 4) using a systemwide adaptive management framework are proposed. A forward-looking systemwide assessment, including a CERP Update based on current authorized projects and likely feasible future projects, is an essential step of this process.

2

The Restoration Plan in Context

This chapter sets the stage for the sixth 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 the Florida Keys 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

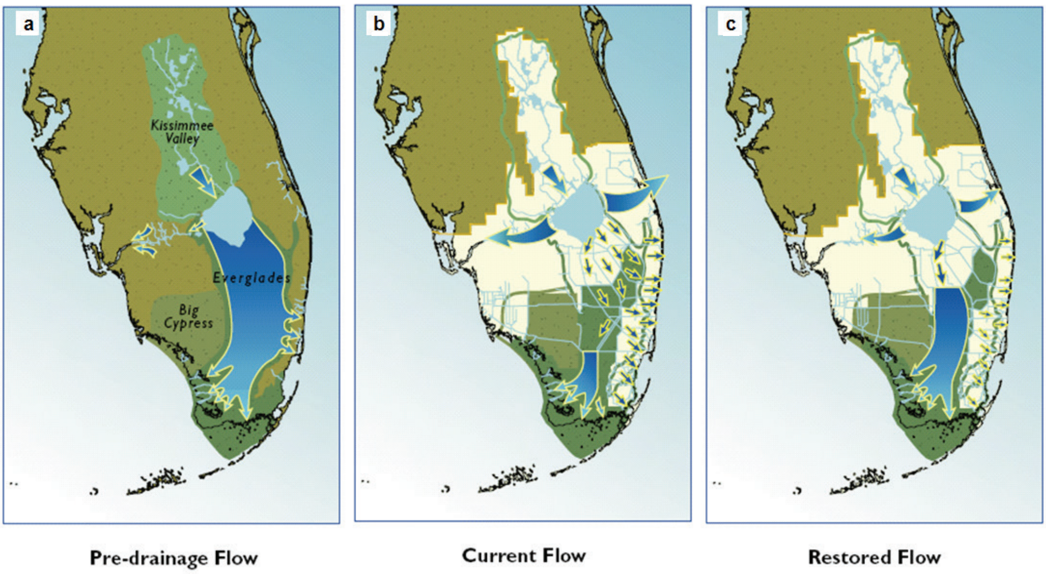

FIGURE 2-1 Water flow in the Everglades under (a) historical conditions, (b) current conditions, and (c) conditions envisioned upon completion of the Comprehensive Everglades Restoration Plan.

SOURCE: Graphics provided by USACE, Jacksonville District.

within the system and an increased susceptibility to drought and desiccation in the southern reaches of the Everglades (NRC, 2005).

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 78 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 3 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 was designed to provide for other water-related needs, including water supply (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 non-native 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 pre-existing 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 that allows 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 non-native 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 as well as monitoring and assessment of progress. This report discusses the challenges to restoration goals arising from major changes that have occurred since the inception of the CERP in 1999 (see Chapter 4). Additional challenges in defining and implementing restoration goals are discussed in the initial National Academies biennial review (NRC, 2007).

What Restoration Requires

Restoring the South Florida ecosystem to a desired ecological landscape requires reestablishment of critical processes that sustain its functioning. Although getting the water right is the oft-stated and immediate goal, the restoration ultimately aims to restore the distinctive characteristics of the historical ecosystem to the remnant Everglades (DOI and USACE, 2005). Getting the water right is a means to that end, not the end itself. The hydrologic and ecologic characteristics of the historical Everglades serve as general 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, then the basic physical, chemical, and biological processes that created the historical Everglades can once again work to create and sustain a functional mosaic of biotic communities that resemble what was distinctive about the historical Everglades.

The history of the Everglades and ongoing global climate change will make replication of the predrainage 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. End results will also often differ from the historical system as climate change and sea level rise, permanently established invasive species, and other factors have moved the ecosystem away from its historical state (Hiers et al., 2012).

Even if the restored system does not exactly replicate the historical system, or reach all 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 more than 40 major projects consisting of 68 project components to be constructed at a cost of approximately $16.4 billion (estimated in 2014 dollars, including program coordination and monitoring costs; USACE and DOI, 2016; Figure 2-2). Major components of the restoration plan focus on restoring the quantity, quality, timing, and distribution of water for the South Florida ecosystem. 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 (AF) of surface 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 below ground.
- **In-ground reservoirs.** The Yellow Book proposes additional water storage in quarries created by rock mining.

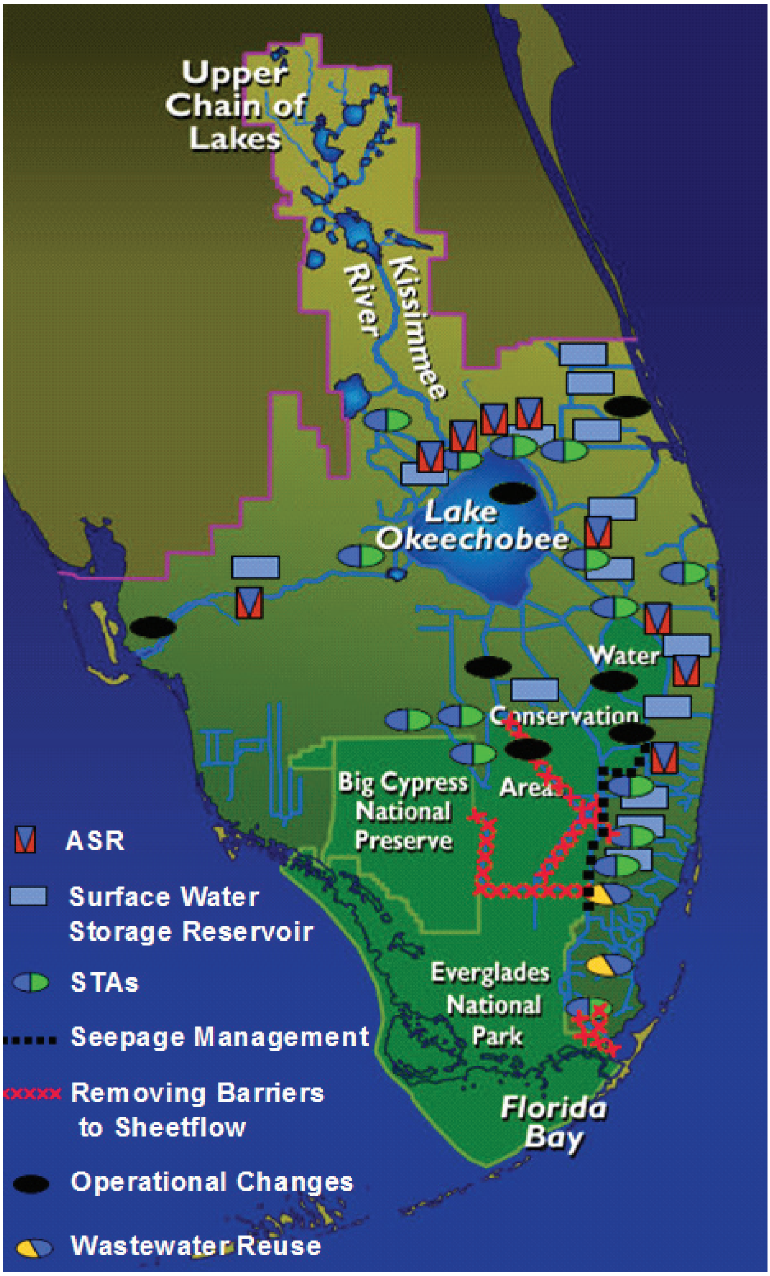

FIGURE 2-2 Major project components of the CERP.

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 remnant Everglades 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 projects (see Chapter 4) 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 3 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, 2007a) 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 (see also Chapter 5).

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 state water quality treatment projects (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 treatment initiatives and programs to establish best management practices (BMPs) to reduce nutrient loading.

Major Developments and Changing Context 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

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 2-1-1).

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,

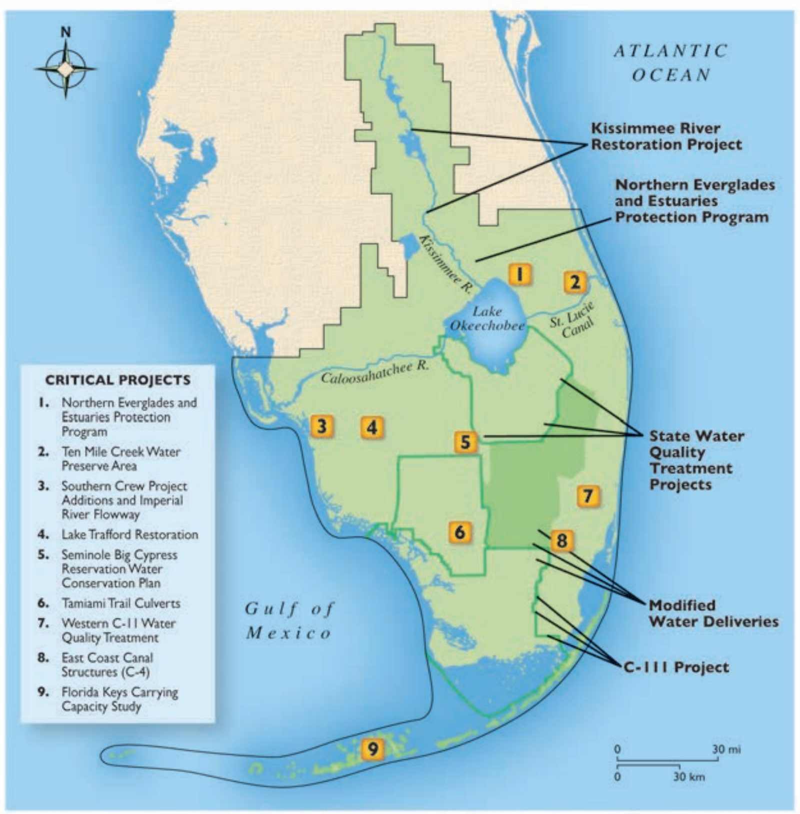

FIGURE 2-1-1 Locations of major non-CERP initiatives.

SOURCE: © International Mapping Associates.

continued

BOX 2-1 Continued

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 3.

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 includes an additional 6,500 acres of STAs and 116,000 acres of flow equalization basins (see Chapter 3).

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 increase the quantity of water entering Everglades National Park. See also Chapter 3.

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 modifica-

to complete all the original tasks, the program led to increased state investment and expedited project construction timelines for several CERP projects.

Operation of Lake Okeechobee has been modified twice since the CERP was developed in ways that have reduced total storage. In April 2000, the Water Supply and Environment (WSE) regulation schedule was implemented to reduce high water impacts on the lake's littoral zone and to reduce harmful high discharges to the St. Lucie and Caloosahatchee estuaries. The regulation schedule was changed again in 2008 to reduce the risk of failure of the Herbert Hoover Dike until the USACE could make critical repairs. This resulted in a loss of 564,000 AF of potential storage from the regional system (see Chapter 4).

tions and installation of a seepage control pump to increase water flow into 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. 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 3.

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 in February 2008 in accordance with LOPA, consolidated the numerous initiatives already under way.

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 Tribe Big Cypress Water Conservation Plan, Tamiami Trail Culverts, Ten Mile Creek Water Preserve Area, and the Lake Trafford Restoration (DOI and USACE, 2011).

In the years since the CERP was launched, the state of Florida has increasingly encouraged the use of alternative water supplies—including wastewater, stormwater, and excess surface water—to meet future water demands (e.g., FDEP, 2015). In 2006, the SFWMD passed the Lower East Coast Regional Water Availability Rule, which caps groundwater withdrawals at 2006 levels, requiring urban areas to meet increased demand through a combination of conservation and alternative water supplies. In 2007, the Florida legislature mandated that ocean wastewater discharges in South Florida be eliminated and 60 percent of those discharges be reused by 2025 (Section 403.086[9], F.S.), representing approximately 180 million gallons per day of new water supply for the Lower

East Coast. The Florida Department of Environmental Protection (2015) recently released a study with a series of recommendations to reduce the barriers to the use of reclaimed water and stormwater to augment water supply and help meet growing urban and industrial water demands. It remains unclear whether or how these new initiatives and mandates will affect the expectations for agricultural and urban water supply from the CERP, particularly since the capture of excess surface water is a key element of the CERP.

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. Phase II of the planning process was halted in May 2010, without completion. In October 2010, the SFWMD closed on the purchase of 26,800 acres of the U.S. Sugar land for approximately $197 million, and in May 2015, the SFWMD governing board terminated the 10-year option to acquire an additional 153,000 additional acres of the U.S. Sugar land.

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 3). 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 by 2025.[2]

Changing Understanding of Restoration Challenges

Much new knowledge has been gained since the launch of the CERP that provides a new understanding of restoration challenges and opportunities and informs future restoration planning and management. RECOVER (2011a) high-

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[2] 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 translated into a flow-weighted mean (FWM) total phosphorus (TP) concentration and applied to each STA discharge points, which 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).

lights key areas of knowledge gained, including predrainage hydrology, modeling, and Everglades landscapes. Considering the many advances in knowledge since 1999, climate change and sea level rise are among the most significant. As outlined in NRC (2014), changes in precipitation and evapotranspiration are expected to have substantial impacts on CERP outcomes. Downscaled precipitation projections remain uncertain and range from modest increases to sizeable decreases for South Florida, and research continues locally and nationally to improve these projections. Sea level rise is already affecting the distribution of Everglades habitats and causing coastal flooding in some low-lying urban areas. CERP planners are now evaluating all future restoration benefits in the context of low, medium, and high sea level rise projections, although NRC (2014) noted the need for greater consideration of climate change and sea level rise in CERP project and program planning. See Chapter 4 for additional discussion of the implications of new knowledge of climate change to the CERP.

Since the CERP was developed, the significance of invasive species management on the success of restoration also has been recognized by the South Florida Ecosystem Restoration Task Force and its member agencies.[3] Non-native species constitute a substantial proportion of the current biota of the Everglades. The approximately 250 non-native plants species are about 16 percent of the regional flora (see NRC, 2014). Southern Florida has a subtropical climate with habitats that are similar to those from which many of the invaders originate, with relatively few native species in many taxa to compete with introduced ones. Some species, especially of introduced vascular plants and reptiles, have had dramatic effects on the structure and functioning of Everglades ecosystems, and necessitate aggressive management and early detection of new high-risk invaders to ensure that ongoing CERP efforts to "get the water right" allow native species to prosper instead of simply enhancing conditions for invasive species.

FLOODS AND DROUGHTS AND THE LIMITATIONS OF WATER MANAGEMENT INFRASTRUCTURE IN 2015-2016

The 2015-2016 period included both localized droughts in the summer of 2015 that triggered seagrass die-off in Florida Bay and record rainfall the following winter, which led to large releases to the Caloosahatchee and St. Lucie Estuaries, high water conditions in the Water Conservation Areas, and harmful algal blooms during the summer of 2016. Both events highlight the limitations of existing infrastructure and water management options to reduce the adverse impacts of low and high water conditions.

[3] See http://www.evergladesrestoration.gov/content/ies/.

Seagrass Die-offs in Florida Bay

Florida Bay is an important nursery for commercially or recreationally important fish and invertebrate species. The bay, which covers about 850 mi^2 (2,200 km^2), is shallow (< 9 ft or 3 m) and is divided by mud banks into somewhat isolated basins in the central and eastern parts of the bay (Fourqurean and Robblee, 1999; NRC, 2002a). In the mid- to late 1900s, Florida Bay was characterized as having clear water and dense seagrasss meadows, but in 1987, hypersaline conditions resulting from chronic and acute shortages of freshwater inflows triggered a cascade of ecological effects in the bay. Together with high temperatures, the hypersaline conditions caused hypoxic conditions and high sulfide levels that caused widespread seagrass collapse in the central and western portions of the bay, algal blooms, and increased turbidity (Deis, 2011; Hall et al., 1999) with major effects on commercial and recreational fishing. Although the most acute impacts lasted between 1987 and 1991, the ecosystem was still recovering as of the mid-2000s (J. Fourqurean, FIU, personal communication, 2015). In 2015, a seagrass die-off (Figure 2-3) was again observed in several locations in the bay. The 2015 seagrass die-off was attributed to local rainfall deficits associated with a strong El Niño which, in addition to the chronic shortage of freshwater deliveries, led to increased salinity in the bay (up to 72 practical salinity units [psu] in Garfield Bight, the highest salinity yet recorded in the bay) (NPS, 2016a). By late 2015, the spatial extents of seagrass die-off included areas such as Johnson Key, Rankin Lake, Pelican Key, Dido Key Bank, and Garfield Bight (NPS, 2016a). In the 1980s, the collapse of Florida Bay brought increased scientific, public, and political attention to the conditions of the Greater Everglades ecosystem and support for restoration actions to increase flows to and restore conditions in Everglades National Park and Florida Bay. Twentieth-century water management in South Florida had decreased freshwater inflow to the bay by about 60 percent compared to predrainage conditions, while altering the distribution and timing of that water (Herbert et al., 2011). CERP and non-CERP projects (e.g., C-111 Spreader Canal Western Project, C-111 South Dade), were authorized and constructed to help restore freshwater flows to Taylor Slough and Florida Bay, but as of 2015, flow restoration implementation was insufficient to prevent a recent reoccurrence of seagrass die-off. The status of these and other projects designed to enhance flow to Florida Bay is discussed further in Chapter 3.

By late summer of 2015, the rains came and continued at unusually high amounts well into the winter, returning salinity levels in Florida Bay to normal levels. No major expansion of die-off has been observed in 2016, but new areas with many small die-off patches have been found. Whether these are unusual or simply the result of more-intensive monitoring efforts is not known at present

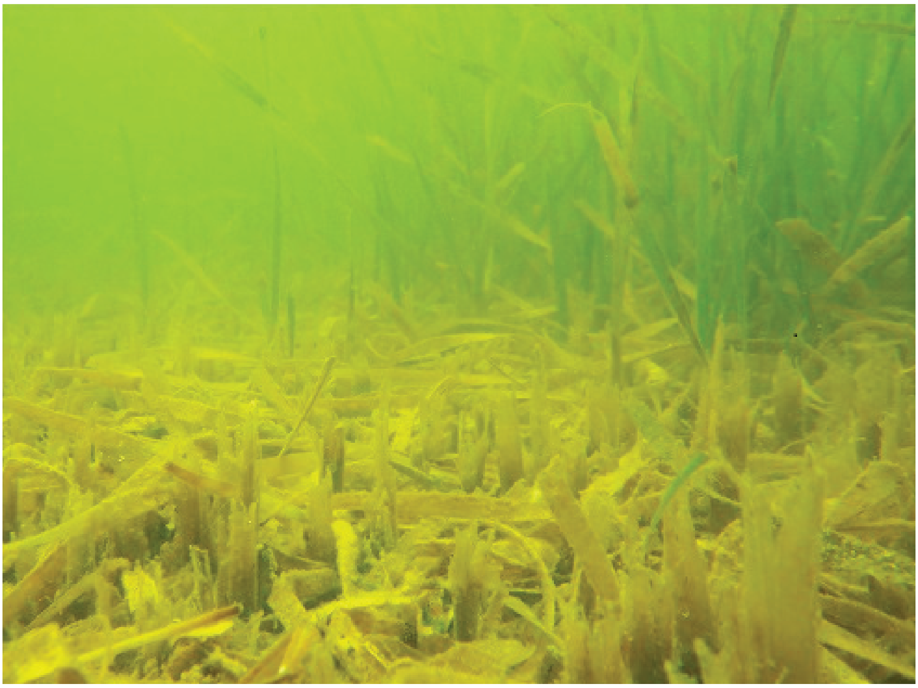

FIGURE 2-3 Seagrass die-off in Florida Bay in 2015.

SOURCE: J. Fourqurean, FIU, personal communication, 2015.

(D. Rudnick, Everglades National Park, personal communication, 2016). Monitoring of the seagrass and water chemistry in Florida Bay continues (NPS, 2016a).

Extreme High Water in 2016

In contrast to the local drought conditions of 2015, the Everglades ecosystem experienced unseasonably high rainfall and extreme high water levels in early 2016, which caused difficult operational challenges for water managers. The November 2015 through January 2016 period (normally the dry season) was the wettest on record, caused in part by a strong El Niño. Above-average rainfall also fell in May 2016, again raising concerns about high water levels in Lake Okeechobee at what is typically the start of the wet season.

With existing water management infrastructure, there are numerous constraints that limit how water can be stored or discharged under extreme high water conditions. The CERP and other non-CERP projects help address some, but not all, of these constraints. Currently, high water levels (above 17.25 feet National Geodetic Vertical Datum [NGVD] 1929) cannot be maintained in Lake Okeechobee due to the risk of structural failure of the Herbert Hoover Dike, which is being rehabilitated (USACE, 2008). Inflow capacity to the lake far exceeds the outflow capacity, and water levels can rise quickly to dangerous levels during periods of heavy rain. Therefore, lake levels must be managed carefully to protect public safety. By mid-February 2016, water levels in Lake Okeechobee were reaching dangerously high water levels (above 16 ft NGVD and still rising[4]), and all existing water storage facilities were at capacity (Staletovich, 2016). To reduce water levels in the lake, water was discharged to the northern estuaries and to other canals at their conveyance capacity, although there was substantial public concern over the high-volume discharges and the accompanying nutrient and sediment loads that are damaging to the estuary ecosystems. Fish kills and algal blooms occurred under similar conditions during 1998 and more recently in 2013 and ultimately occurred during the summer of 2016 (see Box 2-2) (Staletovich, 2016). STA capacity typically limits the amount of water that can be discharged to the Water Conservation Areas, but during much of this period, the water levels in the WCAs were above their regulation schedules and had no capacity to receive more water. Limited capacity existed for discharging water south out of the WCAs based on the conveyance capacities of existing structures, restrictions on the use of the S-12 structures at the southern end of WCA-3A to protect the Cape Sable seaside sparrow, and limitations on water levels in the L-29 canal as part of a phased operations plan for moving water under the new Tamiami Trail 1-mile bridge (J. Mitnik, SFWMD, personal communication, 2016; see also Chapter 3).

Despite these constraints, at the urging of Florida's governor, water managers took creative actions to limit water releases to the St. Lucie and Caloosahatchee estuaries and help alleviate flooding in the Water Conservation Areas (Staletovich, 2016). Several short-term emergency operation deviations were developed to move water out of the WCAs, including increasing water levels in the L-29 canal to increase the flow under the 1-mile bridge into Northeast Shark River Slough and moving water into Big Cypress National Preserve (SFWMD, 2016a). The limitations of the current water management system compromised the emergency deviation plan as well, as water had to be temporarily released through the S-12 structures to avoid overtopping during the prescribed seasonal closure period for protection of the sparrow (FWS, 2016), and thus ultimately efforts to protect the sparrow failed.

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[4] See http://w3.saj.usace.army.mil/h2o/plots/okehp.pdf.

BOX 2-2
Cyanobacteria Blooms in Lake Okeechobee and the St. Lucie Estuary

During summer 2016, a large bloom of the cyanobacterium *Microcystis aeruginosa* occurred in the pelagic (open water) zone of Lake Okeechobee (Figure 2-2-1). *Microcystis* blooms were subsequently reported in the St. Lucie Estuary. For people with waterfront homes on the estuary and for recreational uses of the estuary and lake, blooms create problems due to odor and aesthetics and potentially could have large economic impacts. The bloom also creates ecological and human health concerns because this species of *Microcystis* produces an endotoxin that is released into the water when the cells die. The endotoxin has adverse impacts on aquatic biota (Ibelings and Havens, 2008) and potential

FIGURE 2-2-1 Cyanobacteria bloom in Lake Okeechobee, July 2016.

SOURCE: NASA. (http://eoimages.gsfc.nasa.gov/images/imagerecords/88000/88311/okeechobee_oli_2016184_lrg.jpg)

continued

BOX 2-1 Continued

risks to wildlife and to human health (Falconer, 2008; Pilotto, 2008).

Why do blooms of *Microcystis* occur in Lake Okeechobee? The foundational reason is that the lake receives large amounts of nitrogen and phosphorus from its tributaries and has high levels of those nutrients in the water column to support the growth of phytoplankton. Dissolved phosphorus in the lake results from large watershed inputs and also from internal recycling of sediment-associated phosphorus (Havens et al., 2007). However, external inputs of nitrogen are also needed to support cyanobacteria blooms, because the residence time of nitrogen in a eutrophic lake is relatively short, with considerable losses into the atmosphere by denitrification (McCarthy et al., 2007). Cyanobacteria always are present in Lake Okeechobee but they normally do not bloom in the pelagic zone because their growth is suppressed by light limitation (Phlips et al., 1993). Periodically the weather is just right and there are hot calm days when a sufficient amount of light-blocking sediment particles sink from the water to allow rapid phytoplankton growth. *Microcystis* is well-suited to take advantage of such conditions, and it rapidly proliferates near the water surface (Havens et al., 1998). In September 2004, two hurricanes passed directly over Lake Okeechobee, and the lake received large inflows and inputs of nitrogen and phosphorus, and high winds resulted in massive resuspension of bottom sediments (Havens et al., 2011, 2016). When turbidity declined in the lake in the summer of 2005, an intense *Microcystis* bloom occurred.

What causes *Microcystis* blooms in the St. Lucie Estuary? Phlips et al. (2012) found that internally driven blooms are mainly limited to the north fork of the St. Lucie Estuary and occur during dry periods when water residence time is long enough to allow the algae to proliferate. Those blooms are mainly caused by a kind of algae called a dinoflagellate. In contrast, externally driven blooms are much more severe, happen in the main stem of the estuary, and are caused by *Microcystis*. Phlips et al. (2012) documented that the 2005 algal bloom, which coincided with regulatory water discharges from the lake, was seeded by an upstream bloom that happened in Lake Okeechobee. Concentrations of the toxin microcystin exceeded 1,000 micrograms per liter in the St. Lucie Estuary (compared to below 10 as a typical background level). They noted that seeding of estuaries from nutrient-polluted upstream sources is a worldwide problem (Paerl, 1988). It is highly likely that the same situation occurred in 2016.

The algal blooms in Lake Okeechobee and the St. Lucie Estuary illustrate why it is critical to reduce both nitrogen and phosphorus inputs to Lake Okeechobee to reduce the occurrence of toxic blooms and to establish sufficient regional water storage options so that regulatory releases from the lake do not impact the estuary. Climate change has the potential to make the situation of harmful algal blooms worse, because it has been established that enrichment by nitrogen and phosphorus plus warming synergistically favor cyanobacteria in lakes around the world (Conley et al., 2009, Havens and Paerl, 2015, Paerl et al., 2016a). At low to moderate nitrogen and phosphorus concentrations, warming of 2-3 degrees Celsius does not result in an appreciable increase in the risk of cyanobacteria blooms. However, at high levels of nitrogen and phosphorus enrichment, there is an unpredictable non-linear increase in risk with the same magnitude rise in temperature (Havens and Paerl, 2015). Thus, it will be more challenging to predict and control cyanobacteria blooms in a warmer future, but actions today to substantively reduce nitrogen and phosphorus concentrations in lakes can help to ward off future extreme events such as that which occurred in Lake Okeechobee in the summer of 2016.

A similar situation occurred in the late 1990s after Hurricane Irene and associated heavy rainfall resulted in extreme high water levels in the lake, leading to a decision by the SFWMD and the USACE to make emergency water releases from the lake in spring 2000. Water releases were made primarily to the St. Lucie and Caloosahatchee estuaries because of conveyance and other constraints to sending water south. Large releases of water from the lake[5] lasted for 27 days (Steinman et al., 2002). The decision to make emergency water releases was largely a response to documented damaging effects of high water on the lake's littoral zone (Havens et al. 2001), and involved a rapid drawdown to allow submerged vegetation to recover (Steinman et al., 2002). Monitoring of the St. Lucie and Caloosahatchee estuaries during the period of emergency water releases indicated immediate negative impacts including increased turbidity and reduced salinity. The St. Lucie estuary recovered quickly after the releases ended, but recovery of the Caloosahatchee estuary was slower due to death of seagrass beds during the event. A cyanobacteria bloom also occurred in the upper St. Lucie estuary, but ended when the releases of lake water stopped (Steinman et al., 2002).

Overall, the high-water events of 2016 provide a harsh reminder that water storage remains inadequate to address devastating high water events in the northern estuaries and illuminate the many constraints that still exist in the system that limit conveyance of water south into the remnant Everglades. Even after 16 years of the CERP, little progress has been made in resolving these well-known constraints. Short-term emergency deviations helped mitigate the impacts, but further progress on CERP and non-CERP projects are needed to provide long-term solutions to such challenges by providing more storage and moving more of the floodwaters south, into and through the Everglades.

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 faced changing budgets, refinements in scientific understanding, and an evolving legal context, and they continue

[5] Typical discharge rates during the emergency event were 2,000 to 2,700 cfs to the St. Lucie estuary and 4,000 to 4,500 cfs to the Caloosahatchee River estuary.

to adapt. The seagrass die-offs in Florida Bay in 2015 and the extreme high-water events and associated algal blooms in 2016, however, provide continued reminders of why substantial restoration progress is needed. Implementation progress is discussed in detail in Chapter 3.

3

Restoration Progress

This committee is charged with the task of discussing 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 for the statement of task and Chapter 2 for a discussion of restoration goals). In this chapter, the committee updates the National Academies' previous assessments of CERP and related non-CERP restoration projects (NRC, 2007, 2008, 2010, 2012, 2014). This chapter also addresses programmatic and implementation progress, and discusses the ecosystem benefits resulting from the progress to date.

PROGRAMMATIC PROGRESS

To assess programmatic progress the committee reviewed a set of primary issues that influence CERP progress toward its overall goals of ecosystem restoration. These issues, described in the following sections, relate to project authorization, impacts of the recent Water Resources Development Acts, funding, scheduling, and regulatory constraints.

Project Authorization

Once project planning is complete, CERP projects with costs exceeding $25 million[1] must be individually authorized by Congress.[2] Water Resources

[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), 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

Development Acts (WRDAs) have served as the mechanism to congressionally 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 16 years since the CERP was launched in WRDA 2000, only two WRDA bills have been enacted: WRDA 2007, which authorized Indian River Lagoon-South, Picayune Strand Restoration, and the Site 1 Impoundment projects; and the Water Resources Reform and Development Act (WRRDA) 2014, which authorized four additional projects (C-43 Reservoir, C-111 Spreader Canal [Western], Biscayne Bay Coastal Wetlands [Phase 1], Broward County Water Preserve Areas [WPAs]). WRDA 2016, which includes authorization for the Central Everglades Planning Project and changes to the Picayune Strand project, was passed by Congress on December 10, 2016.[3] The three projects authorized by WRDA 2007 along with the Melaleuca Eradication Project, which was authorized under programmatic authority, are considered Generation 1 projects, and the four projects authorized under WRRDA 2014 represent Generation 2 projects (see Table 3-1; Figure 3-1). With the passage of WRRDA 2014, the federal government is now able to maintain progress on several state-expedited projects already under way (e.g., C-111 Spreader Canal (Western) project, Biscayne Bay Coastal Wetlands [Phase 1]) and initiate construction on two other new projects.

WRRDA Programmatic Changes and Implications

WRRDA 2014 made certain statutory changes to the federal water resource planning process, which has been a concern of Congress for many years (NRC, 1999). Reform of the planning process is probably the most significant change in policy since 1986, when WRDA 1986 brought about fundamental changes to cost-sharing between federal and non-federal project partners. WRRDA 2014 is a complex piece of legislation, with major program reforms and new policies on project deauthorization that directly affect the CERP. WRRDA 2014 transforms the planning process by setting strict timelines for feasibility studies to be completed within 3 years of initiation under $3 million in federal cost. To ensure that final feasibility studies are completed within 3 years, review by three levels of the USACE (district, division and headquarters) are required to be conducted concurrently with field-level planning. These provisions put into law the 3x3x3 process set forth by the USACE in Planning Bulletin 2014-01(USACE, 2014a)

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).

[3] WRDA 2016 was signed into law on December 16, 2016, after the prepublication copy of this report was released.

TABLE 3-1 CERP or CERP-Related Project Implementation Status as of September 2016

Project or Component Name	Yellow Book (1999) Estimated Completion Date	IDS 2016 Update Estimated Completion Date	PIR (or PPDR) Status	Authorization Status	Construction Status; Testing Status for Pilots	Ecosystem Benefits Documented to Date
PILOT PROJECTS						
Hillsboro ASR Pilot (Fig. 3-1, No. 1)	2002	NA	PPDR Final Oct. 2004	Authorized in WRDA 1999	Completed, 2013	NA
Kissimmee ASR Pilot (Fig. 3-1, No. 2)	2001	NA	PPDR Final Oct. 2004	Authorized in WRDA 1999	Completed, 2013	NA
Regional ASR Study	NA	NA	NA	NA	Completed, 2015	NA
LPA Seepage Management Pilot (Fig. 3-1, No. 3)	NA	NA	NA	NA	Completed, 2012	Additional 0.4 ft water depth in wetland near seepage barrier
Decomp Physical Model (Fig. 3-1, No. 4)	NA	2018	NA	Programmatic authority WRDA 2000	Ongoing	NA
GENERATION 1 CERP PROJECTS						
Picayune Strand Restoration (Fig. 3-1, No. 5)	2005	Faka-Union: 2016 Miller: 2018 Remaining feat.: 2020	Submitted to Congress, 2005	Authorized in WRDA 2007; LRR authorized in WRDA 2016.	Prairie Canal completed in 2007; Merritt, Faka Union completed 2015-2016	Increased water levels in 20,000 acres and with early vegetation responses detected

continued

TABLE 3-1 Continued

Project or Component Name	Yellow Book (1999) Estimated Completion Date	IDS 2016 Update Estimated Completion Date	PIR (or PPDR) Status	Authorization Status	Construction Status; Testing Status for Pilots	Ecosystem Benefits Documented to Date
GENERATION 1 CERP PROJECTS (continued)						
Site 1 Impoundment (Fig. 3-1, No. 6)	2007		Submitted to Congress, 2006	Authorized in WRDA 2007		
- Phase 1		2016			Completed, 2016	~16% reduction in seepage loss
- Phase 2		Not specified		*Phase 2 requires further authorization.*	Not begun	NA
Indian River Lagoon-South (Fig. 3-1, No. 7)			Submitted to Congress, 2004	Authorized in WRDA 2007		
- C-44 Reservoir/STA	2007	2019			Ongoing	None to date, construction ongoing
- C-23/24 Reservoir/STA	2010	2030			Not begun	NA
- C-25 Reservoir/STA	2010	2027			Not begun	NA
- Natural Lands	NA	Not specified			Not begun	NA
Melaleuca Eradication and Other Exotic Plants (Fig. 3-1, No. 8)	2011	NA	Final June 2010	Programmatic authority WRDA 2000	Construction completed 2013, operations ongoing	Increased capacity for biocontrol

GENERATION 2 CERP PROJECTS						
C-111 Spreader Canal	2008	2021	Submitted to Congress, 2012	Authorized in WRRDA 2014	Ongoing	
- Western Project (PIR #1) (Fig. 3-1, No. 9)						Current data insufficient to assess response to project
Biscayne Bay Coastal Wetlands (Phase 1) (Fig. 3-1, No. 10)	2018	2021	Submitted to Congress, 2012	Authorized in WRRDA 2014	Ongoing	Some wetland vegetation responses to freshwater inputs; no change in nearshore salinity
C-43 Basin Storage: West Basin Storage Reservoir (Fig. 3-1, No. 11)	2012	2024	Submitted to Congress, 2011	Authorized in WRRDA 2014	Ongoing	None to date, construction ongoing
Broward County WPAs (Fig. 3-1, No. 12)			Submitted to Congress, 2012	Authorized in WRRDA 2014		
- C-9 Impoundment	2007	2029			Not begun	NA
- C-11 Impoundment	2008	2023			Not begun	NA
- WCA-3A & -3B Levee Seepage Management	2008	2021			Not begun	NA
GENERATION 3 CERP PROJECTS						
Central Everglades Planning Project (Fig. 3-1, Nos. 13 and 14)	NA		Submitted to Congress, 2015	Authorized in WRDA 2016	Not begun	NA
- PPA South		2030				
- PPA North		2028				
- PPA New Water		2030				

continued

TABLE 3-1 Continued

Project or Component Name	Yellow Book (1999) Estimated Completion Date	IDS 2016 Update Estimated Completion Date	PIR (or PPDR) Status	Authorization Status	Construction Status; Testing Status for Pilots	Ecosystem Benefits Documented to Date
CERP PROJECTS IN PLANNING						
Loxahatchee River Watershed (Fig. 3-1, No. 15)		NA	NA	NA	NA	NA
- C51 and L-8 Reservoir	2014					
- Loxahatchee River (C-51) ASR	2013					
- Pal-Mar Corbett Hydropattern Restoration	2006					
Lake Okeechobee Watershed (Fig. 3-1, No. 16)		NA	NA	NA	NA	NA
- North of Lake Storage	2014					
- Taylor Creek/Nubbin Slough Reservoir	2009					
- Lake Okeechobee ASR	2020					
Western Everglades (Fig. 3-1, No.17)		NA	NA	NA	NA	NA
- Big Cypress-L-28 Interceptor Modifications	2016					
- Seminole Tribe Big Cypress Water Conservation Plan	2008					
- Miccosukee Tribe Water Management Plan	2008					

REMAINING UNPLANNED CERP PROJECTS						
EAA Reservoir (Phase 2)	2015	NA	NA	NA	NA	NA
WCA Decompartmentalization (Phase 2)	2019	NA	NA	NA	NA	NA
Everglades National Park Seepage Management	2013	NA	NA	NA	NA	NA
Biscayne Bay Coastal Wetlands, Phase 2	2018	NA	NA	NA	NA	NA
C-111 Spreader Canal, Eastern Project	2008	NA	NA	NA	NA	NA
C-43 ASR	2012	NA	NA	NA	NA	NA
Site 1 Impoundment ASR	2014	NA	NA	NA	NA	NA
Agricultural Reserve Reservoir	2013	NA	NA	NA	NA	NA
North Lake Belt Storage Area	2021-2036	NA	NA	NA	NA	NA
Central Lake Belt Storage Area	2021-2036	NA	NA	NA	NA	NA
WCA 2B Flows to Everglades National Park	2018	NA	NA	NA	NA	NA
WPA Conveyance	2036	NA	NA	NA	NA	NA
Caloosahatchee Backpumping with Stormwater Treatment	2015	NA	NA	NA	NA	NA
West Miami-Dade Reuse	2020	NA	NA	NA	NA	NA
South Miami-Dade Reuse	2020	NA	NA	NA	NA	NA
Loxahatchee National Wildlife Refuge Internal Canal Structures	2003	NA	NA	NA	NA	NA
Broward Co. Secondary Canal System	2009	NA	NA	NA	NA	NA

continued

TABLE 3-1 Continued

Project or Component Name	Yellow Book (1999) Estimated Completion Date	IDS 2016 Update Estimated Completion Date	PIR (or PPDR) Status	Authorization Status	Construction Status; Testing Status for Pilots	Ecosystem Benefits Documented to Date
REMAINING UNPLANNED CERP PROJECTS (continued)						
Henderson Creek – Belle Meade Restoration	2005	NA	NA	NA	NA	NA
Southern CREW	2005	NA	NA	NA	NA	NA
Lake Trafford Restoration	2004	NA	NA	NA	NA	NA
Southwest Florida Feasibility Studies	2004	NA	NA	NA	NA	NA
Florida Bay Florida Keys Feasibility Study	2004	NA	NA	NA	NA	NA
Comprehensive Integrated Water Quality Plan	2006	NA	NA	NA	NA	NA

NOTES: Table 3-1 does not include non-CERP foundation projects. NA = not applicable. Remaining unplanned CERP projects include all projects over $5 million (2014 dollars) as reported in USACE and DOI (2016).
SOURCES: www.evergladesrestoration.gov; USACE, 2016n; D. Tipple, USACE, personal communication, 2016; R. Braun, SFWMD, personal communication, 2016.

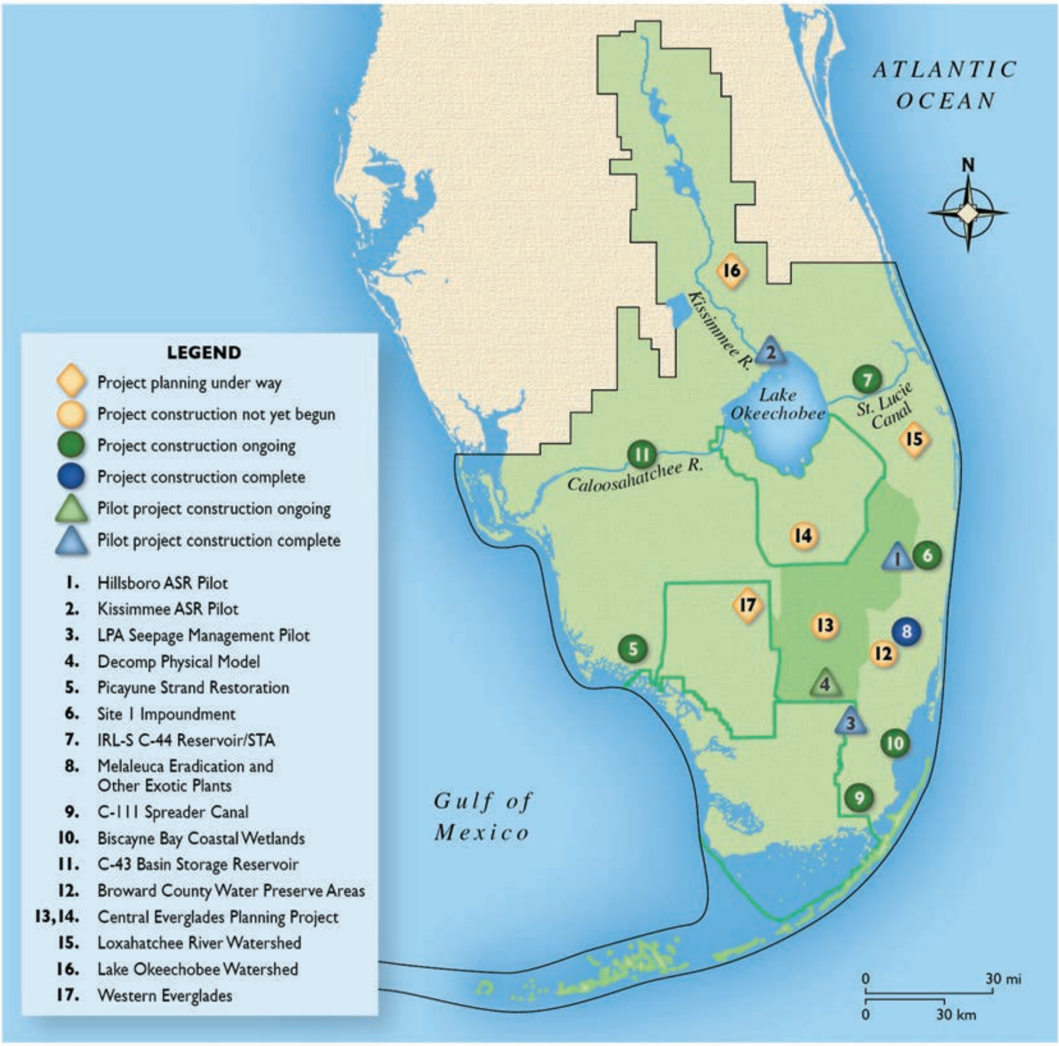

FIGURE 3-1 Locations of CERP and CERP-related projects and pilots listed in Table 3-1. Projects under active construction are noted with a red circle.

SOURCE: © International Mapping Associates that governed the Central Everglades Planning Project (see NRC, 2014). WRRDA 2014 made one significant change to the 3x3x3 process, in that it specifies a total federal cost of $3 million, rather than the total $3 million cost of the Planning Bulletin (including both federal and non-federal costs). However, USACE headquarters chose to keep the more restrictive Planning Bulletin as its guidance for implementing Section 1001 of WRRDA 2014 (USACE, 2015a). All future CERP feasibility studies will be subject to the Planning Bulletin rules so long as it is in effect. As experience with the Central Everglades Planning Project suggests, these tight time limits pose significant challenges to processes for reaching consensus when planning complex projects. Extensions of both time and monetary funds are made possible, however, with sufficient justification.

Possibly the most significant impacts of WRRDA 2014 on CERP relate to deauthorization. WRRDA 2014 outlines the steps to deauthorize at least $18 billion in previously authorized USACE projects. The Act mandated that the USACE prepare an Interim Deauthorization List for public review and comment of all projects that were authorized before November 8, 2007 but have not begun construction or for which construction had begun but no funds had been applied in fiscal years 2010-2015. The USACE was then directed to prepare a final list of projects to be deauthorized totaling at least $18 billion of estimated federal cost. Congress will make the final determination on which projects will be deauthorized. Five separable elements of the CERP that were authorized as part of the program authorization in WRDA 2000 were included on the Final Deauthorization List (see Table 3-2; USACE, 2016a). Two of these projects (North New River and Tamiami Trail) are no longer separable elements because they

TABLE 3-2 CERP Projects Included on the Final Deauthorization List

Project / Element Name	Project/ Element Phase and Status	Latest Fiscal Year Of Federal or Non-Fed. Obligations for Construction	Federal Balance to Complete
Lake Belt In-ground Reservoir Technology Pilot	Construction Not Initiated	2005	$17,000,000
North New River Improvements	Never Funded	No Obligation For Construction	$67,150,000
Raise and Bridge East Portion of Tamiami Trail and Fill Miami Canal	Never Funded	No Obligation For Construction	$21,500,000
Taylor Creek/Nubbin Slough Storage and Treatment Area	Construction Not Initiated	No Obligation For Construction	$67,800,000
Wastewater Reuse Technology Pilot	Construction Not Initiated	2005	$20,500,000

were incorporated into the Central Everglades Planning Project or the Tamiami Trail Next Steps project. Taylor Creek/Nubbin Slough has been judged to be solely state responsibility and transferred outside of the CERP. Deauthorization of the Lake Belt in-ground reservoir and wastewater reuse pilot projects suggests that the related CERP project elements are not considered high priorities for the CERP or that the feasibility and cost effectiveness of these projects are so questionable, that further study is not warranted. If need for these pilot studies is determined at a later date, they would require reauthorization by Congress.

A "Backlog Prevention" provision was included in WRRDA 2014 for newly authorized projects. Any project or separable element of a project that was authorized in WRRDA 2014 for which construction funds have not been applied in the 7 years following enactment of the bill will be automatically deauthorized. That provision will be applicable to the newly authorized Generation 2 and 3 CERP projects listed in Table 3-1. This provision puts increased pressure on the CERP program to move forward on authorized projects, and also suggests that new projects should not be lined up for authorization unless there is a funding stream available to support them.

Funding

Funding for Everglades restoration remains an important constraint on achieving a rate of progress that would be consistent with the original vision for the CERP. There are a few positive signs in the previous 2 years, but funding remains low relative to what is needed to complete CERP in the next half-century. Recent CERP and non-CERP funding trends for the federal government and the state are discussed below.

State Funding for CERP and non-CERP Restoration Efforts

State spending for the CERP over the 5-year period FY2012-2016 is down sharply from the previous 5 years, and it has declined over the most recent 3-year period (Figure 3-2). State spending on non-CERP restoration during FY2012-2016 is also down sharply from FY2007-2011, but in the past 3 years it has shown a modest increase over its historic low in FY2013 (Figure 3-3).

The SFWMD's revenues to support Everglades restoration activities improved in FY2014-2015 from a historic low in FY2013, but they remain well below the average in FY2007-2012 (Figure 3-4). The adopted budget for FY2016 includes revenues of $523 million and expenditures of $750 million (SFWMD, 2016b), both well above FY2015 levels. Restoration projects reflect approximately 80 percent of projected capital expenditures in the SFWMD Capital Improvements Plan for 2016-2020, with the largest CERP commitments being

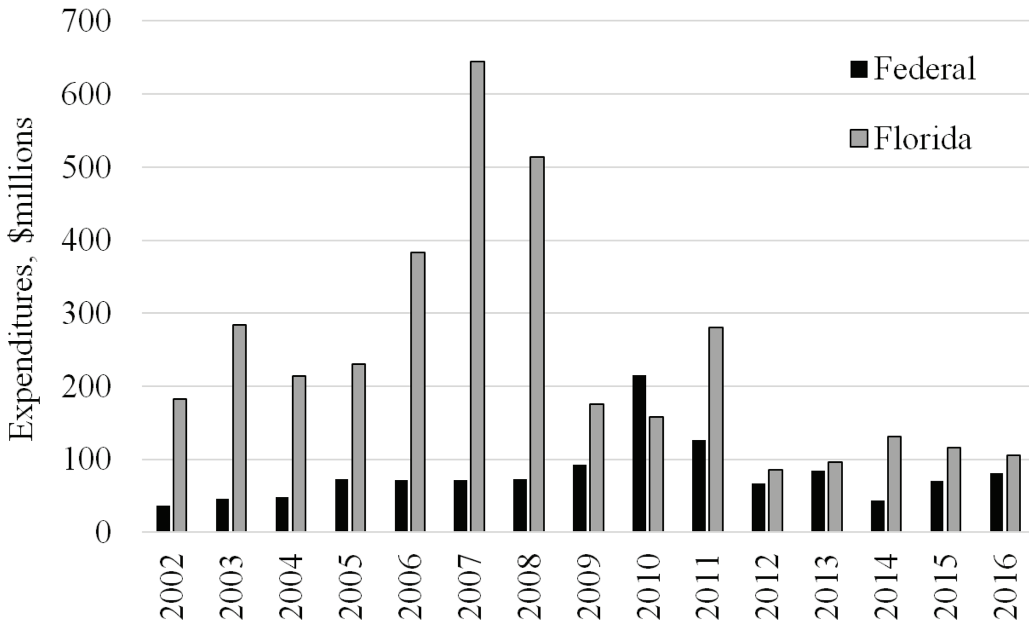

FIGURE 3-2 Federal and state funding for the CERP.

SOURCE: Data from SFERTF, 2016a.

the C-43 and C-44 reservoirs and STAs and Picayune Strand (SFWMD, 2016c). Budgeted revenues to support the Capital Improvements Plan include 53 percent from SFWMD funds (including ad valorem tax sources and reserve funds), 32 percent from State of Florida's Land Acquisition Trust Fund,[4] and 11 percent from the Save Our Everglades Trust Fund.[5]

The 5-year Capital Improvements Plan could change substantially as a result of recent action by the state of Florida. In November 2014, Florida approved Amendment 1 which allocates one-third of state-imposed fees on real estate transactions for environmental protection programs over the next 20 years. In 2015, the Amendment 1 funds generated $750 million (Klas, 2016). Governor Scott proposed a 20-year spending plan (SFWMD and FDEP, 2015) that would

[4] This trust fund was established in 1963 and modified several times. Proceeds are from the sale of bonds repaid with funds collected from documentary stamp taxes on real estate transactions.

[5] Save Our Everglades Trust Fund is a state trust fund with the limited purpose being a repository of local, state, and federal funds for CERP (Florida Statutes 373.472).

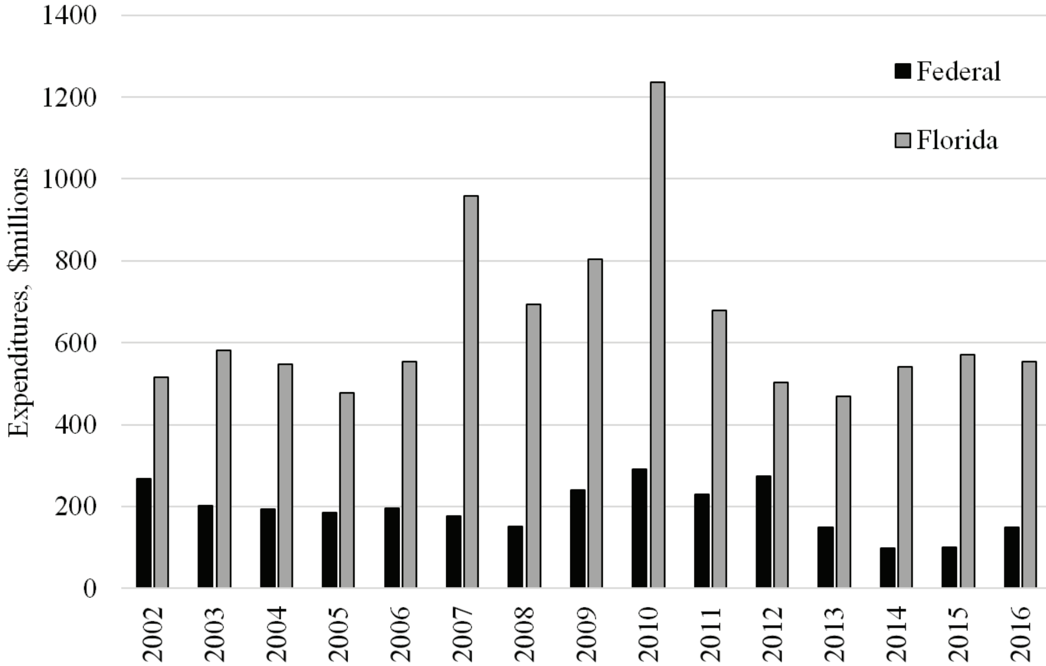

FIGURE 3-3 Federal and state funding for non-CERP Everglades restoration.

