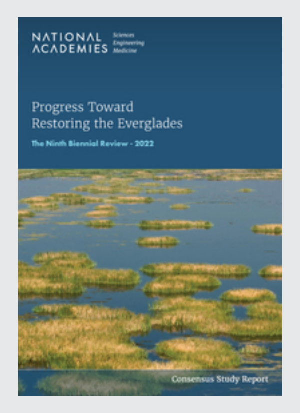

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Progress Toward Restoring the Everglades

The Ninth Biennial Review—2022

Committee on Independent Scientific Review of
Everglades Restoration Progress

Water Science and Technology Board

Division on Earth and Life Studies

Consensus Study Report

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This Consensus Study Report was 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 National Academies of Sciences, Engineering, and Medicine in making each published report as sound as possible and to ensure that it meets the institutional standards for quality, objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

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Although these reviewers provided many constructive comments and suggestions, they were not asked to endorse the conclusions and recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by **George Hornberger** (NAE), Vanderbilt University and **Holly Greening**, CoastWise Partners. Appointed by the National Academies, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments received full consideration. Responsibility for the final content of this report rests entirely with the authoring committee and the National Academies.

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Preface

There are four remarkable things about the effort that this report describes. First, there are the innumerable and varied visions of the Everglades as an extraordinary ecosystem, from the vastness of a “River of Grass” to the incredible diversity of life that can be found in the smallest pocket of a hummock or beneath the seagrass blades in Florida Bay. There are the practical visions, too—its role in the very health and well-being of those who live near and those who visit from afar, to its powering of an economy and a way of life. Whatever vision we individually and/or collectively hold, we sense when it is at risk of being changed or lost. When many of us sense that loss, we do the second remarkable thing—we come together and willingly wrestle with the difficult question that asks what are we trying to restore and to what end. That leads us to the third remarkable thing, the sheer magnitude of the human endeavor to move large amounts of water, the very basis of life, across this vast and varied landscape that occupies most of the state of Florida, to restore it.

The use of the word “restore” dates back to the 14th century, defined as “a means of healing or restoring health, a cure; renewing of something lost.” The word originated as a term applied to efforts directed to an individual or a single object. Now we find ourselves applying it to renewing a diverse and distinctive ecosystem that stretches from the meandering Kissimmee River and associated floodplain and chain of small lakes to the much larger Lake Okeechobee, and on to sawgrass plains, ridge-and-slough wetlands, tree islands, marl prairies, bays, and estuaries. To restore something lost means something far different in the 21st century than it might have in the 14th century because the context in which we restore—a changing climate, changing human needs—requires a diverse and unique set of skills, approaches, and philosophies to deal with both the pace of change and its consequences. The enormous passion, commitment, and collective intelligence of the people engaged in this effort to renew and restore the Everglades is the fourth remarkable thing, and it is an honor and privilege to be given the vantage point to review their efforts.

This document reports on the progress toward restoration of the Everglades natural system. The National Academies of Sciences, Engineering, and Medicine (National Academies) Committee on Independent Scientific Review of Everglades Restoration Progress, or CISRERP, was formed for this purpose in 2004. This report, which is the ninth in a series of biennial evaluations that are expected to continue for the duration of the Comprehensive Everglades Restoration Plan (CERP), reflects the concerted efforts of 12 committee members and 4 National Academies staff representing a wide range of scientific and engineering expertise. A fifth remarkable thing might be the circumstances under which the entire community of scientists, engineers, and stakeholders of the restoration effort helped the committee navigate the new landscape of remote meetings to provide a comprehensive picture of a work in progress unlike any other.

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

The committee is indebted to many individuals for their contributions of information and resources. Specifically, we appreciate the efforts of the committee's technical liaisons— Nafeeza Hooseinny (South Florida Water Management District), Robert Johnson (Department of Interior), and Gina Ralph (U.S. Army Corps of Engineers)—who responded to numerous information requests and helped the committee utilize the vast resources of agency expertise when needed. Many others educated the committee on the complexities of Everglades restoration through their presentations, field trips, and public comments (see Acknowledgments).

The committee had the good fortune to be assisted by dedicated and talented NRC staff: Stephanie Johnson, Sarah Haedrich, Jonathan Tucker, and Padraigh Hardin. Stephanie Johnson has served as senior project officer for all nine CISRERP panels and is a true Everglades expert. Her encyclopedic knowledge and understanding of the science, engineering, and administrative aspects of the CERP, ability to identify and synthesize the complex interrelationships among these aspects, deft management skills, and contacts were critical to the committee's success. She is intellectual shepherd, spiritual director, and choral master, blending voices and modulating rhythms as only she can. We literally can't thank her enough.

The CERP is a bold, challenging, and complex plan with great potential to provide benefits to the ecosystem and the public, and the progressively larger increments of restoration that have been achieved suggest that that potential can be realized. We offer this report in support of that endeavor.

Denice H. Wardrop, *Chair*
Committee on Independent Scientific
Review of Everglades Restoration Progress

Acronyms

A.R.M.	Arthur R. Marshall
AF	acre-feet
Alt-1BWR	Alternative 1BWR
AMO	Atlantic Multidecadal Oscillation
ASR	Aquifer Storage and Recovery
BBCW	Biscayne Bay Coastal Wetlands
BBSEER	Biscayne Bay-Southern Everglades Ecosystem Restoration
BBSM	Biscayne Bay Simulation Model
BISECT	Biscayne and Southern Everglades Coastal Transport
BMP	best management practice
C&SF	Central and South Florida Project
CBP	Chesapeake Bay Program
CEPP	Central Everglades Planning Project
CERP	Comprehensive Everglades Restoration Plan
CFR	Code of Federal Regulations
CISRERP	Committee on Independent Scientific Review of Everglades Restoration
CMIP5	Coupled Model Intercomparison Project Phase 5
COP	Combined Operational Plan
CRIDA	Climate Risk Informed Decision Analysis
CROGEE	Committee on the Restoration of the Greater Everglades Ecosystem
CSSS	Cape Sable Seaside Sparrows
CWA	Clean Water Act
DIP	dissolved inorganic phosphorous
DMSTA	Dynamic Model for Stormwater Treatment Areas
DOI	Department of the Interior
DOP	dissolved organic phosphorus
DRP	dissolved reactive phosphorus
EAA	Everglades Agricultural Area
EAV	emergent aquatic vegetation
ECB	existing conditions baseline
EIS	environmental impact statement
ENP	Everglades National Park
ENSO	El Niño Southern Oscillation
EPA	Environmental Protection Agency
EPC_0	equilibrium phosphorus concentration
ERTP	Everglades Restoration Transition Plan

ET	evapotranspiration
FAV	floating aquatic vegetation
FDEP	Florida Department of Environmental Protection
FEB	Flow Equalization Basin
FW	Flow-way
FWMC	Flow-weighted mean concentration
FWO	future without
FY	fiscal year
GCM	General Circulation Model
GISTEMP	Goddard Institute for Space Studies Surface Temperature Analysis
HLR	hydraulic loading rate
IDS	Integrated Delivery Schedule
IMC	Interagency Modeling Center
IPCC	Intergovernmental Panel on Climate Change
IRL-S	Indian River Lagoon-South
IWR	Institute for Water Resources
LNWR	Arthur R. Marshall Loxahatchee National Wildlife Refuge
LORS	Lake Okeechobee Regulation Schedule
LOSOM	Lake Okeechobee System Operating Manual
LOWRP	Lake Okeechobee Watershed Restoration Project
LTER	Long-term Ecological Research
MAP	monitoring and assessment plan
NA	not applicable
NASEM	National Academies of Sciences, Engineering, and Medicine
NGVD	National Geodetic Vertical Datum
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
NSM	Natural System Model
PDO	Pacific Decadal Oscillation
PDT	Project Delivery Team
PIP	particulate inorganic phosphorus
PIR	Project Implementation Report
PLR	phosphorus loading rate
POP	particulate organic phosphorus
PP	particulate phosphorus
PSTA	Periphyton-based STA
RCP	representative concentration pathway
RECOVER	Restoration, Coordination, and Verification
RSM	Regional Simulation Model
RSM-GL	Regional Simulation Model for the Glades and Lower East Coast Service Areas
SAV	submerged aquatic vegetation
SCG	Science Coordination Group
SCT	Science Coordination Team
SCW	Spreader Canal western
SFER	South Florida Ecosystem Restoration
SFER	South Florida Environmental Report

SFNRC	South Florida Natural Resources Center
SFRCCC	Southeast Florida Regional Climate Change Compact
SFWMD	South Florida Water Management District
SOM	System Operating Manual
SRP	soluble reactive phosphorus
SSG	Science Sub-Group
SSR	System Status Report
SSRF	Strategic Science and Research Framework
STA	Stormwater Treatment Area
STAC	Scientific and Technical Advisory Committee
STAR	Scientific, Technical Assessment and Reporting
STERTF	South Florida Ecosystem Restoration Task Force
TBD	To be determined
TE_P	phosphorus treatment efficiency
TIME	Tides and Inflows to the Mangrove Everglades
TMDL	Total maximum daily load
TN	total nitrogen
TP	total phosphorus
UNESCO	United Nations Educational, Scientific, and Cultural Organization
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WCA	Water Conservation Area
WERP	Western Everglades Restoration Project
WIIN Act	Water Infrastructure Improvements for the Nation Act
WPA	Water Preserve Areas
WQBEL	water quality–based effluent limit
WRDA	Water Resources Development Act
WY	water year

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Summary

The Everglades, one of the world's treasured ecosystems, once encompassed about 3 million acres of slow-moving water, which supported an array of wetland and estuarine habitats from Lake Okeechobee in the north to the Florida Keys in the south. During the past century, the Everglades has been dramatically altered by drainage and water management infrastructure to improve flood management, 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 sectors. The Comprehensive Everglades Restoration Plan (CERP), a joint effort launched by the state and federal governments in 2000, seeks to reverse the decline of the ecosystem. This multibillion-dollar plan was originally envisioned as a 30- to 40-year effort with 68 individual project components including water storage reservoirs, water quality treatment using constructed wetlands, seepage management, and removal of barriers to sheet flow (e.g., canals, levees). Collectively these CERP projects aim to achieve ecological restoration by reestablishing the natural hydrologic characteristics of the Everglades—quality, quantity, timing, distribution, and flow—where feasible, and creating 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, based on Congress's mandate in the Water Resources Development Act of 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 ninth report. Each report provides an update on progress toward natural system restoration during the previous 2 years, describes substantive accomplishments, and reviews developments in research, monitoring, and assessment that inform restoration decision making. The committee also identifies issues for in-depth evaluation stemming from 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 2022 report, the committee reviewed water quality progress for the stormwater treatment areas (STAs) and its importance to CERP progress and the consideration of climate change in CERP planning.

CERP implementation is occurring at a remarkable pace (Figure S-1), thanks to record funding levels. Large-scale restoration of the natural system is now under way, with the Combined Operational Plan increasing flows to the central Everglades through a suite of recently completed CERP and non-CERP projects and through ongoing restoration in Picayune Strand. Both efforts employ intensive project monitoring to track progress and learn from the monitoring results. This accelerated progress has illuminated two challenges that deserve additional attention

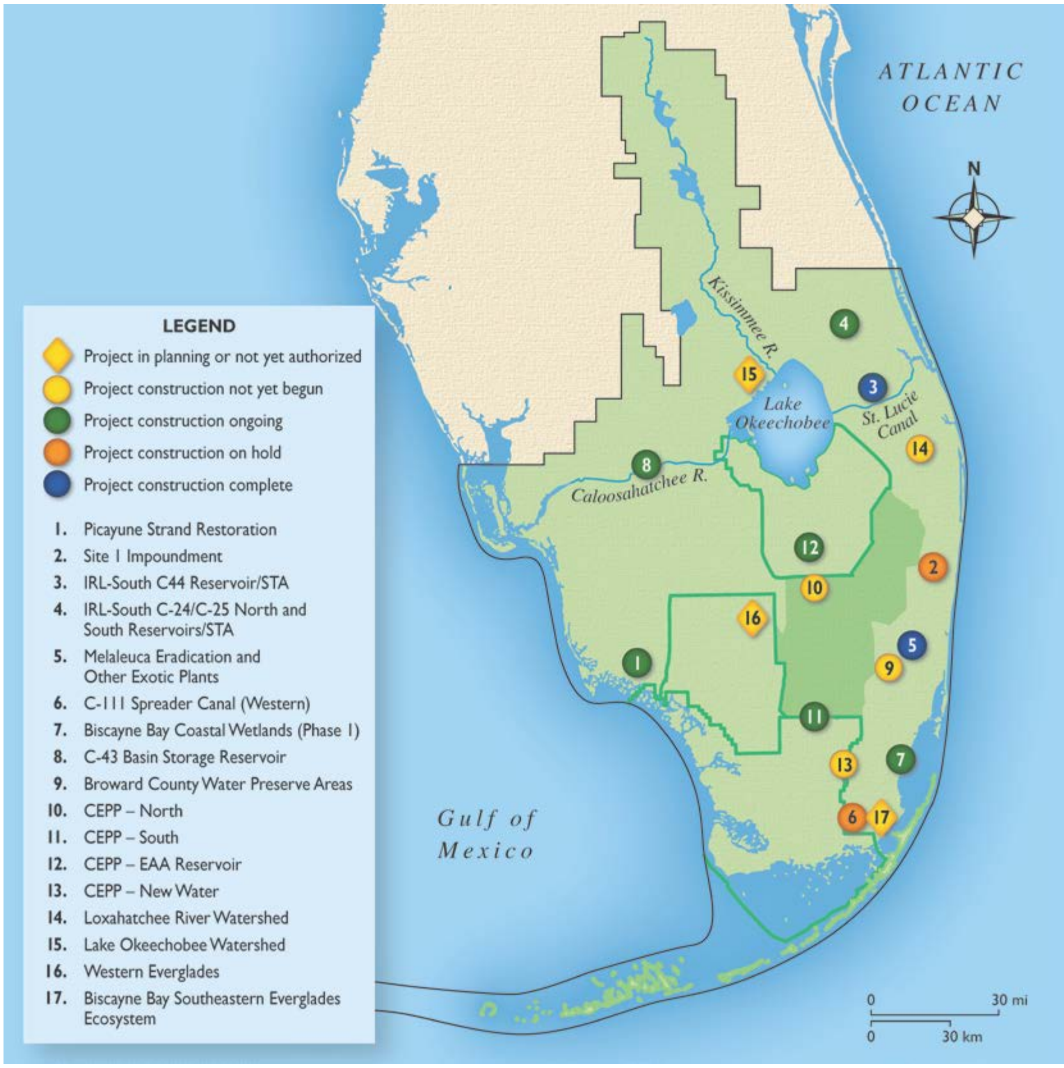

FIGURE S-1 Locations and status of CERP projects. SOURCE: International Mapping Associates. Reprinted with permission; copyright 2021, International Mapping Associates.

moving forward—water quality and climate change. Fortunately, many opportunities exist to leverage scientific expertise to address these challenges without slowing the pace of restoration and to enhance the science support for decision making. Through a renewed initiative to develop a multiagency science plan, the Everglades science enterprise can ensure that the needed tools, research, analysis, and synthesis are available to support these and other critical restoration management decisions.

RESTORATION PROGRESS

In Chapter 3, the committee outlines the major accomplishments of restoration, with an emphasis on natural system restoration progress from the CERP in the past 2 years, and discusses issues that may affect progress.

Record funding levels for Everglades restoration planning, implementation, and construction are further expediting restoration progress and expanding its geographic scope. In 2022, six CERP projects are under construction, one project and one major project components have been officially completed, and the new Lake Okeechobee Systems Operating Manual (LOSOM) was released. Several projects are nearing completion in the next 2-3 years. The Everglades restoration program is exhibiting impressive momentum with three additional CERP projects expected to begin construction in the next 2 years. This implementation progress places the restoration at a pivot point with increasing demands associated with project- and system-wide operation and adaptive management, as well as with planning and implementation of remaining projects. An ambitious proposed implementation schedule (the Integrated Delivery Schedule) is being realized, and the Central Everglades Planning Project (CEPP)—the key project in the restoration of the central Everglades—continues to make impressively rapid implementation progress.

Hydrologic restoration progress and early vegetation response is evident over large areas of the central and western Everglades after implementation of recent CERP and non-CERP initiatives. The Combined Operational Plan, which utilizes seepage management and water conveyance infrastructure from two non-CERP foundation projects that were recently completed (Mod Waters, C-111 South Dade), is rehydrating Northeast Shark River Slough and appears to be facilitating increased flow into Everglades National Park. The rehydration of Northeast Shark River Slough in Everglades National Park represents the largest step yet toward restoring the hydrology and ecology of the central Everglades. Shifts in vegetation in marl prairies are an early indicator that the predicted restoration benefits of the Combined Operational Plan may be realized. During the past 2 years, plugging of canals at Picayune Strand (Figure S-1) has approximately doubled the area with full hydrologic restoration to approximately 13,500 acres. Monitoring wells in the fully hydrologically restored area show immediate increases in hydroperiod and typical water levels. Understory vegetation response is trending toward reference conditions, but tree canopy response has been slower, as expected. The benefits attributable to restoration efforts cannot be adequately distinguished from the effects of other factors, such as unusually wet or dry years without the use of available modeling tools to analyze the effects of these various factors on project outcomes.

Current progress on implementation and record levels of funding increase the need for and importance of analyzing and synthesizing natural system responses. The long-term hydrological, ecological, and water quality trend data needed to assess restoration response are challenging to find, and analyses of these trends are inconsistent across projects. As noted in the committee’s past reports (NASEM, 2018, 2020), quantitative objectives and accompanying expectations of how and when they will be achieved by management actions are critical for adaptive management processes. Some projects invest substantial time and energy in data analysis, while other projects conduct only limited analysis and primarily report recent results, a situation that complicates evaluation of progress toward project objectives. Adaptive management of the partially implemented system requires quantitative objectives as well as resources and staffing to support the assessment of ecosystem response. In addition, as recommended in NASEM (2020), more sophisticated strategies that use modeling tools to compare observed results to model predictions of current conditions based on recent precipitation and climate data (termed “nowcasting”) would help managers understand project responses under a range of weather conditions and improve their capacity to adjust operations as needed.

Water quality is an ongoing concern that could potentially constrain progress on several fronts, including the Combined Operational Plan and the CEPP. Increased dry season flows are a specific objective for the CEPP, but new infrastructure and recent operational changes under the Combined Operational Plan that have facilitated higher dry season flows have also resulted in total phosphorus exceedances. Better understanding of the underlying processes is needed to assess whether additional steps can help to mitigate these impacts without adversely affecting the intended flow benefits. Resolving this issue may necessitate additional research into the ecological implications of increased phosphorus concentrations and loads amid flow restoration and the development of improved water quality modeling tools to analyze the potential consequences of various alternatives.

The final plans for LOSOM and the Lake Okeechobee Watershed Restoration Plan provide for substantially less storage than originally envisioned in the CERP, which highlights the importance of a CERP mid-course assessment (i.e., CERP Update). The new System Operating Manual for Lake Okeechobee generally retains upper lake stages similar to those of the prior Lake Okeechobee Regulation Schedule (LORS 2008), which lowered lake stages to reduce the risk of catastrophic failure of the Herbert Hoover Dike. Consequently, LOSOM poses a potential loss of up to 800,000 acre-feet (AF) of storage in the rainy season compared to the lake regulation schedule in place in 1999 when the CERP was planned. In addition, the final Lake Okeechobee Watershed Restoration Plan includes 55 aquifer storage and recovery (ASR) wells, compared to the 200 ASR wells and 250,000 AF of surface storage proposed in the original CERP. As recommended by NASEM (2016 and 2018), a mid-course assessment of expected CERP outcomes that accounts for newly identified constraints in storage and incorporates the latest climate change science would inform future management decisions regarding restoration planning, funding, sequencing, and adaptive management.

The SFWMD has implemented a rigorous approach to address uncertainties associated with ASR in the Lake Okeechobee Watershed Restoration Plan. The SFWMD appointed an independent peer review panel to provide input in the development of the ASR Science Plan, which includes 26 studies through 2030. The panel will continue to meet annually to evaluate progress on the ASR Science Plan and will provide recommendations on additional studies needed or modifications to ongoing work. The committee commends the SFWMD for soliciting independent input both in the development of the plan and on an ongoing basis, to enhance the effectiveness of the science investments.

The USACE should implement a process for periodic multi-stakeholder review of Lake Okeechobee operations relative to the objectives of LOSOM to build confidence that the flexibility of the new operational schedule is being used as designed and to support learning to enhance future decision making. The final LOSOM regulation schedule is similar to the prior schedule in many ways, including the high and low water management bands. The key differences are found in the lack of specificity of management in the largest band, Zone D. This lack of specificity affords water managers flexibility to use recent data and near-term forecasts to optimize water management. At the same time, this new flexibility leaves other agencies and stakeholders uncertain about how tradeoffs in management objectives will be balanced in the future compared to the balance of outcomes projected by the models during the LOSOM development process. Efforts to routinely report the rationale for operational adjustments within Zone D could be valuable in keeping stakeholders abreast of water management activities. In addition, an annual or semi-annual multi-stakeholder meeting or workshop would enable periodic assessment of how well competing priorities were balanced, increasing understanding, supporting transparency, and identifying lessons learned in support of adaptive management.

STA WATER QUALITY AND CERP PROGRESS

Implementation and refinement of stormwater treatment areas (STAs) over the past nearly 3 decades has resulted in marked reductions in phosphorus concentrations in outflow waters, particularly in STA-3/4, which currently meets the requirements codified in the water quality‒based effluent limit (WQBEL).[1] A considerable volume of rigorous, peer-reviewed, and applicable science has been generated by the SFWMD, as well as their academic and consulting partners, that has helped inform the design and performance of STAs. However, as discussed in depth in Chapter 4, the extent of phosphorus removal varies across STAs, and some STA discharges remain far from target values. The state's current efforts through Restoration Strategies and other actions are expected to continue to improve the function of the STAs, although meeting and sustaining the WQBEL requirements in all STAs starting in water year (WY) 2027 will be a significant challenge. Given the dependence of CERP progress on WQBEL attainment—particularly the timely delivery of full CEPP benefits—the committee offers the following recommendations and conclusions to support the state's efforts to understand and improve the effectiveness of STAs.

To support and sustain WQBEL attainment, the SFWMD should implement a rigorous adaptive management framework that increases efforts in data collection, data analysis, modeling, and synthesis. Talented and experienced SFWMD scientists and engineers are working on the STAs, as evidenced by the phosphorus removal performance to date, and substantial research is under way through the Restoration Strategies Science Plan that should be useful to STA management. Nonetheless, the extent of phosphorus removal needed to meet and sustain the WQBEL will likely require even stronger science support for decision making, cell-by-cell monitoring, new modeling tools, detailed analysis of available data, and frequent feedback between science and management to support rapid, science-informed decision making and to reduce the likelihood of water quality impeding CERP progress.

A rigorous adaptive management program should include development of near-term milestones for each STA flow-way. The WQBEL sets clear quantitative targets to assess STA performance starting in WY 2027, but quantitative interim milestones over the next few years should also be developed based on the activities associated with Restoration Strategies and other STA remediation actions. These milestones would help communicate to managers the science-based expectations of STA function and recovery times in each flow-way and would provide a basis for further analysis and possible action if outcomes do not meet expectations, thereby supporting more nimble decision making. They would also increase transparency of restoration progress to the community interested in water treatment by STAs and Everglades restoration.

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[1] The Florida Department of Environmental Quality set a WQBEL for total phosphorus in STA discharge to not exceed: 19 µg/L as an annual flow-weighted mean in any water year and 13 µg/L as an annual flow-weighted mean in more than 3 out of 5 water years on a rolling basis (FDEP, 2017). This footnote and text in Chapters 3 and 4 were edited after prepublication release of the report to clarify responsibility for setting total phosphorus limits.

Additional monitoring, research, analysis, and modeling will provide insight on ways to optimize and sustain STA performance. Despite decades of research and lessons learned through STA operations, key gaps remain in the understanding of phosphorus mobility and removal processes within STAs and optimal management strategies to manage STA hydrology, vegetation, and biogeochemical processes. Moreover, currently available tools are limited in their ability to forecast STA responses to management actions. The cumulative retention of phosphorus in soils threatens the long-term performance of the STAs. The committee identified several priority research needs:

- Cell-by-cell monitoring along with the development of cell-by-cell phosphorus budgets would help managers identify problem areas and focus additional efforts to better understand and address the mechanisms that drive elevated phosphorus conditions. These activities would identify cells that may be transitioning to conditions of phosphorus saturation.
- Additional analysis of nutrient dynamics (total phosphorus, phosphorus forms, total nitrogen, nitrogen forms and associated secondary elements) along STA flow-ways could illuminate strategies to more effectively manage phosphorus. Dissolved organic and particulate phosphorus can represent substantial fractions of total phosphorus concentrations in STA outflows, but current management efforts are generally focused on total phosphorus, rather than individual forms of phosphorus. The interplay between nitrogen and phosphorus and the significance of nitrogen-limiting conditions deserves additional attention in understanding factors that affect phosphorus removal efficiency.
- Field research in STA cells that appear to be approaching phosphorus saturation and thereby increased internal phosphorus load and that are experiencing reduced efficiencies could provide insight on the effect of soil phosphorus accumulation on the ability of STA cells to retain phosphorus, and the benefits and timing of cell refurbishment in maintaining the effective performance of STAs over the long term. Field research would also provide an opportunity to examine the best strategies for refurbishment and recovery.
- Application and continued refinement of STA biogeochemistry and hydrology models would enhance the understanding of STA function and inform maintenance and operations decisions.
- Additional field research on the effects of STA hydraulics, such as inflow and outflow velocities, hydroperiod, and hydraulic loading, on phosphorus discharge could inform future operations.

An independent, external STA science advisory committee would provide additional perspective and expertise to assist the SFWMD in evaluating water quality progress of Restoration Strategies relative to expectations for phosphorus removal and in identifying areas of concern and promising strategies. An external STA science advisory committee, analogous to the aquifer storage and recovery independent peer review panel convened by the SFWMD, could meet annually to discuss progress toward the milestones and to provide additional expertise and advice to support WQBEL attainment. With a mix of specialists, including biogeochemistry, regional water operations, and agricultural source control measures, this group could also advise on data collection, data analysis, research, modeling, and synthesis efforts that inform actionable management activities.

Although a variety of factors affect outflow phosphorus concentrations, phosphorus inflow concentrations and loading rates are key drivers affecting WQBEL attainment. The only STA (3/4) that consistently meets water quality conditions that approach the WQBEL has an annual phosphorus loading rate that is generally much lower than 1 g/m^2-yr. In contrast, STA-1E, -1W, and -5/6 routinely have phosphorus loading rate that exceeds 1 g/m^2-yr, and in some years exceed this rate by a factor or 2 or more. Recent average flow-weighted inflow concentrations for STA-3/4 were approximately 50 percent (or less) than the inflow concentrations of three worst-performing STAs. Thus, for some STAs the annual phosphorus loads and/or concentrations will likely need to be cut in half to achieve annual effluent TP concentrations that approach the WQBEL. Three approaches can be pursued to manage elevated phosphorus loading rates in a given STA: improve the phosphorus removal efficiency within the STA, increase the footprint (surface area) of the STA (as is under way in STA-1W), and/or decrease the upstream phosphorus loading entering the STA (source control). Restoration Strategies includes all three approaches in some capacity to reach the WQBEL, with most efforts devoted to improving phosphorus removal efficiency, but little progress has been made to reduce subregional phosphorus loads in the Eastern Flow Path. The concentrations of some STAs are so high that efficiencies beyond those of the best performing STA would be needed to meet the WQBEL. In these cases, additional source control measures may ultimately be needed to meet the WQBEL.

RESTORATION IN THE CONTEXT OF CLIMATE CHANGE

The one near certainty regarding Florida climate change is that temperature and sea level will continue to rise. Increases in sea level will alter the salinity and habitats in coastal and near coastal regions, and increases in air temperature will drive increases in evapotranspiration and decreases in runoff, unless compensatory changes in precipitation occur. However, changes in precipitation and resulting discharge will remain uncertain and highly variable during CERP planning and implementation. Progress is under way to increase the rigor in which sea-level-rise scenarios are considered in CERP project planning (e.g., coastal wetland and estuarine salinity changes), but analytical capabilities are limited by the tools presently available. In contrast, minimal progress is being made in the use of precipitation and temperature scenarios in project planning. No clear signal of the direction of change is not equivalent to an expectation of no change. In Chapter 5, the committee reviewed examples of how climate change is being incorporated into CERP planning and operations and offers the following conclusions and recommendations.

The USACE and SFWMD should proactively develop scenarios of future precipitation and temperature change, including changes in variability, and a strategy to use them to inform future project planning decisions and ensure more reliable project performance. USACE project planning efforts seek to identify justifiable solutions to current problems that will ensure performance for the next 50 years at minimum, and USACE policy requires that restoration planning must meaningfully consider climate change trends and potentially increasing climate variability. Past CERP evaluations of climate change effects have been inconsistent and often limited to a step increase in sea-level rise. Meaningful consideration of climate for restoration decision making would include selection of appropriate performance measures and focused analysis and assessment of risk using multiple plausible scenarios of the future. The impacts of changes in interannual variability could be examined based on the historical record (e.g., by using a Monte Carlo approach), which would provide valuable insight into potential project performance. Exploring the effects of trends in air temperature and precipitation—individually, in combination, and with sea-level rise—during the planning process will help ensure that projects that perform reliably under future change move forward. If appropriate, additional data collection and further analysis can be conducted in preconstruction engineering and design.

Existing modeling tools, although effective for many CERP-related purposes, constrain the ability to improve planning to consider the effects of sea-level rise and other climate change impacts. Current models have limited flexibility to incorporate alternative climate futures, especially those that reflect increased variability and non-stationarity. Such limitations introduce risks into the project planning process because projects may not perform as anticipated. The USACE and SFWMD should develop improved tools and analytical approaches that enable the examination of progressive change over time, rather than time slices of future conditions, to enable identification of environmental conditions when ecological thresholds are crossed. Examination of progressive change is especially important for the assessment of sea-level rise. Improved tools are needed to assess the project-related effects of various rates of sea-level rise and its interaction with hydrologic changes, and to examine sensitivity to the magnitude, frequency, and sequence of episodic events. In addition, hydrologic models should be able to readily accommodate a range of plausible future conditions that differ from historical conditions. Development of a modeling and analysis framework to plan for climate change in a system as complex as the Everglades will be a challenging endeavor but should be initiated as soon as possible to provide appropriate tools for future planning and evaluation efforts.

Inadequate consideration of water availability under future conditions and potential variations in the rate of sea-level rise could cause a project to move forward that is not viable under future climate change. The Biscayne Bay and Southeastern Everglades Ecosystem Restoration (BBSEER) planning process is a step in the right direction, especially in its novel consideration of resilience. However, it is constrained by the capacity of the models that support it. Climate change analysis should not be based on a single performance metric; rather, it should underlie all aspects of project planning, and all performance measures should be evaluated for outcomes under different climate conditions. BBSEER provides lessons to inform future CERP planning efforts. Planning should consider the effects of a range of plausible future conditions (precipitation and air temperature) on freshwater availability, including, for example, extended droughts or wet years, to understand the vulnerability of project outcomes to climate change and to avoid delays and additional costs as the project moves forward. Further, progressive change over time due to sea level rise should be considered, rather than just time slices, so that potential tipping points in habitat change can be identified and project alternatives adjusted as needed.

Each revision of the LOSOM and System Operating Manuals should incorporate the latest information on climate change and variability to ensure anticipation of and planning for a wide range of conditions. Regular revisions to the System Operating Manual and other major operational plans, such as LOSOM or the Combined Operational Plan, provide an opportunity to incorporate evolving understanding of climate variability and change into Everglades restoration. Several recent major operational planning efforts, such as LOSOM, have proceeded based on analysis of a prior 52-year climate record, with limited assessment of potential changes in future air temperature or precipitation, providing an incomplete view of their performance under potential future conditions. Efforts to update these operational manuals should identify data collection and information needs to ensure that the manuals reflect the current dynamics of the system and its variability.

Systemwide analysis of climate change on CERP performance is essential to assess the robustness of the restoration effort to possible futures and support program-level decision making. The work being conducted for the CERP Update provides a critical opportunity to examine the functionality of the system as a whole, but whether or how climate change analyses will be included in this work remains unclear. If not included as part of the CERP Update, additional analyses should be conducted outside of this process. These system-level climate change analyses will inform priorities for the remaining unplanned CERP projects and adjustments to system operations and will illuminate potential restoration actions that may be needed to enhance ecosystem resilience, either within or outside the CERP.

The lack of USACE guidance on the use of accepted information related to changes in precipitation and air temperature in quantitative analysis as part of project planning leads to future vulnerabilities to climate change and variability as CERP projects come on line. The science of global climate change is mature and rigorous, and many other water resources planning projects, in the United States and globally, routinely use climate change scenarios to examine project performance under a range of future conditions. The USACE has progressively advanced guidance on the consideration of sea-level change in its activities, but the success of the CERP also relies on understanding the effects of other climate change impacts. To reduce future vulnerabilities, the committee urges the USACE to develop guidance on the use of climate-affected hydrology data for civil works studies discussed in the USACE climate action plan, which was anticipated in 2021. This guidance is critical to support Action 1 of the USACE Climate Action Plan to "[e]nsure that new USACE-built projects are built to last and perform reliably for their intended design lives, despite uncertainty about future climatic conditions." Providing the USACE District with the tools and guidance needed to effectively plan for future conditions is an urgent priority. The lack of guidance on the use of quantitative approaches to considering climate change and variability in hydrologic analyses fundamentally limits the potential success of CERP investments in ecosystem restoration.

THE CASE FOR AN EVERGLADES RESTORATION SCIENCE PLAN

As the CERP pivots from planning to implementation and adaptive management during a time of rapid global change, it requires support from a science enterprise with the collective capacity and ability to contribute financial resources, skills and expertise, and facilities and/or other resources to undertake scientific activities that respond to the critical knowledge impediments to restoration. In Chapter 6, the committee presents three essential, interlinked tasks of a science enterprise directed at the production of an Everglades Restoration Science Plan: (1) identification of knowledge gaps; (2) coordination to advance and exchange knowledge; and (3) identification and establishment of focused science actions necessary to support progress. These tasks can be undertaken concurrent with ongoing work to advance restoration, with new science being incorporated into planning and implementation as it is developed.

Everglades restoration progress is inhibited by the lack of collectively identified science needs to support CERP decision making. There is no recent centralized compilation of critical management questions and associated knowledge gaps that could guide CERP science funding decisions or serve as a basis for proposal solicitations or collaborative initiatives. Instead, short-term demands command the attention of the available staff, and long-term, systems thinking is generally de-prioritized. Clearly identified science needs enable the science enterprise to stay focused, leading to more efficient utilization of science-provisioning resources and the presence of a critical linkage between management and science.

The Everglades science enterprise should develop a science plan to advance and implement essential science actions that directly support restoration decision making. This effort will require extensive multi-agency and stakeholder coordination. This Everglades Restoration Science Plan could serve as a central document that highlights and communicates priority science needs and management linkages to a broad audience of potential funders, much as the Integrated Delivery Schedule does for project implementation. The plan would guide the CERP program, other restoration initiatives, and individual funding agencies in their science investments for research, monitoring, modeling, and synthesis to meet agreed upon priority needs. The plan should be updated every 5 years and with the engagement of a diverse range of stakeholders to respond to changing needs, with annual implementation plans and progress reports to facilitate coordination and communication of progress toward addressing the science needs.

The Science Coordination Group is best positioned to lead an updated multi-agency assessment of priority science needs and gaps at a programmatic level and to develop an Everglades Restoration Science Plan. This group should be clearly tasked to lead this effort and receive appropriate resources to do so from the South Florida Ecosystem Restoration Task Force. This effort would be a much-needed update to the 2008-2010 Plan for Coordinating Science. A lead scientist could guide implementation of the science plan, ensure completion of the work, and consult with decision makers to identify additional science needs to supplement plan activities (see also NASEM, 2018).

1

Introduction

The Florida Everglades, formerly a large and diverse aquatic ecosystem, has been dramatically altered over the past 140 years by an extensive water control infrastructure originally designed to increase regional economic productivity through improved flood management, urban water supply, and agricultural production (Davis and Ogden, 1994). 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 ninth 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.

THE NATIONAL ACADEMIES AND EVERGLADES RESTORATION

The National Academies has provided scientific and technical advice related to the Everglades restoration since 1999. The National Academies' Committee on the Restoration of the Greater Everglades Ecosystem (CROGEE), which operated from 1999 to 2004, was formed at the request of the South Florida Ecosystem Restoration Task Force (hereafter, simply the Task Force), an intergovernmental body established to facilitate coordination in the restoration effort, and the committee produced six reports (NRC, 2001, 2002a,b, 2003a,b, 2005). The National

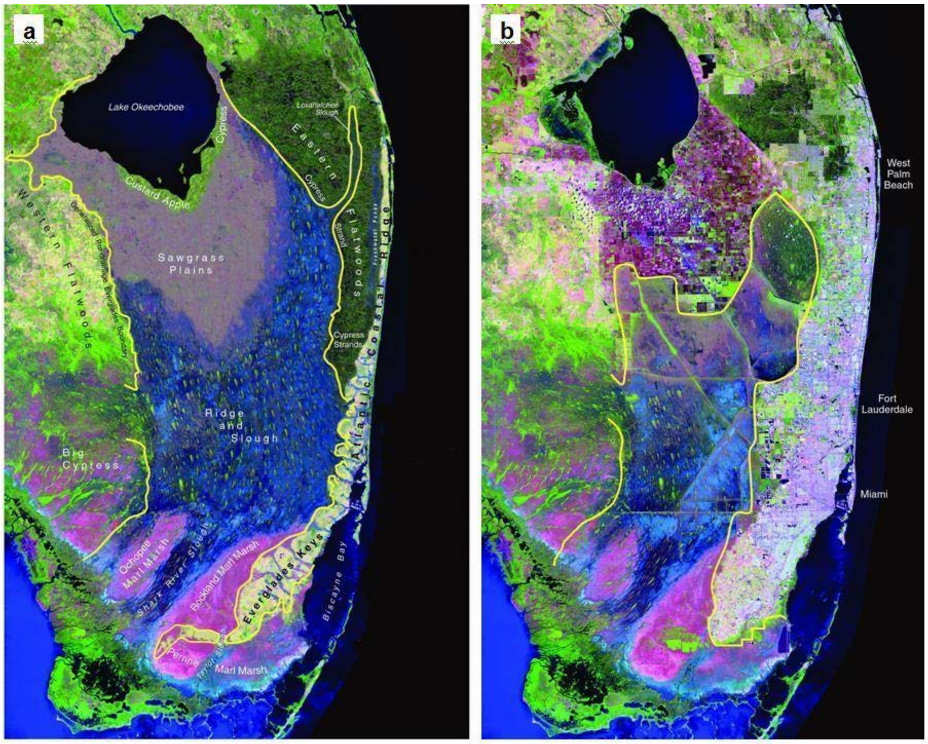


FIGURE 1-1 Reconstructed image of (a) predrainage (circa 1850) conditions compared to (b) a 1994 satellite image of the Everglades ecosystem. NOTE: The yellow line in (a) outlines the historical Everglades ecosystem, and the yellow line in (b) outlines the remnant Everglades ecosystem as of 1994.
SOURCE: Courtesy of C. McVoy, J. Obeysekera, and W. Said, South Florida Water Management District.

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 eight biennial reviews (NASEM, 2016, 2018, 2021; 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

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 **predrainage 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), -2A, -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."

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-#.

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).

The primary audience for the report is Congress, as well as agency staff that are involved in Everglades restoration and stakeholders that are engaged with or deeply interested in restoration efforts.

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 and emphasizes restoration progress since 2020, 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"—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 Lake Okeechobee (NASEM, 2018; NRC, 2008), estuaries (NASEM, 2021), new information impacting the CERP (NASEM, 2016), the need for a midcourse assessment (NASEM, 2016, 2018), climate change (NASEM, 2016; NRC, 2014), invasive species (NRC, 2014), ecosystem services (NRC, 2010) and water quality and quantity challenges and trajectories (NRC, 2010, 2012). Past reports have also discussed various aspects of the CERP monitoring and assessment plan (NRC, 2004, 2008, 2010, 2012, 2014), including project-level monitoring (NASEM, 2018).

The full committee met 12 times using a combination of virtual and hybrid meeting formats during the course of this review and received briefings at its public meetings from agencies, organizations, and individuals involved in the restoration, as well as from the public. The committee also participated in two field trips. In addition to information received during 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 were also 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 July 2022.

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 natural system restoration progress associated with CERP and systemwide operational changes, along with programmatic factors and planning efforts that affect future progress. In Chapter 4, the committee reviews progress with stormwater treatment areas (STAs) and the importance of their success to CERP progress. In Chapter 5, the committee reviews the use of climate change science in CERP projects, operations, and programmatic planning. In Chapter 6, the committee discusses the science enterprise to support decision making.

FIGURE 1-2 The South Florida ecosystem.
SOURCE: International Mapping Associates. Reprinted with permission; copyright 2021, International Mapping Associates.

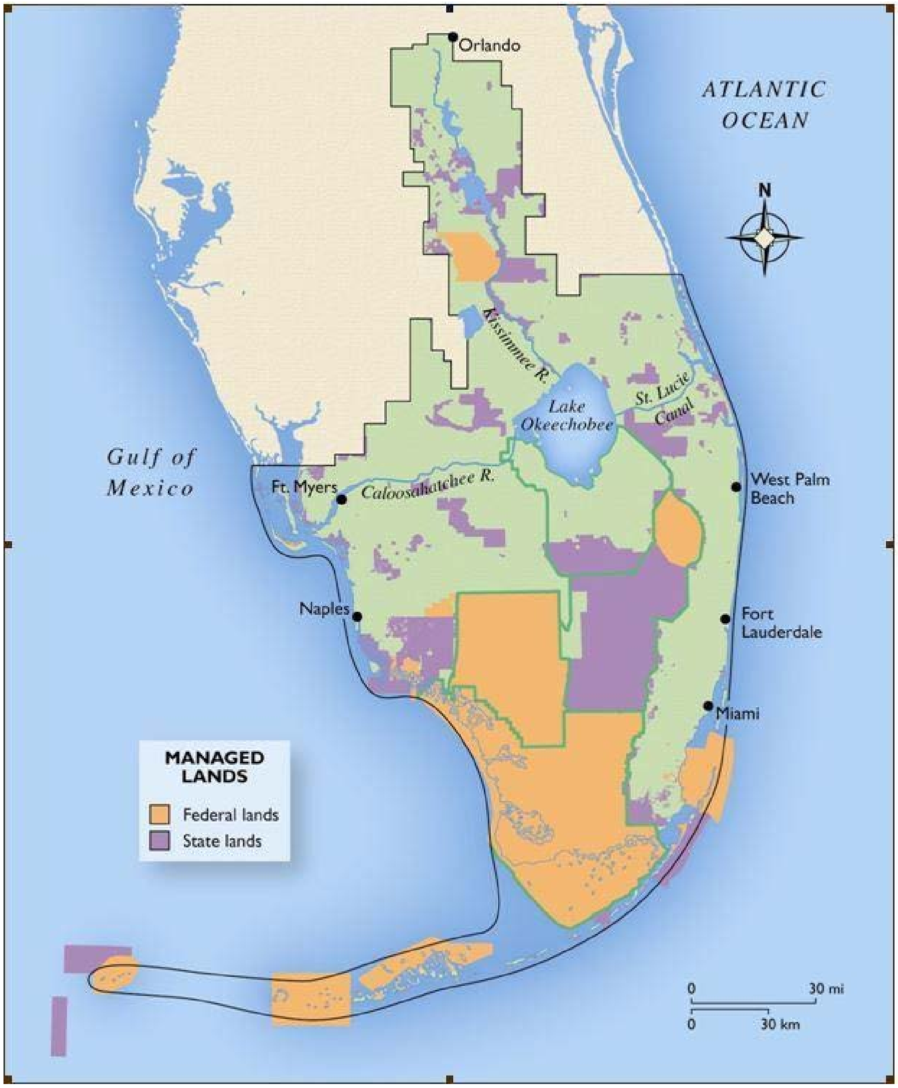


FIGURE 1-3 Land and waters managed by the State of Florida and the federal government as of December 2005 for conservation purposes within the South Florida ecosystem. SOURCE: Based on data compiled by Florida State University's Florida Natural Areas Inventory (http://www.fnai.org/gisdata.cfm), International Mapping Associates. Reprinted with permission; copyright 2021, International Mapping Associates.

2
The Restoration Plan in Context

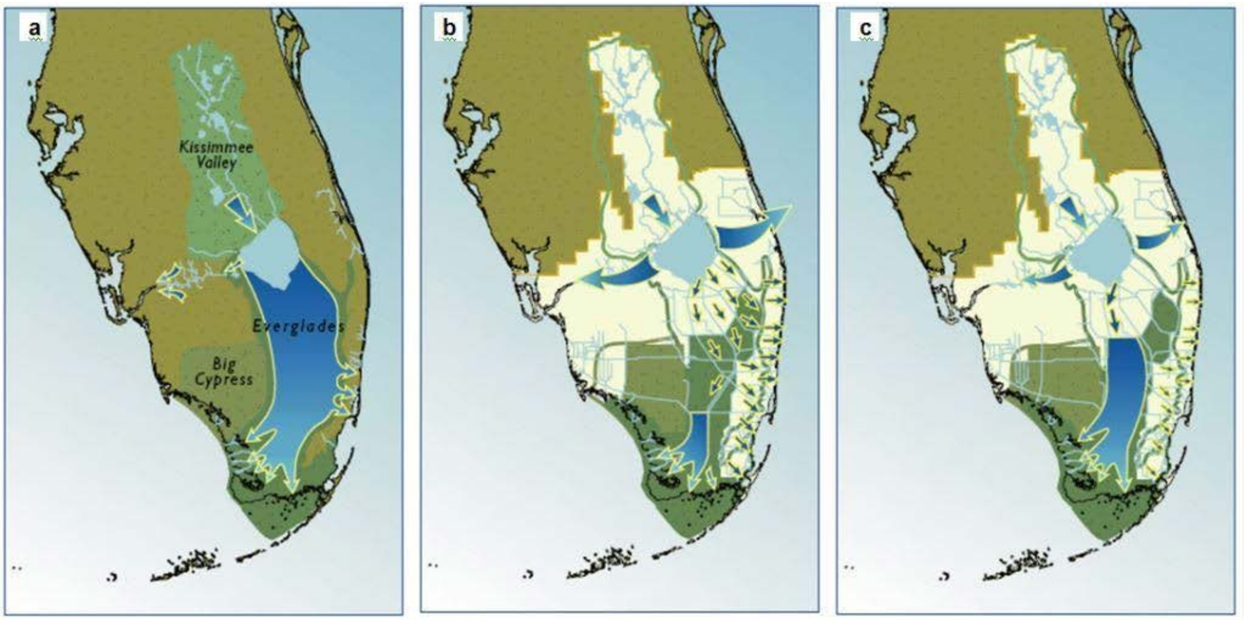
This chapter sets the stage for the ninth of this committee's biennial assessments of restoration progress in the South Florida ecosystem. Background for understanding the project is provided through descriptions of the ecosystem decline, restoration goals, the needs of a restored ecosystem, and the 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 and west 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 due to failures of the earthen dike that bordered the southern edge of the lake, the U.S. Army Corps of Engineers (USACE) replaced the small berm 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 natural water storage 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 management for the expanding population centers on the southeast Florida coast, the U.S. Congress authorized the Central and Southern Florida Project. This project provided flood management 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 predrainage area (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 management structures, including the Central and Southern Florida Project, have diverted large quantities of water directly east and west to the northern estuaries, thereby reducing the dominantly southward freshwater flows 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 from atmospheric deposition (McPherson and Halley, 1996; Orem et al., 2011).



Predrainage Flow Pre-CERP (circa 2000) Flow Restored Flow

FIGURE 2-1 Water flow in the Everglades under (a) predrainage conditions, (b) pre-CERP (circa 2000) conditions, and (c) conditions envisioned upon completion of the Comprehensive Everglades Restoration Plan. Restored flow includes less discharge east and west of Lake Okeechobee to the northern estuaries and more flow south into WCA 3 and Everglades National Park compared to pre-CERP conditions. Additionally, the restoration envisioned sheet flow restoration in WCA 3 rather than conveyance via canals. White areas outline the northern extent of the South Florida ecosystem (see Box 1-1 and Figure 1-2).
SOURCE: Graphics provided by USACE, Jacksonville District.

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). 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 management 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, Native American tribes, state agencies and commissions, 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), authorized by Congress in 2000, which builds on other ongoing restoration activities of the state and federal governments to create what was at the time the most ambitious restoration effort 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 those essential hydrologic 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 in the remnant Everglades. 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 urban and agricultural 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, 2003b; 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 nonnative species and reversing the decline in the spatial extent and compartmentalization of the natural landscape (SFERTF, 2000; SSG, 1993).

The goal of ecosystem restoration can seldom be the exact re-creation of some historical or preexisting state because physical conditions, driving forces, and boundary conditions usually have changed and are not fully recoverable (e.g., see discussions of climate change and CERP goals in NASEM [2014, 2016]). 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 management remains a critical aspect of the CERP design because improving hydrology and sheet flow in extensive wetland areas has the potential, through seepage, to flood adjacent urban and agricultural areas. Artificial storage will be required to replace the lost natural storage in the system (NRC, 2005), and groundwater management also requires attention to boundaries between developed and natural areas. 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 nonnative 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."

The broad CERP goals should be interpreted in the context of the complex Everglades ecosystem in order to guide restoration efforts. Early restoration was motivated by ambitious albeit generalized expectations for the ecosystem. For example, the CERP conceptual plan, also called 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." Currently the systemwide goals for the restoration upon which policymakers agree (USACE et al., 2007) are largely qualitative, indicating a desired direction of change for a number of indicators, without a quantitative objective, providing no clear expectation of how the success of restoration efforts should collectively be assessed. Systemwide ecological indicators with quantitative targets have been established by restoration scientists for assessing restoration success (Brandt et al., 2018; Doren et al., 2009), but these targets have not been endorsed for use in restoration planning. Individual CERP projects have project-specific goals, which are also typically qualitative, and NASEM (2018, 2020) noted the need for quantitative restoration objectives for each project, with accompanying expectations of how and when they will be achieved through management actions, to better support assessment of progress and adaptive management. Continued investment in Everglades restoration proceeds based on improving the current undesirable state of the system rather than toward a specific set of quantitative characteristics desired for the future South Florida ecosystem.

An additional factor challenging the ability of the restoration efforts to meet the "essential hydrologic and biological characteristics that defined the undisturbed South Florida ecosystem" is ongoing climate change, including changes in precipitation patterns, sea-level rise, and ocean warming. Not only have irreversible changes occurred since the 19th century, but also, since the development of the CERP, mean sea levels at Key Largo have risen approximately 11 cm[1] and future projections call for further increases of as much as 2 m in South Florida during the 21st century (NOAA, 2017).

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 proceeds in the face of scientific uncertainty and must consider a range of possible future conditions. NASEM (2016) discusses the challenges to restoration goals arising from major changes that have occurred since the inception of the CERP in 1999, and NASEM (2018) recommended that agencies anticipate and design for the Everglades of the future, rather than focusing restoration only on the past Everglades.

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 ecological 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 (CISRERP) 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;

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

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.

NRC (2007) concluded that if these five critical components of restoration are achieved and the difficult problem of invasive species is 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 albeit of a reduced scale.

The history of the Everglades and ongoing global climate change and sea-level rise 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 because 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) and will continue to change the restored system in the future. The specific nature and extent of the functional mosaic thus depends on not only the degree to which the five critical components can be achieved but also future precipitation patterns, rising sea levels, marine incursion into estuaries and coastal wetlands, and continued investment in water and ecological management.

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 under current conditions. 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. How the reestablished processes interact with future changes within and external to the system will determine the future character of the ecosystem, its species, and communities.

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 Central and Southern Florida 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 (or Yellow Book; USACE and SFWMD, 1999) proposes major alterations to the Central and Southern Florida Project in an effort to reverse decades of ecosystem decline. The Yellow Book includes 68 project components to be constructed at an estimated cost of approximately $23.2 billion (in 2019 dollars, including program coordination and monitoring costs; USACE and DOI, 2020; 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 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.
- **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.[2]
- **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.

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[2] Although some STAs are included among CERP projects, the USACE has clarified its policy on federal cost sharing for water quality features. A memo from the Assistant Secretary of the Army (Civil Works) (USACE, 2007) states: “Before there can be a Federal interest to cost share a WQ [water quality] improvement feature, the State must be in compliance with WQ standards for the current use of the water to be affected and the work proposed must be deemed essential to the Everglades restoration effort.” The memo goes on to state, “[T]he Yellow Book specifically envisioned that the State would be responsible for meeting water quality standards.” However, the Secretary of the Army can recommend to Congress that project features deemed “essential to Everglades restoration” be cost shared. In such cases, the state is responsible for 100 percent of the costs to treat water to state standards for its current use, and federal cost sharing is determined based on the additional treatment needed to meet the requirements of Everglades restoration (K. Taplin, USACE, personal communication, 2018).

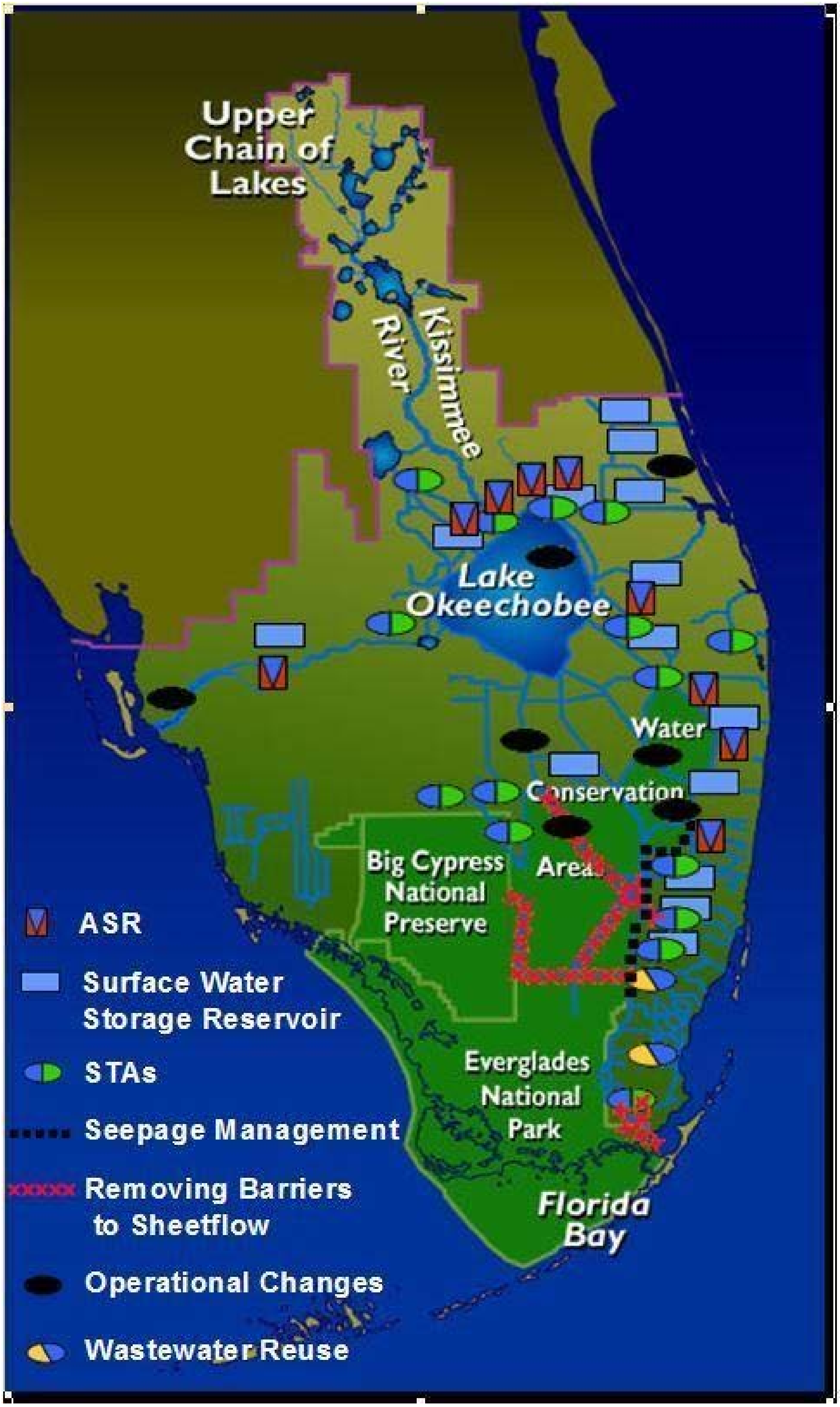

FIGURE 2-2 Major project components of the CERP as outlined in 1999.
SOURCE: Courtesy of Laura Mahoney, USACE.

- **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 and to acquiring the lands needed for them. Implementation progress and documented natural system responses are discussed in Chapter 3.

The modifications to the Central and Southern Florida Project embodied in the CERP were originally expected to take more than three decades to complete (and will likely now take much longer), and to be effective they require a clear strategy for managing and coordinating restoration efforts. The Everglades Programmatic Regulations (33 CFR §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), 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 §385).

WRDA 2000 endorses the use of an adaptive management framework for the restoration process, and the Programmatic Regulations (33 CFR §385.31[a]) 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; discussed further in Chapter 6) was established early in the development of the CERP 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.

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, which 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, C-111 South Dade, and state water quality treatment projects developed under the Everglades Construction Project (see Figure 2-3). Additional restoration efforts have also been

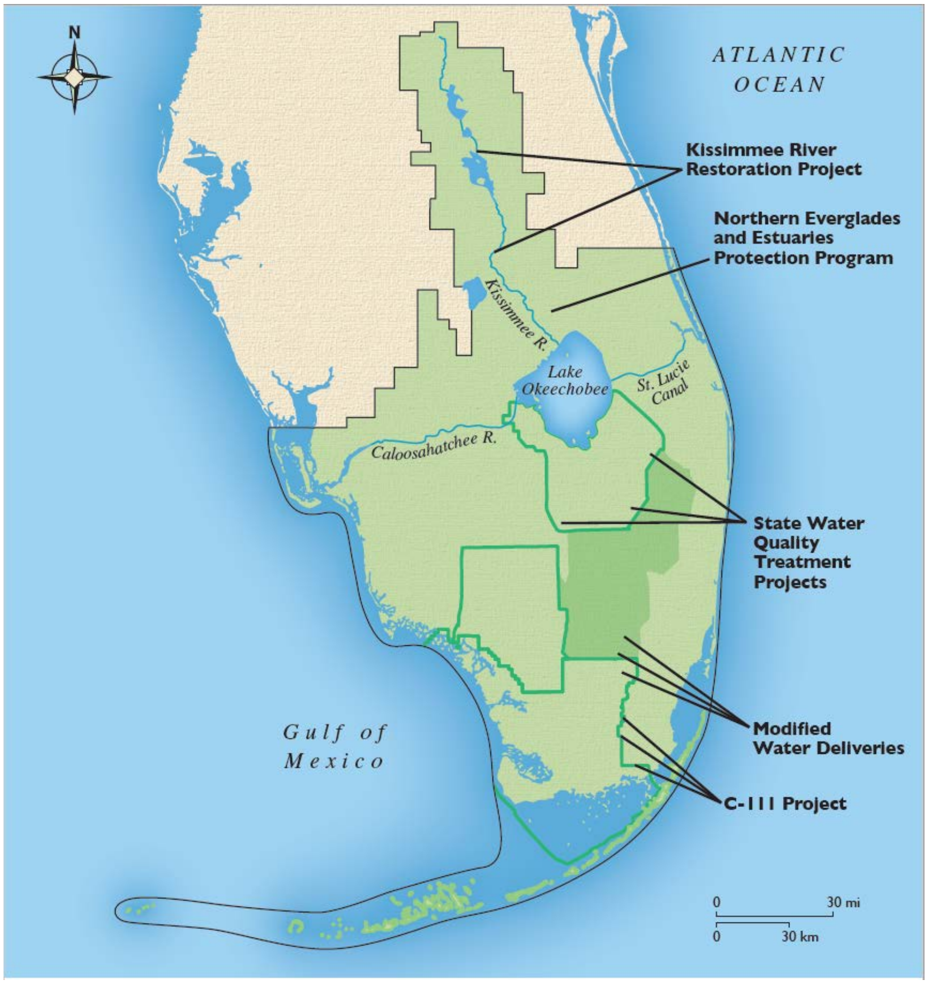

FIGURE 2-3 Locations of major non-CERP initiatives.
SOURCE: International Mapping Associates. Reprinted with permission; copyright 2021, International Mapping Associates.

launched outside of the CERP since that time, including state efforts to improve the quality of water flowing into the remnant Everglades under the Restoration Strategies program (see Chapter 4). Recent progress on key non-CERP projects with critical linkages to the CERP are described in Chapters 3 and 4.

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 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 regulation schedule was implemented to reduce high-water impacts on the lake's littoral zone and 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. The 2008 changes to the regulation schedule resulted in a loss of 564,000 AF of potential storage from the regional system (see NASEM, 2016). With the pending completion of the Herbert Hoover Dike rehabilitation efforts and several CERP projects, a revised Lake Okeechobee regulation schedule has been developed and is being finalized as of late 2022 (see Chapter 3).

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 (Fla. Stat. §403.086[9]), representing approximately 180 million gallons per day (MGD) of new water supply for the Lower East Coast. As of 2018, South Florida utilities achieved 9.8 MGD in potable water use offsets through additional water reuse under this mandate, although Miami Dade County, the largest discharger, stated that "it cannot technically, environmentally, and economically meet the statutorily required reuse" (FDEP, 2020).[3] It remains unclear whether or how these initiatives and mandates will affect the expectations for agricultural and urban water supply from the CERP, particularly because the capture of excess surface water is a key element of the CERP.

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 (EPA, 2010). 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 constructing approximately 6,500 acres of new STAs and three flow equalization basins (116,000 AF; see Chapter 4). These water quality treatment improvements are designed so that water leaving the STAs will meet a new water quality–based effluent limit (WQBEL) to comply with the 10 parts per billion (ppb) total phosphorus water quality criterion for the Everglades Protection Area (see Chapter 4).[4]

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[3] Miami Dade County is proceeding with a plan to reuse up to 15 MGD wastewater for use at the Turkey Creek nuclear plant (FLP, 2021), although this total is less than originally envisioned.

[4] The WQBEL is a numeric discharge limit used to regulate permitted discharges from the STAs so as to not exceed a long-term geometric mean of 10 ppb within the Everglades Protection Area. This numeric value is now translated into a flow-weighted mean (FWM) total phosphorus (TP) concentration and applied to each STA discharge point, which now must meet the following: (1) the STAs are in compliance with WQBEL when the TP concentration of STA discharge point does not exceed an annual FWM of 13 ppb in more than 3 out of 5 years, and (2) annual FWM of 19 ppb in any water year (EPA, 2010; FDEP, 2017).

Changing Understanding of Restoration Challenges

Much new knowledge has been gained since the launch of the CERP that enhances understanding of restoration challenges and opportunities and informs future restoration planning and management. Of the many advances in knowledge since 1999, climate change and sea-level rise are among the most significant. As outlined in NASEM (2016), 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 sizable 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 recent CISRERP reports (NASEM, 2016, 2018; NRC, 2014) have recommended greater consideration of climate change and sea-level rise in CERP project and program planning.

Since the CERP was developed, the significance of invasive species management for the success of restoration has also been recognized by the Task Force and its member agencies.[5] Nonnative species constitute a substantial proportion of the current biota of the Everglades. The approximately 250 non-native plant species comprise about 16 percent of the regional flora (see NRC, 2014). South 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 therefore 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.

SUMMARY

The Everglades ecosystem is one of the world’s ecological treasures, but for more than a century the installation of an extensive water management infrastructure has changed the geography of South Florida and has 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 legal context for the CERP and other major Everglades restoration efforts has evolved and the scientific understanding of Everglades restoration and its current and future stressors has expanded, and the programs continue to adapt. Implementation progress is discussed in detail in Chapter 3.

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

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 (NASEM, 2016, 2018, 2021; NRC, 2007, 2008, 2010, 2012, 2014). The committee also discusses programmatic and implementation progress and 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, funding, and project scheduling.

Project Authorization

Once project planning is complete, CERP projects with costs exceeding $25 million must be individually authorized by Congress before they can receive federal appropriations. Water Resources Development Acts (WRDAs) have served as the mechanism to congressionally authorize U.S. Army Corps of Engineers (USACE) projects. In the 20 years since the CERP was launched in WRDA 2000, five WRDA bills have been enacted:

- WRDA 2007 (Public Law 110-114), which authorized Indian River Lagoon (IRL)-South, Picayune Strand Restoration, and the Site 1 Impoundment projects;
- Water Resources Reform and Development Act (WRRDA) 2014 (Public Law 113-121), which authorized four additional projects (C-43 Reservoir, C-111 Spreader Canal [Western], Biscayne Bay Coastal Wetlands [Phase 1], and Broward County Water Preserve Areas [WPAs]);
- WRDA 2016 (Title I of the Water Infrastructure Improvements for the Nation Act [WIIN Act]; Public Law 114-322), which includes authorization for the $1.9 billion Central Everglades Planning Project (CEPP). WRDA 2016 also authorized changes to the Picayune Strand Restoration Project related to cost escalations to allow for its completion;

- WRDA 2018 (Public Law 115-270), which authorized the CEPP postauthorization change report, included the 240,000 acre-foot (AF) Everglades Agricultural Area (EAA) Storage Reservoir; and
- WRDA 2020 (Public Law 116-260), which authorized the Loxahatchee Watershed Restoration Project and combined the EAA Storage Reservoir and CEPP into a single project.

Authorized CERP projects are sometimes classified by the WRDA bills in which they were authorized—Generation 1 (WRDA 2007), 2 (WRDA 2014), 3 (WRDA 2016 and 2018), and 4 (WRDA 2020), with the Melaleuca Eradication Project, which was authorized under programmatic authority, included in Generation 1. The occurrence of WRDAs every 2 years (since 2014) has ensured that the authorization process does not delay CERP restoration progress.

Funding

Changes in funding can illuminate progress or programmatic constraints on implementation. These are exciting times for Everglades restoration as record federal and state funding during the past 2 years has fueled restoration construction across the Greater Everglades. The history of federal funding for the CERP is illustrated in Figure 3-1, which includes funds for construction and support for planning, design, coordination, and monitoring. Federal funding in fiscal year (FY) 2022 totaled $1.458 billion, buoyed by $1.1 billion from the Infrastructure Investment and Jobs Act (IIJA) of November 2021. An additional $358 million of federal funds was appropriated in FY 2022, and $408 million has been requested in FY 2023, both of which easily eclipse the previous record of $257 million in FY 2021. Over the most recent 5-year period, FY 2018-2022, federal funding for Everglades restoration (including both CERP and non-CERP efforts) averaged $537 million per year, with $434 million for CERP (over twice the rate of funding envisioned in CERP feasibility study (USACE and SFWMD,1999; also called the Yellow Book) and $103 million for non-CERP efforts (Figure 3-2).

The $1.1 billion of CERP funding provided by the IIJA is to

- initiate and fully fund construction of the Broward County Water Preserve Area C-11 Impoundment feature, which must be sequenced before certain CEPP features;[7]
- initiate and fully fund construction of the Indian River Lagoon (IRL) South C-23/24 North Reservoir feature;
- initiate and fully fund construction of Central Everglades Planning Project South S-356 Pump Station feature; and
- complete the project implementation reports for Biscayne Bay & Southeastern Everglades Ecosystem Restoration and Western Everglades Restoration Project.

This infrastructure funding promises to accelerate what was already been a record level of CERP construction. Other major federal CERP construction activities for FY 2022 and FY 2023 include

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[7] This section was altered after pre-publication release of the report to clarify the CEPP sequencing requirements.

completing the IRL-South C-44 Reservoir operational testing and monitoring; continuing construction of the Biscayne Bay Coastal Wetlands (BBCW) L-31 East Flow-way features; construction of CEPP features, including the EAA Reservoir and CEPP South S-355W Gated Spillway; and construction of the Picayune Strand southwest protection features (SFERTF, 2022). See Table 3-1 for a summary of projects under construction as of August 2022.

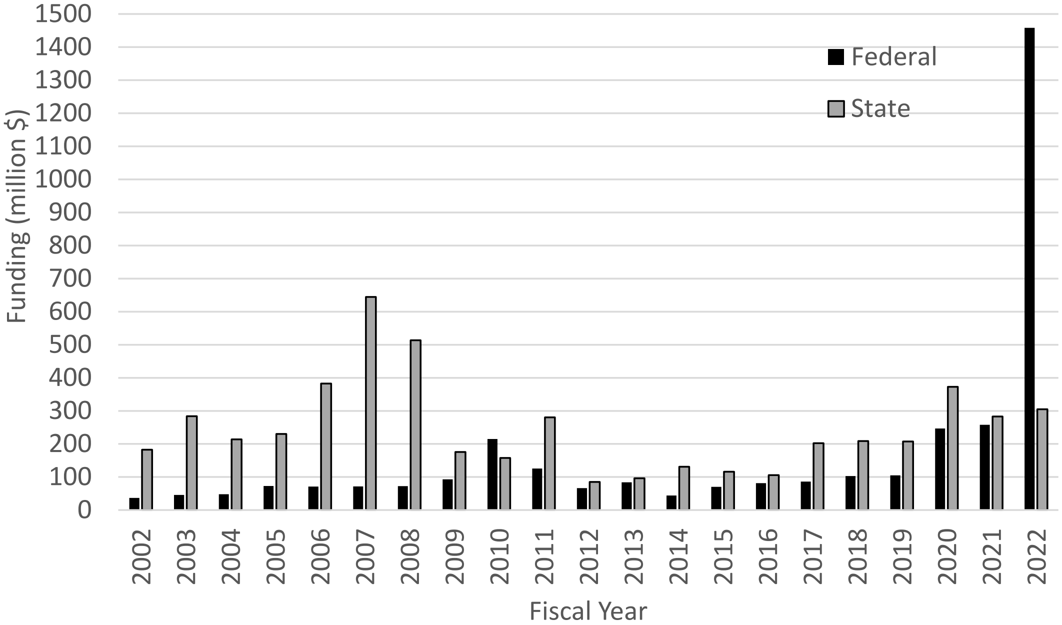

FIGURE 3-1 Federal and state funding for the CERP.
SOURCE: Data from SFERTF, 2022.

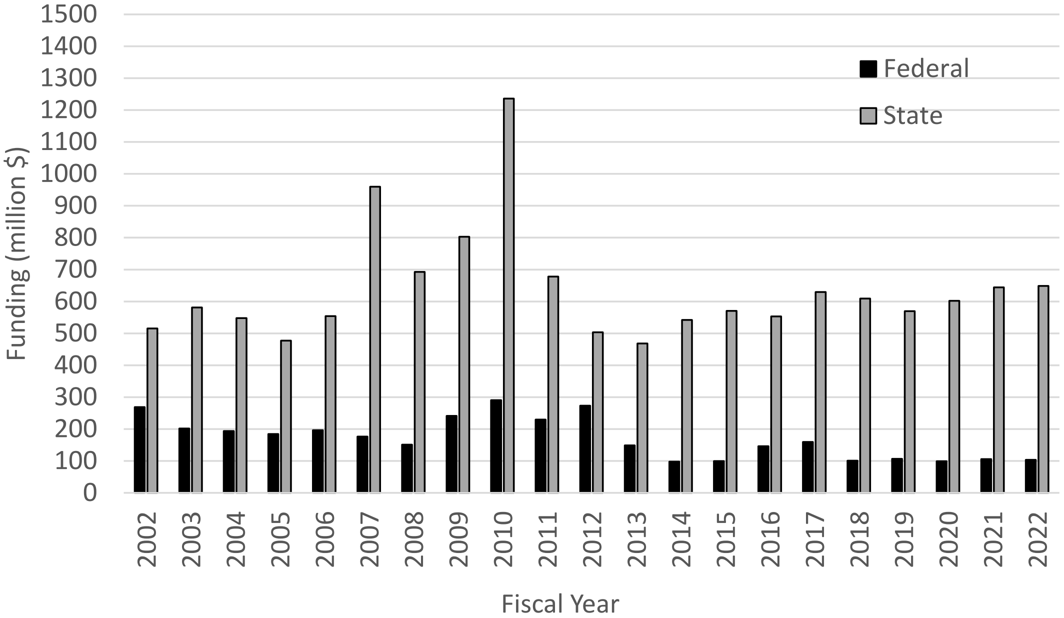

FIGURE 3-2 Federal and state funding for non-CERP restoration projects.
SOURCE: Data from SFERTF, 2022.

State CERP funding reached $305 million in FY 2022 and has exceeded the $200 million per year envisioned in the Yellow Book in each of the past 6 fiscal years. In addition, state CERP funding over the past 6 fiscal years (FY 2017 to FY 2022) was more than double that in the previous 5 fiscal years (FY 2012 to FY 2016; Figure 3-1). State non-CERP funding totaled $649 million in FY 2022 and averaged $615 million over the past 5 fiscal years (Figure 3-2). Total state restoration funding (CERP and non-CERP) has exceeded $775 million per year since FY 2017. The state has requested record FY 2023 funding for CERP of $748 million and for non-CERP of $1.8 billion. Both amounts would eclipse the previous records for state funding of $645 million for CERP set in FY2007 and $1.2 billion for non-CERP in 2010. State CERP funding is focused on several CERP projects including the C-43 West Basin Storage Reservoir; BBCW; the CEPP EAA Reservoir and associated projects; IRL-South; Loxahatchee River Watershed Restoration; and the Lake Okeechobee Watershed Restoration Project (SFERTF, 2022). These record levels of both state and federal funding over the past 4 fiscal years have greatly accelerated construction progress compared to earlier years, accelerating progress on restoration and potentially mitigating ongoing ecosystem degradation (NRC, 2012).

Project Scheduling and Prioritization

The anticipated future progress of CERP projects and the relationships among all the federally funded South Florida ecosystem restoration projects and some highly relevant, state-funded projects are depicted in the Integrated Delivery Schedule (IDS). The IDS is not an action or decision document but rather a communication tool across agencies that provides information to decision makers to guide planning, design, construction sequencing, and budgeting. The schedule is developed by the USACE and the South Florida Water Management District (SFWMD) in consultation with the Department of the Interior, the South Florida Ecosystem Restoration Task Force, and the many CERP constituencies. The IDS replaced the Master Implementation Sequencing Plan, initially developed for the CERP, as required by the Programmatic Regulations (33 CFR §385.31).

The IDS remains a useful tool for CERP project planning, sequencing, budgeting, design, and construction and for communicating internally, across the agencies, and with the public. Updated versions of the IDS were released in October 2020 (USACE, 2020a) and October 2021 (USACE, 2021a). The 2021 IDS provides an updated forecasted project planning, design, and construction schedule for the next 10 years (through 2032). Several projects or project components were removed that have been completed since the 2019 IDS (e.g., Modified Water Deliveries to Everglades National Park, CERP Picayune Strand Faka Union and Miller Pump Stations) and other projects or project components were moved from construction to operations (e.g., Kissimmee River Restoration, IRL-South C-44 Reservoir and STA). Loxahatchee River Watershed Restoration Project was added to the schedule after being authorized in WRDA 2020. In response to feedback that the 2019 IDS did not present a complete picture of the restoration because it did not acknowledge components not included in the IDS, two changes have been made. First, a new “Pending” row has been added at the end of the IDS to account for all of the remaining components from the original 68 Yellow Book projects that have not been otherwise included in the IDS. Second, a table was added to the second page with a component-by-component accounting and associated map indicating the status of all of the original 68 projects by category. These additions help to put the progress highlighted in the IDS into context of the full restoration vision.

TABLE 3-1 CERP Project Implementation Status as of August 2022

Project or Component Name	**Yellow Book (1999) Estimated Completion**	**IDS 2021 Estimated Completion**	**Project Implementation Report Status**	**Authorization Status**	**Construction Status**
GENERATION 1 CERP PROJECTS					
Picayune Strand Restoration (Fig. 3-3, No. 1)	2005	2025	Submitted to Congress, 2005	Authorized in WRDA 2007	Ongoing
Site 1 Impoundment (Fig. 3-3, No. 2)	2007		Submitted to Congress, 2006	Authorized in WRDA 2007	
- Phase 1		Completed			Completed, 2016
- Phase 2		Not specified		Requires authorization	Project on hold
Indian River Lagoon-South (Fig. 3-3, No. 3 and 4)			Submitted to Congress, 2004	Authorized in WRDA 2007	
- C-44 Reservoir/STA (Fig. 3-3, No. 3)	2007	2021			Completed, 2021
- C-23/C-24 North and South Reservoirs/STA (Fig. 3-3, No. 4)	2010	2030			Ongoing
- C-25 Reservoir/STA (Fig. 3-3, No. 4)	2010	2028			Not begun
- Natural Lands	NA	Not specified			Not begun
Melaleuca Eradication and Other Exotic Plants (Fig. 3-3, No. 5)	2011	NA	Final June 2010	Prog. authority WRDA 2000	Completed 2013, operations ongoing
GENERATION 2 CERP PROJECTS					
C-111 Spreader Canal (Western) Project (Fig. 3-3, No. 6)	2008	Final component not specified	Submitted to Congress, 2012	Authorized in WRRDA 2014	Mostly completed in 2012; S-198 construction on hold
Biscayne Bay Coastal Wetlands (Phase 1) (Fig. 3-3, No. 7)	2018	2025	Submitted to Congress, 2012	Authorized in WRRDA 2014	Ongoing
C-43 Basin Storage: West Basin Storage Reservoir (Fig. 3-3, No. 8)	2012	2024	Submitted to Congress, 2011	Authorized in WRRDA 2014	Ongoing
Broward County WPAs (Fig. 3-3, No. 9)			Submitted to Congress, 2012	Authorized in WRRDA 2014	
- C-9 Impoundment	2007	2030			Not begun
- C-11 Impoundment	2008	2028			Not begun
- WCA-3A & -3B Levee Seepage Management	2008	2027			Not begun
GENERATION 3 CERP PROJECTS					
Central Everglades Planning Project (CEPP) North (Fig. 3-3, No. 10)	NA	2026	Submitted to Congress, 2015	Authorized in WRDA 2016	Not begun (1st contract award Nov. 2022)
CEPP South (Fig. 3-3, No. 11)	NA	2029			Ongoing
CEPP New Water (Fig. 3-3, No. 13)	NA	2026			Not begun (1st contract award Aug. 2022)
CEPP EAA (Fig. 3-3, No. 12)	NA		Submitted to Congress, 2018	Authorized in WRDA 2018, 2020	Ongoing
- EAA Reservoir and Pump Station		2029			
- EAA A-2 STA		2023			

GENERATION 4 CERP PROJECTS					
Loxahatchee River Watershed (Fig. 3-3, No. 14)	2013	2029	Submitted to Congress, 2020	Authorized in WRDA 2020	Not begun
CERP PROJECTS IN PLANNING					
Lake Okeechobee Watershed (Fig. 3-3, No. 15)	2009-2020	NA	Third revised draft, Jun. 2022	Requires authorization	NA
Western Everglades (Fig. 3-3, No.16)	2008-2016	NA	In development	Expected 2024	NA
Biscayne Bay Southeastern Everglades Ecosystem (Figure 3-3, No.17)	2008-2020	NA	In development	Expected 2026	NA

NOTES: Table 3-1 does not include non-CERP foundation projects. NA = not applicable. The table was modified after release of the pre-publication version of the report to include all relevant recent contract award dates.
SOURCES: Data from NASEM, 2021; Parrott, 2022a; SFERTF, 2021; USACE, 2021a; Vélez, 2022a.

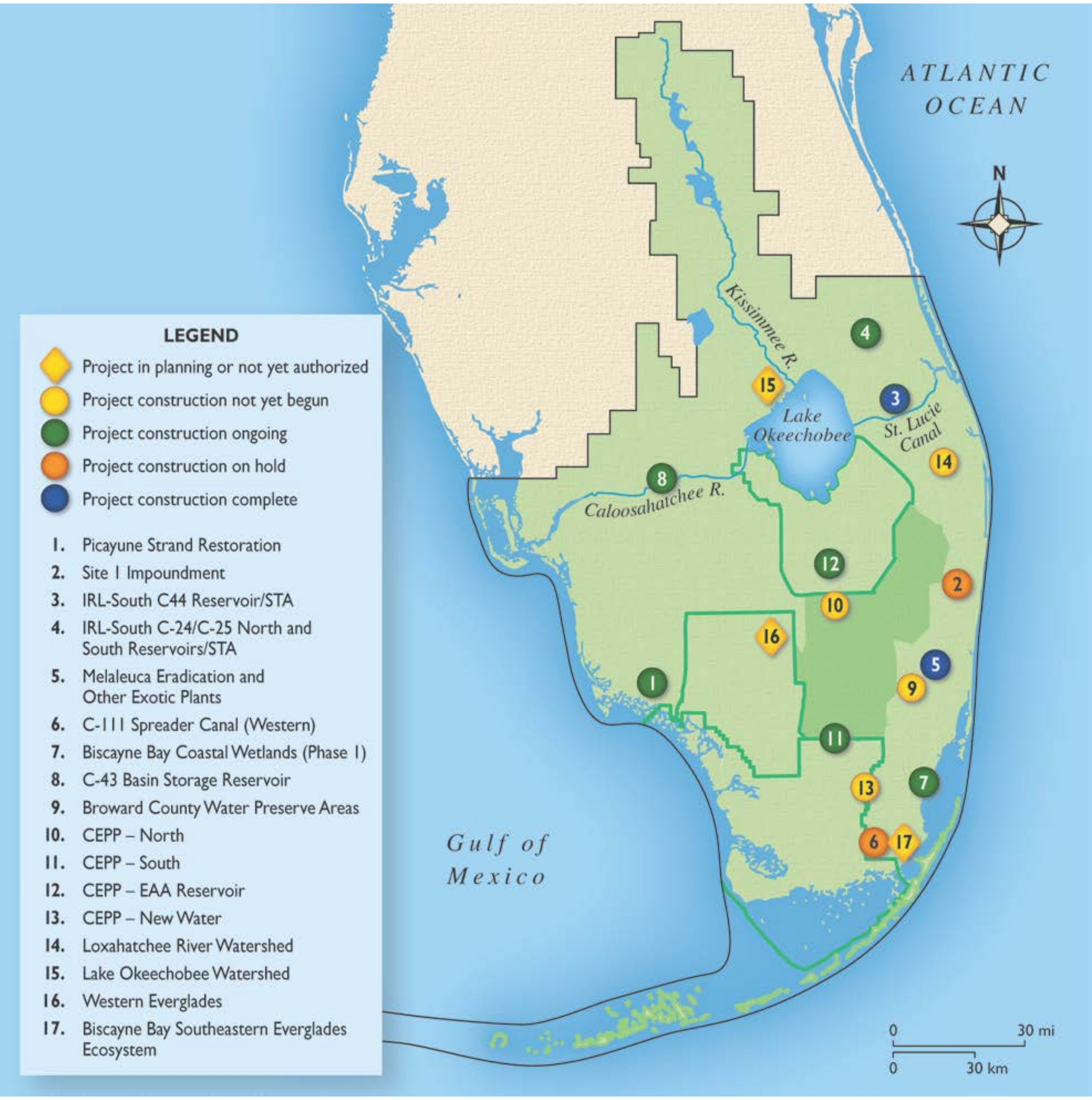

FIGURE 3-3 Locations and status of CERP projects and pilot projects.
SOURCE: Reprinted with permission; copyright 2021, International Mapping Associates.

The addition of a schedule for the development of new regional System Operating Manual reflects the ongoing pivot from an almost exclusive focus on integrated project planning and construction scheduling toward an increasing focus on refining the operation of the system (in concert with ongoing planning and construction). The new System Operating Manual, which is referred to as the "critical last step in getting the water right and achieving maximum system-wide benefits" (USACE, 2021a), will replace the existing Central and South Florida Project Water Control Manuals that were developed in the 1990s. The System Operating Manual will include updated water control plans for each region along with nested CERP Project Operating

Manuals (POMs) for all CERP projects within the region. The System Operating Manual update schedule in the 2021 IDS reflects the integration of project operations for 28 CERP and non-CERP projects (or project components) at various stages of planning (draft POM), detailed design and construction (preliminary POM), and operational testing and monitoring (final POM). The intent is to ensure that managers are well positioned to realize the optimal benefits from the CERP projects as soon as is feasible while meeting all of the system constraints. This important and welcome step in the evolution of the CERP promises to facilitate the realization of interim CERP benefits and the opportunity to learn from adaptive management.

TABLE 3-2 CERP Projects or Components That Have Not Been Addressed in Prior or Ongoing CERP Planning Initiatives as of August 2022

Project or Component Name	Estimated Financial Requirement	Status
PENDING CERP PLANNING EFFORTS		
Southern Everglades: Includes - WCA 3 Decompartmentalization (QQ Phase 2, ZZ) - ENP Seepage Management (BB, U) - Broward Co. Secondary Canal System (CC) - Central Lake Belt Storage Area (S, EEE) - WCA-2B Flows to Everglades National Park (YY) - Lake Okeechobee Aquifer Storage and Recovery (GG)	Not available until project planning completed	Planning process anticipated 2023-2027
PENDING MAJOR UNPLANNED CERP COMPONENTS		
C-43 Basin ASR (D Phase 2)	$439,000,000	Not yet begun
L-8 Basin ASR (K Part 2) and **C-51 Regional Groundwater ASR (LL)**	$370,000,000	Not yet begun
Site 1 Impoundment ASR (M Phase 2)	$223,000,000	Inactive after Hillsboro ASR Pilot
Palm Beach Agricultural Reserve Reservoir and ASR (VV)	$200,000,000	Not yet begun
Caloosahatchee Backpumping with Stormwater Treatment (DDD)	$135,000,000	Not yet begun
Southern CREW (OPE)	$79,000,000	Not yet begun; Portions of this project are currently being pursued under a different program
Florida Keys Tidal Restoration (OPE)	$23,000,000	Suspended
A.R.M. Loxahatchee National Wildlife Refuge Internal Canal Structures (KK)	$15,000,000	On hold
Henderson Creek – Belle Meade Restoration (OPE)	$11,000,000	On hold
Comprehensive Integrated Water Quality Plan (CIWQP)	$8,000,000	On hold
Florida Bay Florida Keys Feasibility Study (FBFKFS)	$6,000,000	Suspended in 2009. The project is planned for the future

NOTES: Remaining unplanned CERP projects include all projects more than $5 million (2014 dollars) as reported in USACE and DOI (2016), for which the components have not been incorporated in other planning efforts or formally removed from the CERP. Letters in parentheses represent project component code from Yellow Book. Estimated financial requirement derived from SFERTF (2021) and rounded to nearest million. The table was modified after release of the pre-publication version of the report to make a correction to the list of program components.

SOURCE: Data from SFERTF, 2021; USACE, 2021a.

NATURAL SYSTEM RESTORATION PROGRESS

In the following sections, the committee focuses on recent information on natural system restoration benefits emerging from the implementation of CERP and major non-CERP projects. The implementation status of CERP projects is shown in Table 3-1, with pending unplanned projects in Table 3-2. The discussions of progress that follow are organized based on geography and describe CERP projects, CERP projects in planning, and systemwide operational plans for

- northern estuaries and Lake Okeechobee,
- central and western Everglades, and
- southern estuaries.

The findings and conclusions are based on reported monitoring data to date for CERP projects for which construction has begun, with emphasis on progress and new information gained during the past 2 years. The committee's previous report (NASEM, 2021) contains additional descriptions of the projects and progress through mid-2020. The South Florida Environmental Report (SFWMD, 2022) and the 2021 Integrated Financial Plan (SFERTF, 2021) also provide detailed information about implementation and restoration progress.

Northern Estuaries and Lake Okeechobee

Substantial work is under way in the northern Everglades and Lake Okeechobee to effect restoration progress. This work includes two CERP projects in progress, one CERP project in planning, and development of a new regulation schedule for Lake Okeechobee.

CERP Projects in Progress

Two CERP projects under construction directly affect the northern estuaries: the C-43 Reservoir and IRL-South. A third project—the Loxahatchee River Watershed project—has been authorized but construction has not yet begun.

C-43 Reservoir. Early in the twentieth century, the course of the Caloosahatchee River was deepened and straightened, and canals were excavated in the river basin that connected the river to Lake Okeechobee and drained agricultural lands and urban areas. As a result, during prolonged dry periods, freshwater flow to the estuary is greatly reduced and saline water can migrate far up the river, killing beds of freshwater submerged plants. Conversely, during periods of heavy rainfall, large volumes of nutrient- and sediment-rich freshwater are transported into the Caloosahatchee River estuary, affecting habitat quality for seagrasses, oysters, and other aquatic organisms. The Caloosahatchee River (C-43) West Basin Storage Reservoir (Figure 3-3, No. 8) 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 (USACE and SFWMD, 2010), hence protecting the estuary from excessive freshwater. 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. Construction is under way, with completion anticipated in 2024

(Parrott, 2022b). Therefore, it is too soon to realize natural system benefits from this project.

The Florida Department of Environmental Protection and the SFWMD are also implementing additional water quality treatment for the C-43 Reservoir, outside of the CERP, because elevated nutrient levels in the stored water could support the growth of algae in the reservoir and seed harmful algal blooms in the Caloosahatchee Estuary. Based on a feasibility study of alternatives (J-Tech, 2020), the SFWMD is planning to implement an in-reservoir alum treatment system, which is expected to be operational by 2024, concurrent with initial operations of the C-43 Reservoir (Parrott, 2022c).

Indian River Lagoon-South. The Indian River Lagoon and the St. Lucie Estuary are biologically diverse estuaries located on the east side of the Florida Peninsula, where ecosystems have been impacted by factors similar to those that have impacted the Caloosahatchee River Estuary—surges of freshwater from Lake Okeechobee and canals in the watershed and polluted runoff from farmlands and urban areas (USACE, 2021b). The IRL-South Project (Figure 3-3, No. 3 and 4) is designed to reverse this damage through improved water management, including the 50,600-AF C-44 storage reservoir, three additional reservoirs (C-23/C-24 South, C-23/C-24 North, and C-25) with a total of 97,000 AF of storage, three new STAs (C-44, C-23/24, C-25), dredging of the St. Lucie River to remove 7.9 million cubic yards of muck, and restoration of 53,000 acres of wetlands. The project also involves the restoration of nearly 900 acres of oyster habitats and the creation of 90 acres of artificial habitat for oysters and submerged aquatic vegetation (USACE, 2021b). Construction was completed on the C-44 STA and C-44 reservoir in January and September 2021, respectively (Figure 3-4; Parrott, 2022b). The reservoir filling was initiated in January 2022, and operational testing is ongoing as of September 2022.

FIGURE 3-4 The IRL-South C-44 reservoir.
SOURCE: SFWMD. https://www.flickr.com/photos/sfwmd/albums/72157720138719111.

Construction of the C-23/24 STA began in February 2022, and construction of the C23/C-24 North Reservoir is anticipated to begin in 2023. Because newly completed features remain in the early stages of operational testing, there is no natural system restoration progress to report.

Loxahatchee River Watershed. Alterations of the Loxahatchee River system and watershed over the past century, including dredging, channelization, and drainage, have substantially altered flows in the watershed and have reduced natural water storage of excess waters, resulting in periods of either excessive or limited flows to the Loxahatchee River Estuary. The resulting changes in natural land cover, including up-river migration of mangrove and the displacement of cypress, raised concern, especially in the area designated as a Wild and Scenic River (FDEP, 2010).

The Loxahatchee River Watershed Restoration Project (Figure 3-3, No. 14), authorized in WRDA 2020, seeks to capture, store, and redistribute freshwater currently lost to tide, rehydrate natural areas in the headwaters, reduce peak discharges to the estuary, and improve the resilience of estuarine habitats by altering the timing and distribution of water from upstream. Planned components of the project include wetland restoration and hydrologic improvements within the watershed, a single 9,500-AF reservoir, four aquifer storage and recovery (ASR) wells, and several structures related to connectivity in the southern part of the watershed. Together the project components are expected to deliver 98 percent of the wet season restoration flow target and 91 percent of the dry season restoration flow target in the Northwest Fork of the Loxahatchee River (USACE and SFWMD, 2020a). In turn, these flows are expected to limit saltwater penetration in the estuary, conserve the remaining cypress, and promote the recovery of freshwater vegetation (e.g., *Vallisneria*) and other habitats important for estuarine species such as manatee and oysters. Construction has not yet begun, so there is no natural system restoration progress to report.

CERP Projects in Planning

Lake Okeechobee Watershed Restoration Project. Located north of the lake, the Lake Okeechobee Watershed Restoration Project (LOWRP) was designed to capture, store, and redistribute water entering the northern part of Lake Okeechobee. The goals of the LOWRP are to "improve lake stage levels, improve discharges to the Caloosahatchee and St. Lucie estuaries, restore/create wetland habitats, re-establish connections among natural areas that have become spatially and/or hydrologically fragmented, and increase available water supply" (USACE, 2022a).

The LOWRP project implementation report and environmental impact statement (PIR/EIS) was released in August 2020 (USACE and SFWMD, 2020b). It recommended a plan called Alternative 1BWR (Alt-1BWR) with the following key components:

- a shallow aboveground, naturally vegetated water storage reservoir (termed, wetland attenuation feature) with a storage volume of approximately 46,000 AF;
- 80 ASR wells with a total storage volume of approximately 448,000 AF per year; and
- two wetland restoration sites, encompassing 4,800 acres.

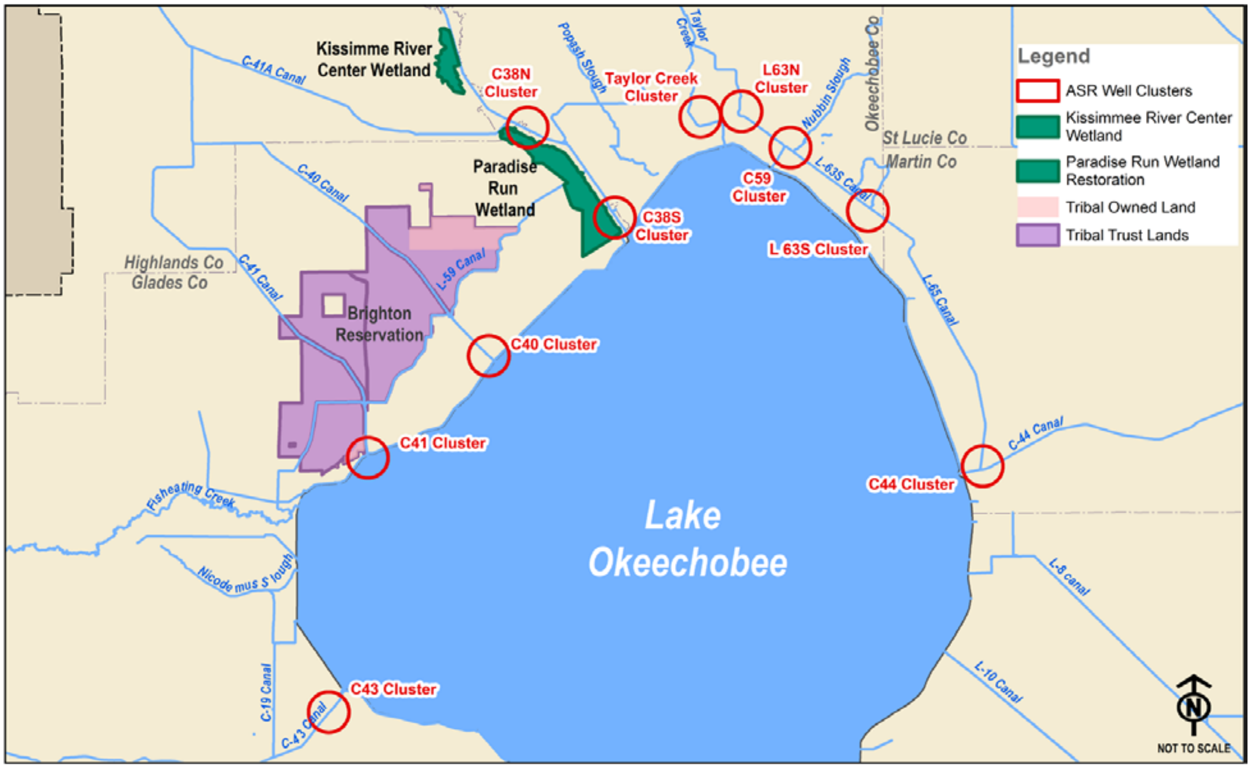

FIGURE 3-5 Features of the tentatively selected plan, Alt-ASR, showing the locations of the 10 ASR well clusters.
SOURCE: USACE, 2021e.

After the release of the PIR/EIS, the USACE determined that a revision of the recommended plan was required to address stakeholder concerns. A principal concern stemmed from the potential impacts of above-ground storage features on flooding, cultural resources, and threatened and endangered species of the Brighton Reservation. Concerns were also raised about the possible effects of the LOWRP on water supply, the scale of ASR, and the cost of Alt-1BWR. In response to these issues, the USACE developed a revised recommended plan, named Alternative ASR (Alt-ASR), which it released in February 2022 for review and public comment (USACE and SFWMD, 2022).

Alt-ASR (Figure 3-5) eliminates the shallow-water retention feature and reduces the number of ASR wells. It consists of 55 ASR wells with a maximum dynamic storage volume of 308,000 AF per year, as well as two wetland restoration sites that cover 4,700 acres (Paradise Run) and 1,200 acres (Kissimmee River-Center). Recreational facilities built within the wetland sites will improve public boat access to increase fishing and wildlife-viewing opportunities. The projected cost of Alt-ASR is $1.22 billion—about $800 million less than Alt-1BWR. Nearly two-thirds of the total cost is associated with ASR well construction (USACE and SFWMD, 2022).

The LOWRP is projected to provide a much smaller increment of additional storage north of Lake Okeechobee relative to that originally envisioned under the CERP (200 ASR wells and 250,000 AF of surface storage) (USACE and SFWMD, 1999). Implementation of Alt-ASR is expected to reduce total flows to the St. Lucie Estuary by only 4 percent compared to a scenario representing the future without (FWO) the project , which includes already authorized projects (CEPP, IRL-South, and the C-43 Reservoir; USACE and SFWMD, 2022). Alt-ASR will have a greater effect on total flows to the Caloosahatchee Estuary, lowering them by 30 percent. Compared to the FWO scenario, Alt-ASR is forecast to reduce high flow and extreme high flow frequencies within the Caloosahatchee Estuary by 11 and 7 percent, respectively.[1] Similar reductions in high-flow frequency are anticipated for the St. Lucie Estuary.[2] By lowering the frequency, volume, and duration of freshwater released from Lake Okeechobee, the LOWRP should reduce turbidity, sedimentation, nutrients, and salinity fluctuations that are detrimental to submerged aquatic vegetation, oyster communities, and fish habitat of the northern estuaries.

The anticipated benefits of the LOWRP to Lake Okeechobee ecology appear to be limited. Although the percentage of time that Lake Okeechobee is expected to be within the ecologically preferred stage envelope is 29.1 percent under Alt-ASR compared to 27.7 percent for the FWO scenario, Alt-ASR increases the percentage of time above 15.5 feet and above 17 feet. A lake-weighted analysis of performance measures (considering lake stage envelope, an ecological indicator score, and extreme high and low lake stages) suggests that Alt-ASR does not perform as well as the FWO scenario (USACE and SFWMD, 2022).

The benefits of Alt-ASR were estimated from model simulations that invoke the current Lake Okeechobee Regulation Schedule (LORS 2008). Lake operations will change when LORS 2008 is replaced by the Lake Okeechobee System Operating Manual (LOSOM), which, in turn, will be superseded by another modification expected in 2029. Thus, the benefits described in the LOWRP PIR/EIS will likely differ from those observed in the future, when modified water-control plans for Lake Okeechobee are in place.

All water storage gained through implementation of Alt-ASR will be provided by 55 ASR wells, each with a pumping capacity of 5 million gallons per day. These wells will store and recover water from the Upper Floridan Aquifer and the Avon Park Permeable Zone and will be distributed in clusters located along various tributaries that drain into the lake (Figure 3-5). The ASR system planned for LOWRP will be larger than any of the 30 ASR systems currently operating in Florida.[3]

The NRC (2015) identified several critical uncertainties stemming from large-scale implementation that were not resolved in the ASR Regional Study (USACE and SFWMD, 2015), including ecotoxicological effects of recovered water, efficacy of disinfection treatments for injected waters, presence of arsenic and sulfate in recovered waters, and low recovery efficiencies of stored water. NRC (2015) recommended further field-scale research to address these outstanding issues, as well as phased implementation of ASR in clusters of 3-5 wells.

The uncertainties raised in the 2015 NRC report have not been addressed, although the Alt-ASR plan is responsive to the NRC recommendations for phased construction of some ASR wells with coordinated studies and monitoring. These studies are outlined in a companion document, the 2021 ASR Science Plan (SFWMD and USACE, 2021), which was developed explicitly for the purposes of informing phased ASR implementation for the LOWRP, with input from an independent peer review panel (Box 3-1). The ASR Science Plan provides a

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[1] High flow and extreme high flow criteria for the Caloosahatchee Estuary are defined as a mean-monthly discharge of 2,800 to 4,500 cubic feet per second (cfs) and >4,500 cfs, respectively (USACE and SFWMD, 2022).

[2] High flow and extreme high flow criteria for the St. Lucie Estuary are defined as a mean-monthly discharge of 2,000 to 3,000 cfs and >3,000 cfs, respectively (USACE and SFWMD, 2022).

[3] See https://www.sfwmd.gov/our-work/alternative-water-supply/asr.

BOX 3-1
Aquifer Storage and Recovery Peer Review Panel

A peer review panel was formed to support the development of the Aquifer Storage and Recovery (ASR) Science Plan, which was prepared by the South Florida Water Management District (SFWMD) and the U.S. Army Corps of Engineers (USACE) to address uncertainties in ASR implementation at the scale anticipated by the Lake Okeechobee Watershed Restoration Plan (LOWRP) (SFWMD and USACE, 2021). The panel, composed of independent scientists from academia and governmental agencies, began its work by providing guidance on how to address uncertainties in ASR that were identified through the NRC's review of the ASR Regional Study Final Technical Report (NRC, 2015; USACE and SFWMD, 2015). This guidance was incorporated into the initial ASR Science Plan (SFWMD and USACE, 2021). The ASR Science Plan is envisioned as a living document that will be routinely updated to reflect the most recent information and findings from a suite of technical investigations planned for the next 8 years. The peer review panel will continue to meet annually during implementation of the ASR program to evaluate progress of the scientific studies outlined in the working version of the ASR Science Plan and will provide recommendations for modifications of ongoing studies, additional investigations or analyses, and adjustments to sequencing of various components of the science plan.

comprehensive accounting of the numerous uncertainties identified in the 2015 NRC report and summarizes 26 studies involving geochemical measurements, hydrogeophysical characterization, laboratory experiments, and field testing on reactivated ASR wells and clusters of new ASR wells to be located along the northern perimeter of Lake Okeechobee. The studies described in the ASR Science Plan commenced in 2021 and are expected to be completed in 2030.

A USACE Chief's Report on LOWRP is still pending. CERP planners are working to resolve remaining concerns, including its high operation and maintenance costs and potential impacts of ASR to aquifers that serve as drinking water sources (G. Ralph, USACE, personal communication, 2022).

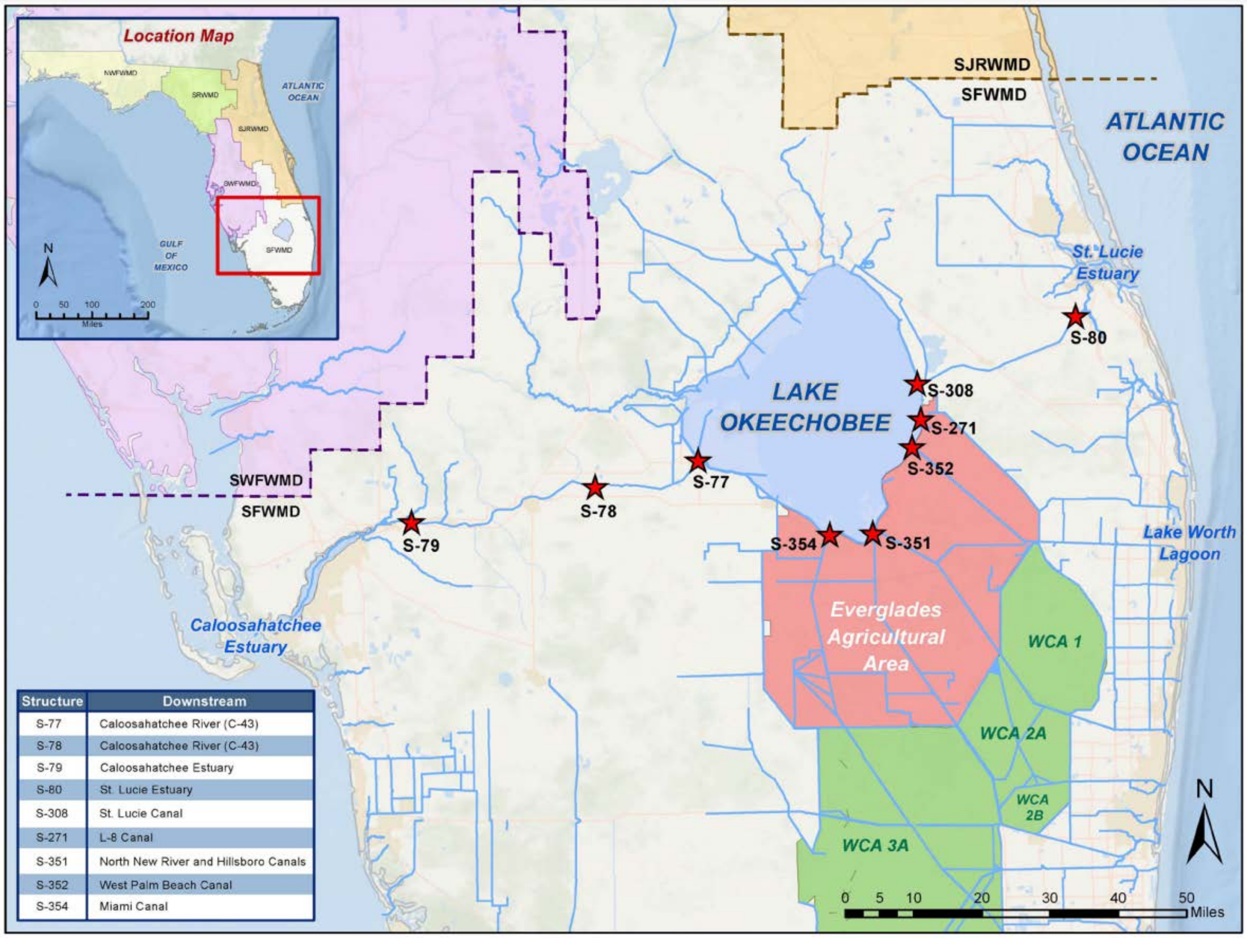
Systemwide Operational Plans: Lake Okeechobee System Operating Manual

Lake Okeechobee is the largest body of freshwater in the southeastern United States, with a surface area of 668 mi^2 (1,730 km^2). It is often referred to as the liquid heart of the Everglades. Up until the early 20th century, the lake was surrounded by a littoral marsh, allowing it to expand and contract depending on water surface elevation. When lake stages became high (estimated at ~20.6 feet National Geodetic Vertical Datum of 1929 [NGVD 29]), water spilled over a natural muck sill and moved as sheet flow directly into the Everglades (Steinman et al., 2002a).

In 1930, Congress authorized the Herbert Hoover Dike, which now encircles most of Lake Okeechobee with 143 miles of embankment, consisting of permeable material including sand, shells, gravel, and limestone; five inlets/outlets; nine navigation locks; and nine pump stations. All inflows and outflows except one (inflow from Fisheating Creek in the west) are regulated by water control structures. Water levels are controlled, in part, through a regulation schedule, which sets operational criteria for structures used to manage releases from Lake

Okeechobee (Figure 3-6). The regulation schedule aims to balance the competing demands for water in the region, including navigation, ecotourism, flood protection, habitat, and water supply.

The capacity of water to flow into the lake exceeds by a factor of six the capacity to flow out, and large rain events can result in a rapid increase in lake level (Kirk, 2018). In 2004, the USACE classified the Herbert Hoover Dike as Level 1 (i.e., highest risk) with regard to safety, and a major rehabilitation project has been under way since 2007 to improve its condition and to reduce seepage, piping, and the risk of dam failure at high water levels, which would cause massive damage and loss of life. The Herbert Hoover Dike Rehabilitation project included 28 culvert replacements and the construction of 56 miles of cutoff walls (seepage barriers within the dike) to reduce seepage and piping through the embankment and around the culverts. The rehabilitation project is scheduled for completion by December 2022, with an estimated cost of more than $1.8 billion in total (USACE, 2022c).[4]



Structure	Downstream
S-77	Caloosahatchee River (C-43)
S-78	Caloosahatchee River (C-43)
S-79	Caloosahatchee Estuary
S-80	St. Lucie Estuary
S-308	St. Lucie Canal
S-271	L-8 Canal
S-351	North New River and Hillsboro Canals
S-352	West Palm Beach Canal
S-354	Miami Canal

FIGURE 3-6 Structures used to release water from Lake Okeechobee.
SOURCE: USACE, 2022b.

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[4] See http://www.saj.usace.army.mil/Missions/Civil-Works/Lake-Okeechobee/Herbert-Hoover-Dike.

The development of the Lake Okeechobee System Operating Manual (LOSOM)[5] as an update to the operations regime for lake management was intended to coincide with the completion of the Herbert Hoover Dike rehabilitation, although LOSOM also considered new CERP features, including the C-43 and C-44 reservoirs. The overall goal of LOSOM is "to incorporate flexibility in Lake Okeechobee operations while balancing the congressionally authorized project purposes: flood control, water supply, navigation, enhancement of fish and wildlife, and recreation." Specifically, the four LOSOM objectives were to:

1. "Manage risk to public health and safety, life, and property" (with emphasis on dam safety and algal blooms in Lake Okeechobee and the Northern Estuaries);
2. "Continue to meet authorized purposes for navigation, recreation, and flood control;"
3. "Improve water supply performance" (with emphasis on water supply to the Lake Okeechobee Service Area, the Seminole Tribe of Florida, and the Lower East Coast Service Area); and
4. "Enhance ecology in Lake Okeechobee, Northern Estuaries, and across the South Florida ecosystem."

The USACE conducted a comprehensive evaluation of alternatives to develop LOSOM, in which thousands of alternative release scenarios were simulated, scored, and screened. A Multi-Criteria Decision Analysis tool was used in the process to communicate the performance of each alternative in a transparent manner based on multiple LOSOM objectives and subobjectives (Figure 3-7; see also USACE, 2022b for more detail). The selection of the preferred alternative, which was subsequently optimized, was based on agency expert and stakeholder feedback and the fact that "it performed relatively well for the majority of LOSOM sub-objectives." (USACE, 2022b) A draft EIS was issued in July 2022, and, if approved, the preferred alternative operating plan (Figure 3-8) will be implemented in 2023 upon completion of the Herbert Hoover Dike rehabilitation.

LOSOM replaces LORS 2008 (USACE, 2007), which was implemented primarily to reduce the risk of catastrophic failure of the Herbert Hoover Dike while rehabilitation efforts were implemented. LORS 2008 kept maximum lake levels about 1 foot lower than the Run 25 regulation schedule (USACE, 1994) under which the CERP was developed (Figure 3-9); Run 25 and the subsequent Water Supply/Environmental (WSE) regulation schedule (USACE, 1999) allowed lake levels to reach 18.5 feet NGVD, while LORS was designed to preclude levels above 17.25 feet and mostly kept lake levels under 16 feet NGVD.[6] This change to LORS resulted in the loss of between 460,000 and 800,000 AF of potential storage capacity from the regional system, depending on the time of year (NASEM, 2016), while providing positive benefits to lake ecology (USACE, 2007).

Under the LOSOM draft preferred alternative regulation schedule (Figure 3-7), LOSOM has a similar maximum and minimum lake level as LORS 2008. Thus, LOSOM has continued the LORS 2008 reduction in water storage, compared to the operations in place when the CERP was originally planned (Figure 3-8). The impacts of this reduced storage on achieving CERP goals remain unclear.

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[5] Authorized under Section 1106 of WRDA 2018.

[6] This text and the corresponding figure have been updated following release of the prepublication report to correct the regulation schedule in place for planning and the WSE implementation date.

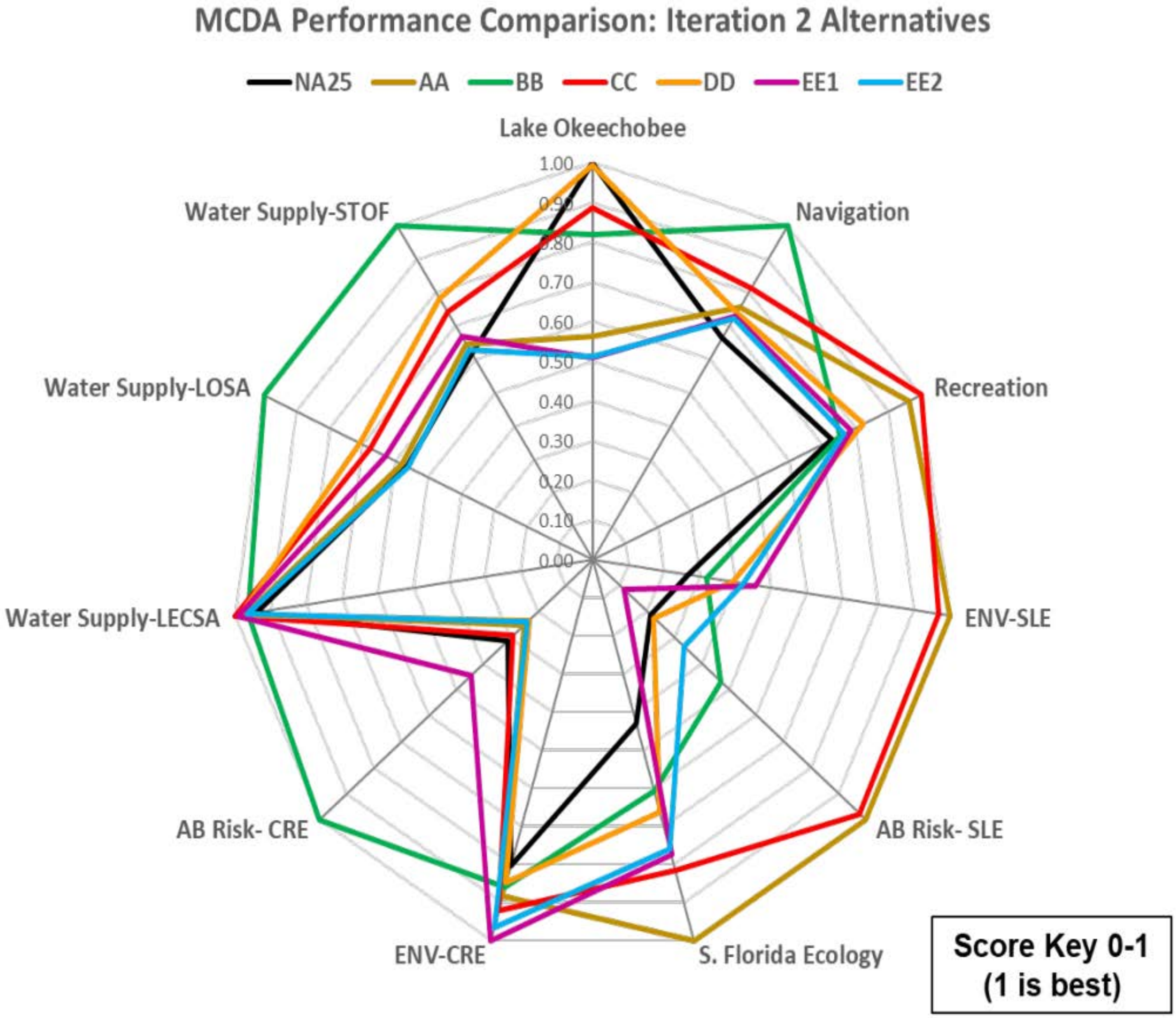
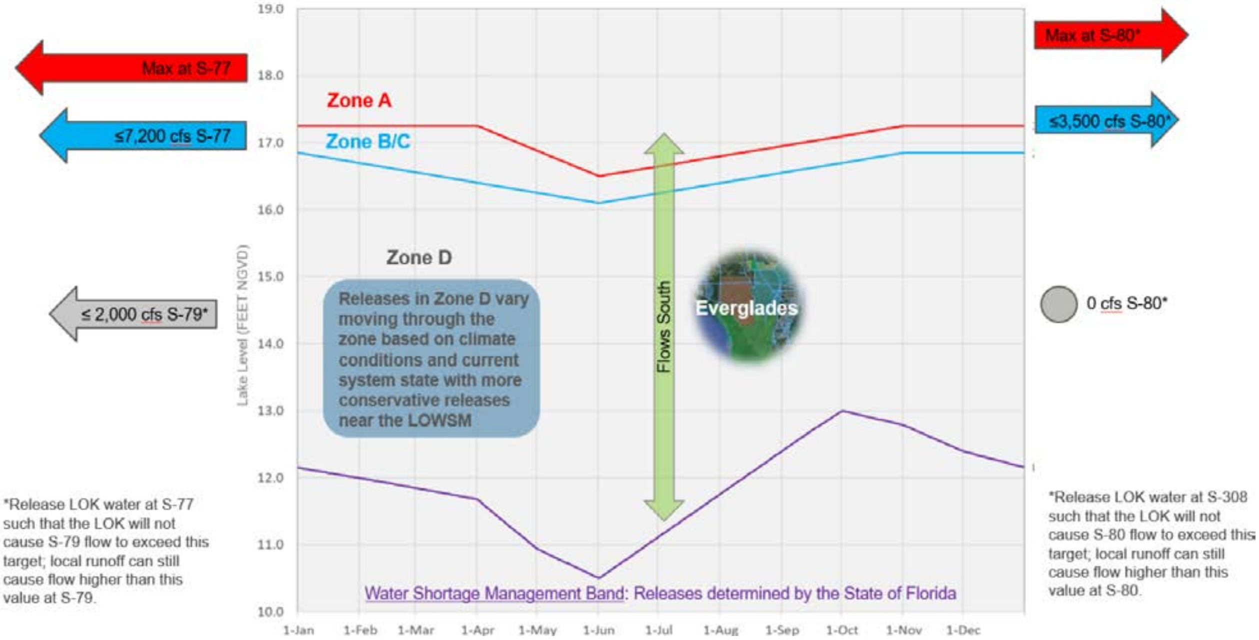


FIGURE 3-7 This multi-criteria decision analysis radar plot visualizes the relative performance of various alternatives against 11 criteria, based on the project objectives and sub-objectives. The performance for each objective (0-1) was determined based on metrics that were selected for their sensitivity and robustness for that objective, with weights assigned to key metrics when multiple metrics were used. In addition to the scored criteria depicted, alternatives were scored for dam safety and flood control ability on a pass/fail basis. Alternative CC was selected for further optimization based on its performance across a wide range of objectives.
NOTES: AB=algal bloom, CRE=Caloosahatchee River Estuary, ENV=environment, LECSA=Lower East Coast Service Area, LOSA=Lake Okeechobee Service Area, SLE=St. Lucie Estuary, STOF=Seminole Tribe of Florida.
SOURCE: USACE, 2022b.



*Release LOK water at S-77 such that the LOK will not cause S-79 flow to exceed this target; local runoff can still cause flow higher than this value at S-79.

*Release LOK water at S-308 such that the LOK will not cause S-80 flow to exceed this target; local runoff can still cause flow higher than this value at S-80.

FIGURE 3-8 The LOSOM preferred alternative water control plan. If lake level exceeds the red line bordering Zone A, water must be released to the northern estuaries at maximum discharge capacity. In Zone B/C, discharge levels are high but below maximum (≤7,200 cfs to the Caloosahatchee River Estuary and ≤3,500 cfs to the St. Lucie Estuary) to lower lake levels. Under Zone D, no water is discharged to the St. Lucie Estuary and up to 2,000 cfs may be discharged to the Caloosahatchee River Estuary.
NOTES: LOWSM=Lake Okeechobee Water Shortage Management; LOK=Lake Okeechobee.
SOURCE: USACE, 2022b.

LOSOM differs from LORS 2008 in several respects. LOSOM has far more flexibility built into water level decisions in the range of 12 to 17 feet NGVD than LORS 2008. Overall, the modeled performance of the preferred alternative represents an improvement with respect to ecological conditions in the northern estuaries and the remnant Everglades (Figure 3-7) with a modest decline in conditions of Lake Okeechobee. LOSOM modeling projected approximately two to eight times as many extreme and moderate high stage events as LORS 2008 (Julian and Welch, 2022), and the normal required spring reduction in water levels is less in LOSOM than in LORS 2008. Greater adverse impacts to lake ecology would be expected if high lake levels are maintained and operations allow minimal rates of decline, potentially resulting in vegetation loss, reduced habitat quality for wading birds, and greater advection of nutrient-rich pelagic water into the nearshore and littoral zones (Havens, 2002; Johnson et al., 2007; Julian and Welch, 2022; Steinman et al., 2002a). The LOSOM Water Control Plan includes guidance on Lake Okeechobee Recovery Operations to enhance ecological recovery after extreme or prolonged high lake stages (USACE, 2022b).

The near-term restoration benefits of several ongoing CERP and non-CERP projects rely on the water deliveries provided under LOSOM. Operational decision making requires a high volume of data related not only to present conditions but also to past and forecasted conditions throughout the upstream and downstream watersheds and potential impacts to sensitive receptors. The USACE coordinates with the SFWMD through weekly Environmental Conditions

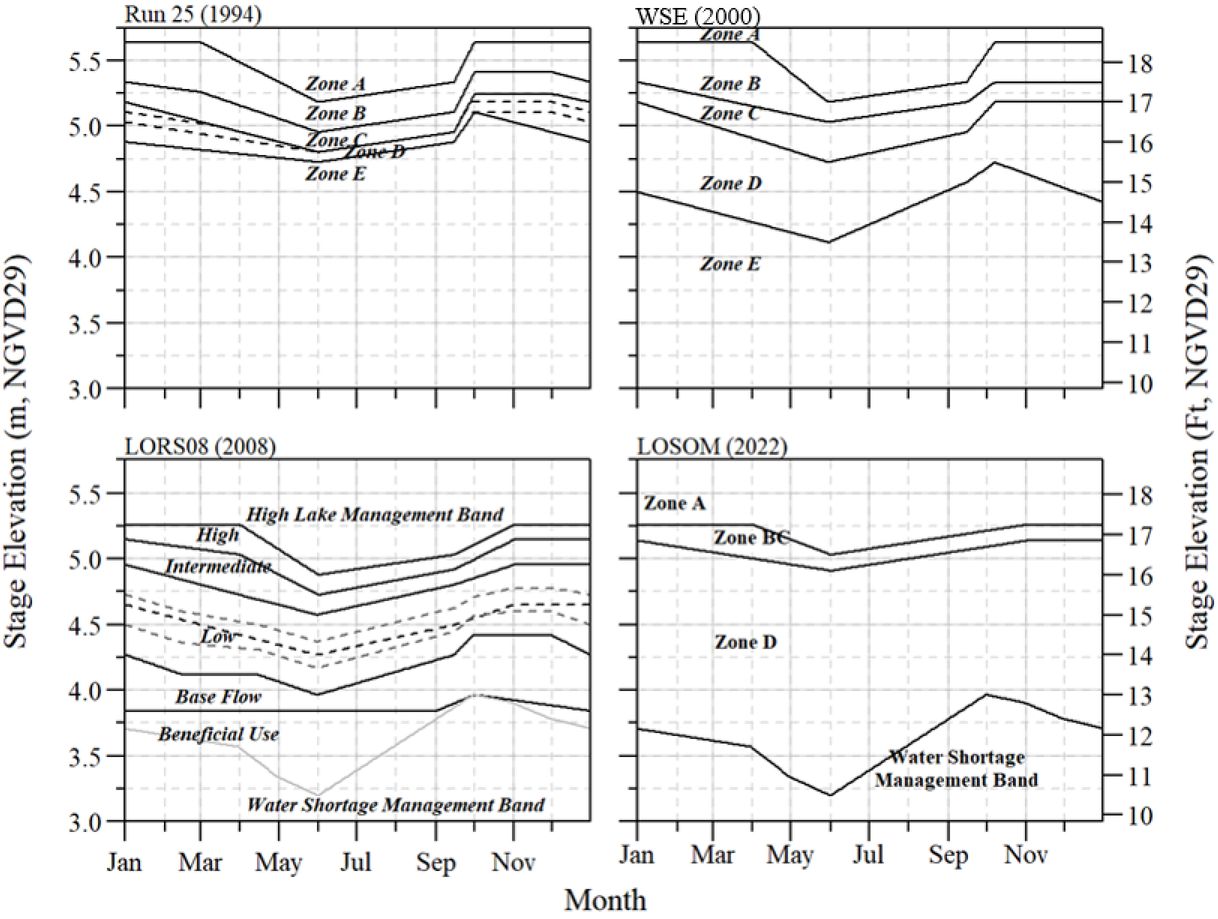


FIGURE 3-9 Lake Okeechobee Regulation Schedules from 1994 to 2022. Each zone or management band corresponds to prescribed management actions to change water levels within the lake by managing inflow and outflow discharges.
SOURCE: Adapted from Julian and Welch, 2022.

meetings and with other stakeholders, including other agencies and local governments, through Periodic Scientist Calls (PSCs) so that lake management decisions are informed by data on the latest conditions. This process requires extremely delicate balancing and weighting of outputs from constantly changing hydraulic, hydrologic, ecological, and meteorological inputs but, if done correctly, LOSOM provides greater flexibility in regulation schedule operations to meet these multiple objectives. However, currently, the lack of detail of how operational decisions will be made within the largest portion of the operational schedule—Zone D (Figure 3-8)—complicates the ability of outsiders to understand or evaluate operational decisions and tradeoffs that have been made.

Given the importance of Lake Okeechobee operations to restoration benefits throughout the system and the intense public pressure on decision makers, additional periodic review of the performance of LOSOM relative to the stated objectives seems merited. An annual multiagency meeting or workshop could review how well competing priorities and project purposes were balanced in a given year and reflect on lessons learned for future management, outside of any specific crisis. Such a convening could also build trust among diverse stakeholders and increase transparency about the many factors that influence water management decisions.

Central and Western Everglades

This section includes CERP and relevant non-CERP projects whose construction progress is significant enough to be affecting the Central and western Everglades. CERP projects discussed include the C-111 Spreader Canal (Western) Project, Picayune Strand Restoration Project, the CEPP, and the Melaleuca Eradication Project. The Combined Operational Plan (COP) is discussed as a relevant non-CERP project. The Western Everglades Restoration Project is currently in planning.

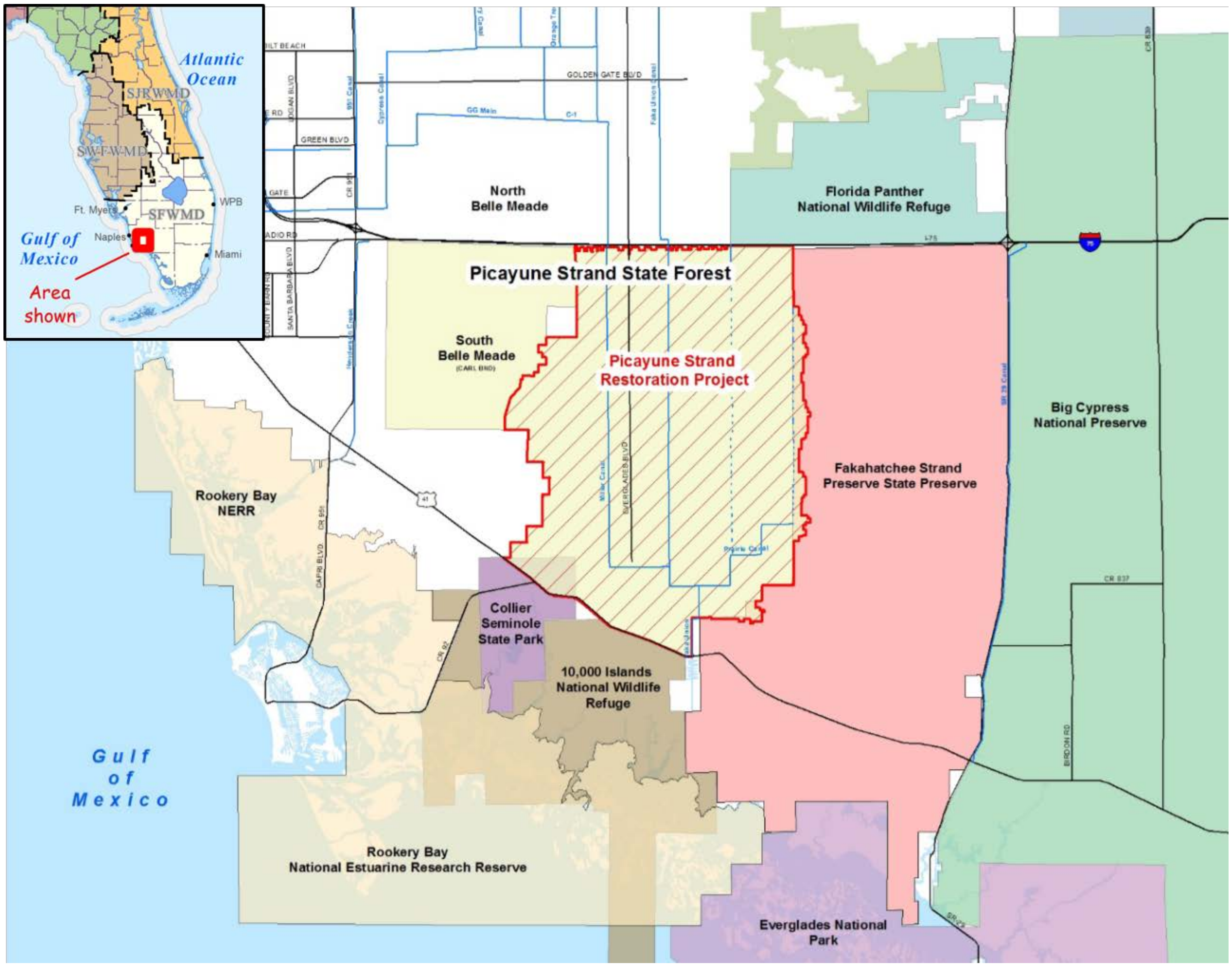


FIGURE 3-10 The Picayune Strand Restoration Project area is surrounded by several other natural areas, including Collier-Seminole State Park, Ten Thousand Islands National Wildlife Refuge, Picayune Strand State Forest, Fakahatchee Strand Preserve State Park, and Florida Panther National Wildlife Refuge. Restoration of water levels within the project footprint will enhance the hydrologic conditions in these surrounding natural areas.
SOURCE: Chuirazzi et al., 2018.

CERP Projects in Progress or Completed

Picayune Strand Restoration Project. The Picayune Strand Restoration Project (Figure 3-3, No. 1) was the first CERP project under construction. The 55,000 acre (86 mi^2) Picayune Strand area in southwest Florida was drained for an intended real estate development, Golden Gate Estates-South, which was abandoned before completion. Construction of drainage canals and an extensive road network drained a large area of wetlands, reduced sheet flow to the south into the Ten Thousand Islands National Wildlife Refuge, and altered regional groundwater flow into surrounding areas (Figure 3-10). Restoring the pre-drainage hydrology should bring multiple ecological and environmental benefits, including an increase in the spatial extent of wetlands,

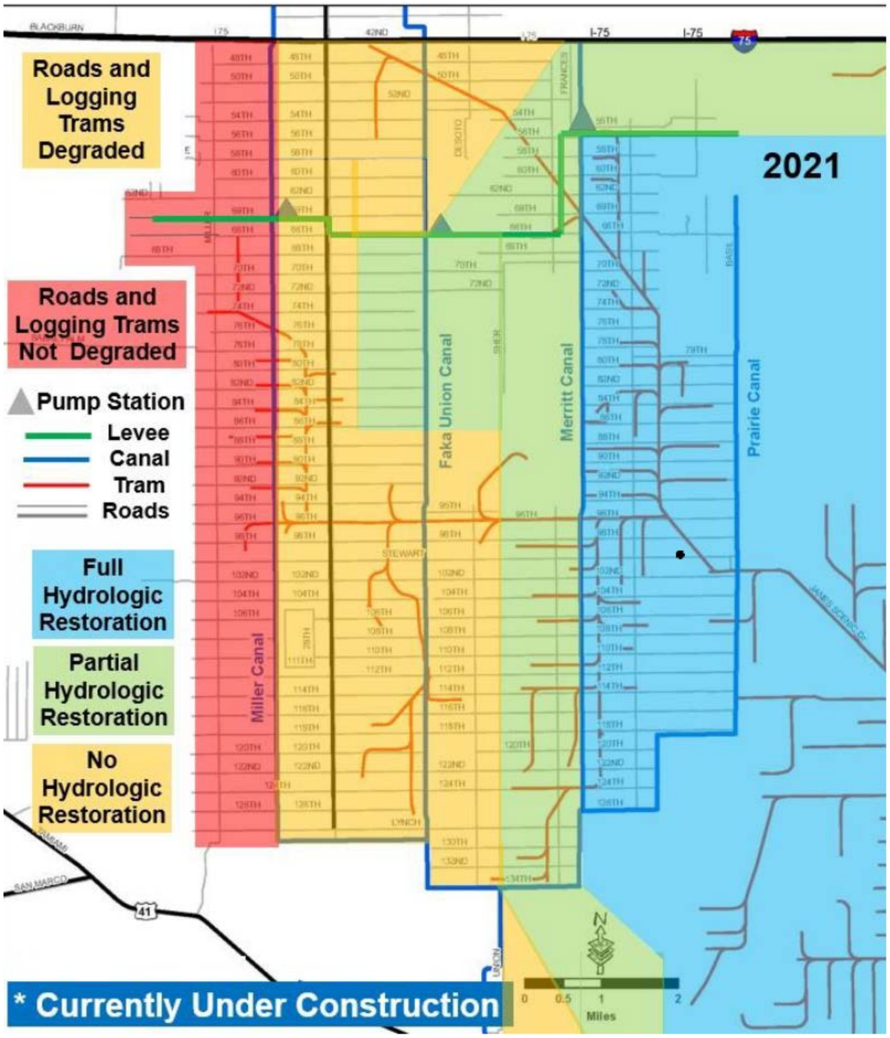


FIGURE 3-11 Map showing areas of partial hydrologic restoration and full hydrologic restoration as of January 2022. The fully restored area (shaded blue) in Picayune Strand was expanded southward after the filling of the eastern stairstep canals, and the partially restored area (green shading) was expanded after 3 miles of canal plugging at the north end of the Faka Union Canal from 2019 to 2021. Black dot indicates the location of Well 15.
SOURCE: Duever and Clark, 2022.

decreased frequency and intensity of forest fires, increased habitat for endangered species such as the wood stork and Florida panther, and a reduction in invasive native and exotic species. The project is also expected to improve groundwater recharge to the City of Naples' eastern Golden Gate well field, as well as coastal estuarine salinities affected by freshwater point discharges from the Faka Union Canal (RECOVER, 2019a).

Project components include plugging drainage canals, degrading roads, and removing logging trams (USACE and SFWMD, 2004). Construction has occurred in stages starting with the easternmost portion of the area and proceeding west (Figure 3-11; Table 3-3). The Eastern Stair-step canal and the upper 3 miles of the Faka Union Canal were plugged during summer 2021. Plugging of the southern portion of the Faka Union Canal and all of the Miller Canal, the westernmost canal, will not occur until completion of the Southwest Protection Feature, a levee on the southwest edge of the project. This levee is intended to reduce flood risk to the agricultural lands to the west of the project and is not anticipated to be completed until 2025. Because of the staged plugging of drainage canals, the degree of hydrologic restoration varies both spatially and temporally. Prior to the 2019-2021 construction, only the northeast corner was considered to have full hydrologic restoration; following that construction, the entire area east of the Merritt Canal was considered to have full restoration (Bonness et al., 2022, Figure 3-11).

NASEM (2021) provided a comprehensive review of the hydrologic and ecological monitoring program. This report focuses on recent information obtained during the past 2 years on hydrologic and vegetation outcomes. Following the 2015 plugging of the Merritt Canal, hydroperiods are longer and water levels have generally shifted higher (Bonness et al., 2022). One example is Well 15, located roughly in the middle of the latest fully restored area (Figure 3-11). The peak water depths are higher, and the hydroperiod is longer after June 2015 (Figure 3-12). Additional elapsed time is necessary to evaluate the effects of filling the Stair Step Canals in 2019-2021. Hydroperiod target bands (Duever and Clark, 2022) have usefully been added to data plots to provide an ecological context and general vegetation-specific targets for a change in hydroperiod (Figure 3-13). These plots suggest that for the partially restored and fully restored sites, the hydroperiod has increased to an amount appropriate for a desired vegetation type.

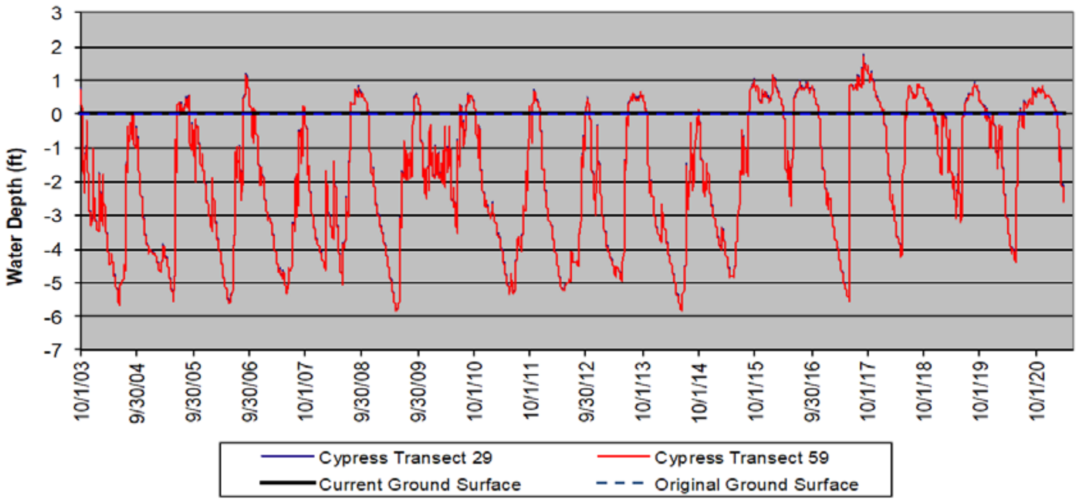


FIGURE 3-12 Water depth at Well 15, located in the fully restored area. Lines for pairs of data are essentially identical, so only the data from one transect are visible on the plot.
SOURCE: Bonness et al., 2022.

TABLE 3-3 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 2017; upper 3 miles canal plugging completed in 2021. The rest is scheduled for 2025 or later.
Miller Canal Phase	Federal/State	77	11	13	Construct pump station, spreader basin, tie-back levee, and private lands drainage canal; remove western stair-step canals	Miller pump station completed June 2019. Road removal completed September 2022; canal plugging to be completed 2025 or later.
Manatee Mitigation Feature	State	0	0	0	Construct warm water refugium to mitigate habitat loss	Completed in 2016
Southwestern Protection Feature	Federal	0	0	0	Construct 7-mile levee, canal, and water control structures for flood protection of adjacent lands	Construction completion scheduled for October 2023
Eastern Stair-step Canals	Federal	0	0	5.2		Plugging completed in June 2021

SOURCE: Data from Bonness et al., 2022; J. Weaver, SFWMD, personal communication, 2020.

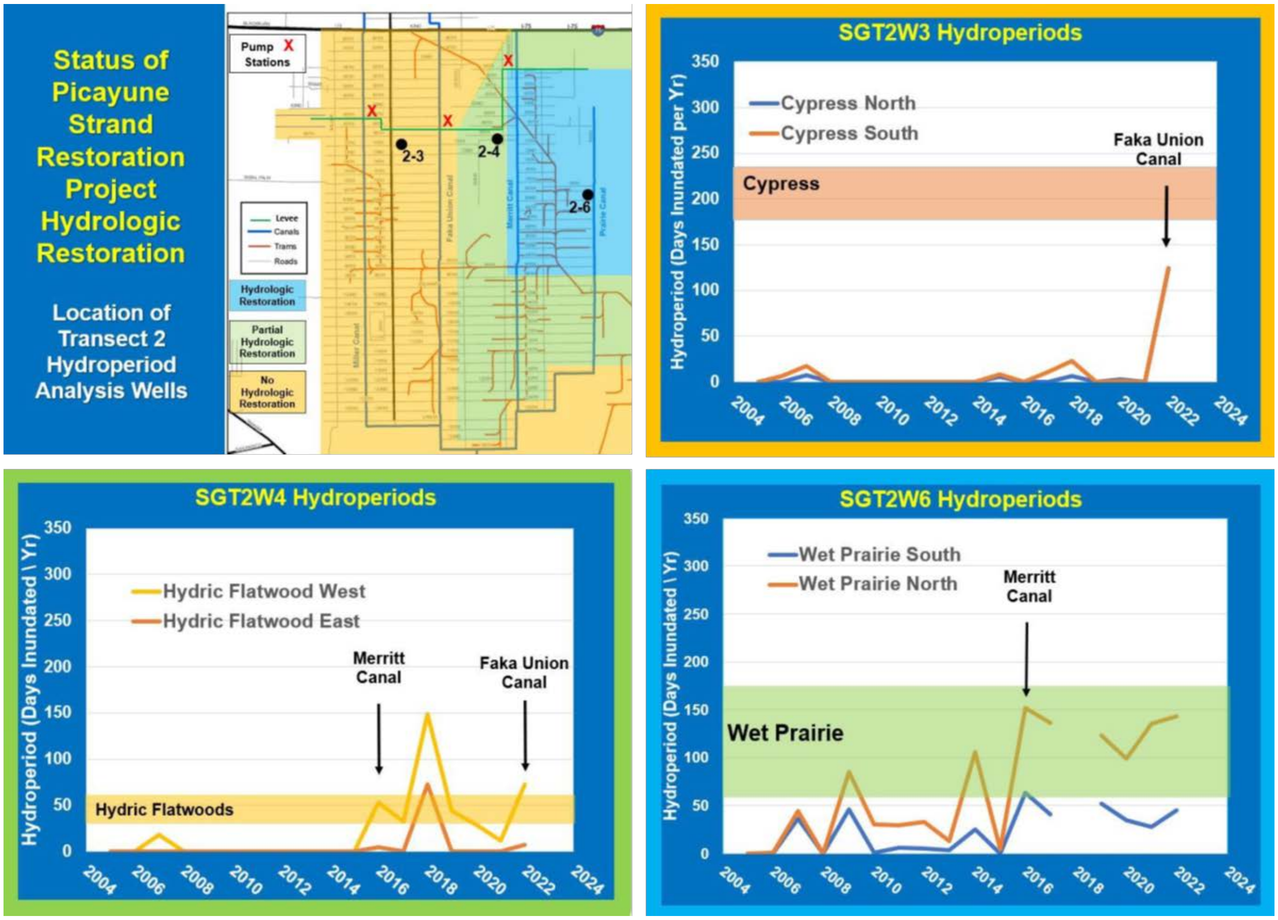


FIGURE 3-13 Hydroperiod (days inundated per year) over time at three sites with varying levels of hydrologic restoration: SGT2W6 (or 2-6), located in a wet prairie habitat that was partially restored in 2006 and fully restored in 2015; SGT2W4 (or 2-4), located in a habitat of hydric flatwoods in an area that was partially restored in 2015; and SGT2W3 (or 2-3), located in a cypress habitat, in an area that was only partially restored in the 2021. The colored bands indicate the desired ranges for each vegetation type. The map on the upper left shows the distribution of partially and fully restored areas from 2015 to 2021.
SOURCE: Duever and Clark, 2022.

Interpreting the data is complicated by the multiple drivers of annual water level patterns, including year-to-year variability in rainfall (e.g., Hurricane Irma in 2017), spatial variability in annual rainfall within the project area, and site- and year-specific variability in the degree of restoration that occurred (Figure 3-13). One example is the potential extension of the hydroperiod by the relatively high rainfall during September, especially in 2020 and 2021 (Bonness et al., 2022). Existing hydrologic modeling tools with updated precipitation and climate data can be used to infer the expected hydrology under current conditions ("nowcasting") but without project features, thus, providing a way to separate the contribution of restoration from the contributions of natural variability.

A network of permanent transects for vegetation monitoring was established in 2005, and in 2016, a subset of 27 transects (including 9 reference transects) were selected to be more frequently measured to quantify vegetation change associated with the project. These transects were sampled in 2005, 2016, 2018, and 2020-2021. The 2020-2021 vegetation sampling, discussed here, occurred after most but not all of the Eastern Stair-step Canal was plugged (Bonness et al., 2022).

The first increments of hydrologic restoration were completed approximately 15 years ago (in 2007), and ecological responses in fully restored areas appear to be trending toward restoration objectives (Bonness et al., 2022). Shorter-lived, faster-growing species, such as those in the understory layer, are expected to respond faster to hydrologic restoration than longer-lived, slower-growing species, such as cypress and pines that form the canopy. Analyses including the 2020-2021 data show that the understory layer is shifting to higher abundance of species characteristic of reference wetland sites (Bonness et al., 2022). Wetland affinity index[1] (WAI) data show a general trend of increasing “wetness” of the groundcover vegetation in the transects (Figure 3-14). Although the overstory composition is changing slowly, cypress saplings are beginning to recruit into the overstory (Bonness et al., 2022).

Progress is also being made in controlling cabbage palms and other exotic plants (Barry, 2021). Reducing the abundance of cabbage palms appears to require continued control activities; cabbage palm abundance increased between 2019-2021 when no control activities were conducted (Barry, 2021).

The high variability between transect locations and years hides signals of restoration effects in the shrub, sub-canopy, and canopy layers. Some of the natural factors contributing to the variability are the year-to-year variability in the magnitude, timing, and location of rainfall events and the consequences of wildfires, which affect only parts of the project area. Variation in sampling dates (e.g., in the wet or dry seasons) contributes to variability in the data for seasonally varying species. Standardization of sampling dates, either by calendar date or relative to phenology, would be desirable to reduce variability due to phenology.

Approximately 15 percent of the project area was covered by roads that have now been degraded. The pattern of vegetation restoration in these areas will differ from that in less disturbed areas; successional dynamics, especially tree seedling colonization and establishment, will be much more important on the degraded roads (M. Duever, Natural Ecosystems LLC, personal communication, 2022). Sampling in these areas has primarily been associated with activities to control exotic plants (Barry, 2021). It would be useful to establish some permanent plots or transects to quantify vegetation trends in these areas.

Increased nutrient loading into Outstanding Florida Waters, including Collier Seminole State Park and Ten Thousand Islands National Wildlife Refuge, associated with the project’s redistribution of flow have recently raised concerns. In response, the SFWMD together with federal, state, and local government agencies and nongovernmental partners are working to evaluate treatment and source control options, which would be implemented outside of the CERP (Stantec, 2021, 2022).[2]

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[1] The wetland affinity index provides a single summary of whether the vegetation is primarily species associated with wetlands, with drier land, or something in between (Wentworth et al., 1988).

[2] See https://www.sfwmd.gov/our-work/picayune-watershed-water-quality-feasibility-study.

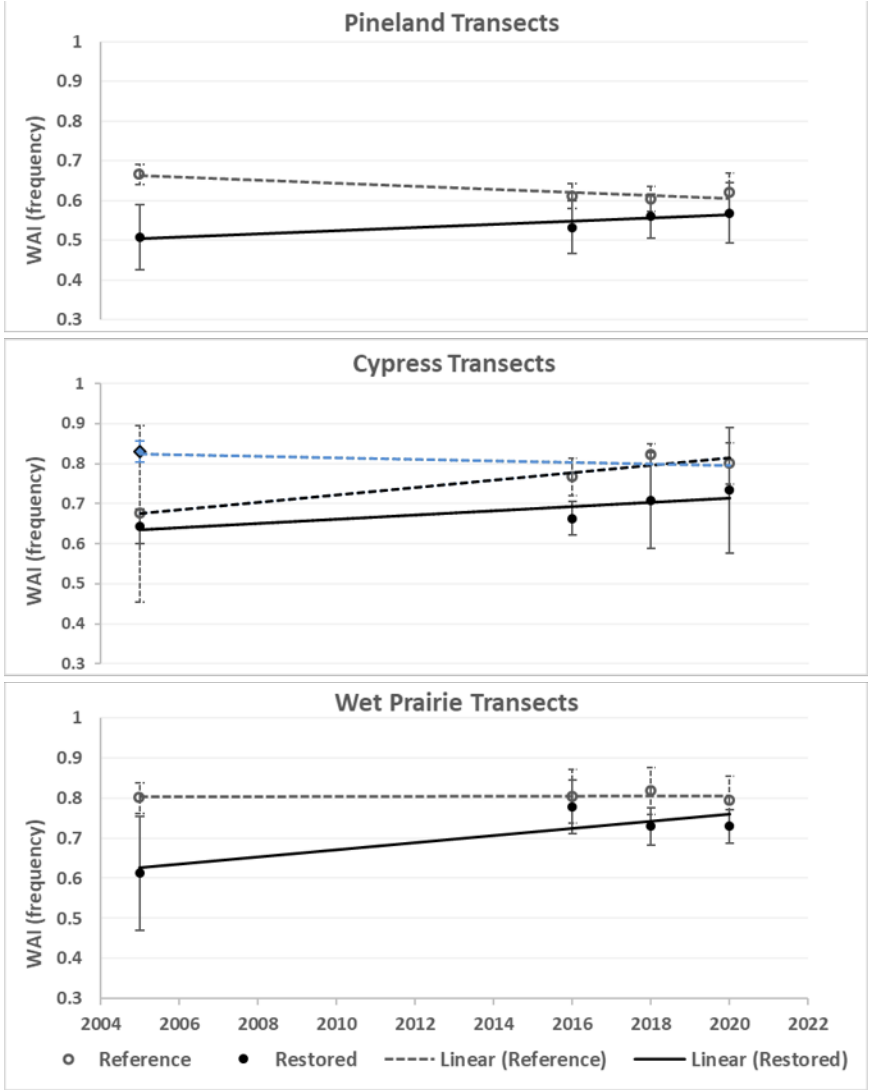

FIGURE 3-14 Mean groundcover WAI by habitat. WAI is based on the frequency of groundcover species. Lines are fitted least-squares regression lines. The blue line in the cypress panel is the regression line omitting data from one 2005 transect with an unusually low WAI. A linear mixed model examining changes in understory WAI while accounting for variability between transects shows significant increases on restored cypress transects (increase of 0.090, p = 0.015) and wet prairie transects (increase of 0.12, p = 0.024) and a smaller increase on restored pineland transects (increase of 0.061, p = 0.23). WAI on reference transects was stable or decreasing between 2005 and 2020 (cypress change = -0.029, p = 0.42; pineland change = -0.046, p = 0.14; wet prairie change = -0.006, p = 0.84).
SOURCE: Bonness et al., 2022.

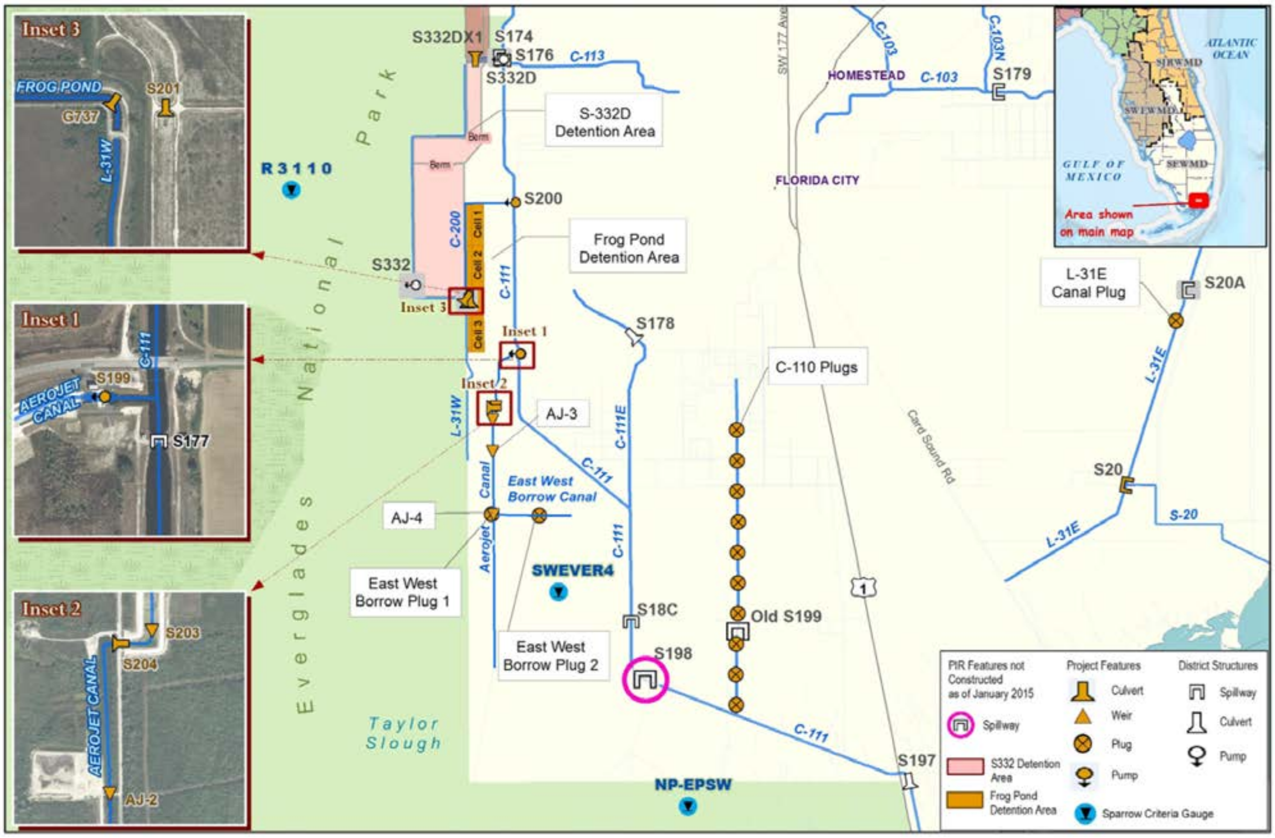

FIGURE 3-15 C-111 Spreader Canal (Western) Project features.
SOURCE: Qiu et al., 2018.