SOURCE: Data from SFERTF, 2016a.

use $5 billion of those funds ($250 million per year on average) to make substantial progress on CERP and non-CERP projects (see Box 3-1 for proposed areas of emphasis). After several questions were raised about how Amendment 1 money was being used in FY2016, the 2016 session of the legislature set more specific criteria for the distribution of funds. The Legacy Florida Act (HB 989), signed by the Governor in April 2016, established an annual minimum appropriation of $200 million or "25 percent of the funds remaining after the payment of debt service"—whichever is less—for Everglades projects. Projects and appropriations covered by that provision are as follow:

- $32 million to SFWMD for the Long-Term Plan;[6]

[6] The Long Term Plan referred to in the bill includes the 2003 Everglades Protection Area Tributary Basins Long-Term Plan for Achieving Water Quality Goals, developed pursuant to the amended Everglades Forever Act, and the 2012 Restoration Strategies Regional Water Quality Plan.

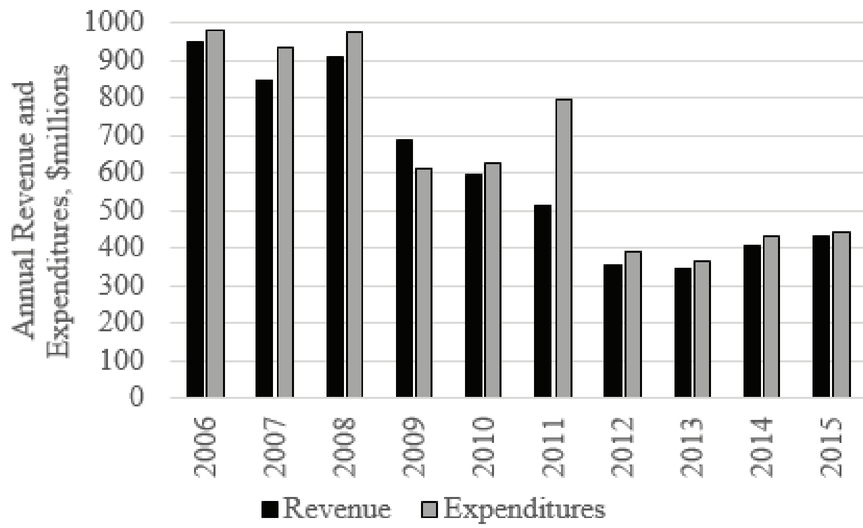

FIGURE 3-4 SFWMD Revenue and Expenditures for FY2006-FY2015.

SOURCE: Data from SFWMD, 2016d.

- the minimum of the lesser of 76.5 percent or $100 million to the CERP, including the Central Everglades Planning Project subject to Congressional approval; and
- the Northern Everglades and Estuaries Protection Program.

The bill further specifies that the Florida Department of Environmental Protection (FDEP) and SFWMD give preference to those projects that reduce harmful discharges from Lake Okeechobee to the estuaries. Consistent with the Legacy Florida Act, the final state budget for 2017 includes $32 million for Restoration Strategies and $100 million for CERP projects, including the C-44 reservoir/STA ($60 million), the C-43 West Storage Reservoir ($37 million), and CERP planning ($3 million). Additionally, $10.8 million of land acquisition funding was provided for the Biscayne Bay Coastal Wetlands (Phase 1) Project ($5.8 million) and the Picayune Strand Restoration Project ($5.0 million). Another $57 million was appropriated in the 2017 state budget for the Northern Estuaries water quality programs, the bulk of which goes to the public-private partnerships. Details of how SFWMD's own source funds might be affected and whether Legacy Florida Act funds supplement existing state and district funding for restoration or simply replace those funding sources remain unclear.

BOX 3-1
Governor Scott's 20-Year Commitment to Restoration

In 2015, Florida's governor launched a 20-year commitment to restoration, pledging additional funding to support increased restoration progress. The following timeline for investments is outlined in the 20-year plan.

2016-2021	A-1 and L-8 Flow Equalization Basins C-43 Reservoir Western Cell Indian River Lagoon C-44 Reservoir and STA Kissimmee River Restoration Broward Water Preserve Area and C-11 Impoundment
2021-2026	C-43 Reservoir Eastern Cell STA 1 West Expansion Indian River Lagoon C-23/24 Reservoir North Northern/Southern Everglades Storage Northern/Southern Everglades Water Quality Improvements
2026-2031	Indian River Lagoon C-25 Reservoir and STA Indian River Lagoon C-23/24 Reservoir South and STA Central Everglades Planning Project (CEPP) South Broward Water Preserve Area and C-9 Impoundment CEPP North and New Water Northern/Southern Everglades Storage Northern/Southern Everglades Water Quality Improvements
2031-2035	Northern/Southern Everglades Storage Northern/Southern Everglades Water Quality Improvements

SOURCE: SFWMD and FDEP (2015).

Federal Funding for CERP and Non-CERP Restoration Efforts

Federal spending for CERP and non-CERP projects as reported in the 2017 Cross-Cut budget (SFERTF, 2016a) is illustrated in Figure 3-2 and Figure 3-3, respectively. Federal funding for CERP grew steadily from the beginning of the program to a peak of $215 million in FY2010, including $87 million in stimulus funding through the American Recovery and Reinvestment Act of 2009. However, funding levels for the CERP were much lower in FY2012-2014, in part due to cost-sharing constraints. Under cost-sharing agreements, federal "creditable obligations" cannot exceed those of the state. Even though the SFWMD has far outspent federal agencies on CERP projects for land acquisition and expedited construction efforts in advance of project authorizations by Congress, a large

TABLE 3-3 Reported Cumulative Expenditures for the CERP through FY2014

	USACE (millions)	State (millions)
Total expenditures, including those not yet credited	$ 1,048[a]	$ 3,379
Creditable Expenditures		
Projects	$ 632	$ 816
Other[b]	$ 306	$ 238
Total	$ 938	$ 1,054

NOTES: The 2015 CERP Report to Congress (USACE and DOI, 2016) reports creditable expenditures for the SFWMD, while the Cross Cut Budget (SFERTF, 2016a) reports total expenditures. How much of the balance of approximately $2.3 billion that will be eligible for cost-share credits under future project partnership agreements remains to be seen.
[a] includes expenditures by Department of Interior agencies.
[b] includes adaptive assessment and monitoring and program coordination; also includes actual estimates of in-kind work for FY2013-2014 yet to be submitted by SFWMD.
SOURCE: SFERTF (2016a); USACE and DOI (2016).

share of those expenditures have yet to meet the criteria for being creditable to cost-sharing under the CERP.[7] Entries in Table 3-3 indicate that through FY2014, 90 percent of the $1.05 billion in federal obligations had been credited to cost-sharing, but only 31 percent of the $3.38 billion in state obligations had been credited. During 2012-2014, there were a limited number of authorized projects, and state spending on authorized projects was reduced (SFWMD, 2015a). As a consequence state creditable expenditures served as a constraint on federal expenditures, and federal government outlays were reduced to maintain the cost-share balance (see NRC, 2014). WRRDA 2014 authorized four additional projects and additional project partnership agreements have been signed that, for the near term, have alleviated concerns that federal spending would lead to a violation in the 50-50 cost share agreement. Since 2014, there has been a steady increase in federal CERP funding, although not yet reaching 2010-2011 levels (see Figure 3-2).

Reflections on Funding Trends

Although both state and federal spending are still modest in the context of total cost for CERP and non-CERP projects, a few positive signs are encourag-

[7] Cost-sharing policies dictate that the SFWMD can only apply specific creditable expenditures toward the 50-50 CERP cost-sharing requirement. Project-related expenses are creditable only if the project has been authorized by Congress, has a signed project partnership agreement, and has 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.

ing. The state's financial position is improving, and federal appropriations are increasing. Dedicated Amendment 1 funding is especially encouraging because it provides increased stability for CERP and non-CERP implementation.

It is unclear from published data, however, as to how much funding is necessary to complete the program. Updated cost estimates in the 2015 CERP Report to Congress (USACE and DOI, 2016) put total program cost at $16.4 billion in 2014 dollars, a net increase of $3 billion over 2010 including both inflation and changes in project scope. Updated estimates put the total cost of projects authorized prior to passage of WRDA 2016 at $10.33 billion in 2016 dollars. The total of obligations by federal and state governments through FY2016 for those projects is $2.72 billion (K. Smith, USACE, personal communication, 2016). One measure of progress is a comparison of cumulative obligations of funds to estimated cost, all in constant dollars. The $2.72 billion obligated since 2000 has not been adjusted for inflation as the cost estimate has, but the reported obligations indicate that at least 26 percent of the $10.33 billion has been funded. That amounts to somewhere in the order of 16 to 18 percent of current estimates of total CERP cost.

Even with uncertainties in cost estimates, it is clear that less than 20 percent of the cost of the CERP has been funded to date, and a substantial financial commitment is needed to see the restoration to completion. As of 1999, the CERP was estimated to require funding at $350-400 million per year over 20 years (USACE and SFWMD, 1999). Considering project spending to date, inflation, and changes in project scope, program staff now estimate that it will take 55 years at $325 million per year (combined state and federal investments) to complete the CERP as currently outlined in the Report to Congress (K. Smith, USACE, personal communication, 2016). That rate is much larger than the FY2014-2016 annual average federal and state funding of approximately $183 million per year (Figure 3-2). By extension of the program staff's estimate, at the current rate, it would require nearly 100 years to complete the CERP, thus delaying restoration benefits and allowing further ecosystem decline before restoration actions are taken (see NRC, 2012). The Central Everglades Planning Project illuminates the implications of the pace of funding on the timeframe to deliver restoration benefits. With full funding, the entire project could be constructed and increased flows provided to the central Everglades within 6 years, but with $100 million/year that does not escalate with inflation, the project was expected to take nearly 27 years (USACE and SFWMD, 2014a).

Project Scheduling and Prioritization

The anticipated future progress of CERP projects and the relationships among all the federally-funded South Florida ecosystem projects as well as some highly relevant state-funded projects are depicted in the Integrated Delivery Schedule (IDS). The IDS is developed in consultation with the South Florida Ecosystem Restoration Task Force and the many CERP constituencies. The Task Force approved a recent version in November 2015 (USACE, 2016b), although a draft 2016 update was released in October 2016 (see Figure 3-5; USACE, 2016n). The reporting horizon for this version extends to 2030 and includes all CERP

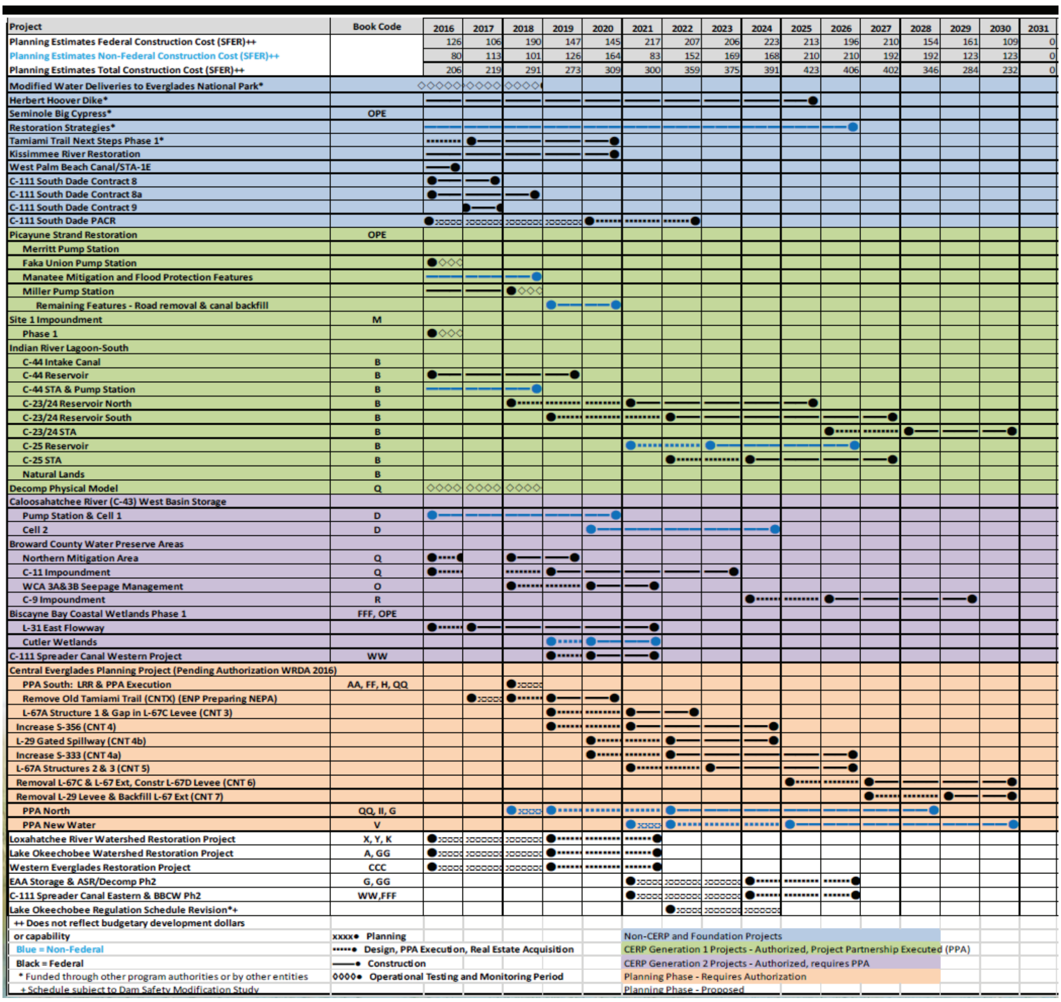

FIGURE 3-5 Draft Integrated Delivery Schedule 2016. Updated October 2016.

SOURCE: USACE, 2016n.

Generation 1, 2, and 3 projects (although not all components of those projects). The inclusion of the proposed Central Everglades Planning Project and the timing of its component parts is a significant addition since the 2011 IDS, reviewed in the committee's last report (NRC, 2014). It also shows the initiation of six new planning activities with three in progress or starting 2016.

The IDS is not an action or decision document but rather a guide for planning, design, construction sequencing and budgeting. The lack of an updated IDS since the last 2011 draft had been a committee concern, with NRC (2014) characterizing it as "badly out of date." During 2015, four stakeholder workshops were held to explore numerous scenarios emphasizing different ecological, water storage, economic, estuary and project completion goals. A key assumption was federal funding at $200 million per year matched equally by the state of Florida. Ultimately, the workshops led to a focus on maximizing "holistic benefits to regional system as early as possible," which is a basis of the current (USACE and SFWMD, 2016b, USACE, 2016n).

Comparing the 2011 IDS draft to the 2016 version shows several notable differences (USACE, 2011a; Figure 3-5). Generation 1 projects showed minor delays to projects and project components up to 4 years, although Site 1 Impoundment – Phase 2 was eliminated from the updated plan. Several Generation 2 projects experienced even greater delays: C-111 Spreader Canal (Western) project (10-year delay), Biscayne Bay Coastal Wetlands, Phase 1 (5-year delay) and Broward County WPAs – Western C-11 Diversion Impoundment (5-year delay). One project, the Broward County WPAs – WCA-3A & -3B Levee Seepage Management had a one-year advancement in the schedule. Irregular funding profiles and lack of project authorization were the primary bases for these delays.

Based on changes since the 2011 draft, this IDS should be seen as aspirational in terms of both available funding and construction durations. The IDS assumes a future flow of federal funding between approximately $140 and 220 million/year for both CERP and non-CERP projects, with state funding ranging from $56 to 210 million/year, although it's not evident which funds are directed toward CERP projects. As several major non-CERP projects are completed in the next 5 years (discussed later in this chapter), more funding may be freed up for future CERP projects. These estimates seem reasonable based on recent CERP and non-CERP program funding and the improved state-funding outlook, but availability of funding remains a substantial scheduling uncertainty, and possible construction schedule contingencies are not considered. Reduced funding will delay progress, whereas expedited funding can accelerate construction completion. In its last review, the committee expressed concern that the projected completion of Central Everglades Planning Project may extend to 2053 with its serial execution, assumed funding, and conservative start assumptions

(NRC, 2014). As depicted in the new IDS, a more aggressive start and parallel construction schedules now forecast completion of all Central Everglades components by 2030, which is a positive outcome.

The revised IDS is a welcome communication tool that reflects diverse stakeholder input. Some limitations exist such as difficulties in easily identifying individual project costs and hard project dependencies. There are no indications of other the CERP projects that have not yet been authorized or planned, giving some a false sense of when restoration may be finished or what projects may no longer be considered. Finally, the original concept in the Programmatic Regulations (33 CFR §385.31) of a Master Implementation Sequencing Plan (now replaced by the IDS) required RECOVER to assess any changes in the Master schedule "for effects on achieving the goals and purposes of the Plan and the interim goals and targets." Documentation of the effects of changes to the schedule on the timing anticipated ecosystem benefits would be valuable additional information to communicate.

Regulatory Constraints: Threatened, Endangered, and Protected Species Issues

Restoration must take place within the context of extensive state and federal laws that govern various aspects of natural resource protection. Thus, agencies involved in restoration planning and implementation projects must negotiate a labyrinth of complex legal requirements, at times at odds with each other. To ensure compliance with water quality standards under the Clean Water Act, a Consent Decree and NPDES permits dictate the quality of the water permitted to be discharged into the Everglades. The profound consequences of this for restoring sheet flow to the central Everglades was a central focus of NRC (2012), and integrating water quality requirements with restoration goals for water quantity and flow has been a central element in recent planning efforts, for example the Central Everglades Planning Project (NRC, 2014; USACE and SFWMD, 2014a). In this section, issues related to the Endangered Species Act (ESA), Migratory Bird Treaty Act (MBTA), and the Clean Water Act are discussed, focusing on current conflicts in which compliance with these laws constrains restoration. These cases exemplify the challenges that will recur as the restoration unfolds.

The South Florida ecosystem contains a rich biota, and accordingly, the restoration is designed to accommodate the needs of this diversity of species within appropriate portions of the system. As the restoration plan has been implemented, challenges to the ability of program managers to meet the needs of particular protected species have repeatedly arisen. As new structures and features are added to the system, and the distribution of water and hydrology change, resident species react, often in unanticipated ways. Some of these responses create challenges in finding ways to meet restoration objectives, while ensuring compliance with wildlife protection and water quality legal requirements. There has been a consensus that all native species will ultimately benefit from the restoration (e.g., FWS, 2016), an assertion examined further in Chapter 4. Even if this is so, as the system transitions from its current state (where hydrologic restoration in the central Everglades has been planned but not yet implemented) to a fully implemented CERP, local adverse effects on some species can be expected.

Integrating STA and FEB Operation with Avian Conservation

The most substantial and challenging conflicts affecting the restoration come into play when two or more federal environmental laws seemingly clash. The first current conflict is of this sort, involving the sometimes-contradictory requirements of the federal Clean Water Act, ESA, and MBTA. For example, requirements for the quality of the water permitted to be discharged onto federal lands and from stormwater treatment areas (STAs) into the Everglades Protection Area may be at odds with the ESA or the MBTA, which requires that operations be adjusted when protected species nest in an STA or flow equalization basin (FEB) to avoid potential "takes" of protected species. Managing the STAs to protect species may ultimately impact discharge water quality (and in the future, water flows), thereby adversely affecting downstream habitat quality for the same species.

STAs represent new wetlands and as such have proved highly attractive habitat to numerous resident bird species, and two—black-necked stilts and snail kites—have proved problematic in that their hydrologic requirements are not compatible with normal operation of STA cells. The black-necked stilt, protected by the MBTA but neither threatened nor endangered, builds nests on the ground or on other surfaces above the water. At the end of the dry season, stilts may nest in STA cells containing little or no water. In normal operations, these cells would refill at the onset of the rainy season, which would destroy stilt nests; thus inflow to cells with nesting stilts is restricted. Managers can also try to keep the water level in STA cells above 0.5 feet to prevent stilts from nesting.

The endangered Everglades snail kite builds nests in thick emergent wetland vegetation and in wet years when water levels are sufficiently high, nests in emergent vegetation in the STAs. In the STAs, normal operations maintain dry season low water levels suitable for kites, but they require a suitable rate of water recession to nest successfully, and nests can flood due to inflows or collapse if outflows result in rapid dry-down. Thus, the presence of nesting kites restricts movement of water in and out of the STA cells.

Although stilts and kites have different habitat needs, both species have recently found opportune conditions within at least some of the STAs. In Water

Year (WY) 2015 one or both species nested in all five STAs, in 17 of 44 (39 percent) cells and in 13 of 21 (62 percent) flow ways (DeBusk et al., 2016). There were 113 kite nests in STAs in the 2014 breeding season and 93 in the 2015 breeding season. Most of the nesting occurs in STA-5/6—73 of 93 nests were there in 2015, including 48 in one cell—and the remainder in STA-1E (and in the past, sometimes in STA-3/4). Stilts nest in all the STAs, with the distribution of nests among them varying greatly among years according to operations of the cells, that is, which cells are dry at the time of nesting. There were 204 stilt nests in STAs in the 2015 breeding season, and 122 in the 2014 breeding season.

The SFWMD has no authorization for incidental take of kites as nesting in STAs was not anticipated in the Biological Opinion for STA construction and operation (FWS, 2005). Currently, there is no explicit option for take under the MBTA. Thus, the birds must be protected, resulting in constraints on STA operations, ranging from 2-9 months among flow ways in WY2015 (DeBusk et al., 2016). FEBs are subject to this same potential concern. This causes deviations from desired operations to meet restoration objectives.

The extent to which protecting nesting kites and stilts compromises STA performance is not clear as this has not been quantified. Managers often need to limit stages within cells and divert water away from particular flow ways or cells, but flow ways and cells are more often taken off line or constrained in operation due to physical repairs or issues with vegetation than due to nesting birds. Despite the impacts of all these factors, STA performance was the best to date in WY2015 (see STA Performance later in this chapter). Whether in the absence of kites and stilts more water could have been treated, or phosphorus levels in outflows reduced even further, is not clear. Managers are just beginning to collect the data necessary to answer this question. Documenting the reduction in STA performance due to protection of nesting birds is critical to determining the importance of this conflict.

Further conflicts of this sort will no doubt arise as other restoration projects are implemented. In particular, any project creating new wetlands, altering current wetlands, or affecting hydrology could create conflicting objectives between the needs of protected species and the needs of restoration. The preemptive strategy employed in the case of STAs was to engage in formal consultation prior to construction to address conflicts that could be anticipated. However, this consultation resulted in a non-jeopardy opinion because the use of the STAs by kites for nesting was not anticipated (FWS, 2005), so this consultation did not address the potential conflict. New information that kites are indeed nesting in STAs, contrary to what was anticipated at the time of consultation, may warrant reinitiating consultation or pursuing some other means of including kite nesting as part of ESA implementation. Nesting by stilts was not anticipated either and was addressed after the fact through development of an Avian Protection

Plan. This plan protects the birds when they do nest in the STAs, and provides managers with guidance on operation of cells to avoid creating nesting habitat. But other operational needs and rainfall patterns sometimes result in conditions in which creation of nesting habitat cannot be avoided in some cells, and thus, performance continues to be compromised.

In the case of the MBTA, some additional flexibility may result from an agency-wide initiative. In May 2015, the U.S. Fish and Wildlife Service (FWS) issued a Notice of Intent to prepare a programmatic environmental impact statement on a proposal to authorize incidental take of migratory bird under the MBTA. In that notice, the FWS stated that it was considering pursuing rulemaking to address various approaches to regulating incidental take of migratory birds, including general authorization for "some types of hazard to birds associated with particular industry sectors . . . [and] memoranda of understanding with Federal agencies authorizing incidental take from those agencies' operations and activities" (80 Federal Register 30032, May 26, 2015). As FWS stated "[a]n authorization system created through rulemaking could encourage implementation of appropriate conservation measures to avoid or reduce avian mortality . . . and could create a regulatory mechanism for bird mortality that cannot be avoided or minimized through best practice or technologies. Compensatory mitigation for incidental take, especially on a watershed or landscape basis, can provide conservation benefits. . . ." To date, the FWS has not published the environmental impact statement or proposed rule. Although explicit regulatory language has not yet been proposed, the rule is expected to provide additional flexibility under the MBTA for STA operation.

Even prior to the adoption of such a rule, the agencies should work together to explore options for increased flexibility necessary to optimize STA efficacy. In the past, the FWS has relied on its existing regulatory authority to allow limited "takes" of birds under specific circumstances. For example, the FWS has issued "special use" permits for incidental takes under certain specific circumstances pursuant to rule 50 CFR 21.27. This rule provides that permits may be issued for special purpose activities related to migratory birds upon a showing of a benefit to the migratory bird resource or for other compelling reasons. The FWS has relied on this rule to authorize the National Marine Fisheries Service to take birds incidental to certain fishing operations in Hawaii.[8] The FWS has also exercised its discretion under the MBTA in other ways, such as through memoranda of understanding with federal agencies. For example, in an MOU with Federal Energy Regulatory Commission (FERC and FWS, 2011), the FWS has recognized that "actions taken to benefit some migratory bird populations may adversely affect other migratory bird populations" and that "actions that

[8] See http://www.fws.gov/pacific/migratorybirds/pdf/pdf/NMFS Permit FONSI.pdf.

may provide long-term benefits to migratory bird populations may have short-term impacts on individual birds." To optimize efficacy of STAs for maximum water quality purposes, the agencies could explore these and other options for flexibility under the MBTA.

Regardless of how the issues with protected bird species in the STAs are resolved, having to deal with each issue on a case-by-case basis as they arise is far from ideal and does not constitute an effective model for avoiding or resolving the conflicts that will arise in the future. There is a need for a programmatic strategy to address this issue—that is, a means to handle potential conflicts for the restoration as a whole rather than on a case-by-case basis resulting from individual projects and events.

Cape Sable Seaside Sparrows: Managing the Transition

Continuing to meet the needs of protected species as increments of restoration are implemented is another important challenge. Even for species and habitats projected to be positively impacted by a fully implemented CERP, local adverse effects of increments of restoration and individual projects have arisen, and more can be expected. For endangered species protected by the Endangered Species Act, these effects can have legal ramifications that can affect water management operations and have the potential to compromise the restoration. Managing such species during the transition from current conditions to a fully implemented CERP is a general problem in need of a solution.

This challenge is perhaps best illustrated by the long-running conflict over water management related to the Cape Sable seaside sparrows. As discussed in more detail below, this conflict currently is impacting water management at the boundary between WCA-3A and Everglades National Park embodied in the Everglades Restoration Transition Plan (ERTP, also discussed later in the chapter). A lawsuit asserting that current water management fails to adequately protect the sparrow was filed,[9] and the FWS issued a jeopardy opinion on the impact of the ERTP on this species (FWS, 2016). The issue is that unsuitable, overly wet conditions for the sparrow have persisted in the habitat occupied by sparrow subpopulation A near western Shark River Slough (Figure 3-6; see also Chapter 4).

In principle, the restoration goal for this area to move more water through northeastern Shark River Slough and less through western Shark River Slough should alleviate the overly wet conditions experienced by subpopulation A. The ERTP aspires to do this, but only to a modest degree, and has failed to meet

[9] Pimm & Bass v. U.S. Fish and Wild Service & U.S. Army Corps of Engineers, No. 1:15-cv-00657 (DC, filed April 30, 2015). This lawsuit was voluntarily dismissed by the plaintiffs on October 6, 2016.

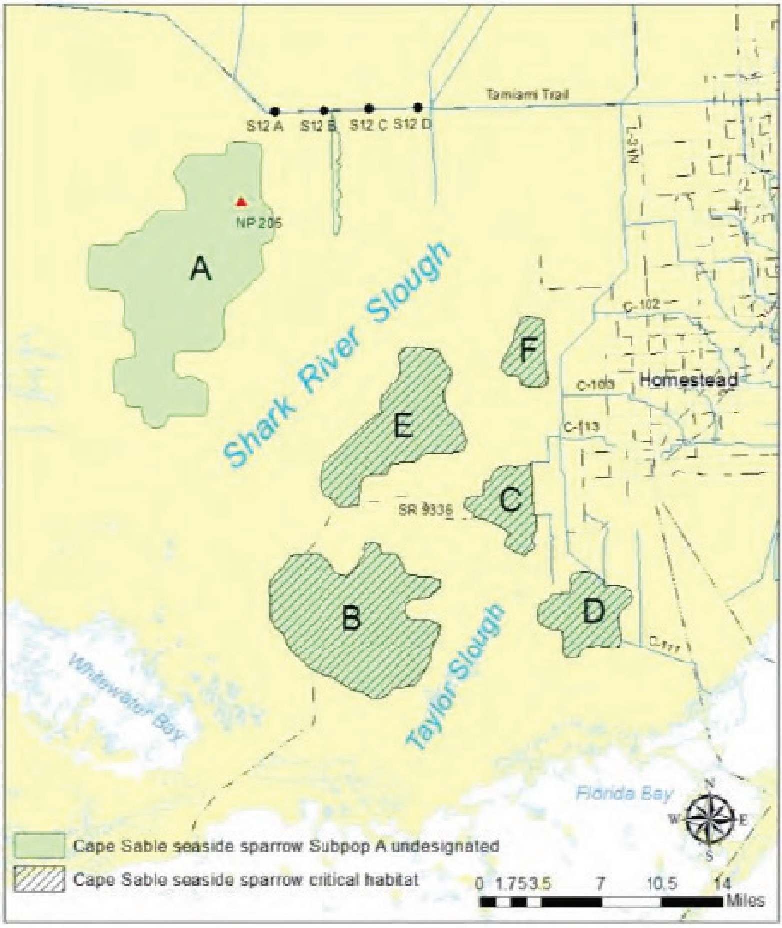

FIGURE 3-6 Location of Cape Sable seaside sparrow subpopulations.

SOURCE: FWS (2016).

its operational targets for endangered species toward that end such that subpopulation A has continued to experience high water conditions (data provided in FWS, 2016). Flows out of Big Cypress National Preserve to the northwest have contributed to this problem. The short-term solution to this issue presented in the Biological Opinion is to accelerate implementation of the Combined Operational Plan that will redirect more flow into northeastern Shark River Slough and address the flows from Big Cypress National Preserve (see below).

However, recent analyses indicate that meeting the needs of Cape Sable seaside sparrows as the restoration unfolds will be far more complicated than simply fixing the problem by moving more water east as envisioned in the CERP. The complexity of the issue is evident in the Central Everglades Planning Project, which represents the first major CERP project to address water management issues along the WCA-3A–Everglades National Park boundary impacting the sparrows. The project implementation report and environmental impact statement (USACE and SFMWD, 2014a) and Biological Opinion (FWS, 2014) associated with the Central Everglades Planning Project provide detailed insight into how the restoration will affect the sparrows. Rather than having a uniformly positive effect, the project is anticipated to result in a complex mix of impacts on sparrows. It is indeed projected to create more favorable conditions in the northeastern portion of subpopulation A where much attention has been focused. However, it produces no improvements in other parts of A and a mix of positive and negative effects in the subpopulations near northeastern Shark River Slough and Taylor Slough, including a substantial negative impact on subpopulation E (Figure 3-7). The Central Everglades Planning Project also is projected to create new marl prairie habitat in areas not currently occupied by sparrows northeast of subpopulation A and between subpopulations C, E and F (Pearlstine et al., 2016).

Thus, analyses associated with the Central Everglades Planning Project confirm that restoration will improve habitat conditions for sparrows in some areas that are currently highly altered and degraded due to being too wet or too dry, but it also reveals that it will convert some areas of current marl prairie to wetter habitat types. The FWS reached a similar conclusion in evaluating the impact of Mod Waters and the Combined Operational Plan, although the impacts were much smaller in this case (FWS, 2016). The C-111 Spreader Canal (Western) and C-111 South Dade projects (discussed later in this chapter) have produced a similar mix of improvements to dry, degraded sparrow habitat and overly wet conditions in previously suitable sparrow habitat near Taylor Slough. Much the same can be expected from future increments of restoration affecting the areas in which the sparrows reside. The net effect on sparrows of the Central Everglades Planning Project and future restoration increments will depend on whether changes in the distribution of water result in shifts in the location of marl prairie habitat (rather than reduction of such habitat) and, if these shifts occur, whether the sparrows colonize this new habitat. The higher the operational target for volumetric flows and water depth, the more likely that marl prairie habitat will be reduced (see Chapter 4).

Even if the restoration is viewed as having a net positive effect on the sparrows, restoration will be impeded if no local negative effects on the sparrows are permitted due to its endangered status. In the case of the Central Everglades

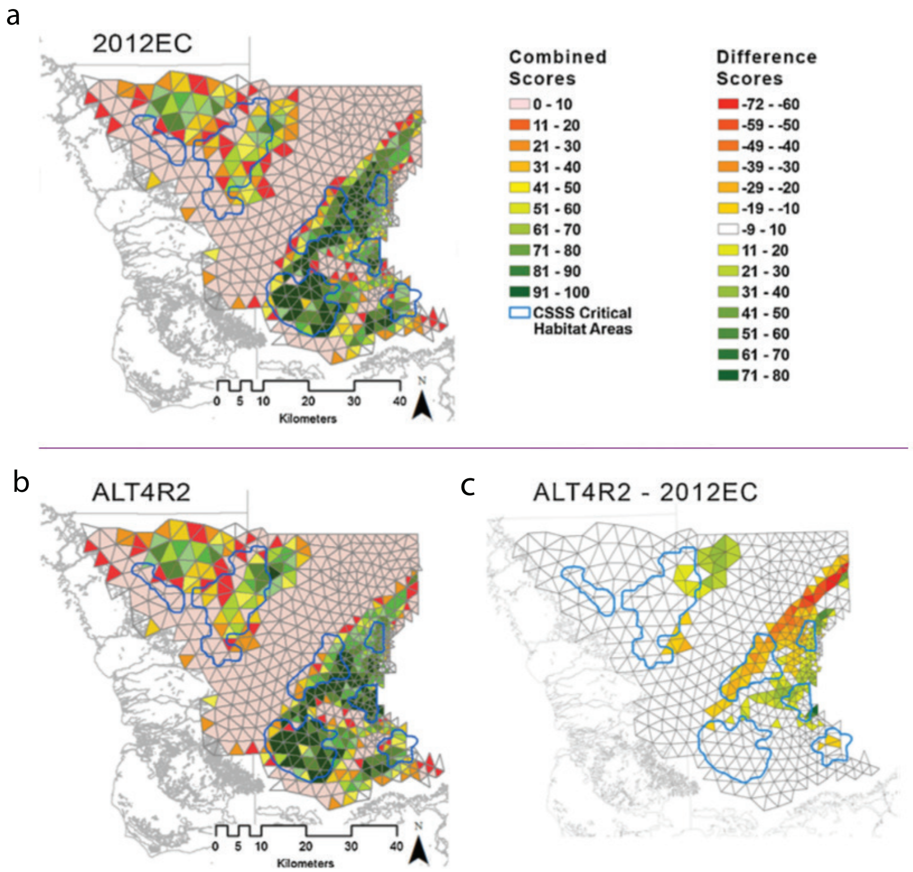

FIGURE 3-7 Marl prairie habitat suitability for the combined marl prairie indicator scores at each RSM cell for (a) Existing Conditions (2012EC) and (b) the Central Everglades tentatively selected plan (Alt4R2). Scores range from 0 (not suitable; pink) to 100 (most suitable; dark green). Figure 3-7c shows the change in habitat suitability from existing conditions for the CEPP Tentatively Selected Plan (Alt4r2 – 2012EC). Green shades are improvements in habitat suitability, oranges to reds are declines. Current Cape Sable seaside sparrow subpopulation habitat boundaries are outlined in blue.

SOURCE: Pearlstine et al. (2016).

project, a negative impact on subpopulation E is projected. The FWS ruled that the project does not jeopardize the sparrow, based on its projected neutral overall impact, but did not authorize incidental take and loss of sparrows from subpopulation E due to restoration activities because project details have not been refined (FWS, 2014). A Memorandum of Understanding was developed to address the impacts of the Central Everglades Planning Project on sparrows (FWS, 2016), but a long-term solution is needed to avoid having protection of sparrows repeatedly being an obstacle to restoration that is played out on a case-by-case basis. As part of the recent consultation over the ERTP, the Corps proposed that a Comprehensive Conservation Plan for the sparrow be developed that includes identification of potential future habitat for this subspecies considering predicted flows associated with Everglades restoration projects and projected sea level rise, identification of habitat and population enhancement techniques to enhance resiliency, and exploration of translocation and captive breeding among other items (FWS, 2016). This appears to have the potential to produce the needed long-term solution to the conflict between sparrow conservation and the restoration, and as such could provide a model for addressing similar issues with other species.

CERP RESTORATION PROGRESS

In the following sections the committee focuses on natural system restoration benefits emerging from the implementation of CERP projects. In order for readers to understand the level of natural system restoration progress to be expected, a brief description of the state of implementation progress for each project is also provided. The committee's previous report (NRC, 2014) contains additional descriptions of the projects, and progress up to March 2014, while this section emphasizes progress over the last 2 years. The South Florida Environmental Report (SFWMD, 2016e), the 2015 CERP Report to Congress (USACE and DOI, 2016), and the 2014 Integrated Financial Plan (SFERTF, 2014) also provide detailed information about implementation and restoration progress. The 2014 System Status Report (RECOVER, 2014) provides additional information on changing ecosystem conditions and discusses linkages to early project construction.

Measuring Restoration Progress

Environmental restoration generated by CERP and non-CERP projects begins with construction and operation of a project (or project component) designed to yield responses in the physical system (e.g., changes in hydrologic conditions, such as depth, duration, and flow) that in turn cause desired changes in the biological system (e.g., individual species, food webs, habitat, trophic-level energy flows). The return of hydrologic conditions more similar to pre-drainage conditions potentially enables plant, animal, and microbial communities to develop that are more similar to pre-drainage communities than current ones are.

Monitoring using formal performance metrics can generate a quantitative record of ecosystem changes resulting from project operations. Repeated monitoring at appropriate intervals during the post-construction period, combined with baseline or reference site data, is essential in judging project success. The monitoring protocol must be rigorous enough to discern whether changes in performance metrics are causally linked to projects rather than to other influences or whether they simply reflect normal variability (NASEM, 2016).

Components of the physical and biological environment respond to project operations on highly variable time frames. Typically, hydrologic changes occur more rapidly than changes in ecological conditions but there is considerable overlap. Microbial and herbaceous plant communities, dominated by species with short life cycles, can respond to hydrologic changes within a few years. Responses of some users of those habitats, such as fishes and wading birds, may be equally rapid. In marked contrast, changes in ecological communities dominated by trees and shrubs are typically slow; more than a century may elapse before new habitats are fully restored.

The need to establish monitoring programs that may have components that last for more than a century, combined with the great richness of environmental attributes and processes that can be measured, stresses the importance of careful selection of indicators and attention to how frequently measurements need to be taken. In general, fast acting variables need to be measured frequently, whereas slow acting ones need to be measured much less often. For example, a major effect of the changed hydrology in the Picayune Strand is likely to be the conversion of extensive pine/palm savannas to bald cypress woodlands, a change unlikely to be completed in less than a century. Vegetation surveys no more often than once per decade should suffice to document those changes. Given the limitations in CERP funding, a small number of carefully selected indicators that are monitored at appropriate temporal and spatial intervals can be suitable to document restoration progress and support adaptive management. The following sections outline the natural system restoration progress based on monitoring to date at four Generation 1 CERP projects and two Generation 2 CERP projects for which construction has begun. Box 3-2 highlights lessons learned from monitoring at several CERP and non-CERP projects to date.

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-

BOX 3-2
Lessons Learned: Monitoring and Assessment

Determination of restoration progress for CERP projects depends on a program of monitoring to describe key ecosystem parameters before, during, and after project construction and operation, and on subsequent assessment of the monitoring results. A rigorous monitoring program is an indispensable component of any adaptive management plan and relies on a series of best practices to assess and, where needed, modify restoration efforts (see NASEM, 2016). A strategy to clearly and concisely communicate the performance of ecosystem restoration to a broad audience is another key element of any monitoring program (for example, see ChesapeakeStat[a] used by the Chesapeake Bay Program). In this box, the committee presents several lessons learned to date that are specific to the monitoring efforts for the Picayune Strand Restoration, C-111 Spreader Canal (Western), Biscayne Bay Coastal Wetlands (Phase 1), and the Kissimmee River Restoration projects. This is not intended as a full review of CERP monitoring, but the experience gained through the implementation of these projects and the early stages of monitoring provides several lessons that should be useful for future CERP projects that are developing or refining monitoring plans.

- Project managers report that the length of the post-project monitoring effort should be longer than the 5 years that often attend restoration projects in order to encompass the unfolding of changes that occur slowly and provide opportunity for corrective actions that might be required (Bauman, 2010; USACE 2011b). Changes in the complex connections among groundwater, vegetation communities, and faunal populations may not be fully expressed for decades, during which continued monitoring will be important. Most of the benefits expected in the Biscayne Bay Coastal Wetlands project are expected to be fully realized between 5 and 10 years post construction. In contrast in the Picayune Strand, funding was provided to support long-term post-project monitoring (Strock, 2005).
- Baseline and/or reference data against which project performance can be evaluated are critical for a successful monitoring program (Trexler et al., 2003). Efforts to locate new monitoring sampling stations where data have been collected historically helps ensure that data are collected in ways that are as consistent and comparable as possible, thus leveraging the power of historical data.
- To demonstrate project benefits, monitoring should be designed to distinguish restoration progress from background variability or other factors unrelated to the restoration project. In addition to developing rigorous sampling designs and sufficient baseline and/or reference data, setting restoration objectives in terms of multi-year running averages can diminish noise associated with climactic and other variables that can vary stochastically over time.
- Successful monitoring plans often emphasize species that are sensitive indicators, such as wading birds and waterfowl that integrate aspects of wetland hydrology, vegetation, and aquatic prey densities. Monitoring species that are of great public interest (like wading birds) can help communicate restoration goals and successes to decision makers and the general public. This approach has been successfully used in the Kissimmee River Restoration project (Cheek et al., 2015).

[a] See http://www.chesapeakestat.com.

South) or by program authority (Melaleuca Eradication). A summary of implementation progress as of September 2016 is provided in Table 3-1. The location of the various projects is shown in Figure 3-1.

Picayune Strand Restoration

The Picayune Strand Restoration project, the first CERP project under construction, focuses on an area in southwest Florida substantially disrupted by a real estate development project that drained 55,000 acres (about 86 mi^2) of wetlands before being abandoned (Figure 3-1, No. 5). The roads and drainage disrupted sheet flow into Ten Thousand Islands National Wildlife Refuge, altered regional groundwater flows in surrounding natural areas and drained a large expanse of wetland habitat (Figures 3-8 and 3-9). There has been considerable progress in constructing the Picayune Strand Restoration Project, including canal plugging, road removal, construction of pump stations (see Table 3-4). Due to cost and scope escalations, the project requires further authorization before it can be completed (SFERTF, 2014).

Natural system restoration benefits from the Picayune Strand Restoration are beginning to be recognized from the project increments completed to date, with improved wetland inundation and increased hydroperiods in 13,000 acres (about 29 mi^2) (SFWMD, 2016a). Wet season surface water levels have increased

FIGURE 3-8 Unrestored portions of the Picayune Strand Restoration project area. The left image shows where the habitat is dominated by palms, which have encroached since groundwater elevations were lowered by drainage. The right image shows the Faka Union Canal, prior to restoration.

SOURCE: W.L. Graf, S. Johnson.

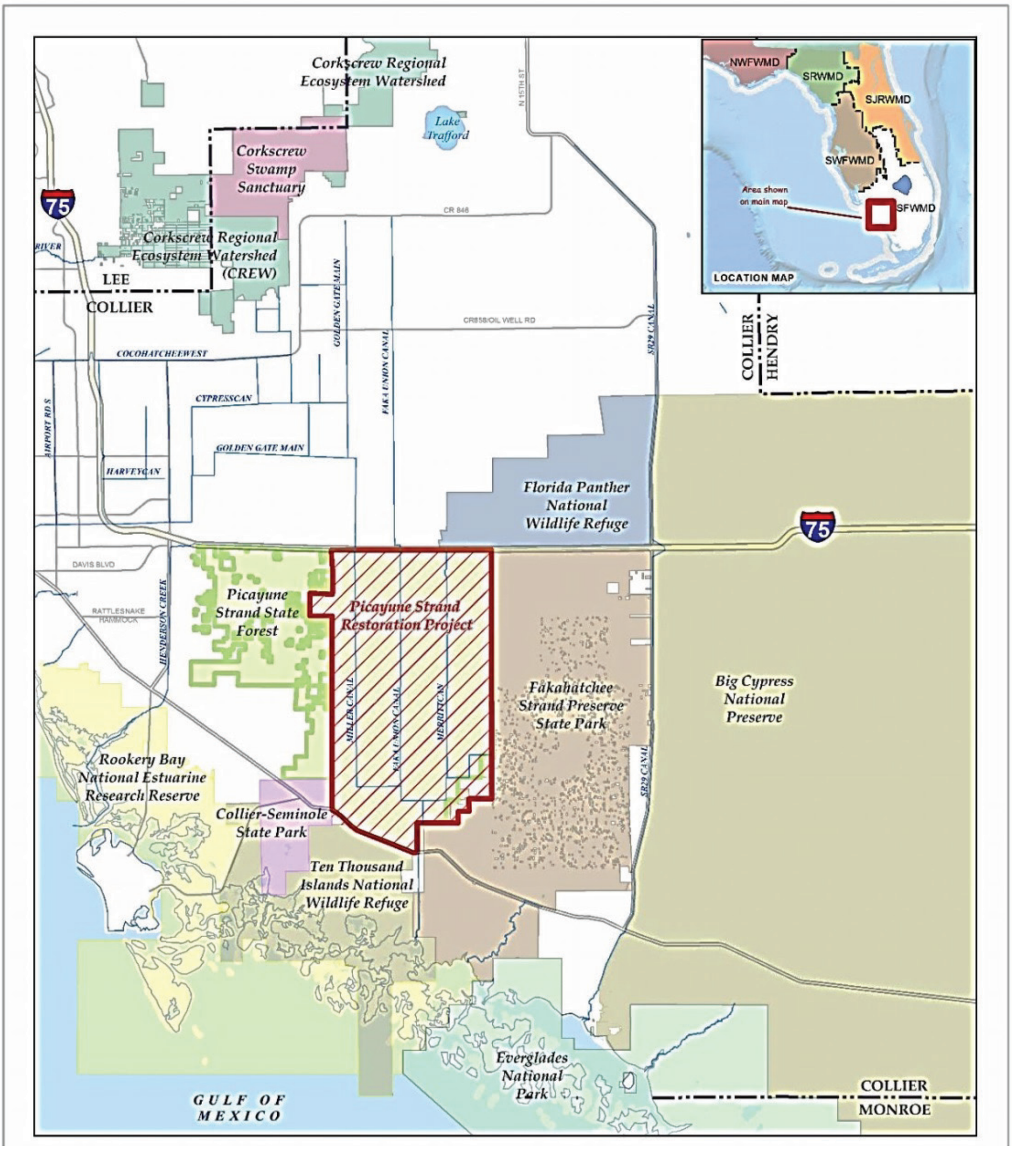

FIGURE 3-9 The Picayune Strand Restoration project area is surrounded by several other natural areas, including Collier-Seminole State Park, Ten Thousand Islands National Wildlife Refuge, Picayune Strand State Forest, Fakahatchee Strand Preserve State Park, and Florida Panther National Wildlife Refuge. Restoration of water levels within the project footprint will enhance the hydrologic conditions in these surrounding natural areas.

SOURCE: USACE and DOI, 2015.

TABLE 3-4 Phases and Progress of the Picayune Strand Project

	Lead Agency	Road Removal (mi)	Logging Tram Removal	Canals to Be Plugged (mi)	Other	Project Phase Status
Tamiami Trail Culverts	State	NA		NA	17 culverts constructed	Completed in 2007
Prairie Canal Phase	State (expedited)	64	30	7	Hydrologic restoration of 11,000 acres in Picayune Strand and 9,000 acres in Fakahatchee Strand State Preserve Park	Plugging and road removal completed in 2007; logging trams removed in 2012
Merritt Canal Phase	Federal	65	16	8.5	Merritt pump station, spreader basin, and tie-back levee constructed	Completed in 2015; pump station transferred to SFWMD in 2016
Faka Union Canal Phase	Federal	81	11	7.6	Faka Union pump station, spreader basin, and tie-back levee constructed	Roads removed in 2013; pump station completed in 2015; operational testing underway; canal plugging scheduled for 2020
Miller Canal Phase	Federal/ State	77	11	13	Construct Miller Canal pump station, spreader basin, tie-back levee, and private lands drainage canal; remove western stair-step canals	Miller pump station under construction to be complete in 2017; road removal and canal plugging scheduled for 2018 and 2020, respectively
Manatee Mitigation Feature	State	0	0	0	Construct warm water refugium to mitigate loss of existing refugium	Completed in 2016
Southwestern Protection Feature	State	0	0	0	Construct 7-mile levee for flood protection of adjacent lands	Construction completion scheduled for 2020
Stair-step Canals between Prairie and Faka Union Canals	Federal	0	0	5.2		Construction completion estimated in 2018

SOURCES: J. Starnes, SFWMD, personal communication, 2016; USACE and SFWMD (2016a).

1 to 2 feet relative to background conditions and dry season groundwater levels have increased 3 to 4 feet due to the plugging of the Prairie and Merritt canals (Figure 3-10), and monitoring results suggest that canal filling has stimulated a rise in groundwater levels within about 3 miles of the filled canal (RECOVER, 2014). Additional increases in water level toward reference conditions (as monitored since 1987 in the neighboring Fakahatchee Strand, an area with similar topography and vegetation) are expected in these areas when the stair-step canals at the southern end of the project are also plugged in 2017 (see Figure 3-9). The Florida panther population is expanding, and they are seen more frequently in

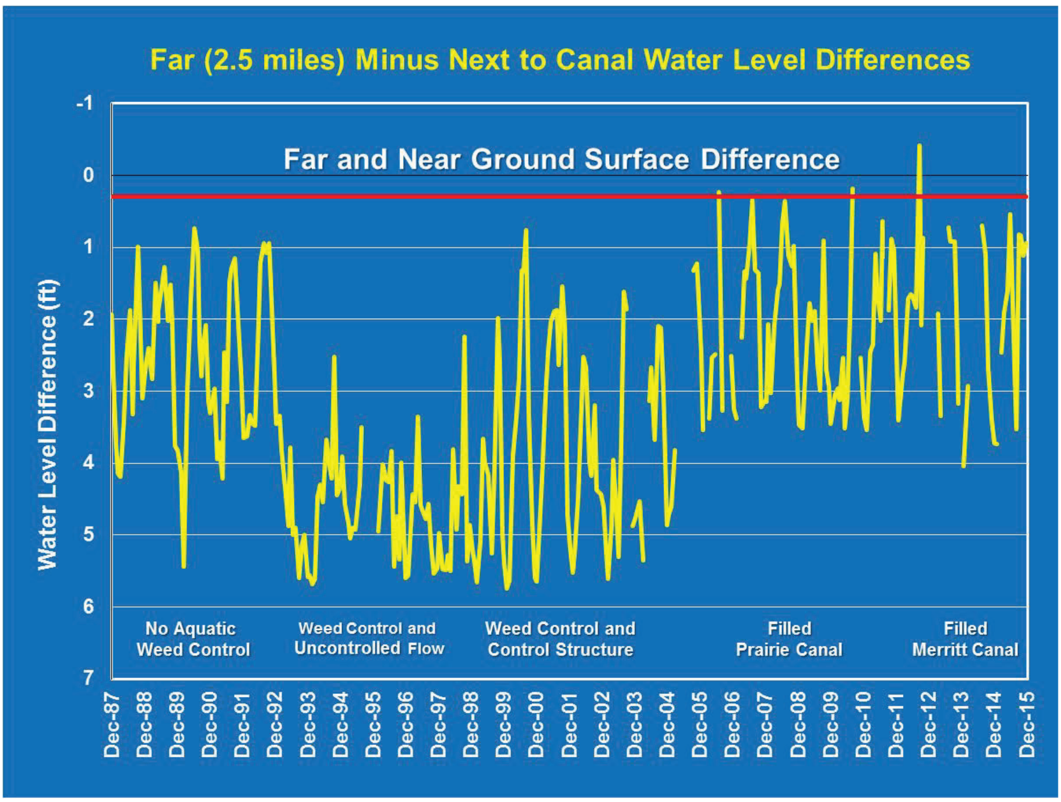

FIGURE 3-10 Difference in water levels between a well located next to the Prairie Canal and a well located 2.5 miles away from the canal in Fakahatchee Strand, where water levels are anticipated to be only minimally affected by canal drainage. These monitoring data relative to background and reference data help document increasing water levels due to canal filling. Changes in weed control management affected water levels over the course of baseline data collection.

SOURCE: M. Duever, Natural Ecosystems, personal communication, 2016.

the project area, although the specific impact of the Picayune Strand project is not clear (USACE and DOI, 2015). Early vegetation monitoring shows that groundcover near the Prairie Canal is becoming more similar to reference conditions (Figure 3-11), although restoration has not yet affected the density of *Sabal palmetto*, a native nuisance species in drained areas (RECOVER, 2014). There are anecdotal reports of wading birds, once absent from the area, now returning for foraging but wildlife monitoring is not planned until all three pump stations are operational. Aquatic faunal monitoring will begin in 2016, and data will be compared to baseline and reference site data. Vegetation transect surveys are also anticipated in 2016. Vegetation monitoring at Picayune Strand will be repeated in years 1, 3, and 5 after the first full growing season following the plugging of the canal (in any given phase) and then every 5 years for years 5-20, and then every 10 years until 2050 (J. Starnes, SFWMD, personal communication, 2016).

Site 1 Impoundment

The Site 1 impoundment project (No. 6 on Figure 3-1) is located 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 (Figure 3-12). The project was originally cast as a single-phase effort to modify local hydrologic conditions to store more water (13,300 acre-feet [AF]) and help 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 LNWR to meet user demands elsewhere. With the Site 1 impoundment, water can be better managed to supply natural system demands within the LNWR (USACE and SFWMD, 2016b). In 2009, the project was divided into two phases (see Figure 3-12). Construction of Phase 1—an $81 million effort included clearing, ground preparation, modifications to the existing L-40 levee, and construction of a 6-acre wildlife wetland area—was completed in January 2016 (USACE and SFWMD, 2016b G. Landers, USACE, personal communication, 2016). USACE (2016c) stated that phase 1 provides a 16 percent reduction in existing seepage at the L-40 levee. It is unclear whether such a change would be detectable in the hydrologic conditions of LNWR.

Phase 2 of the project awaits further congressional authorization necessitated by increased costs (USACE and SFWMD, 2016b). The SFWMD, however, in 2016 communicated to the USACE that it is no longer interested in constructing Phase 2, because of the high anticipated cost of the plan relative to the benefits provided (M. Morrison, SFWMD, personal communication, 2016). The committee has not reviewed the project benefits in detail relative to the benefits of other CERP projects, but such an analysis could reasonably be part of the systemwide assessment of the CERP under alternative future conditions

FIGURE 3-11 Merritt Canal at Stewart Blvd., looking north, showing progress in vegetation growth after canal has been plugged. Above: View in June 2015. Below: View in June 2016.

SOURCE: M. Duever, Natural Ecosystems, personal communication, 2016.

FIGURE 3-12 Location of the Site 1 Impoundment project, looking west-northwest. The Loxahatchee National Wildlife Refuge, is at the upper right of the image. As with many restoration projects, Site 1 has a sharp boundary between its restoration area and neighboring urban development.

SOURCE: Modified from Audubon, 2010.

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proposed in Chapter 5. The future of Site 1 Impoundment, Phase 2, for now, remains unsettled.

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 impacted by polluted runoff from farmlands and urban areas and surges of freshwater (USACE, 2013). The Indian River Lagoon-South (IRL-S) project (Figure 3-1, No. 7) is designed to reverse this damage through improved water management, including the 50,600-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 3-13). The project is anticipated to cost $3 billion in 2014 dollars, an increase of $1.3 billion from 2010 primarily due to changes in scope associated with additional dam safety requirements (USACE and DOI, 2016).

Construction on Indian River Lagoon South has made considerable progress over the last 2 years (since June 2014). Construction was completed on some features included in the C-44 reservoir, including intake and drainage canals, access roads, and staging areas. Construction has also begun on the C-44 reservoir, pump station, and stormwater treatment area (USACE and SFWMD, 2016c). Reservoir construction is anticipated to be completed in 2020 (R. Braun, SFWMD, personal communication, 2016). It is still too soon to see improvements to the natural system as a result of this project.

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 non-native invasive plant species. 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, U.S Department of Agriculture has constructed a 2,700-ft^2 annex to the present laboratory to facilitate additional mass rearing (Figure 3-1, No. 8). The $4.5 million annex was completed in 2013 and has been transferred to the local sponsor (USACE, 2015b; K. Smith, USACE, personal communication, 2016). 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 non-native plant species in the Everglades and South Florida (USACE and SFWMD, 2015a). In 2015, the facility released more than 500,000 brown lygodium moths and mites to control climbing fern, and almost 400,000 insects targeted to water hyacinth (Rodgers, 2016).

The Melaleuca Eradication and Other Exotic Plants project is one effort among many efforts to control invasive plant species in the Everglades, and several federal and state agencies are engaged to control these problem plants. In FY2015, the SFWMD spent $19 million combating 75 nonindigenous plant species in the Greater Everglades region (Rodgers, 2016). As a result, the exact contributions of this CERP project in the overall effort are difficult to parse, although the control of invasive plants is essential to achieve restoration goals

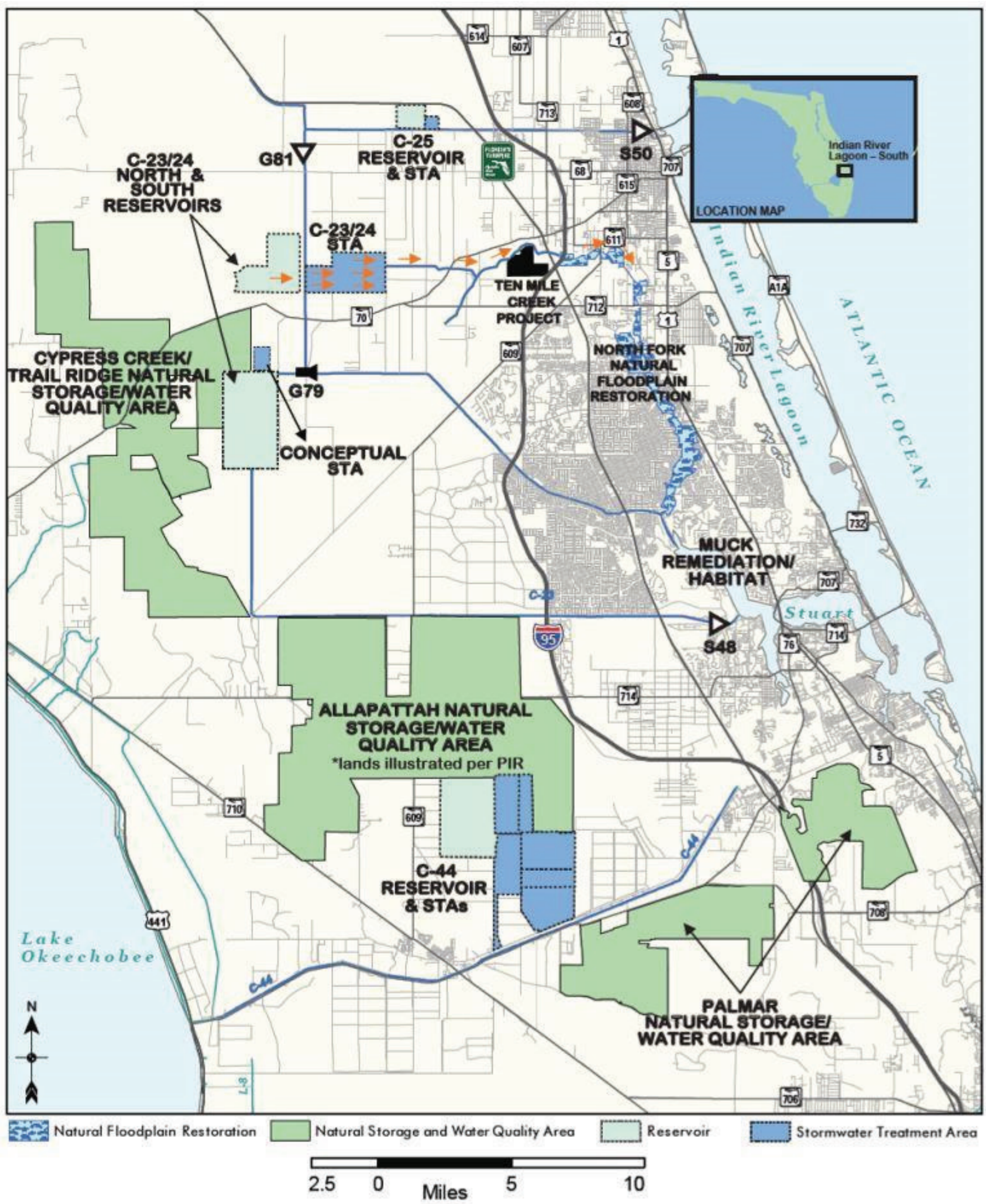

FIGURE 3-13 Components of the Indian River Lagoon-South restoration project.

SOURCE: USACE (2016c).

(NRC, 2014). Discussion of progress coordinating the broad efforts to address invasive species is discussed later in this chapter (see Non-CERP Restoration Progress).

Generation 2 CERP Projects

Four second-generation CERP projects were authorized as part of WRRDA 2014 (Table 3-1). These projects were the Biscayne Bay Coastal Wetlands (Phase 1), the C-111 Spreader Canal (Western) Project, C-43 Reservoir, and the Broward County Water Preserve Areas. No construction has begun on the Broward County Water Preserve Areas, so the discussions will focus on the other three projects.

Biscayne Bay Coastal Wetlands (Phase 1)

The Biscayne Bay Coastal Wetlands are located in Miami-Dade County at the western edge of Biscayne Bay (Figure 3-1, No. 10, and Figure 3-14). Drainage and development has cut off the wetlands from their source of freshwater 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 ditch plugs. The project is proceeding in two phases: Phase 1 is a stand-alone project encompassing three geographic areas (Deering Estates, Cutler Wetlands, and L-31E Flow-way), while Phase 2 has not yet been specifically planned or authorized. The components of the Deering Estates phase—a spur canal extension, spreader structure, and pump station—were completed and became operational in 2012. Four culverts out of ten 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. Continued work on the L-31E component is anticipated to begin in 2017 (USACE, 2016n).

To date, the project increments implemented have been rather small in the context of the original project objectives, but the construction allows partial restoration of flows through the coastal wetlands to Biscayne Bay to help restore a more natural salinity balance (USACE and SFWMD, 2016d). SFWMD has collected monitoring data on water stage, discharge, salinity, and vegetation for the past 4 years to document the effects of the project (Figure 3-15), comparing the results to baseline data collected before project implementation. In WY2014 and 2015, approximately 20,000 and 15,000 AF/year were diverted into the Deering Estate wetlands (Charkhian, 2015, 2016). The response of salinity was mixed; nearshore salinity did not show much response to pumping and remained above the RECOVER target of 20 ppt, while salinity decreased in the remnant wetlands,

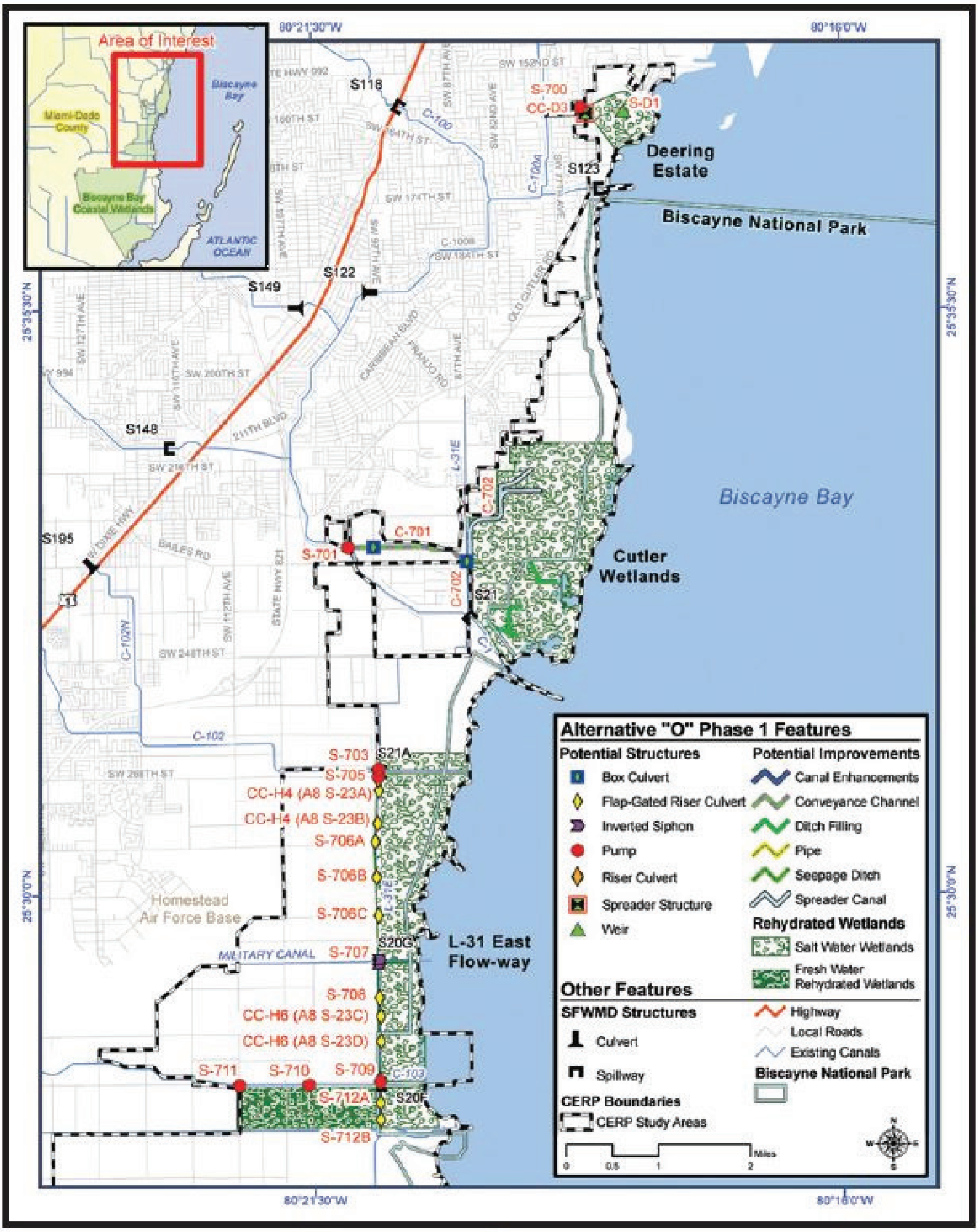

FIGURE 3-14 Biscayne Bay Coastal Wetlands (Phase 1) project area in southeast Florida.

SOURCE: USACE (2016d).

FIGURE 3-15 Vegetation monitoring within freshwater wetlands along a transect downstream of the S-23D culvert at the Biscayne Bay Coastal Wetlands L-31 East Flowway.

SOURCE: Charkhian (2016).

declining from 25-40 ppt to less than 1 ppt within 6 weeks of the start of pumping (RECOVER, 2014). In response, upland vegetation that had encroached into the wetland has begun to die back (Charkhian, 2016).

During 2015, approximately 8,000 AF of water was diverted into the coastal wetlands through the L-31E culverts, representing about 5 percent of available flow and exceeding the project target for the first time since the project began operations (Charkhian, 2015, 2016). Periphyton is now common in the mangrove areas of the project, while east of the L-31E canal sawgrass has increased from 43 acres to 48 acres. Additionally, faunal monitoring showed an increased abundance of fish, wading birds, amphibians, and invertebrates east of the culverts in 2015 (Charkhian, 2016). Field observations show that there has been no significant response in the composition and coverage of the vascular plant communities (RECOVER, 2014). Monitoring to date did not show effects on nearshore salinity.

C-111 Spreader Canal (Western) Project

The C-111 canal (Figure 3-1, No. 9) is the southernmost canal for the entire Central and Southern Florida Project. Designed to provide flood protection for agricultural lands to the east in South Dade County, the C-111 canal also drained water from the Southern Glades and Taylor Slough in Everglades National Park. Much of the water in the canal is a result of seepage from Everglades National Park to the west. This change in flow pattern caused ecological damage to Taylor Slough, which became too dry; at the same time, Barnes Sound and Manatee Bay suffered ecological damages as releases of freshwater upset the salinity balance of their waters. Working in concert with the non-CERP C-111 South Dade project to the north (discussed later in this chapter), the C-111 Spreader Canal (Western) project promises increased flow volumes in Taylor Slough and improved salinity regimes in eastern Florida Bay by reducing seepage along the C-111 corridor (SFWMD, 2013a). The project is structured in two phases, with the first phase (Western Project) to include two pumping stations, a 560-acre detention basin, and various canal modifications. Water from the C-111 canal is pumped into the C-111 Spreader Canal detention and the plugged Aerojet canal areas, creating a 6-mile-long hydraulic ridge along the eastern boundary of Everglades National Park. Most of the water in the detention area seeps back into the canal, but the hydraulic ridge reduces seepage from the Everglades and retains water in Taylor Slough, thus, improving the distribution of flows into Florida Bay (Qui, 2016) (Figure 3-16). The C-111 Spreader Canal (Eastern) project has not yet been specifically planned or authorized. The C-111 Spreader Canal (Western) project was largely completed in February 2012 and is now operational. One additional new structure (S-198) is authorized in the lower C-111 but it is not currently scheduled for construction (USACE and SFWMD, 2016e). The natural system benefits of the C-111 Spreader Canal (Western) Project are difficult to separate from those of the C-111 South Dade project to the north (discussed later in the chapter), because C-111 South Dade project features, including the South Detention Area that has been operating since 2010 have similar overarching objectives. Thus, the results discussed here should be attributed to both projects, until more analysis is available to attribute benefits to a specific project.

Based on the first 4-6 years of project operations and available monitoring data, the hydrologic and ecological effects of the project have not been determined. Initial reports of project benefits, including hydroperiods that were 50 days longer on an average annual basis and reduced salinity levels in coastal waters (Audubon Florida, 2014; Rudnick et al., 2015; USACE and DOI, 2015), cannot be definitively attributed to the project because these outcomes occurred during a period of increased rainfall. The same areas of Florida Bay in which low salinities were originally attributed to the project showed elevated salinities in the summer of 2015 during an extended localized drought (see Chapter 2). Based on model predictions, it may be difficult to detect improvements in salinity in Florida Bay from the C-111 Spreader Canal (Western) Project amidst the natural variability (Qui, 2016).

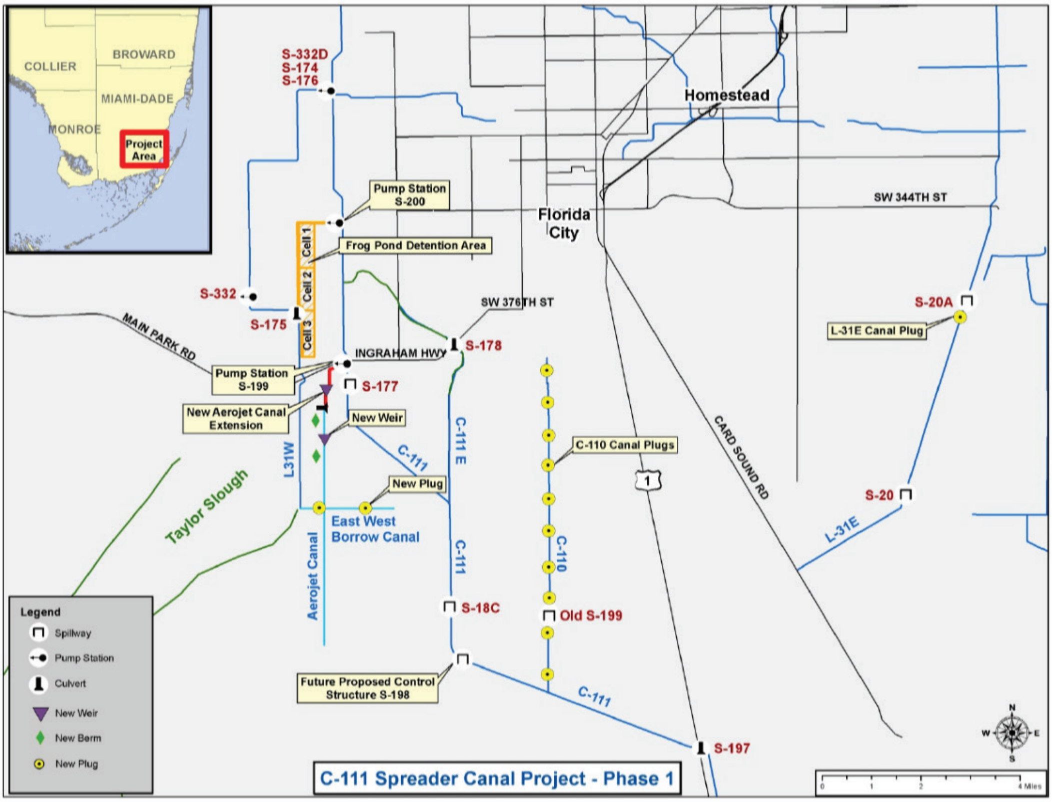

FIGURE 3-16 Project design features for C-111 Spreader Canal Western Project.

SOURCE: USACE and SFWMD (2016e).

Some ecological changes have been noted since 2012 that may be attributable, at least in part, to the two projects. American crocodile nesting and population trends are increasing along the coast (USACE and DOI, 2015). Roseate spoonbills nesting increased from 87 nests in WY2011 to 207 nests in WY2013, and nesting success has also increased (RECOVER, 2014). However, the National Park Service (NPS) (2015) reports declining chick production in northeast Florida Bay in its 2015 assessment. Longer hydroperiods have improved conditions for Cape Sable seaside sparrows in areas that have habitually experienced overly dry conditions previously (i.e., population F, see Figure 3-6) (FWS, 2016). However, portions of population D east of Taylor Slough are now more often experiencing hydroperiods that are longer than the 90-to-210-day target for this species.

Additional gages have been installed to enable more accurate monitoring of conditions experienced by this population (FWS 2016).

A longer monitoring period compared to baseline data will be required to specify the quantitative results and aid in determining the role of the restoration project (Qui, 2016). Reference site monitoring is available for some measures, such as surface-water stages and rainfall, and salinity in Florida Bay, but less so for others, which makes attribution of positive outcomes to the project as opposed to other factors more challenging (USACE and SFWMD, 2011a). In conclusion, this committee agrees with the assessment of Qui (2016) that "because of the relatively short period of operation and monitoring period of record (start-up occurred in 2012), it is too early to fully evaluate the project's success in achieving its objectives. A longer monitoring period and assessment during a wide range of meteorological conditions will reduce uncertainty about the relationship between the project's operations, stages, and flows in Taylor Slough and salinity in Florida Bay." This conclusion applies to effects on biota as well.

C-43 Storage Reservoir

A major environmental issue in the estuary of the Caloosahatchee River on the west coast of Florida is the restoration and maintenance of appropriate salinity levels for aquatic organisms, particularly shellfish. Early in the twentieth century, the course of the Caloosahatchee River was deepened and straightened, and canals were dug in the river basin to provide a capacity for drainage of agricultural lands and urban areas. The result is that during periods of prolonged low rainfall, freshwater flow to the estuary is greatly reduced, to the extent that saline water can migrate far up the river and kill beds of freshwater submerged plants. During periods of heavy rainfall, large volumes of nutrient- and sediment-rich freshwater are transported into the estuary, affecting habitat quality for seagrasses, oysters, and other aquatic organisms. The Caloosahatchee River (C-43) West Basin Storage Reservoir (Figure 3-1, No. 11) is a CERP project designed to impound up to 170,000 AF of stormwater runoff from the C-43 drainage basin or from Lake Okeechobee during wet periods (Figure 3-17; USACE and SFWMD, 2016f). During dry periods, this stored water can be released to supplement low river flows to maintain optimal salinity levels in the estuary and is available for water supply. The area of ecosystem benefits extends to almost 80,000 acres (about 125 mi^2) of riverine and coastal waters (USACE, 2007b).

This first phase of construction began in late 2015 and is anticipated to be completed by 2021 (R. Braun, SFWMD, personal communication, 2016). As of early 2016, the first of two construction phases is under way, including construction of two pumping stations, construction of the western cell of the reservoir

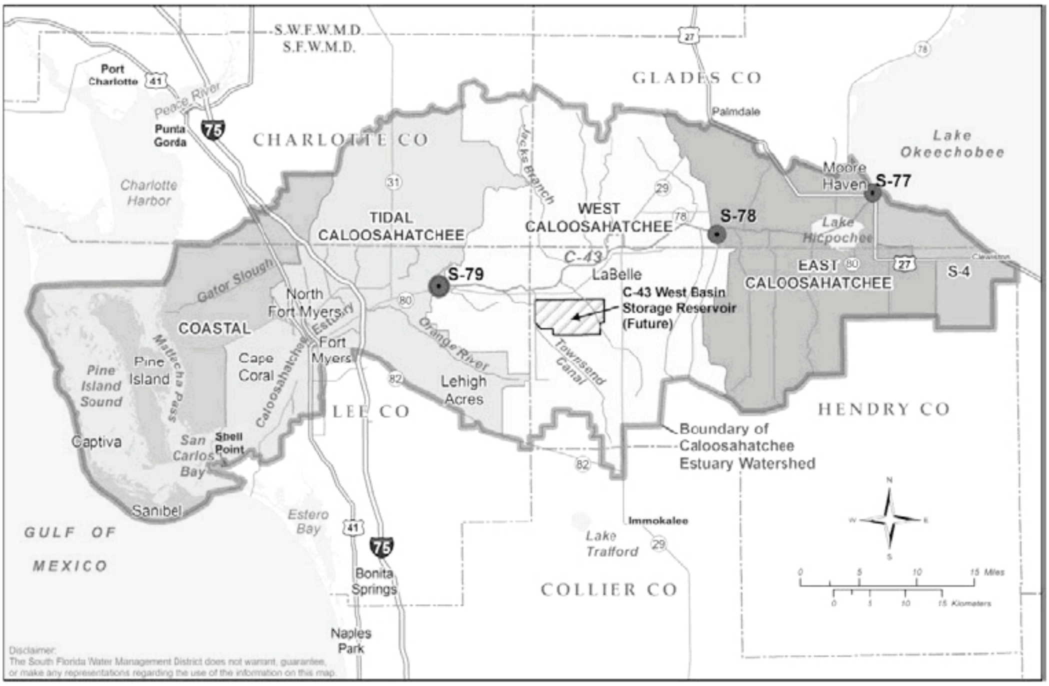

FIGURE 3-17 Location of the C-43 Reservoir, positioned to store runoff from part of the West Caloosahatchee and all of the East Caloosahatchee basins.

SOURCE: Zhang et al. (2016).

(cell 1), and establishment of the perimeter canal. Because reservoir construction is still ongoing, it is too soon to see natural system benefits from this project.

Generation 3 Projects

Generation 3 represents projects that have been pending authorization, with approved project implementation reports, during the 2015-2016 period. The only project in this category is the Central Everglades Planning Project (Figure 3-1, No. 13 and 14), a $1.9 billion initiative designed to expedite restoration of the Water Conservation Areas, Everglades National Park, and Florida Bay. The final project implementation report was completed in August 2014 (USACE and SFWMD, 2014a), after an intensive 2.5-year planning effort (see NRC, 2014). The administrative review of the project and the record of decision were completed in August 2015 (USACE and SFWMD, 2016g). The project was authorized by Congress in December 2016 in WRDA 2016. Construction has not begun and therefore, there are no project-related benefits to discuss.

Generation 4 Projects in Planning

This section describes aspects of several projects for which planning is under way or anticipated to begin soon, including the Loxahatchee River Watershed Restoration, Lake Okeechobee Watershed, and Western Everglades. Progress in project planning has important implications for the location and pace of future restoration progress, because completion and approval of project implementation reports followed by congressional authorization are required steps prior to federal restoration investments.

Loxahatchee River Watershed Restoration

The Loxahatchee River Watershed Restoration Project (Figure 3-1, No. 15) is a CERP project that had been expedited by SFWMD investment. 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. Plans for this project were suspended in 2011, but they have now been restarted and project delivery team is now doing preliminary work on the project implementation report (USACE, 2015d, 2016e).

Lake Okeechobee Watershed

The CERP Lake Okeechobee Watershed Project includes several CERP project components located north of Lake Okeechobee that were intended to increase habitat, reduce phosphorus loading into the lake, and provide additional storage to regulate extreme high and low water levels in Lake Okeechobee and reduce high volume estuary discharges. A general list of management measures to be considered in the project planning includes the 250,000 AF of total storage capacity, aquifer storage and recovery (ASR), wetland restoration, and improved flexibility within the existing lake regulation schedule, based on project features in the 1999 CERP plan.[10] This storage total is far below other estimates of storage requirements to satisfy flow targets in the estuaries. The

[10] Project Delivery Team, meeting of August 10, 2016. See saj.usace.army.mil/Missions/Environmental/Ecosystem-Restoration/Lake-Okeechobee-Watershed-Project/.

River of Grass planning process set a "conceptual level" estimate of storage north of the Lake in the range of 450,000–575,000 AF (Balci, 2010), and the Lake Okeechobee Phase II Technical Plan (SFWMD and FDEP, 2008) identified a storage goal of 900,000 to 1.3 million AF for the watershed under the assumption that no additional water from the Lake could be sent south.[11] A recent independent review by the University of Florida Water Institute (2015) determined that there is a need for as much as 1,000,000 AF of storage north or south of Lake Okeechobee to meet restoration goals for the northern estuaries. It is unknown whether additional storage would be considered during the project planning process to meet broader restoration goals or to address shortfalls in storage in other areas of the CERP (see Chapter 4). Planning began in August 2016; the initial array of alternatives was presented in November 2016. The CERP project would complement other state efforts on water storage and water quality north of Lake Okeechobee, including the Northern Everglades Estuaries Protection Plan, the Lakeside Ranch and Taylor Creek/Nubbin Slough STAs, and the Dispersed Water Management Program.

Western Everglades

The term "Western Everglades" is commonly used to refer to the Everglades landscape at and near the western perimeter of WCA-3A as delineated by the L-28 canal and the watershed reaching northward from this area (Figure 3-18). Although the Northern, Central, and Southern Everglades have been prominent in the CERP and closely related projects, the Western Everglades exist in relative obscurity. This obscurity cloaks the importance of the Western Everglades. Model simulations show that flows issuing from the Western Everglades represent more than 40 percent of inflows to WCA-3A (see Appendix B) and have substantial impacts to water management in WCA-3 and Everglades National Park. The L-28 Interceptor (Figure 3-19) diverts water from Big Cypress National Preserve into WCA-3A, contributing to high water levels and tree island flooding in the latter. In addition, the L-28 drains water out of Big Cypress southward toward the western marl prairie in Everglades National Park, contributing to overly wet conditions for Cape Sable seaside sparrows in that area (see ERTP later in this chapter) (FWS, 2016).

The habitats of the Western Everglades are directly shaped by water depth and topography. Generally, the area west of the L-28 canal is a landscape of pine flatwood forests and forests of cypress and palm trees (Figure 3-20), with elevations 1 to 2 feet higher than the central Everglades (Butcher, 2016). Prior

[11] SFWMD, Lake Okeechobee Protection Plan Update, March 2011. Section 6.3 Watershed Water Storage—Strategies and Promising Solutions.

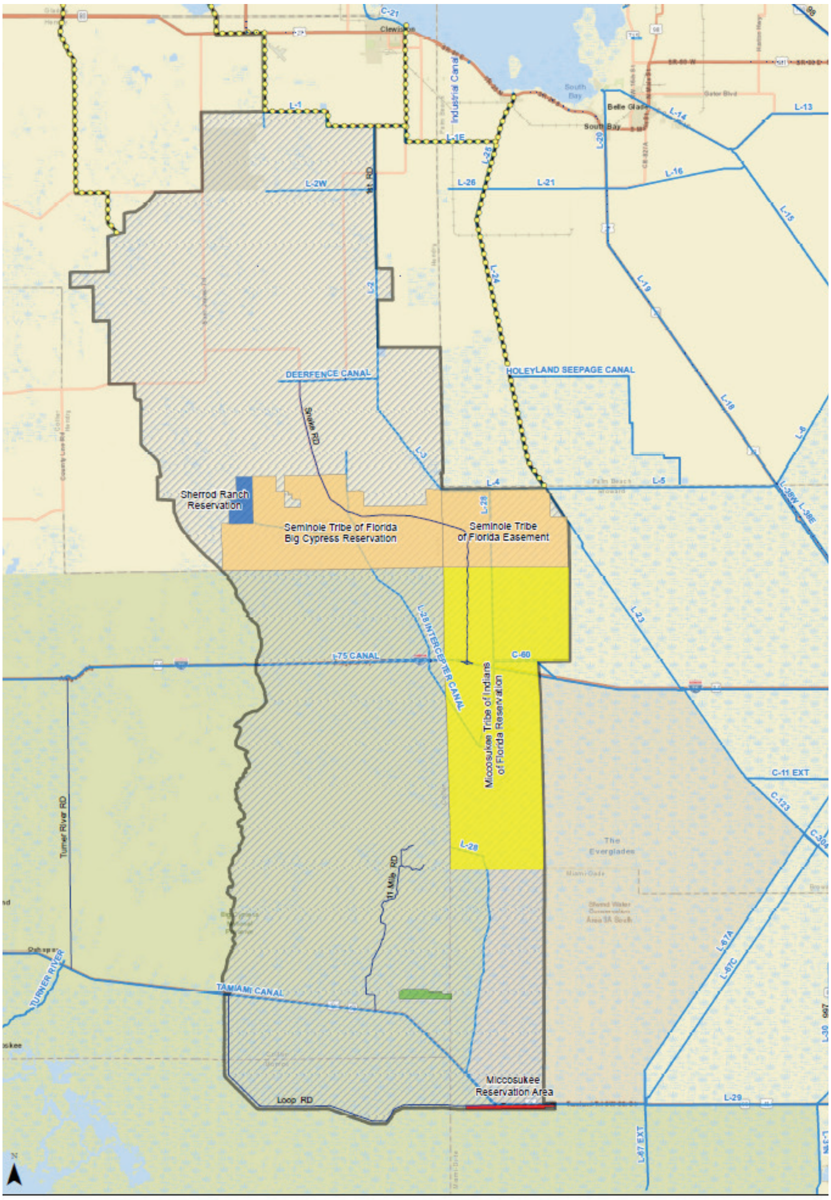

FIGURE 3-18 The officially defined geographic extent of the Western Everglades for the Western Everglades Restoration Project.

SOURCE: http://www.saj.usace.army.mil/Missions/Environmental/Ecosystem-Restoration/Western-Everglades-Restoration-Project/.

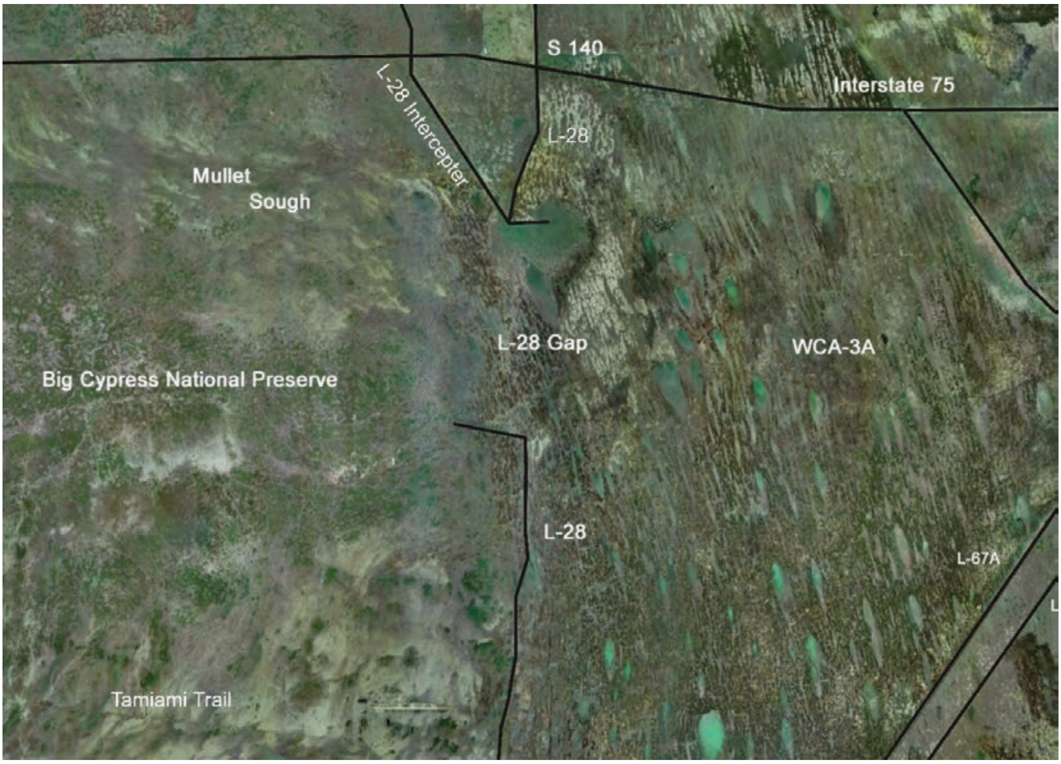

FIGURE 3-19 The transition area from the Everglades on the east (right) to the Big Cypress Swamp on the west (left) in the south-central western Everglades, showing the differences in the two geomorphic and ecological systems, and showing the willow forest as a circular dark green mass at the end of the L-28 Interceptor Canal.

SOURCE: Base image from Google Earth 2005.

to development, water flows in the vicinity of the Western Everglades were shallow-gradient unconfined flows generally from northwest to south and southeast, flowing through Mullet Slough into what is now WCA-3A to join the main Everglades flows (Figure 3-19). Canal drainage for agricultural development has disrupted these flows and over-drained natural areas.

Water quality is also a major issue in the Western Everglades. Waters issuing from the mostly agricultural landscapes located in the northern portions of the Western Everglades (including the C-139 basin and the Feeder basin) have elevated phosphorus content (Figure 3-21) and are of particular concern for

FIGURE 3-20 Typical ecosystem in Big Cypress Swamp with pond cypress and epiphytes, very different from the systems common in the Everglades.

SOURCE: W.L. Graf image.

the Miccosukee Tribe of Indians of Florida. One particularly visible ecosystem effect of these nutrient-enriched waters is a dense forest of willow (*Salix* sp.; Richardson, 2008) growing at the end of the northern stretch of the L-28 that appears as a dense thicket of vegetation expanding over ridge and slough as well as tree islands that were once used as Miccosukee camps (visible as a bright green halo at the end of the L-28 interceptor in Figure 3-19).

The Big Cypress/L-28 Interceptor Modification outlined in the Yellow Book (USACE and SFWMD, 1999) was developed to reestablish sheetflow across the Big Cypress Seminole Indian Reservation into Big Cypress National Preserve and address water quality concerns in the North and West Feeder Canals. A planning

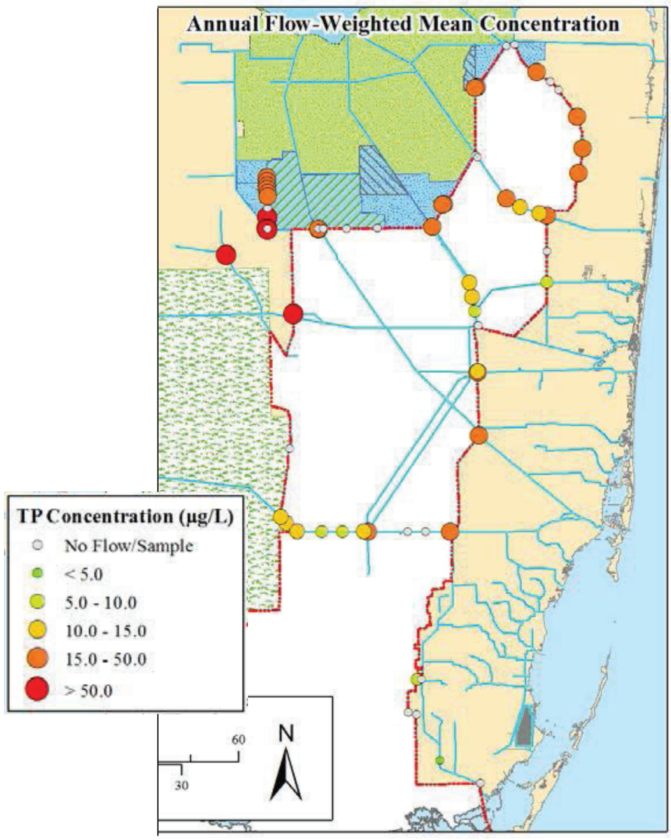

FIGURE 3-21 Annual flow-weighted mean total phosphorus concentrations at water control structures for WY2015 at stations across the Everglades Protection Area. The highest flow-weighted means are located in the Western Everglades project area.

SOURCE: Julian et al. (2016).

process was launched in August 2016 that describes its purpose as improving "the quantity, quality, timing, and distribution of water needed to restore and reconnect the western Everglades ecosystem."[12] Public meetings are under way

[12] See http://www.evergladesrestoration.gov/content/werp/meetings/082316/CERP_WERP_introduction.pdf.

to develop more specific project objectives and ultimately CERP project features, with the goal of a signed Chief's Report by 2019. The contributions of the water management system in the western Everglades to the adverse conditions experienced by Cape Sable seaside sparrows in western Everglades National Park highlighted in the recent jeopardy opinion (FWS, 2016) promises to focus more attention on water management in the western Everglades.

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, progress and key findings of the Aquifer Storage and Recovery Regional Study, and Decomp Physical Model (DPM) pilot projects are discussed.

Aquifer Storage and Recovery Regional Study

The CERP proposed completion of 333 ASR wells, which would store water within the upper Floridan Aquifer during wet periods for recovery for ecosystem purposes during seasonal dry periods. To evaluate and reduce uncertainties stemming from regional effects of large-scale ASR implementation in South Florida, the USACE together with the SFWMD conducted an 11-year ASR Regional Study (USACE and SFWMD, 2015b). The Regional Study involved synthesis of published literature, laboratory testing, field-scale experimentation at two pilot ASR sites, and regional-scale groundwater flow modeling.

Based on results of the model simulations, the Regional Study concluded that only 131 ASR wells, or 200 less than envisioned under the CERP, could be operated without regional effects on groundwater flow. The study acknowledged that further optimization of well placement could possibly permit a greater number of ASR wells, but these configurations were not identified in the technical data report. The study evaluated subsurface chemical changes that occurred during storage, and indicated that water-rock interactions reduced the concentrations of mercury and phosphorus in recovered water and that initially high levels of arsenic were lowered with additional cycles of recharge, storage, and recovery. Results of chronic toxicity testing and water quality modeling did not exclude the possibility of impacts to aquatic ecosystems that may receive recovered water but revealed few adverse effects. The study also examined the potential for hydraulic fracturing during aquifer recharge, concluding that expected operational pressures during water injection were insufficient to cause rock failure.

The National Academies convened a committee to review and evaluate the methods, principles, and data that formed the basis of the Regional Study. This committee endorsed the Regional Study's principal finding that no "fatal flaws" in ASR have emerged, but concluded that many uncertainties remain that warrant further consideration before large-scale ASR should be implemented (NRC, 2015). In particular, the committee recommended more research to (i) identify operation protocols that maximize freshwater recovery and minimize water quality impacts; (ii) reduce uncertainty associated with ecological risks of ASR to the Everglades; (iii) understand the unexplored benefit of ASR in phosphorus removal; (iv) improve disinfection of recharge water; and (v) establish the costs of ASR compared to other storage alternatives. The implications of a sharply reduced regional capacity for ASR are discussed further in Chapter 4.

Decomp Physical Model

One objective of the CERP is to restore the ridge-and-slough landscape of the central Everglades, a distinctive attribute of the historic Everglades that has been degraded by drainage and compartmentalization. It is now widely accepted that the structure of this landscape depends on flow (McVoy et al., 2011; SCT, 2003). Water flow forms and maintains the parallel arrangement of sloughs and ridges by governing the mobilization and redistribution of organic floc, sediments, and nutrients. Without flow, sediments and sawgrass invade open-water sloughs, tree islands drown, water quality deteriorates, and microtopography disappears. These changes, in turn, lead to habitat loss for wading birds and may encourage the proliferation of exotic fish at the expense of native species. Although the importance of flow is recognized and has been the focus of ongoing research at the Loxahatchee Impoundment Landscape Assessment since 2003 (see Box 3-3), the hydrologic conditions needed to restore and sustain the ridge-and-slough configuration are poorly known.

Restoration of flows associated with CERP implementation will be accompanied by decompartmentalization, which involves removal of levees and, possibly, canal backfilling. The need to remove levees to permit sheet flow and sediment transport is obvious; however, the appropriateness of canal backfilling is controversial because ecosystem responses remain uncertain. Recreational fishing interests resist canal backfilling, suggesting that it is unnecessary for wetland restoration and will reduce game-fish habitat and access to fishing areas. Scientists and managers have expressed concerns that failure to backfill canals may imperil landscape restoration by disrupting sheet flow, lowering sediment transport, providing deep water refugia for exotic invasive fauna, and altering phosphorus dynamics.

BOX 3-3
The Loxahatchee Impoundment Landscape Assessment (LILA)

LILA is a large-scale experimental facility designed to test the effects of hydrology on the structure of the Everglades landscape (tree islands), its associated biotic communities, and their interactions. Operational since 2003, it consists of four replicate 20-acre macrocosms, each with highly controlled flows and water depths to allow manipulative experiments on how hydrology generates and sustains the Everglades ecosystem (Figure 3-3-1). Key habitats were created within each macrocosm including tree islands (both limestone and peat based islands), ridge and slough habitat, and alligator holes.

As a model of the Everglades landscape, LILA has allowed a wide range of hypotheses to be investigated. Some of the results of LILA experimentation clarify the processes that create and sustain tree islands, which in turn provide critical wildlife habitat and are valuable as sites of carbon and nutrient sequestration (Rodriguez et al., 2014). Recent studies have emphasized the "trophic hypothesis" to explore the relationship between hydrology, prey availability (fish, crayfish), and wading bird foraging and reproduction. The hypothesis states that restoring the abundance and distribution of wading bird populations depends on establishing historical hydroperiods that will recreate the abundance and seasonal distribution of prey species, ultimately increasing nesting success (Trexler and Gross, 2009).

LILA serves as a laboratory for basic research that will aid in the adaptive management process by reducing decision-critical uncertainties, thereby improving the scientific base for decision making. For example, the improved understanding of prey habitat selection is being used to develop models used to predict the effects of water recession rates on foraging and nesting success. If the models can be used in real-time as planned, model output can inform daily water management decisions (RECOVER, 2012).

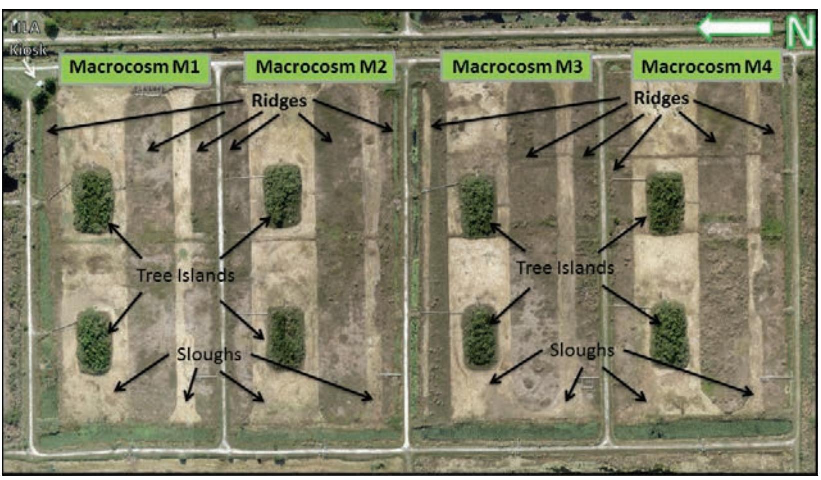

FIGURE 3-3-1 The Loxahatchee Impoundment Landscape Assessment includes four 20-acre test cells, each with two constructed tree islands and one constructed ridge, to examine the effects of hydrology on ecosystem function.

SOURCE: SFWMD.

The DPM was proposed as a large-scale active adaptive management project to help resolve these issues and better inform future restoration decision making regarding engineering design and operational targets. The pilot project is guided by questions focused on ecosystem responses to higher flows and canal backfilling (see questions in Box 3-4). 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" (see Figure 3-22). In preparation for the experiment, ten gated culverts on the L-67A canal (S-152) were constructed, and a 3,000-foot gap was created in the L-67C levee with three back-fill treatments in the adjacent canal. The canal was left completely open for the northern-most treatment, while the center and southern-most treatments have partial and complete backfills, respectively (Figure 3-22). A two-month flow experiment was initiated in November 2013 by opening the ten gated culverts that comprise S-152 (Figure 3-23). A second 3-month flow experiment was conducted starting in November 2014, and a 2-day pulse experiment, was executed in November 2015.

Currently in its third year of operation, the DPM has yielded important insights relevant to the questions in Box 3-4 that improve the understanding of how degraded portions of the ridge and slough landscape might respond to improved water deliveries. Analysis of field-based observations has delimited the flow velocities that must be achieved to mobilize floc and sediments from

BOX 3-4
Key Questions of the Decomp Physical Model Pilot Project

Sheetflow

- Does high flow cause changes in water chemistry and consequently changes in sediment composition, periphyton metabolism, and organic matter decomposition?
- To what extent do entrainment, transport, and settling of sediments differ in ridge and slough habitats under high and low flow conditions?
- What is the role of these processes in sustaining a stable ridge-and-slough landscape?

Canal Backfill

- Do canals need to be completely backfilled to achieve hydrologic restoration?
- 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?

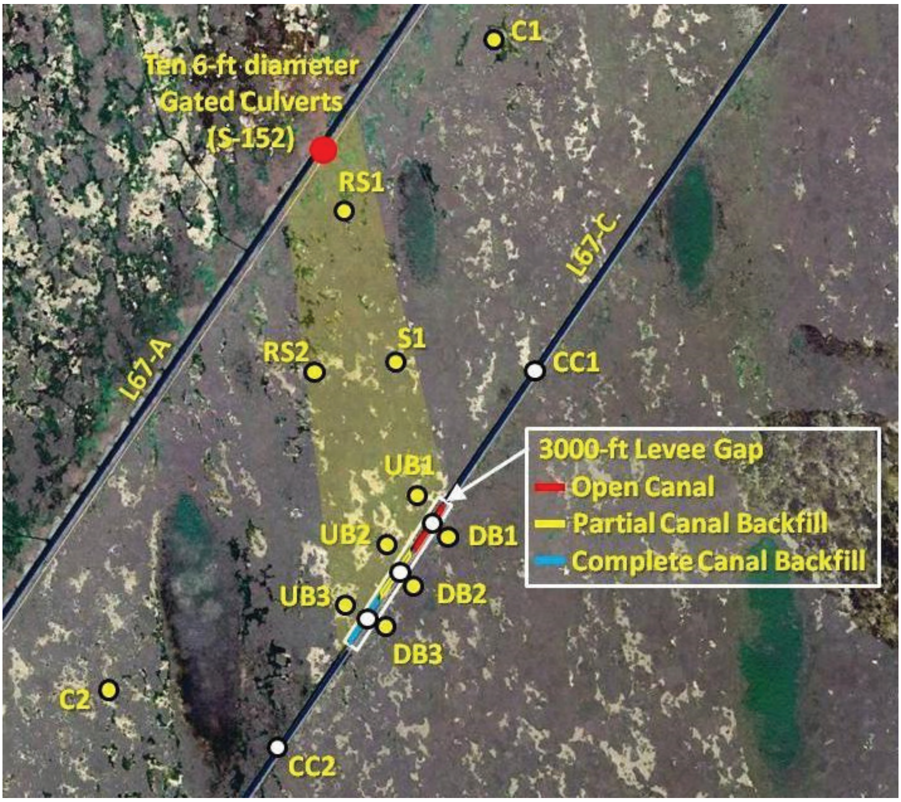

FIGURE 3-22 Map of the Decomp Physical Model located in "the pocket" between L-67A and L-67C.