C-111 Spreader Canal Western Project. The C-111 Canal is the southernmost canal for the entire Central and Southern Florida (C&SF) Project. The canal system was constructed in the 1960s, expanding upon a remnant canal built to transport solid fuel moon rockets from the AeroJet General Corporation. Originally designed to provide flood protection in Dade County, the C-111 Canal spurred agricultural development on lands to the east while draining water from the Southern Glades and Taylor Slough in Everglades National Park. A principal source of the freshwater in the canal is seepage from Everglades National Park. Because seepage drains water from the park and alters the flow pattern of Taylor Slough, the C-111 Canal has had detrimental ecological and environmental effects on Taylor Slough and Florida Bay. The C-111 Canal also discharges large volumes of freshwater through the S-197 structure into Manatee Bay and Barnes Sound, while reducing overland flows that entered the central zone of Florida Bay, altering the natural salinity regime and ecology of those waters.

The construction of the C-111 Spreader Canal project (Figure 3-3, No. 6) was envisioned in two phases—the eastern and western projects. The western project (Figure 3-15) was largely completed in February 2012 through expedited investment by the SFWMD, and operations began in June 2012. Construction of the final project component—the S-198 Spillway (Figure 3-

15)—appears to be on hold, and it remains unclear if it will be constructed.[3] Working in concert with the non-CERP C-111 South Dade Project and the SFWMD Florida Bay Initiative, the C-111 Spreader Canal (Western) (C-111 SCW) Project was designed to help restore the quantity, timing, and distribution of water delivered to Florida Bay via Taylor Slough; improve hydropatterns within the Southern Glades; and lower coastal-zone salinities in central and eastern Florida Bay. Planning for the features and objectives of the C-111 Spreader Canal (Eastern) Project began in mid-2020 as part of the Biscayne Bay-Southern Everglades Ecosystem Restoration (BBSEER) project, discussed later in this chapter (USACE and SFWMD, 2020c).

The C-111 SCW Project creates a 6-mile hydraulic ridge along the eastern boundary of Everglades National Park to reduce seepage from the park and improve the hydrologic conditions of Taylor Slough. This ridge is created by pumping excess water from the canal into the 600-acre Frog Pond Detention Area through S-200 and into the Aerojet Canal impoundment through S-199 (see Figure 3-15). Rather than a persistent feature, the hydraulic ridge is present and functions only when water is available to fill the detention area. The project is also intended to contribute to improved distribution of flows in the Southern Glades through emplacement of earthen plugs along the C-110 Canal and through modified operations of structures located principally along the southern segment of the C-111 Canal.

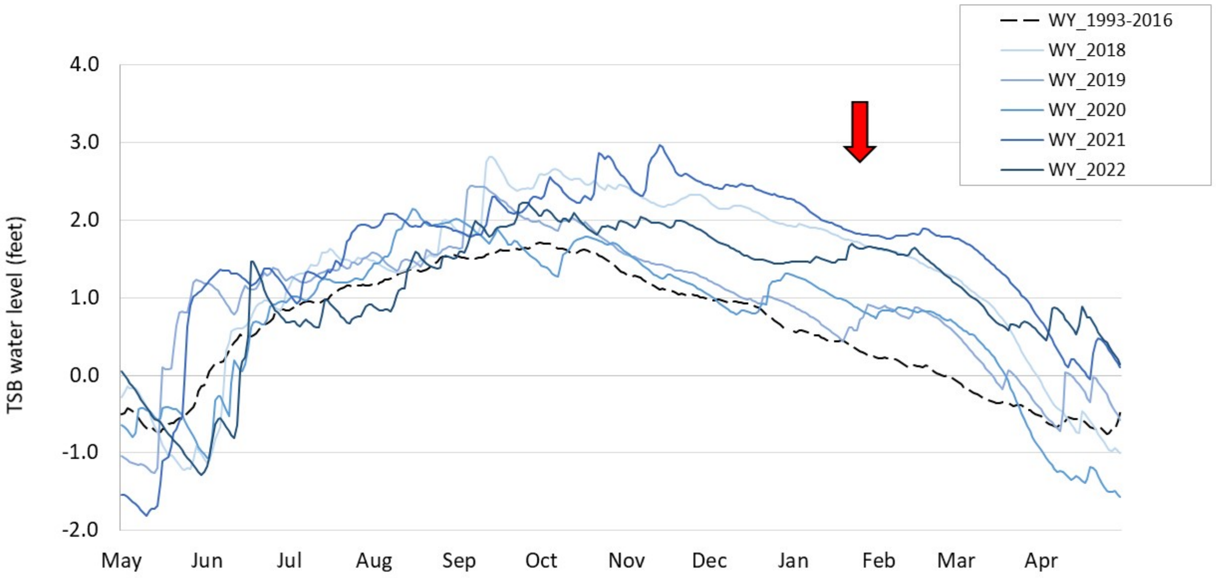

FIGURE 3-16 Daily water levels at Taylor Slough Bridge (TBS) for water years 2018-2022, together with the median daily water level for the period 1993-2016. Red arrow points to the February water levels that range from 0.6 to 1.5 feet higher than the 1993-2016 median levels. Water year (WY) refers to May 1 through April 30 with the year designated as the end of the period (e.g., WY 2022 is May 1, 2021 to April 30, 2022).
SOURCE: F. Sklar, SFWMD, personal communication, 2022.

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[3] Although the S-198 Spillway is an authorized component of the federal project, neither the 2022 Draft Integrated Delivery Schedule (USACE, 2022d) nor the Task Force Integrated Financial Plan (SFERTF, 2021) mention its pending construction as part of C-111 SCW Project. The project fact sheet states: “A new structure in the lower C-111 canal may be scheduled for construction in the future.” (USACE, 2021d).

Several potential signs of restoration progress have been observed since operation of C-111 SCW commenced approximately 10 years ago (Cortez et al., 2021; Redwine, 2022; F Sklar, SFWMD, personal communication, 2022). Within Taylor Slough, dry-season (October to May) water levels have risen, with February water levels at Taylor Slough Bridge for the years 2018 to 2022 ranging from 0.6 to 1.5 feet higher than the 1993-2016 median level (Figure 3-16). Creekflows have also changed. In particular, cumulative flows in the five main creeks feeding eastern and central Florida Bay were nearly two fold greater at the end of the 2021 dry season than the 2015 dry season, despite nearly equal, but below average, rainfall for the two periods (Cortez et al., 2021). Whether the higher flows in 2021 relative to 2015 arise from C-111 SCW operation or reflect the influences of nearby projects is unclear, especially because both periods post-date completion of the C-111 SCW Project. It is encouraging that periphyton across Taylor Slough does not show significant signs of phosphorus enrichment, although some increasing phosphorus levels in periphyton have been observed near the point of greatest inflows (F. Sklar, SFWMD, personal communication, 2022). [4]

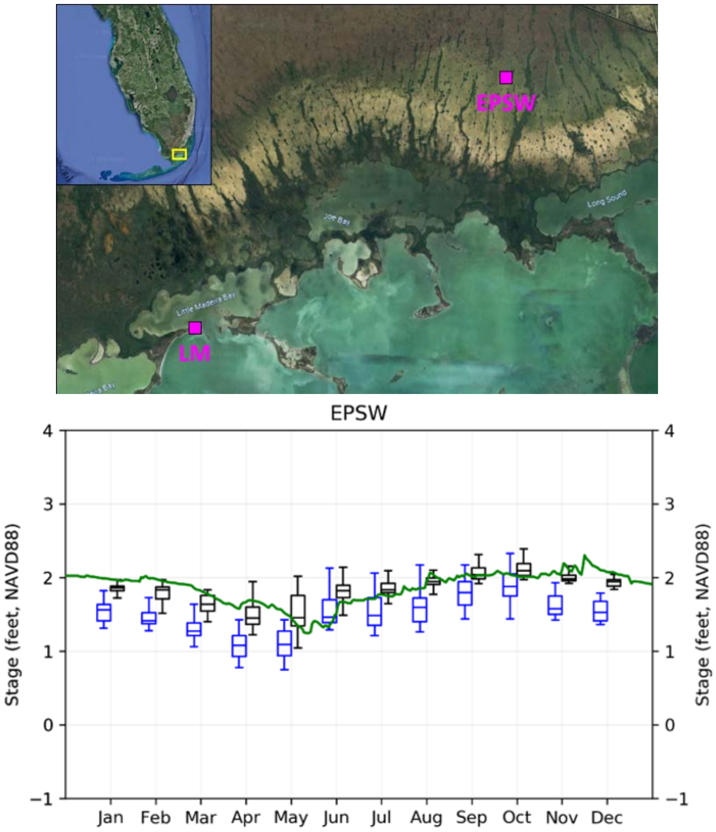

FIGURE 3-17 Surface-water stages at monitoring gage site EPSW in the Southern Glades for 1993-1997 (blue), which represented very wet conditions; 2016-2021 (black), 5 recent years which included 2 very wet years; and 2021 calendar year (green). Map shows location of EPSW and LM monitoring sites.
SOURCE: Redwine, 2022; Google Earth.

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[4] This text has been corrected following prepublication release of the report to more accurately explain phosphorus trends.

Outside of Taylor Slough, stages are rising in the southern portion of the C-111 Basin, which may primarily reflect sea-level rise rather than changes in water management (Figure 3-17). Moreover, the salinity of waters within this area, as well as in northeast Florida Bay, is also rising (Figure 3-18), suggesting that increased flows from C-111 SCW and other recently completed projects within the C-111 Basin have been insufficient to offset the effects of sea-level rise.

Hydrologic and water quality changes are continuing to occur within the vicinity of the C-111 SCW Project footprint. The extent to which these changes can be attributed to implementation of C-111 SCW features is equivocal. This uncertainty arises partly from insufficient baseline data on hydrology and water quality collected prior to completion of C-111 SCW. It also stems from confounding effects of neighboring projects as well as the considerable hydrologic variability during pre- and post-project periods caused by rainfall variability, extreme events (e.g., hurricanes, droughts), and numerous operational changes over the past two decades that have culminated in the 2020 adoption of the COP (see section on the COP). That the benefits of C-111 SCW are presently unclear and difficult to resolve suggests that greater attention should be devoted to updating monitoring programs that are coupled with rigorous data analysis and model applications capable of isolating, in a quantitative way, how the benefits of C-111 SCW vary with recent changes in sea level, rainfall and climate characteristics, and management plans.

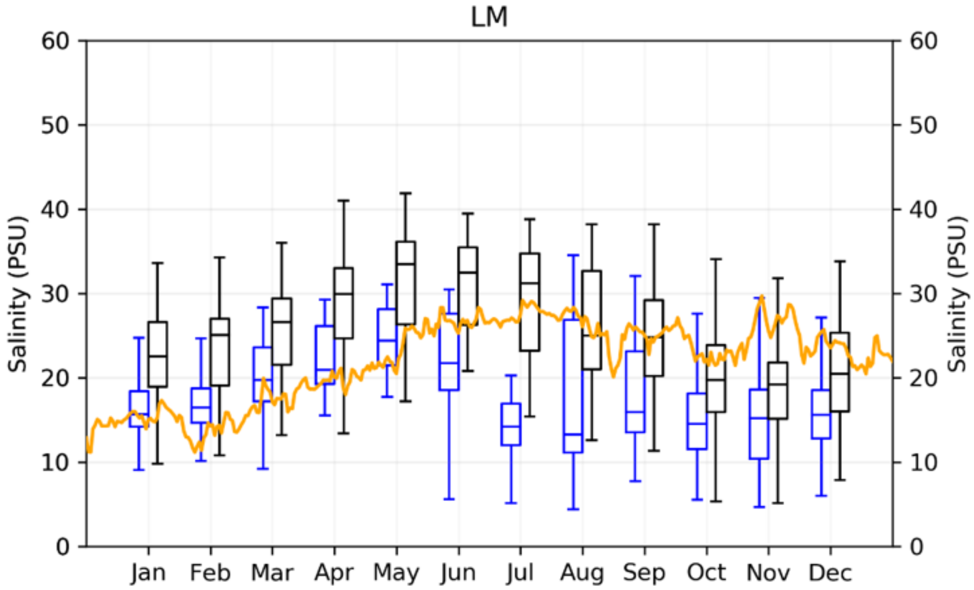

FIGURE 3-18 Salinity at monitoring site Little Madiera (LM) in north Florida Bay for 1993-1997 (blue), which represented very wet conditions; 2016-2021 (black), 5 recent years which included 2 very wet years; and 2021 (orange) calendar year. Figure 3-17 shows location of the LM monitoring site.
SOURCE: Redwine, 2022.

Central Everglades Planning Project. The CEPP represents the next step in the restoration of the central Everglades, building upon recently completed non-CERP infrastructure now operating under the COP (discussed in more detail below). As such, it is an especially critical element of the CERP, and accordingly, CERP leadership, recognizing the urgency of preventing further degradation of the central Everglades (NRC 2008, 2012), has gone to extraordinary efforts to expedite the development, authorization and implementation of the project (NRC, 2014). The CEPP provides the means to send additional water south through the Water Conservation Areas (WCAs) and Everglades National Park to Florida Bay while reducing harmful discharges to the northern estuaries, and it is designed to improve the timing and distribution of flow in the central Everglades (USACE, 2020b; SFWMD, 2018a). Its many parts include improvements in seepage management; improvements in conveyance through filling of canals, levee removal, and addition of new structures such as pump stations and gated spillways; a new large water storage feature (the EAA Reservoir); and construction of the new A-2 stormwater treatment area (STA) to ensure that the new inflows comply with existing water quality requirements (see Figure 3-19). The CEPP is a complex project comprising four phases, each with multiple components: CEPP South, CEPP North, CEPP New Water, and CEPP EAA (Figure 3-3, No. 10-13). The total authorized cost of the project is $5.47 billion (Figueroa, 2022a).

The first phase of CEPP—CEPP South—is transitioning from project design to construction. Two features—removal of 5.45 miles of the old Tamiami Trail and construction of the S-333N Gated Spillway—have been completed. The former eliminates a barrier to flows from WCA-3 into Everglades National Park, and the latter increases capacity to reduce high water levels in WCA-3A by moving higher flows to Everglades National Park during the wet season (Figure 3-19). Construction of other features such as gated culvert structures on the L-67A levee is imminent, and construction of several additional features is scheduled to begin in FY 2024 (USACE, 2021a). Finally, the conveyance features of the Decomp Physical Model are expected to be incorporated as permanent features of CEPP South in 2022. These features, which include 10 gated culverts on the L-67A Canal and a 3,000-foot gap in the L-67C levee, increase capacity for sheet flow between WCA-3A and WCA-3B (Figure 3-19).

CEPP North is beginning to transition from planning to construction as well. CEPP North is designed to improve the distribution of flows into northern WCA-3, which has long been subject to overly dry conditions, to restore its hydrology and ecology. It will also hydrate WCA-2 under high flow conditions. CEPP North includes backfilling of the Miami Canal, as well as several projects designed to improve conveyance (Figure 3-19). Of the five projects comprising CEPP North, the SFWMD construction on one is scheduled to begin in late 2022 and on the other four in FY 2023 or FY 2024 (USACE, 2021a). Connor (2022) recently reiterated that the USACE is not permitted under the CEPP Chief's Report (USACE and SFWMD, 2014) to move forward with CEPP North until water quality requirements for STA discharge[5] are met for the existing STAs (STA-1E, -1W, -2, -3/4, and -5/6; shown in yellow in Figure 3-19). The state's STA rehabilitation and expansion efforts—Restoration Strategies (see Box 4-2)—are not scheduled for completion until 2025, with the first year of water quality compliance

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[5] The water quality-based effluent limit (WQBEL) requires that STA discharge "shall not exceed: 13 ppb [µg/L] as an annual flow-weighted mean [FWM] in more than 3 out of 5 water years on a rolling basis; and 19 ppb [µg/L] as an annual flow-weighted mean [AFWM] in any water year" (Mitchell and Mancusi-Ungaro, 2012; FDEP, 2017).

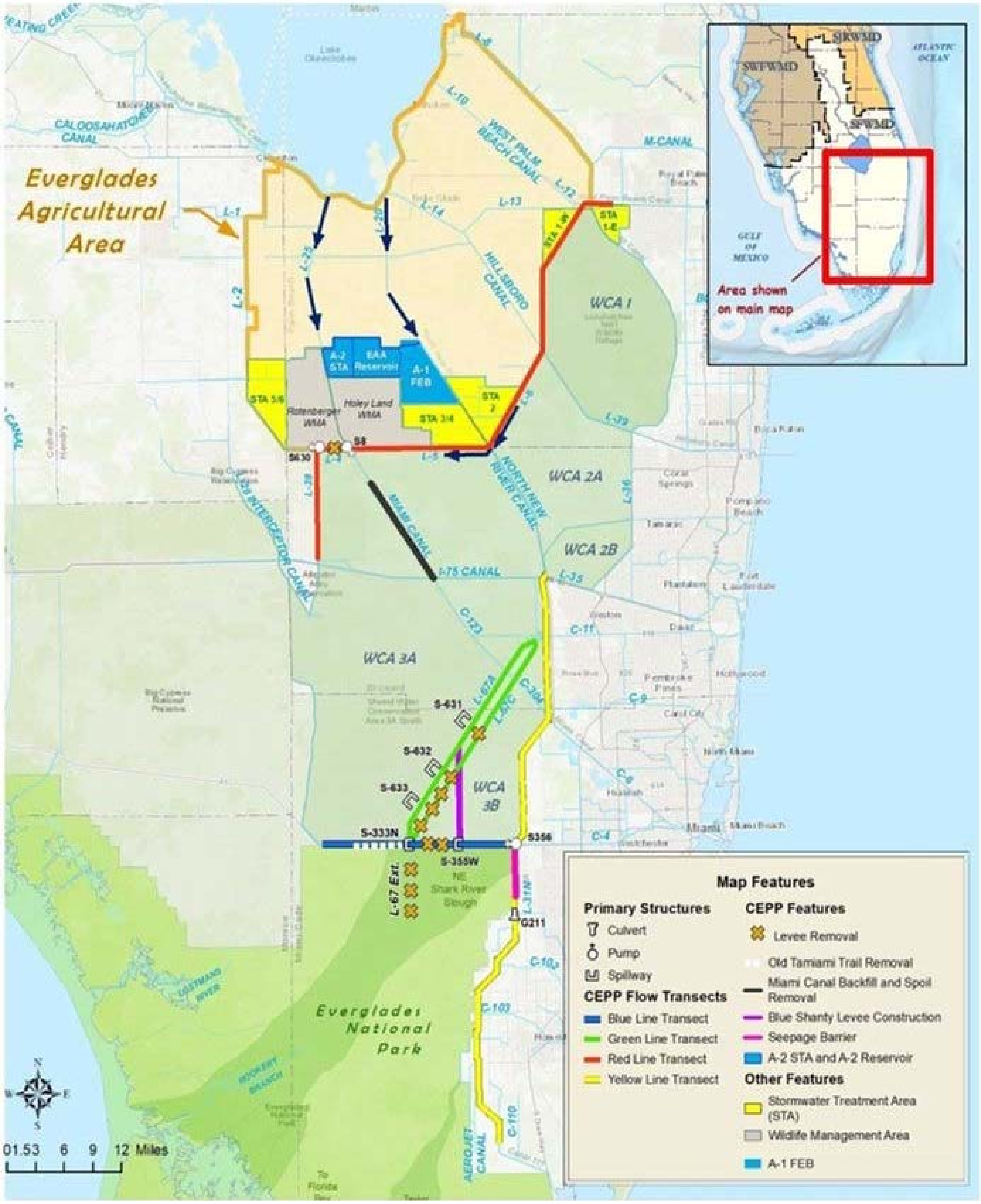


FIGURE 3-19 CEPP features.
SOURCE: Modified from Waugh, 2020.

determination being WY 2027. If STA water quality criteria are not met by the start of the filling of the Miami Canal in FY 2024, CEPP North could exacerbate water quality concerns in previously unimpacted areas. Progress toward meeting water quality criteria in the STAs and implications for CERP progress are discussed in more depth in Chapter 4.

CEPP New Water now consists of a partial depth seepage barrier along the L-31N levee south of Tamiami Trail. Since the CEPP was authorized, the Limestone Products Association constructed 5 miles of seepage barrier (35 feet deep) south of Tamiami Trail along the L-31N levee (also knowns as the L-31N Rock Miners Seepage Wall), and the SFWMD is currently constructing a 2.3-mile, 63-foot deep seepage barrier adjacent to the 8.5 Square Mile Area (Figure 3-20). In August 2022, the SFWMD awarded a contract to construct an additional 4.9 miles of curtain wall (55-65 feet deep) along the northwestern boundary of the 8.5 Square Mile Area between the curtain wall currently under construction and the L31-N Canal to the north (Figure 3-20); the project is estimated to be completed by 2024 (Reynolds, 2022). This project is designed to reduce seepage from Northeastern Shark River Slough into the 8.5 Square Mile Area, thereby reducing flood control constraints on operations in the natural system. There will be a 1.6-mile gap between this new seepage barrier and the existing Rock Miners Seepage Wall (Figure 3-20).

CEPP EAA consists of construction of the EAA (A-2) Reservoir and adjacent A-2 STA (Figure 3-19), and several projects related to the operation of these new features, such as construction of an inflow pump station and seepage and inflow/outflow canals. The objectives of CEPP EAA are to store new water and treat it before moving it south, with projected increases in average annual inflows to the remnant Everglades of 370,000 AF (USACE, 2020b). Construction of the 6,500-acre A-2 STA has been ongoing for several years and is scheduled to be completed in FY 2023 (Figueroa, 2022b). The 23-foot-deep EAA Reservoir, which will provide 240,000 AF of new storage, is currently scheduled to be completed in 2029. The timely delivery of the intended benefits of the EAA Reservoir is dependent on the performance of both the existing STAs and the A-2 STA. The CEPP A-2 STA was sized assuming that excess capacity in the state’s STAs could be used in the dry season to treat water from the EAA Reservoir and increase dry season flows to the south. However, as discussed in more detail in Chapter 4, the USACE has stated that the EAA Reservoir may not discharge water to the state STAs until all meet the required discharge criteria. If the A-2 STA fails to meet its discharge requirements, the EAA Reservoir is only permitted to discharge as much water as the STA can treat to appropriate standards. Lengthy delays in reaching discharge requirements could lead to delays in providing the full CEPP benefits as designed. STA performance and the linkage to CERP progress is discussed in depth in Chapter 4.

The committee commends the agencies carrying out the restoration effort for continuing to move the CEPP forward with the speed its importance merits. During the past 2 years, the CEPP has progressed significantly, with construction under way on multiple fronts, and much more scheduled to begin in the next 2 years. The rapid progress of the CEPP, following the implementation of the COP (see below), has somewhat alleviated the committee’s previous concerns about a too-slow pace of restoration of the central Everglades (NRC, 2008, 2012). However, concerns remain about meeting STA water quality requirements in a timely way to support CEPP progress and the full delivery of benefits to the Everglades. Although the recently completed components of CEPP South may be beginning to make small contributions to the changes in hydrology associated with the COP, overall the CEPP is in the early stage of construction and thus it is too soon to assess the restoration benefits of the project.

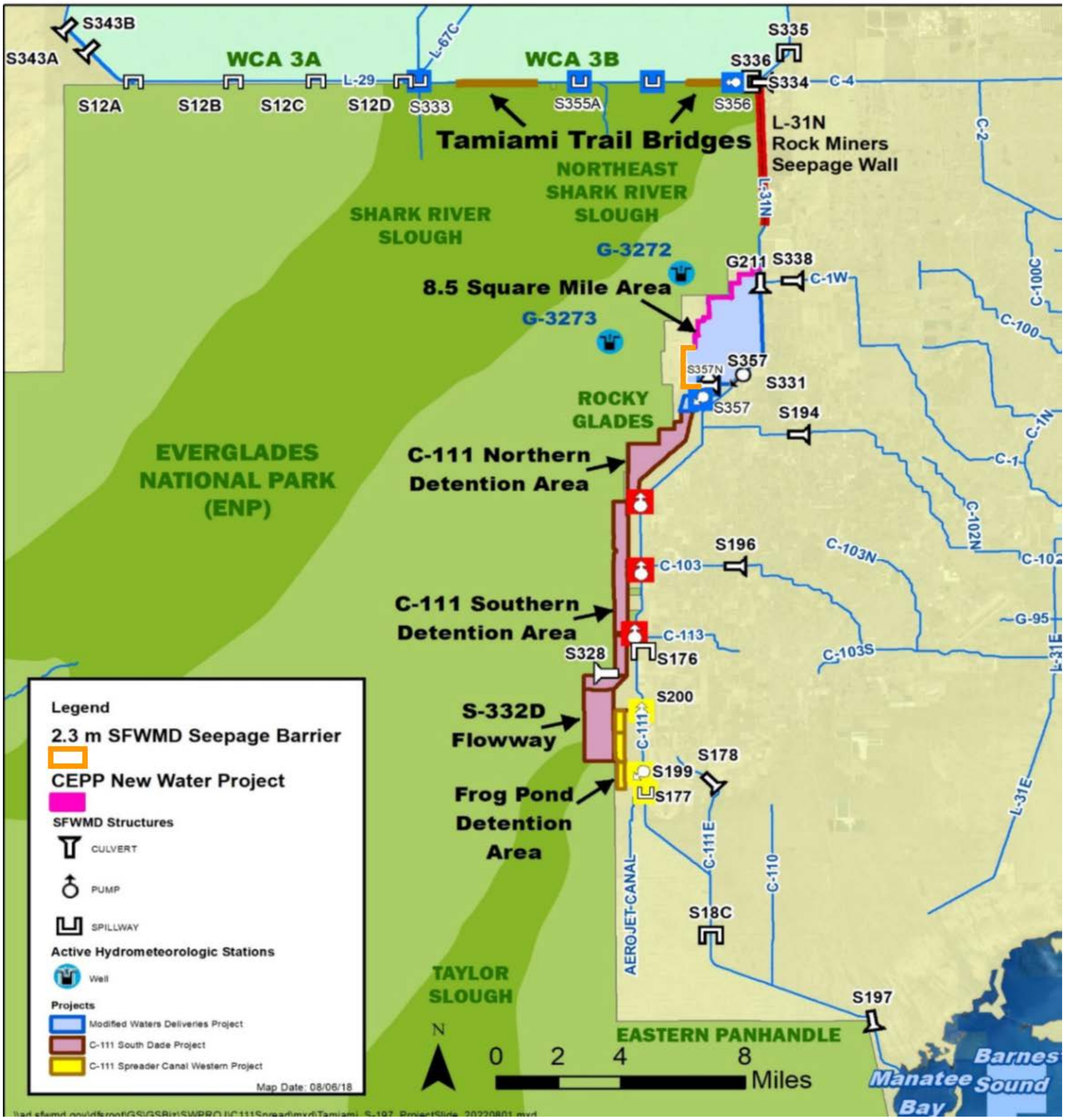


FIGURE 3-20 Location of the 4.9-mile CEPP New Water seepage barrier, adjacent to the 2.3-mile seepage barrier currently under construction by the SFWMD. The combined seepage barrier along the 8.5 Square Mile Area would end 1.6 miles from the end of the 5-mile Rock Miners Seepage Wall.
SOURCE: Modified from Reynolds, 2022.

FIGURE 3-21 Damage to an air potato plant by the air potato leaf beetle. The beetle reduces cover, bulbil size, bulbil production, and vine height. Thanks to successful biological control measures, the air potato is no longer considered a priority invasive species.
SOURCE: Winston et al., 2017.

Melaleuca Eradication and Other Exotic Plants Project. The Melaleuca Eradication and Other Exotic Plants Project is a CERP effort to deploy biological control agents for invasive species control. CERP funds were used to construct the Biological Control Rearing Annex, adjacent to the U.S. Department of Agriculture's Invasive Plant Research Laboratory in Davie, Florida, and the CERP provides operational funding of $660,000 per year to support biocontrol efforts for invasive plants in the Everglades (A. Dray, USDA, personal communication, 2022). Specific biological control agents, primarily insects, are developed and reared for release. Five particularly problematic invasive species are the focus of major ongoing management through the project: Melaleuca (*Melaleuca quinquenervia*), Brazilian peppertree (*Schinus terebinthifolia*), water hyacinth (*Eichhornia crassipes*), Old World climbing fern (*Lygodium microphyllum*), and air potato (*Dioscorea bulbifera*) (M. Smith, USDA, personal communication, 2022).

Melaleuca was once the most vigorously managed plant, but integrated control measures have reduced its spread by greater than 90 percent. Melaleuca is now under maintenance control, with greatly reduced herbicide and mechanical efforts. Biological control of Melaeuca is being continued and expanded. To assist in areas where the melaleuca weevil (*Oxyops vitiosa*), the most impactful insect, does not establish, the pea-galling melaleuca midge (*Lophodiplosis indentata*) will be introduced in 2023.

Brazilian pepper is one of the most widespread weeds in Florida and is also problematic in other areas. It has been primarily controlled by chemical and mechanical means, but two insect species have recently been approved for release. The first species, Brazilian pepper thrips (*Pseudothrips ichini*), is currently being mass reared and distributed. The second species, a leaf galler (*Calophya latiforceps*), is much more difficult to rear, and efforts are under way to obtain a colony for release.

Water hyacinth has been the focus of biological control efforts since the 1970s. Two weevil species (*Neochetina* spp.) have been successful in reducing water hyacinth biomass by greater than 70 percent, but further control is needed. The water hyacinth planthopper (*Megamelus scutellaris*) was released by the CERP project between 2010 and 2013, and best practices for its integration with herbicidal control are being studied by a project funded by the U.S. Department of Agriculture (USDA).

The Old World climbing fern is relatively resistant to chemical control and perhaps the most difficult invasive plant to mitigate. It is now actively managed by rearing and release of brown lygodium moth (*Neomusotima conspurcatalis*) caterpillars and the lygodium mite (*Floracarus perrepae*). The mite shows increasing promise as improved rearing conditions have led to its greater efficacy in controlling the fern.

Successful rearing and releases of a leaf-feeding beetle (*Lilioceris cheni*) have reduced air potato spread (Figure 3-21) to the extent that additional releases as part of the CERP are not warranted. The plant is no longer considered a priority invasive species by CERP managers (Overholt et al., 2016; Rayamajhi et al., 2019; M. Smith, USDA, personal communication, 2022).

CERP Projects in Planning: Western Everglades Restoration Project (WERP)

Planning for WERP (Figure 3-3, No. 6) started in August 2016. The project is intended to reestablish ecological connectivity, restore hydroperiods and pre-drainage distributions of sheet flow, restore low-nutrient conditions to reestablish native vegetation, and promote ecosystem resilience over a 1,200 mi^2 section of the western basin that includes Big Cypress National Preserve and lands of the Florida Seminole and Miccosukee tribes. WERP is one of a small number of CERP projects that address ecological degradation in the western Everglades.

Work conducted by the WERP Project Delivery Team (PDT) between 2016 and 2018 produced three restoration alternatives. Subsequent evaluation of these alternatives led to the development of a hybrid plan referred to as Alternative H (Alt-H), which included STAs, conveyance features to funnel water to historic sloughs, levee removal, canal infilling, and various flood protection features. The preliminary cost estimate for Alt-H was $1.2 billion.

Benefits calculations revealed that this plan was not cost-effective. The distal location of proposed STAs from areas needing treated water was identified as a principal culprit in increasing project complexity and raising costs. The high project costs, together with unmet need for an extensive real estate takings analysis, led to the suspension of WERP planning in 2019.

Despite its suspension, stakeholder support for WERP persisted. The WERP project delivery team gained approval for an exception to the 3x3x3 Smart Planning Policy in January 2022 to re-scope the project and complete the feasibility study. Re-scoping activities during and after the project pause culminated with the Hybrid Revised Alternative (Alt-Hr; Figure 3-22), the tentatively selected plan (TSP) that is currently under consideration.

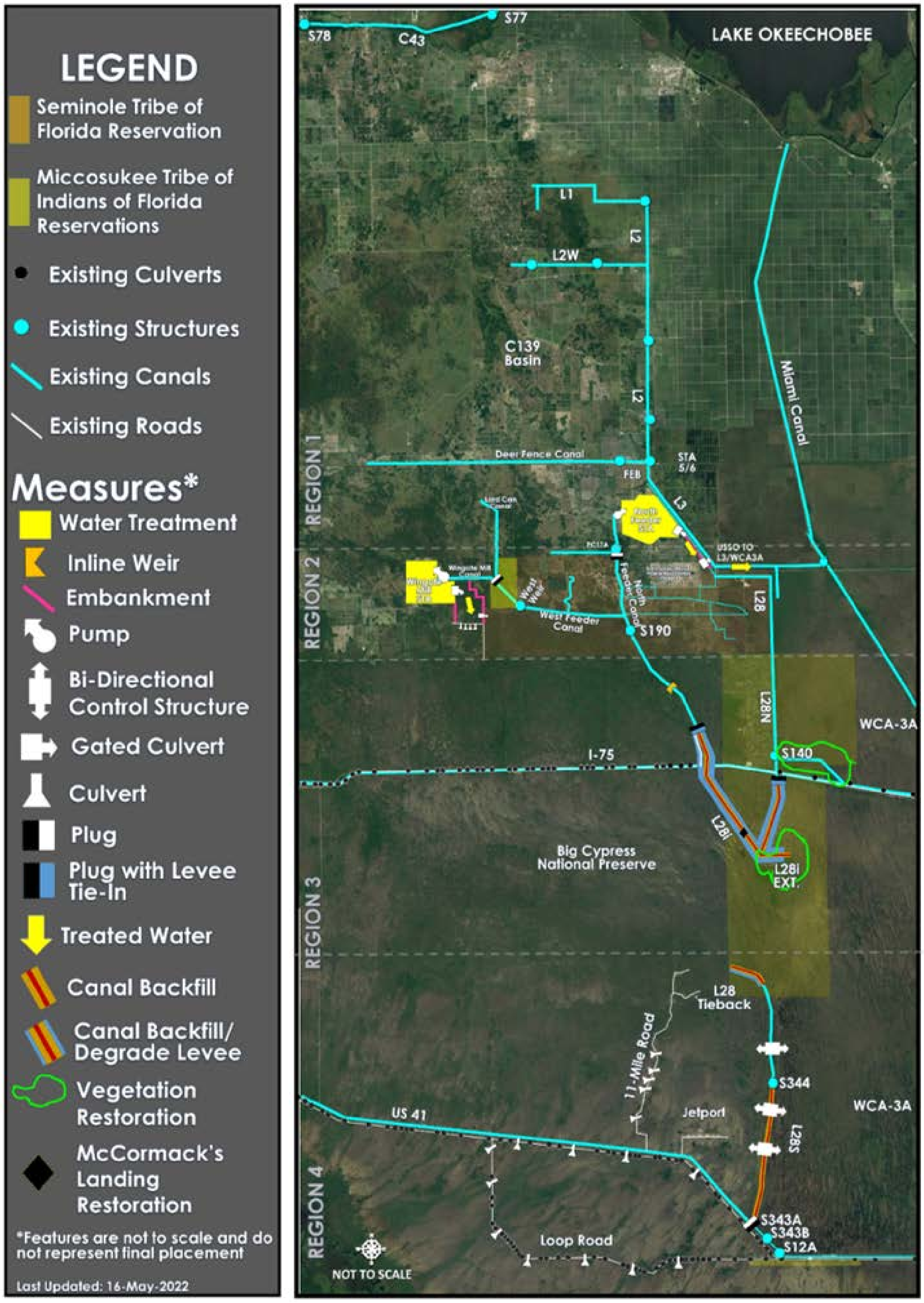


FIGURE 3-22 Components of Alt-Hr, the currently proposed WERP Tentatively Selected Plan. SOURCE: https://www.saj.usace.army.mil/WERP/.

Alt-Hr retains a combination of features identified from previously developed alternatives, as well as changes informed from model simulations completed since 2020. A principal feature of Alt-Hr is two STAs that will cover nearly 7,500 acres and treat runoff entering the northern portion of the project area. To promote sheet flow and conditions favorable for tree-island restoration within the central area of the project, canals that form the “Triangle” south of Interstate 75 (i.e., L-28i, L-28i extension, and L-28N) will be backfilled and their adjacent levees will be degraded. More canals, including the L-28 Tieback and L-28S, will be filled in the southern area of the project, where gated control structures on L-28S will be built to increase exchange between Big Cypress and WCA-3A, and culverts will be added beneath 11-Mile Road, US-41, and the Loop Road to enhance hydrologic connectivity and flows to the southwest (Figure 3-22).

The WERP project delivery team has targeted August 2022 for a final decision on the TSP, with the intention of submitting a Chief’s report to Congress in December 2023. If this timeline were met, WERP could be authorized as early as 2024.

Systemwide Operational Plans: The Combined Operational Plan

The Combined Operational Plan (COP) is a comprehensive, integrated water control plan that defines the operations of the constructed features of the recently completed Modified Water Deliveries to Everglades National Park (Mod Waters) and C-111 South Dade projects (Figure 3-23). It supersedes the Everglades Restoration Transition Plan (ERTP) as the water management plan for much of the central Everglades, including WCA-3 and its boundary with Everglades National Park, as well as the C-111 Basin. The non-CERP projects whose capabilities it incorporates are considered foundation projects for the CERP because they alter the delivery and flow of existing water in ways that are critical to the CERP’s capacity to deliver additional flow volumes and restoration benefits. In addition, completion of Mod Waters and its operations plan was required before federal funding could be appropriated to begin construction of the CEPP. Therefore, the implementation of the COP not only represents by far the largest step toward restoring the hydrology and ecology of the central Everglades yet achieved, but also marks the beginning of the next phase of the restoration of the heart of the Everglades embodied in the CEPP.

Two features of Mod Waters and other related projects are especially critical to the capacity of the COP to make significant changes to the hydrology of the central Everglades (Figure 3-23). First, raising the Tamiami Trail and bridging extensive portions of it enables increased flows into Northeast Shark River Slough and Everglades National Park, and much more of it as sheet flow (see Box 3-2). Second, seepage management and flood mitigation features, including the S-356 pump station, acquisition of roughly one-third of the 8.5 Square Mile Area, and construction of a levee to protect the remainder of this area from flooding, reduced flood risk management constraints that limited flows into Northeast Shark River Slough. The C-111 South Dade Project improved seepage management along the eastern boundary of Everglades National Park further south, enabling more flow through Taylor Slough to Florida Bay and reducing freshwater flows to Manatee Bay and Barnes Sound, while continuing to honor flood risk management constraints for the agricultural lands east of the park (USACE and SFWMD, 2020d). The C-111 SCW Project extends this hydraulic ridge southward, providing additional restoration benefits to Taylor Slough (see C-111 Spreader Canal, above).

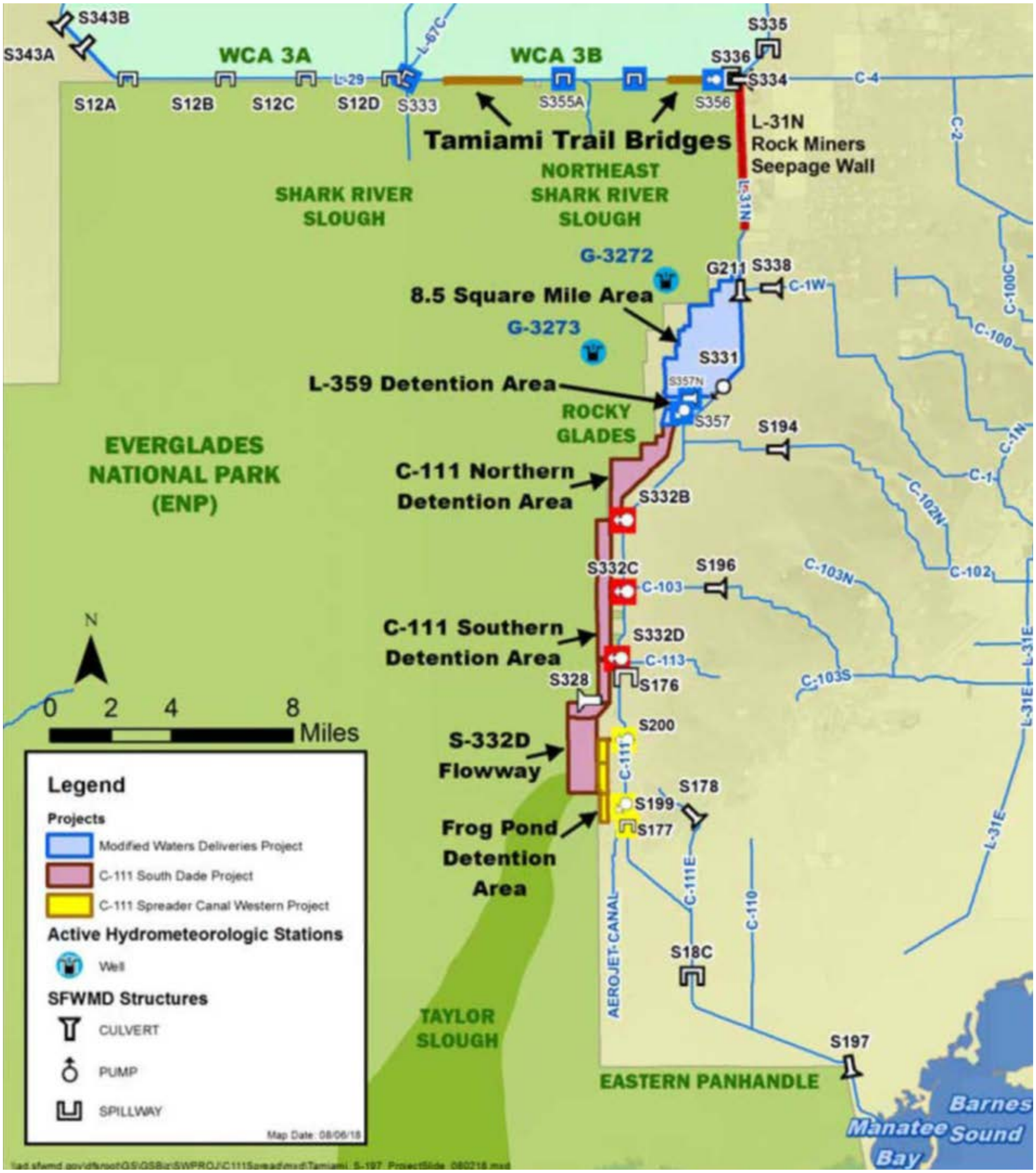


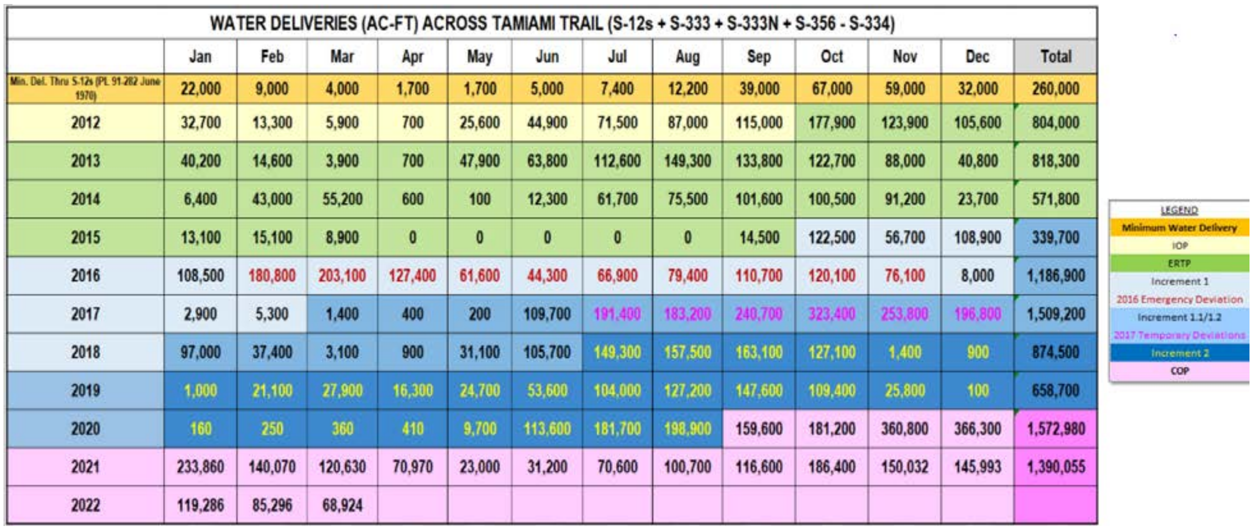
FIGURE 3-23 The non-CERP Modified Water Deliveries and C-111 South Dade projects, the Rock Miners seepage barrier (dark red in the figure), and the CERP C-111 Spreader Canal project all contribute to increased flows in Northeast Shark River Slough and Taylor Slough in Everglades National Park.
SOURCE: USACE, 2020d.

BOX 3-2
Tamiami Trail Next Steps Project

The 10.7 miles of the Tamiami Trail between the L31-N and L-67 extension levees has been an impediment to surface flow from WCA-3 into Northeast Shark River Slough in Everglades National Park since the completion of this highway in 1928. Reducing the impact of this barrier has been an important component of the restoration. The Modified Water Deliveries Project created a 1-mile bridge, completed in 2013, near the eastern end of this portion of the Trail. Phase 1 of the Tamiami Trail Next Steps project, completed in 2019, addressed an additional 2.6 miles of highway with 2.3 miles of bridging at the western end of the 10.7 miles of the Trail (Figure 3-24). The Tamiami Trail Next Steps Phase 2 project will reduce the impact of the remaining 6.7 miles of highway on sheet flow through the addition of six new 60-foot wide slab bridges, improvements to seven culverts, and raising of the highway in unbridged segments. Phase 2 construction began in 2021 and is projected to be completed in 2025 (R. Johnson, DOI, personal communication, 2022). With the completion of this project, the entire 10.7 miles of the Trail will have been modified, which will enable raising of the water level in the L-29 Canal to 9.7 feet to accommodate the CEPP, which will have a profound effect on capacity to manage water moving through WCA-3 into Everglades National Park. At that time managers anticipate developing a new water management plan that will replace the COP and that incorporates these new features.

FIGURE 3-24 Tamiami Trail Next Steps Phase 2 bridging and culvert locations, which complement road raising on the remaining unbridged segments (in yellow).
SOURCE: Johnson, 2020.

The ongoing ecological degradation of the central Everglades (see NRC, 2012 for a review) has long been a major concern motivating restoration efforts, and management of water in this area is a source of controversy. The COP is the latest in a series of water management plans that attempts to address the issues in this region. The development of the COP was informed by data gathered during a period of incremental operational testing, beginning in 2015. Thus, the hydrologic and ecological changes discussed in this section reflect incremental operational changes from 2015 to 2020 and full implementation of the COP in September 2020, which were made possible by the new infrastructure available from the Mod Waters, C-111 South Dade, and Tamiami Trail Next Steps projects.



WATER DELIVERIES (AC-FT) ACROSS TAMIAMI TRAIL (S-12s + S-333 + S-333N + S-356 - S-334)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Min. Del. Thru S-12s (PL 91-282 June 1970)	22,000	9,000	4,000	1,700	1,700	5,000	7,400	12,200	39,000	67,000	59,000	32,000	260,000
2012	32,700	13,300	5,900	700	25,600	44,900	71,500	87,000	115,000	177,900	123,900	105,600	804,000
2013	40,200	14,600	3,900	700	47,900	63,800	112,600	149,300	133,800	122,700	88,000	40,800	818,300
2014	6,400	43,000	55,200	600	100	12,300	61,700	75,500	101,600	100,500	91,200	23,700	571,800
2015	13,100	15,100	8,900	0	0	0	0	0	14,500	122,500	56,700	108,900	339,700
2016	108,500	180,800	203,100	127,400	61,600	44,300	66,900	79,400	110,700	120,100	76,100	8,000	1,186,900
2017	2,900	5,300	1,400	400	200	109,700	191,400	183,200	240,700	323,400	253,800	196,800	1,509,200
2018	97,000	37,400	3,100	900	31,100	105,700	149,300	157,500	163,100	127,100	1,400	900	874,500
2019	1,000	21,100	27,900	16,300	24,700	53,600	104,000	127,200	147,600	109,400	25,800	100	658,700
2020	160	250	360	410	9,700	113,600	181,700	198,900	159,600	181,200	360,800	366,300	1,572,980
2021	233,860	140,070	120,630	70,970	23,000	31,200	70,600	100,700	116,600	186,400	150,032	145,993	1,390,055
2022	119,286	85,296	68,924										

LEGEND
Minimum Water Delivery
IOP
ERTP
Increment 1
2016 Emergency Deviation
Increment 1.1/1.2
2017 Temporary Deviations
Increment 2
COP

FIGURE 3-25 Flows, in acre-feet, from across the Tamiami Trail from WCA-3 into Shark River Slough in Everglades National Park, contrasting flows under ERTP (2012-2016) to those under the incremental testing phase (2016-2020) and full implementation (2020-2022) of the COP. SOURCE: Vélez, 2022b.

Hydrologic Changes. Significant changes in hydrology relative to the ERTP occurred during this incremental testing (NASEM, 2021), and others occurred when the COP became fully operational in 2020. Early indications are that flows across the Tamiami Trail into Shark River Slough in Everglades National Park will be increased significantly under the COP compared to previous water management plans (Figure 3-25). Changes in the distribution of that flow have been even more dramatic, with a shift to greater flows in Northeast Shark River Slough compared to West Shark River Slough, better matching historic patterns. This shift in the distribution of flow from west to east has been an objective of numerous projects for decades, with virtually no progress. The rapid progress that has been made toward this goal during the past 5 years contrasts markedly with the lack of progress during the previous 50 years under the water management plans that preceded the COP (Figure 3-26). The magnitude of these changes is such that the COP can be viewed as succeeding where previous plans have failed. Therefore, the implementation of the COP can be viewed as a landmark event in the restoration of the Everglades, demarcating a shift from a long phase of restoration planning to a new phase of implementing restoration actions and evaluating their success.

The COP began to govern water management operations roughly half-way through WY 2021, and water managers began to employ the Tamiami Trail Flow Formula (TTFF) (SFWMD, 2019) to regulate operations in the latter stages of that water year, in March 2021. Ecological objectives are a greater consideration in daily operations under the COP than they were under previous water management plans that focused almost exclusively on hydrologic targets. As of this writing, the first full water year of operations under COP (i.e., WY 2022) has recently been completed, and the first biennial report evaluating the performance of the COP is being drafted. The information available suggests that the TTFF has been effective in hitting targets for rising water in the wet season and some recession rates in the dry season (Figure 3-27), although stages have been higher than expected in northern WCA-3A. Managers are pleased with the effectiveness of operations management meetings, which include biologists, in making

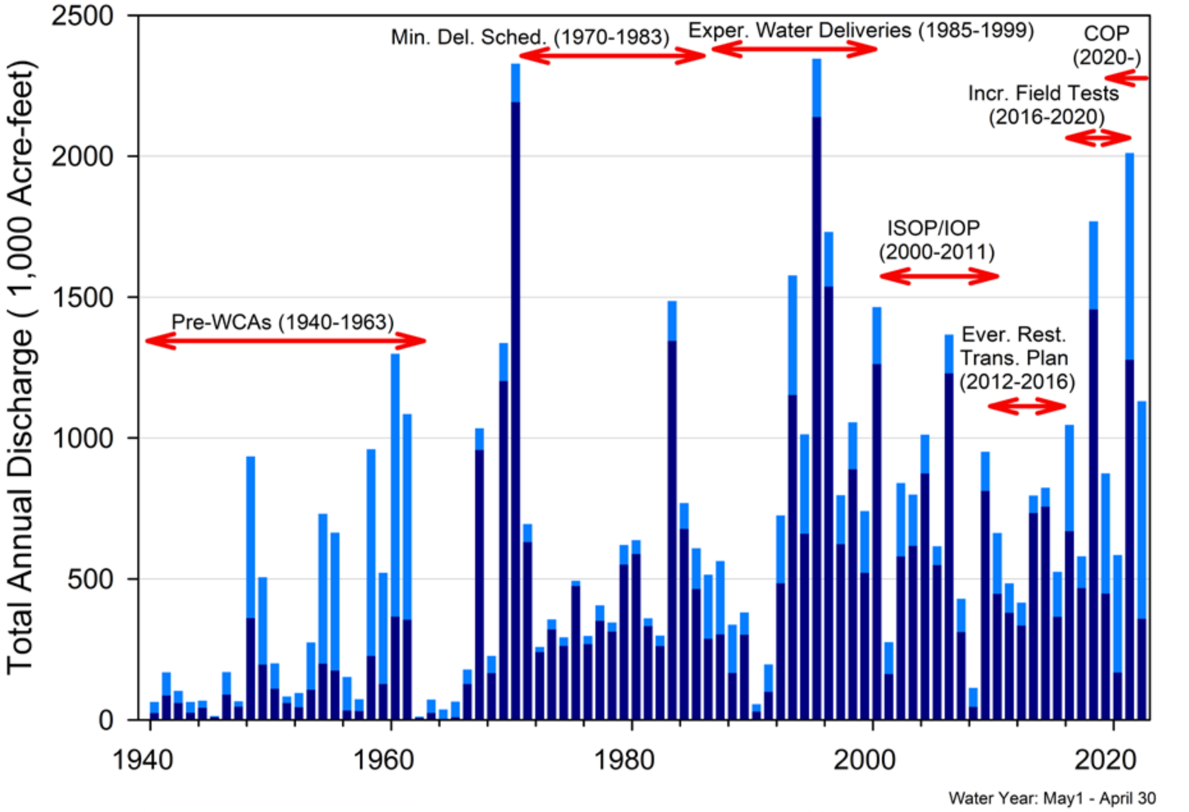


FIGURE 3-26 Water discharges into Everglades National Park by way of Western Shark River Slough (dark blue) and Northeast Shark River Slough (light blue). The red arrows demarcate the water management plans that governed water flows through these pathways from 1940 to 2020. SOURCE: R. Johnson, NPS, personal communication, 2022.

adjustments to operations that enable meeting of targets (J. Redwine, NPS, personal communication, 2022).

Constraints related to flood control in the 8.5 Square Mile Area have been a major obstacle preventing significant ecological restoration in the central Everglades prior to the COP (NASEM, 2021). These constraints continue to hinder operations: there were four events in which these constraints affected operations in WY 2021—a high water year with much of the flow through Western Shark River Slough (Figure 3-26)—and two more in WY 2022. However, these constraints promise to be greatly reduced by the construction of a seepage barrier along the boundary between the 8.5 Square Mile Area and Northeast Shark River Slough (Figure 3-20). Construction of 2.3 miles of this curtain wall, funded by the SFWMD, is due to be completed in September 2022. CEPP New Water will extend this seepage barrier northward along the remaining 4.9 miles of this boundary (see previous discussion about the CEPP). Initial indications of the extent to which the first portion of the seepage barrier reduces constraints on COP operations should be evident in WY 2023.

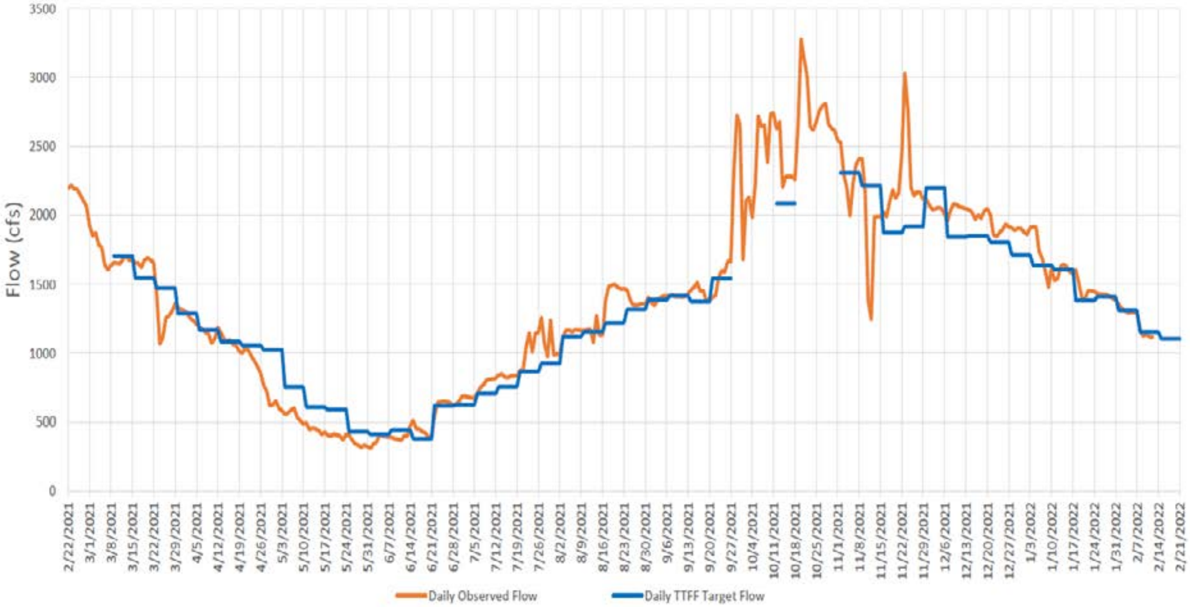


FIGURE 3-27 Targets for flows into Everglades National Park (blue) from WCA-3A and realized flows (orange) using the Tamiami Trail Flow Formula from February 2021 through February 2022.
SOURCE: SFWMD, 2022b.

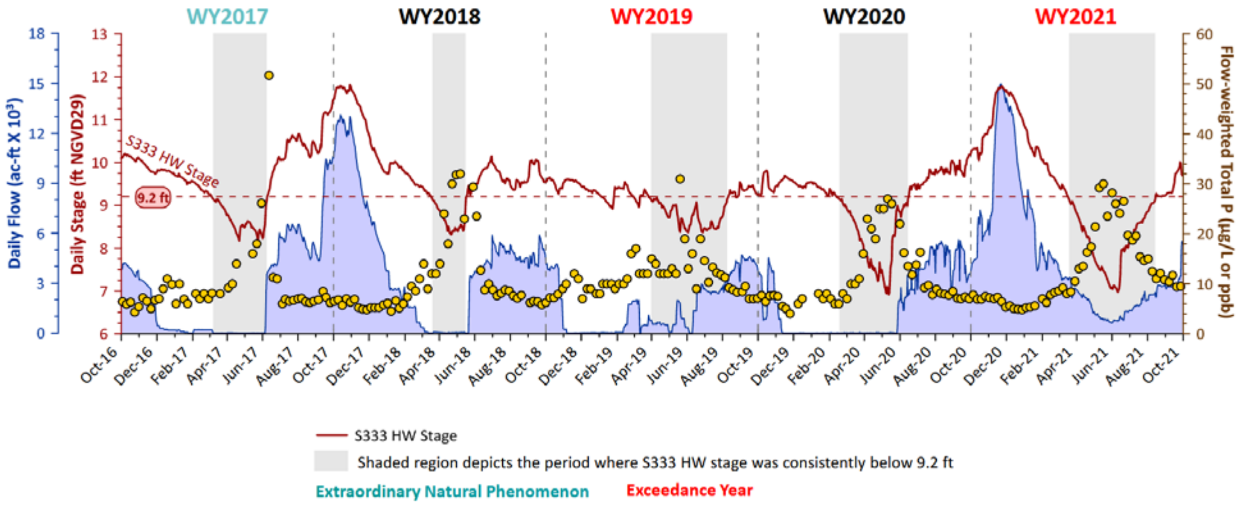


FIGURE 3-28 Flow-weighted mean phosphorus concentrations (yellow dots) and flows into Shark River Slough (blue shading), compared to the stage at S-333, reflecting the stage of southern WCA-3A. High total phosphorus concentrations in the dry season resulted in an exceedance of water quality limits when dry season flows were relatively high in WY 2019 and WY 2021, but not in WY 2018 and WY 2020 when dry season flows were negligible.
SOURCE: Qiu, 2022.

Unfortunately, water quality may be emerging as a new potential constraint on COP operations. Water quality compliance in Everglades National Park is assessed according to methods outlined in Appendix A of the 1991 Settlement Agreement between the State of Florida and the federal government (see SFWMD [2009a] for details). Under the Settlement Agreement, flows that enter Everglades National Park must meet a "long-term limit" for total phosphorus (TP), which is tracked monthly and assessed annually for compliance based on the flow-weighted mean TP concentration over the previous 12 months. This long-term TP limit, calculated monthly, decreases as flow increases. Qui (2022) and Surratt (2022) note that high concentrations of phosphorus occur in water flowing from WCA-3A into Shark River Slough when the headwater stage is low, specifically below 9.2 feet at the S333 (and now S333-N) water control structure. Increased flow into Northeast Shark River Slough under COP includes more flow under these conditions, and indeed such flows contributed to exceedances of the long-term limit in both WY 2019 and WY 2021 (Figure 3-28). Research on the causal factors and ways to mitigate these effects is an ongoing effort to prevent water quality constraints from limiting the quantity of flows through Northeast Shark River Slough.[6]

Ecological Changes. Increased hydration of Northeast Shark River Slough and Taylor Slough under the COP are expected to result in a myriad of ecological effects, many of which are viewed as restoration benefits (NASEM, 2021; USACE, 2020b). Of special concern are changes to marl prairie habitats occupied by Cape Sable Seaside Sparrows (CSSS), an endangered subspecies endemic to Everglades National Park. In the 1980s and early 1990s, the species was distributed in two large subpopulations (A, B), one medium-sized subpopulation, E, and three small subpopulations (C, D, F) (Figure 3-29; FWS, 2020). High water conditions in Western Shark River Slough in the mid-1990s led to greatly extended hydroperiods in the marl prairie occupied by subpopulation A, causing a dramatic decline of this population in (Walters et al., 2000). Subsequently, subpopulation A has declined further to near extirpation, and the other small subpopulations have at times declined to near extirpation because of conditions that were too wet or too dry (i.e., extended or reduced hydroperiods), whereas subpopulations B and E have maintained their status as large and medium-sized subpopulations, respectively (FWS, 2020; Walters et al., 2000). Because of increased flows to Northeast Shark River Slough and Taylor Slough, the COP is expected to increase hydroperiods in the adjacent marl prairie areas. Increased hydroperiods are expected to result in changes in vegetation that affect CSSS habitat suitability and, ultimately, sparrow numbers. Wetter conditions are expected to result in reductions in CSSS habitat suitability in some currently suitable habitats (subpopulations D and E) and increases in habitat suitability in other areas that currently are too dry (subpopulations C and F) (Figure 3-29). Similarly, reduced flows in western Shark River Slough are expected to improve habitat suitability in some areas of subpopulation A that currently are too wet, particularly in areas near Shark River Slough (northern AX in Figure 3-29) that are outside the historical boundaries of the subpopulation. Further hydroperiod changes are expected under the CEPP, which will provide increased flows to Northeast Shark River Slough (USACE, 2014a; FWS, 2014), consistent with restoration goals for the marl prairies.

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[6] This paragraph was edited following prepublication release of the report to clarify the timing of compliance assessments as well as the level of understanding of water quality concerns and drivers.

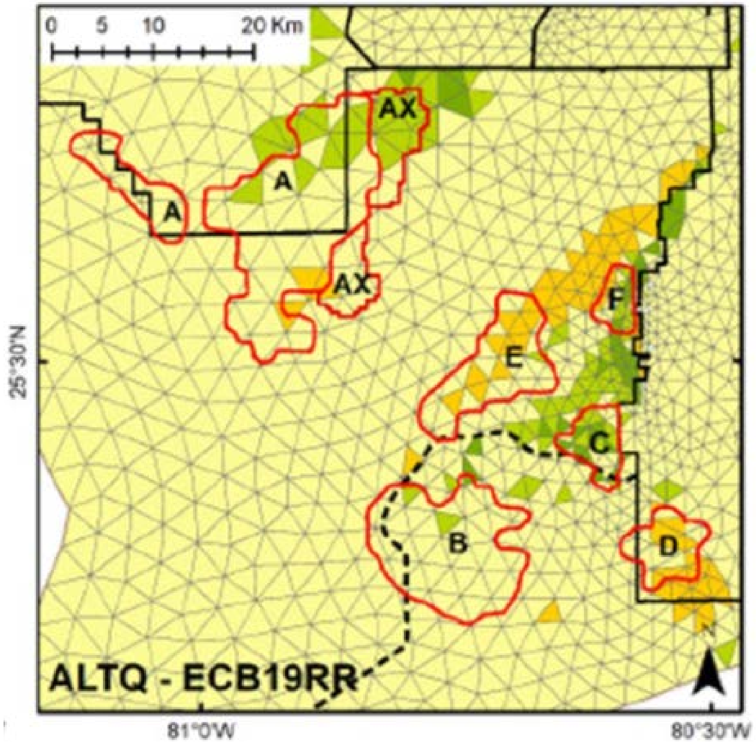

FIGURE 3-29 Predicted changes in marl prairie habitat suitability for the six subpopulations of Cape Sable Seaside Sparrows (A-F, outlined in red) under the COP compared to the pre-COP baseline conditions. Orange indicates predicted reductions in habitat suitability, and green indicates improvements in habitat suitability. AX indicates new habitat outside of the historical boundaries of subpopulation A in which sparrows have recently been observed.
SOURCE: USACE, 2020b.

The projected changes depicted in Figure 3-29 do not fully represent the impact of the new non-CERP infrastructure COP employs on marl prairie habitat because the predictions are based on comparison to a baseline that includes the impact of the incremental testing conducted during the development of the COP. Much of the benefit of the new infrastructure resulting from the Mod Waters and C-111 South Dade projects was realized during the incremental testing (NASEM, 2021). This is particularly the case for changes impacting sparrow habitat, specifically the redistribution of flow between Western and Northeastern Shark River Slough (Figure 3-26). Thus, one expects that sparrow habitat suitability would have begun to shift in the pattern depicted in Figure 3-29 during the incremental testing, and will continue to do so under COP. The available evidence suggests that this is the case, for both hydrology and the changes in vegetation representing the anticipated ecological response to altered hydrology that impacts sparrow habitat suitability.

Available vegetation mapping and hydroperiod data enable a comparison between average conditions during the incremental testing phase of the COP (data have been collected in 2017-2020 for Shark River Slough and in 2018 for Taylor Slough) to conditions prior to ERTP (2003-2005 for Shark River Slough, 2011 for Taylor Slough). These data suggest that, consistent with planning projections, within marl prairie habitat adjacent to Northeast Shark River Slough, hydroperiods generally have become longer. That is, sparrow habitat has become wetter, compared to pre-COP conditions, as employment of new infrastructure associated with the COP has begun, including in portions of subpopulations E where wetter conditions are projected to have adverse effects on habitat suitability, and in portions of subpopulation C and all of subpopulation F where the effects on habitat suitability are expected to be positive (Figure 3-30). Also as predicted, hydroperiods have decreased in the northernmost areas of subpopulation A, including in areas east of the historical boundary of this subpopulation (hN in Figure 3-30). This change is projected to create new habitat suitable for CSSS in this area. South of this area, the flows from the west that have compromised attempts to reduce hydroperiods in subpopulation A continue to maintain wet conditions despite reduced flows to Western Shark River Slough under the COP (Sah et al., 2021). WERP (see above) is expected to help reduce flows from the west, potentially substantially enough to restore habitat for sparrows within the southern portion of subpopulation A (FWS, 2020).

These changes in hydrology should result in ecological changes that impact habitat for sparrows. Most importantly, changes in hydroperiod are expected to cause transitions between vegetation communities that differ in their suitability for sparrows. The vegetation that occurs in the marl prairies that sparrows occupy has been classified into nine communities that vary along a hydroperiod gradient (Ross et al., 2006). Those at the shorter hydroperiod end of the gradient are classified as wet prairies (in order of increasing hydroperiod: *Muhlenbergia* (muhly grass) Wet Prairie, *Schizachyrium* (bluestem) Wet Prairie, *Schoenus* (black sedge) Wet Prairie, *Cladium* (sawgrass) Wet Prairie). Those at the longer hydroperiod end are classified as marshes (in order of increasing hydroperiod, *Paspalum-Cladium* [knot grass-sawgrass] Marsh, *Cladium* Marsh, *Cladium-Rhynchospora* [sawgrass-beaksedge] Marsh, *Rhynchospora-Cladium* Marsh, *Eleocharis-Rhynchospora* [spikerush-beaksedge] Marsh). Discontinuous hydroperiods of 90-210 days are considered optimal for CSSS (FWS, 2020), roughly matching the hydroperiods of wet prairie as opposed to marsh communities, as well as the range of hydroperiods in habitat with the highest rates of occupancy by sparrows. Although vegetation conditions suitable for sparrows occur over a wider range of hydroperiods (60-270 days), habitat with a hydroperiod of fewer than 90 days is prone to fire and encroachment of woody vegetation, both of which greatly reduce its suitability for sparrows. Habitat with a hydroperiod of more than 210 days is unlikely to support sparrows long term as it will eventually convert from wet prairie to marsh (Arementano et al., 2006; Sah et al., 2014). The greater height and density of vegetation as well as species composition of marsh communities is unfavorable for sparrow nesting and foraging compared to wet prairie communities (Ross et al., 2006).

Thus, transitions between wet prairie and marsh vegetation in response to alterations in hydrology are of great interest. This is a particularly appropriate ecological response to assess in the early years of the transition to the COP because it can occur very quickly, in only 3-4 years (Armentano et al., 2006; Sah et al., 2014). In subpopulation E where adverse effects of wetter conditions on habitat suitability are expected (Figure 3-29), conversion of wet prairie to marsh has been considerable and most of the birds are now occupying *Cladium* Marsh or the wet prairie habitat with the longest hydroperiod, *Cladium* Wet Prairie (Figures 3-31 and 3-32). In contrast, in subpopulation F where the considerable increases in hydroperiod that have occurred were projected to improve habitat suitability (Figure 3-29), almost no conversion of wet prairie to marsh has occurred (Figure 3-31) and the birds occupy the full range of wet prairie habitats (Figure 3-32) that, being wetter, have become less vulnerable to fire and encroachment of woody vegetation (Sah et al., 2021).

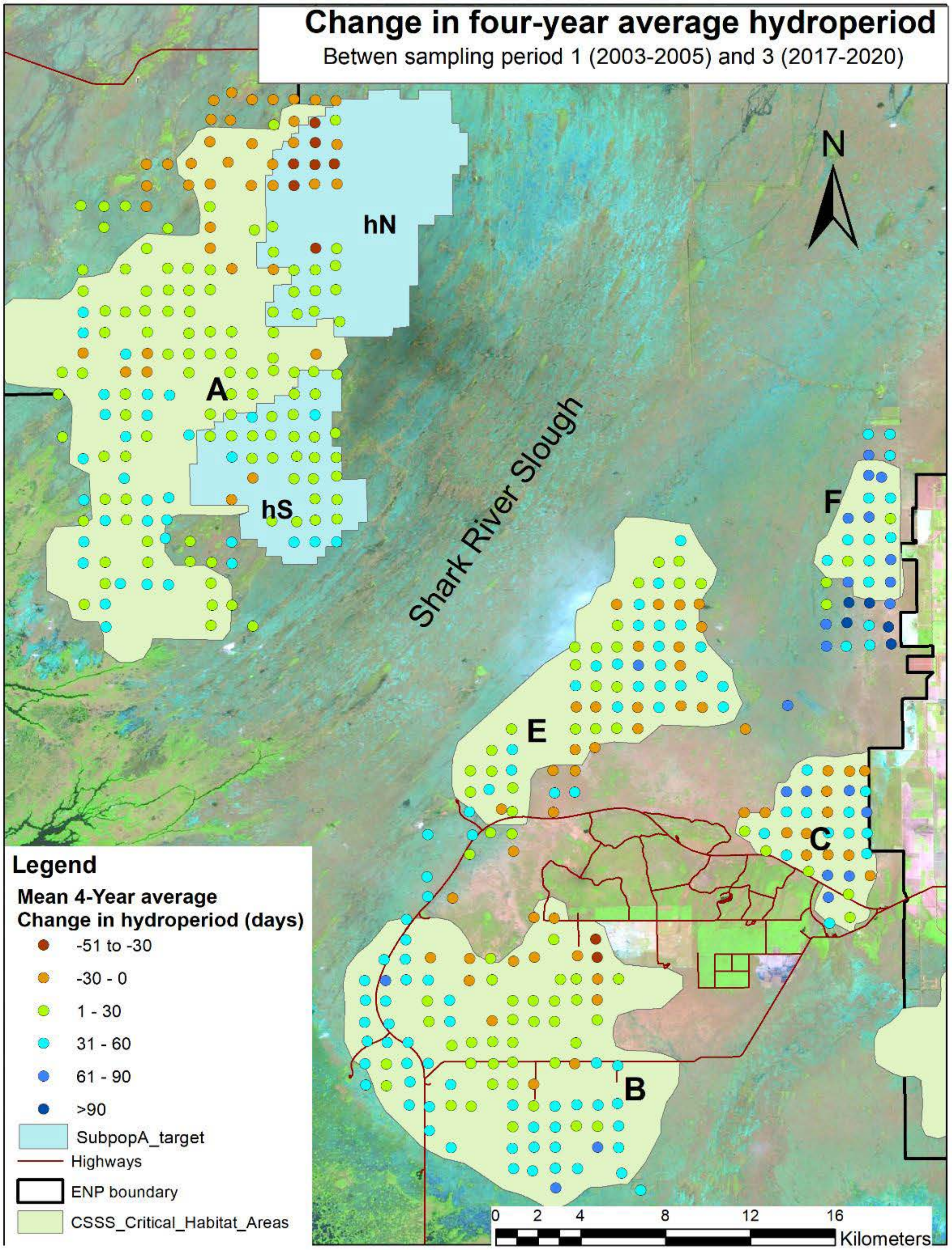

FIGURE 3-30 Change in 4-year mean discontinuous hydroperiod between 2003/2005 and 2017/2020 survey periods at vegetation survey sites in CSSS subpopulations A, B, C, E, and F. SOURCE: Sah et al., 2021.

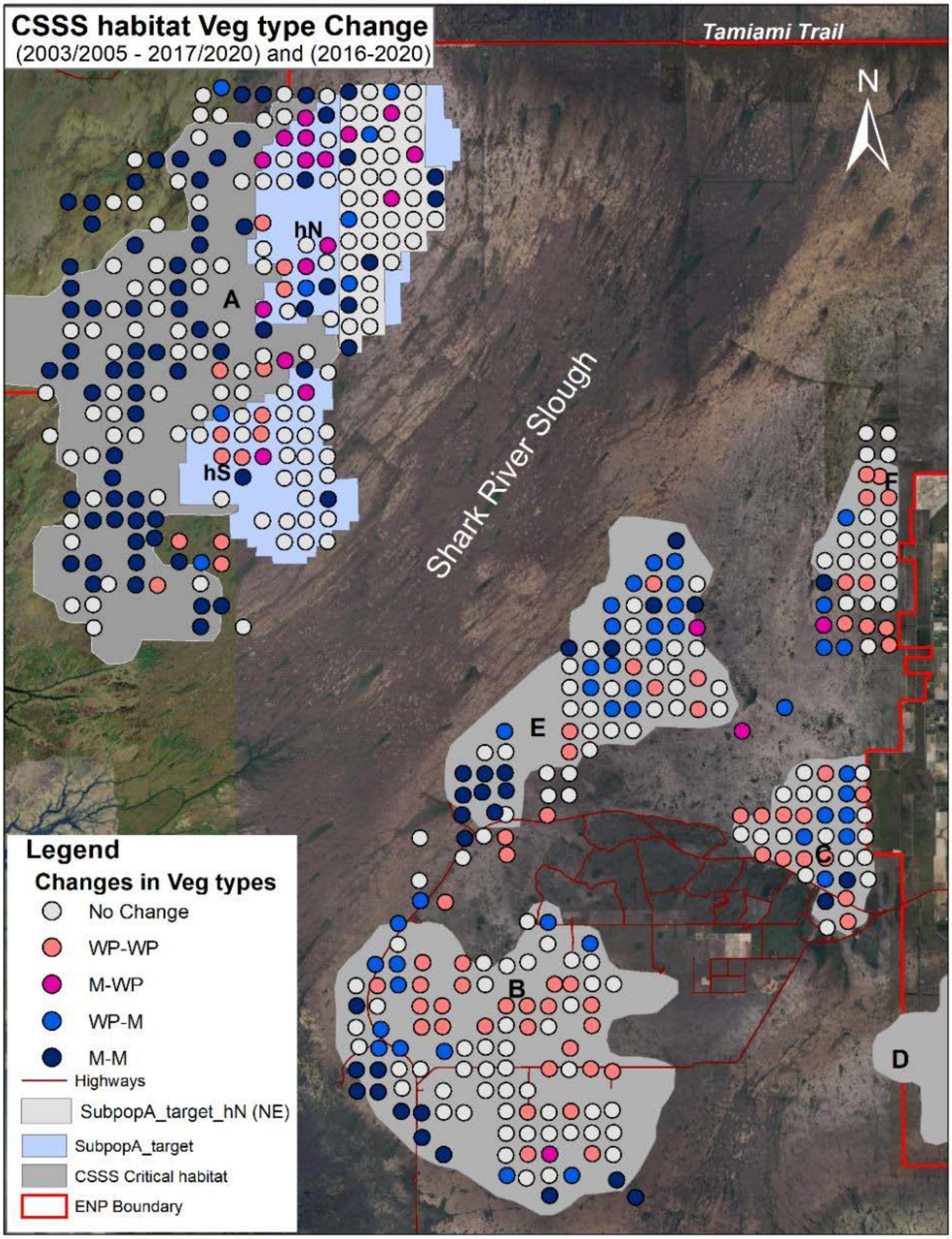

FIGURE 3-31 Change in vegetation types in habitat in CSSS subpopulations A, B, C, E, and F between 2003/2005 and 2017/2020 surveys. WP-WP = one wet-prairie vegetation type to another wet-prairie vegetation type; M-WP = marsh vegetation type to wet prairie vegetation type; WP-M = wet-prairie vegetation type to marsh vegetation type; M-M = one marsh vegetation type to another marsh vegetation type.
SOURCE: Sah et al., 2021.