SOURCE: Sklar (2013).

the slough and to transport these constituents onto adjacent ridges. This analysis suggests that the range of optimal velocities (0.025 to 0.1 m s^{-1}) is narrow and thus may be difficult to maintain across large swaths of the wetland (J. Harvey, USGS, personal communication, 2016). During the 2013, 2014, and 2015 experiments, optimal velocities were achieved over a small fraction of the wetland, ranging from 24 to 48 acres. Flow velocities are sensitive to the fraction of sawgrass, which influences flow resistance (Harvey et al., 2009; Nepf, 1999), but the results of model simulations suggest that the area of optimal flow could be expanded by increasing inflows. In addition to the velocity of restored flows, the duration of restored flows appears to be influential. Short-duration pulses

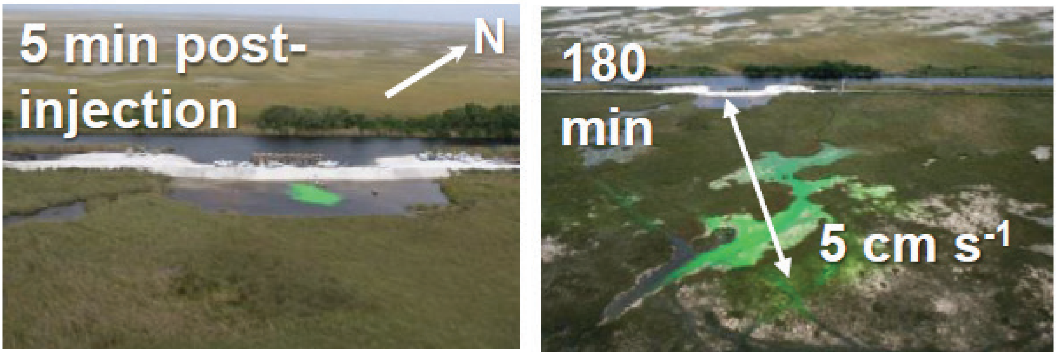

FIGURE 3-23 Dye-tracer distribution during the 2013 restored flow experiment. The L-67A canal and S-152, which is the source of additional water for the experiment, appear in the background.

SOURCE: J. Harvey, USGS, personal communication, 2016.

were found to mobilize the highest concentrations of suspended sediments from the bed and metaphyton, but the sediment sources were quickly depleted. Hence, pulsed high flows may have a limited effect on slough-to-ridge sediment exchange. Sustained high flow, on the other hand, promoted periphyton sinking, break up, and transport that increased sediment transfer from sloughs to ridges. This slough clearing is a self-reinforcing process that further increases flow velocities, which, in turn, entrains and redistributes greater loads of sediments.

The DPM has also begun to illuminate how flow enhancement interacts with landscape modifications that accompany restoration. The data show that sheetflow characteristics, as well as sediment and phosphorus dynamics, are sensitive to the way in which canals are backfilled. For example, unfilled portions of L-67C were discovered to be hot spots for sediment and phosphorus accumulation, while canal backfilling decreased sediment-phosphorus levels. Canal backfilling was also discovered to create more high-quality habitat, leading to the increases in the abundance of large fish. The results to date suggest that canal backfilling affects biogeochemical and ecosystem functioning, but the results are not definitive and are confounded by problems encountered during the restored-flow experiments. In particular, the canal backfill treatments were discovered to be misaligned with the center of experimental flows through the marsh, which led to rerouting of flow and sediments down the L-67C canal and preferential flow over the northern end of the levee gap (Figure 3-24). The disparity between anticipated and actual flow patterns complicates estimates of water, sediment, and phosphorus budgets for L-67C backfill areas, thereby increasing

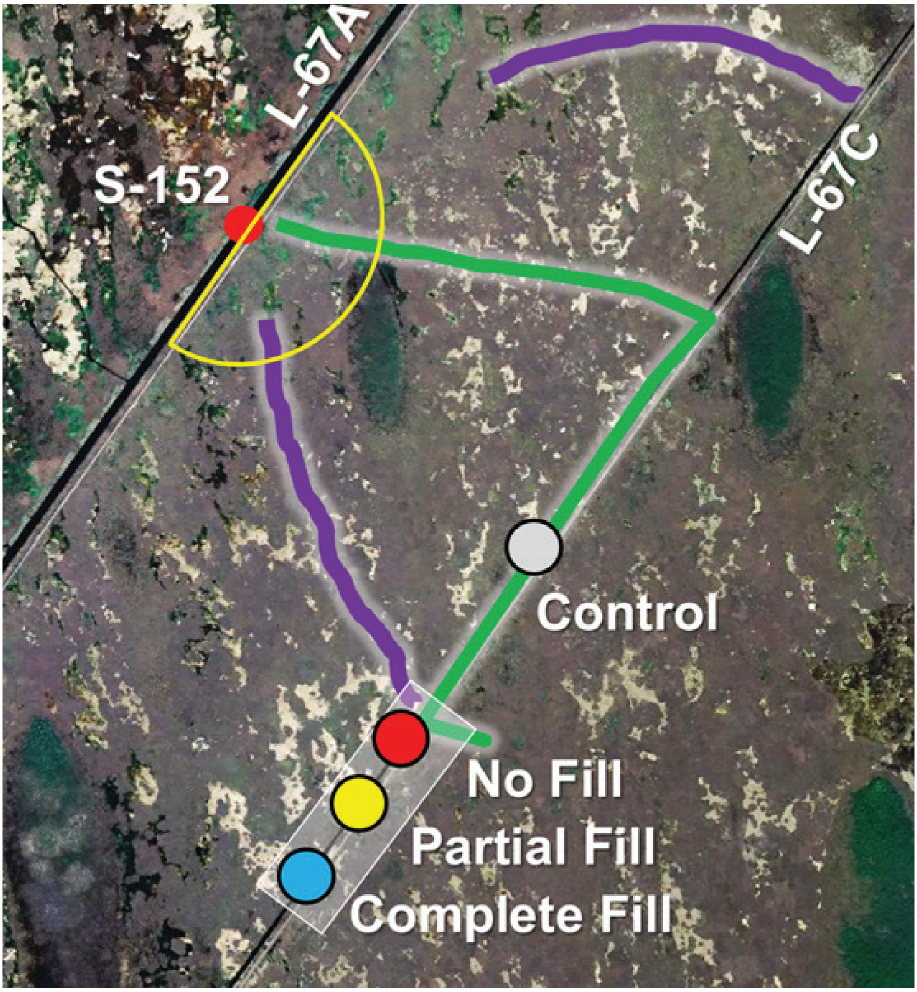

FIGURE 3-24 Surface-water flow directions during the 2013 DPM experiment as resolved by dye (green) and SF_6 (purple) tracers. The direction of surface-water flow exhibited a greater eastward component than expected, leading to short-circuiting of flow down the L-67C instead of across the canal-fill treatments.

SOURCE: J. Harvey, USGS, personal communication, 2016.

uncertainty of inferences on the coupled hydrologic and biogeochemical effects of the backfill treatments. Improvements of the canal backfill experimental design may be feasible but would be expensive to construct. As an alternative, high resolution measurement of water quality and flow velocities using raft-mounted equipment could be used to complement fixed station measurements.

When considered together, the findings from the DPM have improved our understanding of hydrologic and water-quality changes that occur rapidly, soon after the onset of restorative measures. Despite these advancements, the DPM has yet to illuminate how the cumulative effects of these changes will shape the landscape. Existing knowledge is insufficient to predict sediment and floc accretion rates along ridges and tree islands as a function of flow rate, so estimates of time scales for larger-scale improvements in topography and pattern restoration remain beyond our reach. Similarly, the feasibility of achieving and maintaining flow targets over large portions of wetlands exhibiting spatiotemporal heterogeneity with respect to vegetation density and microtopography remain poorly understood. The role of unfilled and backfilled canals as sources (or sinks) of phosphorus and sediments over inter-annual time scales is equally uncertain. These limitations stem from the challenges and vagaries inherent to large-scale experiments in natural systems, as well as insufficient time to detect the effects of restorative interventions on ecosystem improvements that occur gradually, perhaps over a period of decades.

The DPM is authorized through January 2017, with funding in place for a fourth controlled-flow experiment in fall 2016. The SFWMD and USACE are seeking to extend DPM for 3 more years, pending completion of a supporting National Environmental Policy Act documentation and provided funding can be secured.[13] If DPM does proceed beyond January 2017, DPM managers should consider cost-effective modifications to the experimental design to better elucidate if (and when) the short-term phenomena observed to date lead to ridge-and-slough restoration. These modifications might involve extending the current operational window of DPM beyond the dry season to include wet-season flows, while shifting to lower frequency sampling appropriate for understanding longer-term ecological responses to higher flows, thereby informing future project design. Placing an emphasis on marsh-based measurements up-gradient of L-67C may be most advantageous, unless the feasibility of addressing the canal-backfill questions considering shortcomings encountered in the previous experiments can be firmly established.

[13] Note that the DPM is statutorily constrained as a set of temporary features to obtain data to inform the potential design of future decompartmentalization efforts. The time-limited nature of this effort is required by WRDA 2000, which specifically prohibits appropriations for construction of decompartmentalization projects until the completion of the Modified Water Deliveries project (discussed later in the chapter).

NON-CERP RESTORATION PROGRESS

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. New information on major non-CERP efforts are reviewed in this section, with emphasis on natural system restoration benefits or implications for CERP progress. Projects discussed include the Modified Water Deliveries Project, C-111 South Dade, ERTP, the Limestone Products Association L-31N seepage management project, Everglades water quality improvements, the Kissimmee River Restoration Project, invasive species and the Herbert Hoover Dike rehabilitation.

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 insufficient inflows. In 1992, the General Design Memorandum (GDM) 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). Increasing the flow of water from WCA-3A into Northeast Shark River Slough is a central aspect of Everglades restoration, and the capacity for successful southward movement of waters provided by the Central Everglades Planning Project and other future CERP projects depend critically upon the conveyance, seepage management, and flood control provided by Mod Waters. Hence, completion of Mod Waters is essential to the ultimate success of the CERP. An extensive discussion of the history and details of this long-delayed project was provided by NRC (2008), and updates on progress are provided in each of the three succeeding NRC biennial reviews. It is encouraging to begin this similar update by noting the National Park Service pronouncement that long-expected benefits from Mod Waters are finally reaching Everglades National Park (NPS, 2016b).

Mod Waters consists of four major components (SFERTF, 2014; USACE, 2016f):

1. Flood mitigation in the 8.5-square mile area, to protect residences and small businesses adjacent to the Park from possible resultant flooding
2. Conveyance and seepage control features,
3. Tamiami Trail modifications, and
4. Project implementation support.

The status of each component is summarized in Table 3-5, with additional details on the Combined Operational Plan provided in Box 3-5. The locations of the features are shown in Figure 3-25.

The components of Mod Waters have been substantially completed, with 93 percent of the estimated $417 million cost (in 2016 dollars) obligated as of 2016 (K. Smith, USACE, personal communication, 2016). The remaining construction features are anticipated to be complete by 2017 (see Table 3-5). Although the 1-mile Tamiami Trail bridge is now the sole bridging feature within Mod Waters, the Tamiami Trail Modifications: Next Steps Project is under way as a separate initiative, with funding to support a 2.6-mile western bridge from the State of Florida, the National Park Service, and the Federal Highway Administration (FHA, 2014; NPS, 2016c; Scott, 2013). Construction on the western bridge began in November 2016, with anticipated completion in 2020.

The new facilities present under Mod Waters and C-111 South Dade (described in the next section) necessitate a modified operations plan for the region—the Combined Operational Plan (see Box 3-5). Currently, the Everglades Restoration Transition Plan (ERTP; George, 2016) defines operations for the con-

TABLE 3-5 Summary Status of Mod Waters Components

Component	Work Completed	Work Remaining	Anticipated Completion
Flood Mitigation in the 8.5 square mile area	Land acquisition; construction of levee, seepage canal, pump station	Additional seepage canal (C-358) and water control structure (S-357N) to assist with flood mitigation	2017
Conveyance and Seepage Control	• Spillways S-355A and B in the L-29 levee, • S-333 modifications, • Tigertail Camp raising, • S-356 pump station, • Degradation of 4 of 9 miles of the L-67 extension canal and levee, • S-331 command and control	None	Completed
Tamiami Trail Modifications	Raised roadway and 1-mile bridge completed in 2014	Land acquisition and right-of-way	2017
Project Implementation Support		• Monitoring • Incremental field testing of operations plan • Development of Combined Operations Plan	2017-2019, monitoring through 2025

NOTE: See Figure 3-25 for locations.
SOURCES: FHA (2014); George (2016); NRC (2012); Scott, R. (2013); USACE (1992, 2014b, 2016g); R. Johnson, DOI, personal communication, 2016.

BOX 3-5
Developing the Combined Operational Plan

The overarching operational objectives of the Mod Waters and C-111 South Dade projects are to increase flows from WCA-3A into Northeast Shark River Slough (NESRS), maintain higher water levels in Everglades National Park without exacerbating flooding in suburban and agricultural lands to the developed east, increase flows to Taylor Slough and Florida Bay, and reduce regulatory discharges from WCA-3A through the S-12 structures or south through the South Dade Conveyance Canals. The key indicator gage is G-3273 located near the 8.5 SMA (see Figure 3-25). During the three-phase implementation of the Combined Operational Plan, field testing and monitoring is used to evaluate the hydrologic response to the proposed new operations.

- **Increment 1** (2015-2017) relaxes existing constraints on gage G-3273, while maintaining the L-29 Canal at the current stage of 7.5 feet National Geodetic Vertical Datum (NGVD). Increment 1 is also designed to test seepage control provided by the S-356 pump station, which was designed to return seepage water back into Northeast Shark River Slough from the L-31N canal. Under current operating procedures, S-333 must remain closed when the G-3273 gage in NESRS is above elevation 6.8 feet NGVD. Increment 1 testing also includes reduced flow to South Dade from S-331 and conditional increased use of S-197 (USACE, 2015b).
- **Increment 1 Plus** (2017-2018) is an update to Increment 1 and was developed to incorporate lessons learned from the emergency deviation and incorporate the Reasonable and Prudent Alternative (RPA) from the July 2016 Everglades Restoration Transition Plan Biological Opinion (FWS, 2016). Increment 1.1 incorporates these changes while maintaining an L-29 Canal stage of 7.5 feet NGVD, and Increment 1.2 will allow the L-29 canal stage to be raised up to 7.8 feet NGVD under specific conditions. Increments 1.1 and 1.2 began operations on December 1, 2016.
- **Increment 2** (2018-2019) further relaxes constraints set by G-3273 and tests seepage control from the S-356 pump station. Increment 2 will build upon Increment 1 Plus operations by relaxing an additional constraint on S-333 and S-356 operations by allowing the L-29 Canal to reach a maximum stage of 8.5 feet (USACE, 2016g).
- In **Increment 3** (2019) the new combined operational plan for the system will be developed using data collected during Increments 1 Plus (1.1/1.2) and Increment 2.

If implemented according to plans, with full completion of the remaining Mod Waters and C-111 South Dade project elements, these two major non-CERP projects should be fully operational by 2019.

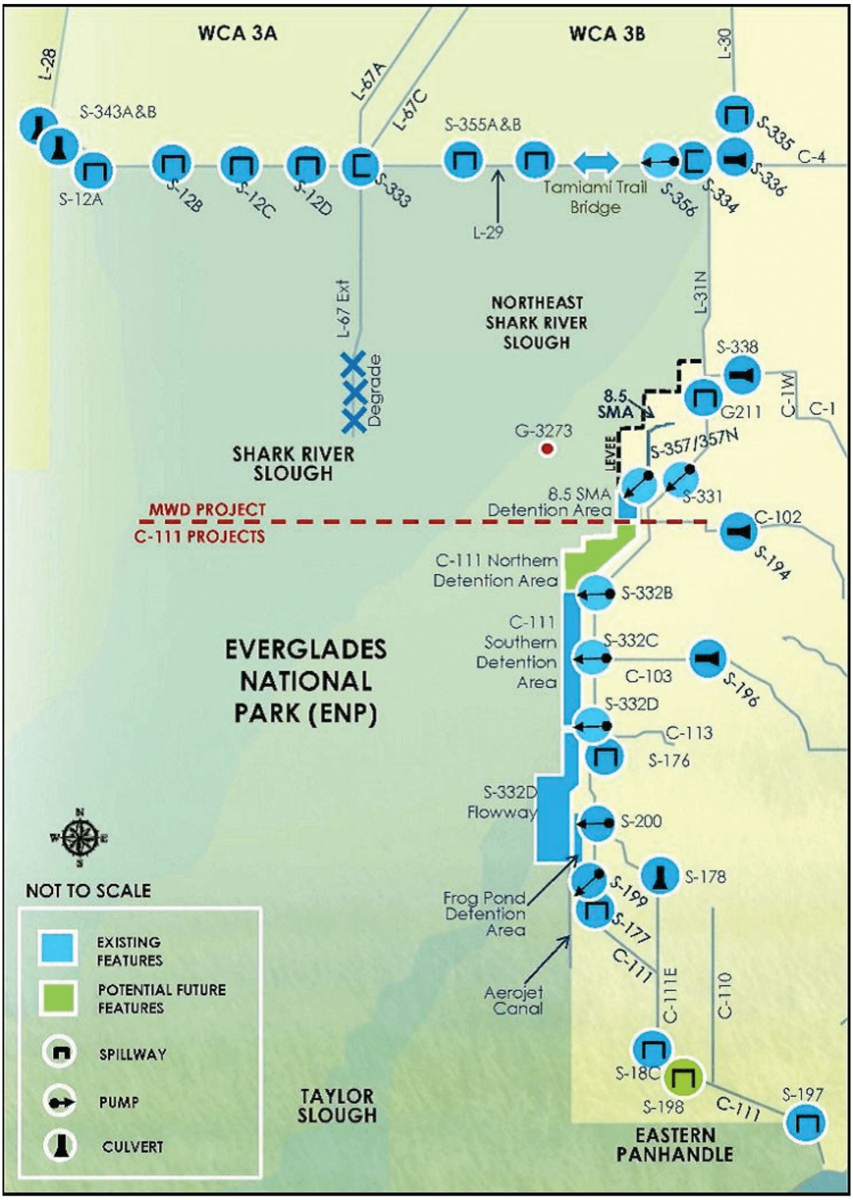

FIGURE 3-25 Elements of incremental implementation of Mod Waters and C-111 South Dade project components (above and below the dashed line, respectively).

SOURCE: USACE (2016f).

structed features of the Mod Waters and C-111 South Dade projects (described in the next section) until the Combined Operational Plan is implemented. In cooperation with Everglades National Park, the Corps of Engineers has begun a phased implementation of operations of Mod Waters and C-111 facilities in three increments to obtain data needed to develop the operating plan (see Box 3-5) (NPS, 2016b; USACE, 2016g).

Water quality and ecological monitoring are also components of the Combined Operational Plan development. It is important that seepage water from L-31N that is pumped back into Northeast Shark River Slough be of acceptable quality. Sampling at the S-356 intake during Increment 1 from October 2015 through January 2016 showed a flow-weighted total phosphorus mean of 7.1 parts per billion (ppb), with a range of 4-17 ppb (Riley, 2016). These values are consistent with a management goal of ≤ 10 ppb total phosphorus for water within the Everglades National Park (Julian, 2015) and are thus encouraging. Tracer testing during this time period demonstrated north to south flows into Northeast Shark River Slough near the 1-mile bridge (Rudnick et al., 2016). Dry weather for much of calendar year 2015 did not allow for a broader initial assessment of most flow-related natural system benefits of Mod Waters.

Unusually high rainfall during November 2015 through February 2016 in South Florida created systemwide flooding challenges (see Chapter 2). Mod Waters structural components allowed additional flexibility for movement of water during the emergency deviations. From February to May 2016, under the 2016 Temporary Emergency Deviation, L-29 canal levels were permitted to be raised up to 8.5 feet, allowing additional water to flow out of WCA-3A through S-333 into Northeast Shark River Slough (SFWMD, 2016f; USACE 2016h). This helped relieve record water levels in WCA-3A, while providing additional benefits to Everglades National Park and Florida Bay.

C-111 South Dade

As shown in Figure 3-25, the C-111 South Dade project provides the connection between Mod Waters to the north and the C-111 Spreader Canal (Western) project to the south (described earlier in this chapter). This major modification to the Central and South Florida (C&SF) Project's C-111 Canal was authorized in 1994 to maintain existing flood protection and other C&SF project purposes in developed areas east of C-111 while restoring natural hydrologic conditions in the Taylor Slough and eastern panhandle areas of Everglades National Park (USACE, 2015c). Increased freshwater flows in these areas also help conditions in Florida Bay.

The C-111 South Dade project consists of a combination of detention areas and levees, pump stations and structures, bridges, and backfilling (USACE, 2015b). The overall project contributes to maintenance of the hydraulic ridge along the C-111 corridor, discussed earlier. Approximately 87 percent of the $323 million total project costs (in 2016 dollars) have been obligated by the state and federal governments through FY2016, (K. Smith, USACE, personal communication, 2016). The South Detention Area was completed and operational as of 2010, and in October 2015, the Corps awarded the construction contract for the largest remaining component of the South Dade Project—the $13.9 million North Detention Area, also known as "Contract 8." The North Detention Area will connect the C-111 South Dade Project to Mod Waters (see Figure 3-25) and is scheduled for completion in October 2017. An additional contract known as "Contract 8A," awarded in September 2016, will construct interior flow-way berms and is scheduled for completion in 2018. The remaining contract ("Contract 9") will provide plugs and modifications to the L-31W canal and is scheduled for construction in 2017 and completion in 2018 (G. Landers, USACE, personal communication, 2016). Other storage and structural modifications have been implemented as part of the C-111 Spreader Canal (Western) Project and are operational. The C-111 South Dade Project will be operated and evaluated as part of the Combined Operational Plan described in Box 3-5. Preliminary benefits from the C-111 South Dade project features implemented to date were discussed earlier in the chapter, in the context of the C-111 Spreader Canal (Western) project.

Everglades Restoration Transition Plan

The current water management plan for WCA-3, the Everglades Restoration Transition Plan (ERTP, USACE, 2012a) reflects a multi-species approach to management of avian species of concern in WCA-3 and Everglades National Park (FWS, 2010). The ERTP was developed to improve conditions in WCA-3A for snail kites and wood storks and to maintain protection levels for the Cape Sable seaside sparrows in Everglades National Park. ERTP established targets for wet season high-water levels, recession rates, dry season low water levels, and ascension rates (USACE, 2011c). It is intended to provide greater operational flexibility relative to the previous water management plan, the Interim Operating Plan (IOP).

The ERTP has failed to produce significant improvement in water management for endangered species, missing many of its targets in its first 3 years of operation. For example, recession rate targets to provide foraging habitat for wood storks were in the optimal range 18-23 percent of the time and were sub-optimal 68-77 percent of the time (FWS, 2016). Generally, ERTP has improved conditions for snail kites modestly compared to IOP, but not sufficiently so to prevent continued degradation of kite habitat (FWS, 2016). The largest short-coming, however, has been its failure to achieve targets for the population of Cape Sable seaside sparrows located west of Shark River Slough (population A; see Figure 3-6). Hydroperiods in this area have far exceeded targets each year. Thus, conversion of marl prairie to marsh habitat unsuitable for sparrows has continued, and the overall sparrow population has fallen below the threshold established for incidental take. Emergency releases of water associated with excessive rainfall in the dry season of 2015-2016 created even greater challenges to ERTP. Some water was released through the S12s to avoid overtopping, and subsequent release occurred through the S344 (located on the L-28 canal) under a planned emergency deviation, adversely affected breeding conditions for sparrows in population A. Against this backdrop of less than desired performance, a lawsuit was filed against the FWS, Department of Interior and USACE based on the claim that the ERTP has failed to protect the endangered sparrows.[14]

As required under the Endangered Species Act and in order to continue operations until the Combined Operational Plan is completed, the Corps reinitiated consultation with the FWS on ERTP in November 2014. In its biological opinion released in July 2016, FWS (2016) concluded that continued water management under the ERTP would affect but not jeopardize the wood stork, the snail kite and its critical habitat, and the critical habitat of the Cape Sable seaside sparrow, but would jeopardize the continued existence of the sparrow. The FWS identified a single Reasonable and Prudent Alternative for the Corps to consider, which includes closing the S12A and S12B structures from October to July 15, raising the stage of the L-29 canal in increments, and using the S-333 for preemptive releases of water. All of these measures will result in more movement of water through Northeast Shark River Slough, thereby increasing restoration benefits to this region, while reducing flows (and associated adverse impacts) in western Shark River Slough. To a large extent, the Reasonable and Prudent Alternative follows the existing plan to develop the Combined Operational Plan (Box 3-5), requiring the ability to raise the L29 canal stage to 7.8 feet by March 2017 (termed Increment 1 Plus; see Box 3-5) and implementation of Increment 2 by March 2018, as allowable by law. The Reasonable and Prudent Alternative in addition includes a provision to explore backfilling the L28 canal and other measures to reduce harmful flows from the northwest out of Big Cypress National Preserve into the western portion of population A (FWS, 2016). At this writing, the USACE has responded with specific actions that they will take to comply with the Reasonable and Prudent Alternative (Kirk, 2016).

[14] Pimm & Bass v. U.S. Fish and Wild Service & U.S. Army Corps of Engineers, No. 1:15-cv-00657 (DC, filed April 30, 2015). The lawsuit was voluntarily dismissed by the plaintiffs in October 2016.

Limestone Products Association Seepage Barrier

Seepage management, in the context of the CERP, involves regulating the exchange of groundwater from natural areas into developed areas, which are separated from one another by canals and levees. 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. A 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.

Substantial progress on seepage management is associated with a non-CERP project sponsored by the Limestone Products Association. The initial phase of this project began in 2012 with the construction of a 2-mile long seepage barrier as a pilot project (Figure 3-26). In the second phase of the project, completed in

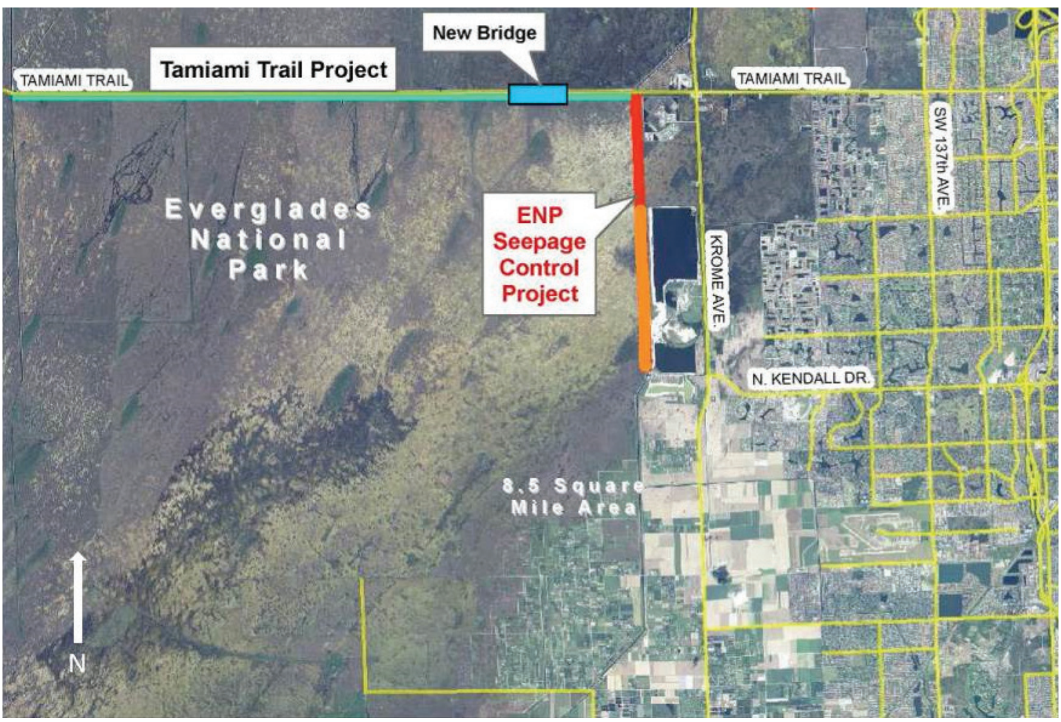

FIGURE 3-26 The 2-mile-long, 35-foot-deep seepage barrier pilot project (shown in red) and the 3-mile extension (shown in orange) are located west of the L-31N Canal. The pilot was completed in 2012, and the 3-mile extension was completed in 2016.

SOURCE: MacVicar (2014).

2016, the barrier was extended to a total length of 5 miles. Construction of the barrier involved excavating a 32-inch wide trench to a depth of 35 feet below the ground's surface (Figure 3-27). The trench was filled with a concrete-bentonite slurry formulated specifically for this application.

Hydrologic monitoring began in 2004, 8 years prior to construction of the seepage barrier and has continued since that time. Although there has been insufficient opportunity to evaluate the performance of the 3-mile extension, more than 3 years of data have been collected since completion of the initial, 2-mile portion of the barrier. These hydrologic measurements reveal that installation of the barrier has increased head gradients between northeast Shark River Slough and the L-31N canal without increasing seepage into the canal (Figure 3-28). That is, for a similar amount of seepage loss to the canal, the barrier provides an additional 0.4 feet of hydraulic head within the wetland to drive sheet flow southwest through Shark River Slough.

These observations are encouraging and suggest that the 2-mile pilot project is thus far satisfying its original objectives. More time is needed to characterize the effects of the 3-mile extension under appropriately broad ranges of operational and hydrologic conditions. In future analyses, the response of surface-

FIGURE 3-27 Southward-looking view of seepage barrier trench, excavated along the western side of L-31N.

SOURCE: MacVicar (2016).

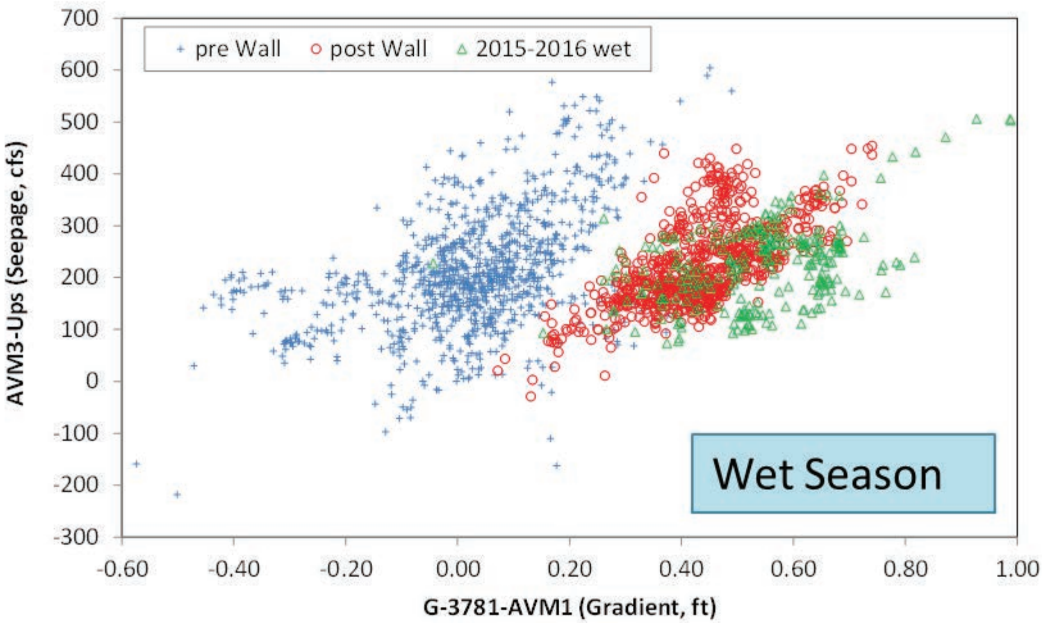

FIGURE 3-28 Seepage into L-31N for pre-barrier and post-barrier conditions as a function of the difference in hydraulic head between the wetland (G3781) and L-31N (AVM1). Pre-barrier data were collected from 2004 to 2011 and post-barrier data were collected from 2012 to June 2016.

SOURCE: MacVicar (2016).

water flow in Northeast Shark River Slough to the increases in hydraulic head should be assessed through hydrologic modeling.

Everglades Water Quality Initiatives

Achieving water quality goals—specifically total phosphorus levels—is critical to progress in moving water into the Everglades Protection Area (see Chapter 2), and therefore, progress addressing water quality throughout the watershed has implications for CERP progress. Additionally, water quality affects the capacity to reach CERP ecological objectives regarding habitat quality in Lake Okeechobee, the northern estuaries, the remnant Everglades, and Florida Bay. For example, the massive harmful cyanobacterial blooms that occurred on Lake Okeechobee and in the St. Lucie Estuary during the summer 2016 (see Box 2-2) caused by unnaturally high levels of phosphorus and nitrogen in the lake are inconsistent with long-term CERP goals. Thus, water quality trends and progress on major state water quality initiatives are reviewed in this section.

Lake Okeechobee Watershed Nutrient Reduction Programs

The state of Florida recently adopted a Lake Okeechobee Basin Management Action Plan (BMAP) focused on six sub-basins located north of the lake. The plan builds on decades of actions completed under the Lake Okeechobee Watershed Construction Project and provides an enforceable framework to achieve restoration. This program supplements existing efforts north of the lake to improve water quality, including the Lakeside Ranch and Taylor Creek STAs, distributed water storage, and hybrid wetland treatment systems (Zhang et al., 2016). These projects are the latest in initiatives that have been happening since the 1980s in an attempt to reduce nutrient exports off of agricultural lands in the watershed, to reduce nutrient export from sub-basins, and ultimately to reduce the total phosphorus load into Lake Okeechobee to meet an EPA-mandated total maximum daily load (TMDL) of 140 metric tons/year (5-year moving average).

Despite these efforts, the phosphorus load entering Lake Okeechobee has not significantly declined since a phosphorus budget was first determined for the lake in 1974 (Figure 3-29). Since 2000, when the EPA established the phosphorus TMDL, the actual load has exceeded that 140 ton/year value (as a 5-year rolling average) by 211-440 tons/year, and over the last 5 years, the rolling-average load has exceeded the TMDL by 369 tons/year. As noted in NRC (2008), even when the external phosphorus loads are curtailed through the implementation of best management practices and other phosphorus management strategies into the watershed, legacy phosphorus associated with sediments and soils will continue to leach into the water, extending the time required for the lake to meet environmental goals. Reddy et al. (2011) estimated that there is sufficient accumulated phosphorus to maintain substantially elevated loads for the next 50-120 years.

Within the lake, where there is a total phosphorus target of 40 μg/L (Havens and Walker, 2002) upon which the TMDL is based, total phosphorus concentrations have significantly increased over the period of record (Figure 3-30). Although phosphorus concentrations have declined since the abrupt increase in 2004 and 2005 in response to three major hurricanes passing over the lake (Havens et al., 2016), total phosphorus has remained at approximately 120 μg/L over the last 5 years, or three times the in-lake target concentration. Although it appears that in-lake total phosphorus concentrations may have plateaued since 2000, other 10-year periods of record also give indication of a plateau, only for the lake to experience a further increase.

The increased phosphorus concentration over time in the lake while loads have not changed is a common phenomenon seen in lakes heavily loaded with

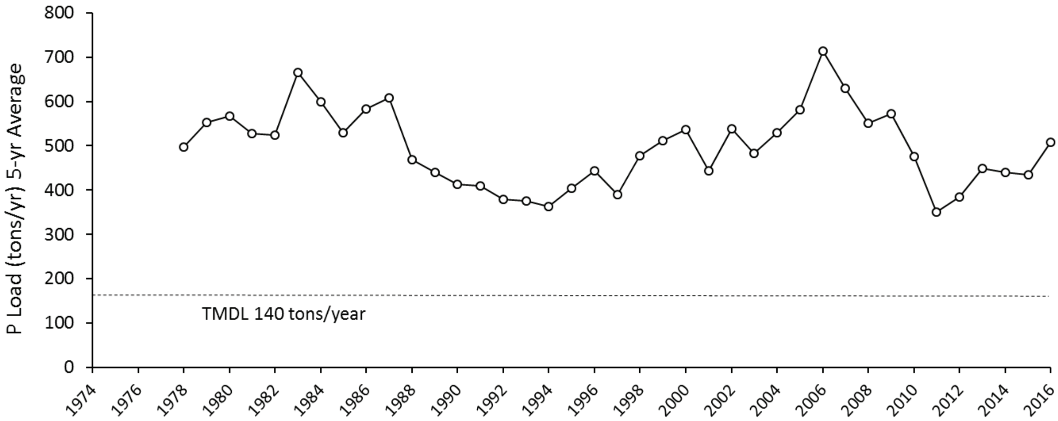

FIGURE 3-29 Phosphorus (P) loading to Lake Okeechobee from all sources including tributaries and precipitation, presented as 5-year rolling averages in order to draw comparisons with the EPA mandated total maximum daily load (TMDL) of 140 tons/year. A rolling average is over the 5 years ending at the indicated date.

SOURCE: Data provided by the SFWMD.

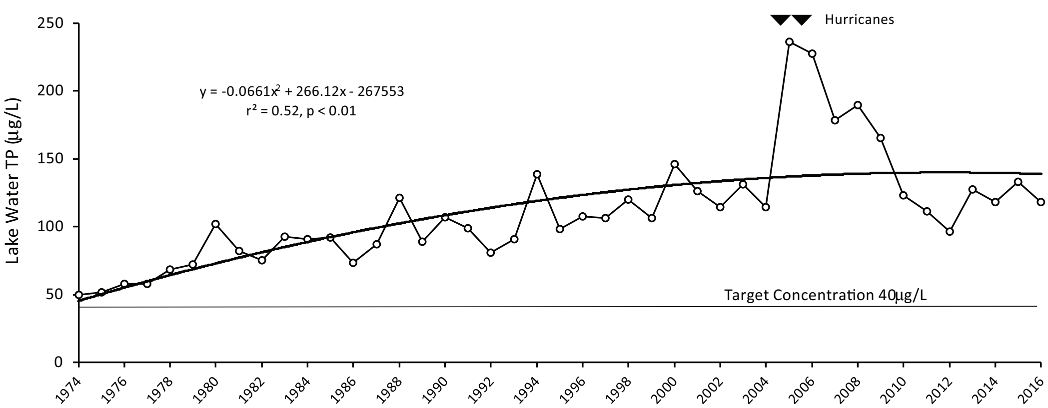

FIGURE 3-30 Yearly mean concentrations of total phosphorus (TP) in Lake Okeechobee, based on data collected at eight long-term monitoring stations. The dashed line is a polynomial regression that explains 52% of the variability in the data, and the triangles indicate the approximate times of occurrence of three major hurricanes that passed directly over the lake (two in September 2004 and one in October 2005). The target phosphorus concentration used to establish the TMDL also is shown as a dashed line.

SOURCE: Data from SFWMD.

phosphorus, as phosphorus-adsorbing sites on the lake sediments are saturated and no longer able to buffer the external inputs (Havens et al., 2007; Moss et al., 1997). This trend can be seen in Figure 3-31, a plot of the lake's phosphorus sedimentation coefficient,[15] which reflects a proportional sorption of phosphorus to the sediments. When the sedimentation coefficient reaches zero, the lake is no longer adsorbing phosphorus, and when it becomes negative, the lake has become a net source, adding phosphorus to what comes in from external sources. Now that the sedimentation coefficient is approaching zero, recovery of the lake after external phosphorus loads are reduced will require more time as the lake buffers itself against change (Moss et al., 1997).

The role of nitrogen inputs in cyanobacteria blooms and the need for increased attention to nitrogen loading to surface waters is currently an emerging scientific finding (Paerl et al., 2016b). Some recent research has suggested that it is necessary to control both phosphorus and nitrogen inputs to eutrophic lakes to effectively reduce the occurrence of cyanobacteria blooms (Conley et al., 2009; Lewis and Wurtsbaugh, 2008; Paerl et al., 2016b). In the case of Lake Okeechobee, cyanobacterial harmful algal blooms recently have been dominated by a species (*Microcystis aeruginosa*) that cannot fix N_2, and therefore it requires some level of nitrogen in the water. It is prudent for South Florida resource managers to stay abreast of the rapidly evolving literature on this controversial topic as it relates to the importance of simultaneous phosphorus and nitrogen control to reduce harmful algal blooms in lakes such as Okeechobee. Overall, nitrogen loads to Lake Okeechobee over the period from 1974 to 2016 have remained relatively steady, while there is a slight (but significant) decline in nitrogen concentrations in the lake.[16] See Box 2-2 for additional discussion of cyanobacteria blooms and the increased stresses posed by climate change.

Concentrations of nutrients in Lake Okeechobee have major consequences for the larger CERP restoration program because they affect the type and amount of treatment features that are needed downstream of the lake. Further, algal blooms in the northern estuaries, as seen in 2000 and 2016 (see Chapter 2), are

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[15] The sedimentation coefficient for a lake can be calculated in many different ways, including from the lake's phosphorus mass balance. The SFWMD calculates sedimentation coefficient in the following manner:

Sedimentation coefficient = $-1 * \{[\Delta M_L - (M_{in} - M_{out})] / M_L\}$

Where:

M_L is the mass of phosphorus in the lake in tons (average of monthly concentration of phosphorus times lake volume)

ΔM_L is the yearly (May 1 in year n to April 30 in year n+1) change in mass of phosphorus (tons) in the lake

M_{in} is the yearly mass input in tons from tributaries and rainfall

M_{out} is the yearly mass output in tons to outflow structures

[16] The committee calculated a linear rate of decline at –0.0098 mg/L/year at p=0.01 considering yearly mean concentrations of total nitrogen in Lake Okeechobee between 1974 and 2016.

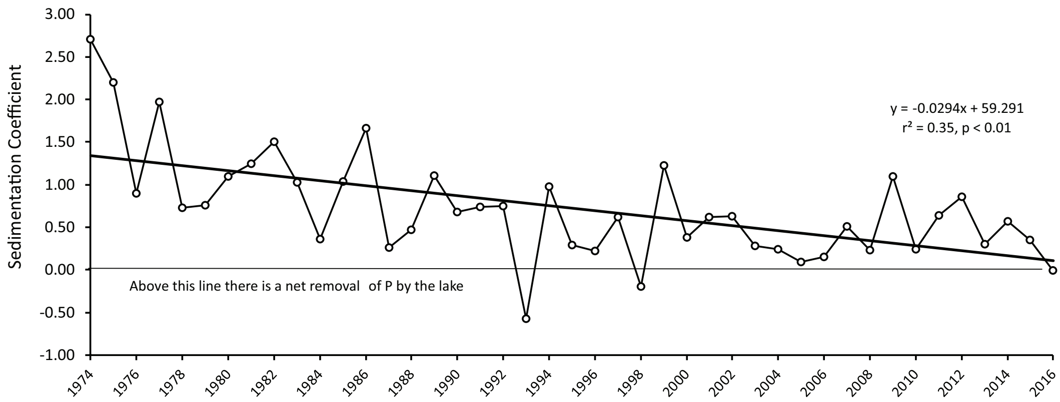

FIGURE 3-31 Historical trend in the phosphorus sedimentation coefficient of Lake Okeechobee (annual values calculated from the lake's phosphorus mass balance), reflecting the degree to which the lake is able to process incoming phosphorus into sediment storage. When the coefficient is positive, the lake is a net sink for phosphorus. When it is zero the lake acts as a flow-through system, with phosphorus inflow and outflow concentrations being approximately equal, and when it is negative, the lake is a source of phosphorus, with phosphorus in outflows exceeding phosphorus in the inflows. The dashed line is the model fit of a least-squares linear regression that explains 35% of the variation in the data.

caused by persistent high nutrient levels and affect the capacity to meet ecosystem restoration goals in those regions. See NRC (2008 and 2010) for further discussions of Lake Okeechobee water quality in the context of systemwide restoration goals.

Water Quality Treatment for the Everglades Protection Area

As part of its Long-Term Plan for Achieving Water Quality Goals, the state of Florida has completed construction of and now has approximately 57,000 acres of STAs, which are permitted to operate to treat phosphorus-contaminated water (Figure 3-32). Meanwhile, some enhancements to maintain or improve the performance of existing STAs were completed in WY2015, such as regrading some cells to decrease hydraulic short-circuiting and converting or reestablishing vegetation as needed (Andreotta et al., 2014).

STA Performance and Implications for the Everglades. Monitoring data presented in Chimney et al. (2015) and Pietro et al. (2016) indicate continued improvement in STA performance. Hydraulic loading rates for WY2014 and 2015 are comparable to relatively wet periods of the past (e.g., 2004-2006,

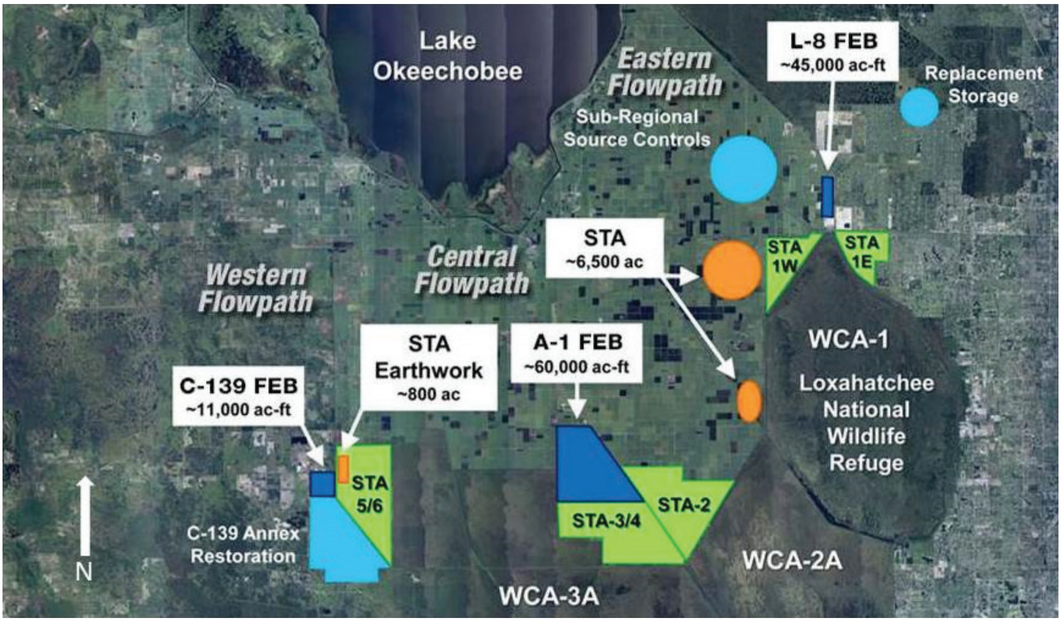

FIGURE 3-32 Location of the Everglades stormwater treatment areas (STAs): STA-1E, STA-1W, STA-2, STA-3/4, and STA-5/6 and the planned locations for additional STAs, STA earthwork, and flow equalization basins (FEBs) associated with the Restoration Strategies plan.

SOURCE: https://www.sfwmd.gov/sites/default/files/documents/map_restoration_strategies_2014.jpg.

2009-2010) while the outflow flow-weighted mean total phosphorus concentrations are less in the recent years than in the past. Indeed, the total phosphorus load retained hovers in the 80 percent range even in relatively wet years since 2009 (Figure 3-33). In WY 2015, flow-weighted mean total phosphorus was reduced from 99 ppb inflow concentration to 17 ppb in outflows, and 83 percent of the inflow total phosphorus load (138 metric tons [mt]) was retained. The outflow mean concentration of 17 ppb is the lowest achieved over 21 years of operation. Although none of the STAs produced a flow weighted mean of 13 ppb (the Water Quality Based Effluent Limit, or WQBEL, see Chapter 2), STA-3/4 came very close with flow-weighted means of 14 ppb and 15 ppb in WY2014 and 2015, respectively. Pietro et al. (2016) attribute the good performance of the Everglades STAs in WY2015 (except for STA-5/6), to a moderate water year with no major storm events or dry-outs (except for STA-5/6 cells dominated by emerging aquatic vegetation), consistently moderate phosphorus loading rates

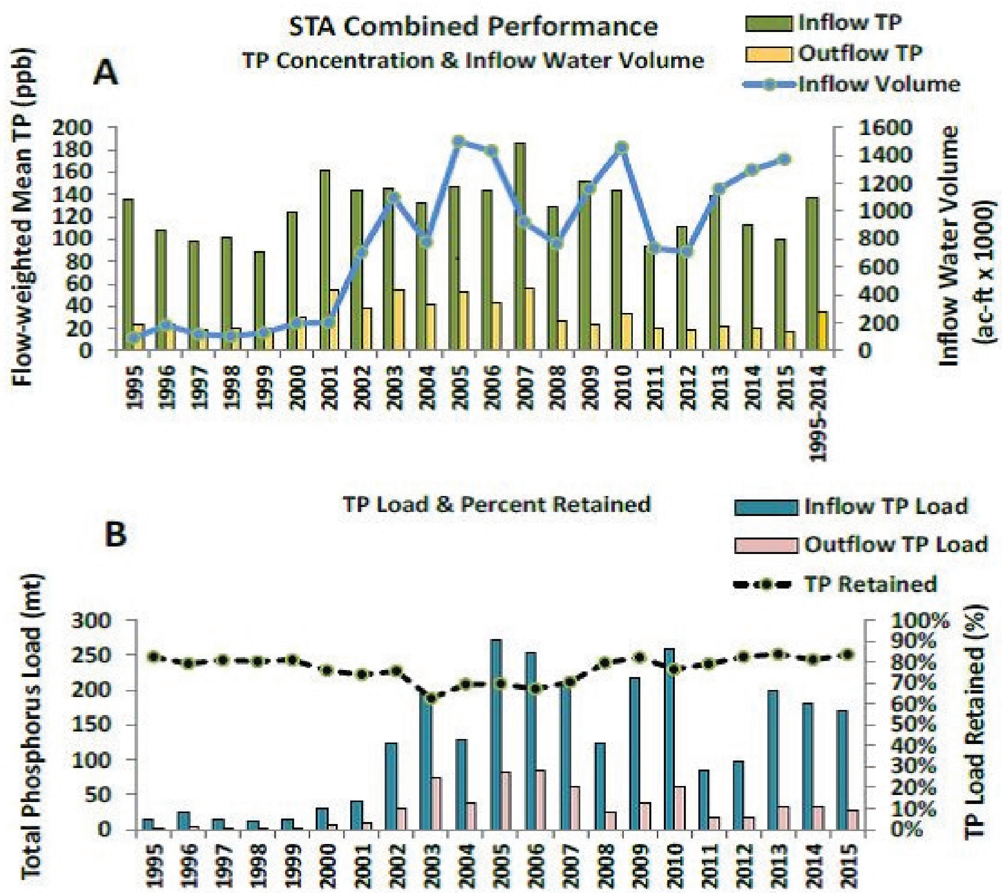

FIGURE 3-33 Summary of combined STA performance over the period of record, 1995-2015. (A) annual and POR average inflow and outflow flow-weighted mean (FWM) total phosphorus concentration and inflow water volume, (B) inflow and outflow total phosphorus load and percent phosphorus load retained.

SOURCE: Pietro et al. (2016).

for all the STAs, as well as the methodical operation of individual flow-ways using real-time information. Additionally, the SFWMD performed extensive vegetation management, improvement, and rehabilitation efforts across the STAs and graded the soil in one cell to maximize phosphorus removal efficiency (Pietro et al., 2016).

While simple in concept, wetland treatment of phosphorus-contaminated water in the STAs is a complex operation (see Box 3-6). Treatment cells may be taken off-line for maintenance and operational flexibility as well as to address water level needs of aquatic vegetation and migratory birds. From the available data, management schemes to date continue to produce good reductions in phosphorus, and additional reductions appear promising through efforts in the Restoration Strategies program (discussed later in this section).

The implications of the encouraging trends in STA performance can be seen in an examination of long-term trends in total phosphorus concentrations in the Everglades Protection Area (see Figure 3-34). The impact of STAs is very noticeable on inflow phosphorus levels into WCA-2 and WCA-3. As agricultural best management practices were initiated and STAs became operational during the Phase I (1994-2004) period, annual mean phosphorus concentrations were reduced markedly and became less variable compared to levels observed during the 1979-1993 period. The downward trend of inflow total phosphorus into the three WCAs is statistically significant when analyzed over the WY1979-2015 period of record (Julian et al., 2016). The same trend is not apparent in inflows to Everglades National Park, although total phosphorus levels within the park are consistently and generally well below 10 ppm. Overall, these trends are encouraging and should reduce the spread of cattails and enhance habitat conditions over time.