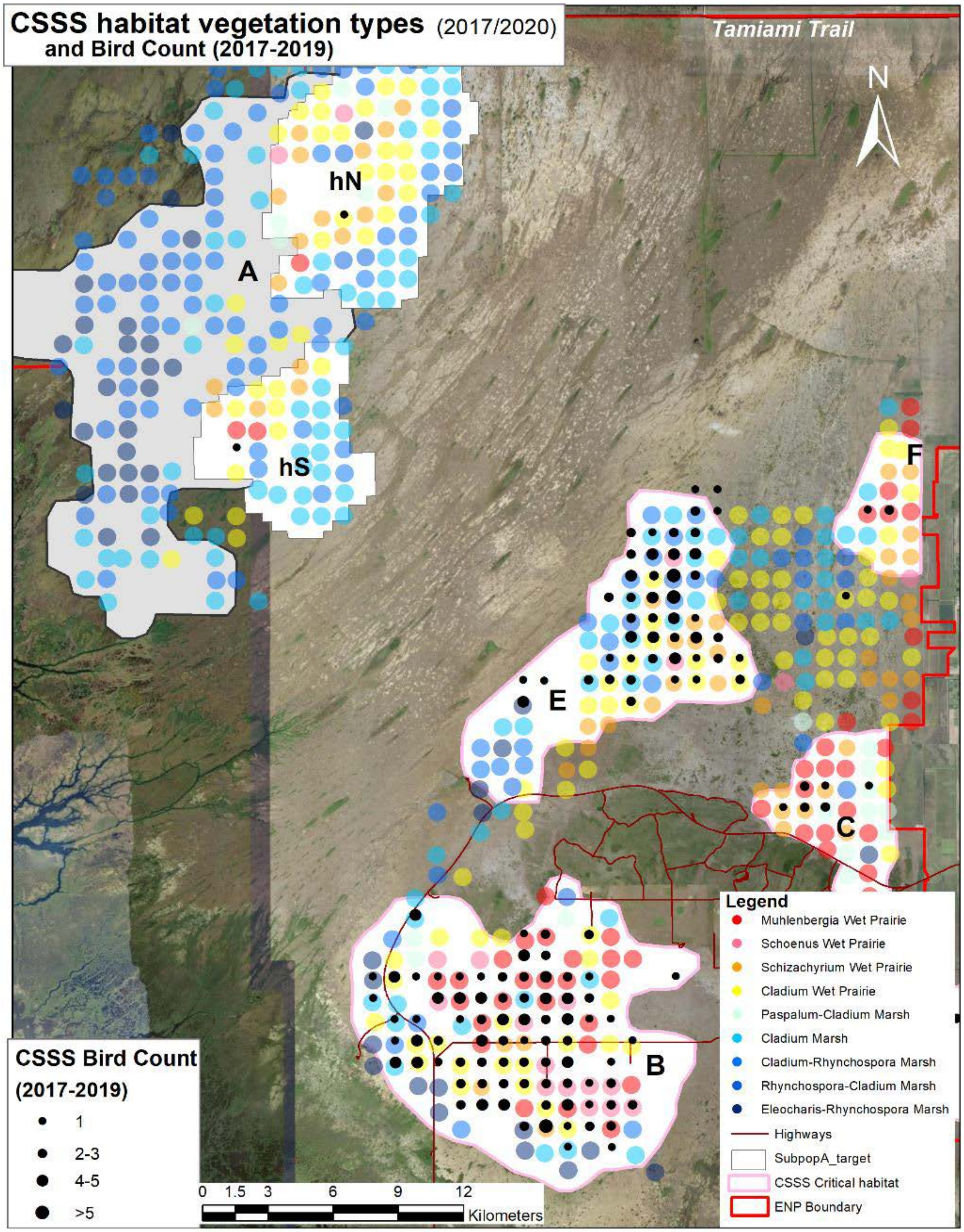

FIGURE 3-32 Map showing the vegetation types at the CSSS census sites surveyed between 2017 and 2020 and the number of birds observed at each point during the annual sparrow surveys over 3 years (2017-2019).
SOURCE: Sah et al., 2021.

Conversion of marsh to wet prairie is almost exclusively limited to an area where drier conditions were predicted to improve habitat for CSSS (northern AX in Figure 3-29) in the new habitat in the northeastern portion of subpopulation A beyond the boundaries of the historical population (hN in Figures 3-30 and 3-31). A significant amount of wet prairie habitat now exists in this area (Figure 3-32). However, reduced hydroperiods in the northern portion of the historical subpopulation A have not resulted in conversion of marsh to wet prairie such that this area remains marsh, most of which consists of communities at the long end of the hydroperiod gradient (Figures 3-30 to 3-32). Thus, the projected improvements in habitat suitability in this area have not yet occurred.

Improvements in habitat suitability are also projected to occur in much of the area not historically occupied by sparrows between subpopulations C, E, and F (Figure 3-29). Although sampling is not sufficient to fully document changes in hydrology (Figure 3-30) or vegetation communities (Figure 3-31) in this area, a considerable amount of wet prairie now exists there (Figure 3-32). Finally, hydroperiods have become longer in a considerable amount of the habitat in subpopulation B (Figure 3-30), resulting in some conversion of wet prairie to marsh along the edges of the subpopulation (Figure 3-31). However, an extensive area of wet prairie still remains, with mostly longer hydroperiod prairies closer to the edge of the subpopulation adjacent to the slough and mostly shorter hydroperiod communities away from the edge (Figure 3-32). Thus, to date no major changes to habitat suitability in subpopulation B have occurred.

Habitat in the area of Taylor Slough occupied by subpopulation D, as predicted (Figure 3-29), has become wetter, resulting in considerable conversion of wet prairie to *Cladium* Marsh (Sah et al., 2020) and, thus, reductions in habitat quality (Figure 3-33). Considerable wet prairie still remains in subpopulation D, however (Figure 3-33b) (Sah et al., 2021).

Overall, the patterns described above are consistent with the anticipated impact of operations employing CERP and non-CERP infrastructure (Figure 3-23) under the COP on marl prairie habitats in Everglades National Park occupied by CSSS. Thus, there is evidence of progress in producing the desired hydrologic and ecological restoration benefits in this portion of the central Everglades. The latter benefits are complicated, because achieving restoration goals, as expected, is resulting in negative as well as positive effects on sparrow habitat. The ultimate ecological change will be the redistribution of the sparrow population in response to the redistribution of its habitat, which will require occupation of new wet prairie habitat, as well as mitigating declines in sparrow numbers in habitat that converts from wet prairie to marsh. To date, only a few sparrows have been detected in new wet prairie habitat in hN and the area between subpopulations C, E, and F, and sparrows remain in habitat that has converted from wet prairie to marsh in subpopulation E (Figure 3-32). It is too early to determine how the sparrows will respond to changes in hydrology and vegetation communities within their habitat, but that the restoration effort will result in major changes in the marl prairies is already evident.

The above examination of changes in marl prairie habitats in no way constitutes an assessment of the performance of the COP, or of the impact of projects such as Mod Waters, C-111 South Dade, or C-111 Spreader Canal. Nor is it an assessment of their contributions toward achieving restoration benefits. Such an assessment will require isolating effects of operations or projects from natural variability in system drivers such as rainfall by comparing empirical observations to model predictions. That is, predicted results of operations under current conditions must be compared to observed results and to model predictions of the same area without the project features. Accomplishing this will require dedication of resources to support such Nearcast modeling and to update models with recent precipitation data (see NASEM, 2021).

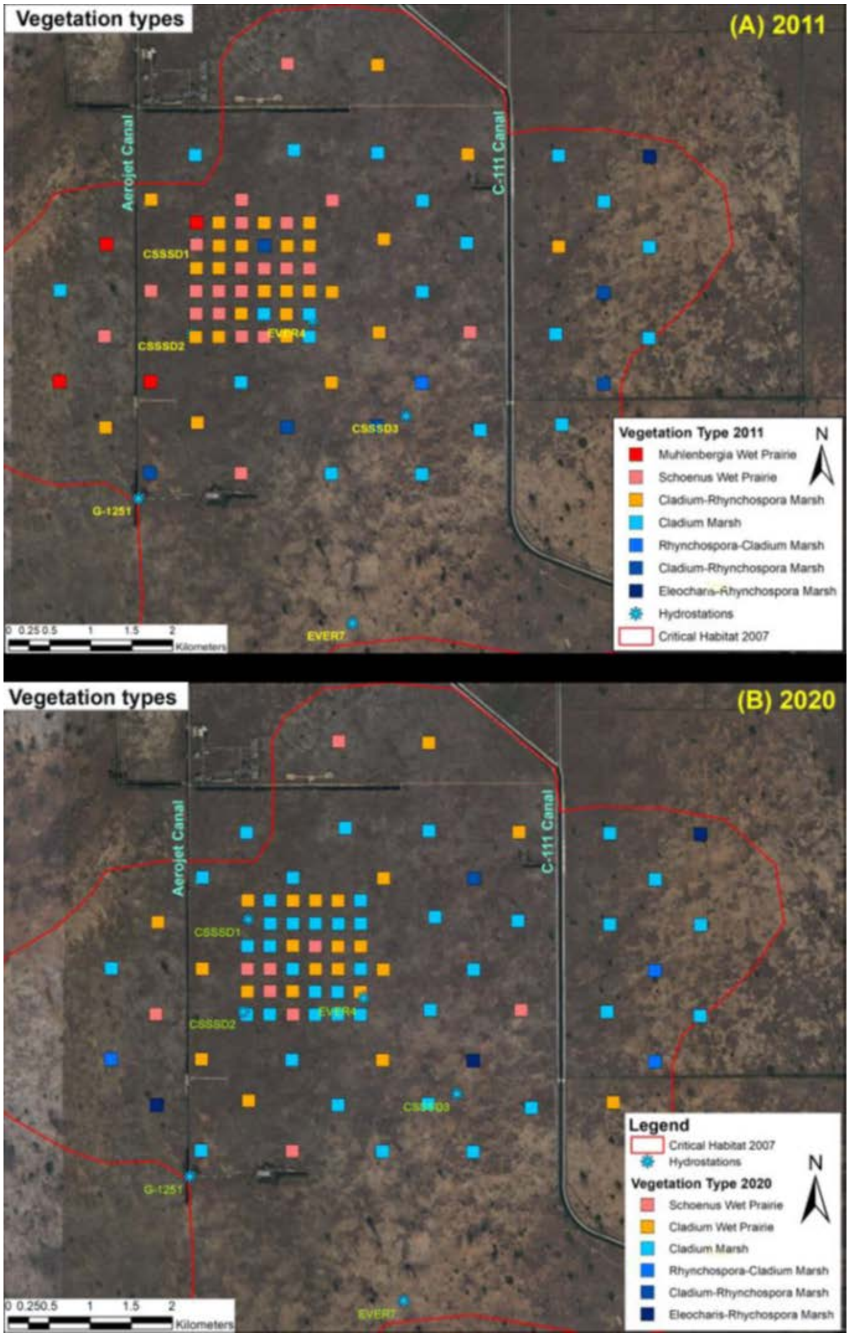

FIGURE 3-33 Vegetation types in the habitat of CSSS subpopulation D in (A) 2011 and (B) 2018. Note that in (A) orange depicts *Cladium* Marsh, not *Cladium-Rhynchospora* Marsh as indicated in the legend.
SOURCE: Sah et al., 2020.

Southern Coastal Systems

Historically, Biscayne Bay received freshwater from overland flow passing through the coastal ridge and wetlands, and from extensive groundwater seepage. As a consequence of historical hydrologic alteration and development, freshwater delivery to Biscayne Bay has been greatly reduced, particularly in the dry season, resulting in loss of wetlands and an increase in salinity along the western margin of the bay. At the same time, controlled freshwater pulse discharges as point sources create altered flow, salinity, and nutrient inputs into the bay. Freshwater wetlands in the Southern Everglades have been reduced in area, altered, and degraded because of water management practices, land development, and sea-level rise. Much of the Model Lands, Southern Glades, and South Dade Wetlands are drained. Water elevations are generally held close to or below land surface and diverted by drainage structures toward other basins and canals. Existing salinity conditions have contributed to landward expansion of saltwater and mangrove wetlands, including low-productivity, sparsely vegetated dwarf mangroves, as well as invasive exotic vegetation. The Biscayne Bay Coastal Wetlands (BBCW) Phase 1 Project (Figure 3-34), currently under construction, and the Biscayne Bay and Southeastern Everglades Restoration (BBSEER) Project in planning, seek to address these issues.

FIGURE 3-34 Biscayne Bay Phase 1 coastal wetlands project locations.
SOURCE: Charkhian, 2022a.

CERP Projects in Progress: BBCW Phase 1

The primary goal of the BBCW Project (Figure 3-3, No. 7) is to reduce near-shore salinity and improve the ecological condition of wetlands, tidal creeks, and other habitats by increasing freshwater flows to Biscayne Bay and Biscayne National Park. The full BBCW Project, as outlined in the Yellow Book (USACE and SFWMD, 1999), envisioned restoration of wetland hydroperiods to 11,300 acres of the total 22,500 acres of wetlands. The footprint of Phase 1 of the BBCW Project is small; its goals are to restore about 400 acres of freshwater wetlands and increase water flows in another approximately 2,000 acres in three geographically distinct components: the Deering Estate Component, just north of the Biscayne Bay National Park, and the Cutler Wetlands and L-3lE Flow-way Components, portions of which are within the national park (Figure 3-34).

Project implementation includes construction of pump stations, spreader canals, and culverts, and the reestablishment of flow-ways (USACE, 2019b). The Deering Estate Component (Figure 3-35) was completed in 2012, and the L-31 E Flow-way is under construction with completion expected in 2025. Construction of the Cutler Wetlands component is scheduled to begin in September 2022 (Charkhian, 2022a). Documented restoration benefits to date from the implemented project components are discussed below.

Deering Estate Pump Station (S-700)

Coastal Structure S-123 on C-100 canal

Deering Estate component features

FIGURE 3-35 Deering Estate Component features, showing insets of the S-700 pump station, which diverts water from discharge in the C-100A Canal through the S-123 Canal structure. Purple colored squares are the project-specific salinity monitoring stations.
SOURCE: Modified from Charkhian, 2022a.

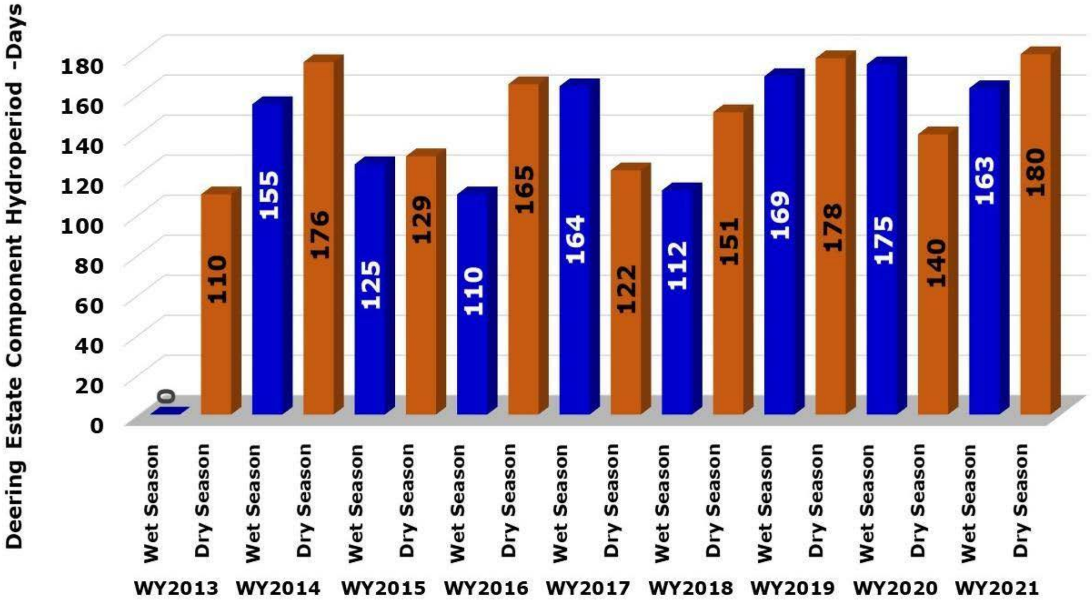

FIGURE 3-36 Hydroperiod (number of days per year that the ground is either saturated or covered with water) in the Deering Estate Component area.
SOURCE: Charkhian, 2022a.

Deering Estate. The S-700 pump station on the C-100A Spur Canal within Deering Estate is designed to restore historic freshwater flows through the Cutler Drain Slough and into the coastal wetlands, reducing near-shore salinity. The hydrologic goal was to redirect up to 100 cfs of water from the C-100A Spur Canal to the coastal wetlands (Figure 3-35), thereby reducing point source freshwater discharges. To alleviate the hydrologic flashiness that occurred with intermittent pulsed releases, in WY 2019 the SFWMD moved to continuous pumping at a minimum rate of 25 cfs (Charkhian, 2022a), which seems to have improved the hydration and increased the hydroperiod in the remnant wetlands over approximately 19 acres in this project area underlain by extremely porous limestone (Figure 3-36).

In WY 2020 and WY 2021, the S-700 pump station diverted 30,951 and 36,948 AF to the coastal wetlands that would have otherwise been discharged through the S-123 structure (Charkhian, 2022b), thereby reducing a driver of variability in near-shore salinity. However, near-shore monitoring stations (see Figure 3-35) show that salinity remains well above the mesohaline target of 5 to 18 psu (Charkhian 2022a), suggesting that much more water would be needed to reach near-shore restoration targets in this region.

L-31E Flow-way. The goal of the L-31E Component is to improve habitat conditions by diverting water that would normally be released through the L-3lE Canal to the adjacent coastal wetlands via 10 newly constructed culverts, thereby lowering near-shore salinities. A chronic challenge for the project is an insufficient supply of freshwater that limits flows from the canal through the L-3lE culverts and into the wetlands. This condition is partially due to the lack of pumps to move water into the canal and raise and maintain canal stage high enough (stage target level is 2.2 feet NGVD) to promote outflow through the culverts. The USACE is expected to finish construction of the L-31E Component in 2025, which will include a total of five pump stations (USACE, 2022d). Overall, there is little to report in terms of substantial new ecological

TABLE 3-4 CERP Projects Integrated into the BBSEER Planning Effort

Project	Goal
BBCW, Phase 2 (No. 4 in Figure 3-37)	Rehydrate coastal wetlands and improve near-shore salinity conditions in Biscayne Bay. The project was intended to help restore wetland and near-shore estuarine habitats by diverting coastal structure flows into freshwater and saltwater wetlands instead of directly to Biscayne Bay. BBSEER will include all remaining components of the BBCW preferred alternative, Alternative O, as well as the BBCW1 components that have been completed.
BBC Canals (No. 5 in Figure 3-37)	
C-111 Spreader Canal Project (No. 6 in Figure 3-37)	Improve water deliveries to enhance the connectivity and sheet flow in the Model Lands and Southern Glades areas, reduce wet season flows to C-111, and decrease potential flood risk in the lower south Miami-Dade County area.
South Miami Dade County Reuse (No. 3 in Figure 3-37)	Enhance regional water supply through advanced treatment of wastewater from the South District Wastewater Treatment Plant located in Miami-Dade County. The Yellow Book describe an initial design with a capacity of 131 million gallons per day.
West Miami Dade Reuse (No. 2 in Figure 3-37)	Enhance regional water supply through advanced treatment of wastewater from a future wastewater treatment plant to be located in the Bird Drive Basin in Miami-Dade County.
North Lake Belt (No. 1 in Figure 3-37)	Enhance regional water storage by capturing stormwater runoff and storing it in lined limestone pits in the North Lake Belt. The Yellow Book project envisioned canals, pumps, water control structures, and an in-ground storage reservoir with a total capacity of approximately 90,000 AF located in Miami-Dade County. The Yellow Book design described a 4,500-acre reservoir with water-level fluctuations up to 20 feet below grade.

SOURCE: https://www.saj.usace.army.mil/BBCW/; USACE and SFWMD, 2020c, 2012.

effects or trends since NASEM (2021), although by the committee's next report, the effects of the new pump stations on wetland and nearshore salinity should be apparent.

CERP Projects in Planning: Biscayne Bay and Southeastern Everglades Restoration

The ultimate goal of the BBSEER Project is ecosystem restoration of wetland and near-shore habitats in Biscayne Bay, Card Sound, Barnes Sound, the Model Lands, Southern Glades, and other wetlands adjacent to these water bodies consisting of low-lying marl prairie, sawgrass wetlands, and mangroves. The BBSEER feasibility study expands on recommended phased project plans implemented for the BBCW and C-111 SC and includes four additional project components included as part of the CERP in the Yellow Book (USACE and SFWMD, 1999; see Table 3-4). The initial BBSEER study area (Figure 3-37) focuses on southeastern Miami-Dade County, representing an area intentionally large in scope to include remaining local CERP components and water sources that may contribute to achieving the project's goals and objectives for Biscayne Bay and nearby wetlands.

This integrated planning effort will evaluate the combined effects of hydrologic restoration scenarios from these six integrated components to evaluate their efficacy toward four project objectives:

1. Improve freshwater wetland water depth, ponding duration, and flow timing within the Model Lands, Southern Glades, and eastern panhandle of Everglades National Park to maintain and improve habitat value.

2. Improve quantity, timing, and distribution of freshwater to estuarine and nearshore subtidal areas, including mangrove and seagrass areas, of Biscayne National Park, Card Sound, and Barnes Sound, to improve salinity regimes and to reduce damaging pulse releases.
3. Improve ecological and hydrologic connectivity between Biscayne Bay coastal wetlands, the Model Lands, and Southern Glades.
4. Increase resilience of coastal habitats in southeastern Miami-Dade County to sea-level rise.

The inclusion of resilience to sea-level rise as a project objective is the first for a CERP project and represents an important shift in CERP planning away from restoring ecosystems of the past to enhancing sustainable ecosystems of the future (NASEM, 2018).

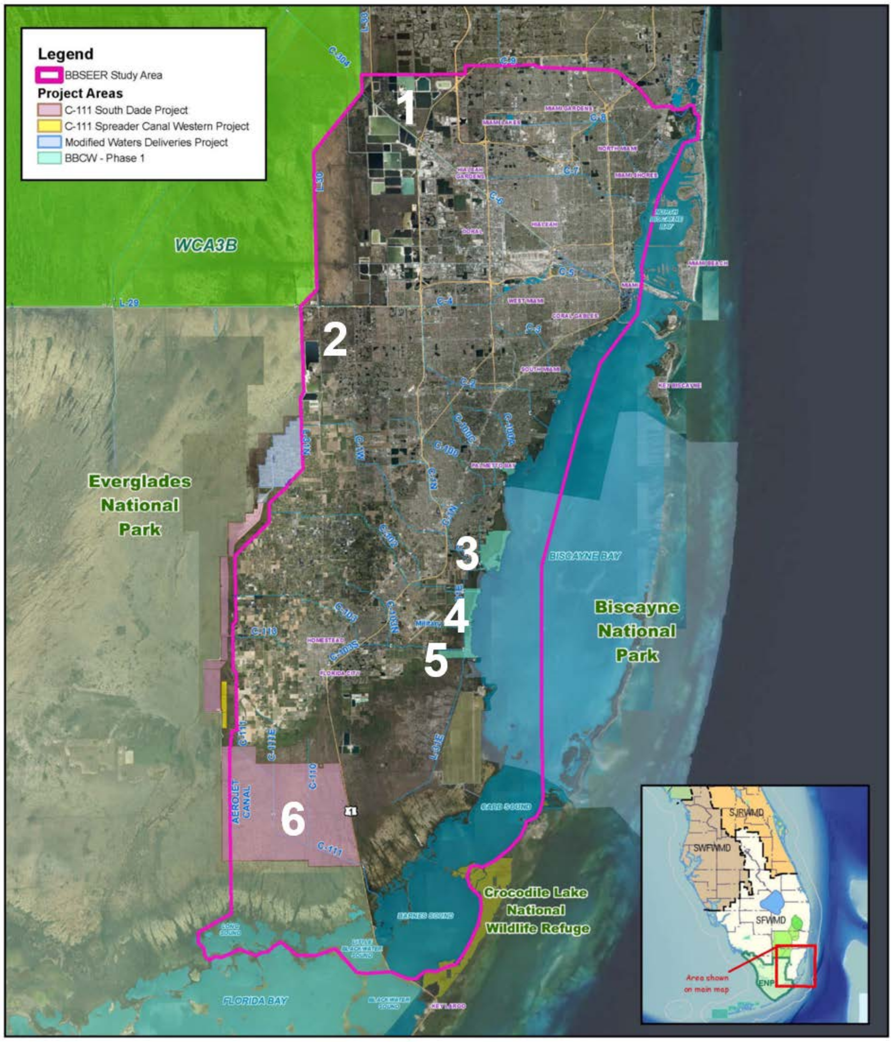

FIGURE 3-37 BBSEER Project footprint with locations of Yellow Book projects integrated into planning effort.
SOURCE: Foster, 2021.

The BBSEER Project includes several CERP components with questionable technical and/or economic feasibility. For example, water storage in the Lake Belt would likely require geomembrane liners of the highly porous limestone formations to hold water, and the technical feasibility of such systems has not been examined. The Yellow Book proposed a pilot project to examine this technology, but no action has been taken to conduct a study. Similarly, concerns remain about the use of wastewater reuse for ecological restoration because of concerns about the ecological effects of low levels of organic contaminants in wastewater if applied to wetland or coastal ecosystems and the cost-effectiveness of the approach. A project management plan was finalized in 2003 for the Wastewater Reuse Technology Pilot, but the pilot project was suspended in 2005 (USACE and SFWMD, 2006), so these questions remain unaddressed.

The project delivery team is working to develop the BBSEER tentatively selected plan by June 2024, and the team is early in this process. As of September 2022, the team was working to define the project alternatives for full evaluation of benefits using hydrologic and ecological modeling tools. The BBSEER study will consider changed conditions and use new data, resources, and information to inform restoration planning. These change conditions include the well-documented increase in the rate of sea-level rise locally and future sea-level projections. Additional evaluation of details of these considerations of climate change in BBSEER planning is discussed in Chapter 5 of this report.

Eight performance measures will be used in the model analysis for the relevant habitats to assess how the various alternatives meet the project objectives (Kirby and Coranado, 2022):

- Salinity in the near shore
- Salinity in wetlands
- Depth of freshwater
- Hydroperiods
- Direct canal releases
- Timing and distribution of flow sources to Biscayne Bay
- Resiliency (see Chapter 5, Box 5-3)
- Connectivity: proximity to natural areas

The first six are hydrologic outcomes and reflect the ways in which restoration measures can alter hydrology toward specific targets that optimize ecological conditions. It seems unlikely that plants and animals will all respond similarly, or even in the same direction (e.g., increase or decrease). Targeting of specific plants and animals as ecological outcomes of interest, including those within the performance measure structure, would provide a clearer framework for assessing measures and alternatives against the project’s goals.

As the planning process moves forward it is important to maintain perspective on the array of changes associated with different alternatives, their spatial and temporal distribution, and their modulation by sea level─rise scenarios. For example, in the USACE project alternative evaluation process, small changes in quality over large areas become equivalent to larger changes over smaller areas. Given the large differences in area for the different habitats, when performance measure scores are combined across zones, small changes in sawgrass/wet prairie may dominate and cause alternatives that benefit that area to rise to the top. The team may wish to consider whether certain habitats display greater increase in performance measure scores than others and the tradeoffs among habitats. In addition, although the team currently plans to weight the different performance measures equally, it may be worth considering whether some factors (e.g., resilience) deserve larger weights than others. Some of the other performance measures are closely related (e.g., hydroperiod, depth of freshwater, salinity in wetlands), therefore diluting the effect of other important performance measures.

Each feature being considered for the project seeks to improve the quantity, distribution, and/or timing of freshwater flows to the coast. Effective discrimination among them based on ecosystem outcomes (versus changes in hydrology) would provide a way to show the tradeoffs among ecological outcomes likely with projects such as this, and how those tradeoffs vary across the project area and over time with climate change. Some measures may result in small but ecologically important changes to ecology and identifying these, and the outcomes they produce, could help to justify delivery of this complex project to local jurisdictions and other interested parties.

RECOMMENDATIONS AND CONCLUSIONS

Record funding levels for Everglades restoration planning, implementation, and construction are further expediting restoration progress and expanding its geographic scope. In 2022, six CERP projects are under construction, one project and one major project component have been officially completed, and the new LOSOM was released. Several projects are nearing completion in the next 2-3 years. The Everglades restoration program is exhibiting impressive momentum with three additional CERP projects expected to begin construction in the next 2 years. This implementation progress places the restoration at a pivot point with increasing demands associated with project and system-wide operation and adaptive management, as well as with planning and implementation of remaining projects. An ambitious IDS is being realized, and the CEPP—the key project in the restoration of the central Everglades—continues to make impressively rapid implementation progress.

Hydrologic restoration progress and early vegetation response is evident over large areas of the central and western Everglades after implementation of recent CERP and non-CERP initiatives. The COP, which utilizes seepage management and water conveyance infrastructure from two non-CERP foundation projects that were recently completed (Mod Waters, C-111 South Dade), is rehydrating Northeast Shark River Slough and appears to be facilitating increased flow into Everglades National Park. The rehydration of Northeast Shark River Slough represents the largest step yet toward restoring the hydrology and ecology of the central Everglades. Shifts in vegetation in marl prairies are an early indicator that the predicted restoration benefits of the COP may be realized. During the past 2 years, plugging of canals at Picayune Strand has approximately doubled the area with full hydrologic restoration to approximately 13,500 acres. Monitoring wells in the fully hydrologically restored area show immediate increases in hydroperiod and water levels. Understory vegetation response is trending toward reference conditions, but tree canopy response has been slow, as expected. The benefits attributable to restoration efforts cannot be adequately distinguished from the effects of other factors, such as unusually wet or dry years without the use of available modeling tools to analyze the effects of these various factors on project outcomes.

Current progress on implementation and record levels of funding increase the need for and importance of analyzing and synthesizing natural system responses. The long-term hydrologic, ecological, and water quality trend data needed to assess restoration response are challenging to find, and analyses of these trends are inconsistent across projects. As noted in the committee's past reports (NASEM, 2018, 2020), quantitative objectives and accompanying expectations of how and when they will be achieved by management actions are critical for adaptive management processes. Some projects invest substantial time and energy in data analysis, while other projects conduct only limited analysis and primarily report recent results, a situation that complicates evaluation of progress toward project objectives. Adaptive management of the partially implemented system requires quantitative objectives as well as resources and staffing to support the assessment of ecosystem response. In addition, as recommended in NASEM (2020), more sophisticated strategies that use modeling tools to compare observed results to model predictions of current conditions based on recent precipitation and climate data (termed "nowcasting") would help managers understand project responses under a range of weather conditions and improve their capacity to adjust operations as needed.

Water quality is an ongoing concern that could potentially constrain progress on several fronts, including the COP and the CEPP. Increased dry season flows are a specific project objective for the CEPP, but new infrastructure and recent operational changes under the COP that have facilitated higher dry season flows have also resulted in total phosphorus exceedances. Better understanding of the underlying processes is needed to assess whether additional steps can help to mitigate these impacts without adversely affecting the intended flow benefits. Resolving this issue may necessitate additional research into the ecological implications of increases in phosphorus concentrations and loads amid flow restoration and the development of improved water quality modeling tools to analyze the potential consequences of various alternatives.

The final plans for LOSOM and the Lake Okeechobee Watershed Restoration Plan provide for substantially less storage than originally envisioned in the CERP, which highlights the importance of a CERP mid-course assessment (i.e., CERP Update). The new System Operating Manual for Lake Okeechobee generally retains upper lake stages similar to those of the prior Lake Okeechobee Regulation Schedule (LORS 2008), which lowered lake stages to reduce the risk of catastrophic failure of the Herbert Hoover Dike. Consequently, LOSOM poses a potential loss of up to 800,000 AF of storage in the rainy season compared to the lake regulation schedule in place in 1999 when the CERP was planned. In addition, the final Lake Okeechobee Watershed Restoration Plan includes 55 5-MGD ASR wells (or a maximum storage capacity of 308,000 AF/year), compared to the 200 ASR wells and 250,000 AF of surface storage proposed in the Yellow Book. As recommended by NASEM (2016 and 2018), a mid-course assessment of expected CERP outcomes that accounts for newly identified constraints in storage and incorporates the latest climate change science would inform future management decisions regarding restoration planning, funding, sequencing, and adaptive management.

The SFWMD has implemented a rigorous approach to address uncertainties associated with ASR in the Lake Okeechobee Watershed Restoration Plan. The SFWMD appointed an independent peer review panel to provide input in the development of the ASR Science Plan, which includes 26 studies through 2030. The panel will continue to meet annually to evaluate progress on the ASR Science Plan and will provide recommendations on additional studies needed or modifications to ongoing work. The committee commends the SFWMD for soliciting independent input both in the development of the plan and on an ongoing basis, to enhance the effectiveness of the science investments.

The USACE should implement a process for periodic multi-stakeholder review of Lake Okeechobee operations relative to the objectives of LOSOM to build confidence that

the flexibility of the new operational schedule is being used as designed and to support learning to enhance future decision making. The final LOSOM regulation schedule is similar to the prior schedule in many ways, including the high and low water management bands. The key differences are found in the lack of specificity of management in the largest band, Zone D. This affords water managers flexibility to use recent data and near-term forecasts to optimize water management. At the same time, this new flexibility leaves other agencies and stakeholders uncertain about how tradeoffs in management objectives will be balanced in the future compared to the balance of outcomes projected by the models during the LOSOM development process. Efforts to routinely report the rationale for operational adjustments within Zone D could be valuable in keeping stakeholders abreast of water management activities. In addition, an annual or semi-annual multi-stakeholder meeting or workshop would enable periodic assessment of how well competing priorities were balanced, increasing understanding, supporting transparency, and identifying lessons learned in support of adaptive management.

4

STA Water Quality and CERP Progress

The historic Everglades ecosystem developed under chronically phosphorus-limited conditions. Runoff from agricultural and urban development beginning in the early 1900s altered these conditions through drainage with high-phosphorus concentrations entering the Everglades Protection Area (defined as Water Conservation Areas [WCAs] 1, 2A, 2B, 3A, and 3B, and Everglades National Park; FAC §§ 62-302.540). In phosphorus-impacted areas, essential characteristics of the Everglades have been altered through the loss of periphyton and the replacement of native sawgrass by dense cattails, which degraded fish and bird habitat (Davis, 1994). In response to this degradation, in 1988 the United States sued the State of Florida for failing to meet standards established under the Clean Water Act.[1] Under the Consent Decree reached in 1992, the state constructed 57,000 acres of treatment wetlands, termed stormwater treatment areas (STAs),[2] and additional STA construction and restoration are under way in response to the subsequent 2010 Amended Determination (EPA, 2010; see next section for details). These constructed wetlands are globally unmatched in spatial and temporal scale and collectively have removed more than 3,200 metric tons of phosphorus as of water year[3] (WY) 2022 (Chimney, 2022b).

Full implementation of key Comprehensive Everglades Restoration Plan (CERP) projects are predicated on water being discharged into the Everglades Protection Area meeting water quality criteria established under the Amended Determination (see next section); thus, the state's efforts to remediate the quality of Everglades inflows is foundational to CERP implementation. Consistent with the study charge to discuss issues that may impact restoration progress, in this chapter the committee focuses on the effectiveness of the STAs and the implications of their performance to CERP progress. This chapter begins with a brief overview of Everglades water quality requirements and criteria, the state's ongoing Restoration Strategies Plan, and implications of the Plan's performance for CERP implementation. The committee then provides an overview of how STAs function and key drivers of their performance, followed by a review of the important progress being made to achieve the water quality standards. Finally, the

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[1] *United States v. South Florida Water Management District*, 847 F. Supp. 1567 (S.D. Fla. 1992).

[2] The 57,000 acres were constructed as part of the Everglades Construction Project and the South Florida Water Management District (SFWMD)'s Long-Term Plan for Achieving Water Quality Goals (Burns and McDonnell, 2003).

[3] Water year refers to measurements made during May 1 to April 30, with the year designated as the year in which it ends. Wet season, which receives 70 percent of the total hydraulic and phosphorus loads, is considered to occur from May 1 to October 31, and dry season is considered to occur from November 1 to April 30. All the monitoring data collected since the construction of STAs are reported on a WY basis.

committee recommends strategies to support the state's ongoing efforts to meet the water quality discharge requirements and sustain STA performance over the long-term.

EVERGLADES WATER QUALITY OBJECTIVES AND CRITERIA

The federal Clean Water Act (33 U.S.C. §§1251-1388) requires states to establish water quality standards to support designated uses of waterways that are then reviewed and approved by the U.S. Environmental Protection Agency (EPA). The act also establishes a permit program for discharges of wastewater and stormwater into receiving waters of the United States. Issues related to compliance with Clean Water Act standards in the Everglades Protection Area have been the subject of two significant, related, and ongoing lawsuits (see Appendix D of NRC, 2012 for a timeline of major events). Both cases make it clear that discharging water into the Everglades Protection Area that does not comply with water quality standards is a violation of the Clean Water Act. See also Chapter 5 of NRC (2010) for a detailed history of Everglades water quality standards and associated issues.

In 1988, the United States sued the State of Florida and the SFWMD, alleging that the state had failed to adequately clean up waters flowing into Everglades National Park and the Arthur R. Marshall Loxahatchee National Wildlife Refuge (LNWR, also known as WCA-1). After several years of litigation, the parties entered into a settlement agreement in 1991 that was implemented through a Consent Decree in 1992. The 1991 settlement agreement contained several provisions, including

- a general commitment on the part of the SFWMD and the Florida Department of Environmental Protection (FDEP) to protect water quality in LWNR and Everglades National Park,
- adoption of interim and long-term total phosphorus (TP) limits,[4]
- certain remedial measures,
- a research and monitoring program, and
- contingencies for enforcement.

Remedial measures under the Consent Decree included a commitment by the SFWMD to construct 35,000 acres of STAs and for the state to develop and implement an interim and long-term regulatory program to ensure that all discharges from the Everglades Agricultural Area (EAA) meet Clean Water Act standards.

The 1994 Everglades Forever Act (Fla. Stat. §373.4592) directed FDEP to develop numeric criteria for phosphorus within the Everglades Protection Area to comply with the

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[4] Interim limits for phosphorus were to be achieved by July 1997 (later amended to October 2003), including annual flow-weighted concentration goals in Shark River Slough of no more than 14 ppb in a dry year and 9 ppb in a wet year. Long-term limits were to be achieved by 2002 (later amended to 2006) including annual flow-weighted concentration goals in Shark River Slough of no more than 13 ppb in a dry year and 8 ppb in a wet year, and the long-term concentration limit for Taylor Slough and the Coastal Basins was set at 11 ppb. Interim and long-term limits for Everglades National Park and LNWR were specified by complex formulas in Appendices A and B of the Settlement Agreement. Interim levels for LNWR were to be between 8 and 22 ppb depending on water levels as measured.

Consent Decree. In 2003, the State of Florida formally adopted a numeric phosphorus rule (FAC §§62-302.540)[5] that established the phosphorus criterion for waters in the Everglades Protection Area as the long-term geometric mean of 10 µg/L (Box 4-1). Achievement of the criterion in WCA-1 (LNWR), -2 and -3 is evaluated across a network of sampling stations using a four-part test[6] to determine whether a violation of standards has occurred (Figure 4-1).[7] Achievement of the criterion in Everglades National Park and LNWR is governed by methods in Appendix A and B, respectively, of the 1991 Settlement Agreement (see SFWMD, 2009a for details).

In 2010, a federal judge found that the water quality regulatory program enacted by Florida in response to the 1992 Consent Decree failed to comply with the requirements of the Clean Water Act and directed EPA and the FDEP to take certain steps to comply with their

BOX 4-1
Scientific Support for the 10 µg/L Criterion

The determination of the 10 µg/L total phosphorus (TP) criterion was based on extensive research (McCormick et al.,1999; Payne et al., 2001, 2002, 2003; reviewed in Noe et al., 2001; Richardson, 2008). The data overwhelmingly demonstrate that even low levels of enrichment in TP concentrations result in elevated phosphorus in macrophyte tissues, soil, the water column, and periphyton, leading to undesirable changes in periphyton and macrophyte biomass and productivity and faunal communities.

Under pre-disturbance conditions, isolation of the surface-water system from bedrock meant that the only significant inputs of phosphorus were from atmospheric sources, estimated to be in the range of 0.03 grams per m^2 per year (Noe et al., 2001). In interior (undisturbed) portions of the Everglades, phosphorus concentrations in plant and periphyton biomass and in soil are very low compared to other wetlands and other peatlands, and the nitrogen:phosphorus ratios in these compartments suggest extreme phosphorus limitation, which Noe et al. (2001) ascribe to several factors, including

- its occurrence on a limestone platform, which promotes removal and sequestration of phosphorus through coupled biotic and abiotic biogeochemical reactions;
- the very large spatial extent of the system, such that groundwater from other regional sources are isolated from all but the periphery of the system and most of the system receives the bulk of its nutrients from precipitation (ombrotrophic);
- conservative cycling of phosphorus by the dominant macrophytes;
- periphyton mats that maintain highly oxidized sediments, so that any phosphorus becomes adsorbed to iron minerals and is not bioavailable under stable redox conditions; and
- the ability of Everglades plants (notably, *Cladium, Eleocharis*, and related species) to grow at unusually low tissue phosphorus concentrations.

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[5] See also *Miccosukee Tribe of Indians of Florida v. United States*, 2008 WL 2967654 (S.D. Fla.).

[6] The four-part test is used to assess compliance according to the following four provisions: (1) 5-year geometric mean is less than or equal to 10 ppb, (2) annual geometric mean averaged across all stations is less than or equal to 11 ppb, (3) annual geometric mean averaged across all stations is less than or equal to 10 ppb for 3 of 5 years, and (4) annual geometric mean at individual stations is less than or equal to 15 ppb (FAC §§62.302.540).

[7] Text was added following the prepublication release of the report to include WCA-1 among areas in which the four-part test is applied.

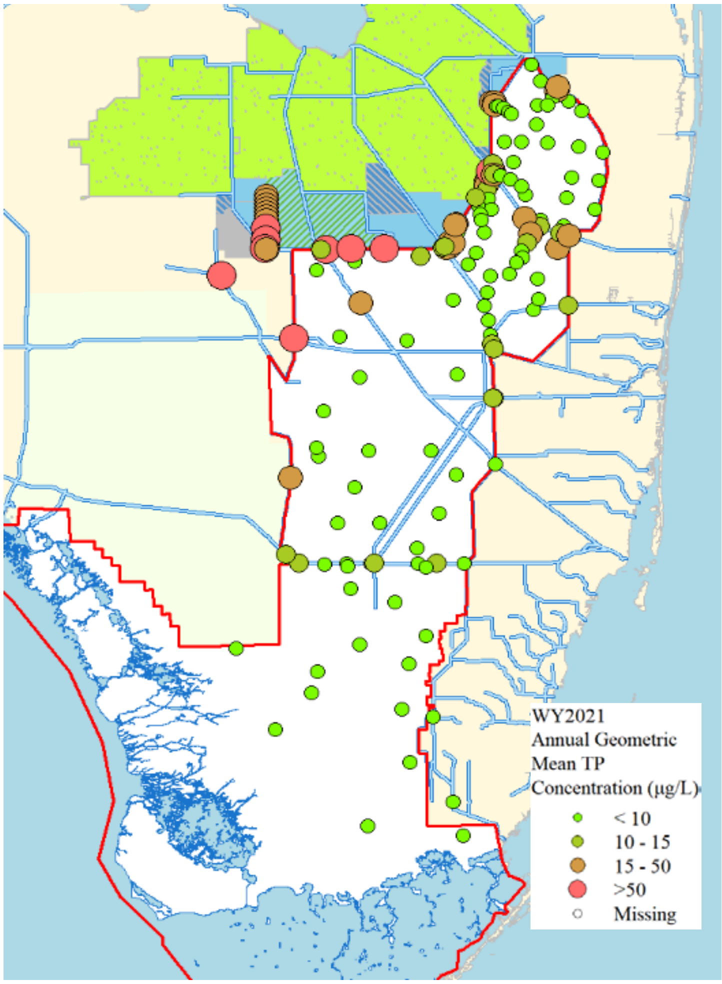

FIGURE 4-1 Location of water quality monitoring stations used to assess water quality criteria exceedance in the Everglades Protection Area and mean TP concentrations for WY 2021. For WY 2021, 83 percent of interior marsh sites had annual geometric mean TP concentrations in water of less than or equal to 10 µg/L and 89 percent had annual geometric means of 15 µg/L or less. In WY 2017-2021, all "unimpacted" sites within the WCAs were judged to be in compliance based on the four-part test, although "the impacted portions of the WCAs routinely exceeded the annual and five-year network TP limits" and therefore failed to meet the TP criterion. "Impacted" areas are defined as those with TP concentrations in the upper 10 centimeters of the soils greater than 500 milligrams per kilogram.
SOURCE: Gilhooly et al., 2022.

mandatory duties. In response, the EPA issued its Amended Determination (EPA, 2010) directing the FDEP to correct deficiencies in meeting its water quality standards and articulated that "the narrative and numeric nutrient criteria in the State's water quality standards are not being met for the Everglades Protection Area."[8] The Amended Determination was intended to provide an enforceable plan for ensuring that the water entering the Everglades Protection Area

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[8] Florida set narrative regulatory criteria to ensure that phosphorus concentrations would cause "no imbalance in flora or fauna," which is now formalized in FAC §§ 62-302.530 (see also Rizzardi, 2001).

from the EAA and the C-139 Basin complies with the previously adopted narrative and numeric phosphorus criteria, for the Everglades Protection Area (FAC §§ 62-302.540).

Of particular significance is the establishment of a water quality-based effluent limit (WQBEL) in the 2010 Amended Determination that must be included in all National Pollution Discharge Elimination System (NPDES) permits for STAs that discharge into the Everglades Protection Area. In 2012, the Florida Department of Environmental Protection set a WQBEL for TP in STA discharge consisting of two components: 1) a maximum annual flow-weighted mean of 19 µg/L and 2) an annual flow-weighted mean of 13 µg/L not to be exceeded in more than 3 out of 5 water years on a rolling basis (Florida Permit FL0778451, FDEP, 2017). The WQBEL was calculated to ensure that water discharged from the STAs is of high enough quality in spite of year-to-year variability to ensure compliance with the previously established narrative and numeric nutrient criteria in the Everglades Protection Area to sustain native vegetation and ecosystems in the Everglades.

In response to the Amended Determination, in 2012 the SFWMD developed the Restoration Strategies Regional Water Quality Plan (SFWMD, 2012), which provides for expanding existing STA acreage and additional infrastructure improvements to meet the WQBEL (Box 4-2; Figure 4-2). Restoration Strategies projects are expected to be fully constructed and operational by 2025. The first annual assessment of WQBEL attainment begins in WY 2027 (May 2026-April 2027).

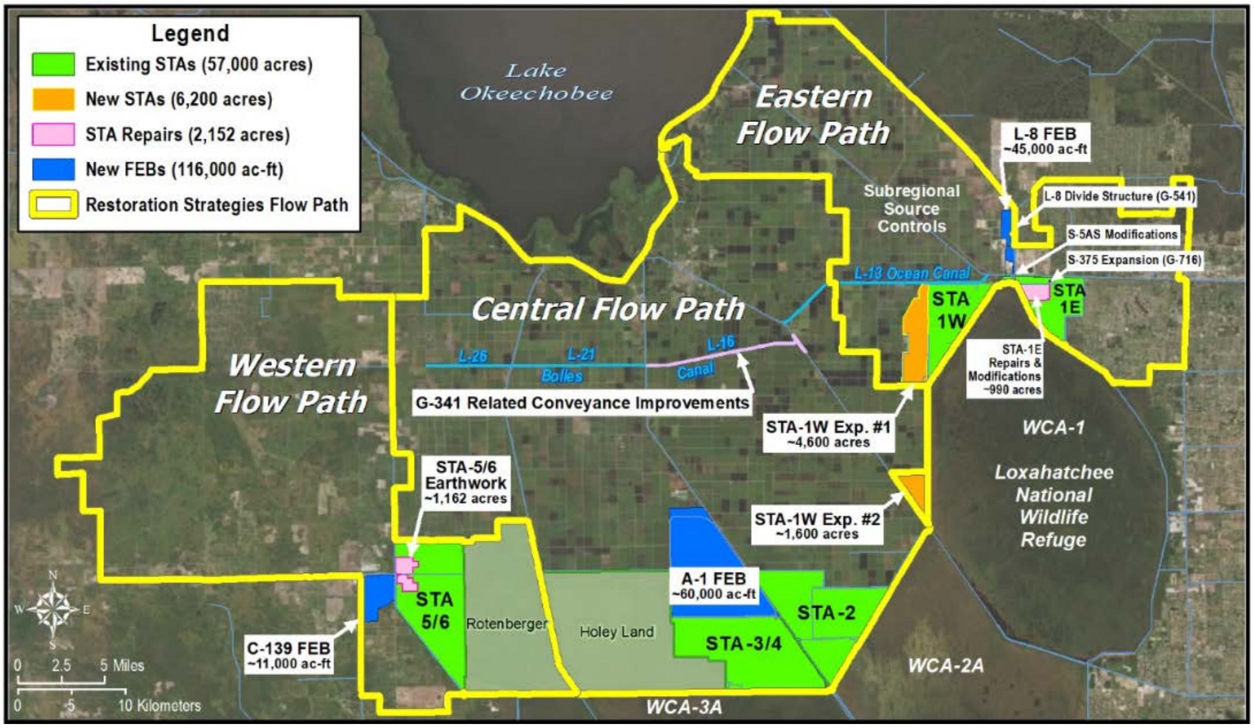

FIGURE 4-2 Location of the Everglades STAs in green: STA-1E, 1W, -2, -3/4, and -5/6 and the locations of Restoration Strategies projects, including expansion of STAs, STA earthwork, and flow equalization basins (FEBs).
SOURCE: Shuford et al., 2022.

BOX 4-2
RESTORATION STRATEGIES

The Restoration Strategies plan, launched in 2012, provides for expanding existing Stormwater Treatment Areas (STA) acreage and additional infrastructure improvements to meet the water quality−based effluent limit (WQBEL) (Table 4-1). Because meeting water quality requirements is a state responsibility, this project is funded by the State of Florida outside of the Comprehensive Everglades Restoration Plan. The plan included 6,300 acres of additional treatment area, repairs to STA-1E and STA-5/6, and three flow equalization basins (FEBs) to attenuate low and high flows into the STAs (Figure 4-2). The STAs are grouped into three flow paths: the Eastern Flow Path (STA-1E and STA-1W), the Central Flow Path (STA-2 and STA-3/4), and the Western Flow Path (STA-5/6). Restoration Strategies projects are expected to be fully constructed and operational by 2025. Progress on Restoration Strategies project implementation is described in Table 4-1.

TABLE 4-1 Summary Status of Major Restoration Strategies Project Components

Component	Purpose	Status
Eastern Flow Path		
L-8 FEB	Attenuate flow into STA-1E and -1W	Construction completed 2017, long-term operations to commence by December 2022
L-8 Divide Structures (G-716, G-541)	Assist movement of inflows and outflows to L-8 FEB	Construction completed 2016, now operational
STA-1E Repairs and Modifications	Improve STA performance	Construction of improvements to Cells 5 and 7 began in April 2020, transport of fill material and regrading is ongoing
STA-1W expansion # 1 (Phase 1)	Increase STA-1W effective treatment area	Construction completed in 2018, now operational
STA-1W expansion # 2 (Phase 2)	Increase STA-1W effective treatment area	Construction completion expected in December 2022
G-341 Related Improvements	Divert flows (600 cfs max) to the west	Construction completion expected in 2024
Subregional Source Controls	Reduce inflow loads from hotspots in the basin	Pilot projects completed in 2015 and 2017; conceptual project planning ongoing
Central Flow Path		
A-1 FEB	Attenuate flow into STA-2 and STA-3/4	Construction completed 2015, now operational
Western Flow Path		
STA 5/6 Internal Improvements	Improve the performance of STA-5/6	Construction completed 2020, now in optimization period
C-139 FEB	Attenuate flow into STA- 5/6	Construction completion expected in 2023

SOURCE: Data from Shuford et al., 2022; Chimney et al., 2022a.

IMPLICATIONS OF STA DISCHARGE QUALITY ON CERP PROGRESS

The Central Everglades Planning Project (CEPP)—the largest CERP project and key to restoring distributed sheet flows through the heart of the remnant Everglades system (see also Chapter 3)—depends on flows that are processed by STAs. Restoring sheet flows is fundamental to "getting the water right" and effectively restoring the River of Grass. Ongoing degradation of the greater Everglades due to the disruption of sheet flows has been well documented (McVoy et al., 2011), including the loss of peat and alteration to ecosystem topography such as the ridge and slough and tree islands. These defining ecosystem characteristics would likely require decades if not centuries to restore if lost. Enhancing sheet flows in the system as soon as possible, particularly in dry seasons when peat loss occurs, is essential to halting the ongoing degradation and beginning the restoration process. Meeting water quality criteria helps ensure that these restored flows do not further degrade ecosystems in the remnant Everglades (e.g., by causing replacement of sawgrass by dense cattails).

Timely WQBEL attainment affects CEPP implementation progress for two major project elements: CEPP North and CEPP EAA Reservoir (see Chapter 3 and Figure 3-19). As discussed previously, the first annual assessment of WQBEL attainment will begin in WY 2027 (Mitchell and Mancusi-Ungaro, 2012). CEPP North is designed to restore sheet flow by spreading inflows across northern WCA-3A and backfilling the Miami Canal (Figure 3-19). This project can provide benefits in the near term using "existing" flows (i.e., water flows through the STAs without implementation and operation of new storage and treatment provided by the CEPP EAA Reservoir project). However, once the Miami Canal is plugged, if inflows do not meet the WQBEL, the redistribution of water as sheet flow through WCA-3A could increase TP concentrations in interior areas not previously affected (see Figure 4-1), possibly adversely affecting the condition of periphyton and enhancing the spread of cattails. The U.S. Army Corps of Engineers (USACE) CEPP 2014 Chief's Report (USACE, 2014b) specifies, and Connor (2022) reaffirms, that no federal investment in CEPP North infrastructure can occur until the WQBEL standard is met in these existing flows. The state, however, has elected to proceed with construction of CEPP North prior to the determination of WQBEL compliance beginning in 2027, including the filling of the Miami Canal starting in 2024. By doing so, the state is accelerating the potential implementation of CEPP North, although it is unclear whether this schedule assumes early attainment of the WQBEL. Delays in STA performance could potentially delay CEPP North implementation and the associated restoration benefits if the risks of proceeding without WQBEL attainment are ultimately judged to be substantial.[9]

The CEPP also provides additional flows ("new water") into the Everglades Protection Area via the CEPP EAA Reservoir project elements. CEPP EAA Reservoir includes a 10,500-acre reservoir with 240,000 acre-feet (AF) of storage (also known as the A-2 Reservoir) along with the new 6,500-acre A-2 STA to help treat the new water volumes conveyed to the Everglades (Figure 3-19). The A-2 Reservoir will be able to receive water from Lake Okeechobee and is designed to be fully integrated into the existing Restoration Strategies infrastructure (A-1 FEB, STA-2, and STA-3/4) and operations (Figure 4-3). The A-2 STA was sized under the assumption that on excess hydrologic inflow capacity in STA-3/4 and STA-2 in the dry season would also be used together with the A-2 STA to treat A-2 Reservoir discharges

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[9] Following release of the prepublication version of the report, this paragraph was modified to correct its description of the compliance process.

to WQBEL requirements, thereby reducing the size of the A-2 STA while promoting dry season flows, as desired. After treatment, the "new" water is dispersed into the Everglades Protection Area through the CEPP North infrastructure. CEPP EAA Reservoir is projected to provide an average of 370,000 AF of "new" water annually, compared to conditions without any CEPP features (USACE, 2020b). CEPP EAA Reservoir is currently scheduled for completion in 2029 according to the 2021 Integrated Delivery Schedule. The state has expedited the construction of the associated 6,500-acre A-2 STA, which is scheduled for completion in 2023 with flooding and optimization in 2024 and 2025.

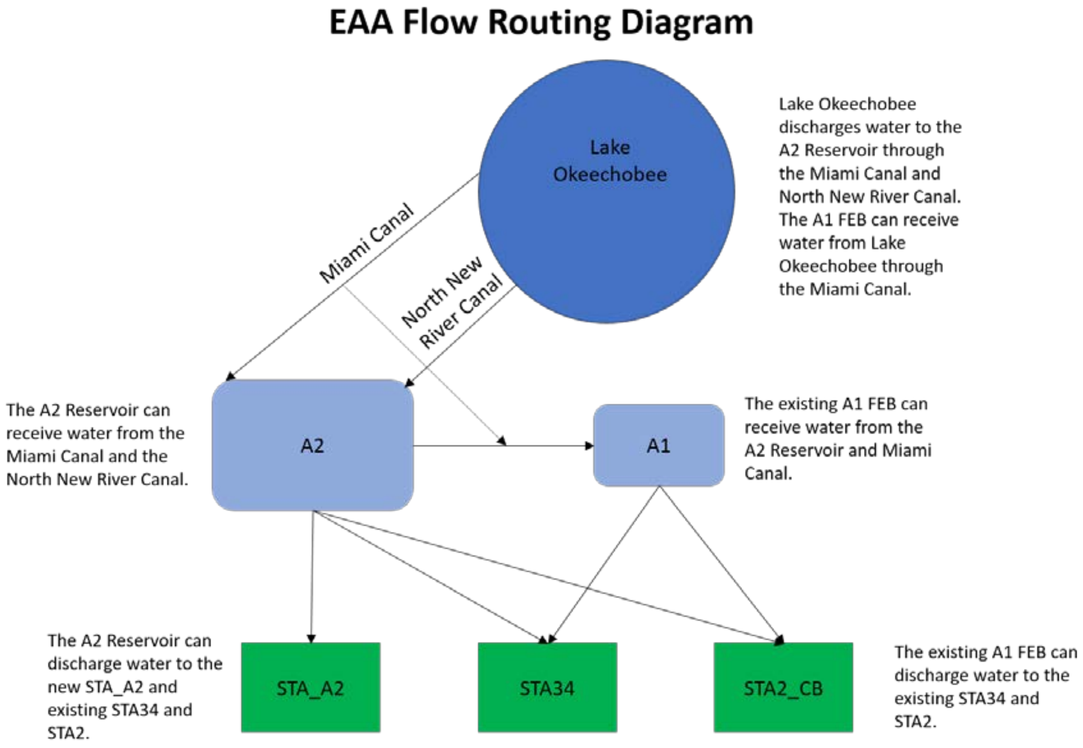

FIGURE 4-3 CEPP EAA flow routing diagram showing linkage of the new EAA (A-2) Reservoir and STA with Lake Okeechobee and the existing STA-3/4 and STA-2.
SOURCE: https://www.saj.usace.army.mil/CEPPEAA/.

Until all Restoration Strategies STAs meet the WQBEL, the USACE will limit operations of, and thus the benefits provided by, the EAA Reservoir. The EAA Reservoir Final Environmental Impact Statement (EIS) Record of Decision (USACE, 2020c) specifies: "All features of the state's Restoration Strategies must be completed and meet state water quality standards prior to initiating any operations which would allow water from the Federal EAA project to enter any of the state's Restoration Strategy facilities." Until the WQBEL is met for the Restoration Strategies STAs, "the EAA reservoir may only be operated to flow the amount of water that the new EAA A-2 STA alone can treat to meet all federal and state water quality standards, as well as any additional treatment necessary for passage of water to Everglades restoration" (USACE, 2020c).[10] Under this policy, before the A-2 Reservoir is allowed to operate at full capacity, the prior 5 years of data from all STAs must show compliance with the WQBEL (i.e., WY 2024-2029 for 2029 operation). Because the A-2 STA was sized based on excess hydrologic loading capacity in STA-2 and STA-3/4, until the WQBEL is met, flows to the Everglades will be limited to the capacity of the 6,500-acre A-2 STA and the 31,800 combined acres in STA-2 and STA-3/4 will not be available. Modeling for the EAA Reservoir planning process calculated that the A-2 STA could treat an average of 162,100 AF/year (out of the 370,000 AF/year that the CEPP was projected to provide on average) and the remaining 207,900 AF/year would be treated by STA-2 and STA-3/4 (SFWMD, 2018a). Thus, until the WQBEL is met, model projections suggest that the CEPP could only deliver 44 percent of the anticipated average annual new flows.

Until the WQBEL is met, USACE (2020) also stated that inflows to the EAA Reservoir must also be limited:

> The EAA reservoir may, in turn, not be allowed to store any extra water other than what can be treated and released to all applicable standards (by the current sampling methods/criteria) by the new EAA A-2 STA facility for benefits determined to be essential to Everglades restoration, until the state satisfies the water quality treatment needs of its Everglades Construction Project and meets all of their Restoration Strategies.

Accordingly, the benefits to the northern estuaries that are derived from moving water south rather than sending damaging high-volume discharges to the estuaries may also be reduced. However, no data are available to estimate the reduced benefits if the WQBEL is not met as expected.

In effect, success of Restoration Strategies is foundational to the implementation of the CEPP and the timely delivery of planned CERP benefits. Substantial delays in reaching the goals of Restoration Strategies would reduce the benefits provided by these CEPP projects until WQBEL compliance is met. In the balance of this chapter the committee turns its attention to a review of the underlying science, engineering, design, and operations of the STAs and a discussion of the progress to date under the Restoration Strategies Plan, with the goal of helping inform the state's efforts to meet the WQBEL criteria by 2027.

OVERVIEW OF STORMWATER TREATMENT AREAS

Constructed treatment wetlands are used globally to remove nutrients and other contaminants from inflow waters and to maintain desired outflow water quality (Kadlec and Wallace, 2009; Vymazal, 2022). Management approaches can vary, depending on the chemical composition of nutrients or contaminants in the inflow water, climate, hydrologic setting, vegetation, and wetland type. For example, small-scale treatment wetlands with active management of hydrology, soils, and vegetation are sometimes integrated with conventional

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[10] According to the CEPP Post Authorization Change Report Project Operating Manual (Annex C, SFWMD, 2018a), "the WQBEL is a numeric discharge limit applied to permitted discharges from EAA STAs, including STA-2, STA-3/4, and A-2 STA to assure that such discharges do not cause or contribute to exceedances of the 10 micrograms per liter (μg/L) TP criterion within the Everglades Protection Area."

water treatment systems to improve outflow water quality. Large-scale treatment wetlands, such as STAs, are usually designed as passive systems with minimal or no active management. The hydrologic and biogeochemical processes in these ecosystems are intended to mimic processes that occur in natural wetlands. Considerable information is available on performance of treatment wetlands operated at multiple scales (Kadlec and Wallace, 2009; Vymazal, 2022).

How STAs Remove Phosphorus

The design and operation of Everglades STAs is based on creating environmental conditions along a flow path that promotes phosphorus removal from the inflow water. Phosphorus removal occurs through short-term retention processes, such as uptake in vegetation, periphyton,[11] and microbial communities, as well as long-term storage through abiotic sorption, precipitation, and soil accretion (Figure 4-4; Kadlec and Wallace, 2009; Reddy and DeLaune, 2008). In the soil and water column, phosphorus is present in organic and inorganic forms, which can be present as dissolved and/or particulate forms (Box 4-3; Appendix B). The relative proportion of these forms affects the mobility and processing of phosphorus in STAs. In addition, biogeochemical conditions (e.g., pH, redox) and interactions with other elements (e.g., carbon, nitrogen, sulfur, calcium, magnesium, iron, aluminum) affect phosphorus mobility and bioavailability, ultimately influencing outflow TP concentrations and the overall performance of STAs.

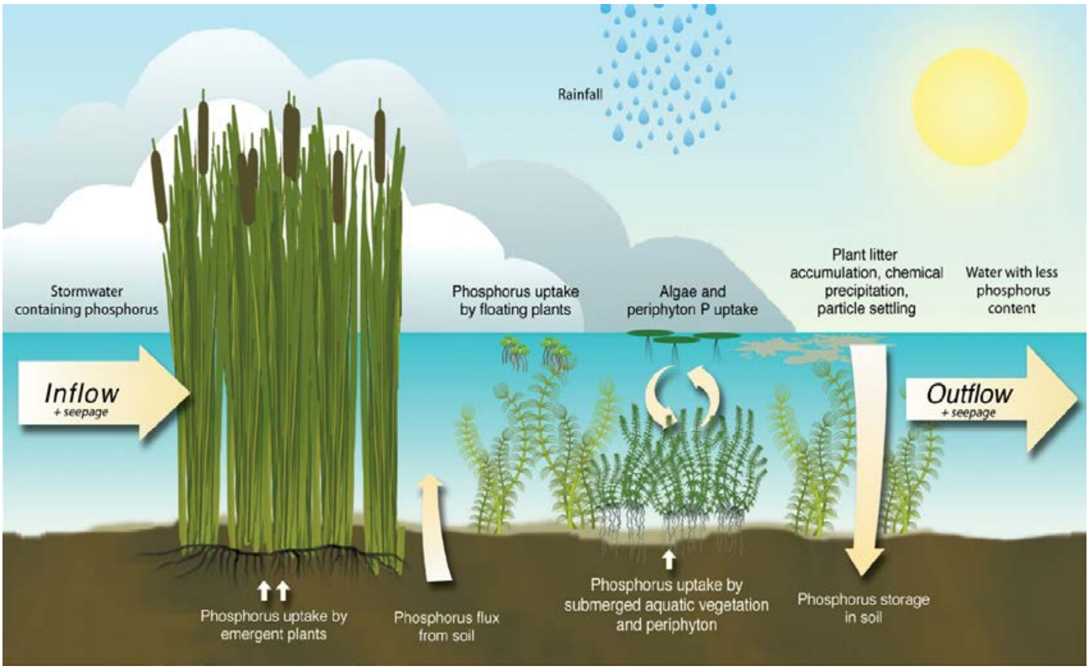

FIGURE 4-4 Conceptual diagram of STA processes that remove phosphorus.
SOURCE: SFWMD.

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[11] Periphyton is a community of attached algae and other microbes that occur throughout the wetlands.

BOX 4-3
Phosphorus Forms and Cycling

Phosphorus can be found in both dissolved and particulate fractions. *Dissolved phosphorus* fractions are considered to be those that pass through a 0.45 µm filter:

- *Dissolved inorganic phosphorus* (DIP) contains predominantly orthophosphate, which is highly reactive and readily bioavailable to biotic communities. DIP is often reported as soluble reactive phosphorus (SRP), based on an analytical method that determines the amount of dissolved phosphorus that reacts directly with molybdate, assumed to represent orthophosphate although this fraction may include some dissolved colloidal organic and inorganic phosphorus that can pass through 0.45 µm filter and hydrolyzed to phosphate during analysis.
- *Dissolved organic phosphorus* (DOP) is produced through the breakdown of plant litter (see Figure 4-5) and is less bioavailable than DIP. Its bioavailability is regulated by hydrolytic extracellular enzymes. DOP is operationally determined by the difference between total dissolved phosphorus and SRP.

Particulate phosphorus (PP) fractions are considered those in water that do not pass through a 0.45 µm filter:

- *Particulate inorganic phosphorus* (PIP) is bound to inorganic minerals in soils such as those containing calcium, iron, magnesium, and aluminum.
- *Particulate organic phosphorus* (POP) is associated with recalcitrant detrital material and soil organic matter.

Formation of POP and PIP decreases its availability to biota.

The relative proportion of these fractions in STA inflows is influenced by land use, best management practices implemented in the basin, hydrology, and the drainage basin soil characteristics. On average for all STAs, SRP represents approximately 50 percent of the TP load as compared to 36 percent PP and 14 percent DOP (Figure 4-6).

Phosphorus forms affect internal release or sequestration of phosphorus in STAs, and as such, phosphorus species provide a detailed understanding of STA function and performance. DIP is highly available and preferentially removed in STAs by plant and microbial assimilation and abiotic immobilization. In contrast, the fraction of DOP in STA effluent increases compared to influent values because this form of phosphorus is less readily removed in STAs and is internally produced in STAs through leaching from plant litter and the subsequent decomposition of detrital organic matter. Once DIP becomes limiting, the available supply of phosphorus to vegetation depends on enzymatic transformation of organic phosphorus to DIP by microbes (mineralization), photodegradation of DOP and POP, and dissolution of phosphate binding minerals. The remaining PP accumulates in the soil, but can also be readily resuspended following disturbance.

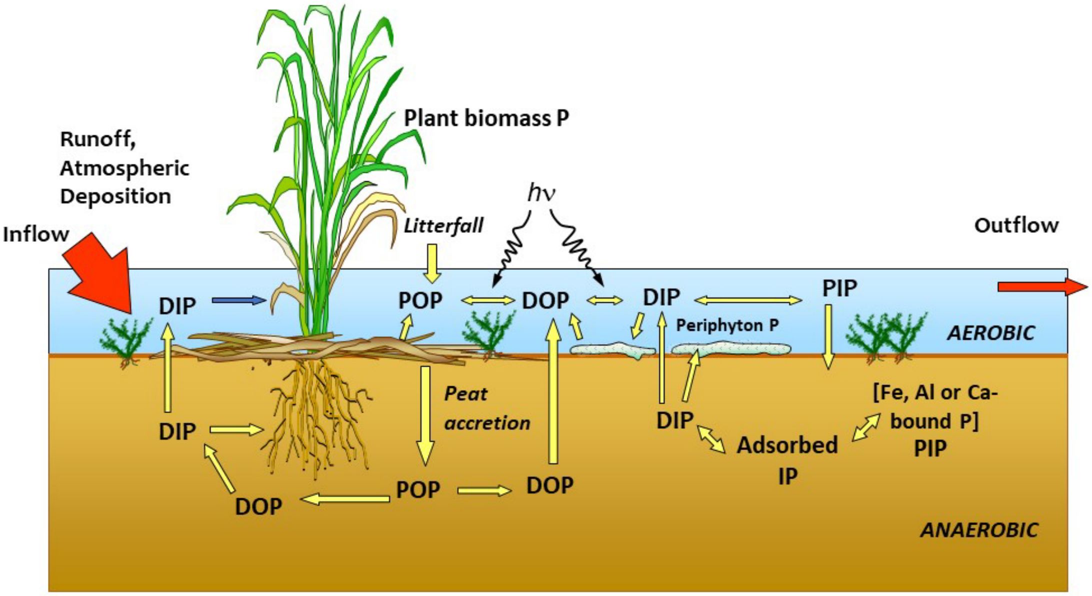

FIGURE 4-5 Phosphorus transformations and fluxes in soil and water column of STAs. DIP = dissolved inorganic phosphorus; DOP = dissolved organic phosphorus; POP = particulate organic phosphorus; and PIP = particulate inorganic phosphorus. SOURCE: Modified from Reddy and DeLaune, 2008.

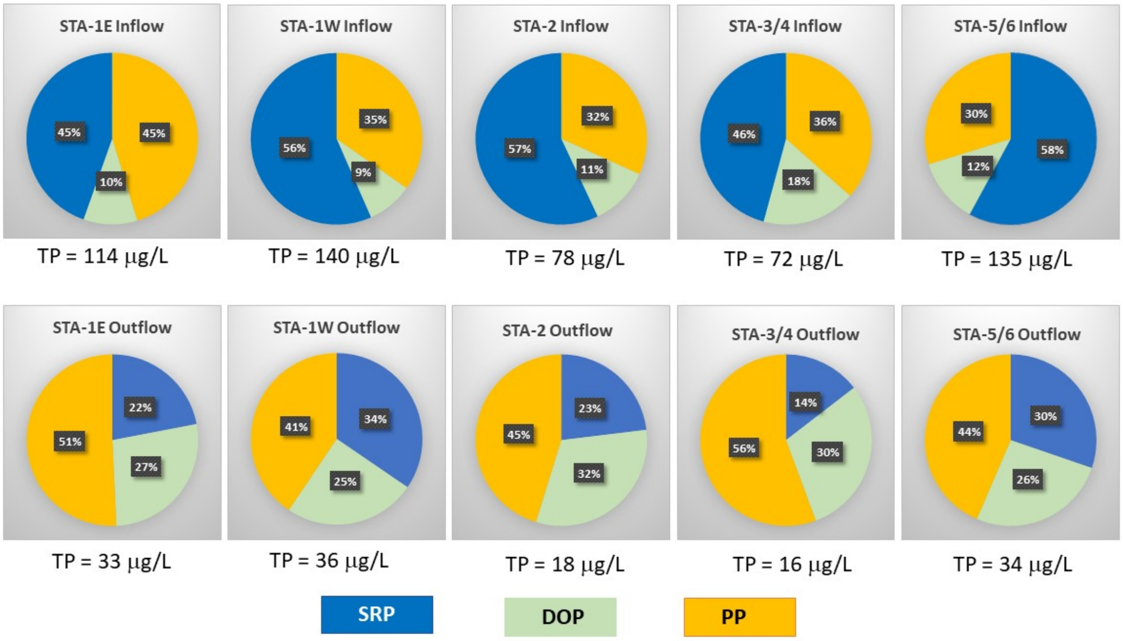

FIGURE 4-6 Average distribution of total phosphorus (TP) including soluble reactive phosphorus (SRP), dissolved organic phosphorus (DOP), and particulate phosphorus (PP) fractions in the inflow and outflow water measured monthly during the operation period. Data for the operation period of WY 2006-2020 for STA-1E, -1W, -2, and -3/4, and WY 2013-2020 were used in calculating average values for STA-5/6.
SOURCE: Data from Hu and James, 2021.

FIGURE 4-7 Soil cores of recently accreted soil and floc from STA cells dominated by emergent aquatic vegetation (EAV. left) or submerged aquatic vegetation (SAV, right). The genesis of soils in STAs is influenced by vegetation type. Soils formed in EAV-based STAs are typically characterized with high organic matter and low bulk density (dry weight per unit volume of soil) similar to peat soils. Soils formed in SAV-based STAs are characterized with mineral matter (mostly dominated by calcium carbonate [$CaCO_3$]) and high bulk density, similar to calcareous mineral soils. SOURCE: J. King, SFWMD.

Aquatic vegetation and periphyton are essential components of STA function. Types of vegetation include emergent aquatic vegetation (EAV), submerged aquatic vegetation (SAV), and floating aquatic vegetation (FAV). STA cells are typically classified by the dominant vegetation type because EAV and SAV function somewhat differently within STAs (see Figures B-2 to B-6 in Appendix B). EAV (mostly dominated by cattails [*Typha latifolia* and *Typha domingensis*]) is particularly effective in sequestering nutrients by uptake through its large root system including rhizomes. In addition to high productivity and standing crop of biomass, EAV supports accumulation of organic matter through biomass decomposition and the production of plant litter (Reddy and Delaune, 2008). EAV soils are characterized by lower mineral matter and higher organic matter.

In treatment cells containing SAV, underwater photosynthesis and primary productivity promote alkalization and calcium carbonate ($CaCO_3$) formation in the water column that is deposited as a fine particulate sediment. This chalky, amorphous $CaCO_3$ provides a substrate to adsorb and precipitate dissolved phosphorus more effectively than soils in EAV areas (Figure 4-7; Dierberg et al, 2002; Reddy et al., 2021). This recently accreted material, or floc, derived from particulate inorganic material and partially decomposed plant litter, is easily resuspended into the water column.

Small areas with deep water zones near STA inflows are sometimes colonized by FAV. Although FAV can assimilate phosphorus in the biomass, it is generally undesirable in STA operations because it spreads rapidly, depletes water column oxygen, lowers pH, and interferes with the underwater growth of shoots of EAV. In addition, FAV also blocks light transmittance through the water column, limiting SAV and associated periphyton growth. Thus, as part of routine maintenance, FAV is removed from STAs or killed using herbicides.[12]

Periphyton-based stormwater treatment areas (PSTAs) have also been explored as a means to reach low discharge concentrations via downstream polishing cells (Zamorano et al., 2018; Zhao et al., 2015). To support the growth and function of periphyton, the soil from the PSTA cell is initially removed down to the underlying limestone caprock to reduce potential internal phosphorus loading from existing soil.

Accretion of organic and mineral matter in sediments is thought to be the major mechanism for the long-term sequestration of nutrients and other contaminants in these wetlands (Bhomia et al., 2015; Kadlec and Wallace, 2009; Reddy et al., 2021). Over time the residual floc material is compacted and becomes part of recently accreted soil (Bhomia et al., 2015). Soil accretion rates for STAs can range from a few millimeters to more than 1 centimeter per year (Bhomia et al., 2015; Dierberg et al., 2021; Reddy et al., 2021). The net accumulation of phosphorus in plant material can be influenced by vegetation type, characteristics of detrital material, and the water column chemistry. With time, STAs will accrete organic and mineral matter with different physical and biological characteristics and nutrient retention characteristics than the underlying soil (Bhomia et al., 2015).

Hydraulic conditions such as hydraulic loading rate, velocity, water depth, flow distribution, and hydroperiod are critical design and operational considerations for effective removal of phosphorus. STAs are designed to promote sheet flow without preferential flow paths. Each STA contains multiple flow-ways and cells to ensure even distribution of flows across the treatment area. Dense vegetation communities near STA inflows are designed to reduce the water velocity, creating a quiescent flow regime that facilitates particulate settling and nutrient removal. High flows or intense wind and storm events can mobilize floc and increase TP in the water column. Simple schematic maps of individual STA showing flow-paths and vegetation configuration within treatment cells are presented in Appendix B.

Role of Flow Equalization Basins

STAs work most effectively when the water and phosphorus inflows are moderated to be appropriate for the capacity of the treatment area. Too much flow or dry-down conditions can impact STA performance, sometimes for an extended period. Flow equalization basins (FEBs) are designed to provide upstream water storage to moderate the flow of water into an STA to optimize performance over a range of hydrologic conditions. Shallow, vegetated FEBs can also serve to remove phosphorus, although that is not their primary purpose. As part of Restoration Strategies, two FEBs (A-1 and L-8) are now operational, and a third is under construction.

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[12] FAV die-off can result in significant increases in water column phosphorus and nitrogen (Reddy and Sacco, 1981).

TABLE 4-2 Key Characteristics of the STAs for Water Years 2017-2022

STAs	Began Operation (WY)	Treatment area[a] (acres)	Inflow Water Volume (MAF/yr)	Average Inflow Conc[b] (µg/L)	Average Outflow Conc[b] (µg/L)	Phosphorus Loading Rate (g/m^2-yr)	Hydraulic Loading Rate (cm/day)	TP Retention Rate (g/m^2-yr)
STA-1E	2006	4,994	0.189	157	29	2.33	4.4	1.91
STA-1W	1994	10,810[c]	0.142	194	33	1.31	1.8	1.04
STA-2	2000	15,495	0.351	102	22	0.75	2.0	0.58
STA-3/4	2004	16,327	0.452	84	13	0.73	2.4	0.62
STA-5/6	1998 and 2000; combined in 2012	14,338	0.160	218	56	0.89	1.1	0.60

[a] Defined as total wetted surface area of the STA.
[b] Concentrations are flow-weighted means.
[c] Total area reflects 4,260 acres in STA-1W Expansion area #1 that became fully operational in WY 2021.
SOURCES: Data from Chimney, 2018, 2019, 2020, 2021, 2022a,b.

EVALUATION OF CURRENT CONDITIONS AND STRATEGIES OF INDIVIDUAL STAS TOWARD THE WQBEL

The recent performance of each of the five Everglades Construction Project/Restoration Strategies STAs are briefly summarized in this section by flow path, and more detailed descriptions and diagrams of each STA are provided in Appendix B. Current performance is discussed relative to the target WQBEL criteria of “shall not exceed: 13 µg/L as an annual flow-weighted mean (FWM) in more than 3 out of 5 water years on a rolling basis; and 19 µg/L as an annual flow-weighted mean (AFWM) in any water year” (FDEP, 2017). Key operational parameters and recent (WY 2017-2022) performance for all STAs are summarized in Table 4-2.

Central Flow Path: STA-3/4 and STA-2

The best performing Everglades STAs are situated in the Central Flow Path (see Figure 4-2) and receive inflows from the EAA, with inflow TP concentrations to STA-2 and STA-3/4 approximately 50 percent lower than those to the other STAs (Table 4-2). STA-3/4 has shown consistently impressive performance over the period of record and has maintained effluent phosphorus concentrations consistent with the WQBEL requirements during the recent 6 years (WY 2017-2022), with a flow-weighted mean discharge of 13 µg/L TP (Figure 4-8; Table B-1). The Restoration Strategies A-1 FEB (15,000 acres, 4 feet deep), completed in 2015, helps attenuate peak inflows to both STA-3/4 and STA-2 and also significantly reduces TP concentrations in the FEB outflows, essentially acting as a large supplemental STA. All Restoration Strategies actions have been completed for STA-3/4, and if best practices and optimal operational metrics are continued, this STA is poised to maintain outflow TP concentrations required by the WQBEL.

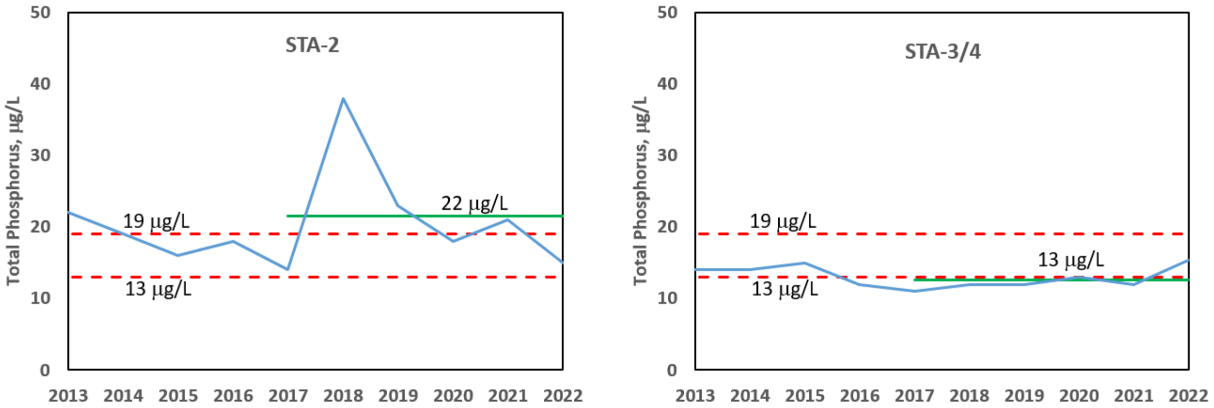

FIGURE 4-8 Flow-weighted annual mean TP concentrations in outflow of STA-2 and STA-3/4 during the operation period of WY 2013-2022. The red horizontal dashed lines represent upper and lower TP thresholds required by the WQBEL. The horizontal solid green line indicates flow-weighted annual mean TP concentrations during the most recent 6 years (WY 2017-2022). SOURCES: Data from Chimney, 2014, 2015a, 2016, 2017, 2018, 2019, 2020, 2021, 2022a,b.

STA-2 has effluent phosphorus concentrations that are close to meeting the WQBEL. In 6 out of the past 10 years, STA-2 discharge has met the upper annual limit (19 µg/L TP) but has never met the lower limit of the WQBEL (13 µg/L TP, required in at least 2 of every 5 years; see Figure 4-8). Efforts are under way to refurbish Flow-ways 2 and 3 (Figure B-3) in WY 2022-2023 by regrading the soil to address vegetation recruitment issues posed by uneven topography and to prevent hydrologic short circuiting. Recent vegetation management efforts have included restoration of damaged cattail stands after disruptions from intense storm events, including Hurricane Irma, and treatment of FAV (Chimney, 2022a). Between March 2021 and March 2022, flow-weighted mean outflow concentrations from Flow-ways 1, 4, and 5 averaged 13 µg/L TP or below, suggesting promise for STA-2 to meet the WQBEL if performance issues in Flow-ways 2 and 3 are successfully addressed (N. Hooseinny, SFWMD, personal communication, 2022).[13]

Eastern Flow Path: STA-1E and STA-1W

The discharges in the STAs of the Eastern Flow Path (see Figure 4-2) far exceed WQBEL requirements (Figure 4-9). STA-1E and STA-1W receive inflows from the C-51 West, S-5A, and L-8 Basins with some regulatory releases from Lake Okeechobee, and average inflow TP concentrations (157 µg/L and 194 µg/L for STA-1E and STA-1W, respectively, for WY 2017-2022) and phosphorus loading rates are much larger than those of the Central Flow Path (Table 4-2). Neither STA has experienced average annual discharges below 19 µg/L during the past 6 years.

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[13] This text has been corrected following prepublication release of the report to correct the reported STA measurement locations.

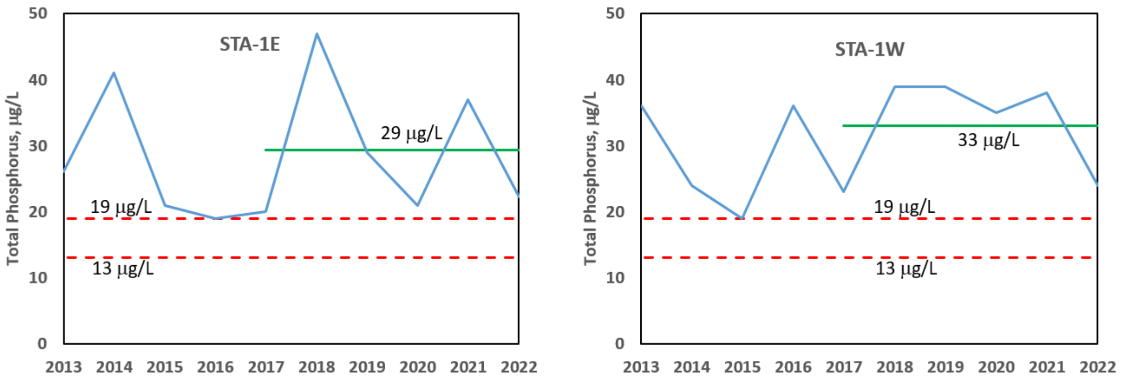

FIGURE 4-9 Flow-weighted annual mean TP concentrations in outflow of STA-1E and STA-1W during the operation period of WY 2013-2022. The red horizontal dashed lines represent upper and lower TP thresholds required by the WQBEL. The horizontal solid green line indicates flow-weighted annual mean TP concentrations during the most recent 6 years (WY 2017-2022). SOURCES: Data from Chimney, 2014, 2015a, 2016, 2017, 2018, 2019, 2020, 2021, 2022a,b.

Significant work is now under way through Restoration Strategies to address performance issues, including efforts to mitigate hydraulic short circuiting, excessive dry downs, and high phosphorus loading rates. Cells 5 and 7 of STA-1E have been regraded to better support growth of EAV, and efforts are under way to improve hydraulics and topographic issues in the three flow-ways of STA-1W, which are scheduled for completion in 2022. Long-term operations of the 45,000-AF L-8 FEB are expected to commence by the end of 2022, which will serve to moderate high and low inflows to STA-1E and STA-1W and thereby improve performance, although this deep belowground reservoir does not provide phosphorus removal, like the A-1 FEB. The SFWMD is working to manage operations to avoid observed increases in TP concentrations from the L-8 FEB after heavy rains (see Appendix B). An additional 5,860 acres[14] of STA-1W expansion area are in progress—Expansion #1 (4,260 acres) became operational in WY 2021, and Expansion #2 (1,600 acres) is expected to be completed in 2024 (Figure 4-2). Together, these two Restoration Strategies expansion areas will increase the total STA area of the Eastern Flow Path by approximately 50 percent.

Subregional source control efforts were included in the Restoration Strategies program to reduce the inflow of phosphorus into STA-1E and STA-1W (SFWMD, 2012), and specific projects "are being considered based on a combination of factors, including water quality of discharges, proximity and potential impact of discharges to STAs, and having willing local participants" (Shuford, 2022). Two pilot studies were conducted to help inform the design of subregional source control projects. From 2013 to 2015, a pilot project was conducted to examine the effects of dredging sediments and vegetation from canals (canal cleaning) in the East Beach Water Control District (CH2M Hill, 2016a). The SFWMD reported that effects of the pilot project were difficult to discern under varying hydrologic conditions with the existing baseline data (Hutchins et al., 2017). The second pilot project involved an analysis of existing water quality data and activities in the S-5A Basin within the EAA (CH2M Hill, 2016b, 2017). Shuford (2022) notes that the SFWMD continues to develop "preliminary subregional source control concepts and to seek participation from S-5A basin stakeholders. Additional concepts are

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[14] Reported as treatment area.

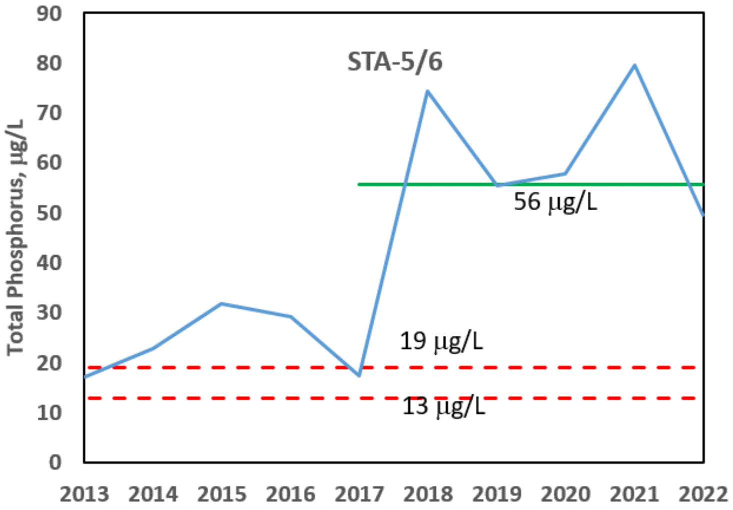

FIGURE 4-10 Flow-weighted annual mean TP concentrations in outflow of STA-5/6 during the operation period of WY 2013-2022. The red horizontal dashed lines represent upper and lower TP thresholds required by the WQBEL. The horizontal solid green line indicates flow-weighted annual mean TP concentration during the most recent 6 years (WY 2017-2022).
SOURCES: Data from Chimney, 2014, 2015a, 2016, 2017, 2018, 2019, 2020, 2021, 2022a,b.

expected to be developed as these discussions continue." In summary, significant progress is under way in STA expansion and refurbishment in the Eastern Flow Path, but no progress in reducing loads is apparent through additional Restoration Strategies subregional source control practices despite a decade of effort.

STA-5/6 (Western Flow Path)

STA-5/6 is challenged by high inflow TP concentrations from the C-139 Basin (218 µg/L on average for WY 2017-2022) and low hydraulic loading (Table 4-2). In recent years, STA-5/6 has far exceeded the WQBEL target discharge concentrations, with only 1 year in the past 6 years with average annual discharges below 19 µg/L (Figure 4-10). Between 2018 and 2020, refurbishment operations were under way on STA-5/6 as part of Restoration Strategies, including earthwork and regrading on more than 1,100 acres to address uneven topography and "non-effective treatment areas" (Shuford et al., 2022).

Runoff from the C-139 Basin is flashy, with long periods of little to no runoff. Portions of STA-5/6 dry out nearly every year (see Appendix B), and the rainy season brings high volume inflows that release high phosphorus concentrations from the STA upon rewetting. To operate most effectively, STAs need steady water delivery throughout the year to maintain saturated conditions in all flow-ways. The new Restoration Strategies C-139 FEB, which is projected to be operational in 2024, is expected to hold 11,000 AF to provide additional water to help maintain hydration of the STA during dry periods (Shuford et al., 2022). However, the C-139 FEB is substantially smaller in volume than the A-1 and L-8 FEBs, and the extent to which it will ameliorate the long dry periods remains unclear.[15] If the FEB cannot maintain saturated conditions, STA-5/6 could benefit from a new connection to the Miami Canal (and Lake Okeechobee) that would provide additional water supply to the STA-5/6 inflows to prevent dry-down conditions and potentially provide additional flexibility for managing inflows to STA-2 and STA-3/4.

Assessment Across All STAs

Efforts undertaken as part of Restoration Strategies are expected to improve the performance of all STAs. The impressive performance of STA-3/4 shows that sustained discharge with TP concentrations below 13 μg/L is possible, especially if associated with low phosphorus inflow concentrations and loading rates. However, the challenge of meeting the WQBEL starting in WY 2027 is substantial. A helpful way to illustrate key challenges across the different STAs is to calculate phosphorus treatment efficiency based on either average flow-weighted mean inflow and outflow TP concentrations or inflow and outflow TP loads.[16]

Phosphorus treatment efficiency of STAs based on average inflow and outflow concentrations over the most recent 6 years (WY 2017-2022) ranged from 74 to 85 percent (Figure 4-11; Table 4-3). The highest and lowest treatment efficiencies were found in STA-3/4 and STA-5/6, respectively. The range of treatment efficiencies across the STAs, however, was relatively small, especially considering the larger range in outflow concentrations. STAs with higher inflow TP concentrations will require substantially greater STA treatment efficiencies to

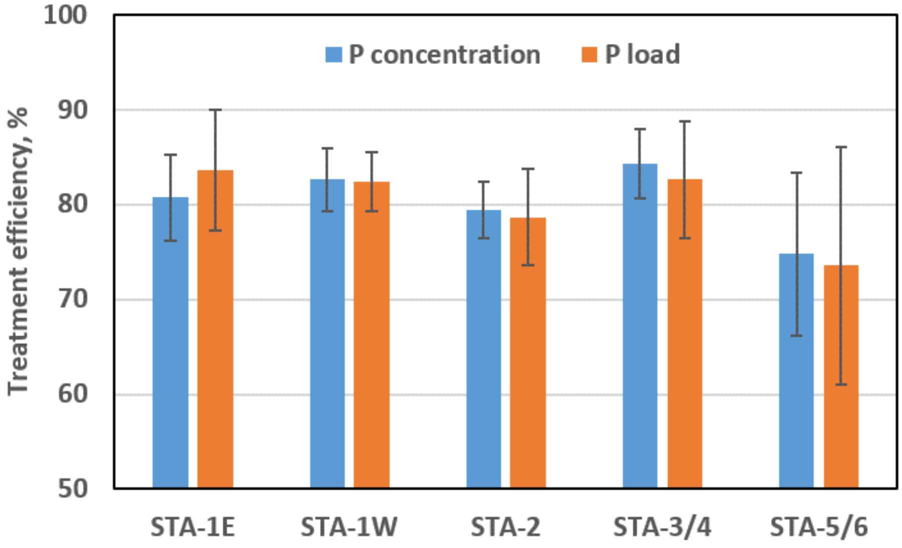

FIGURE 4-11 Average annual phosphorus treatment efficiencies for STAs during the operation period of WY 2017-2022. Whiskers represent one standard deviation of the annual data. SOURCES: Data from Chimney, 2018, 2019, 2020, 2021, 2022a,b.

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[15] Models used as the basis for the 2012 Restoration Strategies Regional Water Quality Plan did not have the ability to reliably simulate durations of dry outs (J. Otero, SFWMD, personal communication, 2022).

[16] TP treatment efficiency = ((Inflow TP – Outflow TP)/Inflow TP)*100

TABLE 4-3 Anticipated Phosphorus Treatment Efficiency to Achieve the WQBEL at the Ambient Inflow TP Concentrations Indicated

	Recent Conditions (WY 2017-2022)			Future Efficiency Needed to Meet an Annual Average of:	
	Inflow TP concentration μg/L	Outflow TP concentration μg/L	Treatment efficiency (%)	13 μg/L TP	19 μg/L TP
STA-1E	157	29	81	92	88
STA-1W	194	33	83	93	90
STA-2	102	22	79	87	81
STA-3/4	84	13	85	85	77
STA-5/6	218	56	74	94	91

NOTE: Treatment efficiency is the bulk treatment efficiency over the operational period WY2017-2022
SOURCES: Data from Chimney, 2018, 2019, 2020, 2021, 2022a,b.

meet the WQBEL compared to those with lower inflow TP concentrations. For example, for WY 2017-2022, the treatment efficiency of STA-2, considered to be a well-performing STA (flow-weighted mean inflow and outflow concentrations of 102 and 22 μg/L TP, respectively) was actually lower than the treatment efficiency of poorly performing STA-1W (flow-weighted mean inflow and outflow concentrations of 194 and 33 μg/L TP, respectively).

As demonstrated in Table 4-3, the STAs that are not currently meeting the WQBEL must increase their efficiency, beyond the current efficiency of STA-3/4, or reduce inflow concentrations and/or loads. For example, to achieve the 13 μg/L TP target with current average inflow concentrations and loads, the treatment efficiency of STA-1W must increase to 93 percent and the STA-5/6 treatment efficiency must increase to 94 percent, which is significantly higher than STA-3/4, which is currently operating at 85 percent removal efficiency (Table 4-3). A few of the STAs may already be functioning at or near their limits of performance, and current STA performance is very good compared to treatment wetlands currently used globally for nutrient reduction to protect downstream water quality.

Efforts are also under way through Restoration Strategies to reduce phosphorus loading rates by increasing the STA treatment area in the Eastern Flow Path. Moreover, Restoration Strategies envisioned efforts to reduce phosphorus loads through subregional source control efforts, although no source reduction projects have been implemented. Inflow TP concentrations must be reduced by 50 to 60 percent to bring the other STAs to the same concentrations as are currently experienced in STA-2 and STA-3/4. For STA-1E and STA-1W, expansion of the treatment area coupled with L-8 FEB will help to reduce phosphorus loads and potentially reduce outflow TP concentrations. Shallow vegetated FEBs in the Western and Central Flow Paths may help reduce inflow concentrations.

The above analysis highlights several common factors among the best performing STAs: low phosphorus loading rates, low inflow TP concentrations, moderate hydraulic loading rates, and large STA sizes (see Table 4-2 and Appendix B). Poor-performing STAs tend to have high phosphorus loading rates, high inflow TP concentrations, and/or high or low hydraulic loading rates. These factors and others will be explored in the next section as drivers of performance, to inform actions that could improve performance.

EXTERNAL AND INTERNAL DRIVERS REGULATING STA PERFORMANCE

The function and ability of STAs to remove phosphorus and ultimately meet the WQBEL is regulated by both external and internal drivers. Key external drivers include inflow phosphorus concentrations and loading rates, hydraulic loading, and inflow water chemistry, which all can be affected by the source of the inflow water (e.g., EAA, C-139 Basin, Lake Okeechobee water). These external drivers are affected by climate change variables such as increasing temperature and irregular rainfall patterns, which are manifested as more intense storms, more frequent hurricanes, and more intense periods of water shortages and drought. Internal drivers include the biological communities within an STA (e.g., vegetation, periphyton, microbes), phosphorus enrichment in soils, water chemistry, and nutrient status over flow-paths. Internal drivers are linked to external drivers, which together influence the overall operating system that supports the function of STAs to remove phosphorus from inflow waters. For STAs, many of these external drivers have been well studied, but understanding of the role of internal drivers in regulating the performance of STAs is more limited.

Key External Drivers

External drivers control inputs of water and nutrients to STAs or disturb those systems. Many of these drivers can be managed with STA treatment area and design criteria and use of FEBs.

Phosphorus Concentrations and Loading Rates

Phosphorus concentrations. The concentration of phosphorus in inflow water is an important controller of STA performance (Kadlec and Wallace, 2009; Zhao and Piccone, 2020). The higher the inflow concentration, the greater the percent removal required of the STA to reach the target concentration of 13 µg/L. Chimney (2022a) noted: “Depending on the averaging period, inflow TP concentration generally accounted for 50 to 60% of the variability in outflow TP concentration…” based on past SFWMD analyses of STA data over the period of record.

Average annual flow-weighted inflow concentrations for WY 2004-2022 across all STAs range from less than 100 to more than 200 µg/L TP (Figure B-1). Long-term average TP concentrations of inflow water during the operation period are approximately 50 percent lower for the best performing STAs (STA-2 and STA-3/4) compared to STA-1E, -1W, and -5/6 (Figure 4-12). With low inflow TP concentrations, STA-2 and STA-3/4 have been highly resilient throughout their operational period. Moreover, STA-3/4 has been able to maintain annual outflow TP concentrations to meet WQBEL since WY2009 (see Figure B-1, Appendix B).

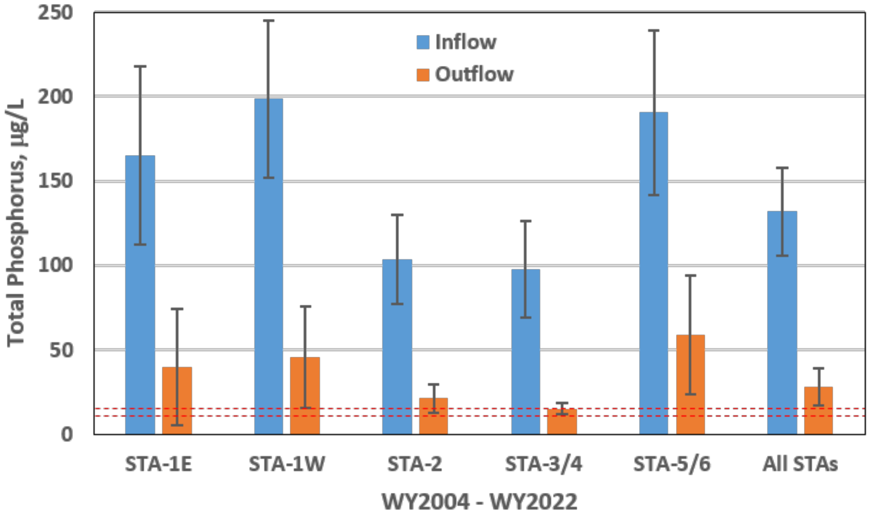

FIGURE 4-12 Long-term average of annual volume-weighted TP concentrations on the STA inflow and outflow water during the operation period of WY 2004-2022 except for STA-1E (WY 2006-2022). Horizontal red dashed lines represent WQBEL upper (19 µg/L) and lower (13 µg/L) limits for outflow TP concentration. Whiskers represent one standard deviation of annual data. SOURCES: Data from Chimney, 2014, 2015a, 2016, 2017, 2018, 2019, 2020, 2021, 2022a,b; Germain and Pietro, 2011; Goforth et al., 2005; Ivanoff et al., 2012, 2013; Pietro et al., 2006, 2007, 2008, 2009, 2010.

Inflow TP concentrations are affected by watershed hydrology, land use, fertilizer and manure applications, legacy phosphorus in soils, storm events, drought, and best management practices applied at the farm and basin scales (see NRC, 2010 for more discussion of source control requirements and strategies). Intense storms can initially flush nutrients from the watershed, although extended wet periods generally dilute TP concentrations. Changing sources of inflow, such as increasing water deliveries from Lake Okeechobee, will also affect TP concentrations in STA inflows (see Box 4-4). Broader or more intensive use of best management practices would provide the best opportunity to reduce TP concentrations and loads in STA inflows.

Phosphorus loading rates. One of the most consistent external factors driving STA performance is phosphorus loading rates from external sources. In a recent study, DB Environmental (2022) reported that phosphorus loading rates less than 1.3 g/m^2-yr with no disturbance (e.g., construction, vegetation damage from severe storms) consistently showed mean annual flow-weighted outflow concentrations less than 25 µg/L TP. In contrast, undisturbed STAs with phosphorus loading rates greater than 1.3 g/m^2-yr exhibited higher mean annual flow-weighted outflow concentrations (Figure 4-14). Over the long-term, low TP loading rates (< 1.0 g/m^2-yr P) to STA-2 and -3/4 have helped to maintain low outflow TP concentrations, compared to the other STAs (Figures 4-15 and 4-16). STA-1E and -1W experienced high phosphorus loading rates of greater than 2 g P/m^2-yr for 7 years, between 1 and 2 g P/m^2-yr for 7 years, and less than 1 g P/ m^2-yr for only 4 years. These observations are consistent with earlier studies reported by Kadlec (1999) and Richardson et al. (1997). STAs experiencing vegetation disturbance showed still greater effluent TP concentrations (Figure 4- 14), suggesting that low phosphorus loading rates are an important but not the sole factor driving STA performance.

BOX 4-4
Lake Okeechobee Water Quality

Elevated supply of nutrients is a water quality concern not only for Lake Okeechobee, but also for the northern estuaries and potentially the Everglades Protection Area. In 2001, a total maximum daily load (TMDL) for total phosphorus (TP) of 140 t/yr was established for Lake Okeechobee (FDEP, 2001). Over the most recent 5-year interval (WY 2017-2021), the average annual load of TP into the lake was 570 t/yr (Zhang et al., 2022), far exceeding the TMDL. The TMDL was established to achieve a TP concentration below 40 µg/L to improve the structure and function of the lake ecosystem. Annual phosphorus concentrations in Lake Okeechobee have increased from the earliest measurements in the 1970s through WY 2021 (see Figure 4-13). The recent (WY 2021) annual volume-weighted concentration (147 µg L^{-1}) was nearly four times greater than the TMDL target. Over the long term, TP concentrations have greatly increased in the lake due to the loading from inflowing waters coupled with a decline in the phosphorus retention capacity of lake sediments (James et al., 2009; Zhang et al., 2022).

Elevated nutrient concentrations in Lake Okeechobee have adverse impacts on the northern estuaries, which receive periodic high-volume discharges when lake stage is high. High nutrient concentrations also have implications for the Central Everglades Restoration Plan and the plans to move more Lake Okeechobee water south into the remnant Everglades. High TP in Lake Okeechobee could challenge the capacity of Stormwater Treatment Area infrastructure to meet the water quality discharge standards.

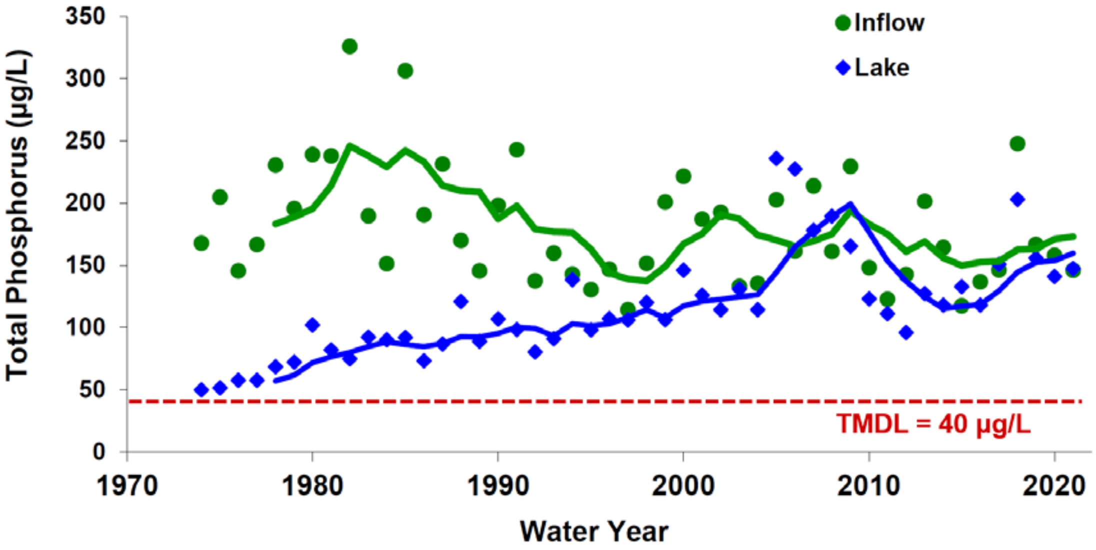

FIGURE 4-13 Total phosphorus concentrations in Lake Okeechobee and its inflows as annual averages and 5-year moving average trend lines. The target TMDL TP concentration is indicated (40 µg/L). SOURCE: Modified from Zhang et al., 2022.

Increasing the size of the STA footprint, as is under way in the Eastern Flow Path, can help address conditions with high phosphorus loading rates. Construction of shallow, naturally vegetated FEBs, as are part of Restoration Strategies in the Central and Western Flow Paths, can reduce both phosphorus loading rates and inflow concentrations.

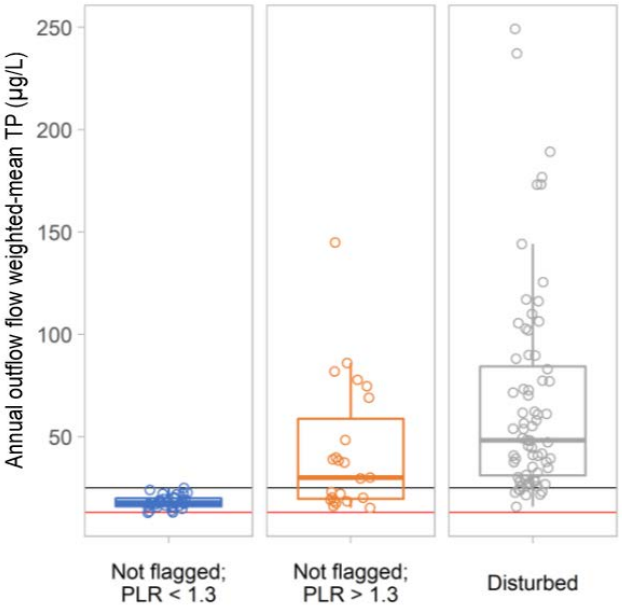

FIGURE 4-14 Box and whisker diagram of annual volume-weighted concentrations of TP in outflows of STA-1E,-1W, -2, and -5/6 for groups of observations that were not flagged to have vegetation disturbance with phosphorus loading rate (PLR) less than 1.3 g/m^2-yr (left panel); that were not flagged to have vegetation disturbance with phosphorus loading rate greater than 1.3 g/m^2-yr (middle panel); and that were flagged to have experienced vegetation disturbance (right panel).
SOURCE: DB Environmental, 2022, under contract to the SFWMD.

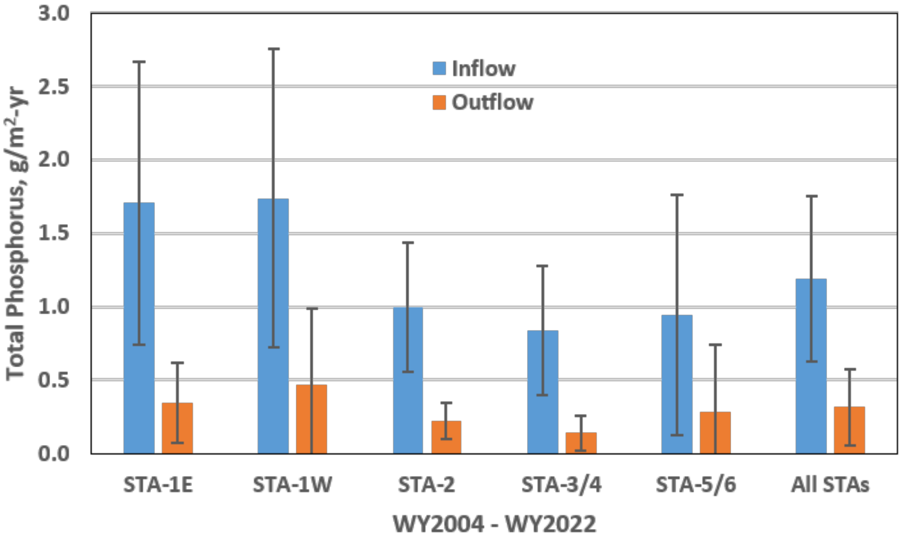

FIGURE 4-15 Long-term average of annual inflow and outflow phosphorus loading rates of STAs during the operation period of WY 2004-2022 except for STA-1E (WY 2006-2022). Error bars are one standard deviation of annual data.
SOURCE: Data from Chimney, 2014, 2015a, 2016, 2017, 2018, 2019, 2020, 2021, 2022a,b; Germain and Pietro, 2011; Goforth et al., 2005; Ivanoff et al., 2012, 2013; Pietro et al., 2006, 2007, 2008, 2009, 2010.

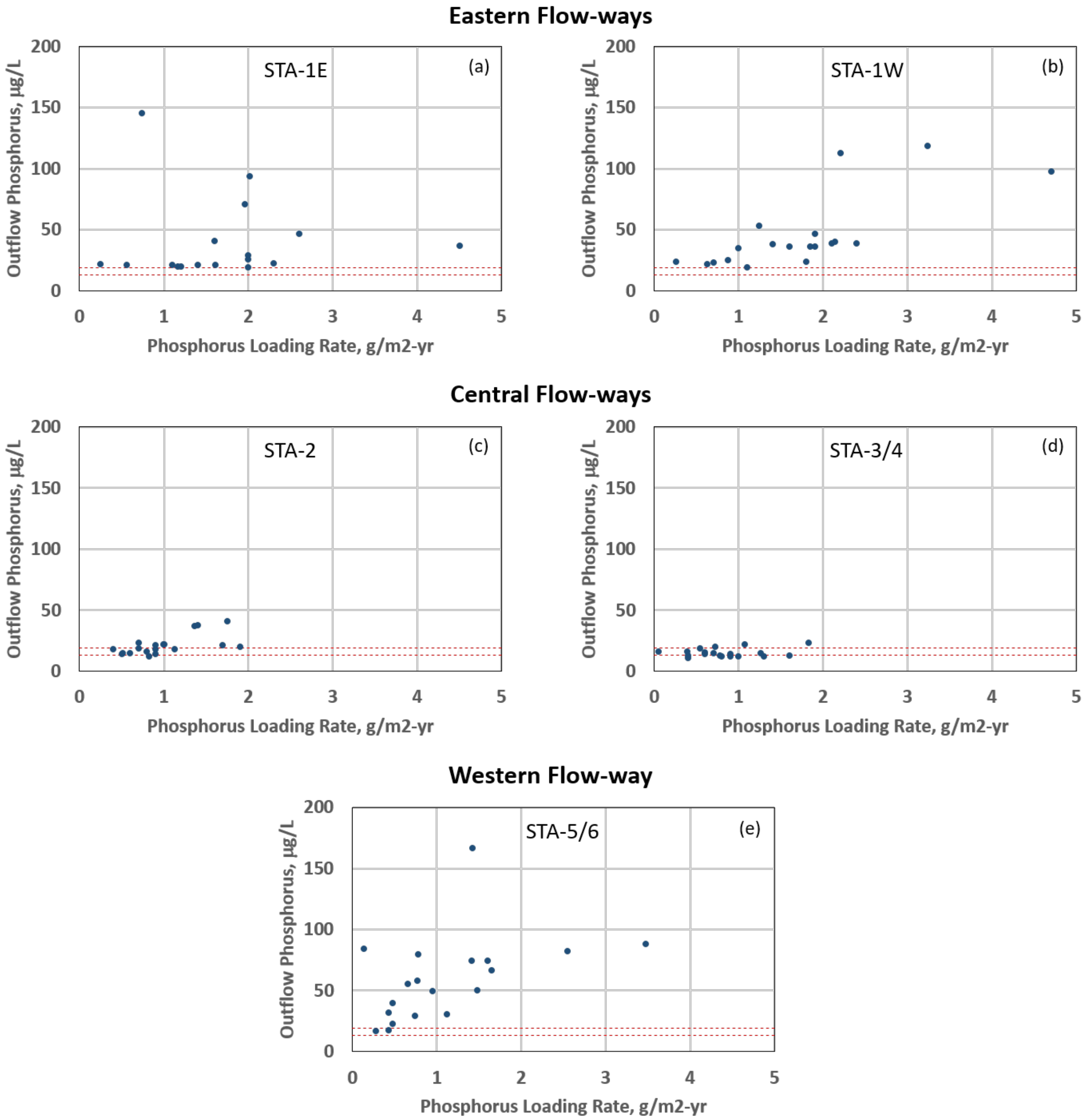

FIGURE 4-16 Relationship between annual volume-weighted mean concentrations of TP in outflow and annual phosphorus loading during the operation period of WY 2006-2022 for STA-1E and WY 2004-2022 for the other four STAs. Dashed red lines represent the requirements of the WQBEL (13 μg/L and 19 μg/L TP) limits.
SOURCE: Data from Chimney, 2014, 2015a, 2016, 2017, 2018, 2019, 2020, 2021, 2022a,b; Germain and Pietro, 2011; Goforth et al., 2005; Ivanoff et al., 2012, 2013; Pietro et al., 2006, 2007, 2008, 2009, 2010.

Disturbance Events: Storms and Droughts

Disturbance events, such as flooding or high winds with vegetation damage, dry-out, and construction, can also affect STA performance. DB Environmental (2022) evaluated the performance along flow-ways over time within STA-1E, -1W, -2, -5/6 (see Figures B-2 to B-6 for diagrams of the flow-ways in each STA) and showed a strong effect of disturbance on outflow TP concentrations. The mean outflow concentrations from flow-ways in which the vegetation was disturbed was nearly double that of undisturbed flow-ways with high loading rates (see Figure 4-14). The period of elevated outflow TP concentrations may range from a few weeks to more than a year depending on the type of the disturbance, its location along the STA flow-way, the type of vegetation affected, floc and soil resuspension, and the efforts to rehabilitate the system after an event.

Storms and high hydraulic loading. Storm events or prolonged wet weather can influence STA performance through changes in hydraulic loading. Storms often coincide with increases in phosphorus inflow concentrations and loads, leading to a decrease in STA performance (Figure 4-17). During the operation period, STA performance was affected by several tropical storms and hurricanes including Francis and Jeanne (WY 2005), Wilma (WY 2006), Ernesto (WY 2007), and Irma (WY 2018). Flood events trigger high pumping rates into the STAs, which are part of the EAA flood protection system, increasing flow velocity and particle entrainment and decreasing the hydraulic residence time within STAs, which can diminish performance. High hydraulic loading can also increase water depth within an STA. Water depths in EAV treatment cells exceeding 3 feet result in physiological stress in plants, reducing biomass and plant density and ultimately decreasing phosphorus removal (Diaz, 2022). Deep water conditions for extended periods can result in widespread mortality of cattails and formation of floating tussocks.

Over the past 7 years, significant quantities of STA inflows have come from Lake Okeechobee regulatory releases, which are used to reduce high lake levels to protect the integrity of the Herbert Hoover Dike and to improve ecological conditions in the lake (see Chapter 3). The Restoration Strategies Regional Water Quality Plan (SFWMD, 2012) assumed average lake regulatory releases of 58,300 AF/yr—all through STA-3/4—but since 2014, average annual regulatory releases have been 245,000 AF/yr (Figure 4-18). These high regulatory releases to the STAs provide benefits to the northern estuaries by reducing harmful discharges and to the remnant Everglades by increasing flows, providing the equivalent of 66 percent of the CEPP’s new water benefits without any new infrastructure. Regulatory releases from Lake Okeechobee to STA-1E, -1W, and -2 (Figure 4-18) have also increased chronically high phosphorus loading rates and have added more stress to STAs that have been unable to meet the WQBEL.

The new CERP A-2 STA has been designed to significantly reduce the adverse effects of storm events on STA operations. The A-2 STA is not part of the EAA flood protection system design, and its inflow capacity (650 cfs; SFWMD, 2018a) is one-tenth the inflow capacity of STA-3/4.[17] With the large A-2 Reservoir effectively serving as a FEB, inflows can be moderated to optimize performance, reduce vegetation stress, and minimize sediment entrainment in canals and mobilization of floc within the STA. The A-2 STA offers an opportunity to learn how well an STA can perform with limited exposure to the effect of storm event runoff and associated high loading events.

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[17] STA-3/4 has a maximum inflow capacity of 6,475 cfs via the G-370 and G-372 pump stations (FDEP, 2017b).

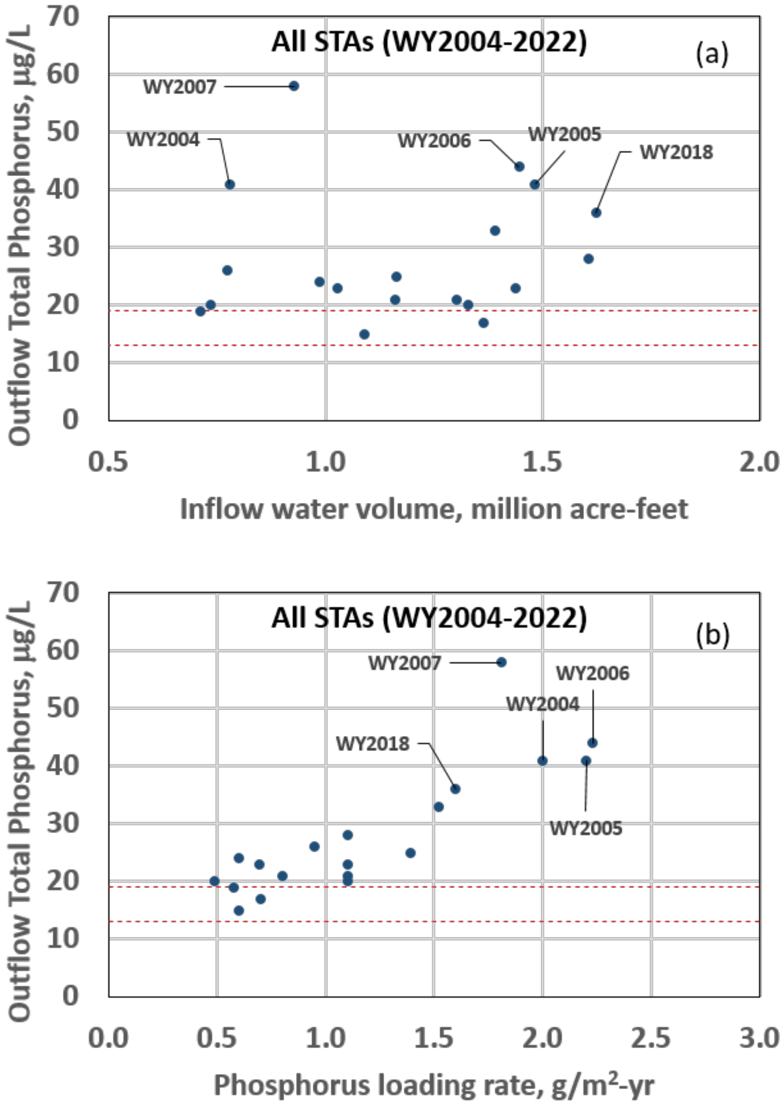

FIGURE 4-17 Influence of (a) annual inflow volume of water and (b) annual phosphorus loading rate on average outflow TP concentration during the operation period of WY 2004-2022 for all STAs. Values reported are average of all STAs. Dashed red lines represent the requirements of the WQBEL (13 µg/L and 19 µg/L TP) limits. Years identified in both figures indicate the effect of intense tropical storms and hurricanes on STA performance, with major hurricanes occurring in WYs 2005 (Francis and Jeanne), 2006 (Wilma), 2007 (Ernesto), and 2018 (Irma). The committee is not aware of what factors contributed to the high phosphorus loading rate in WY 2004. Overall, on an average annual basis, the STAs collectively responded to low phosphorus loading rates of less than 1 g/m^2-yr and produced outflow TP concentrations of less than 25 µg/L once the disturbance event subsided.
SOURCE: Data from Chimney, 2014, 2015a, 2016, 2017, 2018, 2019, 2020, 2021, 2022a,b; Germain and Pietro, 2011; Goforth et al., 2005; Ivanoff et al., 2012, 2013; Pietro et al., 2006, 2007, 2008, 2009, 2010.

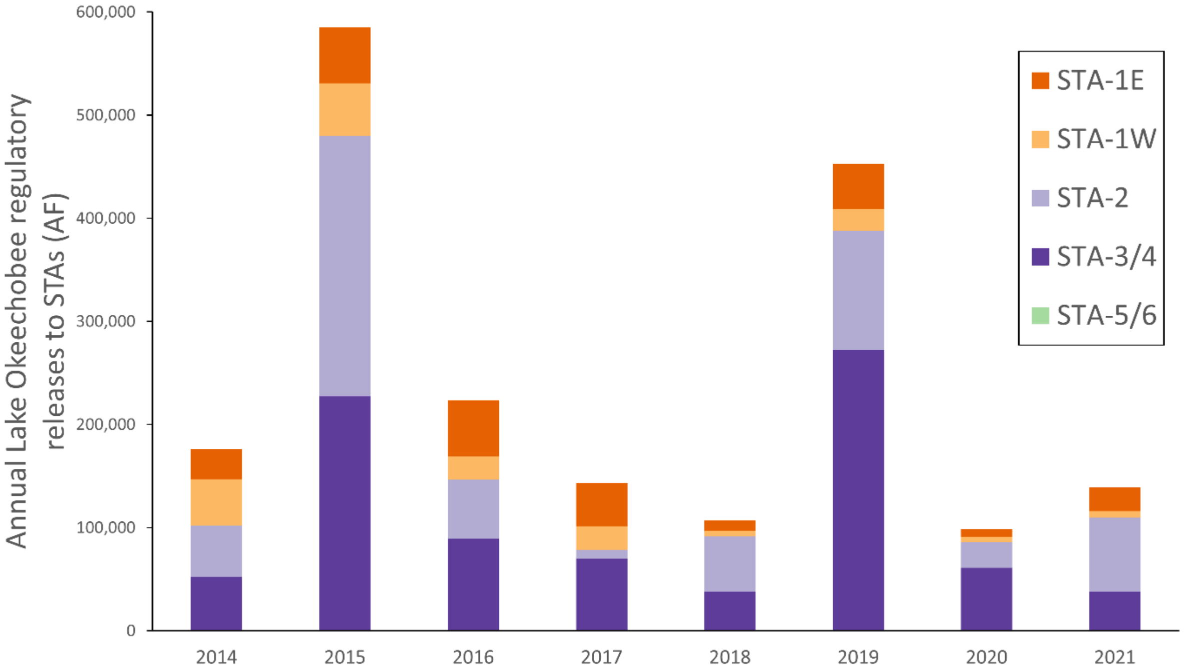

FIGURE 4-18 Annual Lake Okeechobee regulatory releases to the STAs per water year in response to high water conditions in the lake. Restoration Strategies (SFWMD, 2012) assumed average lake regulatory releases of 58,300 AF/yr— all through STA-3/4. For WY 2015, STA-3/4 inflows are reported as a combination of lake water from regulatory releases, water supply deliveries, and a dry season flow test.
SOURCE: Data from Chimney, 2015a, 2016, 2017, 2018, 2019, 2020, 2021, 2022a.

Storms can be associated with high winds and wave action, which can damage vegetation and suspend sediment, respectively, again resulting in a deterioration of phosphorus removal efficiency (DB Environmental, 2022). SAV cells can be particularly sensitive to disturbance. Following intense storm events, substantial declines in SAV coverage and densities have been reported in several STA cells (Dombrowski et al., 2020). Vegetative buffers of EAV, such as those used in STA-3/4 and recently established in STA-2 (Figure 4-19), can reduce the impacts of high winds on SAV.

Droughts and dryout. Dry-out and reflooding is also an important disturbance that can affect STA function (Dierberg et al., 2012; Newman and Pietro, 2001; Pant and Reddy, 2001). Soil desiccation can result in mineralization of detrital soil organic phosphorus, and in turn phosphorus can be mobilized into the water column upon subsequent reflooding (Søndergaard and Jeppesen, 2020; White et al., 2006). In addition, if STA soils experience dry-out, sulfide formed under flooded soil conditions will oxidize, decreasing soil pH and mobilizing phosphorus.

The magnitude of these effects, however, depends on the conditions and location of dry-out and reflooding. If dry-out occurs in outflow cells, the impacts of outflow on water quality are likely more severe than for dry-out in inflow cells (DB Environmental, 2022). Moreover, good vegetation coverage and condition in outflow cells can mitigate against the effects of upstream dry-out due to effective retention of the mobilized phosphorus in downstream cells. Finally, the

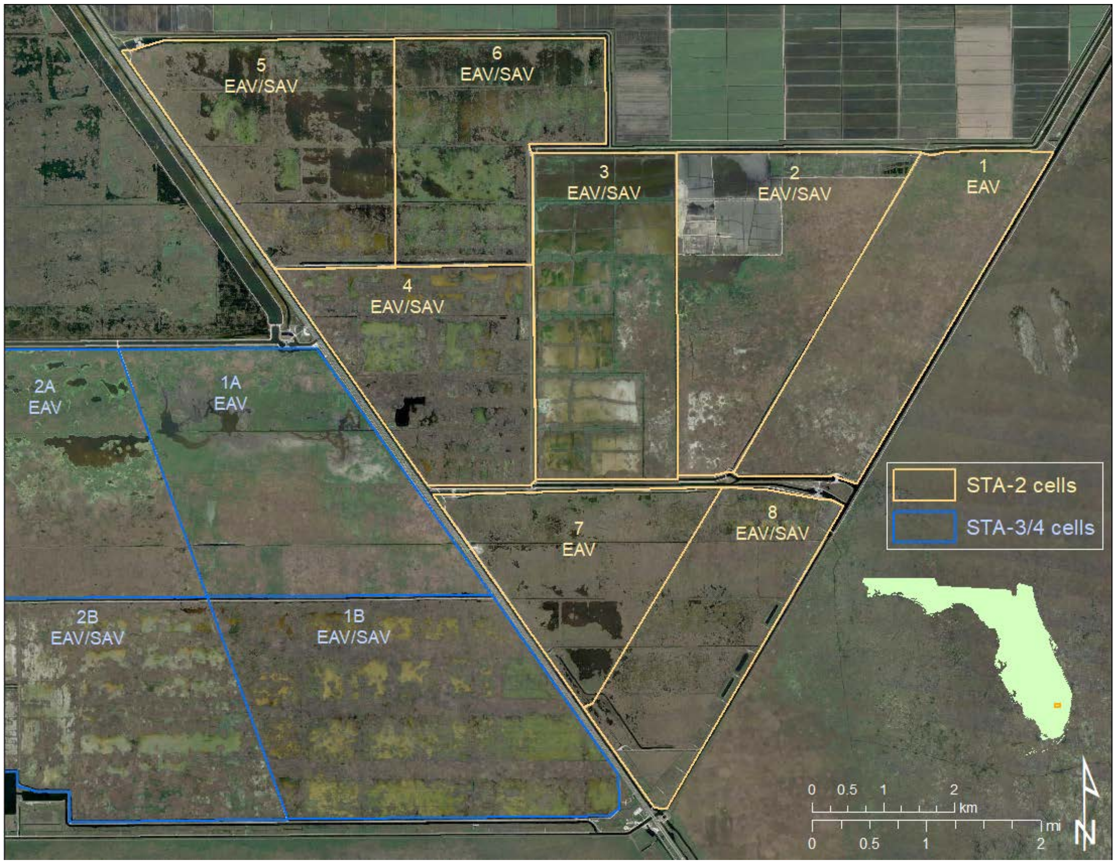

FIGURE 4-19 STA-2 and the eastern side of STA-3/4, with visible EAV strips amidst SAV (e.g., STA-2 Cell 3 or STA-3/4 Cells 1B and 2B) to reduce wind damage.
SOURCE: Modified from Google Earth 2022.

magnitude of reflooding following dry-out will influence the extent of disturbance. Gradual reflooding with limited discharge generally produces limited TP increases, while reflooding involving large discharges results in large TP concentrations in outflow waters (DB Environmental, 2022). Access to water from Lake Okeechobee (currently available to all STAs except STA-5/6) or other sources of water storage, such as an FEB, can eliminate dryout conditions if sufficient water is available.

Other Constituents

Concentrations of other constituents, such as nitrogen and calcium, in inflow waters may also affect the functioning of STAs.

Nitrogen. A balance between nitrogen and phosphorus is needed to support the primary productivity of biotic communities in STAs and other wetlands and aquatic ecosystems (Capek et al., 2018; Conley et al., 2009; Pearl et al., 2016). However, nitrogen availability within STAs is likely an under-recognized potential driver of phosphorus treatment efficiency. Nitrogen in STAs is not currently managed or intensively researched, but differences in nitrogen loads and

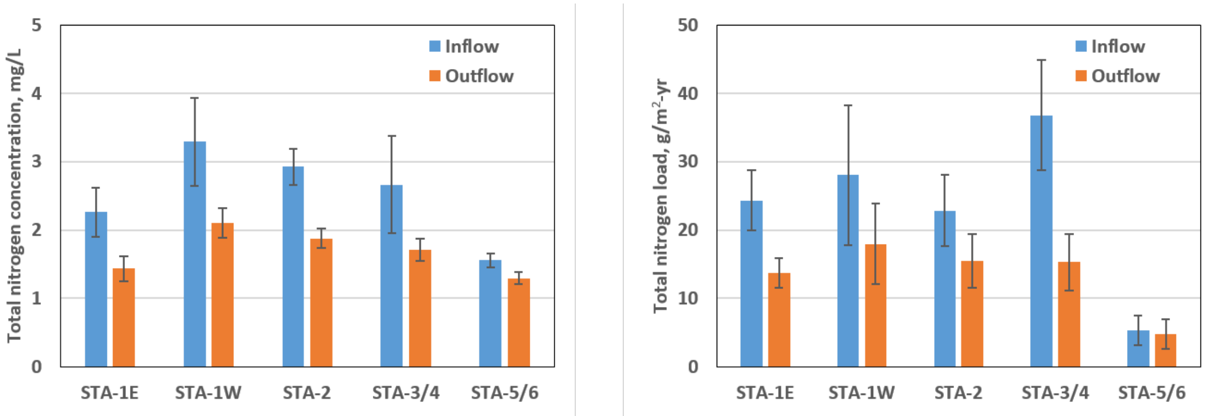

FIGURE 4-20 Average total nitrogen concentrations and loads in the inflow and outflows of STAs during operation period of WY 2014-2020. Whiskers represent one standard deviation of annual data.
SOURCE: Data from Chimney, 2015a, 2016, 2017, 2018, 2019, 2020, 2021.

removal efficiency among the STAs hint at the potential importance of nitrogen to STA performance. For WY 2014-2021, the highest average total nitrogen (TN) inflow loads were evident in STA-3/4, the best-performing STA, while the lowest loads occurred in STA-5/6, which in recent years has performed poorly (Figure 4-20). In general, watershed sources of nitrogen for STA inflows include inorganic and organic fertilizers, animal manures, biosolids, plant litter, and organic matter in soils. Watershed management, hydrology, soil types, redox, and land use will affect nitrogen loads and its forms (e.g., inorganic and organic nitrogen; see Box 4-5) in STA inflow waters.

Nitrogen-to-phosphorus (N/P) ratios of water, vegetation, microbes, litter, floc, and soils commonly serve as indicators of their roles in regulating primary productivity and water quality in aquatic ecosystems (Capek et al., 2018; Koerselman and Meuleman, 1996; Pearl et al., 2016),[18] and thus, N/P ratios in STA inflows may also be indicative of differences in STA performance (Figure 4-22a). Low N/P ratios (11 to 18) are evident in the inflows of the poorly performing STAs (STA-1E, -1W, and -5/6), and relatively high N/P ratios (30 to 32) are observed for inflows in the better performing Central Flow Path (STA-2 and STA-3/4) (Figure 4-22a). STA-3/4 inflows also have the largest average fraction of dissolved inorganic nitrogen (ammonium and nitrate), which is more reactive than organic nitrogen, while STA-5/6 inflows have the lowest (Figure 4-21).

N/P ratios may also potentially serve as indicators of performance along STA flow-ways. Upstream areas of the STAs with phosphorus-saturated soils typically have lower N/P ratios in both water (Figure 4-22) and recently accreted soil and floc (Figure 4-23) compared to downstream areas because of conditions of phosphorus surplus, which can lead to nitrogen limitation or nitrogen and phosphorus co-limitation (Inglett et al., 2009; Pearl et al., 2016). Nitrogen limitation reduces phosphorus uptake by microbes, periphyton, and vegetation by suppressing the activity of phosphatase enzymes (Inglett et al., 2019a,b; Reddy et al., 2005; Tessier and Reynald, 2003). Nitrogen limitation can also decrease the primary productivity of

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[18] In this report, N/P ratios are expressed on a mass basis. Mass-based N/P ratios can be multiplied by 2.2 (31/14) to obtain molar-based N/P ratios.

BOX 4-5
Nitrogen Forms in STA Inflows and Outflows

Nitrogen forms are an external driver of various nitrogen cycling transformations in soil and water column within stormwater treatment areas (STAs). In most STAs, organic nitrogen loads represent approximately 70 percent of the total nitrogen inflow load on average, although organic nitrogen loads are approximately 90 percent in STA-5/6 (Figure 4-21).

Dissolved inorganic nitrogen forms (i.e., ammonium, nitrate, nitrite) are preferentially removed in all STAs through denitrification, which produces nitrous oxide and nitrogen gas (Reddy and Delaune, 2008; White and Reddy, 1999), although some inorganic nitrogen is also removed through uptake by vegetation, periphyton, and microbes and converted into dissolved and particulate forms of organic nitrogen. Because of the biotic availability of dissolved inorganic nitrogen, the vast majority of total nitrogen in STA outflows is associated with organic nitrogen (Figure 4-21). Low concentrations of inorganic nitrogen in STA inflows may affect performance.

Once inorganic nitrogen is depleted in water and soils, vegetation, periphyton, and microbes depend on enzymatic-mediated organic nitrogen mineralization to obtain nitrogen (as ammonium) for their growth. This mineralization process supports vegetation productivity and likely influences treatment efficiency of STAs. Wetlands including STAs are known to produce dissolved organic nitrogen associated with leaching from plants and the incomplete decomposition of organic matter under anoxic conditions in soil. At present the relative proportion of dissolved organic nitrogen entering STAs from external sources compared to that produced through internal biogeochemical processes is not known. Additional research on abiotic and biotic biogeochemical processes regulating the fate of phosphorus and nitrogen forms within the STA soil and water column would enhance the understanding of STA performance.

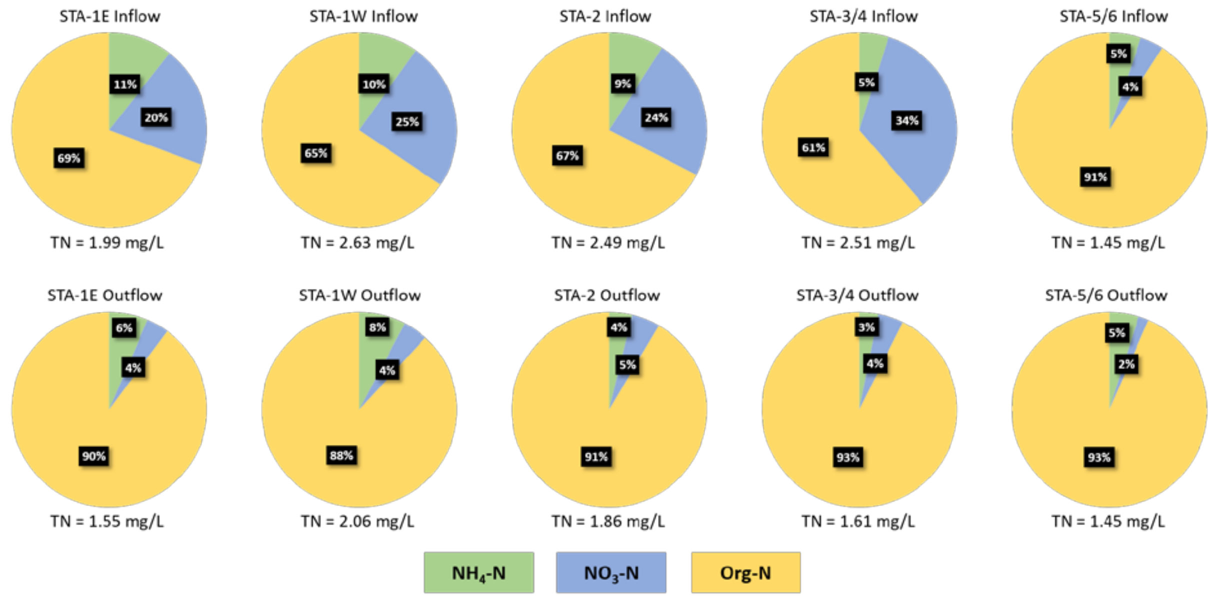

FIGURE 4-21 Average distribution of total nitrogen as ammonium N (NH_4-N), nitrate N (NO_3-N), and organic N (Org-N) in the inflow and outflow water measured monthly during the operation period of WY 2014-2020.
SOURCE: Data from Hu and James, 2021.

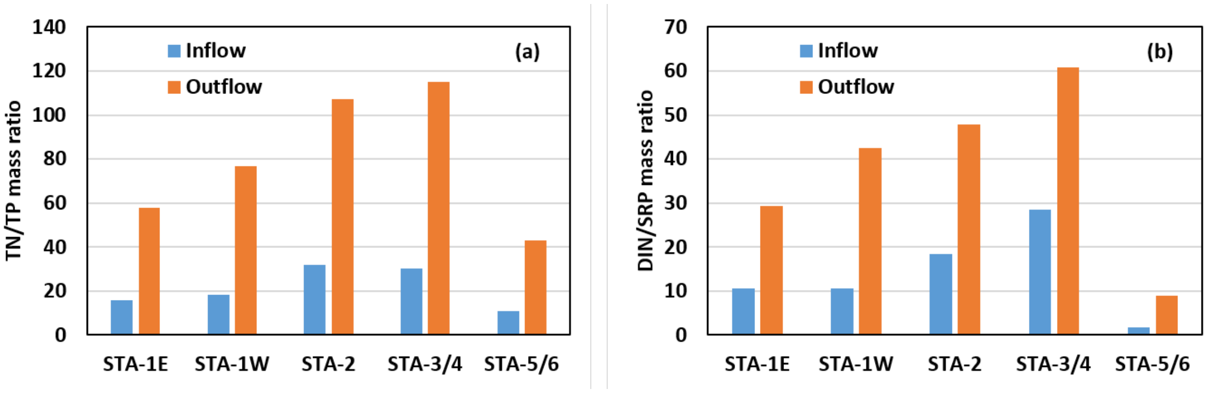

FIGURE 4-22 Long-term average: a) total nitrogen (TN) and total phosphorus (TP) ratio and b) inorganic nitrogen (IN) and soluble reactive phosphorus (SRP) ratios in the inflow and outflow water during the operation period of WY 2014-2020. Data used to calculate long-term averages are based on monthly averages during respective operation periods.
SOURCE: Data from Hu and James, 2021.

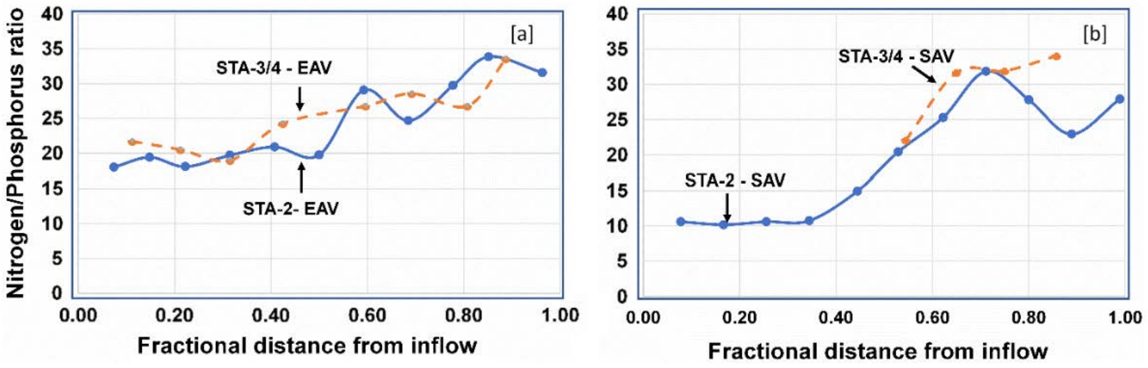

FIGURE 4-23 Mass ratio of nitrogen to phosphorus in floc and recently accreted soil as a function of fractional distance from inflow along transects of (a) STA-2 Flow-way 1 and STA-3/4 Cells 3A and 3B, both consisting of EAV and (b) STA-2 Flow-way 3 and STA-3/4 Cell 3B consisting of SAV. These results indicate a shifting N/P ratio in floc and soil along the STA flow-way and a possible transition from nitrogen limitation near the inflows to phosphorus limitation near the outflows.
NOTES: Length of the flow-way: STA-2 FW-1 = 3.2 miles (5,200 m); STA-2 FW-3 =2.8 miles (4,450 m); and STA-3/4 3A and 3B = 1.9 miles (2,980 m).
SOURCE: Reddy et al., 2021.

aquatic vegetation, thereby reducing plant phosphorus uptake. As water moves through downstream in the STA and more phosphorus is removed along the flowpath from the water column and stored in floc and soils relative to nitrogen, N/P ratios increase (Figures 4-22 and 4-23). At STA outflows, N/P ratios in water are about 3 to 4 times larger than their respective inflow ratios. At most STA downstream areas, there is surplus dissolved inorganic nitrogen relative to SRP (Figure 4-22; see Box 4-5) and higher activity of phosphatase enzymes in floc and soils than at upstream areas, both clear indicators of conditions of phosphorus limitation (Inglett et al., 2019a,b).

Overall, low N/P ratios in the water column coupled to soil phosphorus enrichment may indicate reduced phosphorus removal efficiency and opportunities for management improvements. High surface-water N/P ratios (>100) that drive phosphorus-limiting conditions are likely indicators of high phosphorus removal efficiency. Additional research on the ratios of available nitrogen and available phosphorus in soils and floc and the N/P ratios within tissues of microbes, periphyton, and plants would be necessary to confirm nitrogen limitation. Such research on the role of nitrogen in STA performance could lead to refined management strategies that manage both nitrogen and phosphorus.

Calcium. Calcium plays an important role in removing phosphorus from the water column, and important relationships have been noted between calcium and phosphorus accretion in STAs and the WCAs (Craft and Richardson, 1993; Reddy et al., 1993, 2021). Underwater photosynthesis increases water column pH during the daytime and promotes $CaCO_3$ formation and deposition into floc, which increases conditions for accumulation of phosphorus (Pederson et al., 2013; Pelechaty et al., 2013). High $CaCO_3$ accretion, with rates of up to 1 cm/yr, occurs in SAV treatment cells (Reddy et al., 2021). Phosphorus accumulation rates in SAV cells are approximately 2-3 times higher than in EAV cells, and calcium accumulation rates are 17-42 times higher in SAV than in EAV cells. This pattern suggests that in SAV treatment cells, $CaCO_3$ formation immobilizes phosphorus (occlusion) and/or promotes the formation of insoluble complexes with other elements to facilitate accretion of material with high mineral content.

Average inflow calcium concentrations in the STAs ranged from 68 to 95 mg/L, with slightly higher values observed in the inflows of STA-3/4 and somewhat lower concentrations measured in the inflows of STA-5/6. High calcium concentrations in the inflow waters are likely due to dissolution of limestone in the subsurface soils and in the drainage canals. Overall, calcium concentrations decreased 13-25 percent between inflows and outflows. Calcium

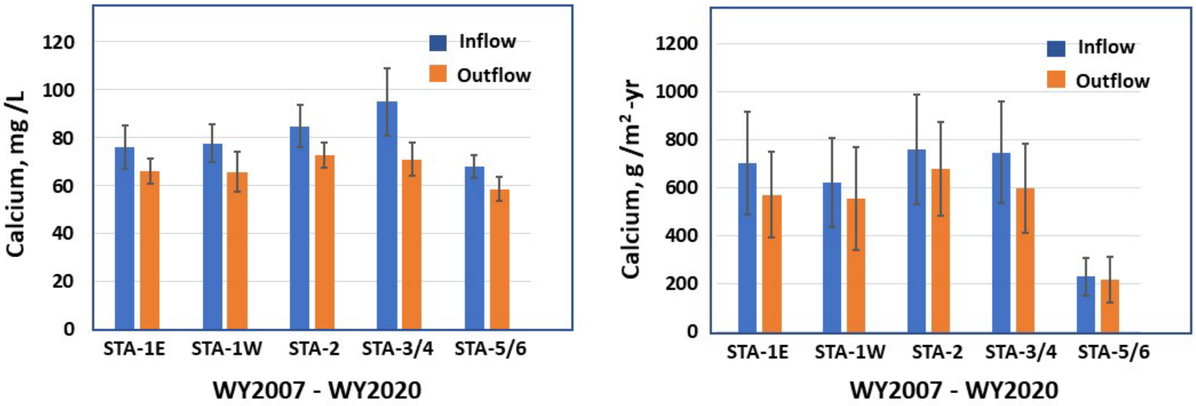

FIGURE 4-24 Average annual calcium concentrations (left) and loading rates (right) in STA inflows and outflow. Data for the operation period of WY 2007-2020 for STA-1E, -1W, -2, and -3/4 and WY 2013-2020 for STA-5/6 were used in calculating average values. Whiskers represent one standard deviation.
SOURCE: Data from Hu and James, 2021.

accumulation rates[19] were highest in STA-3/4 (149 g/m^2-yr) and lowest in STA-5/6 (14 g/m^2-yr) (Figure 4-24), primarily reflecting variation in hydraulic loading rates and SAV activity that influence the production of $CaCO_3$. At present, calcium dynamics in STAs are relatively understudied and merit additional attention in future research, monitoring, and assessment in relation to STA performance given that additional Lake Okeechobee inflows (~50 mg/L calcium) could potentially decrease $CaCO_3$ formation and associated co-precipitation of phosphorus in SAV treatment cells. At this time, the critical calcium concentrations required to support $CaCO_3$ formation in STAs is not known.

Key Internal Drivers

In addition to external drivers, long-term sustainable performance of STAs is also influenced by internal drivers. Understanding the roles of these drivers helps to optimize STA performance. Internal drivers are mediated by the activity of various biotic communities in concert with biogeochemical and physical processes that are supported by hydrologic processes. These processes are not well understood and are often treated as a “black box” because managers consider them to be complex and challenging to measure (Kadlec and Wallace, 2009; Reddy and Delaune, 2008). Moreover, internal processing may not be considered a priority by managers and policymakers because the WQBEL is based on the TP concentration in STA effluent, rather than concentrations within the STA compartments. Thus, a major management emphasis is placed on monitoring inflows and outflows. However, if STAs do not function to the expectations of managers, it is critical to evaluate and understand the internal processes regulating phosphorus speciation, transport, and fate in the soil and water column. These processes can provide insights to improve understanding of internal factors controlling STA performance for long-term function.

Vegetation

EAV and SAV play pivotal roles in STA performance in reducing phosphorus concentrations. Overall, the biogeochemical processes of STAs are regulated by vegetation through uptake of nutrients and production of litter , which serves as organic substrate to microbial communities (DeBusk and Reddy, 2005; Chimney and Pietro, 2006; Reddy and Delaune, 2008). In addition, underwater photosynthesis by SAV creates an environment that facilitates abiotic immobilization of phosphorus from the water column. Thus, healthy and stable vegetation is essential for long-term sustainable performance to reduce outflow TP concentrations to meet the WQBEL. Compared to EAV, SAV areas exhibit three times higher levels of phosphorus storage—a measure of TP storage/accretion per unit area that normalizes for differences in bulk density of floc and soils (Reddy et al., 2020, 2021). In all STAs, the SFWMD has transitioned to managing cells as mixed SAV/EAV (rather than SAV only) because EAV can help stabilize the $CaCO_3$ floc sediment and minimize resuspension during flows and bioturbation by benthic invertebrates, fish, or other animals. Treatment cells in each STA flow-way typically consist of either EAV or mixed SAV/EAV and are operated in a series of EAV

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[19] Calculated as the difference between the mean inflow and outflow loading rates shown in Figure 4-24.

followed by SAV/EAV cells (see Figures B-2 to B-6). Current design of STAs favors mixed SAV/EAV areas over EAV because of the role of SAV in rapid accumulation of phosphorus as calcareous soils.

The use of periphyton-based polishing cells (PSTA) has also been explored due to their ability to attain outflow TP levels near 10 µg/L (Kadlec and Wallace, 2009). In 2005, the SFWMD constructed a field-scale PSTA in STA-3/4 to test its performance.[20] From WY 2008 to WY 2021, the PSTA cells received annual flow-weighted mean inflow TP concentrations of 9-27 µg/L (phosphorus loading rate = 0.14-0.45 g/m^2-yr) and produced annual flow-weighted mean outflow TP concentrations in the range of 8-13 µg/L (Piccone and Dombrowski, 2022; Zamorano et al., 2021). During WY 2017-2021, the average annual PSTA cell outflow concentrations were 25-33 percent lower than the overall STA-3/4 outflow concentrations (Piccone and Dombrowski, 2022). Periphyton-based cells have impressive treatment potential for polishing low concentration flows to meet the WQBEL. However, PSTA cells tend to accumulate loose phosphorus-containing floc that is vulnerable to disturbance, which may lead to discharge of higher concentrations of particulate phosphorus after storm events (Zamorano et al., 2018). Monitoring is ongoing to assess their long-term performance and sustainability.

Sustaining healthy vegetative communities in STAs is key to overall performance. As discussed previously, vegetation disturbance can result from external climatic disturbances such as extremes in flow (both high discharge and drought), windstorms, impacts from herbivory, and earthwork. Loss of aquatic vegetation does not always result in poor performance of STAs; dense communities of EAV or a mixture of EAV and SAV can help buffer STAs against the adverse effects of large flooding events (DB Environmental, 2022; Figure 4-19). Vegetation maintenance including plantings and regulation of hydrologic conditions that promote healthy and functional communities of EAV and SAV are an important and widely recognized component of overall STA management.

Phosphorus Enrichment of STA Soils

Over the period of operation, starting in WY 1994 with STA-1W, the STAs have collectively accumulated more than 3,200 metric tons of phosphorus, with a major portion stored in soils, including floc and recently accreted soil (Chimney, 2022b). Continuous phosphorus loading into the STAs has resulted in distinct phosphorus gradients in the soil and water column with high values in upstream areas and low levels in downstream areas. Spatial gradients of phosphorus in floc and soils in both EAV and SAV flow-ways have been observed along transects in STA-2 and STA-3/4 (Figures 4-25 and 4-26; Osborne et al., 2019a, b), and similar spatial gradients are also noted in the Everglades Protection Area (a synthesis of research can be found in Newman et al., 2017). Approximately one-third of stored phosphorus is highly reactive and susceptible to release from the sediment into the water column via advective and diffusive flux, resulting in high internal loads, especially in upstream areas of treatment cells. In STAs, phosphorus flux from floc to overlying water decreases with distance from the inflows (Wright et

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[20] This 400-acre PSTA test site is composed of a 200-acre upper SAV cell, a 100-acre lower SAV cell, and a 100-acre PSTA cell.