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 of contaminated water currently flowing into the Everglades Protection Area to meet the legally required water quality standard. The plan includes six projects that create approximately 6,500 acres of new STAs and 116,000 AF total capacity in three new FEBs, which are intended to moderate inflows into existing STAs and improve their treatment performance (Figure 3-32).[17] The Restoration Strategies plan was formally launched in September 2012, and the status of individual components is provided in Table 3-6, with completion of all projects set for 2025. Operational testing of the A-1 FEB is ongoing, and should soon result in improved performance for STA-2 and 3/4. Knowledge gained regarding the operations of FEBs can also be used to enhance the operations of the Central Everglades A-2 FEB, once constructed.

The Restoration Strategies program is supported by a $55-million water quality research program designed by the SFWMD (2013b, 2014b) in collaboration

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

BOX 3-6
How Stormwater Treatment Areas Remove Phosphorus

Water containing excess phosphorus is treated in STAs through various hydraulic and biogeochemical processes. Phosphorus is stored in soil and vegetation and microbial biomass.

Hydraulic Processes. Hydraulics is both a critical design and operational component for effective removal of phosphorus. After entering the STA via inflow structures, water velocity decreases mainly due to resistance from dense vegetation communities and causes phosphorus particulates to settle out of the water column.

Biogeochemical Processes. Several biogeochemical processes, which are unique to wetlands, lead to retention and release of phosphorus (Figure 3-6-1). STAs are designed, managed, and operated to optimize both short- and long-term retention/storage mechanisms and minimize the environmental conditions that contribute to phosphorus release (Reddy and DeLaune, 2008). Short-term storage processes occur through direct uptake by emergent vegetation (i.e., *Typha latifolia* and *T. domingensis;* Reddy et al., 1999) and/or periphyton (Reddy and DeLaune, 2008). Long-term storage occurs through phosphorus sorption, co-precipitation, and accretion**.** For phosphorus sorption to occur on mineral surfaces and particulates, the concentration in overlying water must be greater than the equilibrium concentration in the underlying soils/sediments. Inorganic phosphorus can also be removed via co-precipitation with minerals such as calcium. Accretion often refers to the accumulation of material within wetland biological growth (Reddy et al., 1999). The net accumulation of phosphorus in plant material can be influenced by vegetation type, characteristic of detrital material, and characteristics of overlying water column.

Role of Flow Equalization Basins. STAs work most effectively when the water and phosphorus inflows are moderated to meet the capacity of the treatment area. Too much flow and dry-down conditions can impact STA performance, sometimes for an extended period. Flow equalization basins provide upstream water storage to moderate the flow of water into an STA to optimize its performance under a range of hydrologic conditions.

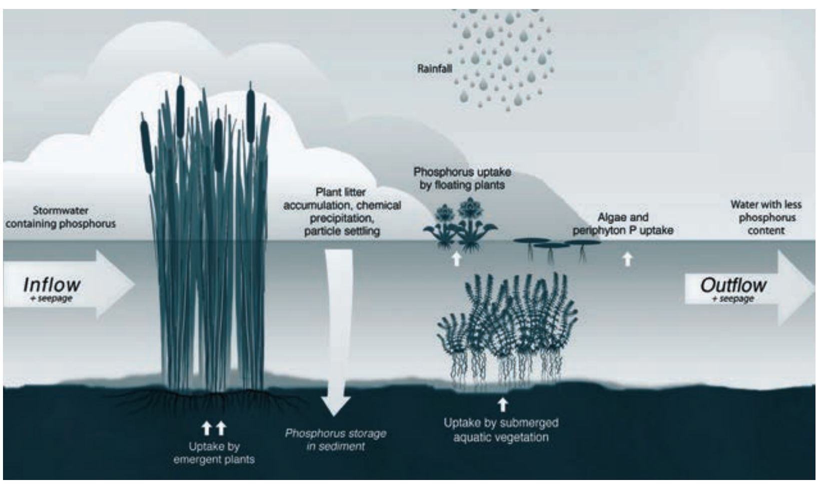

FIGURE 3-6-1 STA processes that remove phosphorus.

SOURCE: SFWMD (2014a).

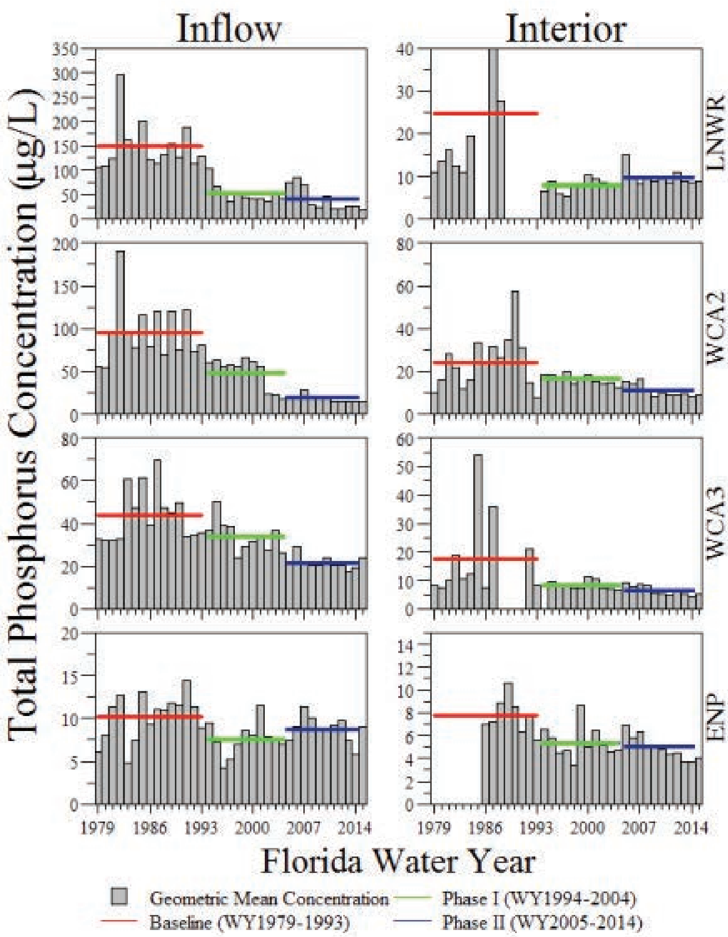

FIGURE 3-34 Annual geometric mean total phosphorus concentrations for inflow (left panels) and interior areas (right panels) of LNWR, WCA-2, WCA-3, and Everglades National Park for the period WY1979-2015. The horizontal lines indicate the mean annual geometric mean total phosphorus concentrations for the Baseline (WY1979-1993), Phase I (WY1994-2004), and Phase II (WY2005-2014) periods. Areas with no bars indicate data gaps. Additionally, for WY1987, LNWR interior annual geometric mean total phosphorus concentrations reached 85 µg/L (outside the current scale).

SOURCE: Julian et al. (2016).

TABLE 3-6 Summary status of Major Restoration Strategies Project Elements.

Component	Purpose	Status	Anticipated Construction Completion
Eastern Flowpath			
L-8 FEB	Attenuate flow into STAs 1E and 1W	Under construction	November 2016
L-8 Conveyance Features (G-716, G-341, G-541)	Assist movement of inflows and outflows to L-8 FEB	Under construction	April 2017
STA-1W expansion (Phase 1)	Increase STA-1W effective treatment area	Under construction	December 2018
STA-1W expansion (Phase 2)	Increase STA-1W effective treatment area	Not begun	TBD
Central Flowpath			
A-1 FEB	Attenuate flow into STAs 2 and 3/4	Ongoing operational testing and monitoring	July 2015
Western Flowpath			
STA 5/6 Earthwork	Improve the performance of STA 5/6	Design to begin in 2019	TBD
C-139 FEB	Attenuate flow into STA 5/6	Design to begin in 2019	TBD

SOURCE: http://www.sfwmd.gov/portal/page/portal/xrepository/sfwmd_repository_pdf/restoration_strategies_update_2016_aug.pdf.

with the U.S. Environmental Protection Agency and the FDEP. The Restoration Strategies Science Plan (SFWMD, 2013a; reviewed in NRC, 2014) identified six key questions (see Box 3-7) that need to be addressed to improve the understanding of various physical, chemical, and biological factors regulating the total phosphorus concentration in STA outflows. Eight ongoing 2013-2018 projects to address these questions and their status are described in Schwartz and Jacoby (2016). 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; see Chapter 2), which is currently a key dependency of moving new water into the Everglades via the Central Everglades Planning Project. Thus, the primary objective of the Science Plan is to improve understanding of the external and internal drivers that regulate the performance of STAs at low phosphorus concentration.

The eight ongoing studies listed outlined in Schwartz and Jacoby (2016) are well-developed toward practical and immediate needs for meeting phosphorus-removal goals in the STAs. This is understandable and appropriate given the concern to meet WQBEL limits. However, as suggested by NRC (2014a), the single-

BOX 3-7
Key Questions Addressed by the Restoration Strategies Science Plan

1. How can the FEBs be designed and operated to moderate phosphorus concentrations and optimize phosphorus loading rates and hydraulic loading rates entering the STAs, possibly in combination with water treatment technologies, or inflow canal management?
2. How can internal loading of phosphorus to the water column be reduced or controlled, especially in the lower reaches of the treatment trains?
3. What measures can be taken to enhance vegetation-based treatment in the STAs and FEBs?
4. How can the biogeochemical or physical mechanisms be managed to further reduce soluble reactive, particulate, and dissolved organic phosphorus concentrations at the outflow of the STAs?
5. What operational or design refinements could be implemented at existing STAs and future features (i.e., STA expansions, FEBs) to improve and sustain STA treatment performance?
6. What is the influence of wildlife and fisheries on the reduction of phosphorus in the STAs?

SOURCE: SFWMD, 2013b.

minded focus on phosphorus cycling is noticeable, to the detriment of important analyses of the role of other macro-elements (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 macro-elements 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. As the initial 5-year studies conclude, future emphasis should include consideration of other macro-elements, such as carbon, nitrogen and sulfur on sustained STA performance, as well as the influence of extreme weather events.

The Kissimmee River Restoration Project

The Kissimmee River basin forms the headwaters of Lake Okeechobee and the Everglades to the south. Originally an integrated mosaic of aquatic habitats (lakes, wetlands, creeks, and the mainstem river and floodplains), the basin was severely altered when the 103-mile, meandering Kissimmee River was channelized in the 1960s to form the 56-mile long, 30-foot deep, C-38 Canal. Channelization caused widespread hydrologic and ecological change to the basin, including loss of in-stream habitat, drainage of the once-extensive floodplain wetlands, and replacement of floodplain wetlands with pastures. Populations of native fish declined and an estimated 90 percent of wading birds were eliminated (USACE, 2016i). The Kissimmee River Restoration Project was authorized in 1992 with the goal or restoring more than 40 square miles (or one-third) of the river-floodplain ecosystem and 44 miles of the river channel. Plans to accomplish this include backfilling 22 miles of the C-38 canal, removing water control structures, and reconnecting remnant river segments. This long-term project is nearly complete, with two phases of restoration construction completed and the remaining components of the other two phases estimated to be complete in 2020, including backfilling the last 9 miles of the C-38 canal and reestablishing flow in 16 miles of river channel (Koebel et al., 2016; USACE and SFWMD, 2015c; G. Landers, USACE, personal communication, 2016). Approximately 84 percent of the $754 million total project costs (in 2016 dollars) have been obligated by the state and federal governments through FY2016 (K. Smith, USACE, personal communication, 2016). The Kissimmee headwaters regulation schedule will be implemented after the river restoration is complete. Issues discussed in NRC (2014) regarding interagency conflicts over land acquisition and cost crediting, which delayed implementation progress, have now been resolved (Koebel et al., 2016), and only two construction contracts (the S-69 Weir and reinforcements of the C-37 embankment) are remaining to be awarded to complete the project (USACE, 2016j; A. Patterson, USACE, personal communication, 2016).

To evaluate project performance, the Kissimmee River Restoration Project adopted a monitoring program quite early in the project to track environmental responses to restoration efforts. Past reports of this committee (NRC, 2010, 2012, 2014) have documented the impressive hydrologic, geomorphic, and ecological responses of the Kissimmee restoration. Interested readers can consult Koebel et al. (2016) for the most recent synthesis of progress. Of note, the first meander breakthrough on the river in over 25 years took place in March, 2014 in the former Micco Run (Kissimmee River Restoration Project Phase I area), resulting from high flows in WY2015. The cutoff created an island, and an oxbow lake appears to be forming adjacent to what is now the main river channel (Figure 3-35; Cheek et al. 2015).

Planning for Invasive Species Management

Invasive species have plagued the Everglades for decades, despite continuing efforts to control them (Figure 3-36). Their impact on Everglades restoration

FIGURE 3-35 The newly formed meander cutoff in the area of Kissimmee River Restoration Project Phase I.

SOURCE: Koebel et al. (2016).

FIGURE 3-36 Double-crested cormorant (*Phalacrocorax auritus*), a native species, with non-native walking catfish (*Clarius batrachus*) in the Everglades.

SOURCE: David Policansky.

and progress in the attempts to deal with them were discussed extensively in the previous biennial review, along with some recommendations (NRC, 2014).

Several factors make South Florida more vulnerable to invasions by non-native species than many other regions. As in other peninsulas, the diversity of biological species and habitat types in Florida decreases toward its tip—South Florida. This peninsula effect (Busack and Hedges, 1984; Jenkins and Rhine, 2008, results from unidirectional colonization, primarily from the direction of the land mass and not from the surrounding ocean. Due to the peninsula effect, the animals and plants of South Florida have had to compete with a relatively small number of species. For this reason, they have been especially vulnerable to extinction after the arrival of people, the habitat modifications they impose, and the exotic animals and plants that always accompany them. South Florida is also vulnerable to invasions because human activities have created extensive habitat types not previously found in the area. Some introduced species are more likely than native species to be adapted to those habitats, and successful invaders of modified habitats may spill over into remnant original habitats. In addition, people bring non-native species with them to new areas, or import them once they have arrived, and those non-native species often escape into the environment. All these factors will ensure that the problem of invasive species in the Everglades will not disappear.

The NRC (2014) review concluded that despite dedicated efforts to manage invasive species in South Florida, 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." The committee added that it was "optimistic that the Strategic Action Framework being developed by the South Florida Ecosystem Restoration Task Force [SFERTF] would be a major step forward. . . ." It recommended the establishment of a "strategic early detection and rapid response (EDRR) system that addresses all areas, habitats, and species," and concluded that there was a lack of a "systemwide mechanism for prioritizing research on and management of invasive species," and a lack of research on "non-native species and their impacts to adequately inform prioritization efforts." In this section, the committee provides a brief update on efforts to manage invasive species since its last report.

The SFERTF released its Strategic Action Framework (SFERTF, 2015), which established four main strategic goals:

1. To prevent the introduction of invasive, exotic species;
2. To eradicate them through EDRR;
3. To contain their spread; and
4. To reduce and maintain the populations of invasive, exotic species at the lowest feasible levels.

These four goals are based on the invasion curve for exotic species (Harvey and Mazzotti, 2014), and should be viewed as being listed in priority order. Each goal was divided into two or three objectives, and each objective had several strategies, totaling 31 in all. The goals, objectives, and strategies appear to be consistent with the conclusions and recommendations in NRC (2014), although they do not provide a mechanism for prioritizing efforts. To address the issue of prioritization, the Task Force prepared a Preliminary Action Assessment Working Draft (SFERTF, 2016b), which is expected to be modified and revised as conditions warrant (C. Beeler-Kanderski, DOI Office of Restoration Initiatives, personal communication, 2016). The document represents the efforts of the assessment team to prioritize the 31 strategies according to their urgency, potential effectiveness, lack of current effort being expended on them, and the degree to which the strategies can be influenced by the Task Force and its members. Eleven priority strategies were identified from all four goals, but the majority of them focused on eradication through EDRR (Goal 2). For each priority strategy, the team reviewed current efforts and identified gaps that if filled, would support the strategy. The committee did not review the priority strategies and identification of gaps in detail.

Overall, the prioritized strategies generally reflect—or at least, are consistent with—the advice provided in NRC (2014), and the details, of course, go far beyond that advice in many cases. It is too soon to judge their effectiveness, which will depend in part on funding, continued cooperation among agencies and other entities, and the skill and energy with which the activities are carried out. Nonetheless, it appears that substantial progress in planning has been made—or at least delineated—in dealing with a pervasive and challenging problem. That progress builds on an already sound foundation.

Herbert Hoover Dike

The Herbert Hoover Dike (HHD) is a 143-mile structure surrounding Lake Okeechobee. Construction of over 80 miles of levee began in 1932 and the remaining structure was completed in the late 1960s. A Major Rehabilitation Report (USACE, 2000) identified erosion problems (seepage, piping, and erosion of the downstream embankment) that posed imminent risk to the people of South Florida, and in 2007, the USACE launched a major effort to rehabilitate the HHD. Between 2007 and 2016, the USACE invested more than $500 million in projects to reduce the risk of catastrophic failure, including 21 miles of cutoff wall, and has approved an additional 6.6 miles for construction by 2020, completing the cutoff wall along the southeastern portion of the dike (see Inundation Zone A in Figure 3-37; Bon, 2016; USACE, 2016k). The Dam Safety Modification Study (USACE, 2016l) proposed a revised rehabilitation plan for the dike based

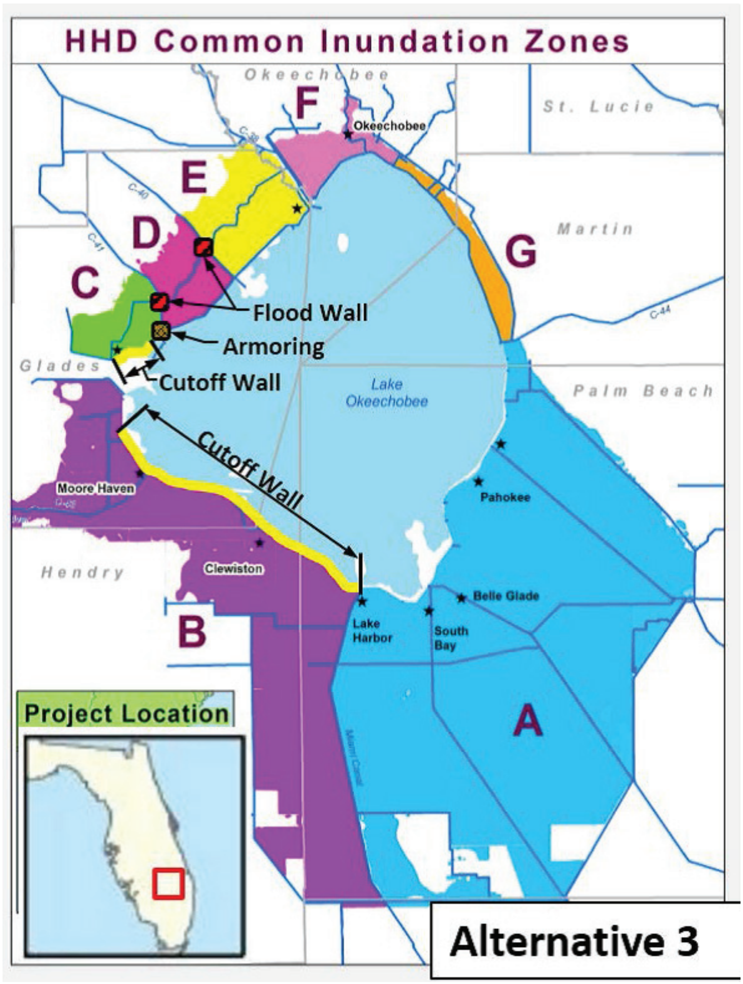

FIGURE 3-37 The approved plan for the HHD Dam Safety Modification Study. Letters indicate common inundation zones designated surrounding the lake.

SOURCE: USACE (2016l).

on an updated systemwide risk assessment. The modified rehabilitation plan includes an additional 28 miles of cutoff wall (Zones B and C in Figure 3-37), two embankment flood walls at two water control structures, and armoring of a bridge abutment—a substantially reduced plan compared to that in USACE (2000), while still meeting expectations for acceptable risk.

Integrity issues and concerns that led to the Dam Safety Modification Study also resulted in a new regulation schedule designed to limit high water levels in the lake and thereby reduce the risk of catastrophic levee failure until substantial progress is made on HHD rehabilitation. The Lake Okeechobee Regulation Schedule (LORS; USACE, 2007c, 2008), implemented in April, 2008, lowered the maximum stage from 18.5 feet to 17.25 feet NGVD (see Chapter 4 for more discussions of regulation schedule changes in Lake Okeechobee and implications for storage). Implementation of the recommended HHD modifications (USACE, 2016l) is expected to begin in FY2019 and take 5-7 years to complete, depending on funding (Bon, 2016). The Dam Safety Modification Study assumes that the current lake regulation schedule will continue into the future, at least until the recommended risk reduction measures are implemented, and does not propose to change LORS 2008 as part of the rehabilitation efforts. USACE (2016l) notes that "any proposed revisions to the current LORS will require an updated risk evaluation and be part of a future and independent lake regulation study for informed decision making. A study for a new regulation schedule could be undertaken concurrently while risk reduction features identified in the DSMR [Dam Safety Modification Study] are constructed."

With implementation of the proposed HHD modifications, higher water levels in Lake Okeechobee *may* be feasible as early as 2024-2026, which would provide substantial additional water storage. However, a process would need to be implemented to develop the new lake regulation schedule in a timely manner and determine whether higher water levels can be maintained with the updated HHD modifications without exceeding acceptable risk.

CONCLUSIONS AND RECOMMENDATIONS

Completed components of CERP projects are beginning to show ecosystem benefits. Several CERP project increments that have been completed or are nearing completion are beginning to yield measurable results, especially in terms of creating hydrologic conditions that are increasingly similar to pre-drainage flows. For example, portions of Picayune Strand are experiencing higher wet- and dry-season water levels even though the project is not yet complete, and vegetation is becoming more similar to reference conditions. The Biscayne Bay Coastal Wetlands project has enhanced wetland inundation for more than 1,600 acres of the project area, although nearshore salinity values remained above the project targets. The documented hydrologic improvements from the CERP to date, however, involve a small proportion of the overall restoration footprint and are located on the periphery of the remnant Everglades.

Major non-CERP projects are nearing completion, with documented early benefits and anticipated large-scale ecosystem restoration outcomes in the

heart of the remnant Everglades once fully implemented. After resolving procedural impediments that led to delays noted in NRC (2014), there is substantial progress under way on the Modified Water Deliveries (Mod Waters), C-111 South Dade, and Kissimmee River Restoration Projects, which are all anticipated to be completed in the next 5 years. Emergency deviations allowed additional water to flow under the Mod Waters 1-mile bridge in the spring of 2016, bringing enhanced benefits to Everglades National Park while reducing high water in WCA-3A. Continued attention to completing the few remaining project components and developing operational plans will help to avoid further delays in the delivery of these large-scale restoration benefits that the CERP will build upon. Rigorous monitoring is essential to document the ecosystem responses to these projects, to communicate restoration progress to decision makers and the public and to inform future restoration projects.

Water quality in the remnant Everglades continues to improve through enhancements in STA management and operation, but water quality entering Lake Okeechobee and in the lake and its outflows remains in a degraded state. South of the lake, STAs are currently removing approximately 80 percent of phosphorus from their inflows, and in WY2015 the flow-weighted mean outflow concentration for all STAs (17 ppb total phosphorus) was the lowest achieved over 21 years of operation. Although the target of 13 ppb has not yet been achieved, some STAs are approaching that goal. Improvements to STA operations are anticipated to continue as progress is made on Restoration Strategies projects and targeted research efforts. Continued progress on the quality of STA outflows is an essential prerequisite to additional and redistributed CERP flows in the central Everglades. In contrast, there is no long-term downward trend in phosphorus loading to Lake Okeechobee, despite implementation of projects that have reduced phosphorus export from agricultural land parcels and certain sub-basins. In the lake itself, phosphorus concentrations at over 100 ppb are more than double what they were in the early 1980s, and concentration of nitrogen also are high. As a result, outflows from the lake continue to contribute nutrient pollution to the estuaries, as evidenced by the algal blooms of 2016, and make it more difficult to reach CERP goals for those areas. Additionally, if high phosphorus loads into Lake Okeechobee are not reduced through more stringent nutrient management in the watershed, larger CERP STAs may be necessary for future projects that move lake water south.

Reports on CERP progress need to clearly describe ecosystem benefits by documenting changes in key indicators relative to expectations, goals, and baseline and/or reference conditions. Timely and effective reporting of CERP ecosystem benefits to decision makers and the public is critical to ensure accountability for those governmental entities that provide funding and for generating continued public support. So far CERP reporting has emphasized construction progress, but clear ecosystem changes are now evident for some projects and ecosystem benefits from other projects are likely in the near future. Therefore, additional attention is needed toward assessing and reporting CERP natural system restoration progress. Reports of CERP progress should describe the ecosystem effects predicted to result from the project relative to baseline and/or reference conditions and the time frame over which they are likely to unfold. Explaining the expected time frame for ecosystem effects is important because, although some ecosystem responses (e.g., hydrologic changes) are typically rapid, others (e.g., changes in vegetation structure) may unfold slowly. To avoid creating unrealistic expectations, funders, the public, and managers need to appreciate and understand why some important ecosystem benefits may only become apparent long after project implementation. Also, understanding ecosystem responses relative to expectations is necessary to support adaptive management and determine the need for subsequent management actions if benefits fall far short of project objectives. CERP reports of restoration progress should also describe and explain the key indicators that need to be monitored to document the predicted changes. This step could help communicate to decision makers the value of carefully chosen indicators and a well-designed monitoring plan that uses resources efficiently to address the needs of assessment and adaptive management efforts. Finally, the performance of individual projects should be linked to a holistic assessment of progress toward systemwide restoration objectives to support systemwide adaptive management (see Chapter 5) and to clearly communicate overall progress.

Although the outlook for CERP funding has shown modest improvements since the all-time low in FY2012, outlays of funds continue to fall short of what is needed to complete the CERP within the next 50 years. Increased CERP funding would expedite project implementation and the delivery of restoration benefits and ameliorate ongoing ecosystem declines. Recent Water Resources Reform and Development Act legislation, new project partnership agreements, and a more stable source of state funds have alleviated constraints on federal spending that had been caused by state-federal 50-50 cost-sharing requirements for the CERP. Although construction is underway on six CERP projects, the pace of progress is dependent on funding. Sixteen years into the restoration (roughly half the original timeline of the CERP), only 16 to 18 percent of estimated total cost has been funded. Thus, substantial additional investment is needed to complete the project as envisioned.

Conflicts between restoration objectives and the needs of protected species are issues that require programmatic solutions. The creation of new wetlands and alterations in hydrology in Everglades restoration creates potential conflicts between broad restoration goals and the specific needs of protected species. The frequent nesting of stilts and snail kites in the STAs affects operations of most flow-ways and a large percentage of individual STA treatment cells. Protecting stilts and kites potentially conflicts with restoration goals related to water quality, although the effect on overall STA performance has not yet been quantified. Documenting the reduction in STA performance due to protection of nesting birds is critical to determining the importance of this conflict. In addition, restoration activities that produce net benefits for a species at the system scale can often create negative, local impacts on that species. Thus, conflicts emerge between the needs of these species and the needs of restoration, as has occurred repeatedly and will likely continue to occur with Cape Sable seaside sparrows. These conflicts merit forward-looking programmatic solutions, so they do not repeatedly cause restoration delays. The USACE has proposed that a Comprehensive Conservation Plan be developed that includes identification of potential future habitat for this subspecies considering predicted flows associated with Everglades restoration projects. This approach has the potential to produce a much-needed long-term solution for the sparrow conflict that integrates systemwide sparrow conservation with the multi-species benefits provided by the restoration. As such, it could provide a model for addressing similar issues with other species. In the case of the conflict over management of the STAs, the agencies could explore options under the MBTA, such as special use permits or memoranda of understanding, that would provide the flexibility necessary to optimize STA performance.

4

Implications of Knowledge Gained Since 1999 for the CERP

The Comprehensive Everglades Restoration Plan (CERP; USACE and SFWMD, 1999) is the manifestation of a large planning effort. It provides a blueprint to overhaul the water management system in South Florida through approximately 50 major projects and 68 project components to be completed over 30 to 40 years. When completed, the CERP was envisioned to restore hydrologic and ecological function across the Greater Everglades ecosystem and a secure water supply for the residents of the region. Core elements of the CERP are vastly increased water storage capacity and reduction of barriers to sheet flow, such that water can be stored in the wet season and released in the dry season to mimic historic seasonal and spatial hydrology (see Chapter 2). Unfortunately, over the first half of the project timetable, the restoration has not proceeded according to plan. CERP implementation progress has been slow, impeded by funding constraints and a cumbersome project planning, approval, and authorization process, among other things. Moreover, the projects advanced have been largely restricted to the periphery of the remnant Everglades (NRC, 2007). Little has been accomplished through the CERP to restore flow velocities and dry season flow volumes in the central Everglades. The heart of the Everglades continues to degrade. Meanwhile, the northern estuaries continue to experience damaging high flows, which impact their ecological condition. In 2005 and 2016, elevated discharge to coastal waters contributed to extensive algal blooms (see also Box 2-2).

Recently, major breakthroughs have been made in CERP planning, approval, and authorization. The Central Everglades Planning Project (USACE and SFWMD, 2013a) was developed and approved as a comprehensive approach to combine components of several CERP projects and provide incremental benefits associated with increased flows through the central Everglades and a modest reduction in damaging regulatory releases to the northern estuaries (NRC, 2014). Numerous other CERP projects are now authorized, with six under construction, and new planning efforts for the Western Everglades, Loxahatchee River, and Lake Okeechobee Watershed are under way (see Chapter 3).

As we approach the mid-point of the original CERP timeline with encouraging momentum in planning and construction, it is appropriate to examine the CERP goals and the evolving restoration plan in the context of conditions that have changed and the improved understanding that has occurred over the past 16 years. In the past few years, restoration planners have learned that some major storage elements in the plan described in the 1999 CERP Feasibility Report (known as the "Yellow Book") are no longer feasible and others remain uncertain. Additionally, a modified regulation schedule has substantially reduced natural storage in Lake Okeechobee, which could impact the capacity to reach CERP goals with the original plan. New understanding of climate change and sea level rise also presents the potential for significant changes in the future conditions that were not anticipated in the Yellow Book (NRC, 2014). In this chapter, the committee examines major changes that have occurred since 1999 that are likely to affect the construction of the CERP as initially envisioned, and the potential for achieving the original objectives.

CHANGING BASELINES

One significant change since the CERP was adopted is that the scientific understanding of the pre-drainage system, on which operational targets to support Everglades restoration are based, is now widely accepted as much wetter than was previously assumed. Although the general goals to restore hydrology, provide for natural habitats and species, and enhance water supply, while sustaining existing flood protection (see Chapter 2) have not changed, assumptions about pre-drainage conditions underlying the specific operational targets (e.g., water depths, duration, flow volumes) that served as the basis of CERP development to achieve those goals are likely no longer valid. These targets are primarily hydrologic and were originally based on the Natural System Model (NSM) v. 4.5[1], which simulates the frequency, duration, and spatial extent of water inundation without the current levees, canals, dikes, and pumps that alter the hydrology. Since the CERP was launched, new versions of the NSM have been developed based on extensive research indicating that wetter conditions prevailed in the historic system than previously thought (McVoy et al., 2011). The Natural System Regional Simulation Model (NSRSM) is the most recent version in use for planning and assessment purposes. Based on knowledge gained and enhanced tools developed over the past 17 years, it is now understood that restoring pre-drainage conditions in the remnant Everglades would require

[1] Subsequently upgraded to v. 4.6.2.

greater water depths, flow volumes, and flow velocities than assumed in the Yellow Book (see Figure 4-1) (RECOVER, 2011a). Comparisons between the NSM and NSRSM show increases in average annual flow volumes ranging from 6 to 67 percent across two different Everglades transects (see Box 4-1).

Past reports of this committee (NRC, 2007, 2008) have emphasized that "getting the water right" is not the goal itself but a means to facilitate the restoration of the physical, chemical, and biological processes that sustained the historical Everglades (see Chapter 2). Thus, NSRSM simulations are not the only information guiding operational targets, because changed conditions may make such targets undesirable or unachievable. For example, it is well understood that increasing the water depth in areas that have subsided because of dry conditions and enhanced oxidation of peat, such as WCA-3B, is likely to adversely affect those habitats. Nevertheless, new information on historic water depths may necessitate renewed discussions of tradeoffs and future CERP design options considering potentially improved conditions associated with higher flows in the southern Everglades. Even if the restored system cannot replicate the pre-drainage system or attain all the physical, chemical, and biological goals, improved ecosystem functioning is still expected from partial achievement of these NSRSM targets, and restoration benefits from incremental restoration steps may, in fact, be significant. Program-level adaptive management (see also Chapter 5), designed to adjust implementation, as necessary, to improve the probability of restoration success (RECOVER, 2015), necessitates that the significance of this new information on expected systemwide restoration outcomes be understood in the context of the original restoration goals, with modifications made to the plan or the goals, as appropriate.

An example that illustrates the challenges of setting restoration goals in the context of changing baselines is management of the Cape Sable seaside sparrow, an endangered subspecies whose entire global distribution is limited to Everglades National Park, and the marl prairie habitat in which it resides. There are three marl prairies in Everglades National Park: Ochopee marl prairie, west of Shark River Slough; Rockland marl prairie, east of Shark River Slough; and Perrine marl prairie, farther south in the vicinity of Taylor Slough. Currently, these sites are characterized by inorganic marl soil (in contrast to organic peat found elsewhere in the Everglades); a particularly diverse vegetation community dominated by grasses, sedges and rushes; and shorter hydroperiods relative to marsh habitats (McVoy et al., 2011). They are the only habitat occupied by Cape Sable seaside sparrows; thus, their protection is mandated under the Endangered Species Act.

Assessments of the impact of the CERP on the endangered sparrows have uniformly concluded that ultimately the species and the marl prairies will benefit from the restoration (FWS, 2016; NRC 2012; SEI 2003, 2007; Walters et al.

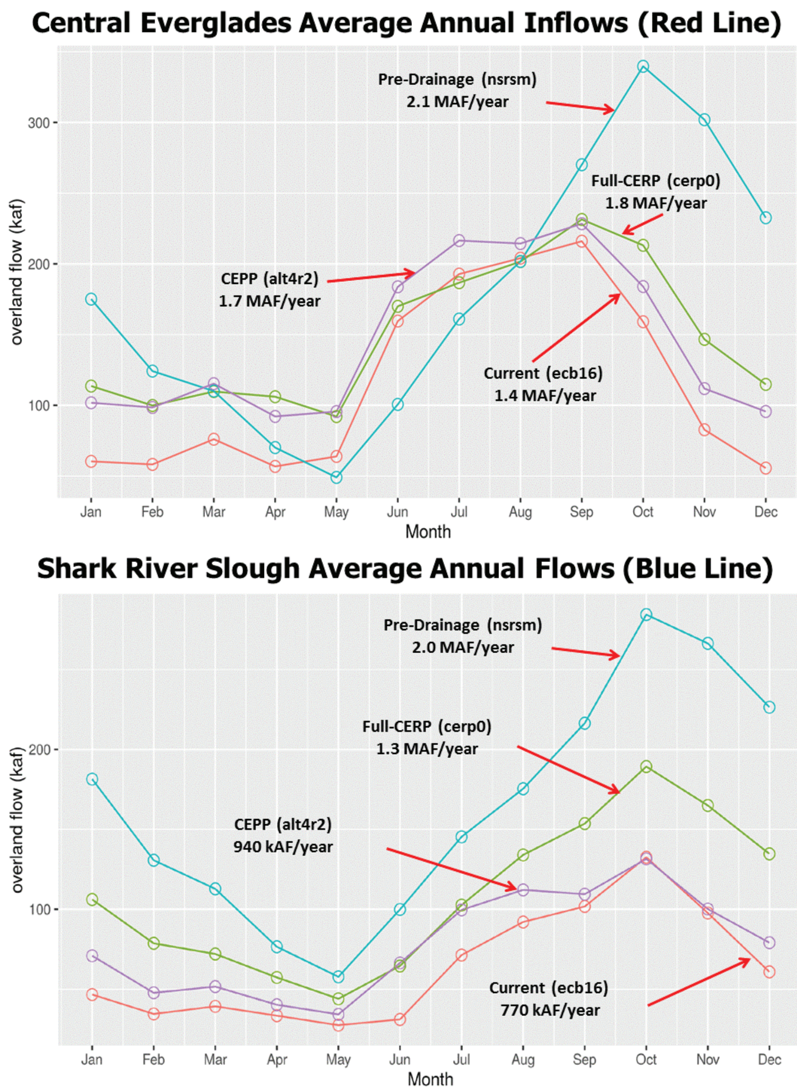

FIGURE 4-1 Modeled average monthly overland flow volumes into the Everglades Protection Area and through Shark River Slough provided under current conditions, pre-drainage conditions (NSRSM shown), and under the CERP. Flows reported in thousand acre-feet (kAF) or million acre-feet (MAF). In Figure 4-1-1 in Box 4-1, the approximate Red Line transect is shown as "the River of Grass" and the Blue Line is shown as "Shark Slough." The central Everglades currently receives about 67 percent of estimated predrainage flows, while full CERP implementation approaches 86 percent. Shark River Slough current receives about 40 percent of the estimated predrainage flows, while full CERP implementation approaches 65 percent.

SOURCE: R. Johnson, DOI, personal communication, 2016.

BOX 4-1
Comparing the NSM and NSRSM

The NSRSM incorporated new understanding of the pre-drainage system and translated that information into a quantitative modeling tool, showing that that the pre-drainage system is now understood to be much wetter than it was thought to be when the CERP was originally developed. Unfortunately, it is not easily possible to plot NSM values on Figure 4-1 because it is difficult to compare flows at identical locations across grids in the 2 x 2-mile square output of NSM versus across faces of the mostly-triangular finite element mesh of the NSRSM. However, Brown (2012) provides a comparison in which output from both models is compared along identical transects by interpolating along a "universal 4 x 4-mile mesh." This provides a "reasonable comparison from a high vantage point." Input and output data for each model are spatially weighted along the universal mesh grids to provide comparisons of annual flows along the transects shown in Figure 4-1-1. The flows themselves are tabulated in Table 4-1-1. Note that the annual flow volumes indicated on Figure 4-1-1 *cannot be directly compared* to those in

continued

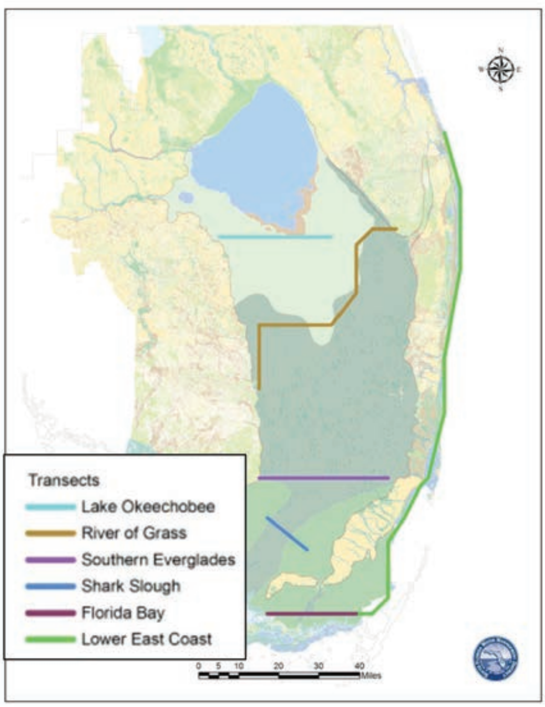

FIGURE 4-1-1 Transects used for comparison of annual overland flow between the NSM and NSRSM. SOURCE: Brown (2012).

BOX 4-1
Continued

Table 4-1-1 because of the different mesh schemes mentioned previously. In addition to differences in the numerical schemes of each model, most of the increases in flow volumes may be attributed to changes in the Lake Okeechobee boundary condition, different methods of computing overland flow roughness, and different methods of inclusion of riverine and flow channels (Brown, 2012), as well as to significant changes in the topography used in each model.

TABLE 4-1-1 Annual Flow Volumes across Transects Shown in Figure 4-1-1 Based on 1996-2005 Precipitation Data

Transect	NSMv4.6.2 kAF/yr	NRSRMv3.5.2 kAF/yr	Percent Change
Lake Okeechobee	773	1100	+42%
River of Grass	1303	2176	+67%
Southern Everglades	1862	1977	+6%
Shark Slough	1377	1706	+24%
Florida Bay	155	226	+46%

2000). This supposition was based on flows being reduced in western Shark River Slough, where current conditions in the adjacent Ochopee marl prairie occupied by sparrow subpopulation A are too wet and increased flows in northeastern Shark River Slough, where current conditions in the adjacent Rockland marl prairie occupied by subpopulations C, E, and F are too dry (see Figure 3-6). In sum, it was anticipated that the CERP would restore marl prairies that are currently in degraded condition. However, in the analysis of pre-drainage conditions that informed the NSRSM, McVoy et al. (2011) characterized the marl prairies as more drastically affected by altered drainage than any other habitats. In the pre-drainage system these areas were marl marshes with shallow peat soils over a marl base, but drainage led to oxidation of the peat layer. Compared to current conditions, the pre-drainage marl marshes had a lower elevation gradient relative to the bordering sloughs, deeper water, and longer hydroperiods. McVoy et al. (2011) estimate former hydroperiods to be 8-9 months. For comparison, current hydroperiods are 4-8 months (Walters et al., 2000) and the current management objective for the prairies under the Everglades Restoration Transition Plan is a hydroperiod of 3-7 months (USACE, 2011b).

Thus, the NSRSM projections for the marl prairies are at odds with current operational water management targets for the Cape Sable seaside sparrow. If NSRSM projections of pre-drainage flows are used to guide future restoration objectives for these areas, the marl prairies could become marl marshes once again, but this change would jeopardize the continued existence of sufficient habitat to support the endangered sparrows. This was not the case when projections were based on NSM and the previous understanding of the pre-drainage system that NSM represented (see Figure 4-2). Providing sufficient habitat for Cape Sable seaside sparrows and duplicating the pre-drainage system require very different hydrology. This illustrates the complexity of establishing restoration goals.

An updated program review of restoration goals is essential to future planning and would include a realistic assessment of what can be achieved, includ-

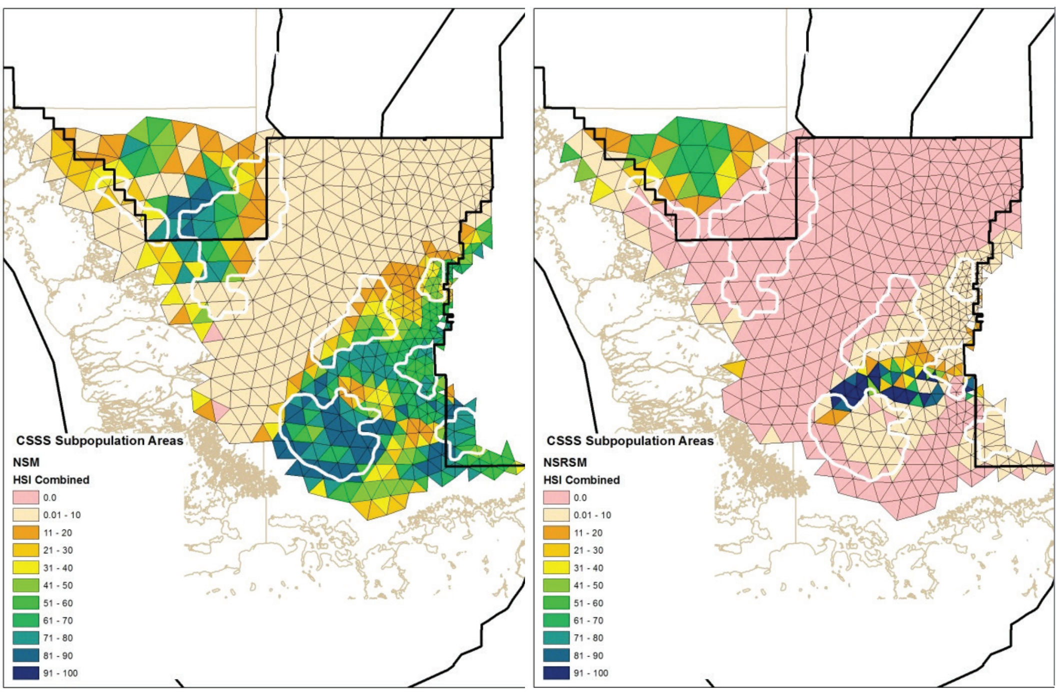

FIGURE 4-2 Projections of habitat suitability for Cape Sable seaside sparrows from NSM (left) and NSRSM (right).

SOURCE: McLean and Pearlstine, 2015.

ing goals for particular areas such as the marl prairies inhabited by the sparrows (see Chapter 5). Restoring pre-drainage features while retaining post-drainage features that are viewed as desirable (e.g., marl prairies inhabited by Cape Sable seaside sparrows) is especially challenging. In many instances, recreating the historical hydrology embodied in the NSRSM may not be a realistic goal, and in the case of the marl prairies, a desirable one. Current restoration plans (Figure 4-1) focus on increasing dry season flows rather than peak flows, although the CERP and the Central Everglades Planning Project more closely approach pre-drainage flows into WCA-3A compared to flows into Everglades National Park (Figure 4-1). Meeting all ecological goals will not be an easy task within a river of grass where everything is connected, but new tools are available that can be used to assess tradeoffs between ecological goals to maximize systemwide restoration benefits. These tools and strategies for refining CERP goals considering new information are discussed in Chapter 5.

UNDERSTANDING SEA LEVEL RISE AND CLIMATE CHANGE

Much has been learned about the potential implications of climate change and sea level rise for Everglades restoration since the CERP was launched (Catano et al., 2015; Havens and Steinman, 2015; Kearney et al., 2015; Koch et al., 2015; Nungesser et al., 2015; Obeysekera et al., 2015; Orem et al., 2015; SFRCC, 2011; van der Valk et al., 2015). These changes and their implications for the CERP were reviewed extensively in the committee's last report (NRC, 2014), and these issues are briefly summarized here with some updated information. Sea level rise and changes in temperature, precipitation, and evapotranspiration have different impacts on the structure and functioning of the Everglades, interactions with the built environment, and restoration plans. Compounding the challenge of the assessment of the anticipated effects on South Florida is the differing levels of certainty in the magnitude and nature of the change in these climatic drivers.

Sea Level Rise

Global sea level rise has been observed to be about 7.5 inches (0.19 m) during 1910–2010 (IPCC, 2013), although recent trends in Florida suggest an acceleration in the rate of sea level rise (see Figure 4-3). The Southeast Florida Regional Climate Change Compact (2015) released a recent "unified sea level rise projection" of 31 to 61 inches (0.8 to 1.5 m) by 2100 (see Figure 4-4). Sea level rise is expected to profoundly impact the coastal zone of the Florida peninsula (IPCC, 2013; Obeysekera et al., 2011a,b; Parris et al., 2012). Sea level rise will alter the structure and functioning of current coastal ecosystems, expanding and deepening Florida Bay and other coastal estuaries, reducing

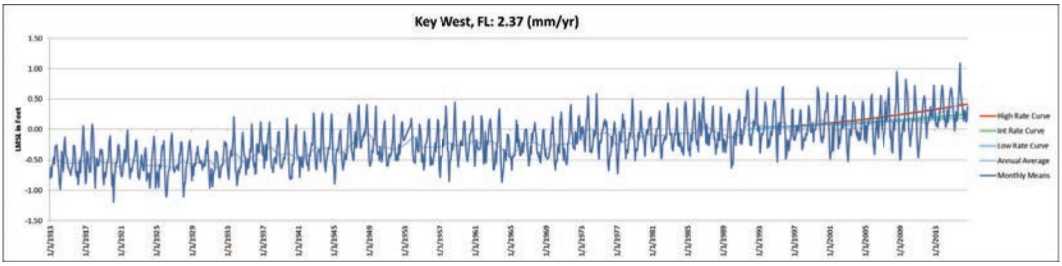

FIGURE 4-3 Monthly time series of mean sea level at the National Oceanic and Atmospheric Administration station at Key West, FL from 1913 to the present. Time-series analysis suggests a rate of change of 0.093 in/yr (2.37 mm/yr) over the period of record. Overlain on this record starting in 1992 are three USACE sea-level rise projections: the historical sea level trend; an intermediate trend projection; and a high rate projection.

SOURCE: G. Landers, USACE, personal communciation, 2016.

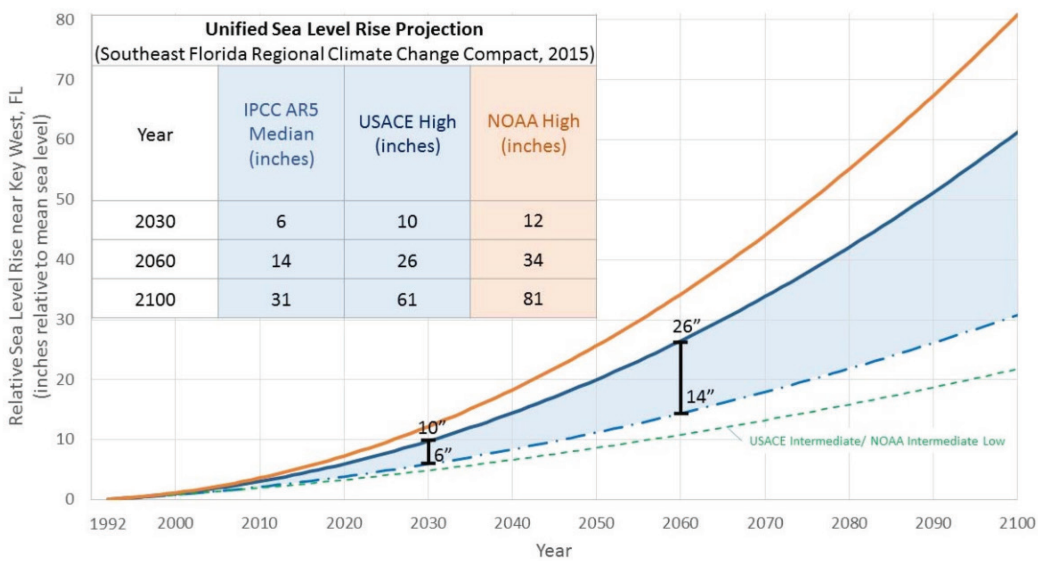

FIGURE 4-4 Sea-level rise projections for southeast Florida through 2100. The USACE low projection shown in Figure 4-3 is not displayed on this plot.

SOURCE: SFRCC (2015).

the extent of inland freshwater wetlands, and causing an inland migration of the mangrove ecotone (Kearney et al., 2015; Koch et al., 2015; NRC, 2014). Rising sea level also is increasing flooding of developed coastal areas and salt water intrusion in coastal aquifers. With intermediate USACE projections of sea level rise (24 inches or 0.9 m by 2100), some restoration project benefits will be substantially reduced (e.g., Central Everglades benefits, by the loss of wetlands within the project footprint; USACE and SFWMD, 2014a) and by 2100 at high projections of sea level rise, no benefits are expected from the Biscayne Bay Coastal Wetland, Phase 1 project (USACE and SFWMD, 2012).

Climate Change

A scenario analysis by Obeysekera et al. (2015) advanced understanding of the potential hydrologic impacts of future changes in precipitation and evapotranspiration. These results were subsequently used to evaluate the ecological implications of changing climate across different Everglades habitats (Catano et al., 2015; Havens and Steinman, 2015; Kearney et al., 2015; Koch et al., 2015; Nungesser et al., 2015; Orem et al., 2015; van der Valk et al., 2015). The scenarios include baseline conditions with a 1.5°C increase in temperature, ±10 percent change in annual precipitation, and a 1.5-foot increase in sea level for a 50-year planning horizon (2010-2060). This analysis suggests that, depending on the rainfall and temperature scenario, there would be major changes in water budgets, ecosystem structure and functioning, and in water supply demands met that could have important implications for CERP goals. Increased sea levels will also compromise flood protection infrastructure in the urbanized areas of southeastern Florida and cause increased salt water intrusion of water supply wells (see Figure 4-5). Projections of changes in precipitation quantity are highly uncertain, but decreases in annual precipitation are probably more likely than increases in precipitation (Obeysekera et al., 2015). Climate projections suggest a greater certainty of increases in temperature which will drive increases in water loss through evapotranspiration. The implications of two specific scenarios developed by Obeysekera et al. (2015) are discussed here—10 percent increased and 10 percent decreased precipitation (each with 1.5°C increase in temperature and 1.5-foot increase in sea level).