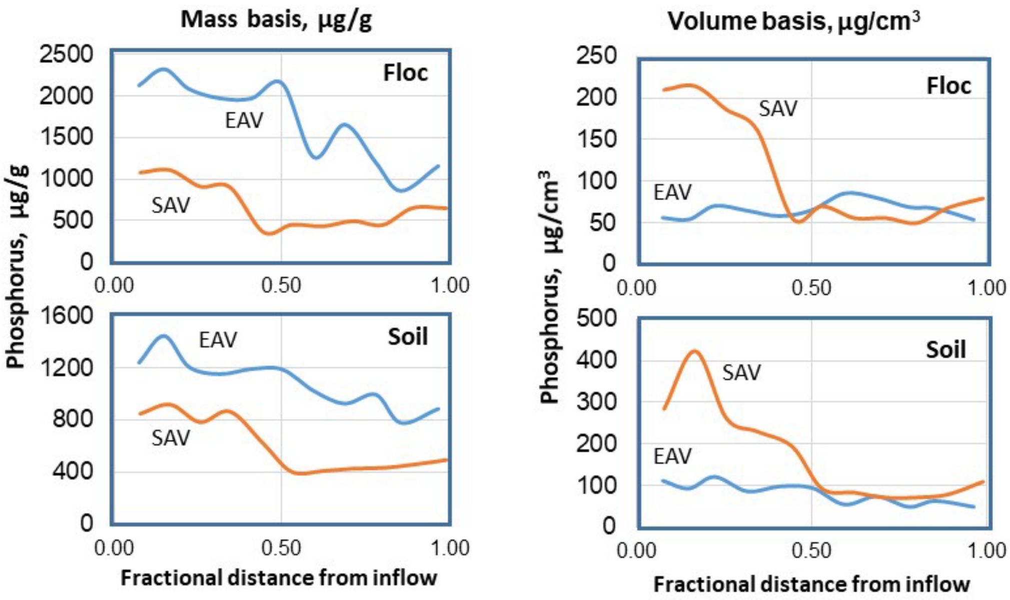

FIGURE 4-25 TP concentration (expressed on both soil mass and soil volume basis) in floc and soils along the distance from inflow of Flow-ways 1 (EAV, blue line) and 3 (SAV, orange line) in STA-2. Phosphorus concentrations in soils (expressed as µg P/g soil dry weight) from EAV-based flow-ways show a higher degree of enrichment per unit weight of soil, as compared to SAV-based soils. When these values are normalized for soil bulk density (dry weight of soil per unit volume) and expressed on a soil volume basis, the phosphorus concentration trends are reversed with SAV soils showing a high degree of phosphorus enrichment as compared to EAV soils. Length flow-ways: FW-1 = 3.2 miles (5,200 m) and FW-3 = 2.8 miles (4,450 m). SOURCE: Data from Reddy et al., 2019b.

al., 2019). The impacts of internal loading are highlighted in Figure 4-27: under no-flow conditions, a pronounced plateau in water column TP concentrations is observed in the upper portion of STA-2 Flow-way 3, suggesting that fluxes of TP from the soil into the water column are offsetting any uptake. Extensive accumulation of phosphorus in STA soils can reduce phosphorus uptake capacity or increase internal TP loading to the water column from phosphorus-enriched soils, thus raising concerns about the long-term capacity to achieve and maintain desirable outflow TP concentrations.

Phosphorus removal efficiency and TP concentrations in upstream treatment cells can serve as an indicator of phosphorus saturation status of the soil and provide early warning signals of the need for management actions. The committee, however, is not aware of analyses that have been conducted on the performance of individual treatment cells as part of routine STA management.[21] Management of newly accreted material by consolidation, hydrologic manipulation (water-level drawdown), or application of soil amendments can potentially improve water quality. Under extreme conditions of phosphorus-saturated soils, an STA cell could be scraped down to remove the surface soils.

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[21] Information received after release of the prepublication version of this report indicates that such analyses do exist.

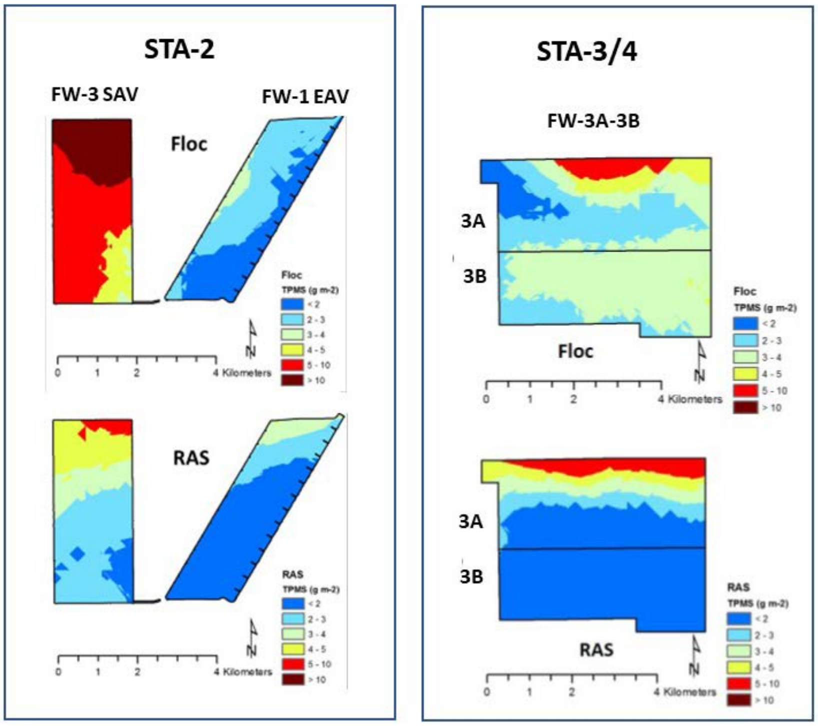

FIGURE 4-26 TP storage (g/m^2) in floc and recently accreted soil (RAS) of STA 2 Flow-ways 1 (EAV) and 3 (SAV) and STA-3/4 Flow-way 3, cells A (EAV) and B (SAV).
SOURCE: Osborne et al., 2019a,b.

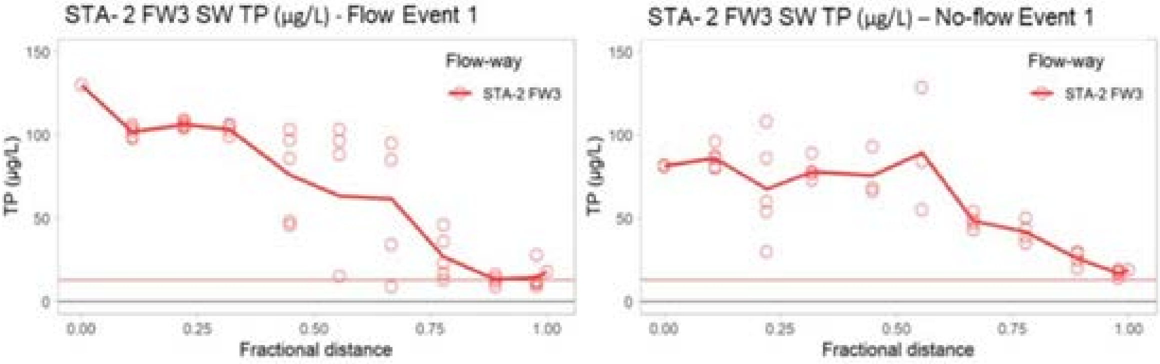

FIGURE 4-27 TP concentrations along multiple transects along SAV-based STA-2 Flow-way 3 (FW-3) during flow (left: September 21, 2021) and no-flow (right: January 25, 2021) events. After 20 years of operation, water column TP concentrations during regular flow events showed a plateau in the upstream areas of flow-way, followed by a steady decrease in water column TP concentrations in the downstream cells, suggesting reduced uptake in upper cells with phosphorus-saturated soils. A more pronounced plateau is observed under no-flow conditions where internal loading is offsetting any TP uptake.
NOTES: Each point represents one monitoring station. The thick red line connects the mean value of TP concentrations at each transect. The horizontal red line is equal to 13 µg/L.
SOURCE: DB Environmental, 2022, under contract to the SFWMD.

ADAPTIVE MANAGEMENT OPPORTUNITIES

Adaptive management has become a well-established concept in both restoration science and in the CERP, in which the scientific enterprise—monitoring, assessment, research, modeling, and synthesis—is used to address decision-critical uncertainties to inform project management actions (NASEM, 2021). These actions may be either reactive to existing challenges or proactive in anticipation of future challenges (Eberhard et al., 2009; Holling, 1978). Because management and/or restoration of complex ecosystems, such as the Everglades, are characterized by inherent uncertainty, adaptive management provides an effective means to meet the project objectives.

A vigorous adaptive management program is merited for an initiative as large and as consequential as Restoration Strategies, which is based on complex natural biogeochemical process whose interactions and dynamics are not fully understood. In this section, the committee discusses key elements of such a program, including the development of near-term milestones toward achieving improvements in STA performance, science tools to support decision making, establishment of an independent advisory committee to provide guidance on STA remediation and operations, and near-term and long-term management options that can be considered in the context of adaptive management to support the state's effort to meet the WQBEL requirements.

Development of Near-term Milestones

Quantitative objectives are essential to adaptive management of ongoing projects. Monitoring and analysis can be used to assess the degree to which management goals are being met, and the full science enterprise can be used to identify issues associated with implementation that may need to be addressed. For the STAs, WQBEL compliance beginning in WY 2027, following the full implementation of Restoration Strategies, represents the key quantitative objective. However, given the importance of WQBEL compliance to the full operation of other CERP features, such as the EAA Reservoir, the committee recommends that the SFWMD establish intermediate milestones for each STA, so that managers remain fully informed about whether the STAs are on their expected trajectories and can address unexpected issues as early as practicable, ideally well before the first year of WQBEL compliance assessment in WY 2027. The committee acknowledges that ecological disturbances, such as hurricanes or tropical storms, may impact the ability of STAs to meet certain milestones. Even when disturbances occur, milestones will inform managers of the effectiveness of the existing structural and operational elements in mitigating those disturbances, and whether additional actions are needed.

These annual milestones would be developed based on the best professional judgment of the performance of each STA and the expected response of the STAs to the ongoing implementation of various Restoration Strategies features. These milestones might be developed consultation with STA experts from academia and federal agencies. The state and the broader science community have extensive knowledge of STA functioning and performance, which continually expands through ongoing research from the Restoration Strategies Science Plan (see Box 4-6; SFWMD, 2013, 2018b).

BOX 4-6
Restoration Strategies Science Plan Projects

Nine studies comprised the 2013 Science Plan (#1-9; SFWMD, 2013). The 2018 Science Plan (SFWMD, 2018) introduced 13 additional studies (#10-22). Ongoing studies are bolded below. These studies were designed to provide critical information that could fill knowledge gaps regarding how the STAs function and ultimately lead to better management and performance.

1. Development of Operational Guidance for Flow Equalization Basins (FEBs) and STA Regional Operation Plans—*completed 2017*
2. Evaluation of Canal Conveyance Features on STA and FEB Inflow and Outflow Phosphorus Concentrations—*completed 2017*
3. Evaluation of Inundation Depth and Duration for Cattail Sustainability—*completed 2021*
4. Investigation of STA-3/4 PSTA Performance, Design and Operational Factors—*completed 2018 (monitoring continuing)*
5. Evaluation of the Role of Rooted Floating Aquatic Vegetation (rFAV) in STAs—*completed 2018*
6. **Use of Soil Amendments or Soil Management to Control Phosphorus Flux—*ongoing***
7. Phosphorus Sources, Forms, Flux, and Transformation Processes in the Everglades Stormwater Treatment Areas—*completed 2019*
8. Stormwater Treatment Area Water and Phosphorus Budget Improvements—*completed 2020*
9. Sampling Methods for Total Phosphorus—*completed 2022*
10. **Evaluation of Factors Contributing to the Formation of Floating Tussocks in the STAs— *ongoing***
11. **Investigation of the Effects of Abundant Faunal Species on P Cycling in the STAs—*ongoing***
12. **Improving Resilience of SAV in the STAs—*ongoing***
13. **Periphyton and Phytoplankton P Uptake and Release—*ongoing***
14. **L-8 FEB Operational Guidance—*ongoing***
15. **Biomarker Study to Quantify the Recalcitrance and Lability of P within STAs—*ongoin*g**
16. **Data Integration and Analysis—*ongoing***
17. **P Reduction Dynamics in STA-1E, STA-2, STA-3/4, and STA-5/6—*ongoing***
18. **Assess Feasibility and Benefits of Consolidating Accrued Marl in the STAs' SAV Cells— *ongoing***
19. **P Removal Performance of Ecotopes in the STAs—*ongoing***
20. **Sustainable Landscape and Treatment in an STA—ongoing**
21. **Effect of Vertical Advective Transport on TP Concentrations in the STAs—ongoing**
22. Prescribed Burn Effects on Cattail Communities—to be merged into Data Integration Study

SOURCE: James et al., 2022; R. Shuford, SFWMD, personal communication, 2022

Science to Support STA Management and Decision Making: Monitoring, Assessment, Modeling, Research, and Synthesis

An extensive monitoring, assessment, modeling, research, and synthesis program is critical to support WQBEL attainment.

Monitoring and Assessment

The assessment of spatial patterns in nutrient dynamics as inflowing water is processed through each of the cells in STA flow-ways could be an effective tool to inform the status of STA functioning and to guide management decisions to improve phosphorus removal. Cell-by-cell measurement and analysis of forms of phosphorus and nitrogen in water and soil would provide insight on mechanisms and status of nutrient processing within STAs. Although cell-by-cell monitoring is more costly than the current whole-STA monitoring, the information derived would help to focus attention on poorly performing cells. Focused cell-by-cell data would help managers understand how a cell is responding to Restoration Strategies rehabilitation efforts, whether phosphorus saturation is occurring that could compromise the removal of phosphorus necessary to attain the WQBEL, and whether additional near-term management steps are needed, such as those discussed later in this chapter.

Modeling, Machine Learning, Data Analysis, and Integration

Models have been primarily used to inform STA design (e.g., Dynamic Model for Stormwater Treatment Areas [DMSTA][22]). These models are relatively simple tools for sizing STAs, but they are not appropriate for understanding and managing the complex behavior of phosphorus in STAs . The SFWMD would benefit from adopting spatially explicit models of STA biogeochemistry and hydrology that could be parameterized through calibration to measurements of water and nutrient fluxes on a cell-by-cell basis. Such models are currently available, and their calibration and testing against observations from Everglades STAs have been documented in the peer-reviewed literature. For example, the Lake Okeechobee Environmental Model for Constructed Wetlands (LOEM-CW) is a fully distributed model that solves coupled equations for transient wetland flow, processes that transform and transport phosphorus and nitrogen, and emergent and submerged vegetation dynamics (Jin and Ji, 2015). Two and three-dimensional versions of this modeling framework have been calibrated and evaluated against time-series data on water levels and concentrations of phosphorus, nitrogen, and dissolved oxygen in STA-2 and STA-3/4 (Ji and Jin, 2016, 2020). An alternative model formulation, the Low-P Wetland Event Model (LPWEM), employs a tank-in-series hydraulic framework with simple expressions for flow-dependent phosphorous removal and internal phosphorus loading (Juston and Kadlec, 2019). Evaluation and testing of LPWEM resulted in good agreement between measured and modeled phosphorus concentrations along longitudinal transects within the C1B flow cell of STA-3/4 and between measured and simulated phosphorus concentrations in outflows from STA-2 and STA-3/4. As a semi-distributed model incorporating a reasonably

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[22] See http://www.wwwalker.net/dmsta/.

simplified representation of phosphorous dynamics, LPWEM is parametrically parsimonious, requiring estimation of fewer parameters from calibration than LOEM-CW. Both LOEM-CW and LPWEM, as well as other wetland water-quality models (e.g., Paudel and Jawitz, 2012), cannot account for all the variation in field data. Nevertheless, their accuracy will improve with continued application and refinement of their process representations. Even in their current form, models such as LOEM-CW and LPWEM can certainly play an important role in illuminating relationships between an STA's attributes and its functioning. They could, for example, be used to infer the sensitivity of phosphorous removal efficiencies to factors amenable to management, such as water depth, flow rate, cell-inflow allocations, and vegetation composition. This knowledge, in turn, could be used to optimize STA operations, inform routine maintenance and refurbishment schedules, and assess potential system modifications intended to increase phosphorous removal. Considering the recent advances in wetland water-quality models and the insights that can be gained through their application, the committee judges that they should play a greater role within an adaptive management framework for WQBEL attainment.

In addition to dynamic simulation modeling, machine learning approaches could provide insight on the behavior of STAs. For example, Baiser et al. (2021) evaluated phosphorus removal by STAs using structural equation modeling to understand better the function of individual STAs. The SFWMD has detailed time series information on individual STAs. With such detailed and robust data sets, machine learning techniques could be an effective tool to enhance understanding of controls on phosphorus removal in STAs.

Scientific Research

Scientific research is essential to support effective operations and management of the STAs. STAs in the Everglades are at the leading edge of performance of treatment wetlands for phosphorus globally. However, despite decades of research on STA function and performance by the SFWMD and its university and consulting partners, further research on opportunities to enhance their phosphorus removal efficiency is needed. The Restoration Strategies Science Plan provides the overall framework for development and coordination of science activities to identify the critical factors that influence phosphorus reduction and treatment performance to meet the WQBEL for the Everglades STAs. The first 5-year Science Plan (SFWM, 2013) was developed in 2013, and the SFWMD is currently implementing the 2018 Science Plan (2018-2023; SFWMD, 2018a). The studies supported by the Science Plan are outlined in Box 4-6.

The Science Plan is organized around six key research categories to inform STA operations and improve their performance:

1. design of FEBs;
2. STA operational or design enhancements to improve and sustain STA performance;
3. vegetation management;
4. the influence of fish and wildlife on STA performance;
5. management of internal phosphorus loading; and
6. management mechanisms to decrease concentrations of forms of phosphorus at the STA outflows.

The science plan provides a road map to improve understanding of how the STAs function and to address key information gaps. The 2018 Science Plan indicates that internal phosphorus loading is an understudied phenomenon in the STAs and that additional research is needed to examine the biological, chemical, and physical factors that influence this process (Orihel et al., 2017; Steinman and Spears, 2020), with particular attention paid to DOP.

Although the regulatory focus of the STAs is phosphorus, other elements influence phosphorus bioavailability, mobility, and fate, as described earlier in this chapter. Phosphorus dynamics through space and time are poorly understood in STAs. Wetlands receiving phosphorus loading may potentially develop nitrogen-limiting conditions that restrict biotic growth/productivity and thereby decrease phosphorus utilization and increase phosphorus discharges. Phosphorus dynamics are also affected by sulfate, iron, and calcium and changing redox conditions. As STA management seeks to sustain extremely low phosphorus outflow concentrations, attention to the many factors that influence phosphorus dynamics is appropriate. Field-based, replicated experiments can be used to manipulate relevant elements (e.g., nitrogen, calcium) and measure how they interact to influence phosphorus cycling and sequestration. The processing of phosphorus and the interactions with other elements vary spatially through STAs, which ultimately affects outflow phosphorus concentrations and speciation. Thus, in addition to manipulative experiments, there is a critical need to monitor phosphorus-element dynamics and mass balances on a cell-by-cell basis, especially in poorly performing STAs.

The role of vegetation in STAs cannot be overemphasized. A variety of studies have been conducted to investigate the resilience of SAV and EAV communities, phosphorus retention by SAV versus mixed SAV/EAV communities, phosphorus retention by specific vegetative taxa, and short-term and long-term phosphorus removal by different vegetative species (Bhomia and Reddy, 2018; DB Environmental, 2020a, 2020b; Julian et al., 2019). Understanding the performance of individual species is also important—*Chara* may respond differently than *Najas* to altered environmental conditions, not only because of differences in phosphorus uptake rates but also because *Chara* can assimilate bicarbonate, resulting in production of $CaCO_3$, which immobilizes phosphorus through abiotic mechanisms (Kufel and Kufel, 2002). Although the periphyton-based STA (PSTA) project met WQBEL standards (Zamorano et al., 2018), it remains unclear to what extent effective phosphorus removal was due to periphyton uptake or other factors such as low phosphorus inflow concentrations and/or lime rock exposure. These uncertainties underscore the need to understand the phosphorus removal efficiencies of different growth forms (e.g., submergent vs. emergent vegetation) and taxa, and the mechanisms driving phosphorus removal. Such an understanding will help inform the management of STAs to meet the WQBEL.

Hydraulic loading is known to affect STA performance, but continued field-scale research would help to determine optimal hydraulic parameters for STA operations and the extent of impact associated with deviations from optimal conditions. For example, the A-2 STA, which is not part of the EAA flood control system, can be used to examine STA performance under steady inflow conditions in contrast to the remaining STAs, which must manage high inflows during storms. Additional research could examine the role of vegetative buffers near STA discharges in minimizing particulate phosphorus discharge.

Synthesis

The data on STAs are abundant, but to date efforts to examine these data in detail, interpret patterns and trends, and provide a synthesis of STA function have been insufficient. The report *Phosphorus Dynamics in the Stormwater Treatment Areas* (DB Environmental, 2022) is a good first step to do so. However, detailed interpretation of the function of STAs and the response of STAs to management efforts needs to be an ongoing endeavor. In particular, the dynamics of STAs should be evaluated along cell-by-cell flow paths, including time-series mass balances of total phosphorus and phosphorus species. Models and machine learning approaches could be effectively used in concert with data interpretation and synthesis efforts. Synthesis should ideally identify actions that can be taken to improve STA performance, either over the short term to achieve the WQBEL or over the long term to maintain effective performance, or critical knowledge gaps affecting STA management decisions (see also Chapter 6).

As part of the synthesis effort, the committee recommends the formation of an external STA scientific advisory committee. This advisory committee would be analogous to the Aquifer Storage and Recovery independent peer review panel convened by the SFWMD (see Box 3-1). The advisory committee could meet annually to discuss progress toward the milestones and provide additional expertise and advice to support WQBEL attainment. It could also provide advice on data collection, data analysis, research, modeling, and synthesis efforts that inform actionable management activities.

Near-term Considerations for STA Management

The comparison of STA performance milestones to monitoring data, informed by other research, modeling, and synthesis, may highlight the need for additional STA management actions. Near-term options to improve STA performance include improving hydraulic loading rates, reducing phosphorus concentrations and loading rates, managing vegetation, and managing floc and soil. The SFWMD is actively using these tools to improve phosphorus removal efficiency, although some additional considerations are noted below.

To function effectively, STAs must be hydrated throughout the year. However, during the dry season when water supply is limited, some treatment cells may experience dry-out. Reflooding of these dry-out areas can potentially mobilize phosphorus from soil to the overlying water column (DB Environmental, 2022). The three Restoration Strategies FEBs (see Figure 4-2) were designed to store water and reduce the frequency of dry downs, although no information is publicly available on how the FEBs are expected to change the projected occurrence of dry-out. Water from Lake Okeechobee may be needed during drought conditions to provide enough water to keep the STAs hydrated, but conveyance structures are lacking to connect Lake Okeechobee via the Miami Canal to STA-5/6 inflow structures. Water allocation prioritization may need to be revisited to support WQBEL compliance, especially when CERP progress depends on it.

Low phosphorus concentrations and loading rates are key characteristics of the best performing STAs. The performance of STA-1W and STA-1E could be significantly improved by decreasing phosphorus loading rates by at least 50 percent (similar to STA-3/4) and creating an option to recirculate the STA outflow through periphyton-dominated cells to further reduce TP concentrations. The completion of STA expansions #1 and 2 in the Eastern Flow Path, which represent an additional 4,260 acres and 1,600 acres, respectively, compared to pre-2021 STA acreage, would reduce the average area-based phosphorus loading rate by about 34 percent.[23] Restoration Strategies includes a project to implement subregional source controls in the Eastern Flow Path to address hot spots in phosphorus loading, although no progress has been made in subregional load reduction. Additional attention toward this load-reduction project could improve STA performance if phosphorus hot spots are addressed.

All STAs have a finite capacity to store phosphorus in vegetation and soils. Upstream treatment cells accumulate phosphorus more rapidly and therefore have a shorter period of effective phosphorus removal than downstream cells. This pattern has been consistently noted in all STAs including STA-3/4. Upstream cells experience enrichment in phosphorus and exhibit signs of nitrogen limitation (based on N/P ratios). Phosphorus management strategies (e.g., removal of enriched soil or application of chemical amendments to soils) may be needed to remediate areas with substantial accumulated phosphorus in soils to achieve adequate outflow TP concentrations. Continued field research and long-term monitoring are needed to evaluate the efficacy of approaches to mitigate phosphorus-enriched soil. For example, lab tests showed that soil inversion (burial of phosphorus-laden surface soil) reduced phosphorus to an impressive 13 µg/L in batch tests (Josan et al., 2019), but field testing under flow-through conditions is needed to assess how quickly these soils would saturate with phosphorus.

Ongoing adaptive management of STAs to optimize phosphorus removal should also consider whether STA cells have the appropriate composition and placement of SAV and EAV and whether increased use of periphyton is merited. Different phosphorus removal mechanisms in EAV and SAV areas result in different soil types and biogeochemical processes. The more organic soils derived from EAV are capable of trapping particulate matter whereas the soils dominated by SAV are characterized by more mineral matter, are flocculent, and are easily suspended in the water column (Reddy et al., 2019a). By using the information available from vegetation and soil types, project managers could create the appropriate mosaic of EAV and SAV to optimize dissolved phosphorus uptake and particulate phosphorus trapping.

Alternative Management Strategies

Despite the significant efforts by the SFWMD to manage phosphorus in the STAs, if the WQBEL target is not met in all of the STAs, alternative management strategies may be needed. The alternative strategies in this section may complement existing approaches to meet the WQBEL.

Control of Internal Phosphorus Loading

In this chapter the committee has highlighted the concern about internal loading of phosphorus from saturated soils or resuspended floc that is discharged from the STAs. The

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[23] Prior to the STA expansions, STA-1E and STA-1W included approximately 11,400 acres. The addition of 5,820 acres through Restoration Strategies will increase the total STA acreage in the Eastern Flow Path to approximately 17,220 acres. If inflow concentrations remain the same and inflows are evenly distributed to spread the loading across the available STA area, the phosphorus loading rate is expected to decrease by 5,820/17,220 or 34 percent.

addition of chemicals could help reduce internal phosphorus loading via direct inactivation of phosphorus.

The chemical characteristics of phosphate allow for salt formation with aluminum, calcium, iron, lanthanum, or other metals with varying degrees of solubility (Lürling et al., 2020). Chemical inactivants that bind phosphorus can be applied in liquid or solid forms. A wide variety of solid-phase phosphorus adsorbents have been developed that utilize a range of precursor materials and substrates. An important consideration is the amount applied: too little will leave sediment uncovered, while too much may impair aquatic biota or otherwise adversely affect biogeochemical processes (Steinman and Ogdahl, 2012). In general, six elements—calcium, magnesium, aluminum, iron, silicon, and lanthanum—in a variety of mineralogical and geochemically reactive forms can serve as phosphorus adsorbents that are commonly applied to aquatic systems, including as active constituents within constructed wetlands. The phosphorus adsorbent receiving the most attention over the past decade is lanthanum-modified bentonite (Spears et al., 2016).

The SFWMD evaluated the feasibility of applying chemical inactivants to the STAs and decided against their use because of the significant costs and logistical challenges of application over such a large surface area (Chimney, 2015b). However, an alternative approach may be to apply these materials strategically, in treatment locations that (1) have historically high phosphorus concentrations, exceeding the WQBEL and (2) are delimited and targeted areas, such as near the discharge points of STAs, where they will be most effective.

Alternative Agricultural Management

A potentially effective approach to reaching phosphorus targets is to control the phosphorus concentrations and loads entering STAs from external sources. Additional attention to source reduction, particularly in the Eastern and Western Flow Paths, may ultimately be necessary and may well prove cost-effective in achieving the WQBEL. Farms in the EAA have reduced their annual TP loads by 55 percent on average since 1994 (Taylor et al., 2019), with most farms contributing to these improvements (Yoder, 2019). However, this improvement has not been continuous over this period, because large initial phosphorus load reductions have not been maintained over time (Yoder et al., 2020). Thus, it may be possible to modify current agricultural practices to further reduce phosphorus loading before the runoff reaches the STAs to help meet the WQBEL requirements.

Non-structural best management practices of potential value include reducing loads from those farms that are the largest contributors (hot spots), even absent an exceedance of the allowable collective load by basin based on the Consent Decree codified in the 1994 Everglades Forever Act. In addition, Yoder et al. (2020) suggested that linking monitoring data to relevant farm management decisions may encourage farm managers to further reduce phosphorus loads based on their analyses, as the data can be used as a feedback or accountability tool.

Structural best management practices have been implemented in the EAA and C-139 basins, contributing to phosphorus load reduction. In addition to installation in hot spots, it may be possible to enhance performance of some structural best management practices, including leveling of fields, maintaining ditch and canal bank berms, deepening/widening main canal sediment sumps and traps, constructing and maintaining sediment sumps in field ditches, regularly cleaning canal and field ditches, slowing drainage near exit pump stations, planting cover crops, installing raised culverts; vegetating ditch banks for stabilization, and using weed booms and trash racks (Adorisio et al. 2006; Diaz et al., 2015).

Inflow Control

Phosphorus loading to the STAs could also be reduced through changes in water operations, although such actions could have adverse effects on other parts of the system. For example, if STAs are not performing adequately, instead of moving water south through the STAs, managers theoretically could opt to reduce hydraulic and phosphorus loading rates by discharging the water to the coastal estuaries. This outcome would result in a cascade of adverse effects by reducing the flow of water south and by increasing the discharge of nutrients to the estuaries. However, STA-specific inflow adjustments could be made with lesser impacts, for example, reducing the rates of inflow pumping during wet weather periods, as is currently planned for the A-2 STA.

If the STAs do not meet the WQBEL under ongoing management, difficult tradeoff decisions based on a rigorous analysis of costs and benefits may be necessary. This analysis would consider the benefits of CERP progress with full EAA Reservoir operation versus impacts to the remnant Everglades and the estuaries from reducing current inflows to the STAs. Implementation of the Lake Okeechobee System Operating Manual, with greater discretion on downstream releases, would provide the flexibility needed to adjust these operations if judged appropriate.

RECOMMENDATIONS AND CONCLUSIONS

Implementation and refinement of STAs over the past nearly 3 decades has resulted in marked reductions in TP concentrations in outflow waters, particularly in STA-3/4, which currently meets the requirements of the WQBEL. A considerable volume of rigorous, peer-reviewed, and applicable science has been generated by the SFWMD, as well as its academic and consulting partners, that has helped inform the design and performance of STAs. However, the extent of phosphorus removal varies across STAs, and some STA discharges remain far from target values. The state's current efforts through Restoration Strategies and other actions are expected to continue to improve the function of the STAs, although meeting and sustaining the WQBEL requirements in all STAs starting in WY 2027 will be a significant challenge. Given the dependence of CERP progress on WQBEL attainment—particularly the timely delivery of full CEPP benefits—the committee offers the following recommendations and conclusions to support the state's efforts to understand and improve the effectiveness of STAs.

To support and sustain WQBEL attainment, the SFWMD should implement a rigorous adaptive management framework that increases efforts in data collection, data analysis, modeling, and synthesis. Talented and experienced SFWMD scientists and engineers are working on the STAs, as evidenced by the phosphorus removal performance to date, and substantial research is under way through the Restoration Strategies Science Plan that should be useful to STA management. Nonetheless, the extent of phosphorus removal needed to meet and sustain the WQBEL will likely require even stronger science support for decision making, cell-by-cell monitoring, new modeling tools, detailed analysis of available data, and frequent feedback between science and management to support rapid, science-informed decision making and to reduce the likelihood of water quality impeding CERP progress.

Rigorous adaptive management program should include development of near-term milestones for each STA flow-way. The WQBEL sets clear quantitative targets to assess STA performance starting in WY 2027, but quantitative interim milestones over the next few years should also be developed based on the activities associated with Restoration Strategies and other STA remediation actions. These milestones would help communicate to managers the science-based expectations of STA function and recovery times in each flow-way and would provide a basis for further analysis and possible action if outcomes do not meet expectations, thereby supporting more nimble decision making. They would also increase transparency of restoration progress to the community interested in water treatment by STAs and Everglades restoration.

Additional monitoring, research, analysis, and modeling will provide insight on ways to optimize and sustain STA performance. Despite decades of research and lessons learned through STA operations, key gaps remain in the understanding of phosphorus mobility and removal processes within STAs and optimal management strategies to manage STA hydrology, vegetation, and biogeochemical processes. Moreover, currently available tools are limited in their ability to forecast STA responses to management actions. The cumulative retention of phosphorus in soils threatens the long-term performance of the STAs. The committee identified several priority research needs:

- Cell-by-cell monitoring along with the development of cell-by-cell phosphorus budgets would help managers identify problem areas and focus additional efforts to better understand and address the mechanisms that drive elevated phosphorus conditions. These activities would identify cells that may be transitioning to conditions of phosphorus saturation.
- Additional analysis of nutrient dynamics (e.g., TP, phosphorus forms, total nitrogen, nitrogen forms and associated secondary elements) along STA flow-ways could illuminate strategies to more effectively manage phosphorus. Dissolved organic and particulate phosphorus can represent substantial fractions of TP concentrations in STA outflows, but current management efforts are generally focused on TP, rather than individual forms of phosphorus. The interplay between nitrogen and phosphorus and the significance of nitrogen-limiting conditions deserves additional attention in understanding factors that affect phosphorus removal efficiency.
- Field research in STA cells that appear to be approaching phosphorus saturation and thereby increased internal phosphorus load and that are experiencing reduced efficiencies could provide insight on the effect of soil phosphorus accumulation on the ability of STA cells to retain phosphorus, and the benefits and timing of cell refurbishment in maintaining the effective performance of STAs over the long-term. Field research would also provide an opportunity to examine the best strategies for refurbishment and recovery.
- Application and continued refinement of STA biogeochemistry and hydrology models would enhance the understanding of STA function and inform maintenance and operations decisions.
- Additional field research on the effects of STA hydraulics, such as inflow and outflow velocities, hydroperiod, and hydraulic loading, on phosphorus discharge could inform future operations.

An independent, external STA science advisory committee would provide additional perspective and expertise to assist the SFWMD in evaluating water quality progress of Restoration Strategies relative to expectations for phosphorus removal and in identifying areas of concern and promising strategies. An external STA science advisory committee, analogous to the aquifer storage and recovery independent peer review panel convened by the SFWMD, could meet annually to discuss progress toward the milestones and to provide additional expertise and advice to support WQBEL attainment. With a mix of specialists, including in biogeochemistry, regional water operations, and agricultural source control measures, this group could advise on data collection, data analysis, research, modeling, and synthesis efforts that inform actionable management activities.

Although a variety of factors affect outflow phosphorus concentrations, phosphorus inflow concentrations and loading rates are key drivers affecting WQBEL attainment. The only STA (3/4) that consistently meets water quality conditions that approach the WQBEL has an annual phosphorus loading rate that is generally much lower than 1 g/m^2-yr. In contrast, STA-1E, -1W, and -5/6 routinely have phosphorus loading rates that exceed 1 g/m^2-yr, and in some years exceed this rate by a factor or 2 or more. The average flow-weighted inflow concentrations for STA-3/4 (84 μg/L TP during WY 2017-2022) was approximately 50 percent (or less) than the average flow-weighted inflow concentrations of the three poorest-performing STAs. Thus, for some STAs the annual phosphorus loads and/or concentrations will likely need to be halved to achieve annual effluent TP concentrations that approach the WQBEL. Three approaches can be pursued to manage elevated phosphorus loading rates in a given STA: improve the phosphorus removal efficiency within the STA, increase the footprint (surface area) of the STA (as is under way in STA-1W), and/or decrease the upstream phosphorus loading entering the STA (source control). Restoration Strategies includes all three approaches in some capacity to reach the WQBEL, with most efforts devoted to improving phosphorus removal efficiency, but little progress has been made to reduce subregional phosphorus loads in the Eastern Flow Path. The concentrations of some STAs are so high that efficiencies beyond those of the best-performing STA would be needed to meet the WQBEL. In these cases, additional source control measures may ultimately be needed to meet the WQBEL.

5

Restoration in the Context of Climate Change

Climate change represents an existential threat to many aspects of the South Florida ecosystem and the people who value and rely on it. The committee discussed the need to consider rise in sea level, change in precipitation patterns, and increasing temperature conditions in several previous reports (NASEM, 2016, 2018, 2021; NRC, 2014). In this chapter the committee reiterates many of the concerns expressed in previous reports and focuses on how climate change and variability can pose risks to the Comprehensive Everglades Restoration Plan (CERP) at various stages of its development and implementation. The committee offers the current Biscayne Bay Southern Everglades Ecosystem Restoration (BBSEER) project as an example of the critical need to consider climate change in planning. Next, the committee discusses how some aspects of climate change can influence the operations of CERP projects, highlighting the Lake Okeechobee operations, and reviews the role of System Operating Manuals in efforts to adapt to climate change. Finally, the committee describes the programmatic implications of recent and future changes in climate and how they influence the ecosystem if they are not meaningfully considered. As the CERP pivots from planning to operating projects to optimize ecosystem responses, both at a project and system scale, it becomes even more important to make climate change a central consideration in all aspects of the CERP to ensure that the nation's investments in restoration continue to reap benefits for decades to come.

CLIMATE CHANGE IN SOUTH FLORIDA

South Florida, a subtropical region surrounded by ocean with strong surface and deep water currents, is characterized by a distinct and highly variable climate regime. The climate is tropical and monsoonal, with variations manifested by large-scale phenomena (El Niño South Oscillation [ENSO], Atlantic Multidecadal Oscillation [AMO], and Pacific Decadal Oscillation [PDO]) that occur over multiple timescales with interspersed periodic extreme weather events. South Florida, like the rest of the world, is experiencing changes in climate and sea-level rise (Chassignet et al., 2017). The evolution of these climate phenomena will affect the CERP's context and success. South Florida is also periodically impacted by tropical cyclones, which can result in storm surge inundation, excessive rainfall, and wind damage to coastal forests (Han et al., 2018). During the past 20 years, the South Florida ecosystem has been impacted by Hurricanes Frances (2004), Jeanne (2004), Wilma (2005), Irma (2017), and Ian (2022) as well as numerous tropical storms. Although the science suggests that more intense tropical cyclones are associated with increased sea surface temperatures (Knutson et al., 2021), statistically significant trends are not yet apparent. A recent analysis in the U.S. Atlantic basin noted no significant overall trend in hurricane landfall or major hurricane landfall over 167 years of available data (Loehle and Staehling, 2020). Thus, the committee focuses here on effects of climate change on temperature, precipitation, and sea level.

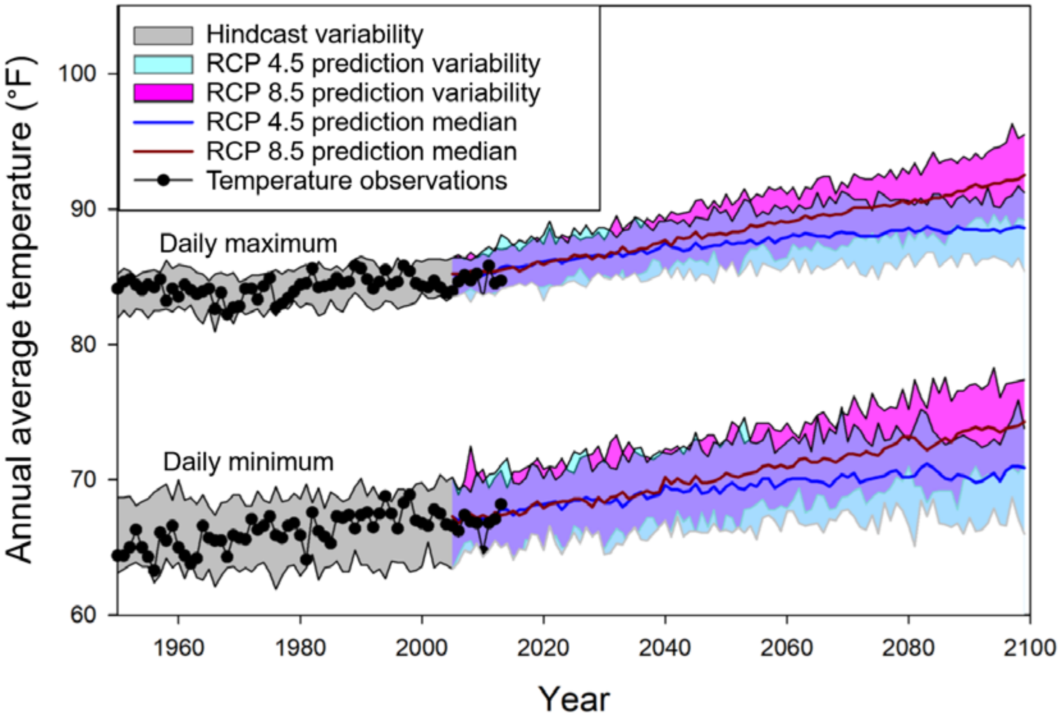

FIGURE 5-1 Historical measurements and future projections of annual average daily maximum and minimum air temperature for Miami-Dade County, Florida. Projections were generated by global climate models for the Coupled Model Intercomparison Project Phase 5 (CMIP5). Climate model data were statistically downscaled using the Localized Constructed Analogs method (Pierce et al., 2014). Shaded area shows uncertainty in general circulation model (GCM) hindcasts and forecasts. Two future emission scenarios are shown: higher emissions (RCP 8.5; red) and lower emissions (RCP 4.5; blue). The lines through the shaded areas represent the median value of GCM projections.
SOURCE: https://crt-climate-explorer.nemac.org.

Recent and Future Air Temperature Trends

Station data from Miami-Dade County for air temperature and precipitation from 1950 to 2013 show an increase in minimum and maximum annual average daily temperature (Figure 5-1) (Livneh et al., 2013, 2015).[1] The long-term average rate of minimum temperature increase was greater (0.23℃ per decade) than the rate of maximum temperature increase (0.028℃ per

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[1] See also https://crt-climate-explorer.nemac.org.

decade), and annual minimum values have been more variable. Jones and Driscoll (2022) evaluated air and sea surface temperature anomaly (GISTEMP Team, 2020) from 1900 to 2020 and, for South Florida, reported a trend of accelerating increases in air temperature: from 0.11°C per decade for the period 1930-2020, to 0.14°C per decade for the period 1950-2020, to 0.21°C per decade for the period 1980-2020. They also found large relative changes in air temperature extremes, with many more extreme hot temperatures and far fewer extreme cold temperatures in recent decades than would be expected based on 20th century data. For example, in the 1990s and 2000s, South Florida had twice the number of months with extreme hot temperatures (defined as >90 percent the 20th century distribution of temperature values) compared to observations during the 20th century, and in the 2010s, it had 4.5 times the expected number of months with extreme hot temperatures. In contrast, in the 1990s and 2000s South Florida had only one-fourth of the expected number of months with extreme cold temperatures (<10 percent of the 20th century distribution of temperature values), and in the 2010s it had only one-half of the expected number of months with extreme cold temperatures based on the 20th century distribution of temperatures.

Future air temperature projections for two emission scenarios—Representative Concentration Pathway (RCP) 4.5, the lower emission scenario, and RCP 8.5, the higher emission scenario—suggest that temperature changes will continue to increase in South Florida through the 21st century (Figure 5-1). For the higher emission scenario, the annual average daily maximum and minimum temperatures are projected to change by 0.042°C and 0.04°C per year, respectively. These rates decrease to 0.036°C and 0.035°C for the lower emission scenario. Increases in air temperature cause increases in evapotranspiration, which would reduce surface-water availability under comparable precipitation conditions.

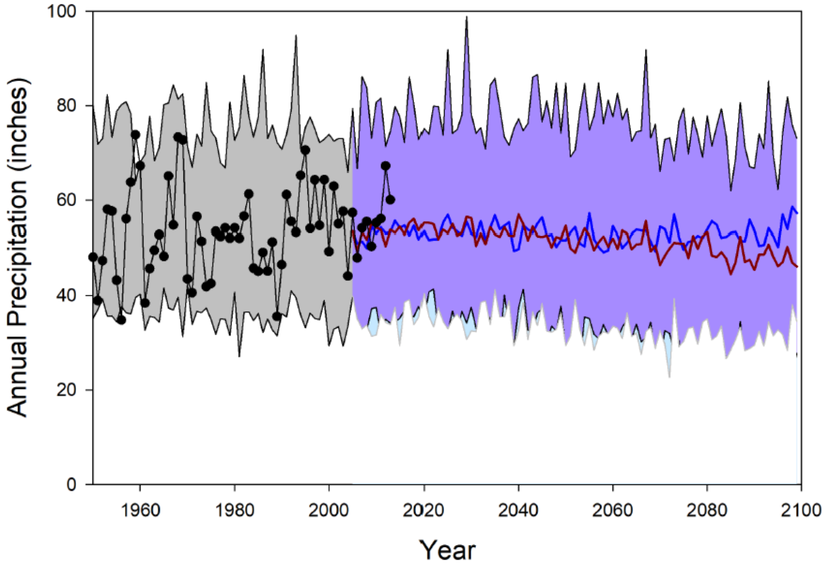

FIGURE 5-2 Historical measurements and future projections of annual precipitation for Miami-Dade County, Florida. Shaded area shows uncertainty in GCM hindcasts and forecasts. Two future emission scenarios are shown: higher emissions (RCP 8.5; red) and lower emissions (RCP 4.5; blue). The line through the shaded areas represents the median value of GCM projections.
SOURCE: https://crt-climate-explorer.nemac.org.

Recent and Future Evaporation and Precipitation Trends

Annual precipitation for South Florida is highly variable from year to year (Figure 5-2) with similar variation year to year in precipitation extremes (Figure 5-3). Future projections of precipitation for South Florida are highly uncertain and do not capture the variability evident in observations. Future projections do not indicate a clear future trend in annual precipitation, the number of dry days, or the annual number of precipitation events over 3 inches (7.6 cm) through the 21st century (Figures 5-2 and 5-3). Little difference in precipitation is projected between the higher and lower emission scenarios, except for a small projected decrease in annual precipitation and an increase in the number of dry days in the latter decades of the 21st century under higher emissions compared to a lower emissions scenario.

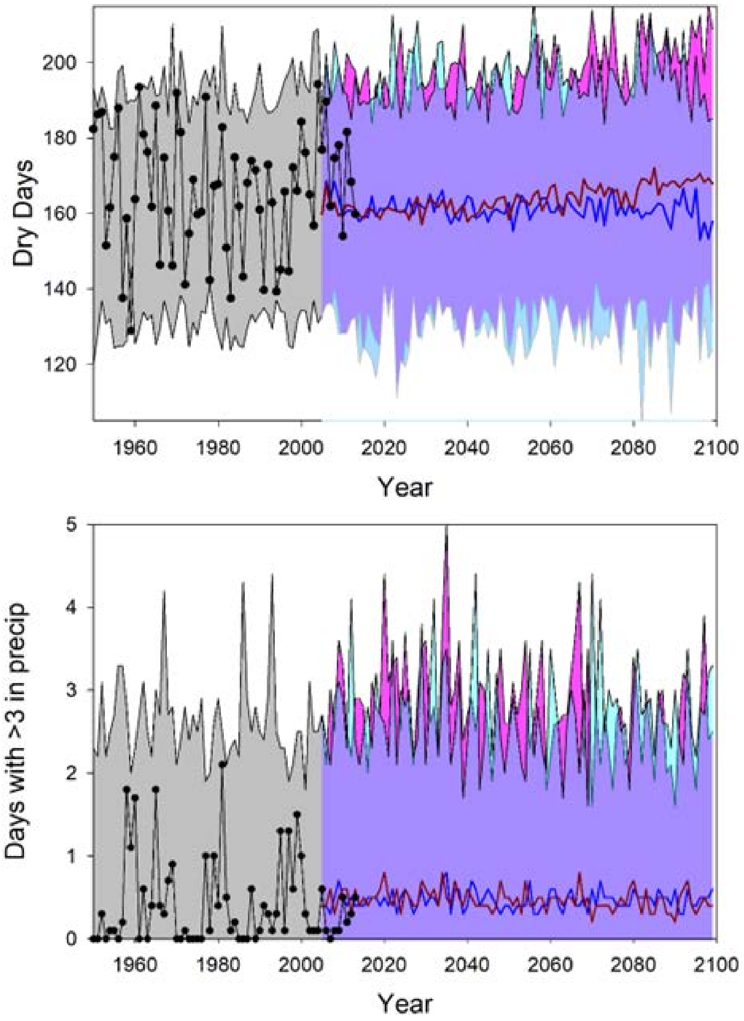

FIGURE 5-3 Historical measurements and future projections of annual dry days (top) and the number of precipitation events per year in which precipitation exceeded 3 inches (7.6 cm; bottom) for Miami-Dade County, Florida. Shaded area shows uncertainty in GCM hindcasts and forecasts. Two future emission scenarios are shown: higher emissions (RCP 8.5; red) and lower emissions (RCP 4.5; blue). The line through the shaded areas represents the median value of GCM projections.
SOURCE: https://crt-climate-explorer.nemac.org.

Similar projections are available for evapotranspiration and runoff.[2] Although future changes in precipitation are highly uncertain and projections of average annual precipitation currently appear relatively stable, it is quite certain that future climate will drive increases in rates of evapotranspiration due to projected increases in air temperature that will subsequently drive decreased runoff (Figure 5-4). For RCP 4.5, mean annual runoff for the ensemble of GCM projections is projected to decrease by 0.7 in/yr (1.8 cm/yr) over the period 2075-2099 relative to values for 1981-2010, while for RCP 8.5 runoff is projected to decrease by 3.6 in/yr (9.1 cm/yr) over the same conditions. The projected decreases in runoff are highly seasonal, with the largest relative changes occurring early in the wet season, during the months of June, July, and August (Figure 5-5). It is important to note that because future projections of precipitation are highly uncertain and variable, projections of runoff are also highly uncertain.

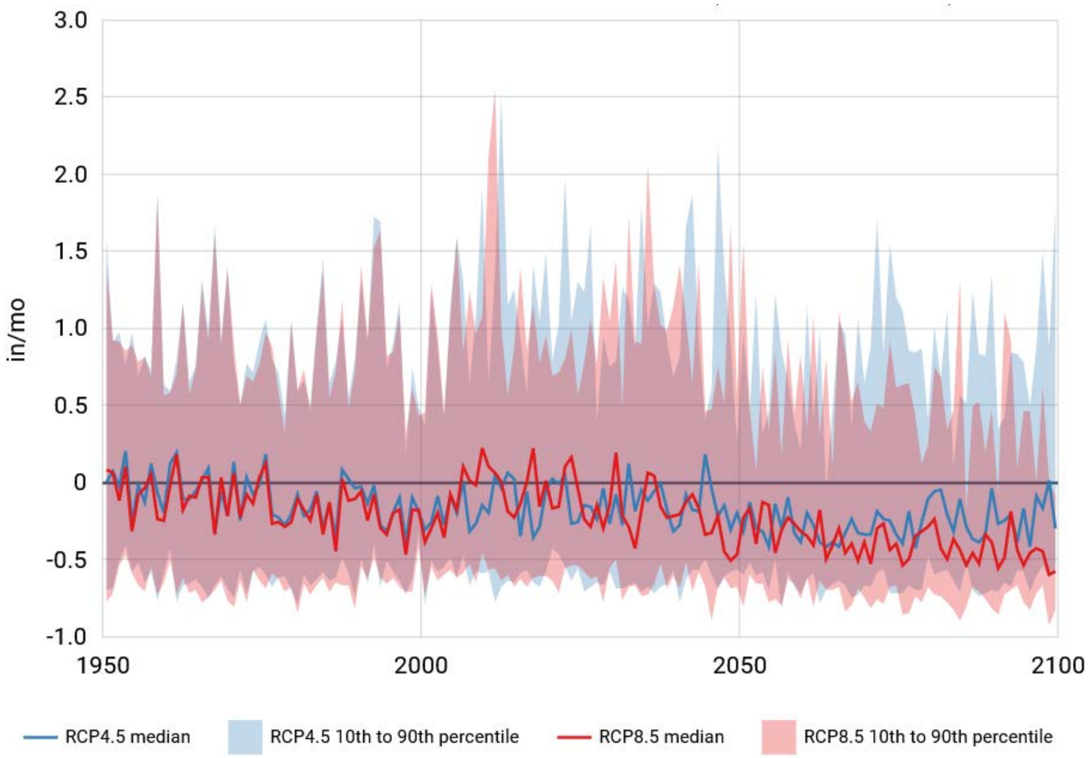

FIGURE 5-4 Historical and future projections of annual runoff (inches/month) relative to the mean of the historical period (1981-2010) for Miami-Dade County, Florida. The shaded area shows uncertainty in GCM hindcasts and forecasts. Two future emission scenarios are shown: higher emissions (RCP 8.5; red) and lower emissions (RCP 4.5; blue). The line through the shaded areas represents the median value of GCM projections.
SOURCE: https://www2.usgs.gov/landresources/lcs/nccv/maca2/maca2_counties.html.

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[2] See https://www2.usgs.gov/landresources/lcs/nccv/maca2/maca2_counties.html.

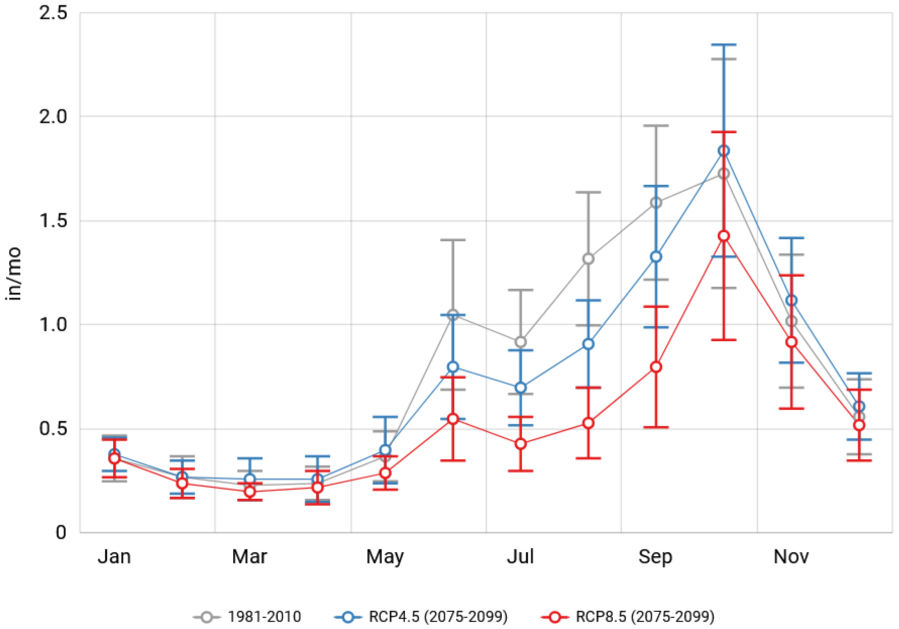

FIGURE 5-5 Historical simulations of monthly runoff (inches/month) for Miami-Dade County, Florida (1981-2010; grey) compared to future projections (2075-2099) of runoff under two emissions scenarios (higher emissions [RCP 8.5; red] and lower emissions [RCP 4.5; blue]), each with projected increases in air temperature and evapotranspiration combined with projected future rainfall. Error bars shows uncertainty in GCM hindcasts and forecasts. SOURCE: https://www2.usgs.gov/landresources/lcs/nccv/maca2/maca2_counties.html.

Sea-Level Rise

Long-term data from Key West, FL (1913-2021) show an increasing sea-level trend of 0.10±0.006 in/yr (2.52+0.14 mm/yr; 95% confidence interval) based on monthly mean sea-level data, which is equivalent to a change of 10 inches (0.25 m) in 100 years.[3] Changes in the speed and thermodynamics of the Florida Current and the Gulf Stream have resulted in a notable regional increase in the rate of sea-level rise between 2010 and 2015 (Domingues et al., 2018; SFRCCC, 2019) (Figure 5-6).

The Southeast Florida Regional Climate Change Compact (SFRCCC, 2019) developed a suite of possible futures of sea-level rise based on the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (IPCC, 2014), as well as projections from the National Oceanic and Atmospheric Administration (NOAA) (Sweet et al., 2017). SFRCCC (2019) also accounted for regional effects, such as gravitational effects of ice melt, changes in ocean dynamics, vertical land movement, and thermal expansion from warming of the Florida Current. This analysis produced regional differences in the rate of sea-level rise for Southeast Florida compared to global projections. All projection curves developed by SFRCCC (2019) are based on the assumption that greenhouse gas emissions continue to increase until the end of the century, consistent with RCP 8.5 of IPCC (2014). Estimates of sea-level rise reflect a baseline year of 2000 and a planning horizon to 2120.

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[3] See https://tidesandcurrents.noaa.gov.

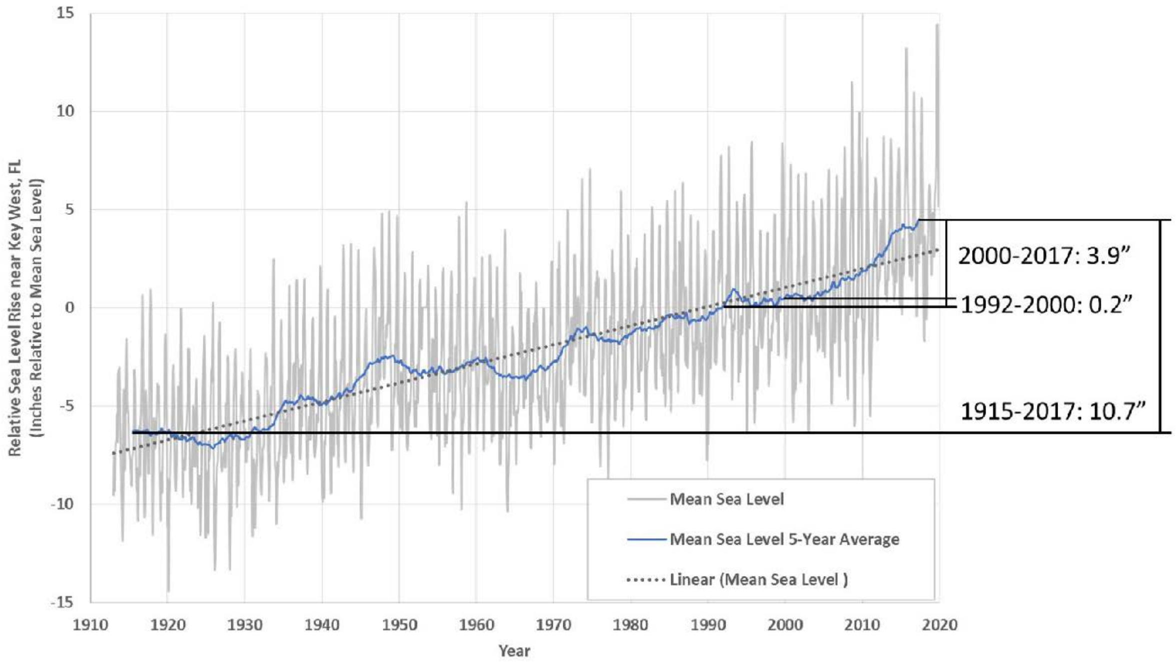
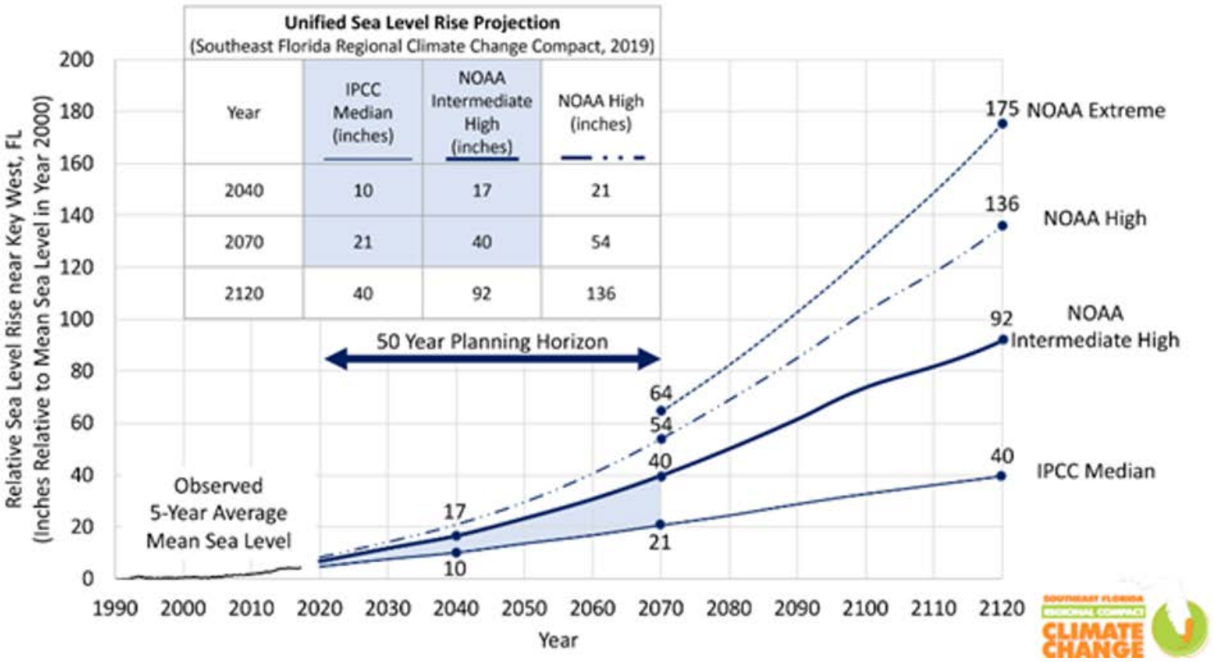


FIGURE 5-6 Relative sea-level rise in Key West, FL (NOAA Station ID 8724580) presented as monthly mean sea level, 5-year rolling average of monthly mean sea level, and linear trend of monthly mean sea level. Annotated measurements on right of figure are computed by subtracting the 5-year average mean sea levels for the years listed. The sea-level rise computed based on the linear trend will differ from the 5-year mean sea-level trend shown. SOURCE: SFRCCC, 2019.


Unified Sea Level Rise Projection
(Southeast Florida Regional Climate Change Compact, 2019)

Year	IPCC Median (inches)	NOAA Intermediate High (inches)	NOAA High (inches)
2040	10	17	21
2070	21	40	54
2120	40	92	136

FIGURE 5-7 Unified projections of sea-level rise for South Florida
SOURCE: SFRCCC, 2019.

The 2019 Unified Sea Level Rise Projection includes three curves for application: the NOAA High Curve, the NOAA Intermediate High Curve, and the curve corresponding to the median of the IPCC (2014) RCP 8.5 scenario (Figure 5-7; SFRCCC, 2019). A fourth curve, the NOAA Extreme Curve, is included for informational purposes, not for application, illustrating the possible upper limit of sea-level rise in response to potential massive ice sheet collapse in the latter part of the century.

In the short term, sea-level rise for South Florida is projected to be 10-21 inches (0.25-0.53 m) by 2040 and 21-54 inches (0.53-1.37 m) by 2070 above the 2000 mean sea level in Key West, FL (Figure 5-5; SFRCCC 2019). Over the long term through 2120, sea-level rise is projected to be 40-136 inches (1.0-3.45 m). The range of variation in projected sea-level rise is substantial, especially beyond 2070, because of uncertainty in future greenhouse gas emissions reduction efforts and associated geophysical effects.

Implications for Everglades Restoration

Sea level is rising, which impacts coastal and estuarine zones in many ways, including inundation or exposure of low-lying coastal areas, changes in storm and flood damages, shifts in extent and distribution of wetlands and other coastal habitats, changes to groundwater levels, and alterations to salinity intrusion into estuaries and groundwater systems. Increasing temperatures and evapotranspiration will reduce runoff and impact water availability, unless precipitation increases to counter these effects. A central CERP objective is to increase water storage and provide additional dry season flows to the remnant Everglades and the southern coastal systems (Chapter 2), but increased air temperature and evapotranspiration will reduce the flows provided by new CERP storage. Such future changes have important implications for both the human system and the natural system.

Both sea-level rise and temperature and precipitation changes will influence the fate of the Everglades coastal wetlands. A critical question for the CERP is whether, and for how long, restoration of freshwater flows can mitigate salinity incursion related to sea-level rise, reduce associated peat collapse (Chambers et al., 2019), and facilitate a landward migration of coastal mangroves to counteract the effects of sea-level rise. Research is examining the factors that influence the relative rates of these processes and the role of freshwater flows to enhance the resilience of the Everglades coastal landscape (Charles et al., 2019; Ishtiaq et al., 2022; Wilson et al., 2018). For example, Wilson et al. (2018) found that dry-down events exacerbated peat loss in brackish wetlands. See NASEM (2018) for additional discussion of the role of sea-level rise on wetland peat and NASEM (2018, 2020) for a review of climate change effects on South Florida estuaries and their restoration goals. Understanding the potential effects of climate change and their relationships to CERP projects is necessary to ensure sound investments that enhance the resilience of the South Florida ecosystem.

USACE APPROACH TO CLIMATE CHANGE

U.S. Army Corps of Engineers (USACE) policy is to integrate climate change adaptation planning and actions into the Agency’s missions, operations, programs, and projects. This concept is further developed in the USACE Climate Action Plan (USACE, 2021c), which includes a “commitment to integrate the best available observed and forward-looking climate information" into the agency's missions, programs, and management functions. Action 1 seeks to "ensure that new USACE-built projects are built to last and perform reliably for their intended design lives, despite uncertainty about future climatic conditions." Although updates to guidance are still in development, the Action Plan sets an expectation that USACE projects will be robust, resilient, and adaptable to future change.

USACE Sea-Level Change Guidance

In 1986 the USACE first developed a guidance letter requiring consideration of sea-level change in the planning and design of coastal flood control and erosion protection projects (USACE, 1986). The guidance followed the concepts outlined in the National Research Council's (NRC's) *Responding to Changes in Sea Level: Engineering Implications* (NRC, 1987), which covers multiple sea-level rise scenarios. USACE updated this guidance in its 2000 Planning Guidance Notebook (USACE, 2000), which informed early CERP planning studies, including the Biscayne Bay Coastal Wetlands. USACE (2000) called for an assessment of the sensitivity of project benefits to the historic and NRC high-rate scenario (equivalent to 4.9 feet [1.5 m] by 2100). In its current guidance, USACE (2019c) requires consideration of three scenarios (low, intermediate, and high rates of sea-level rise, calculated for local conditions based on equations in NRC, 1987). However, USACE planners can consider a higher rate of sea-level change if justified by project conditions to account for changes in statistically significant trends and new knowledge about sea-level change (USACE, 2019c). A subsequent USACE pamphlet (USACE, 2019a) describes procedures to evaluate sea-level change and calls for the use of multiple scenarios (consistent with USACE [2013]) in addition to a "single future," which must be used in National Environmental Policy Assessment evaluations. USACE (2019a) applies to USACE activities as far inland as the extent of estimated tidal influences. It provides options for how the scenarios should be used in USACE decision making, including

- When local conditions and plan performance are not considered highly sensitive to the rate of sea-level change, a single sea level–rise scenario could be used to develop and compare alternatives; the preferred alternative is then tested against other sea level–rise scenarios.
- When local conditions and plan performance are deemed to be very sensitive to the rate of sea-level change, alternatives could be formulated and then evaluated under all sea level–change scenarios.

USACE (2019a) also states the following:

> Alternative plan selection should explicitly provide a way to address uncertainty, describing a sequence of decisions allowing for adaptation based on evidence as the future unfolds. Decision-makers should not presume that the future will follow exactly any one of the SLC [sea level change] scenarios. Instead, analyses should determine how the SLC scenarios affect risk levels and plan performance, and identify the design or operations and maintenance measures that could be implemented to minimize adverse consequences while maximizing beneficial effects.

USACE guidance on the use of sea-level rise has evolved to allow for incorporation of scenario analysis and robust decision making into the planning process. However, the ability of any USACE team to fully embrace the approaches described may be limited by the availability of information (e.g., on the effects of sea-level rise on system dynamics), appropriate tools or models to explore alternatives across scenarios, and time and resources. In addition, for systems such as the Everglades, the interaction of sea-level rise with other climate stressors may be an important determinant of alternative benefits.

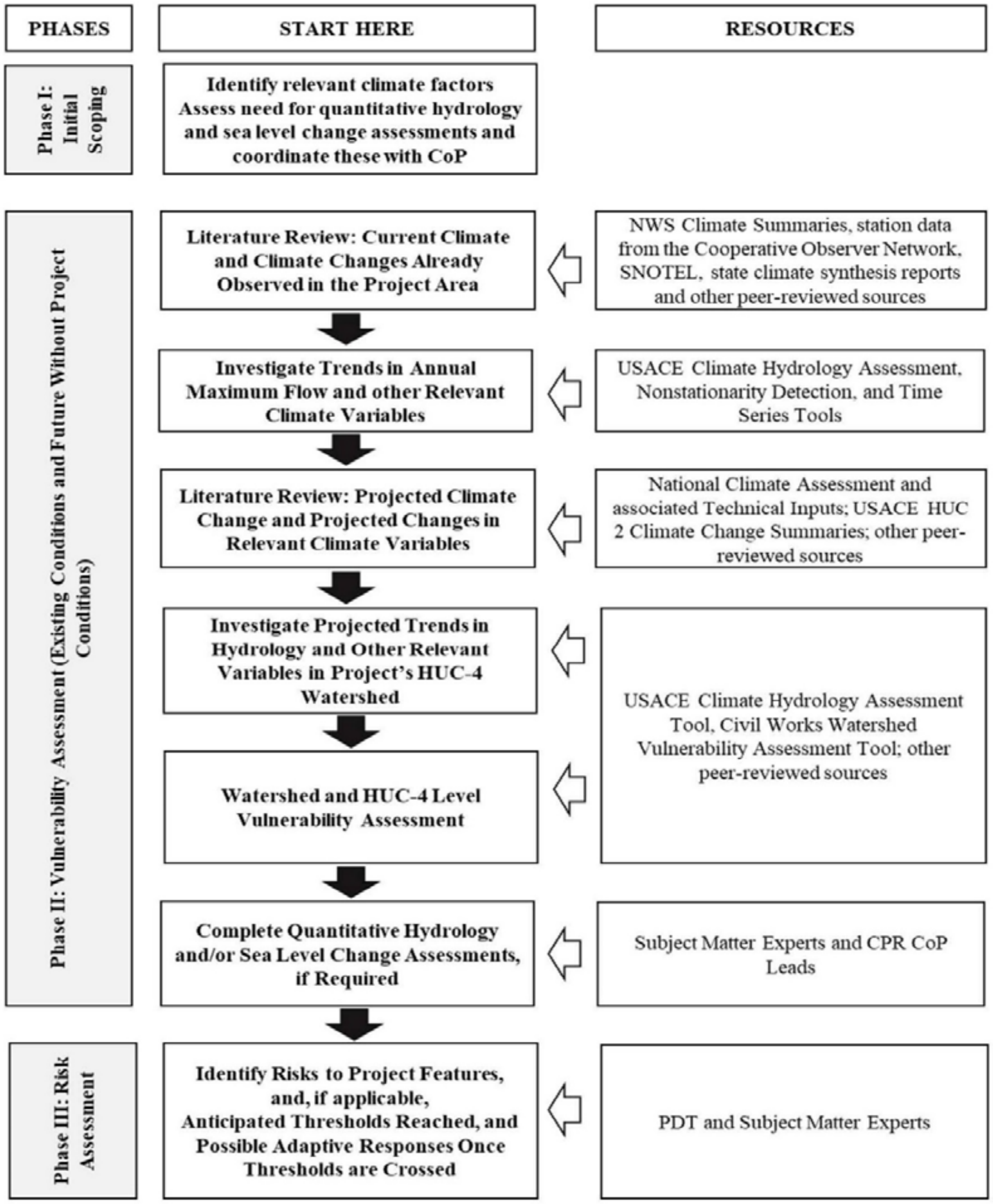


FIGURE 5-8 USACE process for qualitative analysis of climate change impacts on inland hydrology.
SOURCE: USACE, 2020e.

BOX 5-1
South Florida Water Management District Resiliency Planning

The South Florida Water Management District (SFWMD) has implemented programs specifically designed to assess and improve infrastructure resiliency and ensure function under the changing climate (SFWMD, 2021a). Recognizing that the current system will be stressed by climate change impacts such as sea-level rise and changing rainfall patterns, the SFWMD's Flood Protection Level of Service Program assesses the capacity of District flood control infrastructure to perform to both design specification and expected future conditions. Once areas for improvement are identified, Adaptation and Mitigation Planning studies are triggered. Since the program's inception in 2015, nine assessments have been or will be completed by 2022, and all flood control infrastructure will be assessed every 8-10 years (SFWMD, 2021a).

Through these and other assessments, the SFWMD's new Sea Level Rise and Flood Resiliency Plan identifies urgent improvement projects needed to address vulnerabilities to sea-level rise, storm surge, and extreme rainfall events (SFWMD, 2021b). Projects include both traditional "gray" infrastructure as well as nature-based solutions. The list of projects will be updated annually and serve as the basis for implementation priority.

USACE Guidance on Climate Change and Inland Hydrology

The current USACE Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects (USACE, 2020e) outlines the approach that the agency must follow to address climate change in its work related to runoff. The inland hydrology guidance (USACE, 2020e) requires incorporation of climate change into the assessment of all long-term planning and engineering decisions. It emphasizes understanding climate change impacts on plan selection and project objectives, the use of USACE tools and expert judgment, and communication of findings to the public. In particular, the guidance states that the risk of climate change must be identified, communicated, and managed in decision-making processes.

USACE (2020e) requires qualitative analysis of inland hydrology (Figure 5-8) and allows for quantitative analysis once USACE headquarters provides updated climate data and information, which has not yet occurred. The USACE qualitative analysis considers both past hydrologic changes and projected future hydrologic changes based on available modeling. The level of detail and complexity of this analysis will depend on the uncertainty and risks associated with the impact of climate on alternatives. This analysis is not expected to change the quantitative assessment of other factors that are part of project evaluation. However, it may influence future without project conditions, formulation and evaluation of alternative plans, and other aspects of the decision-making process. USACE (2020e) notes that the required qualitative inland hydrology analysis alone provides an insufficient basis for identifying or modifying a tentatively selected plan. However, it may be used by project partners, such as the South Florida Water Management District (SFWMD), to understand potential vulnerabilities and impacts so that they may be addressed outside the evaluation of the project itself. The SFWMD has established certain procedures to ensure the provision of service levels under climate change (see Box 5-1), and it could conduct additional analyses, in addition to the USACE qualitative analysis, to support a request for a "Locally Preferred Plan."

Although guidance is still pending, USACE (2020e) provides a preview of how future quantitative inland hydrology analysis will ultimately be conducted. Methods are expected to be flexible, with some requirements such as the use of USACE analytical tools for trend and non-stationarity detection and the use of a full ensemble of CMIP Phase 5 global climate model projections, stating that use of a subset is not supported. The level of effort for the analysis is expected to be scalable to the level of complexity of the project and its potential sensitivity to climate change. This flexibility will enable quantitative analyses in project evaluation under climate change in ways that could improve the future performance and resilience of the CERP once USACE guidance has been developed.

Approaches to Analyzing Precipitation and Temperature Change in Risk-based Planning

Consistent with the state of professional and scientific opinion, USACE (2020e) emphasizes that the historical record provides a relatively limited sampling of the conditions that will be experienced in the future. It cannot be assumed that the future climate will be well represented by historical conditions or that climate variability will occur over the same range as experienced in the past. Even if precipitation projections remain uncertain, increasing temperature and evapotranspiration trends (Figure 5-1) will affect future runoff and water availability (Figure 5-4 and 5-5), unless countered by increasing rainfall. Nonetheless, choosing an alternative to the historical record to inform planning and operations has been a vexing challenge for the water resources profession. However, methods have been developed, used, and documented that provide the basis for climate change analysis, and, if applied, would provide USACE partners with crucial information for improving the resilience of CERP investments.

For inland hydrology under climate change to be successfully addressed in project evaluation, expectations regarding the uncertainty of future climate must be appropriate. Most uncertainty associated with precipitation under a changing climate is irreducible in the short term. Therefore, there should be no expectation that a climate change analysis will narrow the range of possibilities or produce a single clear vision of future climate. Selecting a single mean estimate of future climate is like planning for each year to have the average annual precipitation, leaving a project unprepared for the risks of the wider range of possibilities. Instead, a pragmatic risk-based approach is necessary.

An objective of project evaluation under climate change is to improve understanding of the risks that climate change poses to the project, so that these risks can be better communicated and managed. A pragmatic approach to achieving this understanding uses modeling to simulate the effects of a wide range of plausible climate scenarios and future climate variability. In the case of precipitation and temperature changes, a well-established body of work in the scientific literature details methods for creating precipitation and temperature scenarios for this purpose (Herman et al., 2020; Kirsch et al., 2013; Mukundan et al., 2019; Seinschneider et al., 2013, 2015). These methods generally employ a set of equally probable stochastically generated time series of precipitation and air temperature that are then perturbed with plausible trends in the variable mean. This approach facilitates robust exploration of the effects of plausible changes to the mean climate state while accounting for the natural variability of the climate system. The futures can be conditioned on the specific climate phenomena that have the most influence in South Florida, such as ENSO, tropical cyclones, or seasonal precipitation, which enables assessment of risk levels based on expectations of changes in these phenomena. Simulations of plausible climate scenarios have been applied to water systems planning throughout the world and may be beneficial to CERP planning efforts. Several examples of successful approaches that could be highly appropriate for CERP project planning are described in Box 5-2.

Application of these methods in CERP planning would be straightforward in principle, notwithstanding the inevitable details of implementation in the existing suite of modeling tools. A systematic approach that uses these methods in CERP models to evaluate the risks posed by climate change to inland hydrology would align with USACE guidance and improve the likelihood of achieving the restoration goals while meeting other water system objectives.

RESTORATION PLANNING IN COASTAL SYSTEMS: THE BISCAYNE BAY AND SOUTHEASTERN EVERGLADES RESTORATION PROJECT

The BBSEER project focuses on ecosystem restoration of wetland and nearshore habitats in Biscayne Bay, Card Sound, and Barnes Sound and in the Model Lands, Southern Glades, and

BOX 5-2
Examples of Quantitative Climate Change Scenario Analysis for Inland Hydrology

A number of recent studies illustrate and, in some cases, provide guidance for applying “bottom-up” approaches to climate change assessment for water resources planning projects. They offer examples of methods that could be directly applied to Comprehensive Everglades Restoration Plan (CERP) planning. Each uses a climate stress testing approach, employing a wide range of stochastically generated climate scenarios that explore the plausible range of climate change. Thresholds on acceptable performance are used to define problematic climate scenarios or the degree of climate change that causes projects to either fail to meet their objectives. Climate projections from general circulation models (GCMs) can then be used to assess the level of concern associated with the vulnerabilities that are identified.

The California Department of Water Resources used this approach in *Decision Scaling Climate Vulnerability Assessment for the California Department of Water Resources* (Schwarz et al., 2019) to assess the vulnerability of the California Central Valley Water System using a regional planning model, Cal-Lite 3.0, to represent more than 30 water storage facilities and 700 miles of canals and pipelines that provide water for 25 million people and 750,000 acres of irrigated farmland. The San Francisco Public Utility Commission used a similar methodology, described in *Long Term Vulnerability Assessment and Adaptation Plan for the San Francisco Public Utilities Commission Water Enterprise* (Water Research Foundation, 2021), to understand the vulnerability of its water supply system to temperature and precipitation changes associated with climate change.

These methods have been documented and promoted by operational organizations including in reports by the World Bank, *Confronting Climate Uncertainty in Water Resources Planning and Project Design: The Decision Tree Framework* (Ray and Brown, 2015), and the USACE, UNESCO, and Deltares partnership, *Climate Risk Informed Decision Analysis (CRIDA): Collaborative Water Resources Planning for an Uncertain Future* (Mendoza et al., 2018). Deltares also developed the concept of Dynamic Adaptation Policy Pathways specifically addressing sea-level rise based on the Dutch experience (Werners, et al., 2021; Kwadijk et al., 2010). These reports provide implementation support based on decision making under deep uncertainty frameworks (Marchau et al., 2019), including decision scaling (Brown et al., 2012), robust decision making (Lempert et al., 2010; Weaver et al., 2013), and dynamic adaptive policy pathways (Mendoza et al., 2018).

other wetlands adjacent to these water bodies (see Figure 3-37). Canals and levees have reduced sheet flow to the coastal wetlands and estuaries and have concentrated discharge in drainage canals, altering nearshore salinity and coastal habitats. As discussed in more depth in Chapter 3, the project seeks to

- Restore ecological conditions in the Model Lands, Southern Glades, portions of Everglades National Park, and coastal wetlands;
- Restore conditions in the nearshore zones of Biscayne Bay, including Biscayne National Park, Card Sound, Barnes Sound, and Manatee Bay;
- Improve ecological and hydrologic connectivity between Biscayne Bay coastal wetlands, the Model Lands, and Southern Glades; and
- Increase resiliency of coastal habitats in southeastern Miami-Dade County to sea-level change (USACE and SFWMD, 2020c).

The BBSEER project builds on work conducted for the Biscayne Bay Coastal Wetlands (BBCW Phase 1) and the C-111 Spreader Canal West projects (see Chapter 3), which were each first increments of a larger regional project. To achieve these objectives, the CERP vision for the BBSEER project includes increasing water flows to the region through new water storage and/or wastewater reuse, improving sheet flow to the freshwater and coastal wetlands and the nearshore estuary ecosystem, and reducing seepage from Everglades wetlands.

In this low-elevation coastal system, the BBSEER project is on the front line of climate change effects. Because the project addresses coastal and near-shore issues and how they can be alleviated by increasing freshwater flows, it exemplifies the ways in which climate change effects on runoff and sea level can influence project performance. Further, because the planning is currently under way, BBSEER reflects the use of current climate change guidance for CERP agencies and provides the opportunity for the committee to review its use of information and tools in the planning process.

BBSEER Objectives and Challenges in Context of Climate Change

Climate change will have major effects on the estuaries (Figure 5-9; NASEM, 2021). Better understanding of these effects in the BBSEER footprint can help to inform management decisions and strategies that will provide long-term restoration benefits. The committee has previously noted that ongoing climate change, including changes in precipitation patterns, sea-level rise, and ocean warming, challenge the ability of many CERP restoration efforts to meet the “essential hydrological and biological characteristics that defined the undisturbed South Florida ecosystem” (NASEM, 2016). In light of sea level rise, the low-lying coastal wetlands of the Model Lands cannot be fully restored to their pre-drainage condition because ongoing sea-level rise is permanently altering the landscape and associated vegetation.

The BBSEER project represents an important evolution in CERP project objectives, from projects that aim to re-create historic conditions to projects whose resilience to future change is a key metric to be evaluated in project planning, marking an important shift in thinking toward the future of the system, consistent with a recommendation in NASEM (2018). This resilience depends upon increased freshwater flows and appropriate salinity to support a resilient mangrove habitat that accretes peat and thereby builds land surface elevation. Although not the sole objective, coastal resilience is central to meeting other objectives over the long term, such as restoring ecological conditions in coastal wetlands and in the near shore. The project team added a specific resilience performance measure (see Box 5-3) to track progress toward this objective in the evaluation of project alternatives, although currently there is no plan to weight this measure more strongly than the other seven performance measures.[4] The BBSEER project also aims to maintain a 500-m nearshore zone within mesohaline conditions (5-18 psu); restore

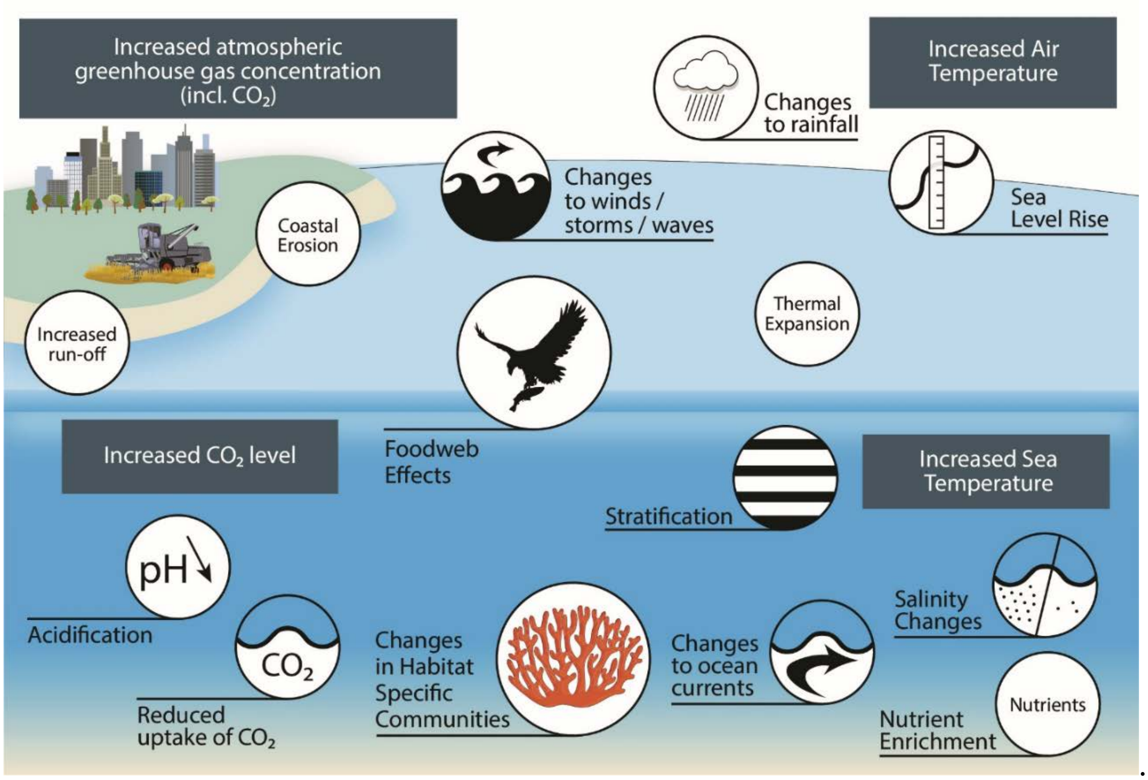


FIGURE 5-9 Conceptual model of impacts of global climate change on Florida estuaries.
SOURCE: Adapted from OSPAR, 2010.

BOX 5-3
The BBSEER Adaptive Foundational Resilience Performance Measure

Ecosystem changes within the Biscayne Bay Southern Everglades Ecosystem Restoration (BBSEER) footprint such as peat marsh degradation, replacement of coastal grasslands by mangrove forests, expansion of sparsely vegetated “white zones,” and introduction of invasive and exotic species have been accelerated by sea-level rise. In principle, increased freshwater flow to the area could promote restoration of peat-accreting vegetation, thereby resisting transgression due to sea-level rise.

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[4] The performance measures are nearshore salinity, direct canal releases, timing and distribution of flow sources to Biscayne Bay, hydroperiods, water depth, wetland salinity, adaptive foundational resilience, and ecological connectivity. See https://usace.contentdm.oclc.org/utils/getfile/collection/p16021coll11/id/5760.

The new Adaptive Foundational Resilience performance measure (F. Sklar, SFWMD, personal communication, 2022) is an estimation of the peat accretion rate based on the hydrologic outputs of the Regional Simulation Model for the Glades and Lower East Coast Service Areas (RSM-GL) and the Biscayne and Southern Everglades Coastal Transport (BISECT) models. Specifically, estimates of porewater salinity, sheet flow volume, and depth duration at each model grid cell are translated into peat accretion rates based on sets of empirical conversions for freshwater and saline habitats (Figure 5-10). The peat accretion rates are integrated over the 52-year model duration and then normalized to the maximum possible peat accretion (based on the empirical formulations of peat accretion), yielding a normalized performance measure score from 0 to 100. The combined scores along various transects through indicator regions of the model domain will be used to directly compare the model-estimated peat accretion under the different flow regimes of existing conditions, future without project, and proposed project alternatives.

Although the Adaptive Foundational Resilience performance measure yields numerical estimates of peat accretion, the accuracy of these estimates is subject to significant uncertainty because of accelerating sea-level rise, other effects of climate change, and lack of dynamic feedback (i.e., vegetation succession), among others. However, because these uncertainties impact alternative measures similarly, the performance measure may still be useful as a relative scoring of the peat accretion potential under different project alternatives (F. Sklar, SFWMD, personal communication, 2022).

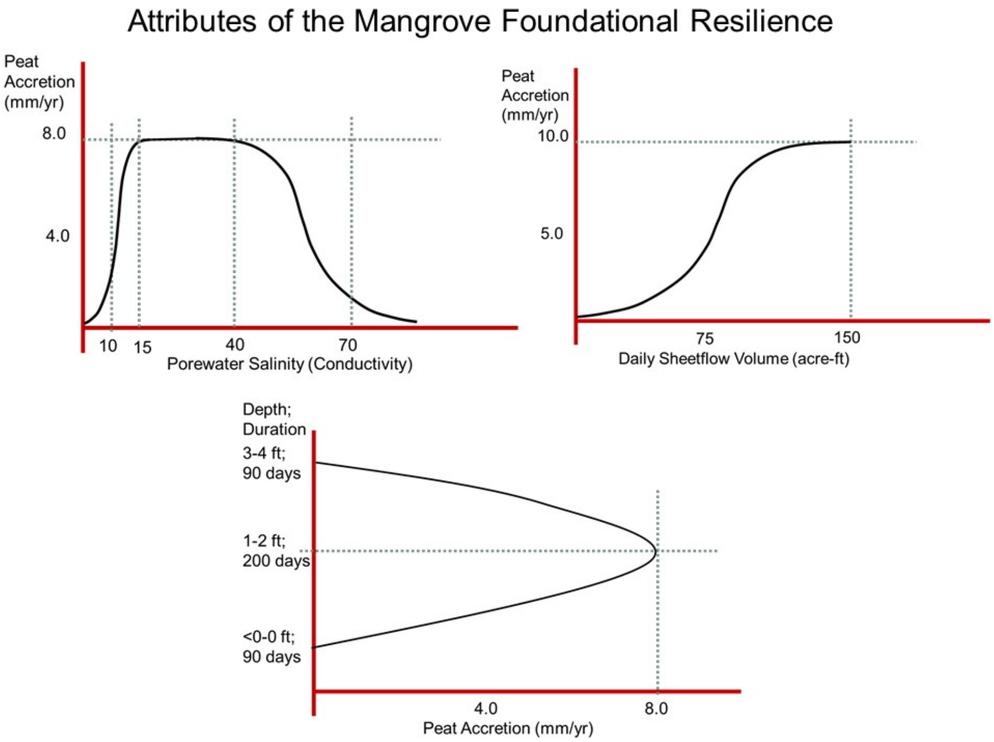

FIGURE 5-10 Graphical functions of the relationship of porewater salinity, sheet flow volume, and water depth and duration, which control peat accumulation in mangroves. These functions will be used in the Adaptive Foundational Resilience performance measure to calculate peat accretion based on various project alternatives that affect flow and salinity. Different graphical functions are used for peat accumulation in freshwater wetlands.
SOURCE: F. Sklar, SFWMD, personal communication, 2022.

freshwater depths, hydroperiods, and flows in terrestrial wetlands; and connect habitats from the sawgrass marsh through saltwater wetlands to open water across a 0-35 psu gradient.[5]

Many of the desired outcomes of the BBSEER project depend upon increased freshwater flow (by volume) in the southern Everglades afforded by new storage and/or wastewater reuse. The collection and delivery of water through the ecosystem for restoration purposes is impacted by climate change through altered precipitation regimes, increased evapotranspiration, increased salinization of coastal surface and subsurface waters, and decreased gravitational drainage as sea levels rise. It is important that all the assumptions being made about the availability and use of these water sources are reasonable given climate change and that effects of potential climate stressors on different water sources (e.g., surface storage, water reuse) are understood. Evaluation of whether alternatives produce meaningfully different outcomes when uncertainty posed by climate change is considered seems consistent with USACE policy and should be an explicit part of the decision process for BBSEER given the reliance on limited sources of freshwater under existing and future conditions.

Modeling Tools and Their Applications for BBSEER Planning in the Context of Climate Change

Previous committee reports have noted the difficulty of using the Regional Simulation Model (RSM) to understand the effects of projects near the coast, and the need for models that can assess the effects of sea-level rise. NASEM (2018) identified advancement of tools to better characterize and quantify the effects of sea-level rise as a critical need and noted that, despite the value of the RSM in understanding changes in water stages and flows, the lack of a coupled connection to the coastal systems and the ability to simulate salinity dynamics and variable density flows was a drawback. Thus, it is not surprising that BBSEER project planning has required a number of model refinements. Three models are being used to evaluate various project alternatives and to determine the effects of the eight performance measures:

- Regional Simulation Model for the Glades and Lower East Coast Service Areas (RSM-GL), which provides an integrated simulation of surface and groundwater from the Water Conservation Areas (WCAs) through Everglades National Park, the lower east coast, and the Model Lands, using a daily time step over a 52-year period (1965-2016) (Bras et al, 2019). The RSM-GL will be used to simulate water depths, hydroperiod, and flows.
- The Biscayne Bay Simulation Model (BBSM), which is a 2D model that uses vertically integrated hydrodynamic equations to simulate water flow and salinity dynamics (Wang et al., 2003; Stabenau et al., 2015). BBSM will be used to simulate nearshore salinity.[6]
- Biscayne and Southern Everglades Coastal Transport (BISECT), which was developed to evaluate South Florida surface-water stages and flows, groundwater levels, and salinity in response to changes in water-management practices and sea-level rise by combining the Tides and Inflows to the Mangrove Everglades (TIME) and FTLOADDS simulator (Swain et al., 2019). In BBSEER, BISECT will not directly simulate project features;

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[5] See also https://www.saj.usace.army.mil/BBSEER/.

[6] Following release of the prepublication report, this text was edited to provide an accurate description of the BBSM.

instead, it will utilize RSM-GL structure flows and stages at canals and project features. The model evaluation will use a 2007-2016 record of coastal forcing and will be used to simulate marsh salinity.

Figure 5-11 summarizes the proposed use of the various models in an early evaluation of project alternatives. Several ecological models are also available to elucidate the ecological implications of various project alternatives, and these models are used in parallel with the process to evaluate performance measures.

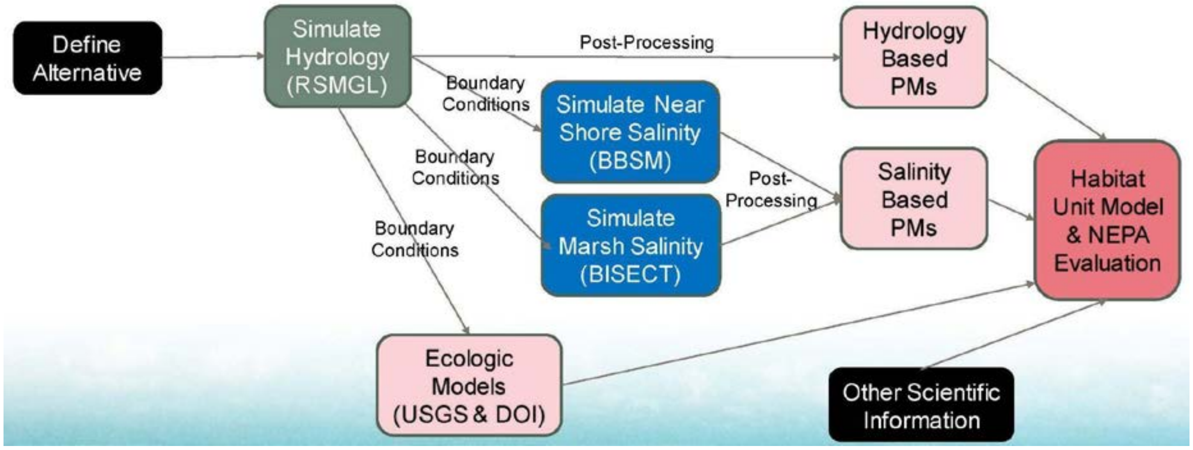

FIGURE 5-11 BBSEER model processing steps for round 1 of plan formulation.
NOTE: DOI=Department of Interior, NEPA=National Environmental Policy Act, PM=performance measure, USGS=U.S. Geological Survey.
SOURCE: Wilcox, 2022.

Significant efforts are under way to refine these hydrologic models to increase compatibility. For example, remeshing has extended the RSM-GL boundary seaward to improve representations of the coastal area. Extensive work has been undertaken to generate the tidal boundary forcing for RSM-GL based on long-term data sets. A limited recalibration was conducted on the BBSM, with added diffusion coefficient zones so that it would better align with the RSM-GL and adjustments to groundwater flow. These models employ slightly inconsistent approaches to assessing salinity changes, and how this plays out in the project planning remains to be seen. The models influence separate salinity-based performance measures. Because all applicable performance measures for any given grid cell will ultimately be combined in project alternative evaluation, the different models should ideally respond to common forcing.

As of July 2022, modeling efforts for project alternative evaluation were still at early stages. These efforts are expected to include development of a 2022 existing conditions baseline (ECB) run (including the Lake Okeechobee Systems Operating Manual [LOSOM] and the 2020 Combined Operational Plan [see Chapter 3]) and evaluation of a “future without project” (FWO) for 2085. The FWO will capture the effect of a step increase in sea level without BBSEER but including authorized CERP projects, including the Central Everglades Planning Project (CEPP) and the Everglades Agricultural Area (EAA) Reservoir. For the various project alternatives, eight performance measures will be examined under the 2085 conditions with projected sea-level rise, and the results will be compared to the ECB and FWO scenarios to evaluate the degree to which the alternatives meet project objectives.

Modeling the Effects of Sea-Level Change on Project Outcomes

One complication with the current approach is that sea-level rise effects are assessed using a step-change in the coastal boundary, whereas the rate of sea-level rise changes incrementally over time (Figure 5-7). Several important aspects of the system, such as mangrove transgression, are responsive to the rate of change in addition to the amount of change. If the rate of sea-level rise exceeds the capacity for mangroves to accrete peat, then vegetated wetlands will be replaced by open estuarine waters. The extent of mangroves may increase as the salt-freshwater transition moves inland, potentially leading to the conversion of sawgrass to mangroves. The modeling team recognizes that the future landscape and the performance of the project can be influenced by the interplay of a higher tidal boundary, adjustments in landscape definition, and topographic change. The current assumption is that accretion rates (and thus topographic change) are based on relationships between accretion, flow, and salinity, which vary by vegetation community (Box 5-3). These relationships have been established based on data from the system as it is now or has recently been. Sensitivity analyses need to be conducted to understand how much these assumptions drive the performance of the project. Uncertainty in soil accretion has been shown in other coastal wetland models to be an important driver of future landscape change (Meselhe et al., 2021). Further, coastal wetland accretion has been shown to be responsive to changes in relative sea-level rise rate (Davis et al., 2005; Saintilan et al., 2022); thus, if the rate of sea-level rise increases, assumptions about accretion rates may need to be adjusted. Plant-soil feedbacks are complex (Wimmler et al., 2021) and physical conditions, including storm effects, can have important implications for mangroves (Chambers et al., 2021; Xie et al., 2022). Including all aspects of coastal wetland dynamics in time-dependent modeling can be complex. However, in coastal Louisiana, focused effort and investment in the development of tools to support planning has yielded a relatively simple model in which simulations show change over time in coastal wetlands in response to changes in sea-level, freshwater inflows, and some storm effects (Reed et al., 2020a).

Further, the survival in place of the mangroves depends on their ability to maintain their relative elevation as sea level progressively rises. Changes in wetland condition may be gradual until thresholds for tolerance of flooding or salinity are exceeded (Chambers et al., 2021). Such thresholds may be exceeded by the gradual encroachment of saline waters, for example, or during extreme events, such as hurricanes. Understanding when the rates of sea-level rise exceed the ability of mangroves to accrete, and the rapidity with which transgression and associated vegetative transitions occur due to both chronic and acute stresses (with and without the project), is key to understanding project performance over the USACE-prescribed 50-year planning period. The step-change approach to sea-level modeling fails to encompass the types of transitions that occur and may provide misleading information about project performance over time.

Modeling the Effects of Variations in Precipitation and Climate Change on Project Outcomes

The only aspect of climate change included in the BBSEER analysis is sea-level rise. Despite ongoing collaborative efforts between SFWMD and Florida International University (FIU) to develop new scenarios of precipitation under climate change to support restoration decision making, future precipitation scenarios will not be incorporated into the BBSEER analysis. The BBSEER modeling for the evaluation of project alternatives will be based on the prior climate record, which assumes that the historical time series of precipitation and air temperature provide an adequate set of conditions to fully test the robustness of the candidate plans to future climate conditions. The drawback of this approach is that the results will not reflect the range of possible future weather conditions that the recommended design is likely to face.

At the spatial scale of BBSEER and for a planning horizon of 50 years, the natural variability of the local climate will be a significant source of variability, while trends in climate due to anthropogenic climate change, including changing air temperature and evapotranspiration (Figures 5-1 to 5-5), are likely have a more subdued effect, at least in the next few decades. Thus, the key question is whether and to what degree the historical observed weather record provides a reasonable simulation of the conditions under which the restoration project will take place. It is worth noting that in the practice of water planning, it is not uncommon that the historical record retains a primacy for project evaluation. Nonetheless, a general conclusion in water resources planning has been that the historical record provides a relatively limited sampling of the conditions that will be experienced. Although the range of variability may not significantly differ, the specific sequence of weather events certainly will. For example, the sequence of above and below normal precipitation years and the magnitude of the departure from mean conditions will likely be unprecedented. There may be years with more intense precipitation or more intense drought simply due to natural variability, or multiple extreme years may occur back to back in ways that have not occurred in the precipitation record. The specific effects of anthropogenic climate changes are difficult to anticipate but they do increase motivation to consider more variation than has been evident in the historical record during evaluation of restoration designs.

A rich literature describes methods to generate climate scenarios for water project design evaluation that precedes more recent concerns related to climate change (Cioffi et al., 2020; Kwon et al., 2007, 2009). Interest in using GCM projections as the basis for such simulations is common. However, alternative methods that do not require GCM projections may better elucidate the sensitivity of a particular project, such as BBSEER, to climate change (Brown et al., 2012; Steinschneider and Brown, 2013; Whateley et al., 2014). Such methods range from incrementally shifting the historical precipitation and air temperature time series to systematically explore plausible climate changes (e.g., ±5 and ±10 percent mean annual rainfall and +1, +2, +3℃ mean annual temperature) to applying climate shifts to stochastically generated new time series that reflect possible variability. Either way, the scenarios can be used with existing models to unveil the robustness or vulnerability of various designs to climate change.

With an understanding of the sensitivity of performance measures to key assumptions and a more rigorous approach to exploring effects of precipitation and temperature change in project evaluation, confidence in the ability of the selected restoration measures to provide the anticipated benefits will increase. Project managers could then select an alternative plan that reflects robustness to future climate uncertainty—thereby increasing the probability of project success. Further, the issue of robustness to future uncertainty can be extended beyond questions of climate uncertainty.

Lessons Learned for Future Coastal Planning

The approach to model alignment and the consideration of sea-level rise represents important steps forward in CERP planning for coastal projects. The committee appreciates the challenges that the modeling team faces in working with existing tools with limited time to make adjustments, as well as the complexities of predicting future change in coastal wetland and nearshore systems, especially one with complex surface-nearshore-groundwater interactions. However, key questions remain regarding the analysis as currently planned, which have implications both for the BBSEER project and for future coastal planning efforts under the CERP.

The committee is concerned that the current analysis could lead to misleading conclusions about the likelihood of project success under any of the alternatives, and therefore ill-informed restoration decisions. The benefits of including climate change in project planning could take many forms, such as the incorporation of project features that better accommodate extremes in runoff or project objectives that reflect an array of potentially desirable outcomes rather than a fixed target condition. Project plans could also include staged implementation that recognizes that features that provide benefit in the near term may need to be replaced by other features in future years. Climate change in South Florida will have a myriad of effects, including monotonic sea-level rise, temperature change, and the potential for increased variability and extremes of precipitation and temperature that will impact not only the surface-water budget but also the ecological dynamics of the system. Project alternatives could be impacted in different ways. For example, nearshore fishes may be influenced by changes in sea surface temperature, while sawgrass is more susceptible to salinity changes, which could be caused by salinity incursion from sea-level rise, rising soil salinity associated with extended drought, and/or more intense tropical storms. Considering only the effects of sea-level rise rather than its effects in combination with other climate-related stressors makes the project planning process vulnerable. Unless these interacting factors are explored in some way, the nature of that vulnerability remains unknown. Ignoring a known risk is problematic. Although the exact future conditions cannot be known, the potential for impacts can be explored.

Rather than redesigning an entire planning process that is already under way, a near-term solution may be to conduct parallel exploratory analyses of some of these potential climate impacts, using modeling tools available from the research community to assess the potential sensitivity of project outcomes to climate change factors, such as more variable rainfall and increasing air temperature and evapotranspiration. Such analyses could inform the planning process, for example by identifying which performance measures are most sensitive to climate change or the range of potential variability in performance metrics associated with climate changes.

The larger question is how to promote the development of a set of integrated predictive models for use in project planning that are broad enough to consider an array of climate change effects on systems dynamics, are nimble enough to enable exploration of a range of plausible conditions, and can show progressive changes over time. The current "pragmatic" approach is to introduce a model developed outside of the CERP, either in agencies or universities, into the project planning process when it can be approved for use in USACE planning and when it serves a need that no other existing model can support. Model development needs should be identified well before project planning starts to ensure the availability of the tools needed to fully support planning.

A dedicated focus on models that can more fully consider climate change effects, including the combined effects of climate stressors, will reduce the risks exemplified in the BBSEER planning discussed above and will ensure project planning can identify measures that will perform under an array of plausible future conditions. Such an initiative will take focused effort, time, financial support, and dedicated expertise. How and where these resources should be aligned is beyond the scope of the committee's charge, but the lack of such tools seems to be a major constraint on effective planning of the CERP for the future of the coastal ecosystem. Project planning will need to continue while such models are being developed—this statement is not a call for a delay. Rather, it is intended to emphasize the need for model development work to support future planning efforts to begin in parallel with ongoing planning. Otherwise, future project planning efforts, especially for the coastal ecosystem (e.g., the Southern Everglades project), will continue to be vulnerable to climate change effects.

MANAGING OPERATIONS

The effects of climate change on the frequency of more extreme conditions, especially a change in the number of dry days, has been described previously in this chapter. Although long-term planning requires thinking about decades into the future, system operation to achieve restoration goals must react to the conditions encountered in terms of runoff and the balance between reducing flood risk and providing water to people and the ecosystem. Here the committee explores the implications of climate change effects on temperature and precipitation on operations through the recent work on the LOSOM. Because this work is recent, the committee expects it to reflect current approaches to the consideration of climate change in inland operations.

Lake Okeechobee Systems Operating Manual

In 2022, the USACE released a draft environmental impact statement for LOSOM (USACE, 2022a) as an update to the 2007 Lake Okeechobee Regulation Schedule in response to the construction of additional CERP projects and rehabilitation of the Herbert Hoover Dike (see Chapter 3). Implementation of LOSOM is anticipated in 2023. LOSOM has an explicit goal to incorporate flexibility into Lake Okeechobee operations while balancing congressionally authorized project purposes. The development of LOSOM included analyses of numerous scenarios based on correlation matrices of performance metrics and use of multi-criteria decision analysis to identify an optimal balance to minimize impacts and/or maximize benefits to the lake itself, the connecting northern estuaries, the remnant Everglades, and water supply to the region. This was not a trivial task, and considerable effort was devoted to both the analyses and the synthesis of the results to better meet the competing demands of the South Florida ecosystem.

LOSOM was evaluated in accordance with USACE climate guidance. LOSOM was based on an analysis of scenarios using the climate record of the past 52 years (1965-2016). That the record was expanded to end in 2016 rather than 2005, and includes the 2006-2008 drought and Tropical Storm Isaac's rainfall in 2012, is a positive step, but the evaluation of how well the alternatives will perform still does not account for the possibility that conditions during the next 50 years will vastly differ from the past record. Indeed, most climate modelers expect the future climate to differ, possibly in unpredictable ways, from that of the past 50 years. In particular, it is surprising that the analysis did not use multiple and equally likely stochastically generated time series of precipitation. Doing so would enable more robust assessment of alternative operating plans over the range of possible weather and climate conditions that may be experienced in the future (e.g., Kwon et al., 2007, 2009). Furthermore, the stochastic time series can be coupled with plausible climate trends to create a set of scenarios that evaluates performance under both future climate variability and climate change (Brown et al., 2012; Steinschneider and Brown, 2013; Whateley et al., 2014). The USACE evaluated non-stationarity (Hirsch, 2011; Milly et al., 2008) with its non-stationarity detection tool, which enables assessment of whether and when the statistical characteristics of a hydrologic data series are not constant through time (USACE, 2022a). The non-stationarity detection tool was applied to a single site, Fisheating Creek, because of its long unregulated period of record, but with the caveat that this tool is not a substitute for engineering judgment. Based its established criteria, the USACE concluded that there was insufficient evidence to support the presence of non-stationarity. However, this conclusion does not rule out the possibility of non-stationarity in the future as the climate continues to evolve under the influence of increasing greenhouse gas concentrations.

The importance of examining climatic conditions that may extend beyond those that have been observed in the past cannot be overstated given the drastic effect of high and low water levels on the Lake Okeechobee ecosystem, as well as the other systems that are hydrologically connected to Lake Okeechobee. For example, stakeholders throughout South Florida have expressed serious concerns about Lake Okeechobee operations. In the northern estuaries, excess releases from Lake Okeechobee result in high nutrient loads and changes in salinity, leading to losses in the shellfish and pinfish communities; loss of *Vallisneria* (Doering et al., 2002), a key food source for the Florida manatee (Bengston, 1983); and proliferation of harmful algal blooms (NASEM, 2021; Phlips et al., 2020). Extreme water levels in the lake itself can lead to the loss of submerged aquatic vegetation and proliferation of invasive species (Havens et al., 2004). The effects of very low water levels due to drought (Steinman et al., 2002b) and very high water levels due to hurricanes (Havens et al., 2016; Kramer et al., 2018) on Lake Okeechobee and its connecting estuaries have been documented. Record water levels have been established in the past few decades, and because of concerns about changing climate and non-stationarity, there is no reason to expect climate conditions to stabilize. Hence, it is prudent to run models that include water levels that transcend past historical bounds.

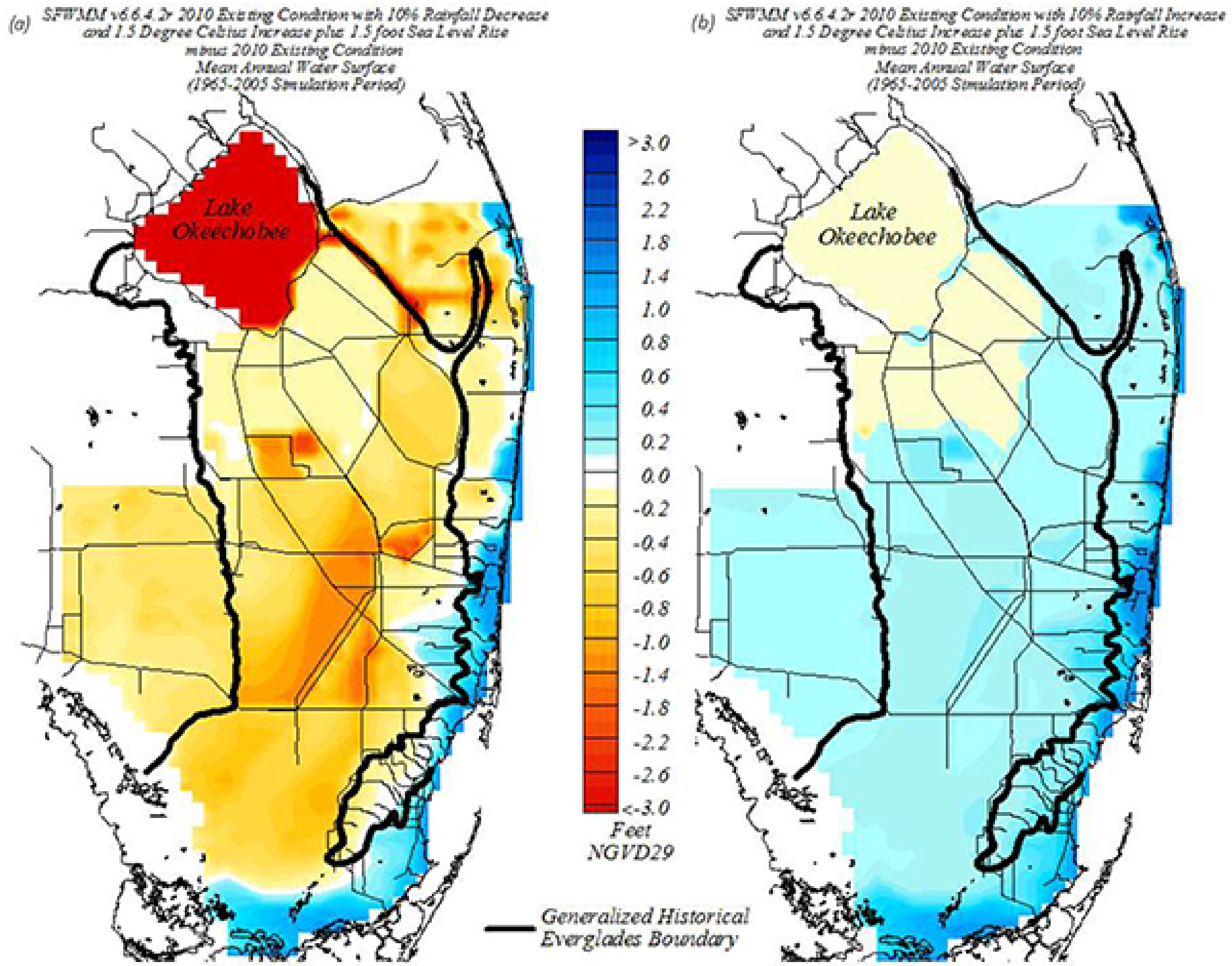

FIGURE 5-12 Differences in annual average water stage between scenarios of: a) a 10% decrease in average annual rainfall, and b) a 10% increase in average annual rainfall. Both scenarios include 1.5 ˚C temperature increase and 1.5 feet of sea-level rise and changes in rainfall were equally distributed across the year.
SOURCE: J. Obeysekera, SFWMD, personal communication, 2014.

Indeed, a set of future scenarios for year 2060 that were developed based on outputs from the South Florida Water Management Model (Obeysekera et al., 2015) examined potential impacts associated with changing rainfall (±10 percent) combined with increasing air temperature and evapotranspiration rates. Analyses of these scenarios show that mean outflows from the lake declined by 11 percent through evapotranspiration increases alone. Under the 10 percent decrease in rainfall scenario, outflows decreased by 26 percent and the median lake level decreased by approximately 4 feet (Figure 5-12). The scenario with a 10 percent increase in rainfall condition plus increasing evapotranspiration showed a 4.5 percent increase in outflows compared to the base scenario (Table 5-1) (Havens and Steinman, 2015).

Under the relatively modest change of a 10 percent reduction in future rainfall combined with increasing evapotranspiration, some elements of the water budget show dramatic changes, including a substantial reduction of inflows from the watershed north of Lake Okeechobee. The largest relative reduction of lake outflows was projected in regulatory releases to the northern estuaries and to the L-8 Basin for agricultural uses (Table 5-1). Another potentially significant impact is the reduction in environmental releases to the Caloosahatchee River, which may impact the health of *Vallisneria* beds, which require freshwater releases from the lake to maintain an optimal salinity regime (Doering et al., 1999; NASEM, 2021). In the scenario with 1.5℃ increase in air temperature and an associated increase in evapotranspiration with no difference in rainfall, surface elevations in Lake Okeechobee were projected to decrease to an elevation of 6.9 feet (2.1 m) NGVD29[7] or below for 20 percent of the simulation and to a minimum lake stage of 4.9 feet (1.5 m), exposing the littoral and nearshore zones, which support emergent and submerged vegetation respectively. Under this condition, the surface area of the lake is reduced to less than half of its full area (Figure 5-13). This scenario could result in a reduction in lake stage of more than 6 feet (2 m). When increased evapotranspiration is combined with reduced rainfall, the scenario predicted that the littoral and nearshore zones were dry 55 percent of the time compared to less than 4 percent in the base run with no change in temperature or precipitation (Havens and Steinman, 2015). Conversely, the modest 5 percent increase in outflows under the 10 percent increase in rainfall scenario has relatively small effects on outflows relative to the base condition (Table 5-1), because of offsets from greater evapotranspiration.

Although the committee recognizes the considerable uncertainty about long-term changes in climate and precipitation, this uncertainty should not preclude, and in fact elevates, the need for broad exploratory analysis to understand the possible implications of a changing and variable climate. These “what if” model runs could be used to consider a more expansive view of climate change variables. It is likely that LOSOM, with its expanded zone D that permits greater latitude in operational decision making, will accommodate changing climatic conditions when lake stage is between ~12 and 17 feet NGVD. However, the flexibility in zone D operations does not extend to the extremes that may occur with greater frequency in the future. It would be useful to project how frequent those extremes could occur in the future, which could increase understanding of the challenges associated with operating lake discharges during extended droughts or intense precipitation.

As stated in previous reports, uncertainty about the direction and magnitude of future climate is not an impediment to a comprehensive understanding of how the Everglades ecosystem responds to climate changes. This consideration applies to LOSOM as well. The use of large ensembles of climate simulations or, often more effectively, stochastically generated climate change scenarios facilitates the ability to sample and infer the system response to a wide range of possible changes. Indeed, this approach is an extension of the well-established methods of synthetic hydrologic simulations that are commonly used in engineering practice to evaluate the performance of designs in the face of new hydrologic variability. The USACE Institute for Water Resources has applied and contributed to the development of these methods (e.g., Mendoza et al., 2018; Poff et al., 2016; Spence and Brown, 2018). Restoration leaders would be well served by applying them to future revisions of the Lake Okeechobee operating schedule.

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[7] National Geodetic Vertical Datum of 1929.

TABLE 5-1 Comparison of the Mean Water Budgets for Lake Okeechobee (1965-2006) under Four Future Climate Scenarios

Water Budget Element	**Scenario**			
	Base Condition	+1.5℃	+ 1.5℃ /+10% Avg. Rainfall	+1.5℃ /-10% Avg. Rainfall
Inflows (ha-m/yr)				
Rainfall	197	198	217	178
Kissimmee River	128	99	133	**66**
Others	102	85	96	**70**
TOTAL INFLOW	427	382	446	**314**
Outflows (ha-m/yr)				
Evapotranspiration	252	258	268	241
St. Lucie (regulatory)	21	**8**	22	**1**
Caloosahatchee River (regulatory)	58	**26**	60	**6**
Caloosahatchee (environmental)	5	4	5	**1**
Water supply to EAA	33	34	35	25
Water supply to Lower East Coast Service Area	4	5	3	**6**
L8 agricultural demands	6	**4**	5	**2**
Others	46	41	46	**33**
TOTAL OUTFLOW	425	380	444	**315**

NOTE: The four scenarios included (1) base: a future condition that assumes no change in climatic conditions; (2) a future with an increase in air temperature of 1.5°C and associated evapotranspiration; (3) a future with an increase in air temperature of 1.5°C and associated evapotranspiration plus a 10 percent increase in average rainfall; and (4) a future with an increase in air temperature of 1.5°C and associated evapotranspiration and a 10 percent decrease in average rainfall. Numbers in bold indicate a >25% change from Base Scenario conditions.
SOURCE: Havens and Steinman, 2015.

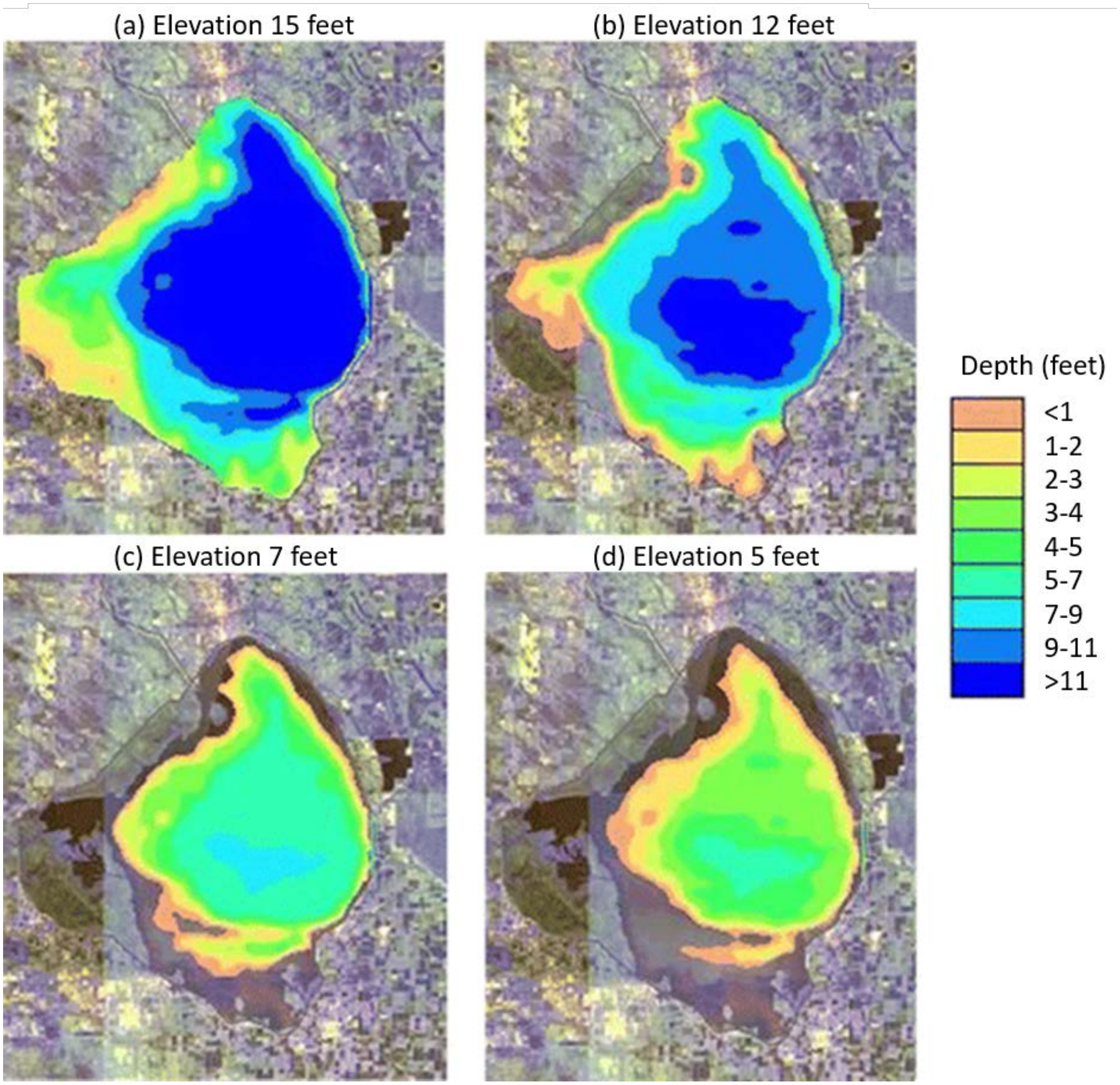

FIGURE 5-13 Water depths and spatial extent of Lake Okeechobee inside its levee at four different lake levels (surface elevations relative to NGVD29). Lake surface elevations of 12 feet (3.7 m) (b) to 15 feet (4.6 m) (a) fully hydrate the littoral marsh, and then allows it to dry out but leaves sufficient water in the nearshore zone for submerged aquatic vegetation to flourish. At 15 feet (4.6 m), the water surface extends to the edge of the levee, and at 12 feet (3.7 m), the nearshore zone and part of the littoral zone remain hydrated. At a lake surface elevation of 7 feet (2.1 m) (c), an elevation reached nearly 20 percent of the time in the -10% rainfall + evapotranspiration scenario, submergent vegetation is dry; and (d) at 5 feet (1.5 m), approximately the lowest elevation reached in that same scenario, large areas of emergent vegetation are dry.
SOURCE: Modified from Havens and Steinman, 2015.

Opportunities to Incorporate Climate Change in System Operations

The 2021 Integrated Delivery Schedule (USACE, 2021c) includes a schedule for the development of updates for the regional System Operating Manual. The System Operating Manual consists of seven volumes, organized according to geographical regions, that are designed to collectively provide a system-wide framework for the operation of components of the Central & Southern Florida Project and CERP projects to ensure that they function in a coordinated, systematic way. The Programmatic Regulations (33 CFR §385.3) call for the System Operating Manual to plan for flooding events to minimize the need for short-term deviations and establish a drought contingency plan. The System Operating Manual is considered the “critical last step in getting the water right and achieving system-wide benefits” (USACE, 2021c). The focus on the System Operating Manual, and associated Project Operating Manuals, reflects the pivot in the CERP from project planning to operations discussed in NASEM (2021). Work to update several volumes of the System Operating Manual is scheduled for completion by October 2025 (USACE, 2021c).

According to the Programmatic Regulations, the System Operating Manual should be revised whenever deemed necessary by the agencies to ensure that the goals and purposes of the CERP are achieved. This provision recognizes that changes can occur between project planning and operations of the final projects, because of changes not only in individual project features but also in other aspects of the system. Because CERP principles dictate the use of adaptive management based on the best available science, it is appropriate that the System Operating Manual be viewed as a vehicle to modify system operations based on evolving understanding of climate change and its effects to achieve CERP goals. For example, updates to the System Operating Manual may incorporate new knowledge of rainfall-runoff relationships and rising sea levels. Further, because the Project Operating Manuals are updated throughout the project life (Figure 5-14), they can incorporate new information that arises, for example, during engineering and design and during the operation, testing, and monitoring of project phases as they come on line. Project Operating Manuals can also be updated as understanding improves about climate change effects on the management of the South Florida ecosystem, including the influence of extreme events. The latter may be an especially useful way to incorporate new information on progressive change in the ecosystem due to climate change when there is an extended period between the end of project planning and project operation.

Periodic revisions to the System Operating Manual will ensure that an updated climate record, reflecting recent records of climate variability and trends (which may differ from the patterns shown in longer-term records), is used to operate the system and plan for droughts and floods. As more CERP projects are completed, updates to Project Operating Manuals may increase in frequency to capture the effects of project interactions, which will further consideration of climate trends and variability.

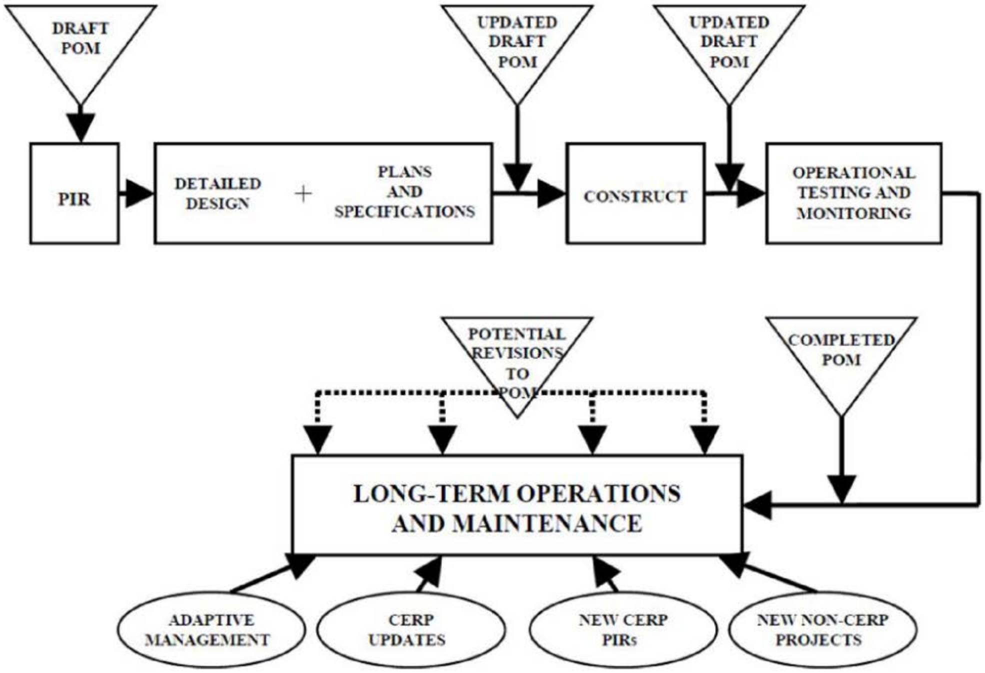

FIGURE 5-14. Evolution of the Project Operating Manual.
NOTE: POM= Project Operating Manual, PIR=project implementation report.
SOURCE: SFWMD, 2018a.

PROGRAM MANAGEMENT

NASEM (2018) called for a systemwide, program-level assessment of the resilience and robustness of the CERP to the changing conditions that will drive the Everglades of the future. The time and resources needed to move a project from planning through to construction and operation are extensive. Therefore, it is essential to consider the risk posed by climate change as early in the process as possible, at both the project and system scales, considering the long time scales of implementation relative to those of ongoing change. Identifying opportunities and risks at the program scale in the face of a changing climate can inform ways in which adaptive management or a change in project sequencing can be applied to better meet CERP goals. Further, a program-level analysis of climate change effects could help determine the need for additional actions beyond those envisaged in the Yellow Book (USACE and SFWMD, 1999).

A review of the 2021 draft Integrated Delivery Schedule (USACE, 2021c) shows the considerable progress that has been made on project planning. Of the 68 projects originally outlined in the Yellow Book, only 18 are still pending for project planning (13 of these are in the Greater Everglades). This pattern suggests that only a few project planning efforts remain, with the largest of these being the Southern Everglades project, although efforts are also under way to update the System Operating Manual, which could provide important opportunities for adaptive management at the system scale in the context of climate change. Understanding the systemwide outcomes of the CERP in the context of its original goals and the programmatic risks associated with climate change would improve the capacity to develop the System Operating Manual and plan these final projects.

The USACE has announced that it is moving forward with a Periodic CERP Update, as required by the Programmatic Regulations (33 CFR Part 385), although no timetable for its completion has been announced. The CERP Update will provide a vehicle for evaluating the ways in which current and planned projects will alter the system compared to original CERP expectations (USACE and SFWMD, 1999).[8] However, it remains unclear whether or how these analyses will consider climate change and examine the robustness of the proposed plan to future climate effects. The Committee reiterates its discussion of NASEM (2016): "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." The CERP Update will provide an important assessment of how and where restoration progress may be made with the current projects. but unless climate change is considered, the utility of those results for communicating the future state of the system will be limited, and an unrealistic view of future success could be presented. Now that such a large portion of the CERP has been planned, this is an opportune time to stress test the current program against selected climate change scenarios. CERP agencies will then have a solid foundation for considering the objectives, implementation schedules, and operating manuals of pending projects. In addition, CERP agencies can work with the Science Coordination Group and others to identify what additional projects may be needed, within or outside of the CERP, to ensure a sustainable ecosystem. If the CERP update does not include an analysis of climate change, additional system-level analyses should be conducted. These analyses are outlined in NASEM (2018).

RECOMMENDATIONS AND CONCLUSIONS

The one near certainty regarding Florida climate change is that temperature and sea level will continue to rise. Increases in sea level will alter the salinity and habitats in coastal and near coastal regions, and increases in air temperature will drive increases in evapotranspiration and decreases in runoff, unless compensatory changes in precipitation occur. However, changes in precipitation and resulting discharge will remain uncertain and highly variable during CERP planning and implementation. Progress is under way to increase the rigor in which sea-level–rise scenarios are considered in CERP project planning (e.g., coastal wetland and estuarine salinity changes), but analytical capabilities are limited by the tools presently available. In contrast, minimal progress is being made in the use of precipitation and temperature scenarios in project planning. No clear signal of the direction of change is not equivalent to an expectation of no change. The committee reviewed examples of how climate change is being incorporated into CERP planning and operations and offers the following conclusions and recommendations.

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[8] According to the Programmatic Regulations, "The periodic CERP updates will be accomplished by the Corps of Engineers and the South Florida Water Management District, in consultation with Tribes, Federal, State, and local agencies, to conduct an evaluation of the Plan using new or updated modeling that includes the latest scientific, technical, and planning information. The periodic CERP updates will provide a basis for determining if management actions are necessary to seek improvements in 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." The periodic CERP update will also "determine the total quantity of water that is expected to be generated by implementation of the Plan, including the quantity needed for the natural system and human environment."

The USACE and SFWMD should proactively develop scenarios of future precipitation and temperature change, including changes in variability, and a strategy to use them to inform future project planning decisions and ensure more reliable project performance. USACE project planning efforts seek to identify justifiable solutions to current problems that will ensure performance for the next 50 years at minimum, and USACE policy requires that restoration planning must meaningfully consider climate change trends and potentially increasing climate variability. Past CERP evaluations of climate change effects have been inconsistent and often limited to a step increase in sea-level rise. Meaningful consideration of climate for restoration decision making would include selection of appropriate performance measures and focused analysis and assessment of risk using multiple plausible scenarios of the future. The impacts of changes in interannual variability could be examined based on the historical record (e.g., by using a Monte Carlo approach), which would provide valuable insight into potential project performance. Exploring the effects of trends in air temperature and precipitation—individually, in combination, and with sea-level rise—during the planning process will help ensure that projects that perform reliably under future change move forward. If appropriate, additional data collection and further analysis can be conducted in preconstruction engineering and design.

Existing modeling tools, although effective for many CERP-related purposes, constrain the ability to improve planning to consider the effects of sea-level rise and other climate change impacts. Current models have limited flexibility to incorporate alternative climate futures, especially those that reflect increased variability and non-stationarity. Such limitations introduce risks into the project planning process because projects may not perform as anticipated. The USACE and SFWMD should develop improved tools and analytical approaches that enable the examination of progressive change over time, rather than time slices of future conditions, to enable identification of environmental conditions when ecological thresholds are crossed. Examination of progressive change is especially important for the assessment of sea-level rise. Improved tools are needed to assess the project-related effects of various rates of sea-level rise and its interaction with hydrologic changes, and to examine sensitivity to the magnitude, frequency, and sequence of episodic events. In addition, hydrologic models should be able to readily accommodate a range of plausible future conditions that differ from historical conditions. Development of a modeling and analysis framework to plan for climate change in a system as complex as the Everglades will be a challenging endeavor but should be initiated as soon as possible to provide appropriate tools for future planning and evaluation efforts.

Inadequate consideration of water availability under future conditions and potential variations in the rate of sea-level rise could cause a project to move forward that is not viable under future climate change. The BBSEER planning process is a step in the right direction, especially in its novel consideration of resilience. However, it is constrained by the capacity of the models that support it. Climate change analysis should not be based on a single performance metric; rather, it should underlie all aspects of project planning, and all performance measures should be evaluated for outcomes under different climate conditions. BBSEER provides lessons to inform future CERP planning efforts. Planning should consider the effects of a range of plausible future conditions (precipitation and air temperature) on freshwater availability, including, for example, extended droughts or wet years, to understand the vulnerability of project outcomes to climate change and to avoid delays and additional costs as the project moves forward. Further, progressive change over time due to sea level rise should be considered, rather than just time slices, so that potential tipping points in habitat change can be identified and project alternatives adjusted as needed.

Each revision to LOSOM and the System Operating Manual should incorporate the latest information on climate change and variability to ensure anticipation of and planning for a wide range of conditions. Regular revisions to the System Operating Manual and other major operational plans, such as LOSOM or the Combined Operational Plan, provide an opportunity to incorporate evolving understanding of climate variability and change into Everglades restoration. Several recent major operational planning efforts, such as LOSOM, have proceeded based on analysis of a prior 52-year climate record, with limited assessment of potential changes in future air temperature or precipitation, providing an incomplete view of their performance under potential future conditions. Efforts to update these operational manuals should identify data collection and information needs to ensure the manuals reflect the current dynamics of the system and its variability.

Systemwide analysis of climate change on CERP performance is essential to assess the robustness of the restoration effort to possible futures and support program-level decision making. The work being conducted for the CERP Update provides a critical opportunity to examine the functionality of the system as a whole, but whether or how climate change analyses will be included in this work remains unclear. If not included as part of the CERP Update, additional analyses should be conducted outside of this process. These system-level climate change analyses will inform priorities for the remaining unplanned CERP projects and adjustments to system operations and will illuminate potential restoration actions that may be needed to enhance ecosystem resilience, either within or outside the CERP.

The lack of USACE guidance on the use of accepted information related to changes in precipitation and air temperature in quantitative analysis as part of project planning leads to future vulnerabilities to climate change and variability as CERP projects come on line. The science of global climate change is mature and rigorous and many other water resources planning projects, in the United States and globally, routinely use climate change scenarios to examine project performance under a range of future conditions. The USACE has progressively advanced guidance on the consideration of sea-level change in its activities, but the success of the CERP also relies on understanding the effects of other climate change impacts. To reduce future vulnerabilities, the committee urges the USACE to develop guidance on the use of climate-affected hydrology data for Civil Works studies discussed in the USACE Climate Action Plan, which was anticipated in 2021. This guidance is critical to support Action 1 of the USACE Climate Action Plan to “[e]nsure that new USACE-built projects are built to last and perform reliably for their intended design lives, despite uncertainty about future climatic conditions.” Providing the USACE Districts with the tools and guidance needed to effectively plan for future conditions is an urgent priority. The lack of guidance on the use of quantitative approaches to consider climate change and variability in hydrologic analyses fundamentally limits the potential success of CERP investments in ecosystem restoration.

6

Science Plan to Support Restoration of the South Florida Ecosystem

The Everglades restoration effort has always recognized not only the importance of a solid scientific underpinning for restoration planning, but also a need for continual scientific and engineering information to support ongoing restoration decision making, most of which must proceed despite uncertainty about aspects of system function and future conditions. Evolving scientific and engineering knowledge is incorporated into the Comprehensive Everglades Restoration Plan (CERP) as part of the adaptive management process, defined as a structured management approach for addressing uncertainties by testing hypotheses, linking science to decision making, and adjusting implementation as necessary to improve the probability of restoration success (RECOVER, 2011). CERP managers face an array of restoration decisions under the umbrella of adaptive management, including those related to assessments of restoration performance, near-term operational adjustments, project prioritization and coordination, and investments in additional science to fill knowledge gaps to reduce uncertainties. The committee's last report (NASEM, 2021) identified an increasing need for science at this point in the program's development to support decision making as the restoration program pivots from a focus on planning and advancing individual projects toward operations and adaptive management of the partially restored system, in parallel with ongoing planning for the remaining CERP projects.

The Everglades restoration science enterprise, including work by local, state, and federal agencies, academia, Tribal nations, and nongovernmental organizations, has made tremendous advances over the past two decades. Examples include advancing the understanding of the role of flow in creating and maintaining the Everglades landscape (McVoy et al., 2011), achieving consistently impressive nutrient reduction in Stormwater Treatment Area (STA)-3/4 (see Chapter 4), determining the mechanisms of Florida Bay algal blooms (Koch et al., 2007; Zieman et al., 1999), and advancing innovative modeling tools that support restoration planning. These and other efforts provided a firm foundation for the extensive planning that was required for the CERP and the initial operations of specific system components. As projects come on line and the partially restored system begins to signal its response, new questions and needs will arise, such as assessment of vulnerabilities and risks to the newly restored system posed by climate change and continued development and associated water resource needs.

NASEM (2021) recommended that the best science should be actively integrated and synthesized so that restoration benefits are maximized and opportunities for learning from CERP and non-CERP projects are not lost. Characterizing the capacity of the science enterprise to support joint learning and fact-finding among and between scientists and managers, and where that capacity may need to be expanded, is essential to support future restoration. Thus, the committee builds upon the NASEM (2021) recommendations to strengthen Everglades science capacity in this chapter. To this end, the committee identifies the need for a focused science plan, assesses processes to continually update key science questions relevant to management, and discusses how science resources across agencies can be effectively coordinated and leveraged to produce science that informs restoration decisions.

THE NEED FOR A SCIENCE PLAN

The accelerating pace of restoration decision making, as more projects come online and the South Florida ecosystem responds to changes in water management, increases demands for science support. These demands include, but are not limited to, the synthesis and analysis of monitoring data, identification of critical knowledge gaps and how to address them, and refinement of models. In addition, continued learning about the vulnerabilities associated with changes in climate is needed to periodically refine both project and systems operations to respond to changing conditions and inform new project planning and design. For example, project-scale planning that considers the potential effects of climate change requires greater understanding of the drivers of peat accretion and loss under different flow and water quality conditions so that rates can be refined in predictive modeling tools (see Chapter 5). Chapter 5 further highlights the need for improved modeling, identification of climate change scenarios to guide future planning, and, at the programmatic scale, science to inform the advancement, prioritization, and coordination of major projects (e.g., development of the Integrated Delivery Schedule) and the refinement of goals. The science needs will be numerous and beyond the capacity of any single organization to meet; therefore, a roadmap is needed to ensure that the critical uncertainties that could hamper system-wide restoration progress are identified and shared so that resources from a range of parties can be directed to meet them. Such a roadmap is used by many large restoration efforts and is often termed a science plan.

A science plan is a set of specific activities that can help to guide the investment of resources across multiple agencies and the application of the skills of agency scientists, academia, or contractors to fill knowledge gaps that are critical for restoration decision making. A science plan is not simply a list of science needs that have been collected across multiple individual projects or efforts. Rather, it identifies science actions that are recognized as multi-group priorities and are feasible to implement and perform—gathering and coordinating scientists, managers, and policymakers around a common set of priorities no single organization has the capacity to address on its own. The committee envisions a consolidated list of high-priority science actions, including model development, targeted data collection, data analysis, and research and synthesis, that along with routine monitoring will support the restoration of the South Florida ecosystem and the array of agencies and other entities working toward that goal.

The Everglades Restoration Science Plan envisaged here could be a parallel document to the Integrated Delivery Schedule that anticipates science needs, enables alignment of a wide range of resources in an efficient manner, and ensures that information is available when it is needed to support the program (see Box 6-1). The science activities included in the plan will vary in terms of the complexity of the work, the length of time to produce results, and the types of expertise, skills, and facilities that may be required. Therefore, the activities are specified in a way that recognizes the approximate level of resources required so that a path toward completion of the work can be charted.

Although no current, overarching coordinated science plan exists that meets these criteria, a variety of organizations within the Everglades restoration science enterprise have produced science or work plans, of more limited scope, that could contribute or serve as foundational pieces to such a science plan. The RECOVER 5-Year Plans (RECOVER, 2016, 2022) generally determine the most crucial tasks that must be accomplished to assist CERP implementation and typically include tasks that address systemwide science needs. However, these science needs relate only to CERP-related challenges, and so are not placed into the wider context of both CERP and non-CERP activities. In addition, the RECOVER 5-Year Plans specify tasks to be performed within the resource confines of RECOVER itself and does not engage the complete network of agencies and science providers, thus limiting its ability to serve as guidance for broad investment. Although the RECOVER 5-Year Plan cannot serve as an Everglades Restoration Science Plan for these reasons, it can contribute significantly to broader science planning. The recently completed 5-Year Plan indicates that RECOVER intends to address science synthesis needs by organizing a series of topic workshops, each focused on a key management issue, to summarize the relevant current research and state of knowledge, discuss needed tools, and make recommendations for future research, modeling, and monitoring. The workshops are topic focused and may not identify more integrative needs, but the resulting recommendations should be relevant to CERP and can be integrated into the Everglades Restoration Science Plan.

In addition, coordinated science plans already exist for some specific components of the restoration, although they do not address systemwide science needs. For example, the Aquifer Storage and Recovery (ASR) Science Plan (SFWMD and USACE, 2021; see Chapter 3, Box 3-1) focuses on science needs specifically associated with employment of ASR technology in the restoration. The ASR Science Plan describes critical uncertainties associated with ASR

BOX 6-1
Example of a Restoration-related Science Plan

The Sacramento River Science Partnership (SRSP) is a voluntary science enterprise established to inform joint learning on species recovery and water management on the mainstem of the Sacramento River. The SRSP Science Plan (Reed, 2020) is structured around the need to "predict, detect and understand" change in the system. Activities include targeted data collection, analysis of existing data, modeling, focused research studies, synthesis, and integrated studies that combine field data collections, modeling, and experimentation (either in the lab or field) to increase understanding of critical cause-effect relationships. The SRSP Science Plan, like the anticipated science plan discussed in this chapter, supplements ongoing monitoring efforts. The plan was developed soon after the SRSP was established, and the members of the partnership, through a Science Subcommittee, track progress on the 31 science activities identified in the plan. Ad hoc groups have been convened for some of the more complex activities that require collaboration and/or detailed planning prior to work commencing. SRSP members, who are involved in the restoration of the system, provide financial support and/or expertise to the planning and execution of the science and regularly discuss emerging findings.

(including those identified in NRC [2015]) and articulates 26 studies to be conducted to address them. The Restoration Strategies Science Plan does the same for improved performance of STAs (see Box 4-2), with 22 studies designed to address key uncertainties and improve management decisions and tools in the effort to meet STA discharge water quality requirements (see Chapter 4). Such plans can serve as smaller-scale models for the overarching, coordinated Everglades Restoration Science Plan.

Agency-specific science plans have also been developed. For example, the Department of the Interior (DOI) released its *Science Plan in Support of Ecosystem Restoration, Preservation, and Protection in South Florida* in 2005 to represent science needs from DOI's interests, which extend beyond the CERP (DOI, 2005).

A potentially promising template for development of a multiagency Everglades Restoration Science Plan already exists and is discussed in detail later in this chapter. The Science Coordination Group (SCG) previously developed a Plan for Coordinating Science (SCG, 2008), which was more comprehensive in scope than the smaller scale efforts mentioned above. Its preparation was in accordance with the SCG's duties, as outlined in its charter (SCG, 2003), to develop a "draft science coordination plan that tracks and coordinates programmatic-level science and other research, identifies programmatic level priority science needs and gaps, and facilitates management decisions." Because restoration is now well under way, a revision is overdue and necessary as the science enterprise shifts to meet its new challenges. Such a plan could provide a central means to prioritize science, monitoring, modeling, and synthesis investments at the federal, state, or local levels.

In the following sections the committee discusses how a science plan can be developed and implemented based on the identification of key science gaps and coordination across various organizations.

ENGAGING THE SOUTH FLORIDA RESTORATION SCIENCE ENTERPRISE

Many different organizations contribute to the science that underpins the restoration of the South Florida ecosystem. Here the committee considers the South Florida restoration science enterprise to include local, state, and federal agencies, Tribal nations, academia, nonprofits, and private-sector organizations that have scientific capacity and the ability to contribute financial resources, skills and expertise, facilities, and/or other resources to undertake scientific activities.

Leveraging the work of many in a coordinated fashion is necessary for large restoration efforts so that implementation of learning can occur as quickly as possible and maximum progress can be made toward restoration. Several other efforts (e.g., Chesapeake Bay, California Bay-Delta, Baltic Marine Environment Protection Commission—Helsinki Commission [HELCOM]) have organized the science enterprise around the following three spheres of science activity, which each contribute to the development and implementation of science plans (Figure 6-1):

- **Identification of key science gaps:** the assessment of the state of knowledge related to key management questions and identification of associated knowledge gaps, with continual refinement

- **Science coordination:** the identification of entities that can contribute to the development of science and coordination of their work to advance and exchange knowledge relevant to restoration objectives
- **Advancing essential science actions:** the identification of specific science actions that serve to guide multi-agency work plans and funding decisions. This activity may also involve the tracking of ongoing science progress and adjusting to emerging needs.

These activities and their linkages are presented in Figure 6-1. In the following sections, each of the three activities is discussed separately in the context of the CERP.

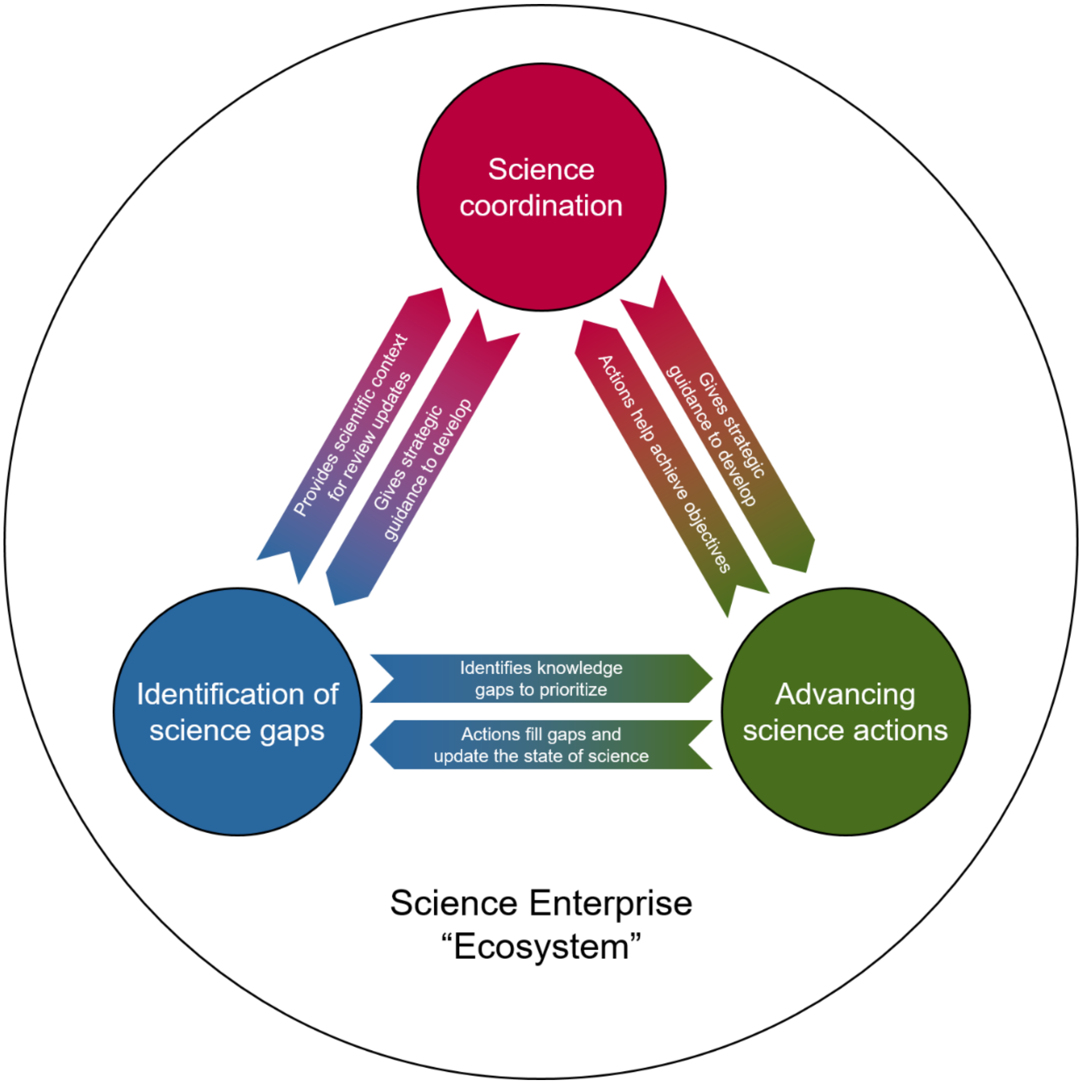

FIGURE 6-1 Three major spheres of science activity within a restoration science enterprise and their linkages necessary to support development of a science plan.
SOURCE: Adapted from DSC, 2019.

Identification of Key Science Gaps

The identification of knowledge gaps related to key management questions is a necessary developmental step of the Everglades Restoration Science Plan and should be driven by the issues that represent significant impediments to restoration progress. That is, what new knowledge, tools, or synthesis of information is needed to answer a key management question (or group of questions) and accelerate progress on a systemwide scale to the maximum extent possible? RECOVER produces a System Status Report (SSR) every 5 years (RECOVER, 2014, 2019b), which informs the periodic Reports to Congress (e.g., USACE and DOI, 2020) and provides a useful compendium of data about different aspects of the system. However, as noted in NASEM (2021), the SSR provides only a snapshot of current conditions, failing to provide a synoptic view of how or why the system is changing, why degradation is particularly problematic in specific locations, and what key management questions or knowledge gaps are proving to be obstacles.

During the past 14 years, efforts have been made to identify and curate key management questions and associated critical knowledge gaps, but they have not been directly linked to impediments to restoration progress and decision making at both the project and program levels. In 2008 the South Florida Ecosystem Restoration Task Force (Task Force), assisted by the SCG, identified strategic-level science priorities and systemwide assessments for restoration success, but the resulting document has not been updated since 2010. The 2015 RECOVER Program-Level Adaptive Management Plan (RECOVER, 2015) identified and prioritized uncertainties and then proposed strategies to resolve them in each region (Northern Estuaries, Lake Okeechobee, Greater Everglades, and Southern Coastal Systems), but direct links to program implementation were unspecified. Currently, knowledge gaps can be identified through several interactions and processes, including the following:

- Prior to and during development of the project implementation report (PIR) and the project-level adaptive management plan, key uncertainties may be identified which, if addressed, may influence selection of the recommended project plan or the final design of the project.
- Public workshops or requested reviews of project design may identify questions which need to be answered to gain a greater degree of stakeholder support.
- Advisory groups, such as RECOVER (e.g., RECOVER, 2015) and the Task Force, or CERP agencies may identify concerns that require additional knowledge.
- The biannual Greater Everglades Ecosystem Restoration (GEER) conference and annual science workshops and meetings present new science questions emerging from research.
- Bi-annual National Academies of Sciences, Engineering, and Medicine (NASEM) reviews identify research needs associated with issues that may impact restoration progress, such as climate change (NASEM, 2018; NRC, 2014) and water quality threats to coastal systems (NASEM, 2020) or invasive species (NRC, 2014).

All the above processes result in the identification of knowledge gaps. However, without a synthetic effort to determine which gaps are critical to the restoration effort and then characterize, compile, organize, and sequence them, the restoration is at significant risk of not addressing key impediments to restoration in a timely fashion.

This identification of critical knowledge gaps requires collaboration among scientists and decision makers engaged in ongoing restoration work to identify the critical operational risks that could be substantially reduced through improved science investments. In addition, scientists can work together to identify emerging issues with management implications that warrant further study to understand the risk, or benefit, they pose to restoration outcomes. This conversation between decision makers and scientists is critical for the efficient utilization of intellectual resources. Thus, science needs are not only assembled but also curated into a succinct representation of critical uncertainties associated with key management questions—defined as those uncertainties that, if resolved, could change the management course of action.