Increased Rainfall Scenario

Analysis of the 10 percent increased rainfall scenario suggests an increase in damaging high water events in the northern estuaries. Increasing rainfall would help meet agricultural and urban water demands, although increased evapotranspiration is anticipated to counter-balance the effects of increased rainfall

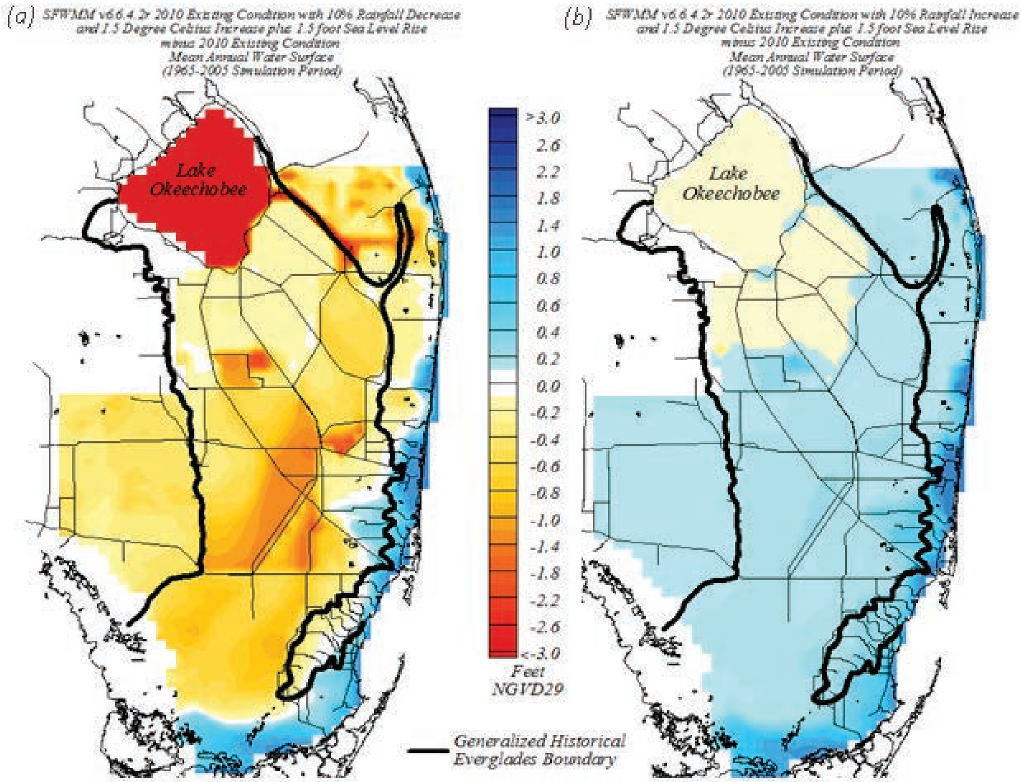

FIGURE 4-5 Differences in annual average water stage between scenarios of increased (+10%) rainfall and decreased (-10%) rainfall/increased evapotranspiration with sea level rise.

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

on water levels of Lake Okeechobee (Havens and Steinman, 2015). Minimal adverse impacts are anticipated in the Everglades landscape (Nungesser et al., 2015). The 10 percent increase in rainfall scenario is expected to have beneficial impacts on carbon accretion as organic soils in most areas, although peat soil oxidation will continue during dry years in areas currently experiencing peat loss. Greater flow through Shark River and Taylor Sloughs will likely mitigate the impacts of sea level rise to some degree, reduce hypersaline conditions in Florida Bay, and promote mangrove growth leading to reduced impacts from cyclonic storms (Orem et al., 2015). Increased rainfall is projected to benefit aquatic prey productivity and apex predators (Catano et al., 2015).

Reduced Rainfall Scenario

The reduced rainfall scenario showed dramatic effects on the Greater Everglades ecosystem. Compared to a future base condition with climate conditions consistent with the past 30 years, water levels in Lake Okeechobee are lowered substantially (on average by more than 3 feet), with multiple years well below the historic range, although some years are projected to experience very high levels following rainfall events. The littoral and near-shore zones—areas that support emergent and submerged plants—are projected to be dry for more than 50 percent of the time (compared to less than 4 percent under the future base scenario). It is uncertain whether a shallow lake that would result under the reduced precipitation scenario could support submerged vascular plants, which are critical to the recreational fishery and for migratory birds. The substantial decline in lake levels could result in considerable unmet water demand and loss of agricultural revenue. Reduced rainfall would also result in dramatic (90-95 percent) reductions in regulatory releases to the northern estuaries but also an 80 percent decline in the capacity to provide environmental water releases under low flow conditions (Havens and Steinman, 2015).

Median marsh water depths of the remnant Everglades would be reduced by 5-114 cm and inundation duration shortened periods by 14-47 percent. These shifts in hydrologic pattern would likely translate into ecologically significant changes. Moreover, severe decreases in water flow would likely alter the structure and functioning of the Everglades through severe drought, increased wildfires, extensive peat loss, loss of the ridge and slough landscape pattern, and changes in vegetation composition (Nungesser et al., 2015; Orem et al., 2015; van der Valk et al., 2015). With the loss of peat soils, the likely enhanced release of nutrients and contaminants stored in the organic soil (e.g., nitrogen, phosphorus, sulfur, mercury) may exacerbate eutrophication and contamination downstream (Orem et al., 2014). All wildlife indicators are negatively affected under the reduced rainfall scenario, including iconic animals such as wading birds and alligators (Catano et al., 2015).

Implications of Climate Change and Sea Level Rise for CERP

Disturbance in ecosystem functioning associated with sea level rise and climate change may necessitate that restoration goals be revisited (NRC, 2014). For example, would increases in the depth of Florida Bay help mitigate the hypersalinity issues that the CERP is designed to address? Kearney et al. (2015) analyzed the effects of potential climate change scenarios (with 1.5 feet or 0.5 m of sea level rise in 50 years) on a variety of juvenile fish and lobster species in Florida Bay and found only small changes in habitat suitability across the scenarios for six of seven species examined. Only one of the seven species investigated (*Lagodon rhomboides*, i.e., pinfish) would likely experience a sizable decrease in optimal habitat under any of the scenarios. This analysis suggests that the estuarine fauna of Florida Bay may not be as vulnerable to climate change as other components of the greater Everglades, such as those in the marine/terrestrial ecotone. However, these models are relatively simplistic, examining only single species effects of physical drivers without consideration of the many interspecific interactions that may occur as the ecosystem responds to changing sea level rise and climate. More complex models that capture the mechanistic links among physics, chemistry, and biology, as well as the dynamics of the estuarine food web, may be necessary to further understand the potential effects of climate change on the Florida Bay ecosystem.

Although NRC (2014) stated that "climate change provides a strong incentive for accelerating restoration," the committee did not suggest that changing climate and sea level rise provides a blanket endorsement of all CERP projects. Instead, the report recommended that climate and sea-level rise projections be used to rigorously evaluate individual project benefits, which may lead to changes in priorities or plans from a systemwide perspective. The loss of benefits for some projects may necessitate that projects that have not yet been constructed be reconfigured or even eliminated. In contrast, projects with strong benefits in mitigating the impacts of climate change and sea level rise may merit advancement in restoration scheduling. For example, Koch et al. (2015) noted that greater freshwater flows targeted by Everglades restoration efforts could enhance mangrove peat accumulation and reduce saltwater intrusion. However, these benefits have not been quantified at the project or systemwide scale. Analysis of benefits or drawbacks of projects under anticipated climate change should then be used to reevaluate CERP project implementation and inform planning.

Of particular importance for CERP planning in the context of climate change is a critical assessment of water storage needs (see next section). Although the analysis conducted by Obeysekera et al. (2015) provides valuable insight, it represents simplified conditions. For example, the analysis evaluates potential hydrologic response of the current Everglades to hypothetical future meteorological conditions and sea level rise, not how the CERP would alter, attenuate, or exacerbate this response. Also, only annual perturbations to meteorological conditions were examined. A useful next step would be to examine the hydrologic response to seasonal shifts in the distribution and quantity of precipitation and the subsequent effects of these changes on habitats and species (see also the Chapter 5 section on Tools to Support Forward-Looking Analyses). It is likely that extreme events will become more common under future climatic conditions (NASEM, 2016; Melillo et al. 2014). Increases in the occurrence of extreme events will likely increase the need for additional capacity for storage. There is a critical need for additional storage under high water conditions to protect the northern estuaries and the WCAs. These conditions are likely to become more acute in a future where seasonal shifts in precipitation patterns and extreme events are more common. Modeling tools and approaches to assess the implications of climate change and sea level rise to the CERP are discussed in more detail in Chapter 5.

The benefits and costs of projects anticipated to be impacted by climate change and sea level rise need to be evaluated in a systemwide context, considering how ecosystem changes may influence restoration goals. For example, how does sea level rise affect restoration goals for Everglades National Park? Should climate change and sea-level rise mitigation and adaptation be considered equally among other CERP goals? These issues can be addressed through a combination of sound project planning and forward-looking analysis that rigorously considers climate change and sea-level rise scenarios, project-level adaptive management, and program-level adaptive management (see Chapter 5).

STORAGE

Storage of water in surface and in-ground reservoirs and in aquifers is a critically important part of the CERP for attenuating extreme high and low water discharges to the northern estuaries and the Everglades and low water discharges to Florida Bay (see Chapter 2). With sufficient storage capacity, peak discharges and water levels can be reduced by storing portions of high flow events for later release either when flows are below damaging levels or during periods of low flows to enhance ecological conditions downstream and also to supplement water supplies for urban or agricultural water uses (see Box 4-2).

In the Yellow Book (USACE and SFWMD, 1999), major elements of CERP storage included the following:

- **New surface water storage reservoirs** in the Caloosahatchee and St. Lucie basins, north of Lake Okeechobee, in the Everglades Agricultural Area, and in Palm Beach, Broward and Miami-Dade counties with a capacity to store 1.2 million acre-feet (AF)
- **In-ground water storage** in existing limestone quarries in Miami-Dade County and western Palm Beach County, with engineered liners as needed to manage seepage and a combined capacity of 325,000 AF
- **Underground water storage** in over 330 aquifer storage and recovery (ASR) wells around the northern boundary of Lake Okeechobee, in Water Preserve Areas, and the Caloosahatchee Basin to capture and store water during high flows to supplement flows during dry periods

BOX 4-2
Example of the Role of Storage in Restoration Outcomes

When large volumes of freshwater are released to the northern estuaries from Lake Okeechobee, they cause estuarine salinity to decrease to levels that are outside the tolerance ranges of estuarine biota (USACE, 2007d) and transport high loads of nutrients and sediment that are damaging to the coastal ecosystem. The value of varying levels of storage is exemplified in a simple modeled scenario of runoff within the Caloosahatchee watershed, excluding regulatory (high water) releases from Lake Okeechobee.[a] In an analysis for the River of Grass planning effort, low and high monthly average flow targets at station S-79 on the Caloosahatchee River were set at 27,000 and 169,000 acre-feet (AF), respectively. Without any additional storage to manage the runoff within the watershed, monthly flows were below the target minimum levels over 50 percent of the 492 months of recorded data analyzed. Low flow frequency could be reduced to 17 percent with 100,000 AF of storage and to 2 percent with 200,000 AF. Without any storage, monthly Caloosahatchee River flows (excluding high volume regulatory discharges from Lake Okeechobee) would exceed the high-flow target 9.1 percent of the months, but the frequency of exceedances from basin drainage could be reduced to 1.6 percent with 200,000 AF of flood storage. Similar analyses have been conducted through the Northern Everglades planning process to assess storage needs north of Lake Okeechobee (SFWMD et al., 2008).

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[a] **Reservoir Sizing and Operations Screening (RESOPS) Model.** This simplified model was constructed for use as a broad screening model with monthly averaged flows, spatially averaged watershed runoff, and omission of net effects of precipitation and evaporation on reservoir surfaces. The results consider only undiverted flow from C-43 watershed and exclude regulatory releases from Lake Okeechobee. sfwmd.gov/portal/page/portal/xweb%20about%20us/reviving%20the%20river%20of%20grass%20-%20resops%20model

- **Management of Lake Okeechobee as an ecological resource** by modifying the lake's regulation schedule to reduce the extreme high and low levels that damage the lake and its littoral zone, while allowing the lake to continue to serve as an important source for water supply

Specific locations and engineering details for most storage projects were not determined in the Yellow Book (USACE and SFWMD, 1999), but those characteristics were deferred to later project-specific feasibility studies.

The major components of CERP storage are outlined in Tables 4-1, 4-2, and 4-3 and Figure 4-6. Table 4-1 summarizes the original planned storage capacity of each of the major storage features and their updated capacities based on recent planning (if completed), but it is important to recognize that ecosystem benefits from storage are linked to the way the storage features are operated and not only on the storage capacity. Different operational plans and other system

TABLE 4-1 Proposed and Updated Capacities of Non-ASR Storage Components of the Restoration Plan

STORAGE COMPONENT	Yellow Book Storage Capacity Acre-Feet	Updated Storage Capacity Acre-Feet
Existing System Storage		
Lake Okeechobee	3,817,000[a]	3,253,000[a]
Water Conservation Areas	1,882,000	1,882,000
Total lake/WCA storage	**5,699,000**	**5,135,000**
Above-ground Reservoirs		
North Storage Reservoir (Kissimmee)	200,000	TBD
Taylor Creek/Nubbin Slough	50,000	TBD
Caloosahatchee (C-43) Basin[b]	160,000	170,000
C-44 Reservoir[b]	40,000	50,600
Other Upper East Coast Storage[b,g]	349,000	109,400[g]
EAA Reservoirs	360,000	56,000 (FEB)[c,h]
Central Palm Beach Reservoir	19,920	TBD
Site 1 Reservoir	14,760	TBD[d]
Bird Drive Reservoir[b]	11,600	0[c,e]
Acme Basin[b]	4,950	0[f]
Seminole Tribe Big Cypress	7,440	TBD
Total above-ground reservoir storage	**1,217,670**	
Projects planned to date	925,550	386,000 *(includes A-2 FEB)*
Potential storage in projects not yet planned, or planning not finalized:	292,120	
In-ground reservoirs		
North Lake Belt	90,000	*Feasibility unproven*
Central Lake Belt	187,200	*Feasibility unproven*
L-8 Basin[b]	48,000	*FEB operated for water quality, not storage*
Total in-ground reservoir storage	**325,200**	
Projects planned to date	48,000	0
Potential storage in projects not yet planned, or planning not finalized:	277,200	

[a] Updated capacity based on difference between an assumed low level of 9 feet and the highest stage in the upper band (17.25 feet for Lake Okeechobee Regulation Schedule (LORS) 2008 and 18.5 feet for Water Supply and Environment [WSE]), based on calculator in http://www.sfwmd.gov/gisapps/losac/sfwmd.asp based on the polynomial model.
[b] Planning completed.
[c] 2015 Report to Congress suggests that these features are fully replaced by CEPP storage.
[d] The Site 1 Impoundment plan would provide 13,280 AF if constructed, but policy conversations are underway that propose not completing the reservoir. Thus, the committee considers planning incomplete for this feature.

TABLE 4-1 Continued

[e] The project delivery team determined this project to be infeasible.
[f] Land sold before it could be acquired. Remaining project elements completed outside of CERP.
[g] Includes C-23, C-24, C-25, and St. Lucie North and South Fork reservoirs (which have been estimated at 130,000 AF when combined with the C-44 Reservoir). The updated estimate includes the Indian River Lagoon-South (IRL-S) natural storage areas (30,000 AF). Note that although the storage capacity decreased significantly between the original CERP framework and the final IRL-S PIR, modeling analyses showed that the CERP objectives for the IRL-S project could be reached with substantially less storage.
[h] An FEB is operated with the primary objective to optimize performance of the STAs (e.g., reduce excessive loading and periods of drydown) rather than to optimize the quantity or timing of water flow to the natural system. Therefore, the hydrologic benefits may be less than other storage features, depending on their operational plans and objectives.
SOURCES: USACE and SFWMD (1999, 2004a, 2010, 2014a) and NRC (2005).

TABLE 4-2 Summary of Average Annual and Maximum Inflows and Outflows by Storage Feature

STORAGE COMPONENT	Avg. Annual Acre-Feet In	Avg. Annual Acre-Feet Out	Max Annual Acre-Feet In	Max Annual Acre-Feet Out	Max Annual Inflow-Outflow	Yellow Book Capacity Acre-Feet
Lake Okeechobee	2,537,300	1,803,400	4,263,200	4,022,700	2,231,900	3,817,000
Water Conservation Areas	1,633,200	316,100	3,138,600	567,200	2,879,200	1,882,000
Total Above-Ground Reservoirs	1,279,270	1,084,900	2,643,930	2,411,180	912,610	1,217,670
Total In-Ground Reservoirs	323,100	314,300	519,400	546,900	285,600	325,200
Aquifer Storage and Recovery	573,310	269,630	1,662,400	871,600	1,637,000	Not applicable

Notes from NRC (2005): "Many values in the table are based on simulation output [Alternative D13R of the South Florida Water Management Model, 11/98 version], which are reported to more significant figures than can be verified. These values provide only general comparisons of the magnitudes of flows and storage capacity, as no quantitative estimates of uncertainty are available. . . . Inputs to reservoirs do not include local precipitation or seepage. Outputs from reservoirs do not include evapotranspiration or ASR injection losses. Water fluxes to and from Water Conservation Areas (WCAs) include overland flow and groundwater seepage."
SOURCE: Adapted from NRC, 2005.

constraints may lead to different outcomes in terms of mitigating high water releases from Lake Okeechobee, providing supplemental water to the ecosystem, and meeting other water demands. A 300,000-AF reservoir, if operated primarily to meet agricultural or urban water demand, may provide similar ecosystem benefits as a 70,000-AF reservoir operated primarily to supplement flows to the natural system. Similarly, a 50,000-AF flow equalization basin (FEB) designed to optimize performance of a stormwater treatment area (STA) would likely provide lower ecosystem flows than a similarly sized storage reservoir designed to

TABLE 4-3 ASR Components of the Restoration Plan

	# of Wells	Maximum Injection/ Withdrawal Capacity at 5 MGD/well (in AF/yr)	Avg. Annual Acre-Feet In	Avg. Annual Acre-Feet Out	Max Annual Inflow, Acre-Feet
Lake Okeechobee	200	1,120,185	259,100	134,600	1,120,100
Caloosahatchee (C-43)	44	246,441	97,910	47,630	170,500
C-51	34	190,431	80,500	24,200	135,700
West Palm Beach (L-8)	10	56,009	37,800	11,700	54,600
Central Palm Beach Reservoir	15	84,014	42,300	28,500	74,700
Site 1 Impoundment (Hillsboro)	30	168,028	55,700	23,000	106,800
All	**333**	**1,865,108**	**573,310**	**269,630**	**1,662,400**

See Note to Table 4-2, which applies also to Table 4-3.
SOURCE: Adapted from NRC, 2005 with updated numbers of ASR wells based on USACE and SFWMD (2015b).

maximize hydrologic benefits. The benefits of storage features are best examined through regional hydrologic and ecological modeling. Tables 4-2 and 4-3 summarize original CERP modeling results to allow basic comparison of the inflows and outflows provided by the different storage features. Scenario modeling of the ecological impacts of reduced storage is discussed later in the chapter.

In addition to new reservoirs, storage in Lake Okeechobee and the Water Conservation Areas (WCAs) were included as part of the integrated plan. Lake Okeechobee offers the largest storage capacity in the South Florida ecosystem (see Table 4-1) and is managed to address the multiple objectives of protecting and preserving lake habitat while providing flood control, water supply, and water deliveries for downstream ecosystems. Changes in Lake Okeechobee management and implications to water storage are discussed later in the chapter. The WCAs are not currently operated as reservoirs, although flows in and out of the WCAs are managed according to regulation schedules that have been established to address multiple objectives, including limiting seepage (and associated flooding) to the east, enhancing conditions for endangered species, and providing rain-driven flows to Everglades National Park and water supply to the Lower East Coast.

Additional CERP elements were proposed to enhance water availability for the natural system through seepage management or water reuse. Seepage man-

Max Annual Outflow Acre-Feet	Max Annual Inflow-Outflow	Maximum Inflow or Outflow as % of Annual Pump Capacity		Updated Estimate with Proportional Max Inflow/ Outflow		
		Inflow	Outflow	# Wells	Max Inflow	Max Outflow
521,700	1,120,100	100.0	46.6	78	436,839	203,463
139,200	170,500	69.0	56.5	10	38,750	31,636
73,000	132,000	97.5	38.3	14	55,876	30,059
32,800	54,600	71.3	58.6	6	32,760	19,680
48,700	59,500	88.9	58.0	13	64,740	42,207
56,200	100,300	63.6	33.4	10	35,600	18,733
871,600	**1,637,000**	**89.1**	**46.7**	**131**	**664,565**	**345,778**

agement is a critical feature of the CERP and recent planning efforts (see USACE and SFWMD, 2014a; and the L-31N seepage management project[2]). The role of wastewater reuse in restoration plans is much less certain, as a pilot study to examine wastewater reuse as a source of fresh water for Biscayne Bay has not been advanced. Despite the importance of these projects to overall system benefits, they will not be discussed in this chapter because the incremental storage and volumetric flow benefits associated from these individual projects are difficult to determine with existing information.

The major CERP storage features, including surface and in-ground storage and aquifer storage and recovery, and their updated status are discussed in the following sections. The various components of storage are discussed in detail elsewhere and will only be summarized briefly here in the context of major developments in planned storage since the launch of the CERP. Readers interested in more detail should consult NRC (2005), the Yellow Book (USACE and SFWMD, 1999), and the Task Force 2014 Integrated Financial Plan (SFERTF, 2014) for additional information.

[2] See also http://www.l31nseepage.org/index1.html.

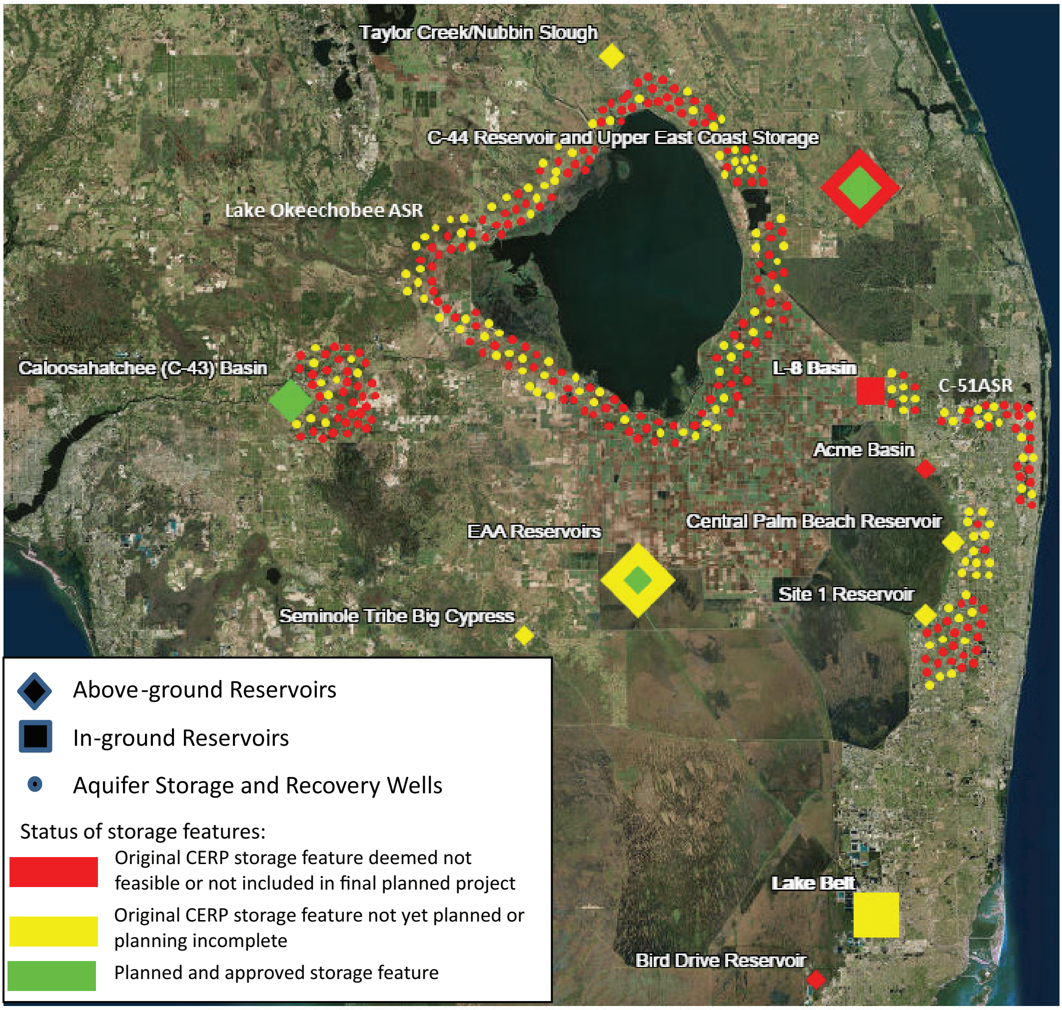

FIGURE 4-6 CERP storage elements, as proposed in the Yellow Book with color coding to reflect status and updated feasibility or sizing in final design. Symbols for surface and in-ground reservoirs are scaled by capacity. In sum, out of more than 1,500,000 AF of storage capacity proposed in above-ground and in-ground storage features in the Yellow Book, projects planned to date represent only 386,000 AF of storage (including the 56,000-AF A-2 FEB). A sizeable portion of the remaining storage has not yet been deemed feasible or is no longer to be constructed. Additional losses in storage have occurred due to changes in the Lake Okeechobee regulation schedule and lack of feasibility of ASR on the scale originally envisioned.

Above-Ground Storage Reservoirs

In this section, the largest conventional above-ground reservoir features in the Yellow Book plan are described, organized by area (see also Table 4-1 and Figure 4-6). Smaller surface storage features are described in Box 4-3.

Kissimmee River Area

Storage north of Lake Okeechobee, could, by virtue of its location, benefit multiple geographic regions (e.g., Lake Okeechobee and areas to the east, west, and south of the lake). The CERP originally envisioned two reservoirs north of Lake Okeechobee: the 200,000-AF North Storage Reservoir and the 50,000-AF Taylor Creek/Nubbin Slough reservoir (each with accompanying STAs). The Taylor Creek/Nubbin Slough reservoir was one of ten initially authorized CERP projects. These reservoirs, paired with 200 ASR wells (discussed separately later in this section), would mitigate high and low flows to Lake Okeechobee, decrease stress on the lake's littoral zone, and reduce the duration and frequency of damaging high and low flows to the Caloosahatchee and St. Lucie estuaries. No substantial planning progress has been made on either reservoir. They have now been combined into the Lake Okeechobee Watershed project, for which planning began in 2016 (see Chapter 3).

These CERP projects will complement other ongoing efforts outside of the CERP by the state of Florida as part of its Northern Everglades and Estuaries Protection Program. As of 2015, the SFWMD has established over 89,000 AF of dispersed water storage capacity in the Kissimmee, Caloosahatchee, and St. Lucie watersheds through a program that pays ranchers for providing storage on private lands (SFWMD, 2015b). The Lake Okeechobee Watershed Construction Project Phase II Technical Plan (SFWMD et al., 2008) identified 900,000 to 1,300,000 AF in storage projects to meet the state's goals for water quality and quantity management for Lake Okeechobee and the northern estuaries (see Box 4-4). The 2016 Legacy Florida Act now provides steady state funding for projects in the northern Everglades (see Chapter 3).

Caloosahatchee River Area

The Yellow Book included the 160,000-AF Caloosahatchee C-43 West Reservoir in the Caloosahatchee River basin, along with 44 ASR wells. The project is intended to reduce the frequency of damaging high and low flows to the Caloosahatchee estuary by capturing local runoff and retaining a portion of the high-water regulatory releases from Lake Okeechobee and supplying water to the estuary during low flow conditions. The reservoir also provides a local

BOX 4-3
Other Smaller Above-Ground Reservoirs

The Yellow Book also included several smaller reservoirs (20,000 AF or less of storage). Several of these features are no longer feasible, and the fate of others remains unclear.

- **Palm Beach County Agricultural Reserve Reservoir**. The largest of the smaller projects is the 20,000-AF Central Palm Beach Reservoir (12-feet deep), which was proposed to be located with a cluster of 15 ASR wells (5 MGD each). The primary purpose was to provide water supply to Palm Beach County and reduce demands on Lake Okeechobee and Loxahatchee National Wildlife Refuge. No planning has been initiated for this project (SFERTF, 2014).
- **Site 1 Impoundment**. The CERP proposed a 15,000-AF reservoir (6-feet deep) in Southern Palm Beach County located adjacent to a cluster of 30 ASR wells to supplement local water supplies and provide water to canals in dry periods, reducing demands on Loxahatchee National Wildlife Refuge. Because of cost escalation, this project has been divided in two phases. Phase 1, which was completed in 2016, involved modifications to an existing levee, which serves as two sides of the planned reservoir. As a stand-alone project, Phase 1 reduces existing seepage by 16 percent (USACE, 2016m). Phase 2 involves construction of the remaining two sides of a 13,280-AF reservoir, only slightly smaller than the preliminary design (USACE and SFWMD, 2016b).[a] However, the fate of the project is unclear, as the state has withdrawn support for completing the project (H. Gonzales, USACE, and M. Morrison, SFWMD, personal communication, 2016). The implications for the natural system or alternative strategies to provide those benefits have not been publicly detailed.
- **Acme Basin**. Adjacent to the Loxahatchee National Wildlife Refuge, the Acme Basin project included a 5,000-AF storage reservoir (8-feet deep) paired with a water treatment component to capture and treat stormwater discharges before discharging the water into either the Refuge or the Palm Beach Agricultural Reservoir, depending on the water quality. After the CERP was developed, the land originally intended for the reservoir was sold to a developer, foreclosing options for storage at this site. The SFWMD is continuing to develop the water treatment aspects of the project outside of the CERP (SFERTF, 2014).
- **Bird Drive Recharge Area**. An 11,600-AF reservoir (4-feet deep) was envisioned in the original CERP in western Miami-Dade County to reduce seepage from the Everglades National Park buffer areas, reduce flooding, and augment flows to South Dade Conveyance System and Northeast Shark River Slough. The project delivery team determined that a reservoir at this site was not feasible because surficial materials at the site are highly transmissive.[b] The project was instead merged into the Everglades National Park Seepage Management Project. The 2015 Report to Congress indicates that the objectives of this feature would be provided by the Central Everglades Planning Project.
- **Seminole Tribe Big Cypress**. An irrigation storage area (up to 7,440 AF capacity, 4-feet deep) was included in the Seminole Tribe Big Cypress project to attenuate flows into a wetland resource area designed to operate like STA (USACE and SFWMD, 1999). These cells also would provide agricultural water supply and stormwater protection. Because of high seepage rates, irrigation cells at the Critical Project site have not functioned as designed (USACE and DOI, 2016). The Seminole Tribe is looking to future CERP planning in the western Everglades to provide needed water storage.

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[a] See also http://141.232.10.32/pm/projects/proj_40_site_1_impoundment.aspx.
[b] See http://www.sfwmd.gov/portal/page/portal/xrepository/sfwmd_repository_pdf/bird_drive_rchrge_prjct_n_lnds.pdf.

BOX 4-4
Analyses of Storage Needs to Reduce Harmful Discharges to the Northern Estuaries

Several studies have identified storage needed to meet water quality and water level management objectives in Lake Okeechobee and to reduce harmful estuary discharges. The SFWMD's Lake Okeechobee Phase II Technical Plan in 2008 identified an overall "water quantity storage goal of 900,000 to 1.3 million acre-feet" in the northern Everglades (SFWMD et al., 2008). This total (900 kAF-1.3 MAF) could be achieved through existing and planned CERP and non-CERP projects and other non-CERP projects to be developed. The estimate was made under the assumption that the Everglades Agricultural Area (EAA) Reservoir would be constructed as recommended in the CERP, but no additional non-CERP storage would be located in the EAA. The report noted that above 900 kAF-1.3 MAF, increases in storage provided "relatively small improvements in damaging releases to estuaries" (SFWMD et al., 2008).

In 2015, the University of Florida Water Institute released an independent report at the request of the Florida Senate on the amount of storage needed to meet state water quality and quantity goals. The report stated that approximately 400 kAF of storage is needed within the Caloosahatchee River watershed to achieve restoration targets. Currently, only one 170 kAF reservoir is planned. In the St. Lucie River watershed, 200 kAF of storage is needed. One 50 kAF reservoir is currently under construction (although a total of approximately 130 kAF is planned in the Indian River Lagoon-South [IRL-S] project). The UFL Water Institute (2015) also stated that approximately 1 MAF of storage is needed, either north or south of Lake Okeechobee, to provide "90% reduction in lake-triggered discharge to the estuaries, meet 90% of the Everglades dry season target, and provide approximately 350,000 additional acre-ft of annual flow to the Everglades." In summary, the UFL Water Institute (2015) stated that the total estimated required storage to meet the state's restoration goals is 1,600 kAF. This report is based on modeling that used the higher Water Supply and Environment (WSE) regulation schedule (see Lake Okeechobee Operations, later in this chapter), so the report may have underestimated the shortage of storage. The CERP (USACE and SFWMD, 1999) planned for a total of 1.217MAF storage capacity plus up to 1.865 MAF/year of ASR injection capacity (see Tables 4-1 and 4-2), although some of this storage was expressly for water supply. Current authorized CERP projects plus the A-2 FEB provide a total of 386 kAF of storage (not including the A-1 and L-8 FEBs), which is less than half the amount originally planned and less than one quarter of what now is estimated as the amount necessary to meet state objectives, not considering the storage lost in Lake Okeechobee due to regulation schedule changes (see Table 4-1).

In 2009, the SFWMD asked a wide range of constituents to develop concepts of how land in the EAA might be used to store, treat, and convey clean water to the south. The SFWMD then used a regional water routing model called RESOPS (Reservoir Sizing and Operations Screening) to examine the benefits provided by a range of alternatives. Alternatives were evaluated by their to ability to meet a set of performance measures that included percent reduction in high discharges to the St. Lucie and Caloosahatchee estuaries and ability to provide clean water in the dry season to the Everglades, in addition to their cost and land requirements. The SFWMD modeled a range of proposed designs including deep and shallow reservoirs and shallow flow-ways.[a] Several of the modeled alternatives had excellent performance regarding the two key outcomes—reduced estuary regulatory discharges and increased dry season flow to the Everglades. Alternatives that performed best for the estuaries tended to be the most engineered. Overall, the River of Grass evaluation demonstrated that there are several possible solutions to damaging high flows to the estuaries and low flows in the Everglades that involve large amounts of additional storage in the EAA and north of Lake Okeechobee, beyond what was originally conceived in the CERP. Additional STAs would also be needed to provide appropriate water treatment before water is released to the Everglades Protection Area. These preliminary screening evaluations of alternatives were never developed further because the River of Grass Phase II planning process was halted in 2010.

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[a] For details on the various plans and their modeled performance, see http://www.sfwmd.gov/portal/page/portal/pg_grp_sfwmd_koe/pg_sfwmd_koe_restoration_project_plan.

water supply. The C-43 West Reservoir was authorized in WRRDA 2014 as a 170,000-AF reservoir (16-feet deep; USACE and SFWMD, 2010). The ASR wells associated with the reservoir were not included in the project implementation report and have not been authorized.

Indian River Lagoon and the Upper East Coast

The CERP Yellow Book included plans for extensive storage in the Upper East Coast to attenuate high flows by capturing local runoff, providing water supply including low-flow augmentation for the Indian River Lagoon and St. Lucie River Estuary, and improving estuarine water quality. The plan included the 40,000-AF C-44 reservoir and an unspecified number of reservoirs on the north and south forks of the C-23/C-24/C-25 canal system in Martin and St. Lucie Counties representing an additional 349,000 AF storage capacity (see Figure 3-13).

In the development of the Indian River Lagoon-South (IRL-S) project implementation report, the project team determined that the goals and objectives of the CERP could be met with substantially less storage. The final plan, included 130,000 AF of reservoir storage, including the C-44 reservoir (50,600 AF, up to 15-feet deep; USACE and SFWMD, 2015d), with the remainder from other reservoirs. Additionally, 30,000 AF in natural storage will be provided from restored wetlands (USACE and SFWMD, 2004a). The project was authorized in WRDA 2007, and construction progress is under way at the C-44 reservoir.

Everglades Agricultural Area (EAA)

The Everglades Agricultural Reservoir was envisioned in the Yellow Book as a 360,000 AF storage unit (60,000 acres, 6-feet deep) consisting of three compartments. Compartment 1 (120,000 AF, filled from excess EAA runoff) was designed to meet irrigation demands. Compartment 2 (120,000 AF, filled from overflow to compartment 1 or Lake Okeechobee regulatory releases) was designed to meet demand for environmental uses but could supply irrigation needs if all environmental demands were met. Compartment 3 (120,000 AF, filled with overflow from compartment 2 or Lake Okeechobee regulatory releases) was to be used solely to enhance environmental deliveries. Overall, the project was intended to reduce flooding in the EAA, WCAs, and northern estuaries and provide water supply for irrigation and the remnant Everglades ecosystem (146,000 and 274,000 AF/year respectively). Compartments 1 and 2 were among the initially authorized projects (EAA Reservoir Phase 1) because of the environmental, flood control, and water supply benefits provided and because the lands had already been acquired (USACE and SFWMD, 1999).

Efforts were made to develop final plans for the Phase 1 EAA reservoir (USACE and SFWMD, 2006) considering a broad array of potential configurations and land footprint alternatives (USACE and SFWMD, 2004b). However, the project implementation report was never finalized, in part because of difficulties documenting benefits of the stand-alone reservoir to the WCAs and Everglades National Park (NRC, 2007). Construction of the A-1 reservoir (190,000 AF) began in 2006, expedited through the state's Acceler8 program, but construction was halted in 2008 amidst legal challenges (Buermann, 2008) and shortly before the announcement of the U.S. Sugar land purchase.

Ultimately, prior to resolution of the reservoir project planning, the state and federal lands originally intended for use by the EAA reservoir system (see USACE and SFWMD, 2004b) were converted to other uses. Approximately 8,800 acres were added to STA-2 and 6,400 acres added to STA-5/6 as part of a SFWMD STA expansion project completed in 2012.[3] The Restoration Strategies, launched in 2012 to satisfy state water quality standards for the Everglades Protection Area, used 16,600 acres for the 60,000-AF capacity A-1 FEB at the site where construction had already begun for the EAA Phase 1 Reservoir. The A-1 lands and initial construction were readily adaptable to the new purpose. The A-1 FEB was completed in 2015 (see Chapter 3) and is now operating, although it is intended to improve the quality of existing flows from EAA basin runoff and improve the functioning of the STAs to meet existing water quality requirements, rather than to increase flows to the Everglades ecosystem. Thus, its storage volume is not included among the updated storage capacity in Table 4-1.

The A-2 FEB included in the Central Everglades Planning Project has a capacity of 56,000 AF and was situated on the 14,500-acre Talisman property, also originally intended for the EAA reservoir. Although a 12-feet deep reservoir offered the greatest benefits of the Central Everglades Planning Project alternatives considered and was included among the cost-effective alternatives, a deep reservoir was judged to be too expensive ($1.8-2 billion estimated) for a project that was intended as a first increment of restoration. Like the A-1 FEB, the A-2 FEB will not be managed as a traditional reservoir but operations will be optimized to ensure that the STAs meet the required water quality criteria as the primary objective, with increased flow to the natural system from Lake Okeechobee as a secondary objective.

Overall, the storage provided in the EAA on state and federal lands in the CERP is substantially lower than that envisioned in the Yellow Book. The 240,000-AF capacity in the EAA Reservoir devoted to providing new water supply for the environment has effectively been replaced by a 56,000-AF FEB that

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[3] See http://my.sfwmd.gov/portal/page/portal/xweb%20protecting%20and%20restoring/restoration%20progress.

is optimized for water quality rather than storage. The 60,000-AF A-1 FEB is not included in this revised storage total because it is designed to treat existing flows. The A-2 FEB in the Central Everglades project will increase flows to the Everglades by approximately 210,000 AF/yr on average (USACE and SFWMD, 2014a; see Figure 4-1). This flow is 77 percent of the 274,000 AF/yr new water originally intended to be supplied to the Everglades by the CERP EAA Reservoir (as modeled for the Restudy; see NRC, 2005). Thus, the A-2 FEB, despite its much smaller size, provides a large proportion of average annual new CERP flows to WCA-3 but delivers a smaller proportion of the new CERP water to Shark River Slough (see Figure 4-1). As noted in a report by the University of Florida (UF, 2015), the A-2 FEB will not fully meet the dry season flow requirements of the Everglades, nor does it provide substantive relief to the St. Lucie and Caloosahatchee Estuaries by reducing the frequency of damaging high-volume freshwater discharges from Lake Okeechobee.

Future plans for storage in this region remain unclear. The Central Everglades project implementation report (USACE and SFWMD, 2014a) states that the A-2 FEB could be converted to a deep reservoir at a later date to provide an additional increment of storage. Likewise, the A-1 FEB was constructed with space outside the levee embankment to allow room for increasing the height to allow for greater storage. But no plans have documented remaining storage needs, and support for future action is uneven. Even though the Central Everglades Planning Project made clear that its investments in storage were intended as a first increment, the 2015 Report to Congress (USACE and DOI, 2016) states that the Central Everglades project features would replace the EAA Reservoir, and no future CERP costs are projected associated with the EAA Reservoir project. There has been no analysis to evaluate the implications of various levels of additional storage in the EAA (including no additional storage beyond CEPP) on achieving CERP objectives, although such planning is scheduled for 2021-2024 (USACE, 2016b).

Summary of Above-Ground Reservoir Storage

Plans have been developed and are being implemented to construct 386,000 AF of CERP storage in the South Florida ecosystem, out of the original 1.2 MAF outlined in the 1999 plan. Of this storage, 85 percent is located in either the Caloosahatchee or St. Lucie watershed, and only 15 percent can be used to enhance flow to the remnant Everglades ecosystem. Another 292,000 AF of above-ground storage originally envisioned in the CERP is not yet planned but is likely to be addressed in future planning efforts. However, it appears that more than 500,000 AF in storage is no longer envisioned to be constructed. In some cases (e.g., IRL-S), smaller storage reservoirs were able to meet the original

CERP project objectives, but in other cases, the land is no longer available or the project has been deemed infeasible, and no CERP analysis has evaluated the implications of these project changes to the overall restoration outcomes.

In-Ground Storage: Lake Belt and L-8 Features

The CERP included 325,000 AF of storage capacity in large in-ground reservoirs (see Table 4-1) located at former limestone mining sites in Palm Beach and Miami-Dade Counties. At this time, one reservoir has been repurposed for optimizing STA function and the two Lake Belt reservoirs have yet to be judged to be feasible storage alternatives. This section discusses the implications of these developments for the CERP.

L-8 Basin

The L-8 Basin reservoir was originally envisioned as a 48,000-AF capacity in-ground reservoir, paired with 10 ASR wells. Located in western Palm Beach County, the L-8 reservoir was intended to mitigate high and low discharges to the Loxahatchee River and Lake Worth Lagoon in addition to providing water supply. The L-8 Basin reservoir was converted to an FEB in Restoration Strategies, and because the FEB is operated to optimize the function of the STAs with existing flows, it will not provide the storage benefits intended in the original design. As of 2016, the Loxahatchee River Watershed Restoration project delivery team is evaluating other storage alternatives to replace this feature, including natural storage, shallow storage, and a storage reservoir paired with 2-4 ASR wells.

Lake Belt Reservoirs

Two large reservoirs were proposed in the Lake Belt region in Miami-Dade County. These sites were part of an “eastern flow-way” that captured urban stormwater runoff in Broward and Miami-Dade Counties and routed this water, in addition to water from WCAs 2 and 3, into Northeast Shark River Slough and Biscayne Bay. The Lake Belt reservoirs provided storage to alter the timing of flows and provide water when it is most needed during the dry season. The North Lake Belt reservoir (90,000 AF) was intended to augment canal flows in the dry season and enhance water deliveries to Biscayne Bay. The Central Lake Belt reservoir (190,000 AF) was envisioned to provide excess water from WCAs 2 and 3 to Northeast Shark River Slough, WCA 3B, and Biscayne Bay (USACE and SFWMD, 1999). The Lake Belt reservoirs provided an additional 342,000 AF/year to the Everglades, accounting for 68 percent of the new water provided under the CERP to Everglades National Park. Given that the modeled water budgets showed that the CERP provided approximately 500,000 AF/year of new water to Shark River Slough in Everglades National Park (Figures B-1 and B-2 in Appendix B), loss of the Lake Belt reservoirs and the eastern flow-way could significantly reduce or possibly eliminate the new water provided to the park and Florida Bay.

Seepage barriers are necessary at the Lake Belt sites due to the high transmissivity of the groundwater aquifers in the area. NRC (2005) stated, "The technology required to create these seepage barriers at the required scale in permeable limestone has not yet been developed or tested, and hence both costs and feasibility associated with this storage component are uncertain." No action has been taken on pilot studies of in-ground reservoir technology (originally scheduled to be completed from 1999-2012), even though the findings are essential to determine the feasibility of the Lake Belt reservoirs or the need for replacement storage options to meet the CERP objectives. Reforms included in WRRDA 2014 will sunset the pilot studies, and without them, the future of the Lake Belt reservoirs is unclear. No CERP analyses have been conducted to determine the impact to CERP outcomes if the Lake Belt features are never constructed or the feasibility of replacing these features with storage elsewhere in the system.

Aquifer Storage and Recovery

In the original Yellow Book plan, ASR represented a large fraction of the total CERP storage and provided important long-term storage benefits. The CERP envisioned 333 ASR wells (each 5-MGD) distributed across the region and often paired with reservoirs to enhance their storage capacity (see previous sections on above-ground reservoirs and NRC, 2015). The benefits of ASR are difficult to compare to reservoirs, because of the notable differences in the way ASR wells are operated. ASR wells have almost limitless storage capacity in the subsurface, and their benefits are primarily determined by recovery rates and pumping rates. Reservoirs typically can be filled much more quickly, depending on conveyance capacity. ASR wells often inject water for extended periods, and if suitable subsurface conditions exist, ASR wells are capable of providing recovered water over multi-year droughts in ways that even the largest reservoirs cannot. South Florida reservoirs more typically store water during wet periods and supply it in the immediately following dry season. Original CERP model simulations over a 31-year period (see Table 4-2) show that ASR provided a maximum annual storage (maximum annual inflow) of 1.7 MAF—more than 50 percent of the total provided by all other engineered CERP storage projects. In extreme dry years, ASR recovered as much as 872,000 AF of water (approximately 30 percent of the maximum outflow from all other engineered CERP storage). Average annual ASR recovery is less than half of that injected, by volume (see Table 4-3).

Uncertainties about science and engineering aspects of large-scale ASR in Everglades restoration led project planers to include a series of pilot projects in the recommended plan. USACE and SFWMD (2013a and 2015b) summarize the results of two single-well pilot projects and an 11-year regional study to address aggregate hydraulic, geophysical, and ecotoxicological effects of a system with 333 ASR wells (for more on the ASR Regional Study, see also Chapter 3 and NRC, 2015). Although the Hillsboro and Kissimmee ASR pilot projects reported "no fatal flaws" in the use of ASR at the single-well scale, the 11-year $25 million regional study (USACE and SFWMD, 2015b) reported that it is unlikely that the aquifer will sustain 333 wells as defined in the CERP. Modeling showed that a substantially reduced number of wells were needed to meet aquifer pressure and well pressure limits (94 in the Upper Florian Aquifer and 37 in the Avon Park Permeable Zone). Overall, the amount of water that can be stored and retrieved from ASR has been reduced by about 60 percent compared to what was envisioned in the original formulation of the CERP (Table 4-3). Planners could explore alternative well placement scenarios, including additional injection wells in the highly permeable Boulder Zone, where water recovery is not feasible. Although no modeling was conducted in the Regional Study to assess systemwide implications of only 131 ASR wells, the lost ASR storage would likely impact the ability to meet CERP goals and targets.

Lake Okeechobee Operations

A major factor that affects regional surface water storage in South Florida, and thus the ability of CERP to meet restoration goals, is the manner in which water levels are managed in Lake Okeechobee. Lake inflows and outflows are managed according to guidelines identified in lake regulation schedules. All regulation schedules for Lake Okeechobee have been developed in the context of a constraint created when the Herbert Hoover Dike was constructed—that the yearly inflow volume greatly exceeds the capacity of outlet structures to remove that water (USACE, 2007d). This situation demands a strategy of dropping the lake to a low level before the wet season so that water does not rise to dangerous levels where the dike could be breached, and then allowing the lake to become deeper prior to the dry season to ensure that there is adequate water for downstream agricultural and other uses.

Background and History of Lake Regulation Schedules

In 1951, the USACE implemented a formal schedule with distinct regulatory bands, which define seasonally varying water levels that, when exceeded, triggered water discharges from the lake (USACE, 1978). Refinements to the USACE lake regulation schedules have been made several times primarily in response to periods of prolonged drought when the lake did not provide adequate water for regional uses that had been growing over time (SFWMD, 1988). The 1978 schedule in particular was focused on providing water supply and routinely held the lake at a relatively high level (up to 17.5 feet National Geodetic Vertical Datum [NGVD] 1929) to meet a large demand for irrigation water. An evaluation of the 1978 regulation schedule (SFWMD, 1988) concluded that the schedule's high water levels were not necessary to meet water use demands and resulted in damaging large volume releases of freshwater to the Saint Lucie and Caloosahatchee estuaries. A new schedule (Run 25) was subsequently adopted, with the aim of reducing the frequency of occurrence of stages above 17 feet NGVD, reducing high volume releases of water to the estuaries, and still meeting requirements of water users. Run 25 was the federally-authorized regulation schedule during the development of the CERP, and therefore it is the operating schedule that was included in all regional hydrologic modeling used to screen restoration alternatives and develop for the CERP (USACE, 1999).

In the years since the CERP was developed, the regulation schedule for Lake Okeechobee has been modified twice. The first revised schedule, called Water Supply and Environment (WSE), was implemented in April 2000 and was developed to further reduce adverse impacts to the lake's littoral zone and the estuaries (beyond what was accomplished by Run 25), while still meeting water supply demands. In the years leading up to development of the WSE schedule, a substantive number of research projects (e.g., Aumen and Wetzel, 1995) identified numerous values provided by the lake's littoral zone. During the development of the WSE, USACE (1999) affirmed that the lake's littoral zone—the western wetland region of the lake encompassing an area of approximately 500 km^2—is biologically diverse; contains a mosaic of habitats including low-nutrient interior regions of sawgrass, spikerush, and periphyton that function much like the Everglades; and provide habitat for the federally endangered snail kite. The littoral zone also provides habitat for a diverse assemblage of fish and reptiles including economically important sport fish (Aumen and Wetzel, 1995; Havens and Gawlick, 2005). The ecological conditions of the littoral zone are affected by high water levels due to the configuration of the dike that surrounds the lake. Historically, when water levels in the lake increased in the wet season, the lake expanded in spatial extent into marsh regions to the northeast, south, and southwest (Havens et al., 1996). With an encircling dike, the lake became more constrained spatially, like a bathtub, and when water levels rise above 15 feet NGVD, the lake encompasses the entire surface area inside the dike. As depth increases in the littoral zone, several adverse impacts occur: the submerged plant community shifts from vascular plants to phytoplankton; phosphorus transport into the littoral zone increases, which can lead to cattail expansion; and increased wave energy can cause a loss of emergent plants at the edge of the littoral zone (Johnson et al., 2007).

The WSE schedule incorporated, for the first time, a proactive "decision tree" into lake operations. Decisions about holding or releasing water were done not only based on current water levels but also on short- and long-term outlooks of inflow volume. Short-term outlooks were based on the hydrologic conditions (wet vs. dry) of the tributaries north of the lake, and the long-term outlooks were based on ocean circulation cycles that influence rainfall in South Florida, in particular the El Niño Southern Oscillation (ENSO) and Atlantic Multi-Decadal Oscillation (AMO).

In 2007, because of concerns for the structural integrity of the dike, the USACE began a comprehensive rehabilitation effort, to reinforce the Herbert Hoover Dike that surrounds Lake Okeechobee with total costs estimated at $1 billion (SFERTF, 2009; USACE, 2012b). The USACE also adopted a new lower Lake Okeechobee regulation schedule (LORS; USACE, 2007d), implemented in 2008, that was designed to hold the lake at what the USACE considered to be safe levels until dike rehabilitation was complete. Like the WSE, LORS 2008 has seasonally-varying bands that identify the amounts of water to be released from the lake to protect the dike and releases of water from the lake for flood control purposes are determined by rainfall projections, tributary hydrologic conditions, and multi-season climate projections (USACE, 2007c). A major difference from WSE is the explicit objective of LORS 2008 to hold Lake Okeechobee at a lower level, generally between 12.5 and 15.5 feet NVGD (USACE, 2007c) by continual low-volume releases to the estuaries and when necessary by high volume regulatory releases. This condition is done by managing water within bands shown in Figure 4-7 and described in Box 4-5. LORS 2008 was envisioned as an interim schedule until rehabilitation of key sections of the Herbert Hoover Dike were completed (USACE, 2007d).

Consequences of the LORS 2008 Regulation Schedule

Because Run 25 and the WSE schedule have the same upper band, there was not a reduction in the potential amount of water that could be held in the lake, even though operations were quite different. In contrast, the maximum water level in the LORS 2008 schedule is 1.25 feet lower than in Run 25 and WSE, which is equivalent to a loss of 564,000 AF of potential storage capacity in the lake. Considering monthly variations in the schedules, the LORS high management band is 1.00 to 1.75 feet lower than the WSE, reflecting equivalent losses in storage ranging from 460,000 to 800,000 AF depending on the time of year.[4] As a

[4] Calculated based on http://my.sfwmd.gov/gisapps/losac/sfwmd.asp.

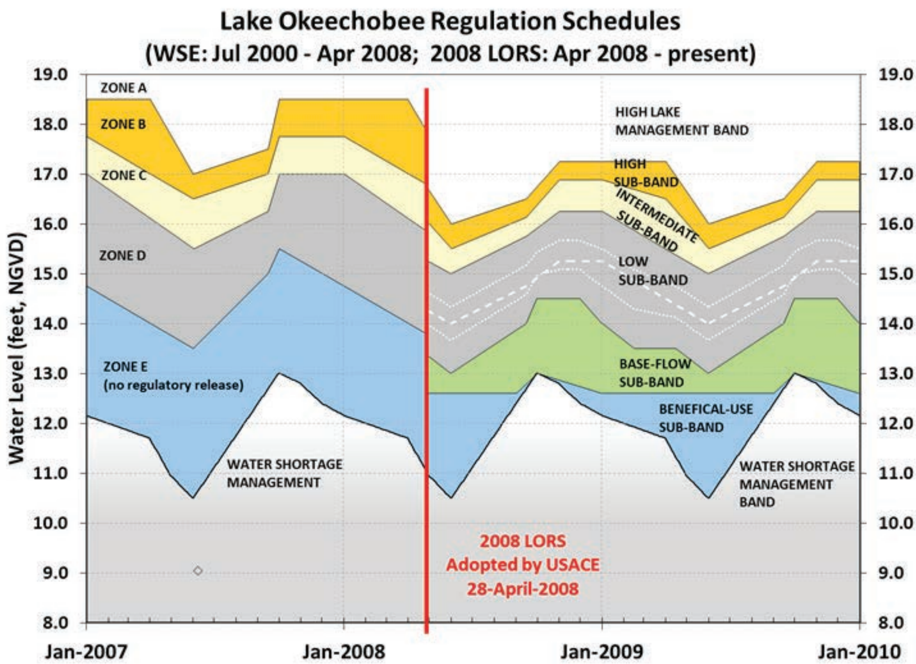

FIGURE 4-7 A comparison of the release zones of the USACE regulation schedules for Lake Okeechobee before and after April 2008.

SOURCE: SFWMD (2015b).

result, if CERP is implemented exactly as planned in the Yellow Book (USACE and SFWMD, 1999) and operated under today's LORS 2008 lake regulation schedule, there would be a large potential shortfall in regional storage capacity. Options to make up for this lost storage could include surface storage in reservoirs, dispersed storage on land, and/or raising the water storage capacity of Lake Okeechobee.

If the upper band of lake regulation schedule is not increased once the Herbert Hoover Dike repairs are completed or if the storage is not replaced by other projects, this would result in substantially reduced water availability for environmental, agricultural, or urban uses and a lower reduction in harmful high-volume discharges to the estuaries than anticipated in the original CERP. On the other hand, the environmental impact statement for the current schedule indicated that it would provide substantive benefits for the lake's littoral zone, and in fact, the acreage of submerged and emergent plants has been at record

BOX 4-5
LORS 2008 Management

LORS 2008 manages water within the following general bands also shown in Figure 4-7:

- **High lake management band** – includes lake levels above 16 feet NGVD in advance of the wet season, or levels above 17.25 feet NGVD during the dry season. Within this band, operations are focused on reducing the lake level, freeing up additional capacity for runoff from future heavy rain events. Maximum water releases typically occur when the lake is in this band.
- **Operational bands** – these are five sub-bands that guide decisions to balance the needs of all users, while maintaining a lake level in the USACE preferred range of 12.5 and 15.5 feet NGVD.
- **Water shortage management band** – this band includes lake levels below 10.5 feet NGVD in advance of the wet season, or levels below 13 feet NGVD at the start of the dry season.

When water levels are in the lower operational bands and in the water shortage zone, the SFWMD balances human and environmental needs and makes recommendations to the USACE about water releases (e.g., environmental water deliveries to the Caloosahatchee Estuary) based on Adaptive Protocols, which are procedures adopted by the SFWMD Governing Board in September 2010 (SFWMD, 2010). It is the USACE that makes the final decision as to whether those releases occur. One of the strategies for keeping the lake lower in the adaptive protocols is to continually release a low volume of water to the estuaries year-round, as part of an approach to reduce the risk of damaging high volume estuary releases.

high levels in recent years (Zhang et al., 2016)—though it is unclear whether this is because of the regulation schedule or a period of below-average rainfall in some of the years.

Options for Increased Future Water Storage in Lake Okeechobee

At this time, the USACE has not determined what, if anything, will be done with the Lake Okeechobee regulation schedule once rehabilitation of the Herbert Hoover Dike (see Chapter 3) is complete. A process to revise LORS 2008 is not scheduled to begin until 2022, after the start of the planning efforts on Lake Okeechobee Watershed (2017-2019), the Western Everglades (2017-2019), and EAA storage (2021-2023). The Herbert Hoover Dike Dam Safety Modification Study (USACE, 2016l), however, states that the regulation schedule can be revised concurrently with the rehabilitation efforts under way.

Any consideration of a new regulation schedule will need to take into account the various costs and benefits to the lake's littoral zone, the northern estuaries, the Everglades WCAs, and water supply, considering the interdependencies of existing water storage, conveyance, and treatment infrastructure as well as that under construction (e.g., Restoration Strategies, C-43, C-44) and future projects that are authorized or likely to be authorized (e.g., Central Everglades) and storage options in other locations (e.g. Lake Okeechobee Watershed, EAA, Western Everglades). Given the many system interdependencies, it is difficult to fully assess these future costs and benefits from the LORS 2008 environmental impact statement (USACE, 2007d) analyses, which was based on existing infrastructure and other constraints that existed at that time. The comparison between LORS 2008 and WSE in USACE (2007d) indicated that under the WSE schedule, there was a five-fold greater risk of extreme high water levels (above 17 feet NVGD) in the lake that could (1) damage submerged vegetation and shoreline emergent plants; and (2) cause more phosphorus transport into the littoral zone. At the same time, WSE had a lower risk of long-lasting high flow events to the northern estuaries, which can negatively affect estuarine biota. The EIS indicated little difference between the two schedules regarding WCA performance measures (tree island flooding and peat dry-out), which likely reflects water quality treatment infrastructure constraints that still exist today regarding sending more treated water to the Everglades Protection Area. If those constraints are lessened by the CERP and other storage and treatment projects, then one can reasonably expect that a change in the lake schedule, in particular holding more water for delivery to the south, could have downstream benefits.

Estimated project costs of regaining 564,000 AF of lost storage by raising the lake can be compared against other storage options (Zhang et al., 2016). The financial costs for raising the lake levels likely are negligible, aside from the costs of conducting an environmental impact statement and any enhanced costs of operations. By comparison, the estimated annualized cost to store water in surface reservoirs has been estimated to range between $162-325 per acre foot capacity per year (Hazen and Sawyer, 2011; Lynch and Shabman, 2011) and the annualized costs of dispersed water management have been estimated between $77-268 per acre foot capacity per year (Gray and Lee, 2015; Meiers, 2013). The annualized cost for replacing the lost 564,000 AF storage capacity in the lake is estimated at $43-183 million/year. This simplified cost comparison does not include a full assessment of economic costs and benefits, including environmental costs and benefits and other social and economic factors, which would need to be included in a full consideration of storage alternatives.

Effects of Lost Storage on CERP Performance

A recent analysis of several restoration scenarios through the Synthesis of Everglades Research and Ecosystem Services (SERES) project (Arik et al., 2015) provides insights into the systemwide impacts that could occur with the loss of major elements of CERP storage. The SERES study focused on two of what they considered to be a short list of CERP components that have the largest effect on restoration: (1) storage and (2) the extent of levee removal and canal filling or decompartmentalization. Formulation of the storage alternatives was guided in large part by the findings of the *ASR Regional Study Technical Data Report* (USACE and SFWMD, 2015b), which suggested that ASR may only be feasible at a scale one-third of that proposed in the CERP, and the concern that the Lake Belt in-ground storage and Bird Drive reservoirs may not be feasible. In light of those observations, the SERES project formulated five scenarios to evaluate effects of loss of storage as well as options to offset those losses:

A. Existing Condition (operated under LORS 2008)
B. CERP, as designed in the Yellow Book
C. Scaled-back CERP storage (approximately 1/3 of CERP ASR, no Lake Belt, no Bird Drive Reservoir), representing about half of the constructed storage in CERP; decompartmentalization is the same as CERP
D. Expanded decompartmentalization and surface storage, no ASR
E. Greatly expanded decompartmentalization and storage, no ASR

The following discussion focuses on the SERES project findings regarding the different benefits provided by the CERP as originally designed (SERES Scenario B) and a CERP plan with substantially reduced storage (Scenario C) compared to existing conditions. The storage features in these three scenarios are described in Table 4-4. Note that Scenario C (scaled-back CERP) still includes 360,000 AF water storage in the EAA Reservoir, even though the land at this time has been designated for low volume FEBs. Also, in the original SERES analysis, the lake regulation schedule for Scenarios B and C was assumed to be the WSE, which provides an additional 564,000 AF of potential storage. Upon request of the committee, the SERES team provided additional hydrologic modeling of the alternatives using LORS 2008 (R. Paudel, Everglades Foundation, personal communication, 2016), to illuminate the difference in restoration benefits from the current lower regulation schedule, in case the water levels allowed within this schedule are not increased in the future schedule modifications. These modified alternatives are Scenarios B_{LORS} and C_{LORS}.

The South Florida Water Management Model (SFWMM) was used to evaluate the hydrologic performance of each alternative and other model tools,

TABLE 4-4 Storage Features for Three Alternatives Considered in the SERES Analysis of Restoration Options

	Alternative Scenarios		
Component	**A: Base Conditions**	**B: CERP**	**C: Scaled-back CERP**
Lake Okeechobee ASR (MGD)	0	1000	250
EAA Reservoir (kAF)	0	360	360
Lake Belt Reservoirs (kAF)	0	280	0
Bird Drive Reservoir (kAF)	0	11.6	0
Lake Regulation Schedule	LORS	WSE	WSE

SOURCE: SERES Project (Arik et al. 2015).

including ecological and landscape models, were used to assess the ecological, water quality, and landscape impacts related to specific performance measures. The SFWMM was run using the 1965 to 2000 period of record of rainfall as the driver of the model. As was the case in the development of the CERP, this evaluation assumes future stationarity in the temporal distribution of rainfall. Particular attention is given in this review to water levels in Lake Okeechobee, high volume discharges to the St. Lucie and Caloosahatchee estuaries, and select hydrologic features in the Everglades.

Lake Okeechobee

Compared to Scenario B (CERP), Scenario C (scaled-back CERP) resulted in a slight increase in the occurrence of low and high water levels. However, when LORS 2008 is retained as the regulation schedule in CERP (Scenario B_{LORS}), there is a substantial increase in low water levels compared to current conditions, which is further exacerbated under Scenario C_{LORS} with reduced storage (see Table 4-5). Under LORS, the median water level in the lake under future restoration scenarios (B_{LORS} and C_{LORS}) is more than a foot lower than under WSE (Scenarios B and C), which generally would be beneficial to the lake's submerged plant assemblage and the emergent littoral zone and its flora and fauna.

Northern Estuaries

As shown in Table 4-6 and Table 4-7, all the restoration scenarios lead to large reductions in the volume of discharges to the estuaries relative to base conditions. However, reducing regional storage results in a substantial increase in high volume discharges to the northern estuaries. Scenario C (scaled-back

TABLE 4-5 Lake Okeechobee Performance Measures for SERES CERP Scenarios

	A:	WSE Reg. Sched.		LORS 2008 Reg. Sched.	
	Base Conditions (LORS)	**B: CERP**	**C: Scaled-Back CERP**	**B_{LORS}: CERP**	**C_{LORS}: Scaled-Back CERP**
Low Water Performance Measure (<10 ft NGVD), 100 is best	85	74	69	66	60
High Water Performance Measure (>17 ft NGVD), 100 is best	99	93	88	100	99
50% Water Level (ft NGVD)	13.4	13.8	13.8	**12.6**	**12.6**

NOTE: For the low and high water performance measures, higher numbers are better, with 100 being the best possible score to optimize lake habitat. A detailed description of calculation of the high and low lake stage performance measure can be found in RECOVER (2007c).
SOURCE: SERES Project (Arik et al., 2015); R. Paudel, Everglades Foundation, personal communication (2016).

TABLE 4-6 St. Lucie Estuary Performance Measures for SERES CERP Scenarios

	A:	WSE Reg. Sched.		LORS 2008 Reg. Sched.	
	Base Condit ions (LORS)	**B: CERP**	**C: Scaled-Back CERP**	**B_{LORS}: CERP**	**C_{LORS}: Scaled-Back CERP**
Mean annual flood control (regulatory) releases (kAF)	150	28	**49**	**45**	**57**
High discharges (months, with avg. 2000-3000 cfs)	45	20	17	19	19
Very high discharges (months, with avg. >3000 cfs)	30	8	**15**	9	**11**
Low flow (months, with avg. <350 cfs)	103	51	54	**104**	**105**

NOTE: Months are based on model results over 1965-2000. For both high and low discharges, a lower number is better for estuarine conditions and desired salinity.
SOURCE: SERES Project (2015); R. Paudel, Everglades Foundation, personal communication (2016).

TABLE 4-7 Caloosahatchee Estuary Performance Measures for SERES CERP Scenarios

	A:	WSE Reg. Sched.		LORS 2008 Reg. Sched.	
	Base Conditions (LORS)	**B: CERP**	**C: Scaled-Back CERP**	**B_{LORS}: CERP**	**C_{LORS}: Scaled-Back CERP**
Mean annual flood control (regulatory) releases (kAF)	390	78	**131**	**182**	**208**
High discharges (months, with avg. 2800-4500 cfs)	67	16	**21**	**43**	**48**
Very high discharges (months, with avg. >4500 cfs)	32	10	**14**	**16**	**18**
Low flow (months, with avg. <450 cfs)	121	55	**63**	**77**	**77**

NOTE: Months are based on model results over 1965-2000. For both high and low discharges, a lower number is better for estuarine conditions and desired salinity.
SOURCE: SERES Project (2015); R. Paudel, Everglades Foundation, personal communication (2016).

CERP with WSE) results in a 75 percent increase in regulatory releases by volume to the St. Lucie estuary and a 68 percent increase to the Caloosahatchee estuary compared to Scenario B (CERP with WSE) (see row 1 [mean annual flood control releases] of Tables 4-6 and 4-7). A reduction in CERP storage (Scenario C) also is associated with an increased number of months with high and very high flows, which can adversely impact the biota of the estuarine ecosystems.

Retaining the LORS regulation schedule in the CERP also results in higher flood control releases by volume compared to the CERP with WSE. Compared to the original CERP with WSE (Scenario B), CERP with LORS (Scenario B_{LORS}) results in a 61 percent increase in regulatory discharges by volume to the St. Lucie estuary and a 133 percent increase for the Caloosahatchee (see row 1 of Tables 4-6 and 4-7). Additionally, in the Caloosahatchee, compared to CERP with WSE (Scenario B), CERP with LORS (Scenario B_{LORS}) causes the number of months with high discharge to more than double and the number of months with very high discharge to increase by 60 percent. The number of months with low flow conditions (on average) in CERP with LORS (Scenario B_{LORS}) is 40 percent higher than the original CERP with WSE (Scenario B) in the Caloosahatchee and approximately double (equal to the base condition) in the St. Lucie (see Tables 4-6 and 4-7).

With both scaled-back CERP and LORS (Scenario C_{LORS}), the restoration benefits to the northern estuaries are substantially reduced from that envisioned in the CERP with WSE (Scenario B); the scaled-back CERP under LORS (Scenario C_{LORS}) results in 104 and 167 percent increases in regulatory releases by volume to the St. Lucie and Caloosahatchee estuaries, respectively, compared to the original CERP projections with WSE (Scenario B).

Water Levels and Flows in the Remnant Everglades

Changing the lake regulation schedule has little effect on water levels or flows to various parts of the remnant Everglades. This was determined by comparing the hydrologic outputs from Scenarios B and C against Scenarios B_{LORS} and C_{LORS} for select areas:

- Stage duration curves for northern and southern WCA 3B;
- Stage duration curves in northern and central WCA 2A and WCA 2B;
- Stage duration curves in northeast Shark River Slough and the Rocky Glades;
- Stage duration curves in western Shark Slough; and
- Stage duration curves in the eastern and western Marl Prairies.

There are, however, noticeable systemwide effects of the removal of water storage features (i.e., differences between Scenarios B [CERP] and C [scaled-back CERP]). Three examples of hydrologic effects are presented here. First, under Scenario C, there are substantial changes in ponding depth throughout the Everglades compared to Scenario B (see Figure 4-8). The differences seem largely driven by the removal of the Lake Belt reservoirs in Scenario C. Without the reservoirs, substantively lower ponding depths (0.05-0.5 ft) are observed in WCA 3B and the eastern side of Everglades National Park. In contrast, water

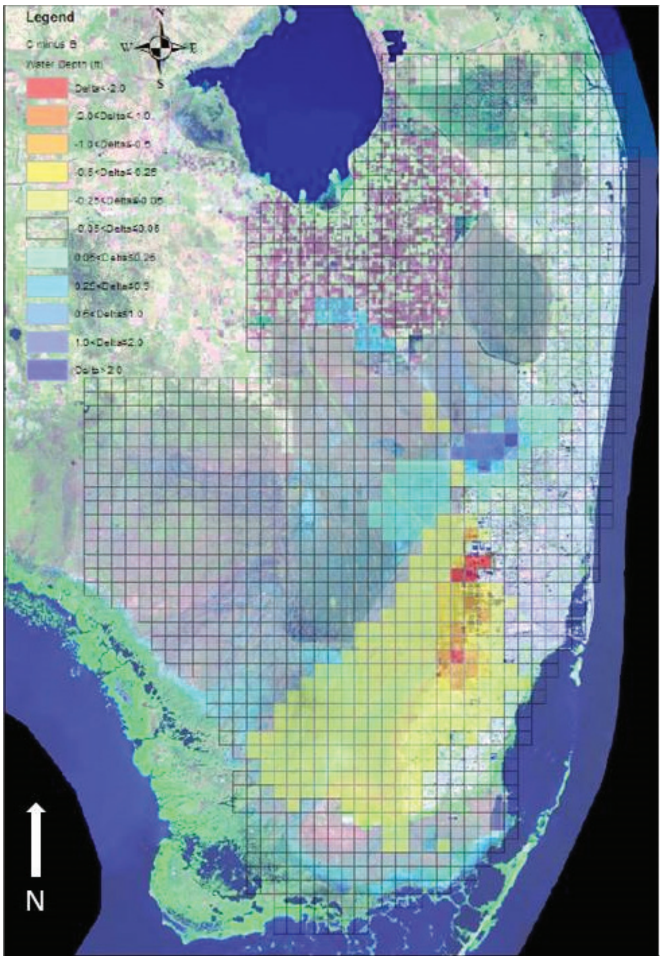

FIGURE 4-8 Ponding depth differences between CERP and scaled-back CERP (red = greatest reduction of depths in the scaled-back CERP compared to CERP; blue = greatest increase in depth in the scaled-back CERP compared to CERP; colorless cells = no difference).

SOURCE: SERES Project (Arik et al., 2015).

levels in WCA 2B become substantively higher, because excess water is no longer being moved to the south via the eastern flow-way.

At a local scale, there is a substantive reduction in the flow of water across Transect 27, which bisects Shark River Slough and reflects the amount of water that flows seasonally toward the Gulf estuaries. Compared to Scenario B (CERP), under Scenario C, the average annual reduction in flow is 111,000 AF, with 49,000 AF less during the wet season and 62,000 AF less flow in the dry season on average. This potentially could have effects on the flora and fauna of the southern Everglades as well as on the salinity of the downstream estuaries. As a result of reduced flow in Scenario C (scaled-back CERP), average salinities in Florida Bay are increased by approximately 1 ppt (see Table 4-8), although it is not clear whether it is statistically or ecologically significant.

TABLE 4-8 Performance Measures under Scenario B (CERP) and Scenario C (Scaled-back CERP) Compared to Base Conditions

	Scenario A: Base Conditions, LORS 2008	**Scenario B: CERP + WSE**	**Scenario C: Scaled-Back CERP + WSE**
Florida Bay Salinity (avg.) in ppt[a]	28	26	27
Flood control releases, Caloosahatchee (kAF)[b]	390	78	131
Flood control releases, St. Lucie (kAF)[b]	150	28	49
Average annual overland flow into northern WCA-3A from EAA (kAF)[c]	170	424	425
Average annual overland flow to Gulf Estuaries (kAF)[c]	704	1314	1200
Apple snail habitat quality in WCA-3A, North[d]			
Change in wading bird flock abundance (ENP)[e]		+12%	+9%
Change in Fish Density (SRS)[f]		+31%	+28%
Number of fire closure days[g]		–78%	–67%

NOTES: Shading reported from SERES Project (Arik et al., 2015).
[a] Green shading represents a difference from historic salinity levels of 2 ppt or less; while yellow is 3-5 ppt difference from historical conditions (24 ppt).
[b] Green indicates flood control releases reduced 75% or more compared to existing conditions; yellow is reduced less than 75%; red is existing conditions.
[c] Green is equal or exceeding 80% of NSM flows; yellow is 60-79% of NSM flows; red is less than 60% of NSM flows.
[d] Green reflects 0-20% of years with dry soil, yellow reflects 21-33% of years with dry soil, and red with more than 33% of years with dry soil. Colors based on weighted averages of likelihood of dry soil conditions in indicator regions. Data in Arik et al. (2015) are provided for each indicator region and colors are only provided for the overall average.
[e] Green reflects >5% average annual increase in wading bird abundance relative to Scenario A.
[f] Green reflects >5% average change in fish density relative to Scenario A.
[g] No color coding provided.
SOURCE: Data from SERES project (Arik et al., 2015).

This same pattern characterized other performance measures that reflect objectives of restoration of the central Everglades, such as apple snail habitat quality, wading bird abundance, and fish density (Table 4-8). Both Scenario B (CERP) and Scenario C (scaled-back CERP) produced benefits, but the former produced greater improvement than the latter. Reductions in benefits due to scaling back the CERP were not as dramatic as in the northern estuaries, but were consistent.

Implications for CERP Planning

Collectively, the knowledge gained since the start of the CERP has profound implications for restoration outcomes. Steps that could be taken to consider this information at a systemwide scale in the context of program-level adaptive management are discussed in Chapter 5. However, there are also near term implications for CERP planning, particularly related to water storage.

Systemwide Screening Analysis of Storage Alternatives

In light of the substantial storage that has been lost from the CERP plan, a systemwide screening-level analysis of alternatives formulated around key yet-to-be-initiated storage projects is needed. The purpose of the analysis is to identify the systemwide outcomes of various water storage alternatives, considering what has been learned about water storage feasibility to date, and the most cost-effective combinations of yet-to-be implemented storage alternatives to achieve CERP goals. Such a systemwide analysis is necessary to inform project planning.

Alternatives considered in this screening exercise should include various combinations and sizes of storage projects in the authorized CERP plan as well as any newly identified opportunities located north or south of Lake Okeechobee. This analysis should include in-lake, above-ground, and in-ground storage alternatives and ASR, although feasibility should be a key consideration of each element included. Effects of climate change on cost-effective alternatives, especially potential changes in precipitation and evapotranspiration, should also be examined. Examination of multiple direct outputs of a relatively large number of combinations and alternative capacities of interrelated projects is not trivial, but is manageable. Such analyses are consistent with early screening analyses conducted for the River of Grass and the Central Everglades planning processes, and output from these screening analyses can highlight the most cost-effective projects or combinations of projects that deserve further detailed analysis (i.e., those that deliver the largest intended benefits, such as habitat improvement or reduction in regulatory releases, for the cost without unacceptable impacts). Estimating impacts of those outputs on downstream ecological systems is a more complex undertaking, one that could be limited to only a few alternatives or may be deferred to project planning efforts.

A hydrologic simulation model of storage facilities for this analysis can be much less complex than SFWMD's systemwide model. The simpler model can be used to estimate relationships between storage capacities and direct outputs, such as frequencies of high and low flows, frequency distributions of downstream releases, distributions of reservoir states, and other performance measures. Those results, combined with storage-cost curves, can be used to estimate marginal increases in output with respect to cost leading to identification of storage capacities at which further expansion leads to diminishing returns to investments. Once cost-effective alternatives for storage have been identified, this information will inform more detailed analyses of performance measures, environmental benefits, and environmental risks. The committee recommends that a screening-level analysis of this type be undertaken as a preliminary step before proceeding to more detailed project planning north and south of the lake as well as for the lake itself.

Revisions to the Lake Okeechobee Regulation Schedule

The future lake schedule is critically important to future CERP planning decisions regarding storage north or south of the lake. The adoption of the LORS 2008 schedule, intended to reduce life safety risks in light of structural problems with the Herbert Hoover Dike (see Chapter 3), alone reduced potential storage by 564,000 AF. Yet, the potential for increasing lake levels in a future schedule remains unresolved. Replacing the storage lost by a return to a WSE-like schedule, could offset the need for some other constructed storage. In contrast, keeping LORS indefinitely could necessitate increased CERP storage to achieve the original restoration objectives.

Developing a new lake schedule would require a planning process, with extensive public involvement, that weighs ecological benefits to the lake, the northern estuaries, and the remnant Everglades; related economic impacts/benefits; and water supply. Much good science has been developed over the past decade to inform these discussions. Additionally, the Central Everglades Planning Project developed processes and tools to consider multiple benefits and tradeoffs, and to engage interested stakeholders in a way that promoted transparency and also enhanced interagency communication (see NRC, 2014).

According to the 2015 Integrated Delivery Schedule (USACE, 2016b), the planning process to revisit the lake regulation schedule is not anticipated to begin until 2022—after the planning process for storage north of the lake (Lake Okeechobee Watershed; 2016-2019) has been completed and the planning for south-of-the-lake storage (EAA storage and ASR/Decomp Phase 2; 2021-2024) is already under way. Because of the huge quantity of storage provided (or lost) in small adjustments to the regulation schedule and the implications of those storage changes on CERP outcomes, an expedited evaluation of the Lake Okeechobee regulation schedule is needed to better inform ongoing and near-term storage planning. If storage plans are developed north or south of the lake prior to a reconsideration of LORS 2008, these project plans may need to be revisited considering changes to the regulation schedule. If agencies choose to delay planning efforts on projects to provide storage north or south of the lake until the revised lake schedule is determined, such delays should not adversely affect the pace of restoration progress. There is sufficient construction work associated with approved and authorized projects and for the Central Everglades Planning Project, which is pending authorization, to last at least the next 15 years with typical funding levels. The committee understands that the lake schedule may need to be again revised once the storage plans north and south of the lake have been established and constructed, but such a revision is anticipated to be relatively straight-forward.

Expediting a review of the lake regulation schedule could also potentially expedite benefits to the northern estuaries. Because the USACE requires a new assessment of dam safety and risk with any change to the regulation schedule (see Chapter 3), more time may be needed to finalize the new regulation schedule so that it is ready to be adopted as soon as the Herbert Hoover Dike rehabilitation is sufficiently complete to sustain higher water levels.

CONCLUSIONS AND RECOMMENDATIONS

Knowledge gained regarding the pre-drainage system, climate change, and sea level rise suggests that a reexamination of the CERP restoration goals—including both ecology and hydrology—is in order, together with a realistic assessment of what can be achieved. It is now widely accepted that the Everglades ecosystem was much wetter historically than previously thought. As a result, re-creating historic hydrology will require more new water and have different ecological outcomes than envisioned in the CERP. This information raises new issues and opportunities that should be considered in the context of future CERP design options, including the potential for improved conditions and likely risks associated with higher flows in the southern Everglades. Restoring pre-drainage features while preserving post-drainage features that are viewed as desirable, for example the presence of marl prairies inhabited by Cape Sable Seaside Sparrows, will be especially challenging. Even if the restored system cannot replicate the pre-drainage system or attain all the physical, chemical, and biological goals, improved ecosystem functioning is anticipated from partial attainment of objectives for historical water depth, and benefits from incremental restoration steps may be significant. Revised goals should also reflect the dynamic nature of the system and developing constraints imposed by climate change and sea level rise. Climate change has the potential for marked effects on the structure and functioning of the Everglades, increasing the need for CERP benefits that are robust in the face of climate change uncertainties or outcomes that help mitigate the effects of changing climate and sea level rise.

New information, project designs, and revised lake management rules have reduced the storage capacity envisioned originally in the CERP by over 1 million AF compared to the 1999 plan, which could have serious ecological consequences in both the northern estuaries and the Everglades ecosystem if this shortfall is not addressed. Major reductions in storage capacity are associated with the replacement of the EAA and L-8 Reservoirs with FEBs, the largely reduced capacity of regional ASR, the uncertain feasibility of the Lake Belt reservoirs, and the implementation of a new Lake Okeechobee regulation schedule. The amount of storage capacity provided by planned and authorized CERP projects to date plus the Central Everglades Planning Project (386,000 AF) is less than the 564,000 AF lost by the lower 2008 Lake Okeechobee regulation schedule. Additionally, based on the conclusions of the ASR Regional Study, estimated feasible ASR storage has been reduced by approximately 60 percent, reducing its maximum outflow capacity to a level comparable to a single large CERP reservoir and reducing CERP benefits provided in multi-year droughts. Recent scenario analyses by the SERES project show how loss of storage reduces restoration performance in the northern estuaries in terms of mean annual flood control releases and months with low flow. The SERES analyses show additional impacts to restoration benefits in the remnant Everglades ecosystem and Florida Bay. Further analysis is warranted to examine the implications of various levels of storage on CERP outcomes. It is possible that updated storage designs may be distributed and operated more effectively than originally envisioned, but sufficient information is not publicly available to predict the hydrologic and ecological effects of various changes in storage on the expected systemwide benefits of the CERP. Meanwhile, climate change scenario analyses suggest an increased need for water storage under both reduced and increased precipitation scenarios to mitigate future ecosystem and water supply impacts.

Considerable uncertainty exists regarding future Lake Okeechobee regulation, available water storage beyond Lake Okeechobee, and the impacts of a changing climate. This uncertainty should not be ignored; rather, it should be addressed and incorporated into CERP planning. To address scientific and planning uncertainties associated with climate change and water storage, there is a critical need to analyze these factors and their interacting effects in CERP planning efforts. A systemwide screening analysis of feasible, yet-to-be-implemented CERP storage alternatives is needed to evaluate modeled restoration outcomes with various levels of storage. This screening could also identify the most cost-effective combinations of storage alternatives, which could be examined in more detail in individual project planning efforts. Assessments of hydrologic responses to changes in precipitation (including quantity, intensity, distribution, and changes in seasonality) under anticipated increases in temperature and evapotranspiration should be conducted on the most promising alternatives to demonstrate the outcomes of the CERP in the face of climate change and sea level rise with variable quantities and locations of storage.

The process to revise the Lake Okeechobee regulation schedule should be initiated as soon as possible in parallel with the Herbert Hoover Dike modifications to inform near-term project planning involving water storage north and south of the lake. The large impacts on water storage with just modest changes in the lake regulation schedule suggest that Lake Okeechobee is a central factor in future considerations of water storage. Decisions made on the future regulation schedule will affect storage needs both north and south of the lake and overall restoration outcomes and costs. A planning process, with substantial public engagement, would need to evaluate different regulation schedule options and their differential benefits for the lake, the northern estuaries, and the remnant Everglades as well as related economic and water supply impacts. Expediting the revision to the lake regulation schedule would also ensure that the process is complete (including a required dam safety risk assessment) so that the new schedule can be put into place as soon as the Herbert Hoover Dike repairs are determined to be sufficient to sustain higher water levels, thereby expediting ecological benefits to the northern estuaries. Once other storage elements are constructed, the lake schedule will likely need to be revisited to optimize its operations considering the additional storage features.

5

Looking Forward

Many of the emerging challenges to implementation due to newly available knowledge and information are described in Chapter 4. Advancements in scientific and engineering knowledge related to the understanding of pre-drainage hydrology, climate change and sea level rise, and the feasibility of storage alternatives each are likely to have significant, systemwide impacts on the outcomes of restoration efforts. Climate change, now nationally and internationally recognized as crucial in ecosystem restoration planning, was less of a prominent issue during the development of the Central Everglades Restoration Plan (CERP; USACE and SFWMD, 1999, known as the Yellow Book). In this chapter, the committee revisits how the CERP was originally framed to accept such challenges during implementation and considers what needs to be accomplished, in parallel with ongoing project implementation, in order to set a sound course for long-term implementation and system-level ecosystem restoration.

Accordingly, in this chapter the committee describes the importance of a programmatic adaptive management approach to ensure systemwide goals are achieved. The goals and objectives at an ecosystem-scale, which have not been modified since 1999, need to be revised in light of new information that is available. A new systemwide analysis of the future of the Everglades ecosystem based on changes anticipated or likely in the CERP is needed to inform programmatic adaptive management and regional and local planning efforts, and to provide insight into the establishment of revised long-term goals and objectives. Many new tools/models are available to support this work, and they need to be used much more fully than they have been in project-level planning as well as part of the systemwide analysis.

CERP VISION FOR ADAPTING TO NEW INFORMATION

When the U.S. Congress approved the CERP in the Water Resources Development Act of 2000 (WRDA 2000), there was clear recognition that the Yellow Book (USACE and SFWMD, 1999) provided only a general outline for restoration of the Everglades and not a detailed restoration plan. To facilitate restoration actions in the face of uncertainty, an adaptive management approach (Holling, 1978) was embraced as a mechanism to incorporate emerging scientific and engineering information into the plan and to address unforeseen issues related to the restoration project. Congress approved funding for an adaptive management and monitoring program in WRDA 2000, and the Programmatic Regulations (33 CFR §385.31) directed the U.S. Army Corps of Engineers (USACE) to adopt an adaptive management approach.

The Programmatic Regulations define adaptive management as "a means for analyzing the performance of the Plan and assessing progress toward meeting the goals and purposes of the Plan as well as a basis for improving the performance of the Plan." Specifically, the Regulations (33 CFR §385.31) require the CERP adaptive management program:

> to assess responses of the South Florida ecosystem to implementation of the Plan; to determine whether or not these responses match expectations, including the achievement of the expected performance level of the Plan, the interim goals established pursuant to §385.38, and the interim targets established pursuant §385.39; to determine if the Plan, system or project operations, or the sequence and schedule of projects should be modified to achieve the goals and purposes of the Plan, or to increase net benefits, or to improve cost effectiveness; and to 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 integrated into the implementation of the Plan. Endorsement of the Plan as a restoration framework is not intended as an artificial constraint on innovation in its implementation.

Since the launch of the CERP, substantial progress has been made in developing principles and frameworks for CERP adaptive management, along with detailed guidance for implementing adaptive management at the project level (RECOVER, 2006a, 2011b; USACE and SFWMD, 2011b). Recent attention has turned toward adaptive management at the program level (RECOVER, 2015). Nine major activities identified for CERP adaptive management at the project or program level are summarized in Table 5-1. Two major activities—establishing goals and assessment—are discussed in more detail below because of their important roles in program-level adaptive management.

TABLE 5-1 CERP Adaptive Management Activities and Associated Program or Project Activities

Adaptive Management Activities	Program- and Project-Level Activities
1. Engage Stakeholders	• Collaborate with government partners • Identify and engage non-government stakeholders
2. Establish/Refine Restoration Goals and Objectives	• Define and reach agreement on vision of restoration success • Identify and refine goals and objectives
3. Identify and Prioritize Uncertainties	• Identify and prioritize decision-critical uncertainties • Determine adaptive management approach (passive, active)[a]
4. Apply Conceptual Models, and Develop Hypotheses and Performance Measures	• Use conceptual models to develop testable hypotheses to explain decision-critical uncertainties • Develop performance measures and restoration targets that reflect defining characteristics of the system to be restored • Identify predictive tools, models, and evaluation methodology associated with each performance measure
5. Alternative Plan Development and Implementation	• Integrate adaptive management principles into alternative plan development, design, implementation, and operations • Initiate development of management options matrices, linking goals and objectives with monitoring and management actions
6. Monitoring	• Develop and implement monitoring plan to assess progress toward goals and objectives and address decision-critical uncertainties
7. Assessment	• Assess monitoring data and evaluate restoration progress • Identify performance issues requiring management response
8. Feedback to Decision Making	• Implement management decisions to adjust program/project plans, project sequencing, and/or operations
9. Adjustment	• Modify goals, objectives, and desired endpoints, as appropriate

[a] This activity is largely for the project level.
SOURCE: USACE and SFWMD (2011b).

Establishing Goals and Objectives

What is the CERP trying to achieve for the ecosystem? As discussed in Chapters 2 and 4, at a high level, this is relatively easy to articulate and generally agreed upon. The stated goal of the CERP 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" (WRDA 2000). 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." The CERP goal is frequently also stated as "get the water right," although getting the water right is a means to ecological ends, not an end itself (see also Chapter 2).

To establish objectives that can be used to guide project- and program-level restoration investments, these broad goals need to be interpreted in the context of the complex Everglades ecosystem, which is naturally highly variable in space and time and has been substantially altered over the past century. At the time of authorization, the CERP laid out some ambitious albeit generalized expectations for the ecosystem. For example, the Yellow Book (USACE and SFWMD, 1999) stated: "At all levels in the aquatic food chains, the numbers of such animals as crayfish, minnows, sunfish, frogs, alligators, herons, ibis, and otters, will markedly increase." The expectations for CERP ecosystem outcomes were founded on hydrologic outputs from the NSM and the River of Grass Evaluation Methodology (ROGEM),[1] although the Yellow Book notes that the NSM and ROGEM are useful tools for comparing alternatives but not for predicting specific responses.

Objectives provide a "means by which the restoration success of the Plan may be evaluated at specific points by agency managers, the State, and Congress throughout the overall planning and implementation process" (33 CFR § 385.3). Development of measurable objectives is crucial to effective planning, implementation, and assessment at both the project and programmatic levels and requires consideration of the inherent tradeoffs that must be made in any complex ecosystem restoration program (Reed, 2006).

Progress on articulating objectives that are sufficiently quantitative to enable such an evaluation has been limited under the CERP. In 2005, RECOVER produced a set of recommendations for quantitative "interim goals" by subregion using available models and data, assuming that the original CERP schedule as documented in USACE and SFWMD (1999) would be realized. These interim goals were determined for 2010, 2015, and 2050 with full CERP implementation, compared to 1995 base conditions. Whether these quantitative goals were appropriate and well supported by validated models can be questioned, but the objective quantification of expected outcomes in this way showed an ability to consider the future state of the system and the influence of restoration actions on that state. Examples of the expected outcomes for the Everglades with full CERP implementation (2050) include the following:

- Increase by 103,709 acres the total spatial extent of natural areas;
- 1,871,000 acre-feet (AF) of "new" water captured by the CERP;
- Increase by 31 percent fish abundance in Northeast Shark River Slough, and
- 80,000 nesting pairs of wading birds (see Figure 5-1).

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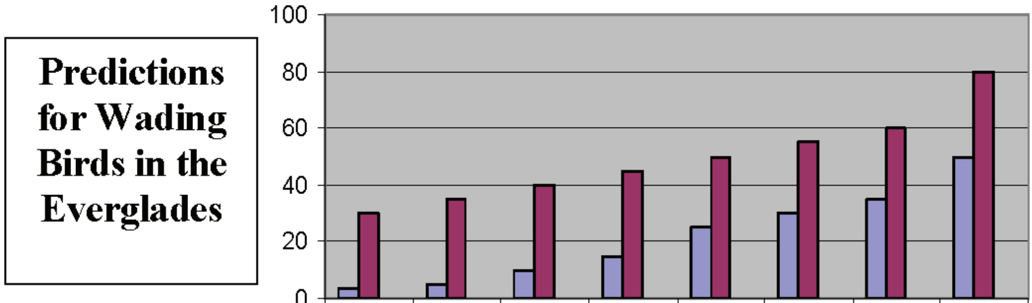
[1] ROGEM was developed and used during the development of the CERP to quantitatively describe potential habitat quality responses to alternative plans. Most of the variables in the tool are driven by hydrology and equations were developed for each of the subregions based on linkages between hydrologic conditions and habitat quality in natural areas.



	1995	2005-2010	2010-2015	2015-2020	2020-2025	2025-2030	2030-2035	2050
Location % Estuarine	3.7	5	10	15	25	30	35	50
Total # of Pairs (thousands)	30	35	40	45	50	55	60	80
Timing of Storks	Feb-Mar	Feb-Mar	Feb-Mar	Jan-Feb	Jan-Feb	Dec-Jan	Dec-Jan	Dec-Jan
Frequency of Super Colony	1 in 8yr	1 in 8yr	1 in 8yr	1 in 8yr	1 in 6yr	1 in 6yr	1 in 6yr	1 in 4yr

FIGURE 5-1 Interim goals for wading birds in the Everglades, based on model predictions of the results of the CERP, assuming that the restoration is implemented according to the originally proposed schedule.

SOURCE: RECOVER, 2005a.

However, these quantitative interim goals were not adopted. Instead, the goals listed in the 2007 Interim Goals agreement (USACE et al., 2007) are largely qualitative, indicating a desired direction of change in each indicator, without a quantitative objective. For example, for the Everglades indicator of "system-wide spatial extent of natural habitat," the goal is simply stated as "increase spatial extent of natural habitat." The signatories noted that the assumptions made regarding implementation in the RECOVER (2005b) report are substantial and instead reiterated the "high priority [for] continued development and refinement of the recommended indicators and interim goals contained within the RECOVER Recommendations consistent with the requirements of the programmatic regulations" (USACE et al., 2007).

To the committee's knowledge, no further work on quantitative goals to guide restoration or to evaluate past or future success has been conducted, and no adjusted assumptions regarding implementation have been incorporated into such modeling. In 2010, an effort was launched to summarize new science since the advent of the CERP and use this information to develop a "shared definition of restoration" that could be used to develop quantitative and measurable restoration goals (Working Group, 2010). The first phase of that process resulted in the *Scientific Knowledge Gained* report released in August 2011 (RECOVER, 2011a). Planned subsequent phases in which this synthesis of new information was to be used to revisit and update restoration goals and targets at a systemwide scale were never initiated, although this new information has been used to inform project planning.

As noted in Chapter 4, substantial new information on pre-drainage hydrology, climate change, and sea level rise has been obtained since restoration goals were developed. The implications of this new knowledge for restoration goals and objectives are varied. Climate change scenarios suggest that under both reduced and increased precipitation scenarios, more storage than originally envisioned will be required to meet performance targets. Sea level rise projections indicate the original hydrologic and ecological objectives for some areas cannot be achieved. New knowledge of the pre-drainage system indicates that restoring pre-drainage hydrology will not result in the ecological outcomes originally envisioned for a particular area, as exemplified for marl prairie habitat in Chapter 4.

Even if the broad goals of the restoration remain unchanged, the details of specific hydrologic and ecological objectives in space and time, especially quantitative objectives, need to be revisited. The Shared Definition initiative (Working Group, 2010) may have been an appropriate vehicle for this task, but it would need to be reinitiated on the basis of current knowledge. The capacity to identify achievable goals and objectives is much improved since CERP authorization due to advances in modeling, especially in the development of systemwide ecological models (discussed later in this chapter). The capacity now exists to identify an ecological goal and then determine the hydrology necessary to achieve it. The establishment of clearly defined goals and quantitative objectives will involve evaluation of tradeoffs among various hydrologic and ecological objectives, and perhaps some rethinking of priorities, especially with respect to expectations for particular species. Establishing quantitative restoration objectives may be especially challenging in situations that involve the restoration of pre-drainage features together with the preservation of post-drainage features that are deemed desirable (e.g., the littoral zone community in Lake Okeechobee; marl prairie habitat inhabited by Cape Sable seaside sparrows, see Chapter 4). The development of these objectives should involve reassessment of the essential characteristics of successful restoration, what is desirable but not essential, what can be achieved, and what cannot.

Whether such goals for the future system should be as specific as that presented in Figure 5-1 merits reconsideration when efforts to develop quantitative goals are reinitiated. It is important for adaptive management that goals are expressed in quantities that can be both predicted with confidence in the models and measured in the field. When quantifying goals, RECOVER scientists and other experts need to consider both modeling skill and monitoring resources.

Assessment and Evaluation

The Programmatic Regulations define assessment as "the process whereby the actual performance of implemented projects is measured and interpreted based on analyses of information obtained from research, monitoring, modeling, or other relevant sources." This step is critical to the adaptive management process, so that monitoring data can be compared to quantitative objectives to gauge restoration progress. As noted in Table 5-1, this process is also used to identify performance issues that may need to be addressed through project- or program-level modifications. However, the definition is perhaps too narrow for what is needed for the incorporation of new information into the CERP. Assessment could also reasonably include an evaluation of modeling results based on new scientific and engineering information to determine how well on-the-ground ecosystem achievements are aligned with CERP objectives and how these might change in the future. For instance, such an assessment could be used to evaluate how various levels of storage or climate change impact the ultimate attainment of CERP goals, thereby informing future planning.

The Programmatic Regulations call for RECOVER to prepare a report every 5 years that presents an assessment of whether the goals and purposes of the CERP are being achieved, including whether the interim goals are being achieved or are likely to be achieved. To date no such reports have been produced. There is an established system status report process (RECOVER, 2007a, 2010, 2012, 2014) but to date those reports have been largely based on assessment of trends in monitoring data and are not responsive to the need stated in the Programmatic Regulations to be forward looking and identify whether goals are likely to be achieved. For a long-term program like the CERP, continually looking forward to consider the state of the system and how it will change in the future is as important as looking back to document progress.

As part of the Adaptive Management Program, the CERP Programmatic Regulations also call for the agencies to "conduct an evaluation of the Plan using new or updated modeling that includes the latest scientific, technical, and planning information." These evaluations, termed "CERP Updates," are to be conducted "whenever necessary to ensure that the goals and objectives of the Plan are achieved but not any less often than every 5 years." These evaluations can result in consideration of adjustments in operations, CERP components (removing, adding or changing), or any combination of these. The Initial CERP Update (RECOVER, 2005b) was conducted and published in 2005, which included revisions to performance measures, model updates, and changes in modeling assumptions regarding existing and future conditions. No such evaluation of the CERP has been conducted since 2005 despite substantial changes in scientific, technical, and planning information, as described in Chapter 4.

In 2000, when the CERP was authorized with its strong emphasis on adaptive management, it was seen across the United States as a leader in approaches to incorporating new and developing information into the restoration plan (e.g., Kallis et al., 2009; Linkov et al., 2006). The frameworks and processes developed still provide a model for others, but what were the leading concepts of the time in ecosystem restoration have not been realized, particularly at the system scale. Tools are now available to support follow-up on key components, such as quantitative goals for the system and forward-looking assessment and evaluation. Given the new information and knowledge outlined in Chapter 4, it is even more important to look forward and anticipate issues, rather than only looking to the past and present to monitor restoration progress. Whether storage limitations really do compromise the overall success of the CERP is now a question that can be answered. Some critics say climate change will fundamentally limit the success of restoration (Holthaus, 2015), but the implications of climate change and sea level rise to CERP goals under various scenarios can be quantified, and other benefits not envisioned in the original restoration plan can be explored. Climate change is now widely recognized as critical to planning any new large scale coastal ecosystem restoration. By using new tools (discussed later in this chapter) and continuing to think about the future, even while in the midst of massive project implementation, the CERP can continue to lead in adaptive management and adaptation to changing circumstances and new science.

PROGRAM-LEVEL ADAPTIVE MANAGEMENT FOR CERP

The CERP Program-Level Adaptive Management Plan (RECOVER, 2015) was recently released and outlines a structured approach to implement systemwide adaptive management. Project-level adaptive management has been addressed in a previous report (RECOVER, 2011b). The RECOVER (2015) report is an important step in the evolution of the Monitoring and Assessment Plan (MAP) that has been developed over the past decade (RECOVER 2006b, c, 2007b, 2009b). The latest report addresses three program-level components missing from the MAP, specifically to

1. identify and prioritize (rank) programmatic uncertainties that might limit meeting CERP goals and identify strategies to address them,
2. develop an adaptive management approach to address the prioritized uncertainties, and

3. develop management option matrices containing options of how to improve restoration performance if goals are not being met.

Uncertainties were grouped into three tiers based on the level of knowledge, relevance to improving the design or operation of CERP projects, and the risks of not meeting CERP goals if the uncertainty is not addressed (see Box 5-1). Uncertainties designated with a combination of high risk, low knowledge, and high relevance were considered Priority 1 programmatic uncertainties and have been designated as "decision critical." They are referred to as "showstoppers." RECOVER (2015) states that if these are not addressed then a component of the restoration could be "paralyzed" and progress toward meeting CERP goals will be effectively stopped. A total of 13 Priority 1 programmatic uncertainties are identified that reflect uncertainties related to both planning and scientific questions (Box 5-1). The Priority 1 uncertainties identified by RECOVER (2015) include system-scale strategic issues as well as issues that are of concern in only some parts of the ecosystem. Some address large-scale sequencing and feasibility while others address more tactical issues related to project design. An additional 22 Priority 2 uncertainties of medium relevance and knowledge and medium or high risk are identified.

The Program-Level Adaptive Management Plan provides details on the identified uncertainties, including an explanation of how CERP progress would benefit from addressing each, and it identifies existing and potential strategies for dealing with the uncertainty. The report also specifies the information needed to complete the adaptive management feedback loop and presents management options matrices (MOMs), to summarize actions that could be taken if restoration efforts are not meeting performance targets. The MOMs describe the indicators used to assess performance, the thresholds for those indicators that define when corrective action should be taken, and options that could improve performance. Both the uncertainty tables and the management options matrices summarize a wealth of information and are intended as a quick-reference guide for managers.

A key element of the Program-Level Adaptive Management Plan is the summary of the project-specific goals, interim goals from RECOVER (2005b), "full restoration targets" that indicate good CERP performance relevant to a specific indicator based on RECOVER's documentation of performance measures (RECOVER, 2007b), and triggers for management action. This information can be used to assess when options for adaptive management actions, specified in the document, are needed. However, for many of the identified uncertainties, the goals and targets have not been defined and are shown in the tables simply as "TBD" (to be determined). As discussed earlier in this chapter, quantitative objectives are critical to successful adaptive management. The lack of specific, program-level quantitative restoration objectives is a long-standing issue in

BOX 5-1
Priority 1 Mission Critical Uncertainties Identified by the CERP Program-Level Adaptive Management Plan

Each uncertainly identified in the Program-Level Adaptive Management Plan (RECOVER, 2015) was evaluated using three criteria:

1. Knowledge – what is known about the uncertainty (high, medium, low) and how it should be addressed,
2. Relevance – what is the level of confidence (high, medium, low) that addressing the uncertainty will help improve the design or operation of CERP projects, and
3. Risk – what is the risk (high, medium, low) that CERP goals won't be met if the uncertainty is not addressed.

Generally, those uncertainties with high risk, low knowledge, and high relevance were designated as Priority 1 CERP programmatic uncertainties—no further prioritization was conducted within the Priority 1 uncertainties. A total of 13 Priority 1 programmatic uncertainties were identified under topics such as storage capacity, climate change, project targets, and goals. The committee has not examined the rationale behind the identification of these uncertainties or evaluated the priorities established; they are listed here to illustrate a key development in adaptive management.

Storage

- Will enough storage be constructed to allow Lake Okeechobee water levels to be kept at ecologically beneficial levels (i.e., reduce extreme high and low periods)?
- Will storage projects (e.g., Aquifer Storage and Recovery) provide enough storage to protect the estuarine resources in both dry and wet seasons?

Oysters

- What are the water quality (nutrients and suspended solids) impacts on larval oyster recruitment, given an adequate numbers of spawning oysters in the estuaries (i.e., are larvae killed by poor water quality or are they washed downstream)?

Processes

- What is the role of flow velocities and flow volumes in maintaining characteristic ridge-and- slough patterns?

building the adaptive management program (NRC, 2008). Without the articulation of relevant, quantitative restoration objectives for the program, progress in evaluating the CERP cannot be achieved.

Overall, the Program-Level Adaptive Management Plan asks highly relevant questions about the CERP (see Box 5-1), touching on many of the systemwide issues highlighted in Chapter 4, such as storage, defining goals, and climate

Design

- Which areas can be restored quickly (decadal) vs. slowly (century-millennia)? If areas are currently degrading, will waiting to start restoration extend the time of their recovery? Can ridge and slough patterns be reestablished simply by restoring hydrology?
- Is complete backfilling of canals and removal of levees necessary for restoration? Is partial or no backfilling of canals a viable alternative?

Water Quality

- How should restoration projects be designed to deliver increments of clean water to priority restoration areas, i.e., how best can water quantity and water quality goals be balanced to optimized restoration project performance?

Targets

- What water volumes and patterns of flow are required to restore submerged aquatic vegetation, oysters, and fish communities in the coastal Everglades?
- What are the hydrologic needs of the Everglades ecosystem (natural) compared to the human (urban and agricultural) systems? How much of this need is provided by CERP and how much more storage is needed?

Climate Change

- How will sea level rise affect restoration efforts? How will sea level rise affect coastal soils and the transition between brackish to oligohaline wetlands?
- What hydrologic/ecological/human changes could be affected by uncertain future demands for water for agriculture and urban users, as well as changes to the system due to climate change (changes in regional water balance) and sea level rise?
- How will climate change affect the regional water balance? How will this affect the hydrologic assumptions used for CERP projects?

Balance Goals

- If the target lake stage in Lake Okeechobee is achieved, will the discharge problems to the Northern Estuaries be relieved? Which is more damaging to the estuaries, the volume and timing of Lake Okeechobee water releases or the nutrient loads in the water?

change. The document also helps to outline some of the steps that need to be taken (and when) to address these questions and inform future decision making. Project-level and systemwide monitoring, while informative, is not sufficient to inform the challenges and tradeoffs in decision making and management at the program level. Strategies for addressing uncertainties, for example, to determine how sea level rise will affect restoration efforts, also require continuing research and modeling with specific application to the South Florida ecosystem. The CERP programmatic adaptive management strategies identified to address the Priority 1 uncertainties include research, modeling, and synthesis, in addition to monitoring, and where specified, these strategies provide concrete actions to inform future decisions. In general, the strategies are only described briefly, and some need to be expanded to be fully responsive to the uncertainty from a systemwide perspective (for example, including downstream performance measures in an analysis of the sufficiency of storage). These research, modeling, and synthesis efforts should be forward-looking, and consider a range of future conditions under climate change, even for questions that are not specifically focused on climate change. The management options matrix is presented only for assessing monitoring results of "actual performance" but those options could just as easily apply to the results of forward-looking modeling analyses or research. Adaptive management should not be viewed as an activity that is only needed 5-10 years after several projects are fully constructed and monitoring data is collected—instead, RECOVER (2015) recommends that adaptive management at the program level is needed "now" or "immediately" for nearly every Priority 1 uncertainty with an action time identified.

Implementing Program-Level Adaptive Management

Adaptive management is a required and essential component of the CERP designed to ensure that new knowledge is linked to decision making so that restoration goals can be achieved in the most effective way possible, but little progress has been made in implementing program-level adaptive management to date. Successfully addressing the mission critical uncertainties identified in the CERP Program-Level Adaptive Management Plan (RECOVER, 2015) requires a structured implementation strategy that is currently lacking. An implementation strategy would identify tasks that require immediate action, a timeline for accomplishing this work, and a budget to accomplish each of the tasks. Additionally, an implementation strategy should outline the entities qualified to conduct each of the tasks (i.e., RECOVER, the Interagency Modeling Center, CERP agencies, universities, consultants), so that staffing and other resource needs can be better understood. Addressing these program-level uncertainties will require additional agency resources. RECOVER funding and staffing have been cut substantially over the past decade. Additional dedicated resources may be necessary to make sufficient progress and ensure systemwide and forward-looking perspectives on each of the questions, and effective communication of the results to CERP decision makers and the public. If resources are not sufficient to address all the priority uncertainties for which action is needed "now" or "immediately," additional prioritization will be needed, with the potential risks of such delays clearly articulated.

Rapid implementation of a fully developed Program-Level Adaptive Management Plan is critical and long overdue given the timelines identified in the Programmatic Regulations. As a means to track implementation progress, the CERP should develop plans for periodic reporting on the extent of progress made toward restoration goals, whether thresholds for action have been crossed, what decisions have been made or modified, and what the outcome of the management response has been. Although the Systems Status Report (RECOVER, 2014) provides an existing structure for such reporting, it focuses on recent trends and current status rather than considering expectations of future performance. Communication strategies that focus on providing detailed information on the progress made in addressing the highest priority uncertainties is needed. The CERP can learn from approaches used in other systems. Reports with clear graphics that quickly convey progress, summarize the overall conclusions, and indicate the trends in recovery are valuable to communicate progress. To complete the adaptive management feedback cycle, the CERP needs to go further and specify how decisions are being made and will be made to adjust program management if uncertainties are not resolved. If the CERP adopted this strategy, annual reports would be a useful and timely way to indicate progress towards the resolution of the most important scientific questions related to restoration. Such reports should also indicate what changes to CERP goals are necessary if uncertainties cannot be resolved within the specified timelines.

SYSTEMWIDE ANALYSES NEEDED TO ENSURE CERP ACHEIVEMENT

A program as extensive and complex as Everglades restoration must by necessity be implemented a few projects at a time, but this fact makes the need for a periodic holistic look at system-scale response ever more critical. Renewed attention is needed toward the future of the ecosystem and how society can shape it through the CERP and other non-CERP restoration efforts, considering the new information that has developed since the CERP was launched. Current system status reports focus primarily on documenting the character of the current system; they do not look forward or stimulate thinking about the future state of the system. A periodic holistic assessment would consider new scientific and technical information, changing conditions in both natural and human system, and the very real constraints imposed by funding and regulatory processes, and it provides a means of assuring that each project can be planned, designed, and implemented to work within the system context. As outlined above, the programmatic regulations for CERP envisage this need by requiring the development of goals against which progress can be measured, as well as periodic assessment and evaluation resulting in CERP Updates. Such assessment and evaluation goes above and beyond the activities necessary to address the program-level adaptive management uncertainties, although, if structured correctly, could help address some of these uncertainties (e.g., storage). CERP Updates were considered a key component of programmatic adaptive management in the Programmatic Regulations, and the CERP agencies need to renew their attention to these key forward-looking evaluations of progress and performance at the program scale.

Components of a Forward-Looking CERP Assessment and Evaluation

What is envisioned in such a holistic assessment? In Chapter 4 the committee identified a number of new developments and issues that potentially constrain the achievement of the originally envisaged restoration (e.g., feasibility of planned CERP storage, climate change). Coincidentally, many of these issues have also been identified as Priority 1 uncertainties in the Program-Level Adaptive Management Plan (RECOVER, 2015), reiterating their importance to the future of the program. The committee recommends that existing and developing models (discussed later in this chapter), together with any new tools needed to provide a complete assessment, be used to address important questions about the future of the ecosystem and the role of the CERP. These questions include but are not limited to the following:

- What is the effect of reductions in storage in the degree of change that can be achieved relative to CERP goals?
- How does presence vs. absence of particular future CERP components affect future ecosystem conditions systemwide?
- How sensitive is this future system state to key assumptions about important but currently unknown externalities such as future climate or sea-level rise rates?
- Does the knowledge gained since the late 1990s (e.g., pre-drainage hydrology, sea level rise) require refinement of the broad directional goals laid out by the CERP agencies?

The analyses appropriate to address these questions at the system scale need not be as detailed as has been conducted for project-level analysis. That does not mean this system-level analysis is straightforward. The committee recognizes that consideration of the entire system limits the complexity that can be considered, and some simplifications or generalizations will be needed. Limitations in analyses conducted in the near-term should be acknowledged while continued investments are made to improve system-level predictions of ecosystem condition (as discussed later in this chapter). This new effort will not be simple or easy—but it is essential to the long-term success of Everglades restoration.

Experience with other large-scale ecosystem restorations indicates that conducting assessments of future states at the system scale highlights many of the challenges of implementation (e.g., Lund et al. 2010; Peyronnin et al., 2013). For example, the lack of an optimal solution for all desirable facets of the system, the role of uncertainty about future conditions (e.g., rainfall amounts and timing), and changed circumstances over decades (e.g., sea level rise, encroachment on the natural system by development) can limit the ability to achieve outcomes that were once considered possible. Although some might consider that illuminating such issues makes a complex stakeholder interaction even more challenging, not confronting these issues in a science-based, objective manner can lead to even less desirable circumstances, such as unrealistic expectations, litigation, and waning public or congressional support.

Continued long-term restoration support demands that a clear vision of the future is articulated and that the program is responsive to new information. Ultimately, such analyses can help all engaged and interested in Everglades restoration see the future that those on the ground are so diligently striving for. Such analyses stretch the bounds of our science, and they may also show the bounds of our ability to change the system. But they can also demonstrate the benefits of continued investment, even under alternate futures and the severe consequences of not following through with the restoration vision.

Shortcomings in restoration outcomes identified in this assessment will illuminate the need for modifications, either in future project planning efforts or in the restoration goals and objectives themselves. The Programmatic Regulations identify a process for those modifications to occur (i.e., a CERP Modification Report) that can be initiated if appropriate. From the perspective of national discussion of large-scale ecosystem restoration, this is a true application of the adaptive management promise of the CERP. The CERP can again be an example to other large-scale programs with multi-decadal implementation that considering new information and changing circumstances can lead to better long-term outcomes.

Effecting a Systemwide CERP Assessment/Update

This forward-thinking analysis, assessment, and evaluation require a focused effort and a dedicated team. The Science Coordination Group could provide important leadership and serve as a forum for public input, as was done in the Central Everglades Planning Project. RECOVER staff may be available to contribute to this effort, but CERP agencies need to ensure that the right team is in place to execute this system-level analysis and not rely solely on the skill sets and experience they use for other existing tasks. This systemwide assessment should not take effort away from ongoing and anticipated project planning efforts as different skill sets and tools are required; neither should it slow down or delay the current implementation of projects identified in the Integrated

Delivery Schedule (IDS). Continued implementation of projects already planned, authorized, and funded should continue. However, proceeding with continued project-scale planning without a systemwide understanding of the implications of major changes could lead to poorly informed decisions. If the system-level analysis does detract from project-level planning, the committee suggests that the system-level analysis be prioritized to provide an improved context for project-level decisions. Any delays in ongoing or near-term project-level planning should not delay overall restoration progress, because there are enough authorized (or soon to be authorized) projects that are expected to fully use available funds for at least the next 15 years, as noted in the IDS.

The goal is to develop within a limited time frame (i.e., 18-24 months) a clear vision of what successful CERP implementation might achieve under anticipated or possible future conditions. CERP agencies should commit the necessary resources to meet such a timeline. This analysis can utilize many of the modeling tools and approaches discussed in the next section.

Once this forward-looking assessment is conducted (including but not limited to a CERP Update, as described in the Programmatic Regulations), it should be used by CERP agencies to consider their path forward and whether adjustments to the CERP are needed. This process—the realization of program-level adaptive management, as originally envisioned in WRDA 2000 and the Programmatic Regulations—requires clear communication of the findings of such technical assessments to decision makers and to stakeholders. Building clear and credible linkages between science and decision making is challenging. Adaptive management at the program scale may illuminate the need for further refinement of CERP governance structures (including the linkages between the CERP decision-making agencies [i.e., USACE and SFWMD] and RECOVER, the Task Force, and the Science Coordination Group) to ensure that new information generated is used appropriately to guide restoration decisions to best support long-term restoration objectives.

TOOLS TO SUPPORT FORWARD-LOOKING ANALYSES

Since the CERP was developed, much has been learned and new tools have been developed based on advances in knowledge and data availability, supported by advances in computation efficiency. Such advances enable thinking about the future of the Everglades, how the forces of people and nature shape that change, and which actions can best promote a vibrant and sustainable Everglades ecosystem. In this section, the committee discusses how these tools could be leveraged to address some of the program-level uncertainties and improve the restoration to maximize benefits and avoid unacceptable impacts, even under changing climate conditions. Substantial advances have been made in the capabilities of CERP hydrologic and hydraulic models, which have been the primary means by which alternatives have been evaluated, particularly in the early years of CERP planning. Those advances are not documented in this review, but interested readers could consult NRC (2007) and Obeysekera et al. (2011c) for more information. Instead, this section focuses on models that are linked to hydrologic models to evaluate the ecological and water quality outcomes of restoration alternatives. The committee also discusses strategies to use hydrologic models to assess future climate scenarios. These tools are available or can be readily developed, as demonstrated by other large-scale ecosystem restoration programs (e.g., Peyronnin et al., 2013), to take advantage of the extensive available monitoring data to show what the future might hold for the Everglades based on options for project implementation and operation, and climate change.

Ecological Modeling

The use of ecological models was limited in the development of the CERP (USACE and SFWMD, 1999) and the planning and implementation of the restoration that followed. In contrast, restoration planners had more experience and confidence in hydrologic models and have relied on these tools for assessment and planning (see NRC, 2007). As a result, hydrologic restoration goals have been emphasized over ecological restoration goals in the restoration effort (see Chapter 4). Hydrology is not viewed as more important than ecology. However, as hydrology is manipulated through restoration and an important ecological driver, hydrologic goals became primary by default, with ecological outcomes projected by assumption rather than analysis.

During the development of the CERP, this approach was necessary as only hydrologic models could be applied for systemwide analysis necessary to evaluate alternative management scenarios. Past reports of this committee have been critical of the lack of progress in developing and integrating linked hydrologic, water quality, and ecological modeling tools (NRC, 2007, 2008, 2010, 2012). Fortunately, ecological modeling capacity has advanced considerably since the committee's last assessment of ecological modeling (NRC, 2012). This advancement has been stimulated by the activities of the Joint Ecosystem Modeling (JEM) effort, a partnership among state and federal agencies, universities, and other organizations dedicated to research and development of ecological modeling in support of the restoration.[2] A number of useful ecological models are now available that can link to hydrologic models to simulate effects of restoration activities on particular species or habitats, at local to systemwide scales (Appendix C, Table C-1). The capability now exists to evaluate restoration alternatives based on

[2] See https://www.jem.gov/.

predicted ecological outcomes, coupled with the predicted hydrologic outcomes that have traditionally been used. Indeed, these ecological models are now being regularly employed in evaluating restoration alternatives, some on a systemwide scale. Thirteen ecological models were used in the development of Central Everglades Planning Project (USACE and SFWMD, 2014a); ecological models of marl prairie habitat and wood stork foraging conditions were heavily employed in evaluating water management alternatives in the biological opinion issued for the Everglades Restoration Transition Plan (ERTP; FWS, 2016) (see Chapter 3).

The marl prairie index model, employed in analyses associated with both the Central Everglades Planning Project and the ERTP, is one example of an ecological model with capability to make systemwide projections. It does so through linkages with the Regional Simulation Model (RSM) and Natural System Regional Simulation Model (NSRSM)—models capable of simulating the hydrologic conditions under pre-drainage, current, and future (with or without restoration) scenarios. This marl prairie index model enables analysis of one of the most difficult aspects of the restoration, continuing to provide the habitat on which the endangered Cape Sable seaside sparrow depends while restoring other habitats in the southern Everglades (see Chapters 3 and 4). Another example is the suite of wading bird models (Wader Distribution Evaluation Modeling, WADEM) that forecast potential wildlife responses to changes in water management and climate (Beerens et al., 2015). Using those models, investigators have the ability to forecast the changes in water levels that drive the spatial patterns of suitable foraging habitat for wood storks and other wading birds, enabling managers to predict the likely effects of changes in water management options.

Given the capability of these and other ecological models, such tools should be routinely employed during restoration planning, at both project and systemwide scales, as they were in evaluating alternative restoration scenarios related to the Central Everglades Planning Project and the ERTP. The development of EverVIEW tools that enable visualization of some ecological model outputs add to the utility of employing ecological models. Ecological models will be useful in evaluating not only impacts of alternative restoration scenarios on individual species and habitats but also tradeoffs between the needs of different species and restoration goals. Efforts are under way to integrate models to enable multispecies assessments that could be used to evaluate ecological tradeoffs among alternative management plans. Inverse ecological modeling tools are also being developed that could be used to optimize restoration features to reach multiple ecological targets. Ecological models also can be used to explore the implications of climate change and sea level rise, changes in CERP project feasibility, and the improved understanding of the pre-drainage system (see Chapter 4). The incorporation of ecological models linked to hydrologic models into evaluation of restoration alternatives is an important recent advance in restoration planning.

Biogeochemical Modeling

Improvement of both water quality and hydrology are needed to reverse the decline of key Everglades attributes (NRC, 2012). Although water quality is an important component of "getting the water right," water quality modeling continues to lag behind the development and application of hydrologic and ecological modeling as part of the CERP toolbox. The reasons for this lack of emphasis are several. Water quality modeling is a challenging undertaking, particularly for a large, complex landscape like the Everglades. Also, under the consent decree, water will not be redistributed within the WCAs and Everglades National Park unless the total phosphorus concentrations are below established limits, and under these conditions, the risks of adverse water quality may be diminished. However, given the potential for water quality criteria to limit new water inputs or the redistribution of existing flows, water quality modeling becomes even a more important tool to examine the implications of CERP projects on total phosphorus throughout the ecosystem, especially when water quality is close to the established phosphorus criterion. Without such modeling tools to foster further examination of scenarios at the interface of water quality and quantity, decision makers are more likely to be risk averse when confronted with decisions pertaining to water quality possibly to the detriment of key ecosystem components driven by the system's altered hydrology. Water quality modeling could also be used to better understand the transport and fate of contaminants within the Everglades. Environmental quality should be an important driver affecting wetland habitat (e.g., stands of cattails), but water quality is not addressed in current ecological models. An improved capacity to simulate water quality could lead to improved ecological modeling tools. The development of a regional coupled hydrologic water quality model would provide an important tool for quantitative evaluation of a range of alternative restoration scenarios and their potential short- and long-term effects on biotic and abiotic attributes.

Some limited water quality modeling has been used to inform Everglades restoration projects. The Everglades Landscape Model (ELM) was been used in the Decomp planning process to assess water column phosphorus concentrations and sediment accumulation rates within the WCAs. The Dynamic Model for Stormwater Treatment Areas (DMSTA) was used in the Central Everglades Planning Project (USACE and SFWMD, 2014a) to assess mean phosphorus concentrations and water quality constraints in project implementation. The Watershed Assessment Model was used to develop the basin management action plan for Lake Okeechobee (FDEP, 2014). Additional details and a summary of relevant water quality models that have been used in Everglades-related research is summarized in Childers et al. (2011).

Water quality modeling requires a hydrologic modeling framework, and the current RSM potentially provides this framework for the Everglades. The RSMWQ (the water quality engine for the RSM) is a model designed to run with the RSM. It has two components to simulate water quality—the first is for transport of soluble and dissolved constituents, and the second is a flexible biogeochemistry module that allows the model user to define the state variables and algorithms to describe biogeochemical cycling in aquatic ecosystems. Unfortunately, little progress has been made in the development and application of the RSMWQ in recent years, even though it has been under development for over a decade (James and Jawitz, 2007; Jawitz et al., 2008).

The development of a comprehensive water quality model remains an important but ambitious goal. Such a tool would allow the user to address a host of interconnected issues beyond the management and fate of inputs of total phosphorus, including loss and accretion of peat, effects on wetland habitat, and linkages to other water quality contaminants like nitrogen, sulfur and mercury, in the Everglades and in downstream coastal ecosystems.

Climate Modeling Tools and Approaches

The CERP was originally designed for the next 5 or 6 decades assuming that historic climate will continue, but this stationarity assumption is no longer appropriate for multidecadal restoration and water supply plans. As discussed in Chapter 4, it is essential to assess the performance of CERP under a changing climate—that is, to project the systemwide hydrologic and ecological outcomes from the restoration plan under different climate scenarios. Several modeling tools and strategies are available to support forward-looking evaluations of the CERP.

Climate change scenario analysis in CERP planning has been limited to project-based assessments of the loss of benefits associated with sea level rise (e.g., USACE and SFWMD, 2014a). Additionally, analyses have been performed to assess the hydrologic and ecological impacts on base conditions of a 1.5°C increase in temperature coupled with ±10 percent change in average annual precipitation (Obeysekera et al., 2015; see also Chapter 4). An important next step is to examine the hydrologic and ecological responses a broader range of feasible future scenarios, including seasonal shifts in the distribution and quantity of precipitation. These analyses should consider not only changes to base conditions but also the effect of the CERP and various feasible storage configurations on hydrologic and ecological outcomes. Such an analysis could help address the critical uncertainty of how much storage is needed to meet the goals of the CERP under alternative future conditions. These analyses are possible with existing hydrologic and ecological models, and over time improvements in regional climate modeling tools and refined regional climate projections will narrow the uncertainty associated with current analyses. With existing and improving modeling tools, including ecological models that incorporate climate change factors, scenario analyses considering a variety of feasible future conditions can be used to evaluate potential impacts of climate change and sea level rise on ecosystems, key species, and habitats as well as how restoration efforts can be used to alter these outcomes.

It is not only possible, but likely, that optimizing restoration planning for one scenario may preclude choices that accommodate other scenarios, and decision making focused on robust outcomes can provide more assured outcomes for public investments. Thus, decision-making tools are needed that address uncertainty and vulnerability of both human and natural systems. A number of modeling and data-supported approaches have been developed to aid in planning and managing integrated natural and built infrastructure projects such as the Everglades restoration under scenarios of climate change. Robust decision making (e.g., Groves et al., 2013) is an analytic framework that helps identify potential robust strategies, characterize the vulnerabilities of such strategies, and evaluate tradeoffs. Robust decision making has been used to evaluate vulnerabilities and climate adaptation options for the Colorado River Basin and evaluate tradeoffs among different scenarios of climate change and water management strategies. Poff et al. (2015) introduced *eco-engineering decision scaling*, a methodology that explicitly and quantitatively explores tradeoffs in stakeholder-defined engineering and ecological performance metrics across a range of possible management actions under unknown climate and hydrologic futures. This methodology was applied in the analysis of flood management adaptation options in the Iowa River, in a USACE-built system consisting of a dam (Coralville) and floodplain levees that have been found to be increasingly vulnerable to extreme events. Ray and Brown (2015) developed a decision-tree framework to assimilate climate change information into water resources project planning and design. This approach has been used in a number of studies (e.g., California, Mexico City, Brahmaputra River basin, Bangladesh) to improve the resiliency of water resources infrastructure to climate change, sea level rise, and extreme events. These approaches explicitly incorporate the types of decisions to be made within restoration program planning, a feature that could be particularly useful to the CERP.

CONCLUSIONS AND RECOMMENDATIONS

When the CERP was launched in 2000, adaptive management was embraced as a means of incorporating new information into the plan and addressing unforeseen issues related to the plan, and the CERP was widely viewed as a leader in adaptive management. Since that time, a framework for CERP adaptive management has been developed, and a structure for implementation at a project-level adopted, but the original vision of adaptive management at the program level remains unfulfilled. In this chapter, the committee outlines steps that need to be taken for the CERP program to continue to lead in adaptive management and, more importantly, to ensure restoration success by incorporating new knowledge and changing circumstances into the restoration plan at the systemwide scale.

The CERP has made limited progress in articulating restoration objectives that are sufficiently quantitative to support effective planning, implementation, and assessment. An effort is now needed to develop quantitative restoration goals that capture new science and address potential conflicts in restoration. When authorized, the CERP goals were broad narrative statements on restoring the South Florida ecosystem and ensuring that the water needs of the region were met. Reaching these goals requires that realistic, quantitative objectives be developed and applied to project- and program-level restoration, which in turn requires consideration of the inherent tradeoffs that must be made in any complex ecosystem restoration program (as discussed in Chapter 4). Work has stalled on improving the quantitative interim goals (RECOVER, 2005a), which were not adopted because of the substantial assumptions that were made in their development. Developing quantitative objectives is an essential component of adaptive management, and once established, these objectives should be periodically revisited to ensure they are still desirable and achievable given new knowledge and modeling capability and major changes that affect future systemwide operations under the CERP.

The CERP Program-Level Adaptive Management Plan is an important first step in identifying critical uncertainties affecting restoration progress, but it requires an implementation plan and sufficient resources to be effective. The plan asks highly relevant questions about the CERP that are related to questions of storage, design and implementation, and climate change. Many of the questions can and should be addressed now through new research and modeling in addition to ongoing monitoring. Monitoring alone cannot address the challenges and tradeoffs required for decision making and management at the program level. The RECOVER (2015) report concludes that a failure to address the Priority 1, mission-critical uncertainties will paralyze progress toward meeting CERP restoration goals and that many of these uncertainties need to be addressed immediately, but no actions have been taken to implement the plan. To expedite implementation of the Program-Level Adaptive Management Plan, an implementation strategy to address the Priority 1 uncertainties is needed that identifies tasks, timelines, resources, and staffing needed, and the highest priorities if sufficient funding is not available for the ideal implementation plan.

A systemwide analysis of the potential future state of the Everglades ecosystem, with and without CERP and other restoration projects, should be conducted in conjunction with a CERP Update, which is long overdue. The regular 5-year CERP updates called for in the Programmatic Regulations to evaluate the restoration plan considering new scientific, technical, and planning information have not been routinely conducted. A holistic, forward-looking analysis of the possible future state of the ecosystem is needed in the light of new knowledge gained over the past 16 years. This analysis should consider various scenarios for climate change and sea level rise, and explore the ecosystem implications of various options for future CERP implementation. By exploring alternative future scenarios, considering uncertainties in climate or funding to support implementation, decision makers and stakeholders will be better informed of the implications of near- and long-term decisions. The halfway point in the original CERP timetable is an appropriate time for such analysis and evaluation of the future condition of the ecosystem. Challenges identified by this analysis may illuminate the need for modifications, either in future project planning efforts or in the restoration goals and objectives themselves. Although some might consider that illuminating such issues makes a complex stakeholder interaction even more difficult, failing to confront these problems in a science-based, objective manner can lead to even less desirable circumstances, including unrealistic expectations, litigation, and reduced public or congressional support. The analysis and evaluation process conducted as part of the CERP Update will enable the CERP agencies to ensure restoration expectations are clear and can be achieved and to determine if further modifications of the CERP, as allowed for in the Programmatic Regulations, are needed.

Developed and developing tools exist that can support forward-looking analyses of the CERP for project and systemwide analyses. Tools and strategies are available to explore future climate change and sea level rise scenarios, examine the robustness of the CERP to these potential futures, and enhance decision making under uncertainty. These approaches can illuminate opportunities to adapt the restoration plan to changing precipitation, hydrology, and sea level rise and mitigate the impacts of climate change. The capability for ecological modeling has advanced in recent years, to the point that models can be used to project systemwide effects of restoration activities for a variety of ecological performance measures. Ecological models link the response of species and habitats to underlying hydrologic models at local or systemwide scales and allow alternatives to be evaluated based on projected ecological outcomes. Ecological models are now being used along with hydrologic models in planning and assessments related to restoration—a major advance. Ecological models may be especially useful in evaluating tradeoffs between restoration goals and targets. In contrast, development and application of water quality models in the CERP continues to lag behind the use of hydrologic and now ecological models. Robust and well-tested water quality models are important tools to inform restoration strategies, particularly those that involve new water flows or redistribution of existing flows, and continued attention is needed to developing these models. The development of a robust Everglades water quality model is a key need moving forward. Improved water quality modeling tools also should lead to further refinement of ecological models, since Everglades habitat, species distribution, and ecological functioning are closely linked to water quality. As modeling advances toward an integrated set of tools to evaluate hydrologic, water quality, and ecosystem response to changes, there is a need for comprehensive sensitivity and uncertainty analysis of these linked models to inform and guide assessment and planning decisions.

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Appendix A

The National Academies of Sciences, Engineering, and Medicine Everglades Reports

Review of the Everglades Aquifer Storage and Recovery Regional Study *(2015)*

Increasing water storage is a critical component of the restoration, and the Comprehensive Everglades Restoration Plan (CERP) included projects that would drill over 330 aquifer storage and recovery (ASR) wells to store up to 1.65 billion gallons per day in porous and permeable units in the aquifer system during wet periods for recovery during seasonal or longer-term dry periods. To address uncertainties regarding regional effects of large-scale ASR implementation in the Everglades, the U.S. Army Corps of Engineers (USACE) and the South Florida Water Management District conducted an 11-year ASR Regional Study, with focus on the hydrogeology of the Floridan aquifer system, water quality changes during aquifer storage, possible ecological risks posed by recovered water, and the regional capacity for ASR implementation. At the request of the USACE, this report, authored by the National Research Council (NRC) Committee to Review the Florida Aquifer Storage and Recovery Regional Study Technical Data Report, assesses progress in reducing uncertainties related to full-scale CERP ASR implementation. This report considers the validity of the data collection and interpretation methods; integration of studies; evaluation of scaling from pilot-to regional-scale application of ASR; and the adequacy and reliability of the study as a basis for future applications of ASR.

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

This report is the fifth biennial evaluation of progress being made in the CERP, authored by the NRC Committee on Independent Scientific Review of Everglades Restoration Progress. Despite exceptional project planning accomplishments, over the past 2 years progress toward restoring the Everglades has been slowed by frustrating financial and procedural constraints. The Central Everglades Planning Project is an impressive strategy to accelerate Everglades restoration and avert further degradation by increasing water flow to the ecosystem. However, timely authorization, funding, and creative policy and implementation strategies will be essential to realize important near-term restoration benefits. At the same time, climate change and the invasion of non-native plant and animal species further challenge the Everglades ecosystem. The impacts of changing climate—especially sea level rise—add urgency to restoration efforts to make the Everglades more resilient to changing conditions.

Progress Toward Restoring the Everglades: The Fourth Biennial Review, 2012 *(2012)*

The 2012 biennial report finds that 12 years into the CERP, 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)*

The 2010 biennial 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)*

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. 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.

Systemwide indicators at the ecosystem level 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"—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.

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.

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 the 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.

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 aquifer storage and recovery (ASR) 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)*

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

CERP Water Budgets

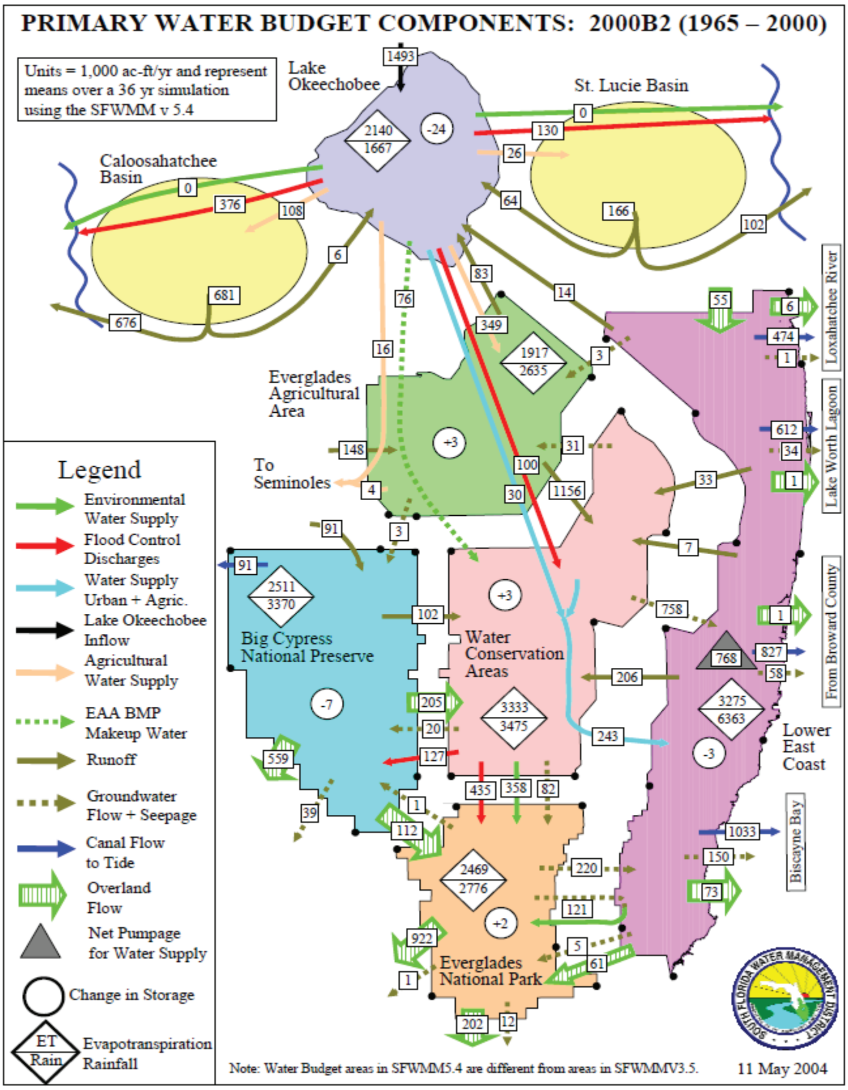

FIGURE B-1 Estimated annual water budget for the Kissimmee-Okeechobee-Everglades drainage basin under post-drainage and post-development conditions, calculated using a 36-year simulation using the South Florida Water Management Model (SFWMM) with structures in place as of 2000 (usually considered the typical "current" situation). The numbers in rectangles represent mean annual flow volumes in 1,000 AF/year, based on model simulations using a 36-year precipitation data set. Change in storage, shown in circles, represents the net inflows minus outflows over the period of record.

SOURCE: J. Obesekera, personal communication, SFWMD, 2009.

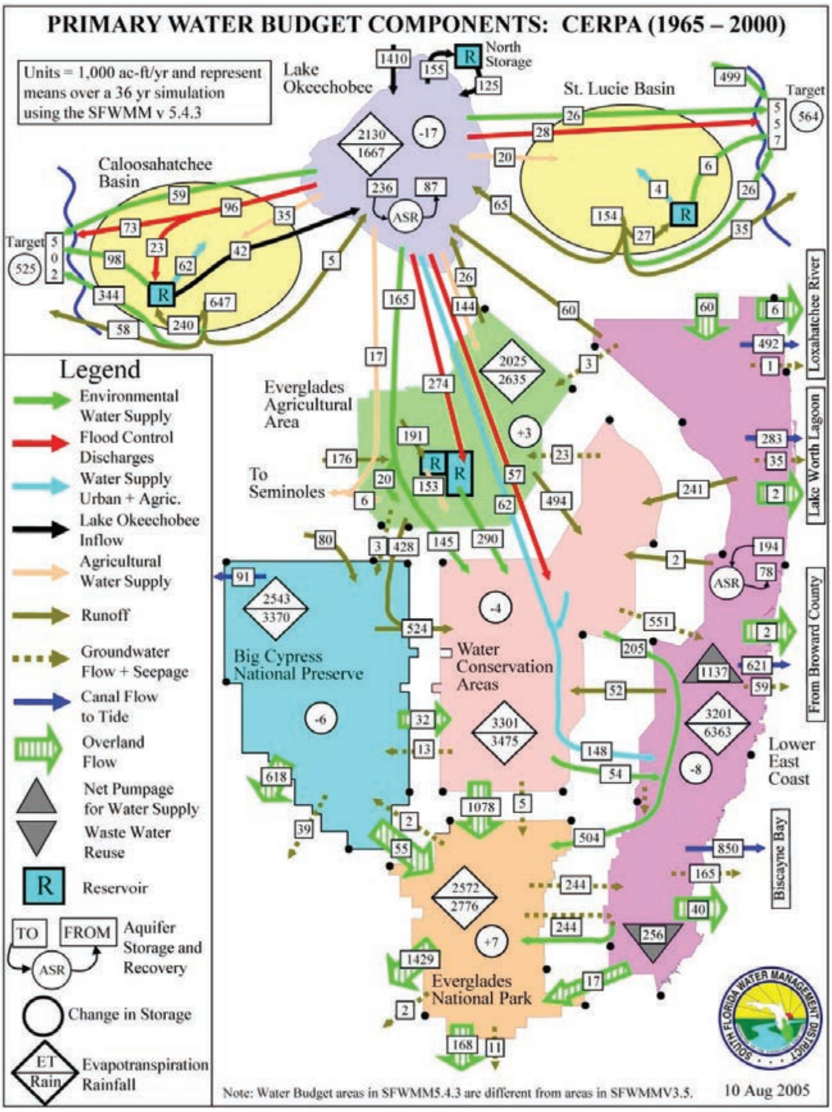

FIGURE B-2 Estimated annual water budget for the Kissimmee-Okeechobee-Everglades drainage basin under full CERP implementation, calculated using a 36-year simulation using the SFWMM v. 5.4.3. Model run CERP A shown simulates the CERP preferred alternative (D13R). The numbers in rectangles represent mean annual flow volumes in 1,000 acre-feet/year. Change in storage, shown in circles, represents the net inflows minus outflows over the period of record.

SOURCE: J. Obesekera, personal communication, SFWMD, 2009.

Appendix C

Ecological Modeling

TABLE C-1 Current Everglades Ecological Models and Use

Model	Version Number	Lead (Point of Contact)
Alligator Production Suitability Index Model (Shinde et al., 2014)	2.2.0.512	ENP-SFNRC w/Brandt-Mazzotti (D. Shinde)
EverSnail: Native Apple Snail Population Model (Darby et al., 2015)	1.1	UWF-USGS (P. Darby, D. DeAngelis, S. Romañach)
Amphibian Community Species Richness (v.2.0.0) (JEM, 2011)	2.1.421	JEM-USGS (H. Waddle, S. Romañach)
Biscayne Bay Nearshore SAV	none	UM (R. Santos, D. Lirman)
Cape Sable Seaside Sparrow Marl Prairie Index (Pearlstine et al., 2016)	2.2.2	ENP-SFNRC (L. Pearlstine)
Cape Sable Seaside Sparrow Species Distribution Model	none	USGS/ENP-SFNRC (J. Beerens S. Romañach, L. Pearlstine)
Estuarine Prey Fish Biomass (Romañach et al., 2011a)	1.0.0	JEM-Audubon (J. Lorenz, S. Romañach)
Everglades Landscape Model (Orem et al., 2014; Fitz et al., 2015)	2.9.0	www.EcoLandMod.com (C. Fitz)
Everglades Vegetation Landscape Succession (Pearlstine et al., 2011)	2.3.1	ENP-SFNRC (L. Pearlstine)
Florida Bay SAV (Madden and McDonald, 2014)	15.1	SFWMD (C. Madden)
Juvenile Spotted Seatrout (Kearney et al., 2015)	none	NOAA-AOML (C. Kelble)
Mangrove Fish	none	NOAA-NMFS (J. Serafy)
Prey-Based Freshwater Fish Density Performance Measure (Donalson et al., 2011)	none	USACE/ENP-SFNRC (J. Trexler, D. Donalson)
Roseate Spoonbill Landscape Suitability Index (Romañach et al., 2011b)	1.0.0	JEM-Audubon (J. Lorenz, S. Romañach)
Slough Vegetation Performance Measure / spatial model (Lo Galbo et al., 2013)	1.0.0	ENP-SFNRC (M. Zimmerman, G. Reynolds) / (G. Reynolds, L. Pearlstine)
WADEM model for Great Egret, White Ibis, Wood Stork (foraging,nesting effort, nesting success) (Beerens et al., 2015a; Beerens et al., 2015b)	1.1	USGS (J. Beerens)
Burmese Python Marsh Habitat Suitability	none	USGS (J. Beerens)
Crocodile Habitat Suitabiity	none	USFWS/UF (L. Brandt, F. Mazzotti)
EverVIEW Data Viewer (Romañach et al., 2014)	2.7	JEM (C. Conzelmann, M. McKelvy, S. Romañach)
Biscayne Bay Mangrove Fish - goldspotted killifish HSM (McManus, 2014)	none	IBBEAM (NOAA-NMFS, NPS BNP, UM RSMAS)
Biscayne Bay Mangrove Fish - yellowfin mojarra HSM	none	IBBEAM (NOAA-NMFS, NPS BNP, UM RSMAS)

Accepts RSM Input	Accepts EDEN Input	Accepts BBSM Input	Used in Project Planning	Date Last Updated
Yes (converted RSM)	Yes	No	Yes	2/14/2014
Yes (converted RSM)	Yes	No	Yes	10/1/2015
Yes (converted RSM)	Yes	No	Yes	8/14/2012
Yes	No	Yes	No	unknown
Yes	Yes	No	Yes	8/11/2015
Yes	Yes	No	No	2016
No	No	No	No	2011
Yes (for daily structure flows)	N/A	N/A	Yes	7/15/2015
Yes (converted RSM)	Yes	No	No	10/20/2014
Yes	No	No	Yes	4/1/2016
Yes[a]	No	Yes	Yes	6/2/2016
Yes	No	No	No	unknown
Yes	Yes	No	Yes	2014
No	No	No	No	2011
Yes	No	No	Yes	9/23/2014
Yes	Yes	No	Yes	5/23/2016
Yes	Yes	No	No	2016
No	No	No	Yes	2009
Yes (converted RSM)	Yes	No	Yes	6/4/2015
No	No	Yes	No	5/1/2016
No	No	Yes	No	5/1/2016

continued

TABLE C-1 Continued

Model	Version Number	Lead (Point of Contact)
Biscayne Bay Mangrove Fish - gray snapper HSM (Serrano et al., 2010)	none	IBBEAM (NOAA-NMFS, NPS BNP, UM RSMAS)
Biscayne Bay Epifauna - pink shrimp HSM	none	IBBEAM (NOAA-NMFS, NPS BNP, UM RSMAS)
Biscayne Bay Epifauna -grass shrimp HSM	none	IBBEAM (NOAA-NMFS, NPS BNP, UM RSMAS)
Biscayne Bay Epifauna - gulf pipefish HSM	none	IBBEAM (NOAA-NMFS, NPS BNP, UM RSMAS)
Biscayne Bay Epifauna - goldspotted killifish HSM	none	IBBEAM (NOAA-NMFS, NPS BNP, UM RSMAS)
Biscayne Bay SAV - Thalassia HSM	none	IBBEAM (NOAA-NMFS, NPS BNP, UM RSMAS)
Biscayne Bay SAV - Halodule HSM	none	IBBEAM (NOAA-NMFS, NPS BNP, UM RSMAS)
MANTRA - Mangrove-Glycophyte competition model (Teh et al., 2015)	none	USGS (D. DeAngelis)
GEFISH - spatially expicit Everglades fish model (Yurek, 2013)	none	USGS (D. DeAngelis)
Melaleuca model, individual-based (Bo Zhang, submitted)	none	USGS (D. DeAngelis)

[a] This model uses the Marshall et al. (2013) conversions to calculate salinity in Florida Bay from stage heights in the Everglades.
NOTE: This table is intended to provide information about ecological models linked with hydrologic models, and whether they have been used in CERP projects. Information is from federal sources (USACE, NPS, USGS, FWS) and reflects progress as of June 2016.
SOURCE: S. Romañach, USGS, personal communication, 2016.

Accepts RSM Input	Accepts EDEN Input	Accepts BBSM Input	Used in Project Planning	Date Last Updated
No	No	Yes	No	5/1/2016
No	No	Yes	No	5/1/2016
No	No	Yes	No	5/1/2016
No	No	Yes	No	5/1/2016
No	No	Yes	No	5/1/2016
No	No	Yes	No	5/1/2016
No	No	Yes	No	5/1/2016
No	No	No	No	6/1/2015
No	No	No	No	1/1/2016
No	No	No	No	1/1/2016

Appendix D

Water Science and Technology Board and the Board on Environmental Studies and Toxicology

WATER SCIENCE AND TECHNOLOGY BOARD

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MIRSADA KARALIC-LONCAREVIC, Manager, Technical Information Center

Appendix E

Biographical Sketches of Committee Members and Staff

David B. Ashley (*Chair*) is a professor of engineering practice in the Department of Civil and Environmental Engineering at the University of Southern California. Dr. Ashley retired as a professor at the University of Nevada, Las Vegas (UNLV) in 2015 where he also served as its eighth president 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 and the Committee on Independent Scientific Review of Everglades Restoration Progress (since 2010). 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.

Mary Jane Angelo is a 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 has served on several National Research Council committees, including the Committee on Ecological Risk Assessment under FIFRA and ESA and the Committee on Independent Scientific Review of Everglades Restoration Progress (since 2010). She received her B.S. in biological sciences from Rutgers University and her M.S. and J.D. from the University of Florida.

William G. Boggess is a 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 Committee on Independent Scientific Review of Everglades Restoration Progress (since 2008) serving as chair of the fourth committee. He received his Ph.D. from Iowa State University.

Charley 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, 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 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). He also has served on the Committee on Independent Scientific Review of Everglades Restoration Progress since 2006. 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.

M. Siobhan Fennessy is the Jordan Professor of Biology and Environmental Science at Kenyon College, where she studies wetland ecosystems, particularly how wetland plant communities and biogeochemical cycles respond to human disturbances such as altered land use and factors associated with climate change. Her work has resulted in the development of biological assessment methods for wetlands that were recently employed in the National Wetland Condition Assessment effort led by the U.S. Environmental Protection Agency (EPA). She previously served on the faculty of the Geography Department of University College London and held a joint appointment at the Station Biologique du la Tour du Valat investigating human impacts to Mediterranean wetlands. She was a member of the U.S EPA's Biological Assessment of Wetlands Workgroup, a national technical committee working to develop biological indicators of ecosystem condition. She recently co-authored a book on the ecology of wetland plants. Her current research focus is the alteration of ecosystem services that results from ecosystem degradation. Dr. Fennessy received her B.S. in botany and Ph.D. in environmental science from The Ohio State University. She served as a member of the National Academies' Committee to Review the St. Johns River Water Supply Impact Study.

William L. Graf is University Foundation 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 NRC's Water Science and Technology Board and the Board on Earth Sciences and Resources and has served on numerous NRC committees, including the Geographical Sciences Committee and the Committee on Restoration of the Greater Everglades Ecosystem. He has served on the Committee on Independent Scientific Review of Everglades Restoration Progress since 2004. 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.

Karl E. Havens is a professor and director of Florida Sea Grant at the University of Florida. He has worked with Florida aquatic ecosystems and the use of objective science in their management for the past 23 years. His areas of expertise are in the fields of the response of aquatic ecosystems to natural and human-caused stressors, including hurricanes, drought, climate change, eutrophication, invasive species and toxic materials, with particular attention to Florida's lakes and estuaries. Before coming to the University of Florida, Havens was the chief environmental scientist at the South Florida Water Management District. He received his B.A. from SUNY Buffalo, and his M.S. and Ph.D. from West Virginia University.

Wayne C. Huber is a professor emeritus of civil and construction engineering at Oregon State University. His research interests are principally in the areas of urban hydrology and stormwater management, nonpoint source pollution, and transport processes related to water quality. He is one of the original authors of the Environmental Protection Agency's Storm Water Management Model (SWMM) and more recently contributed to EPA's development of version 5 of that model. Dr. Huber is a former member of the Committee on Restoration of the Greater Everglades Ecosystem and served as chair of the first Committee on Independent Scientific Review of Everglades Restoration Progress. He received his B.S. degree in engineering from the California Institute of Technology. He received his M.S. and Ph.D. degrees in civil engineering from the Massachusetts Institute of Technology.

Fernando R. Miralles-Wilhelm is the executive director of the Cooperative Institute for Climate and Satellites, a cooperative institute between the University of Maryland and the National Oceanic and Atmospheric Administration, and a professor in the Department of Atmospheric and Oceanic Science at the University of Maryland. Dr. Miralles-Wilhelm specializes in hydrology and water resources engineering, with a particular focus on hydrology and climate interactions in the Everglades' vegetative ecosystems, which he has been studying for the past decade. Previously, he served on the faculty of Florida International University and the University of Miami. He received a mechanical engineering diploma from Universidad Simón Bolívar in Venezuela, an M.S. degree in engineering from the University of California-Irvine, and a Ph.D. degree in civil and environmental engineering from the Massachusetts Institute of Technology.

David H. Moreau is a 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 Committee on Independent Scientific Review of Everglades Restoration Progress (since 2006). 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. degrees from Mississippi State University and North Carolina State University, respectively, and his Ph.D. degree from Harvard University.

Gordon H. Orians (NAS) is a professor emeritus of biology at the University of Washington. Most of Dr. Orians's research has focused on behavioral ecology of birds and has dealt primarily with problems of habitat selection, mate selection and mating systems, selection of prey and foraging patches, and the relationship between ecology and social organization. Recently, his research has focused on environmental aesthetics and the evolutionary roots of strong emotional responses to components of the environment, such as landscapes, flowers, sunsets, and sounds. Dr. Orians has served on the Science Advisory Board of the U.S. Environmental Protection Agency and on boards of such environmental organizations as the World Wildlife Fund and the Nature Conservancy. He has also served on many National Academies committees, including the first Committee on Independent Scientific Review of Everglades Restoration Progress, the Committee on Cumulative Environmental Effects of Alaskan North Slope Oil and Gas Activities, and the Board on Environmental Studies and Toxicology. He is a member of the National Academy of Sciences and the American Academy of Arts and Sciences. Dr. Orians earned his B.S. degree in zoology from the University of Wisconsin and his Ph.D. in zoology from the University of California, Berkeley.

Denise J. Reed is the chief scientist at the Water Institute of the Gulf. She is a nationally and internationally recognized expert in coastal marsh sustainability and the role of human activities in modifying coastal systems with over 30 years of experience studying coastal issues in the United States and abroad. Prior to joining the Water Institute, Dr. Reed served as Interim Director of the Pontchartrain Institute for Environmental Sciences and as a professor in the University of New Orleans' Department of Earth and Environmental Sciences. She has served on numerous boards and panels addressing the effects of human alterations on coastal environments and the role of science in guiding restoration, including the NRC Committee on Sustainable Water and Environmental Management in the California Bay-Delta, and has been a member of the USACE Environmental Advisory Board and the Ecosystems Sciences and Management Working Group of the NOAA Science Advisory Board. Dr. Reed received her B.S. degree in Geography from Sidney Sussex College, and her M.S. and Ph.D. degrees from University of Cambridge.

James E. Saiers is a professor of hydrology, the 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. Dr. Saiers was a member of the NRC's Committee on Independent Scientific Review of Everglades Restoration Progress and chaired the Committee to Review the Florida Aquifer Storage and Recovery Regional Study Technical Data Report. Additionally, he served as a member of the Hydraulic Fracturing Research Advisory Panel of the EPA Science Advisory Board. He earned his B.S. in geology from the Indiana University of Pennsylvania and his M.S. and Ph.D. in environmental sciences from the University of Virginia.

Jeffrey R. Walters 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. 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 is best known for his long-term studies of the cooperatively breeding red-cockaded woodpecker, an endangered species endemic to the southeastern United States. He has extensive experience with issues related to the restoration of the Everglades, having 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, served in two panels of the Sustainable Ecosystems Institute that addressed issues with endangered birds in the Everglades restoration, served as a member of the NRC's Committee on Restoration of the Greater Everglades Ecosystem, and served as a member of the first and fourth, and chair of the fifth, Committees on Independent Scientific Review of Everglades Restoration Progress. Dr. Walters devotes considerable time to providing such reviews and syntheses of science relevant to conservation issues, for example chairing a recent panel that reviewed the conservation of the endangered California Condor and heading an initiative for the ornithological societies to establish a process for conducting such reviews in the area of avian conservation. He holds a B.A. from West Virginia University and a Ph.D. from the University of Chicago.

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 fifteen committees, including the Panel to Review the Critical Ecosystem Studies Initiative and all six 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 and director of the Program in Applied Ecology and Natural Resources 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.

Ed Dunne is a program officer with the Water Science and Technology Board. Since joining WSTB in 2014, he has worked on topics covering flood insurance, watershed management, remote sensing of water resources, and reuse of water from the oil and gas industry. Prior to joining the Academies, Dr. Dunne was an environmental scientist with the Saint Johns River Water Management District in Florida. He managed large-scale constructed wetlands and contributed to projects that included aspects of ecological engineering, restoration ecology, limnology, and watershed management. Prior to that, he was an assistant research scientist and postdoctoral research associate in the Soil and Water Science Department at the University of Florida, where he undertook research and managed projects on wetland restoration and biogeochemistry. Dr. Dunne received a B.S. in biology from Bangor University, Wales. He also received his M.S. and Ph.D. in environmental resource management from University College Dublin, Ireland.

Brendan R. McGovern is a senior program assistant with the Water Science and Technology Board. Mr. McGovern has contributed to a number of studies and projects on municipal water, aquifer storage and recovery, community-based flood insurance, and coastal risk reduction. He previously worked with the American Association for the Advancement of Science and Stimson Center on international water security issues. He earned his B.A.s from the University of California, Davis in political science and history.