Once knowledge gaps that are critical to decision making are identified, additional information can help to prioritize and sequence actions across a huge array of potential needs, such as:

- Scale of risk/vulnerability being addressed
- Number of restoration projects impacted
- Timing of implementation (i.e., when is the science needed) and expected time for completion
- Level of complexity and challenge
- Resources required (expertise, facilities, full-time equivalents)
- Whether the need is already being addressed as part of another effort

This information can also help guide science providers in matching their capacity and capability to the specific need. Because the sequencing of new pieces of knowledge has implications for the progress of systemwide restoration, identification of critical linkages and cross-project benefits should accompany the science need.

Several processes have been used by others to identify science needs (Box 6-2), ranging from a general repository and database of science needs derived organically from the efforts of teams responsible for specific goals (Chesapeake Bay Program) to large, facilitated stakeholder efforts that result in a focused science action agenda (Delta Science Strategy). Both of these examples present tradeoffs. Lists of needs that are generated independently by stakeholders across all program areas offer a comprehensive picture with many opportunities for engagement by a diverse group of science providers (e.g., universities, agencies, consultants, nongovernmental organizations) but may suffer from inaction because of a lack of focus or prioritization. If a focused science agenda is pursued, then the process used to develop it must be carefully constructed and opportunities for input may be limited to a smaller group of stakeholders.

Science Coordination

The science enterprise to support the activities in Figure 6-1 necessarily consists of a large and diverse set of organizations and individuals. Science support for the CERP specifically, and South Florida restoration generally, includes a complex, diverse set of agencies, organizations, and individuals including academic institutions; federal, state, and local agencies; Tribal Nations; nongovernmental organizations; and external consultants. These players work together across both established structures and informal networks of experts. Organizational

BOX 6-2
Example of Efforts to Assess the State of the Science and Knowledge Gaps

Delta Stewardship Council

Three guiding documents form the Delta Science Strategy: the Delta Science Plan (DSC, 2019), the State of Bay-Delta Science,[a] and the Science Action Agenda (DSC, 2022a). The State of Bay-Delta Science communicates the state of knowledge to address key management needs, highlights progress, and identifies remaining knowledge gaps. The Science Action Agenda establishes focused science actions to fill these knowledge gaps and serves as a common agenda from which agencies and programs can develop more detailed, shorter-term work plans. The Delta Science Plan establishes mechanisms for the development of science in support of the Delta Plan and a shared framework for science coordination and communication.

Chesapeake Bay Program

The Chesapeake Bay Program (CBP) maintains a Strategic Science and Research Framework (SSRF)[b] to help focus existing science resources, leverage the research enterprise, and more effectively provide science to advance decision making—providing a more consistent manner to track and assess the abundance and breadth of science needs across the partnership. The SSRF is developed in coordination with members of the science enterprise who serve in various roles in the restoration program, including those tasked with implementing management actions, coordinating internal science activities, and serving in an independent advisory capacity. It was specifically designed to consider both short-term operational and long-term fundamental science needs of managers, integrate recommendations made by external advisory bodies, and be repeatable and consistent by connecting to the formalized adaptive management process. Through the SSRF, the CBP can better look at science needs across the program, assess whether those needs are being met, and recommend approaches to address them.

[a] See https://stateofbaydeltascience.deltacouncil.ca.gov/.
[b] See https://star.chesapeakebay.net/.

structure may be extensive but loose and informal, as in the Bay Delta (see Box 6-3), or more formalized as in the Chesapeake Bay Program where organizational roles and coordination mechanisms are hierarchical and clearly documented (see Box 6-4).

The Everglades science organization is likely best described as a network of connected individuals and groups, with substantial overlapping participation of individual experts, which enhances coordination while potentially stretching those individuals thin with many coordination responsibilities. The following subsection describes the major groups (RECOVER, Science Coordination Group, Integrated Modelling Center, U.S. Geological Survey Priority Ecosystems Program, National Park Service South Florida Natural Resources Center, and Universities and Nongovernmental Organizations in general) and their responsibilities, along with an assessment of how the current organization may be improved to support the work to identify key gaps and advance essential science action.

BOX 6-3
Example Organizational Scheme of the Science Enterprise: California Bay-Delta

The Delta science enterprise includes 12 main collaborative Delta science venues that contribute to science governance via the wide range of organizations participating in those venues. The formal, ongoing, and multi-party venues represented in the network diagram (Figure 6-2) do not capture the full range of science collaboration in the Delta. The network diagram visualizes the connections between the 12 main collaborative Delta science venues (ringed circles) and all of the organizations (colored circles) that participate in more than one such venue (the "core" network). Taken together, the venues coordinate across a diverse range of actors, from the private to government to non-profit sectors, working on multiple science activities and study topics in the Delta.

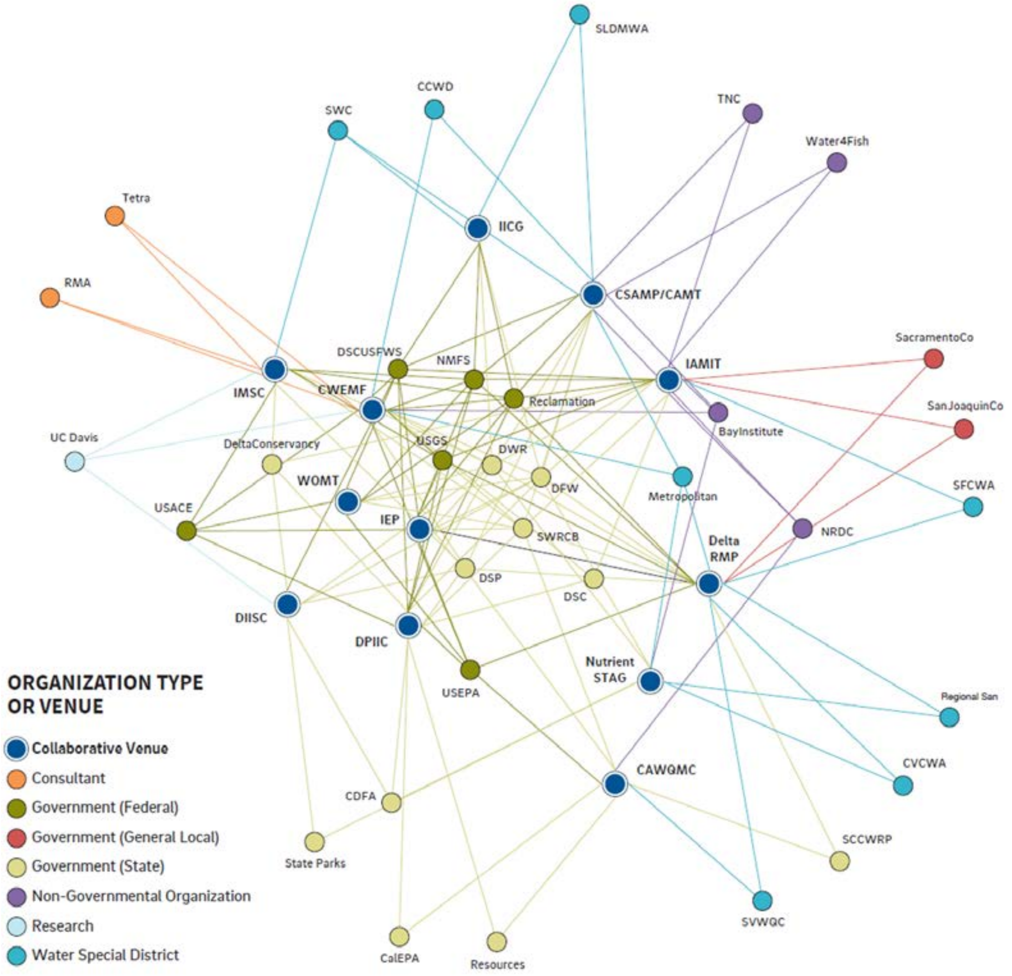

FIGURE 6-2 Network diagram showing the participation of numerous organizations within 12 main collaborative Delta science venues in support of restoration efforts in the California Bay-Delta as described in the Delta Science Plan. Colored lines connect each organization to venues they participate in. The more ties an organization or venue has, the more centrally located it is in the diagram.
NOTES: BayInstitute = The Bay Institute; CalEPA = California Environmental Protection Agency; CAWQMC = California Water Quality Monitoring Council; CCWD = Contra Costa Water District; CDFA = California Department of Food and Agriculture; CSAMP/CAMT = Collaborative

Science and Adaptive Management Program/Collaborative Adaptive Management Team; CVCWA = Central Valley Clean Water Association; CWEMF = California Water and Environmental Modeling Forum; Delta RMP = Delta Regional Monitoring Program; DeltaConservancy = Sacramento-San Joaquin Delta Conservancy; DFW = Department of Fish and Wildlife; DIISC = Delta Inter-agency Invasive Species Coordination Team; DPIIC = Delta Plan Interagency Implementation Committee; DSC = Delta Stewardship Council; DSP = Delta Science Program; DWR = Department of Water Resources; IAMIT = Interagency Adaptive Management Integration Team; IEP = Interagency Ecological Program; IICG = Interagency Implementation and Coordination Group; IMSC = Integrated Modeling Steering Committee; Metropolitan = Metropolitan Water District of California; NMFS = National Marine Fisheries Service; NRDC = Natural Resource Defense Council; Nutrient STAG = Nutrient Stakeholder Technical Advisory Group; Reclamation = U.S. Bureau of Reclamation; Regional San = Sacramento Regional County Sanitation District; Resources = California Natural Resources Agency; RMA = RMA Companies; SacramentoCo = County of Sacramento; SanJoaquinCo = County of San Joaquin; SCCWRP = Southern California Coastal Water Research Project; SFCWA = State and Federal Contractors Water Agency; SLDMWA = San Luis & Delta-Mendota Water Authority; SVWQC = Sacramento Valley Water Quality Coalition; SWC = State Water Contractors; SWRCP = State Water Resources Control Board; Tetra = Tetra Tech; TNC = The Nature Conservancy; UC Davis = University of California, Davis; USACE = U.S. Army Corps of Engineers; USEPA = U.S. Environmental Protection Agency; USFWS = U.S. Fish and Wildlife Service; USGS = U.S. Geological Survey; Water4Fish = Water 4 Fish; WOMT = Water Operations Management Team.
SOURCE: DSC, 2019.

Key Organizations in Everglades Science Enterprise

RECOVER. RECOVER is a multiagency[1] team, whose role is to “organize and apply scientific and technical information in ways that are most effective in supporting the objectives of CERP” (USACE and DOI. 2020). RECOVER does this by “applying a system-wide perspective to the planning and implementation of the CERP” (RECOVER, 2021). The work of RECOVER is envisioned to fall within three main areas: evaluation, assessment, and planning. The scale and type of resources required for RECOVER’s work range from those required to address recurring tasks of limited scope to those requiring systemwide integration and synthesis over longer time periods. The recurring tasks support CERP project planning and include regional evaluation of project alternatives in a systemwide context and reviews of performance measure consistency, monitoring plan consistency, and draft operating manuals in the context of CERP systemwide goals. Systemwide tasks involve several CERP reporting requirements, including development of the System Status Report (e.g., RECOVER, 2019) every 5 years, which reviews ecological status and trends of the Everglades ecosystem by region and provides updates on progress toward Interim Goals and Interim Targets. RECOVER also conducts the

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[1] The RECOVER Leadership Group consists of the RECOVER program managers—one each from USACE and SFWMD — plus one member from each of the 10 following agencies/groups: Environmental Protection Agency, National Oceanic and Atmospheric Administration, U.S. Fish and Wildlife Service, U.S. Geological Survey, National Park Service, Miccosukee Tribe of Indians of Florida, Seminole Tribe of Florida, Florida Department of Agriculture and Consumer Services, Florida Department of Environmental Protection, and Florida Fish and Wildlife Conservation Commission. A five-member executive committee manages day-to-day responsibilities.

analysis of Interim Goals and Interim Targets (RECOVER, 2005, 2020) and supports other reporting requirements such as the 5-year Report to Congress (USACE and DOI, 2020). RECOVER is currently working with the Science Coordination Group (described below) to assess and identify opportunities to integrate information to address current reporting requirements to better serve the needs of the effort.[2]

BOX 6-4
Example Organizational Scheme of the Science Enterprise: Chesapeake Bay Program

Within the Chesapeake Bay Program's science enterprise, there is a clear hierarchical structure for managing and provisioning science. An independent Science and Technical Advisory Committee (STAC) provides advice, in the form of independent review and recommendations to the restoration governance to enhance science (monitoring, modeling, and research) for decision making. In contrast, the Science, Technical Assistance and Reporting (STAR) group is internal to the restoration program and coordinates with science providers and project teams (Goal Implementation Teams) to address their needs and report on the progress of their management actions in a manner that supports decision making. STAR is primarily a day-to-day science coordinator, and the science needs that it addresses are usually at the 1- to 3-year timescale. Although STAC certainly responds to science needs in this time frame, it also looks much farther down the road and identifies issues that could impact progress and restoration (e.g., climate change). Both groups work collaboratively.

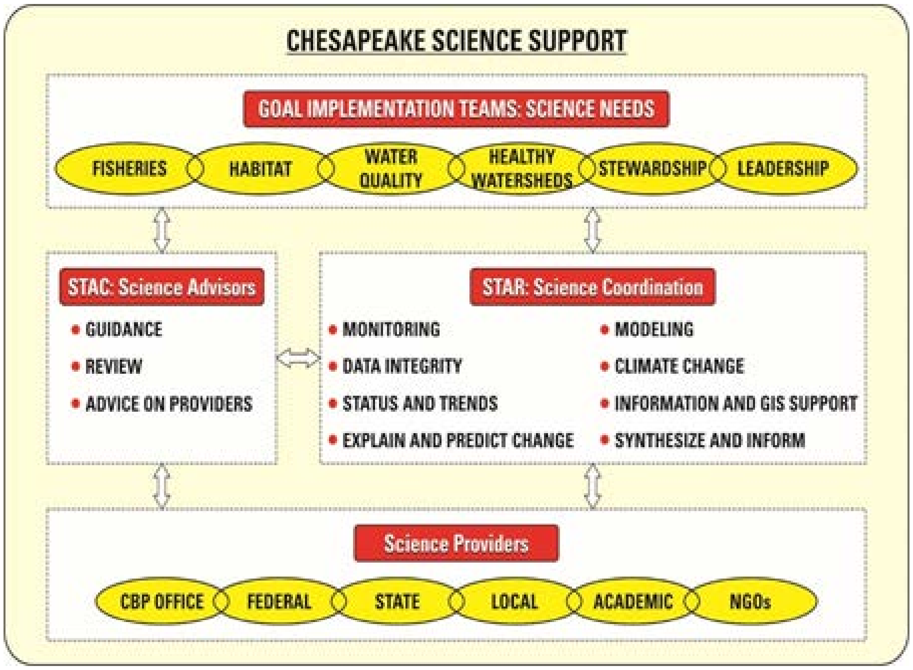

FIGURE 6-3 Organization of the Chesapeake Bay Program science enterprise.
SOURCE: Chesapeake Bay Program, 2015.

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[2] This paragraph was edited following release of the prepublication report to clarify reporting requirements.

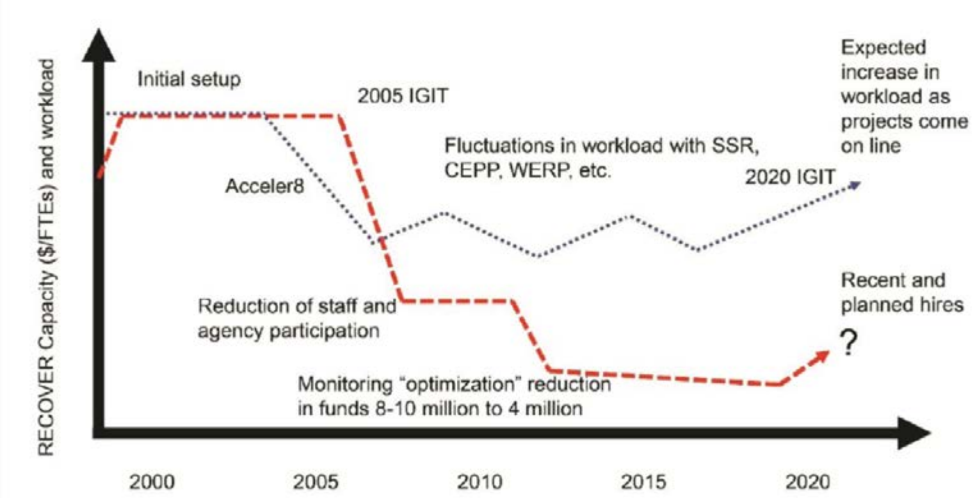

FIGURE 6-4 Conceptual RECOVER capacity (red dashed line) versus workload (blue dotted line) over time.
SOURCE: Brandt et al., 2020.

In recent years, staffing and budget constraints have limited the number of separate initiatives that RECOVER has been able to complete. Although the number of projects in the planning and implementation stages has increased in the past decade, which has increased RECOVER's basic project support responsibilities, the capacity (staffing and funding) of RECOVER has been reduced (Figure 6-4; NASEM, 2021). Required reporting and consultations with ongoing project planning efforts have taken priority over adaptive-management-related initiatives, such as updates to the monitoring and assessment plan (MAP). The major tasks that RECOVER intends to perform during the next 5 years include updating performance measures in fiscal year (FY) 2022 and supporting the CERP Update (anticipated in FY 2024), along with required reporting (Ralph, 2022).

RECOVER leaders work closely with CERP agency decision makers and therefore are well positioned to identify critical knowledge impediments and accompanying science needs. However, RECOVER's focus is limited to the CERP. Thus, its science needs must be integrated with those identified by others to arrive at a far-reaching Everglades Restoration Science Plan.[3]

Science Coordination Group. The SCG operates under the South Florida Ecosystem Restoration Task Force, an intergovernmental body charged with coordinating restoration activities in South Florida, beyond the boundaries of the CERP. Current SCG membership is diverse and includes an array of city, state and federal agencies, Tribal nations, and a university scientist.[4] The SCG's specific duties, as outlined in its charter, are "to support the Task Force in its efforts to coordinate the scientific aspects of policies, strategies, plans, programs, projects, activities, and priorities, … and to coordinate scientific and other research associated with the restoration of the South Florida ecosystem…." Specifically, the SCG is tasked to develop a

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[3] This section of the report was modified after release of the pre-publication version of the report to clarify RECOVER's focus and its intended plans for the next 5 years.

[4] See https://www.evergladesrestoration.gov/science-coordination-group/membership-and-operating-procedures.

"draft science coordination plan that tracks and coordinates programmatic-level science and other research, identifies programmatic level priority science needs and gaps, and facilitates management decisions," for approval by the Task Force, as well as to assist with required reporting activities and other support as requested (SCG, 2003). As previously mentioned, the last Plan for Coordinating Science Update was released in 2008 (SCG, 2008).

The SCG has no separate resources (beyond those of the Task Force) to support science or modeling projects and no dedicated staffing. All SCG members have multiple responsibilities within their own organizations, of which SCG participation is only a small part. In recent years, few if any separate meetings of the SCG have been held. Instead, combined meetings have been held with the Working Group to receive briefings on CERP progress, and little meeting time has been devoted to coordination or science needs. SCG has features that make it particularly effective in certain situations, namely its mandate to consider both CERP and non-CERP restoration efforts and its capacity to address issues quickly and to interact with stakeholders outside of the restrictions of the Federal Advisory Committee Act. In addition, its envisioned role to identify programmatic priority science needs and gaps fits well with the development the Everglades Restoration Science Plan envisaged here.

Interagency Modeling Center. The Interagency Modeling Center (IMC) generates analyses used in planning and designing projects and evaluating alternative water management plans (e.g., Lake Okeechobee System Operating Manual [LOSOM]). Within the Everglades restoration science enterprise, the IMC houses the greatest share of modeling capacity, including primary capacity to run the systemwide and regional models (e.g., Regional Simulation Model [RSM]) used to project hydrologic responses to projects and changes in water management. The U.S. Army Corps of Engineers (USACE) and the South Florida Water Management District (SFWMD) have direct input in setting priorities for the IMC through its board, and the Department of Interior provides technical support to the IMC modeling teams.

As the CERP pivots to implementation and assessment, there is a need for modeling that compares predicted system response to observed response. The effects of a particular project are difficult to separate from other factors affecting the system, such as variation in precipitation (NASEM, 2021). Model runs from the IMC that incorporate these other factors to generate predicted system behavior are necessary to measure the impact of changes in water management, including those of projects as they come on line (see Chapter 3). Although the IMC does not have the authority to prioritize a new emphasis on the use of models to analyze ecosystem response to restoration projects, it can play a critical role in both identifying science needs and providing tools to meet the needs identified in the Everglades Restoration Science Plan.

U.S. Geological Survey (USGS) Priority Ecosystems Program. The USGS Priority Ecosystems Science Program is intended to provide "science to support management and restoration of America's Everglades."[5] Its $6 million annual budget enables it to fund roughly 35 projects per year. Recent initiatives have addressed invasive species detection and control, ecosystem modeling, and climate change effects. Program priorities are informed by direct requests from and interaction with partner agencies and stakeholders; topics identified by the Task Force, Working Group, Science Coordination Group, and RECOVER; the DOI Everglades

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[5] See https://www.usgs.gov/programs/environments-program/science/everglades?qt-science_center_objects=0#overview.

science plan; USGS mission area and science priorities; and the expertise, interest, and availability of USGS scientists (N. Aumen, USGS, personal communication, 2022).

South Florida Natural Resources Center. The South Florida Natural Resources Center (SFNRC) supports applied science, monitoring, restoration assessments, and management for the South Florida units of the National Park Service (NPS). It also supports a science staff of NPS hydrologists, ecologists, biologists, and modelers and also funds competitive research proposals from academic and nongovernmental organizations through its Critical Ecosystems Studies Initiative, which has a budget of approximately $4 million per year.

Universities and Nongovernmental Organizations (NGOs). Academia and NGOs also represent a vibrant component of the Everglades science enterprise. The biennial GEER science conference attracts about 400-500 scientists, including many from academia and NGOs, and represents the rich diversity of science under way that complements government initiatives. Numerous NGOs that work in the Everglades, including the Everglades Foundation, Audubon, and the Sanibel-Captiva Conservation Foundation, contribute to the science enterprise through original research, modeling and/or analysis. A major ongoing initiative is the Florida Coastal Everglades (FCE) Long-Term Ecological Research (LTER) program, supported by the National Science Foundation and housed at Florida International University, which is exploring "how climate change and disturbances interact with shifting management of freshwater resources to determine the dynamics and fate of coastal ecosystem properties, functions and services to people."[6] The LTER program is funded outside of any specific restoration effort, but works very closely with federal, state, and local agencies and NGOs to accomplish shared goals. The SFWMD and Everglades National Park are represented on the external executive committee and are involved in all aspects of the LTER program, and, conversely, the LTER program leverages substantial additional support from these agencies. LTER program data are used by the agencies in reporting, and many LTER scientists serve on advisory committees for the SFWMD and Everglades National Park. Childers et al. (2019) provide examples of co-produced science through academic-agency collaborations.

Current Organization and Coordination

CERP decision makers believe that the current organizational structure for science support of Everglades restoration, albeit informal, works well. Several individuals who have extensive experience in the Everglades and serve in multiple organizations within the science enterprise appear to be central to network functions, act as trusted advisors for decision makers, and ensure coordination across key groups. This structure poses risks because it is highly dependent on those individuals and therefore vulnerable to shifts in personnel (e.g., retirements, changing job responsibilities of key individuals, or new restoration leaders with no prior relationship with the science community). The lack of a formal Everglades organizational structure for science may also serve to advance the interests of individuals who have the trust of leadership rather than the collective interest. Other large ecosystem restoration programs have invested substantial energy in the structures and mechanisms for organization and coordination,

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[6] See https://fcelter.fiu.edu/.

which would reduce the risk of major disruptions from staff turnover and ensure that the needs of all stakeholders are represented.

As implementation proceeds, learning will accelerate and more structured processes for science coordination will be needed to support restoration efforts. The hierarchical role-based structure utilized by the Chesapeake Bay Program employs a clear definition of roles (coordinating, advising, providing), although some roles overlap (Box 6-4). In comparison, the organizational guidance within the Delta Stewardship Council's 2019 Delta Science Plan (DSC, 2019) focuses on creating effective interactions across a network of participating entities, by laying out protocols and methods to coordinate, advance, and integrate Delta science, manage and reduce scientific conflict, and support effective adaptive management (Box 6-4). Both cases highlight the utility of defining an organization's place in the structure, the various roles it serves based on its position, and its interactions with participating entities.

The need to refine science organization within a large restoration program is common and ongoing, primarily because of the natural evolution of a restoration effort. During program development, the major science tasks are conceptual and long term in nature (e.g., conceptual models, hypothesis clusters). As projects are planned, the program must assess the tradeoffs and operational concerns, which are geographically specific and short term in nature. As individual projects come on line, the program must consider management of the partially restored system, requiring systems thinking and synthesis. Sea-level rise (see Chapter 5) and/or the reduced availability of water storage (see NASEM, 2016) may also necessitate reconsideration of targets and goals. These tasks need to utilize multiple levels of learning (Box 6-5). Thus, over time, the organization of the science enterprise will require revision to be responsive and effective, and individual organizations may need to assess whether they are aligned with the levels of learning for which they are responsible and whether they possess the necessary bandwidth. For example, RECOVER is tasked with learning at two levels (both single and double loop; see Box 6-5), and the appropriate resources to learn at those levels do not appear to be in place.

The preparation of an Everglades Restoration Science Plan should be under the auspices of a group that can focus on long-term goals across CERP and non-CERP efforts, evaluate prior success and failure in science support of restoration decision making, and, if needed, identify reforms to the existing science enterprise (i.e., triple loop learning; see Box 6-5). An organization with the necessary remit across South Florida restoration programs and science entities is the Science Coordination Group. As mentioned previously, the SCG developed a Plan for Coordinating Science (SCG, 2008) to comply with a provision in its charter (SCG, 2003) to develop a "draft science coordination plan that tracks and coordinates programmatic-level science and other research, identifies programmatic level priority science needs and gaps, and facilitates management decisions." A major revision to this plan is warranted as the science enterprise shifts to meet its new challenges—presenting an opportunity to prioritize science, monitoring, modeling, and synthesis investments at the federal, state, and local levels. SCG could initiate the revision several ways, including by standing up an ad hoc committee to develop a draft plan or by assigning a contractor to take the lead. In either case, the individuals drafting the plan must be aware of documented needs and have the ability to, at least conceptually, link skills, facilities, and resources with those needs.

Also of note, both the Bay-Delta and the Chesapeake Bay programs have dedicated, centralized, and trusted science leadership (Lead Scientist and Director, respectively), which is important to ensuring that the diverse science enterprise is effective and meets the needs of decision makers. The long-anticipated pivot of the CERP from planning to operations and adaptive management, and the development of the science plan envisaged here, require dedicated science leadership with influence across all aspects of the restoration effort. A Lead Scientist could play a key coordinating role in science plan development, communicate progress, interact with decision makers, promote best science practices, and stay abreast of emerging issues or innovations that could add value to the science being conducted under the Everglades Restoration Science Plan (see also NASEM, 2018).

BOX 6-5
Levels of Learning and General Definitions

Adaptive management requires an environment that promotes intentional learning, and the type of learning may differ when applied at different levels of the restoration governance structure (Pahl-Wostl, 2009). One available framework that can help to articulate these differences is termed single-, double-, and triple-loop learning, originally introduced in the organizational change literature in the 1970s (Aregyris and Schon, 1974; Bateson, 1973) and well documented in a large range of endeavors including environmental management and restoration.

1. **Single-loop learning** is directed at the question of whether we are doing things in a way that improves performance without changing guiding assumptions and calling into question established routines. Learning is directed at incremental refinement of actions to improve the ability to achieve goals and reduce uncertainties to improve implementation. Thus, single- loop learning is mostly about resolving day-to-day operational problems. CERP project-level adaptive management (RECOVER, 2011) is an example of single-loop learning.
2. **Double-loop learning** forces us to ask whether we are doing the right things, we have the right objectives (articulated as goals and targets), and the right options on the table. Learning involves a deeper reflection on emerging patterns or trends over various spatial and temporal scales. The Adaptive Management program for the Combined Operational Plan and RECOVER program-level adaptive management (RECOVER, 2015) are examples of double-loop learning, although it has not been rigorously implemented.
3. **Triple-loop learning** is focused on longer time frames, considering organizational principles and goals (values, mission, vision) in the context of patterns of success and failure. It considers why we do what we do and who we should be as an organization or large-scale effort; it also considers large-scale organization restructuring as a possible outcome. The Government Accountability Office (e.g., GAO, 2003), the Congressional Research Service (e.g., Stern, 2017), and the National Academies (NASEM, 2021; NRC, 2005, 2015) have contributed to triple-loop learning.

Organizations are not generally structured to have specific units dedicated to a specific type of learning (nor should they necessarily do so), although some alignment between a type of learning and unit’s responsibility is necessary. For example, the ability to question objectives may be beyond the scope and capacity of portions of the organization. In contrast, changes in operational schedules (single-loop learning) are widespread across many of the formalized protocols of project planning and operations.

Developing and Implementing the Science Plan: Advancing Essential Science Actions

The committee's vision for a restoration science plan—that is, a list of high-priority science actions that can help to guide the investment of resources across multiple agencies and the application of the skills of agency scientists, academia, or contractors to fill knowledge gaps that are critical for restoration decision making—is discussed in depth earlier in the chapter (see The Need for a Science Plan). The actions outlined in a science plan are recognized as multi-group priorities that are feasible and important to address. A restoration science plan addresses the needs of managers, scientists, and policymakers by identifying and providing a mechanism to advance and prioritize the essential science actions needed to support restoration decision making. In general, a science plan provides a roadmap for collaboration to get the science done. Development of a useful and responsive science plan to advance science actions depends on the effectiveness of the other two previously discussed components of the science enterprise—identification of key science gaps and science coordination (Figure 6-1)—as well as the time and staffing devoted to the effort.

Implementation of the science plan requires matching the specified science needs with the necessary resources (including financial support, facilities, and expertise) to meet them. The SCG, with its diverse membership, can liaise with agencies, universities, and state and federal programs to identify and leverage resources, both in the near term and the long term to support the work. The attributes of the various science actions, discussed above, can be used to sequence the work so that findings are available when needed. Implementation will require attention to both resourcing (e.g., personnel and facilities to be leveraged across organizations as needed) and the level of effort needed to address the critical science need. Intense multi-agency and stakeholder coordination will be necessary to coordinate a plan to advance essential science actions but will also add transparency about, and accountability for, the science foundation for the restoration, in the same way that as the Integrated Delivery Schedule lays out a path for the restoration actions.

Identifying funding for science to support the restoration of the South Florida ecosystem will be particularly challenging. Although the lack of a centralized source of funding may preclude collective funding for science needs, some agencies may be able to direct funds to portions of the Everglades Restoration Science Plan that align with their specific mission and interests. As activities across agencies become further aligned, a greater sense of the existing available resources may become clearer. An annual Implementation Plan would identify where agencies are prepared to dedicate funds for particular activities.

An annual progress report for the Everglades Restoration Science Plan could document specific science funding, which would reveal where shortfalls exist. The Delta Stewardship Council produces an annual report of science funding, which shows, retroactively, which state and federal agencies and water contractors are funding which types of work[7] (Figure 6-5; DSC, 2022). Such an accounting enables collective discussion of whether the allocation across categories is appropriate for maximum effectiveness. Although the lack of alignment of accounting systems across agencies makes overall assessment of spending an approximation at

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[7] Several types of science activities are defined Delta science enterprise: core monitoring, status and trends monitoring, synthesis, targeted foundational research, and targeted immediate research (Delta Stewardship Council, 2022).

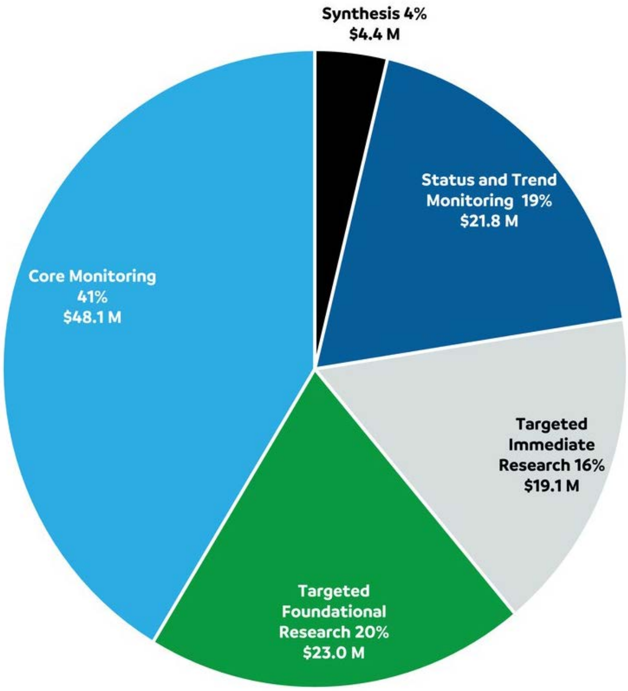

FIGURE 6-5 Total FY 2020-2021 science expenditures by project category for the California Bay-Delta (in percent of total funds and millions of dollars). Substantial funding is directed to monitoring but a relatively modest amount to synthesis.
SOURCE: DSC, 2022.

best, such an assessment for science currently supporting South Florida restoration can provide a better sense of where changes may be needed.

Resources can be directed to scientists conducting the work through competitive processes or through directed action, depending on the procedures used by each funding source. Competitive processes can help to ensure that all interested and capable parties are provided an opportunity to conduct work identified in the science plan and are routinely used by organizations such as Sea Grant to develop management-relevant research. The Florida RESTORE Act Centers of Excellence Program awards grants via a competitive, peer-reviewed process to support sustainable Gulf Coast Region ecosystem goods and services, including living resources, fisheries and wildlife habitats, beaches, wetlands, and coastal communities. The Bay-Delta Science program funds science through competitive proposal processes and also via directed actions, which it describes as critical science investigations that are awarded through a noncompetitive process when time is of the essence (i.e., rapid response; DSC, 2019). Directed actions can also enable use of novel technology or unique expertise and are used to further collaboration in science and promote equity. An Implementation Plan could show where flexibility may exist to ensure timely response to emerging needs, or where novel technical or expertise in an area precludes a reasonable competitive process.

The work conducted under the Implementation Plan must maintain its connection to management of the system. Each activity should be coordinated to ensure that managers and users of the information are either consulted regularly or included on the team conducting the work. For example, the National Oceanic and Atmospheric Administration RESTORE Science

Program (see Box 6-6) funds science through a competitive process but requires inclusion of resource managers or users on the research teams.

The Everglades Restoration Science Plan should be revisited at least every 5 years to document progress and respond to the evolving science needs; this time period allows for a reasonable amount of progress on funded initiatives while allowing for emerging priorities. By laying out essential science activities across the restoration program for the next 5-10 years, along with associated resource needs and links to a schedule of when information is needed,

BOX 6-6
Linking Science to Management Decisions—The NOAA RESTORE Science Program

The National Oceanic and Atmospheric Administration’s (NOAA) Gulf Coast Ecosystem Restoration Science, Observation, Monitoring, and Technology Program (RESTORE Science Program) was established to conduct, coordinate, and integrate science; integrate and coordinate observations; and provide useful scientific information to inform management decisions, science-based restoration projects, and ecosystem sustainability. The program’s long-term priorities include achieving comprehensive understanding on many aspects of the Gulf of Mexico ecosystem and specifically

- construction of management-ready and accessible ecosystem models;
- improved monitoring, modeling, and forecasting of climate change and weather effects on the sustainability and resiliency of the ecosystem; and
- development of decision-support tools to assist resource managers with management decisions planned to sustain habitats, living coastal and marine resources, and wildlife.

Program priorities were developed using engagement events and extensive meetings with stakeholders, universities, federal and state agencies, and nongovernmental organizations, to gather input that was incorporated into the priority identification process. The long-term priorities are linked to identified management and restoration needs and anticipated outcomes.

Recent requests for proposals have been focused on research that fosters an integrated understanding of the Gulf of Mexico ecosystem and the use of this understanding to guide natural resource management, including restoration. This focus is based on the recognition that effective management of the Gulf of Mexico ecosystem and its natural resources is supported when natural resource managers and natural resource management bodies have access to the best available science and local knowledge, and then use it to inform their decisions (i.e., take action). To be actionable, research should be designed to produce findings and products that meet the information needs of resource managers, including matching the spatial and temporal scale of their decisions and being shared in a timely manner and a comprehensible format.

The project teams must include one or more natural resource managers, one or more researchers, and one or more representatives from the stakeholder community, such as resource users. The natural resource managers must be from the management bodies responsible for the identified resource management decision.

Proposals must clearly describe the specific natural resource management decision to which research findings and products generated by their project will be applied including the context of the decision, the information needed to inform the decision, uncertainties related to the decision, and how those uncertainties would be reduced by their proposed research.

SOURCE: https://restoreactscienceprogram.noaa.gov/.

agencies and other entities can incorporate this information into their own science plans and/or ensure that their resources are efficiently directed for maximum effectiveness. Some agencies may have resources available in the near term, while others may need to include their contributions in out-year budget proposals. The multi-year Science Plan could be used by organizations within the science enterprise to seek additional funds and would provide clear communication to stakeholders, agencies, and Congress about the importance of science and the value of investments to support the ongoing program.

CONCLUSIONS AND RECOMMENDATIONS

As the CERP pivots from planning to implementation and adaptive management during a time of rapid global change, it requires support from a science enterprise with the collective capacity and ability to contribute financial resources, skills and expertise, and facilities and/or other resources to undertake scientific activities that respond to the critical knowledge impediments to restoration. The committee presents three essential, interlinked tasks of a science enterprise directed at the production of an Everglades Restoration Science Plan: (1) identification of knowledge gaps; (2) science coordination to advance and exchange knowledge; and (3) identification and establishment of focused science actions necessary to support progress. These tasks can be undertaken concurrently with ongoing work to advance restoration, with new science being incorporated into planning and implementation as it is developed.

Everglades restoration progress is inhibited by the lack of collectively identified science needs to support CERP decision making. There is no recent centralized compilation of critical management questions and associated knowledge gaps that could guide CERP science funding decisions or serve as a basis for proposal solicitations or collaborative initiatives. Instead, short-term demands command the attention of the available staff, and long-term, systems thinking is generally de-prioritized. Clearly identified science needs enable the science enterprise to stay focused, leading to more efficient utilization of science-provisioning resources and the presence of a critical linkage between management and science.

The Everglades science enterprise should develop a science plan to advance and implement essential science actions that directly support restoration decision making. This effort will require intense multi-agency and stakeholder coordination. This Everglades Restoration Science Plan could serve as a central document that highlights and communicates priority science needs and management linkages to a broad audience of potential funders, much as the Integrated Delivery Schedule does for project implementation. The plan would guide the CERP program, other restoration initiatives, and individual funding agencies in their science investments for research, monitoring, modeling, and synthesis to meet agreed upon priority needs. The plan should be updated every 5 years and with the engagement of a diverse range of stakeholders to respond to changing needs, with annual implementation plans and progress reports to facilitate coordination and communication of progress toward addressing the science needs.

The Science Coordination Group is best positioned to lead an updated multi-agency assessment of priority science needs and gaps at a programmatic level and to develop an Everglades Restoration Science Plan. This group should be tasked to lead this effort and should receive appropriate resources to do so from the Task Force. This effort would be a much-needed update to the 2008-2010 Plan for Coordinating Science. A lead scientist could guide implementation of the science plan, ensure completion of the work, and consult with decision makers to identify additional science needs to supplement plan activities.

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Appendixes

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

This report represents the 17th report by the National Academies of Sciences, Engineering, and Medicine on Everglades restoration. This Appendix recaps key findings of the previous reports.

Progress Toward Restoring the Everglades: The Eighth Biennial Review, 2020 (2021)

The 2020 report highlighted signs of restoration progress that were evident from multiple Comprehensive Everglades Restoration Plan (CERP) projects, buoyed by increased funding that expedited the pace of project construction. However, the committee noted that assessments of restoration progress were stymied by a lack of monitoring, analysis, and communication of restoration benefits. For the 2020 report, the committee reviewed the recently developed Combined Operational Plan and examined issues facing the northern and southern estuaries, including priorities for science to support restoration decision making.

With several projects nearing completion, the 2020 report noted that the CERP is now pivoting from a focus primarily on project planning and construction toward an expanding emphasis on operational decisions, evaluation of restoration success, adaptive management, and learning. This transition requires a strong organizational foundation for science, systematic monitoring and assessment, effective communication, and new strategies to support decision making. From this analysis, key principles emerged that are relevant across different projects and regional contexts. First, effective monitoring and ongoing data analysis are critical to support assessments of restoration progress, learning, and adaptive management. Synthesis, improved integration of modeling and monitoring, and enhanced applications of modeling tools can be used to turn available information into better understanding to evaluate tradeoffs and strengthen decision making. Finally, strong science leadership and appropriate staffing are key elements of an organizational infrastructure to maximize learning and to support more nimble decision making. Investments in the science and decision-making infrastructure for the CERP would improve the value of information developed through monitoring, modeling, and synthesis and would lead to more effective restoration outcomes.

Progress Toward Restoring the Everglades: The Seventh Biennial Review, 2018 (2018)

In the 2018 report, the committee noted that a vision for planned Comprehensive Everglades Restoration Plan (CERP) storage, at least in the northern portion of the system, was now becoming clear, although the future storage to be provided by Lake Okeechobee remains unresolved. The committee concluded that documentation and analysis of incremental restoration benefits from project implementation to date have been inadequate, primarily because of limitations in project-level monitoring and assessment efforts. Improvements to the monitoring and assessment program, at both project and systemwide scales, were recommended to increase the usefulness of monitoring data for CERP decision makers. The report also recommended a mid-course assessment that analyzes projected CERP outcomes in the context of future stressors. Rather than continuing its primary focus on restoring predrainage conditions and basing decisions on the ability to achieve those conditions under contemporary climate (1965-2005), the report recommends that the CERP emphasize restoration focused on the future of the South Florida ecosystem and build upon the accumulating knowledge base to support successful implementation of this program. This effort requires an integrated assessment of the performance of planned CERP projects under future climate and sea level–rise scenarios and other stressors. With seven large projects authorized and awaiting appropriations for construction and three additional projects nearing the end of their planning processes, the report states that the time is right for a mid-course assessment. This information could then inform robust decisions about future planning, funding, sequencing, and adaptive management. Implementing a restoration program that is resilient to future conditions also requires a science program that can bring the latest information and tools into CERP planning and implementation.

Progress Toward Restoring the Everglades: The Sixth Biennial Review, 2016 (2016)

The 2016 biennial report finds that, 16 years into the CERP, completed components of the plan are beginning to show ecosystem benefits, but the committee had several concerns regarding progress. 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 CERP. Sea-level rise will reduce the footprint of the system, temperature and evaporative water losses will increase, rainfall may become more variable, and more storage will likely be needed to accommodate future increases or decreases in the quantity and intensity of runoff.

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

The Florida Everglades is a large and diverse aquatic ecosystem that has been greatly altered over the past century by an extensive water control infrastructure designed to increase agricultural and urban economic productivity. The CERP, launched in 2000, is a joint effort led by the state and federal government to reverse the decline of the ecosystem. Increasing water storage is a critical component of the restoration, and the CERP included projects that would drill more than 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 reviews the ASR Regional Study Technical Data Report and 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. 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 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 the 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 trade-offs between water quality and quantity, considering timescales of reversibility, are needed to inform future prioritization and funding decisions. Understanding and communicating these trade-offs 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 trade-offs 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.

Furthermore, 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 for assessment of trade-offs over broad spatial and long temporal scales, especially for the entire ecosystem, and gives an example of what an overall performance indicator for the Everglades system might look like.

Adaptive Monitoring and Assessment for the Comprehensive Everglades Restoration Plan (2003)

A key premise of the CERP is that restoring the historical hydrologic regime in the remaining wetlands will reverse declines in many native species and biological communities. Given the uncertainties that will attend future responses of Everglades ecosystems to restored water regimes, a research, monitoring, and adaptive management program is planned. This report assessed the extent to which the restoration effort's "monitoring and assessment plan" included the following elements crucial to any adaptive management scheme: (1) clear restoration goals and targets, (2) a sound baseline description and conceptualization of the system, (3) an effective process for learning from management actions, and (4) feedback mechanisms for improving management based on the learning process.

The report concludes that monitoring needs must be prioritized, because many goals and targets that have been agreed to may not be achievable or internally consistent. Priorities could be established based on the degree of flexibility or reversibility of a component and its potential impact on future management decisions. Such a prioritization should be used for scheduling and sequencing of projects, for example. Monitoring that meets multiple objectives (e.g., adaptive management, regulatory compliance, and a "report card") should be given priority.

Ecosystem-level, systemwide indicators should be developed, such as land cover and land use measures, an index of biotic integrity, and diversity measures. Regionwide monitoring of human and environmental drivers of the ecosystem, especially population growth, land use change, water demand, and sea-level rise are recommended. Monitoring, modeling, and research should be well integrated, especially with respect to defining the restoration reference state and using "active" adaptive management.

Does Water Flow Influence Everglades Landscape Patterns? (2003)

A commonly stated goal of the CERP is to "get the water right." This has largely meant restoring the timing and duration of water levels and the water quality in the Everglades. Water flow (speed, discharge, direction) has been considered mainly in the coastal and estuarine system, but not elsewhere. Should the restoration plan be setting targets for flows in other parts of the Everglades as well?

There are legitimate reasons why flow velocities and discharges have thus far not received greater emphasis in the plan. These include a relative lack of field information and poor resolution of numerical models for flows. There are, however, compelling reasons to believe that flow has important influences in the central Everglades ecosystem. The most important reason is the existence of major, ecologically important landforms—parallel ridges, sloughs, and "tree islands"—that are aligned with present and inferred past flow directions. There are difficulties in interpreting this evidence, however, as it is essentially circumstantial and not quantitative. Alternative mechanisms by which flow may influence this landscape can to some extent be evaluated from short-term research on underlying bedrock topography, detailed surface topographic mapping, and accumulation rates of suspended organic matter. Nonetheless, more extensive and long-term research will also be necessary, beginning with the development of alternative conceptual models of the formation and maintenance of the landscape to guide a research program. Research on maintenance rather than evolution of the landscape should have higher priority because of its direct impact on restoration. Monitoring should be designed for the full range of flow conditions, including extreme events.

Overall, flows approximating historical discharges, velocities, timing, and distribution should be considered in restoration design, but quantitative flow-related performance measures are not appropriate until there is a better scientific understanding of the underlying science. At present, neither a minimum nor a maximum flow to preserve the landscape can be established.

Florida Bay Research Programs and Their Relation to the Comprehensive Everglades Restoration Plan (2002)

This report of the Committee on Restoration of the Greater Everglades Ecosystem evaluated Florida Bay studies and restoration activities that potentially affect the success of the CERP. Florida Bay is a large, shallow marine system immediately south of the Everglades, bounded by the Florida Keys and the Gulf of Mexico. Some of the water draining from the Everglades flows directly into northeast Florida Bay. Other freshwater drainage reaches the bay indirectly from the northwest.

For several decades until the late 1980s, clear water and dense seagrass meadows characterized most of Florida Bay. However, beginning around 1987, the seagrass beds began dying in the western and central bay. It is often assumed that increased flows to restore freshwater Everglades habitats will also help restoration of Florida Bay. However, the CERP may actually result in higher salinities in central Florida Bay than exist presently, and thus exacerbate the ecological problems. Furthermore, 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 phosphorus from freshwater sources, especially in their organic forms; effects on nutrient fluxes of decreasing freshwater flows into the northeastern Bay, and of increasing flows northwest of the Bay; and the development of an operational Florida Bay circulation model to support a bay water quality model and facilitate analysis of CERP effects on the Bay.

Science and the Greater Everglades Ecosystem Restoration: An Assessment of the Critical Ecosystems Study Initiative (2003)

The Everglades represents a unique ecological treasure, and a diverse group of organizations is currently working to reverse the effects of nearly a century of wetland drainage and impoundment. The path to restoration will not be easy, but sound scientific information will increase the reliability of the restoration, help enable solutions for unanticipated problems, and potentially reduce long-term costs. The investment in scientific research relevant to restoration, however, decreased substantially within some agencies, including one major Department of the Interior (DOI) science program, the Critical Ecosystem Studies Initiative (CESI). In response to concerns regarding declining levels of funding for scientific research and the adequacy of science-based support for restoration decision making, the U.S. Congress instructed the DOI to commission the National Academy of Sciences to review the scientific component of the CESI and provide recommendations for program management, strategic planning, and information dissemination.

Although improvements should be made, this report notes that the CESI has contributed useful science in support of the DOI's resource stewardship interests and restoration responsibilities in South Florida. It recommends that the fundamental objectives of the CESI research program remain intact, with continued commitment to ecosystem research. Several improvements in CESI management are suggested, including broadening the distribution of requests for proposals and improving review standards for proposals and research products. The report asserts that funding for CESI science has been inconsistent and as of 2002 was less than that needed to support the DOI's interests in and responsibilities for restoration. The development of a mechanism for comprehensive restoration-wide science coordination and synthesis is recommended to enable improved integration of scientific findings into restoration planning.

Regional Issues in Aquifer Storage and Recovery for Everglades Restoration: A Review of the ASR Regional Study Project Management Plan of the Comprehensive Everglades Restoration Plan (2002)

The report reviews a comprehensive research plan on Everglades restoration drafted by federal and Florida officials that assesses a central feature of the restoration: a proposal to drill more than 300 wells funneling up to 1.7 billion gallons of water a day into underground aquifers, where it would be stored and then pumped back to the surface to replenish the Everglades during dry periods. The report says that the research plan goes a long way to providing information needed to settle remaining technical questions and clearly responds to suggestions offered by scientists in Florida and in a previous report by the National Research Council.

Aquifer Storage and Recovery in the Comprehensive Everglades Restoration Plan: A Critique of the Pilot Projects and Related Plans for ASR in the Lake Okeechobee and Western Hillsboro Areas (2001)

Aquifer storage and recovery (ASR) is a major component in the CERP, which was developed by the U.S. Army Corps of Engineers (USACE) and the South Florida Water Management District (SFWMD). The plan would use the upper Floridan 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 charge to the Committee on Restoration of the Greater Everglades Ecosystem was to examine a draft of its 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.

B
STA Performance Summary

In this section, the committee provides a brief evaluation of the performance of each Stormwater Treatment Area (STA), organized by flow path. Primary emphasis is placed on performance during more recent water years (WY 2017-2021) as related to meeting the goals of the water quality−based effluent limit. Summaries of the comparative performance of the STAs are shown in Table 4-2 and Figure B-1).

CENTRAL FLOW PATH (STA-2 AND STA-3/4)

Inflows and land use

STA-2 and STA-3/4 largely receive drainage from the Everglades Agricultural Areas (EAA) basin, which is dominated by sugarcane along with turfgrass and vegetables. Soils in EAA are organic soils underlain by limestone. The limestone contributes to higher calcium content in the inflows compared to the Western Flow Path. Lake Okeechobee can be discharged to the STAs if there is capacity to process these waters, and during the dry season, if water is available to send south, Lake Okeechobee water is used to maintain hydration of STA cells. Long-term average total phosphorus (TP) concentrations of inflow water between WY 2004-2022 are approximately 50 percent lower for STA-2 and STA-3/4 than inflow water of the other STAs (Figure 4-12), which has supported their performance.

The Central Flow Path benefits from the 60,000-acre feet (AF) A-1 Flow Equalization Basin (FEB) constructed in WY2016 as a storage feature to moderate inflows to STA-3/4. The A-1 FEB is a large shallow reservoir filled with naturally seeded SAV and EAV located upstream of STA-2 and STA-3/4. Stored water can help avoid dry-downs during the dry season, and the storage provided can help attenuate peak inflows. Considerable removal of TP also occurs in the A-1 FEB because the operational depth range promotes the growth of wetland vegetation. The A-1 FEB in many ways acts as a supplemental STA, providing a pre-treatment system by removing approximately 75 percent of inflow TP within the FEB and discharging water with TP concentrations ranging from about 13-15 µg/L (calculated as an arithmetic mean; Wakefield, 2021; Laham-Pass, 2022).

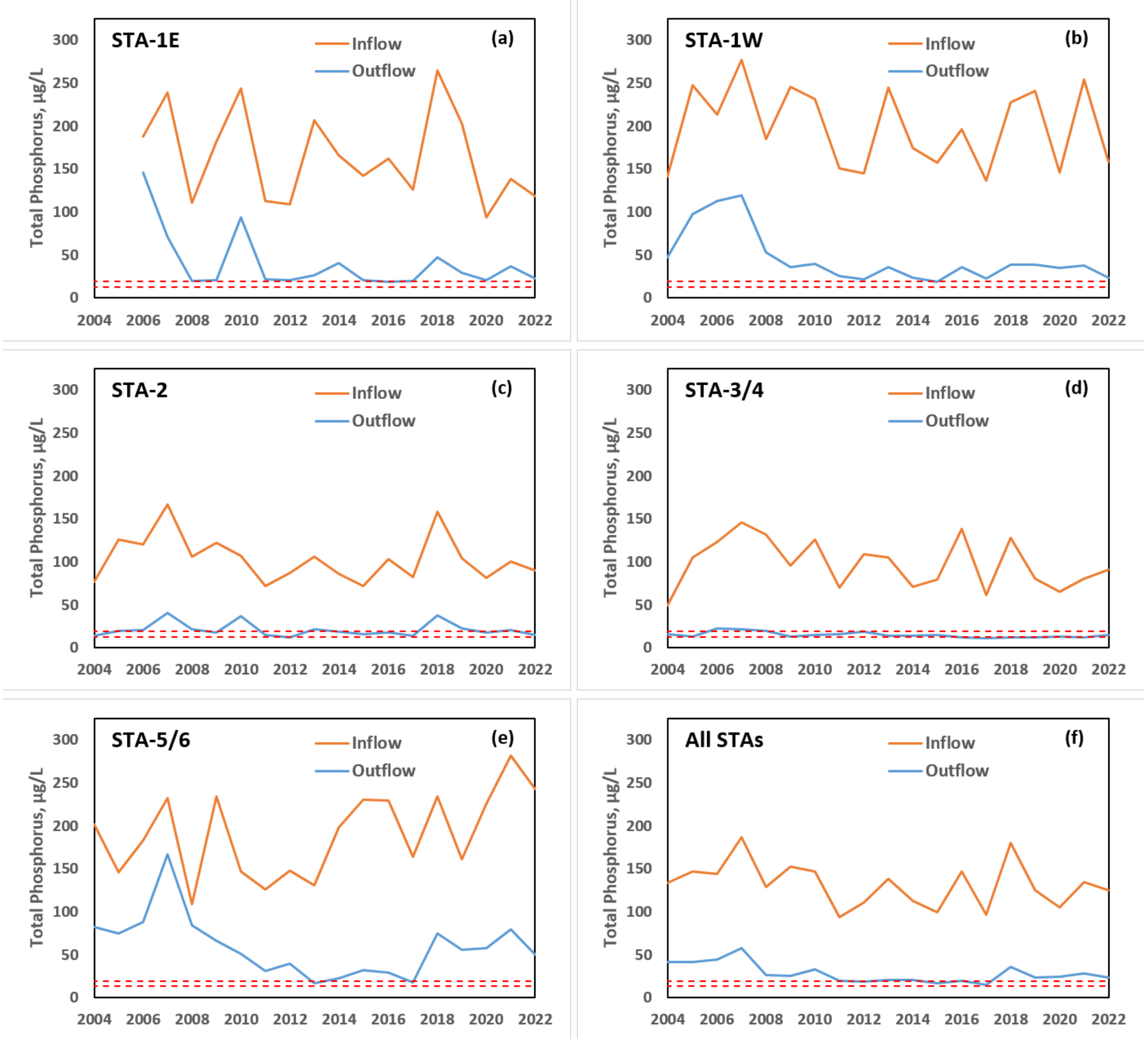


FIGURE B-1 Long-term patterns of annual flow-weighted total phosphorus concentrations on the STA inflow and outflow water during the operation period of WY 2006-2022 for STA-1E and WY 2004-2022 for other STAs. Horizontal dashed line represents the upper and lower limit (19 and 13 µg/L) of total phosphorus concentrations required by WQBEL.
SOURCES: Data from Chimney, 2014, 2015a, 2016, 2017, 2018, 2019, 2020, 2021, 2022a,b; Germain and Pietro, 2011; Goforth et al., 2005; Ivanoff et al., 2012, 2013; Pietro et al., 2006, 2007, 2008, 2009, 2010.

STA-3/4 Performance

STA-3/4 is the largest treatment wetland as part of the Everglades STA network (Table 4-2). It is divided into three flow-ways, each with two cells—an upstream EAV cell and a downstream mixed SAV/EAV cell (Figure B-2).

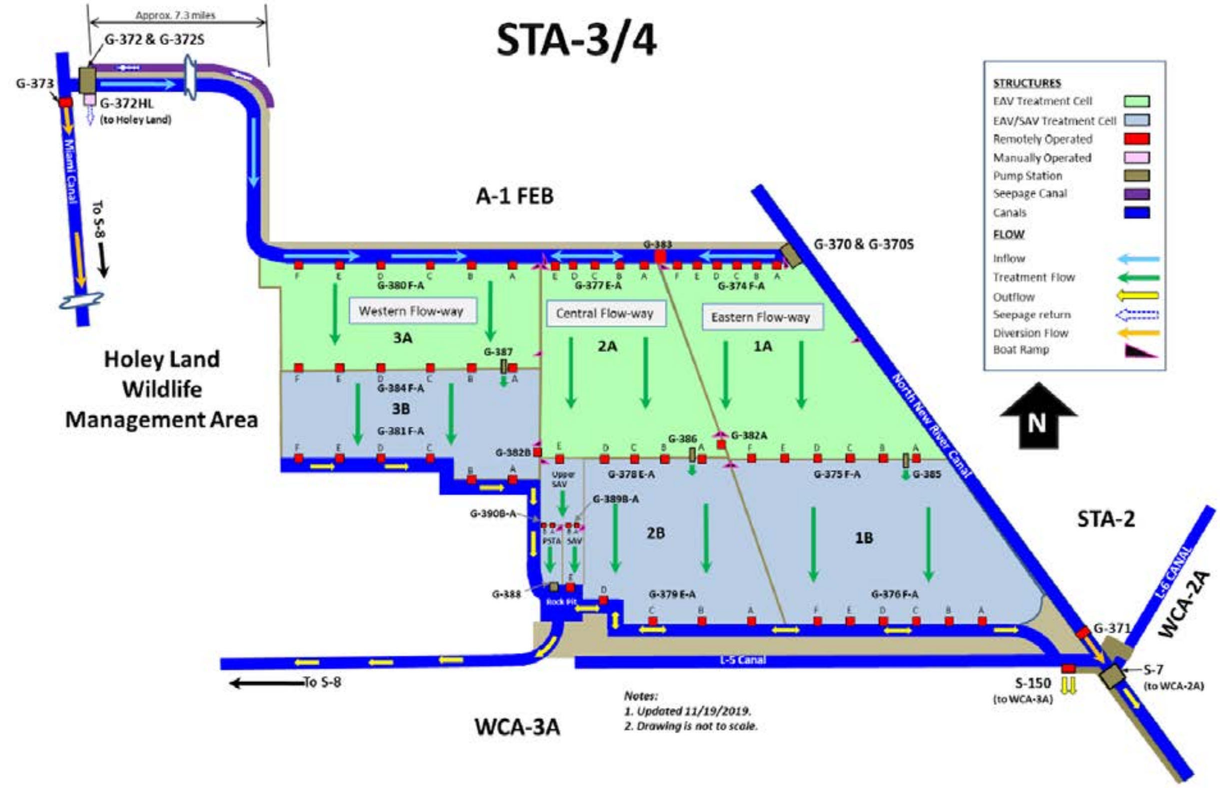


FIGURE B-2 A simplified schematic of STA-3/4 showing major inflow and outflow water control structures, the treatment area of each cell, flow direction, and dominant/target vegetation types. SOURCE: Modified from Chimney, 2022a.

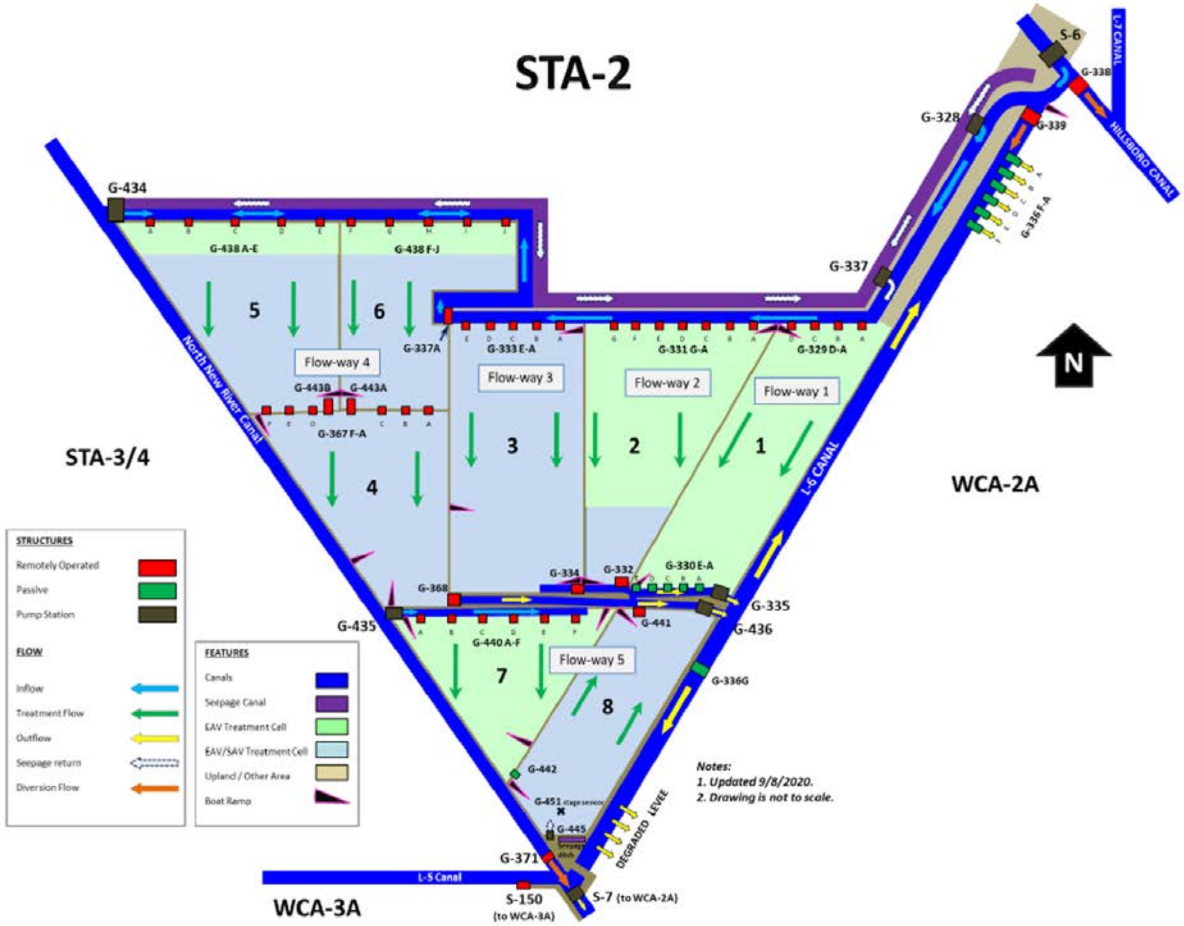
TABLE B-1 Summary of Select Hydrologic and Phosphorus Loading Characteristics of STA-3/4 During Recent Six Water Years (WY 2017-2022)

STA-3/4	Treatment Area (acres)	Adjusted Effective Treatment Area (acres)	Inflow TP (conc'n) (µg/L)	Outflow TP (conc'n) (µg/L)	Phosphorus Loading Rate (g/m^2-yr)	Hydraulic Loading Rate (cm/day)	Inflow Water Volume (MAF)
WY2017	16,327	16,327	61	11	0.4	1.9	0.377
WY2018	16,327	16,327	128	12	1.3	2.8	0.543
WY2019	16,327	16,327	80	12	0.9	3.2	0.631
WY2020	16,327	16,327	65	13	0.4	1.6	0.311
WY2021	16,327	15,245	80	12	0.8	2.9	0.521
WY2022	16,327	15,245	91	15	0.6	1.8	0.330

NOTE: MAF = million acre-feet.
SOURCE: Data from Chimney, 2018, 2019, 2020, 2021, 2022a, 2022b.

STA-3/4 has been in operation for the past 18 years (since WY 2004) and has performed well over this period by reducing inflow flow-weighted mean TP concentrations from 101 µg/L to 15 µg/L in the outflow when averaged over the period of record (WY 2004-2021) (Chimney, 2022a). Since 2014, STA-3/4 has consistently met the WQBEL requirements by producing outflow TP concentrations of 11 to 15 µg/L (Figure 4-8; Table B-1).

During the period of record, STA-3/4 retained approximately 844 tons of phosphorus or approximately 128 kg P/ha on an area basis (Chimney, 2022a). As indicated in Figure 4-26, a majority of this phosphorus is retained in the upstream treatment cells resulting in distinct phosphorus gradients in water, biotic communities, and soils along the flow-ways of STA-3/4. Spatial patterns of phosphorus enrichment in litter, floc, and recently accreted soil has been observed in Cell 3A of STA-3/4 (see Figure 4-26; Osborne et al., 2019b).



Notes:
1. Updated 9/8/2020.
2. Drawing is not to scale.

FIGURE B-3 A simplified schematic of STA- 2 showing major inflow and outflow water control structures, the treatment area of each cell, flow direction, and dominant/target vegetation types. SOURCE: Modified from Chimney, 2022a.

STA-2 Performance

STA-2 is the second largest treatment wetland of the Everglades STA network (Figure B-3). Since it began operation in WY 2000, STA-2 has been expanded twice. Flow-way 4 was added in WY 2007, and Flow-way 5 was added in WY 2013. Approximately 22 percent of the treatment area is managed as emergent aquatic vegetation (EAV) and 78 percent is managed as EAV/SAV (mixed marsh).

Over the period of record, STA-2 has reduced inflow flow-weighted mean TP concentrations from 101 to 22 µg/L in the outflow (Chimney, 2022a). Over the past 10 years (WY 2013-2022), STA-2 produced outflow TP concentrations of 14 to 38 µg/L and in 6 out of 10 years met the upper annual limit of WQBEL (19 µg/L) but has never reached the lower limit (13 µg/L, required in at least 2 of every 5 years; see Figure 4-8). Although average annual TP concentrations were generally declining from WY 2013 to WY 2017, STA-2 performance deteriorated in the past 6 years (Table B-2), including a spike in TP concentrations in outflows in WY 2018 due to disruption to vegetation in Cell 3 including damage by hurricane Irma. The South Florida Water Management District (SFWMD) is currently working to refurbish STA-2 by filling the deeper areas in the northwest corner of Cell 2 to enhance vegetation growth and by remediating Cell 3 to reduce hydrologic short-circuiting . Between March 2021 and March 2022, flow-weighted mean outflow concentrations from Cells 1, 4, and 5 averaged 13 µg/L TP or below, suggesting promise for STA-2 to meet the WQBEL if the issues in Cells 2 and 3 are successfully addressed (J. King, SFWMD, personal communication, 2022). WY 2022 data suggest that the system is recovering (Table B-2).

Vegetation management including herbicide spraying to kill floating aquatic vegetation (FAV) and other undesirable vegetation that probably contributed pulses of phosphorus release into the water column, resulting in an increase of outflow TP concentrations (Reddy and Sacco, 1980). Large portions of STA-2 are heavily dependent on SAV, which can be a concern for the overall stability of the system during intense storm events. The SFWMD's recent introduction of some EAV as buffer strips (similar to STA-3/4) in SAV treatment cells will likely help to improve overall stability and reduce sediment resuspension.

TABLE B-2 Summary of Select Hydrologic and Phosphorus Loading Characteristics of STA-2 During Recent Six Water Years (WY 2017-2022)

STA-2	Treatment Area (acres)	Adjusted Effective Treatment Area (acres)	Inflow TP (conc'n) (µg/L)	Outflow TP (conc'n) (µg/L)	Phosphorus Loading Rate (g/m^2-yr)	Hydraulic Loading Rate (cm/day)	Inflow Water Volume (MAF)
WY2017	15,495	15,495	82	14	0.5	1.8	0.324
WY2018	15,495	15,495	158	38	1.4	2.4	0.445
WY2019	15,495	15,495	104	23	0.7	2.0	0.362
WY2020	15,495	15,495	81	18	0.4	1.3	0.247
WY2021	15,495	14,910	100	21	0.9	2.5	0.440
WY2022	15,495	13,947	90	15	0.6	1.7	0.289

NOTE: MAF = million acre-feet.
SOURCE: Data from Chimney, 2018, 2019, 2020, 2021, 2022a, 2022b.

During the period of record, STA-2 retained approximately 600 tons of phosphorus, or approximately 96 kg P/ha (Chimney, 2022a). A majority of this phosphorus is retained in the upstream areas of cells resulting in distinct phosphorus gradients in water, biotic communities, and soils along the flow-ways of STA-2 (Figures 4-25 and 4-26; Osborne et al., 2019a).

Key Operational Factors Affecting Performance in the Central Flow Path

The following operational factors contribute to the strong performance of STA-2 and -3/4 (see also Table 4-2):

- low phosphorus loading rate (average = 0.8 g/m^2-yr and 0.7 g/m^2-yr for STA-2 and STA-3/4, respectively, during the recent 6-year period of record);
- low inflow TP concentrations;
- large treatment areas;
- high N/P ratios of inflow water; and
- the 60,000-AF A-1 FEB, which attenuates peak inflows and also reduces TP concentrations and loads.

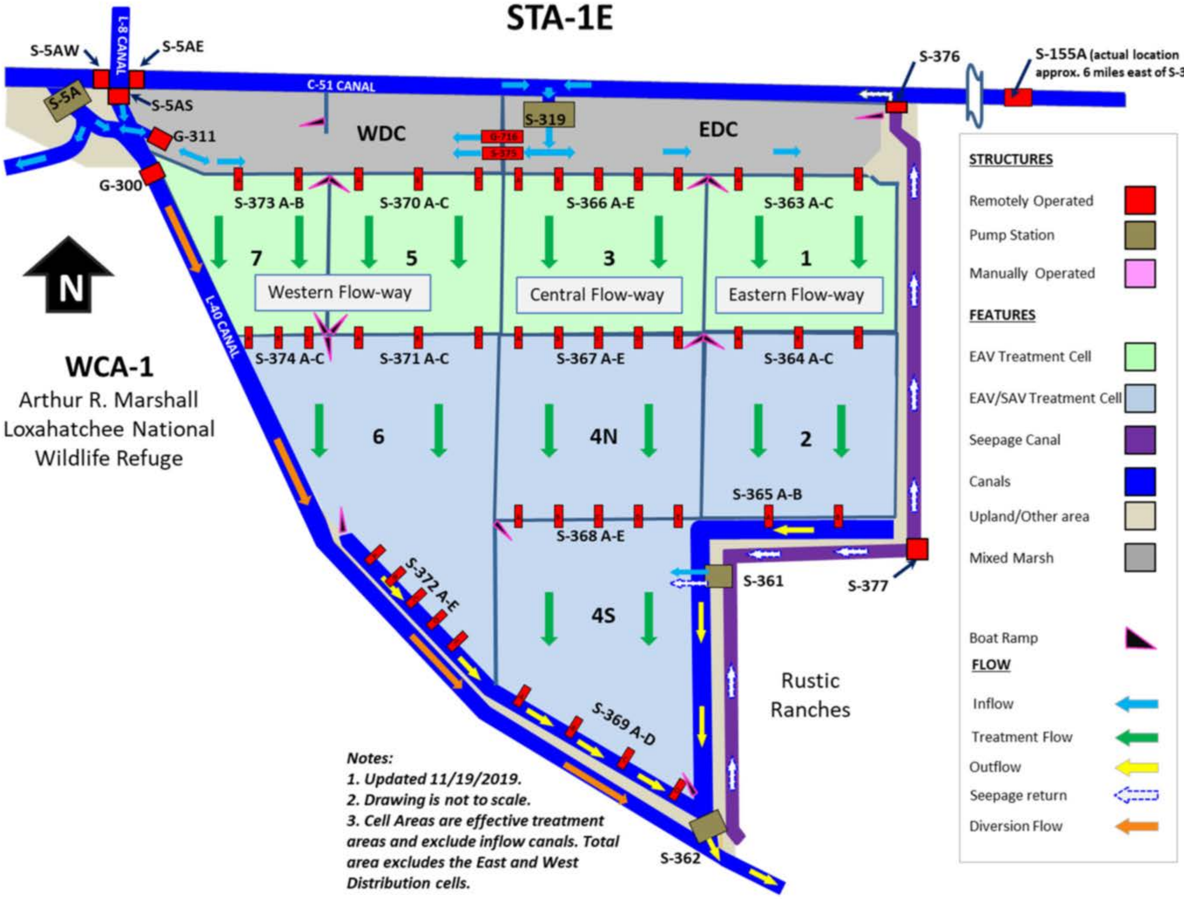
In addition, both STA-2 and STA-3/4 have benefited from active vegetation management including the use of EAV buffer strips in SAV-based flow-ways to control mobility of floc and , improve the stability of the system during intense storm events (Figure 4-19; Chimney, 2021, 2022a; Reddy et al., 2019a).

Eastern Flow Path (STA-1E and STA-1W)

Inflows and land use

STA-1E and STA-1W in the Eastern Flow Path receive inflow water from the C-51 West, S-5A, and L-8 with some small regulatory releases from Lake Okeechobee. During the dry season, if water is available, Lake Okeechobee water is used to maintain hydrated conditions. Flow-weighted mean inflow concentrations averaged 166 μg/L and 181 μg/L, respectively, over the period of record, which is 65-80 percent higher than inflows in the Central Flow Path.

The L-8 FEB was established in 2017 as a 45,000-AF below-ground reservoir (58 feet deep) located on a former rock mining site in Palm Beach County (Figure 4-2). The FEB is designed to moderate inflows to STA-1E and STA-1W. In contrast to the A-1 FEB, which significantly removes phosphorus, phosphorus removal in L-8 FEB is much more modest. After large inflow events, TP concentrations in L-8 FEB spike for weeks, resulting in outflow TP concentrations exceeding inflows. This is likely due to the resuspension of accrued phosphorus-enriched organic sediments, which increase particulate phosphorus in the water column (Powers, 2022). However, except for WY 2018, the annual flow-weighted mean of outflow TP concentration was less than the inflow for WY 2019-2021 (Powers, 2022).



Notes:
1. Updated 11/19/2019.
2. Drawing is not to scale.
3. Cell Areas are effective treatment areas and exclude inflow canals. Total area excludes the East and West Distribution cells.

FIGURE B-4 A simplified schematic of STA-1E showing major inflow and outflow water control structures, the treatment area of each cell, flow direction, and dominant/target vegetation types. SOURCE: Modified from Chimney, 2022a.

STA-1E Performance

STA-1E is the smallest treatment wetland of the Everglades STA network (Table 4-2; Figure B-4). Approximately 60 percent of the treatment area is managed as EAV/SAV (mixed marsh) and 40 percent is managed with exclusively EAV.

STA-1E has been in operation for the past 17 years (since WY 2005) and over the period of record has reduced flow-weighted mean inflow TP concentrations from 166 µg/L to 38 µ/gL in the outflow (Chimney, 2022a). Over the most recent 10 years (WY 2013-2022), outflow concentrations met the upper annual average limit of the WQBEL (19 µg/L) in only 1 year (Figure 4-9). High annual average outflow TP concentrations were observed during WY 2018 due to the effects of Hurricane Irma and in WY 2021, when construction activities were ongoing in Cells 5 and 7 and a portion of the inflow water normally delivered to STA-1W was directed to STA-1E due to construction activities in STA-1W. This resulted in substantial increase in hydraulic and phosphorus loading rates (Table B-3; Chimney, 2022a).

STA-1E has historically suffered from poor performance. During WY 2005-2012 the average flow-weighted mean outflow TP concentration was 56 µg/L, even though the average phosphorus loading rate was 1.2 g/m^2-yr. During the most recent 6 years (WY 2017-2022),

TABLE B-3 Summary of Select Hydrologic and Phosphorus Loading Characteristics of STA-1E During Recent Six Water Years (WY 2017-2022)

STA-1E	Treatment Area (acres)	Adjusted Effective Treatment Area (acres)	Inflow TP (conc'n) (µg/L)	Outflow TP (conc'n) (µg/L)	Phosphorus Loading Rate (g/m^2-yr)	Hydraulic Loading Rate (cm/day)	Inflow Water Volume (MAF)
WY2017	4,994	4,994	126	20	1.2	2.7	0.162
WY2018	4,994	4,994	265	47	2.6	2.7	0.161
WY2019	4,994	4,187	203	29	2.0	2.7	0.138
WY2020	4,994	3,533	94	21	1.4	4.1	0.174
WY2021	4,994	3,021	138	37	4.5	8.9	0.323
WY2022	4,994	2,733	119	22	2.3	5.3	0.173

NOTE: MAF = million acre-feet.
SOURCE: Data from Chimney, 2018, 2019, 2020, 2021, 2022a, 2022b.

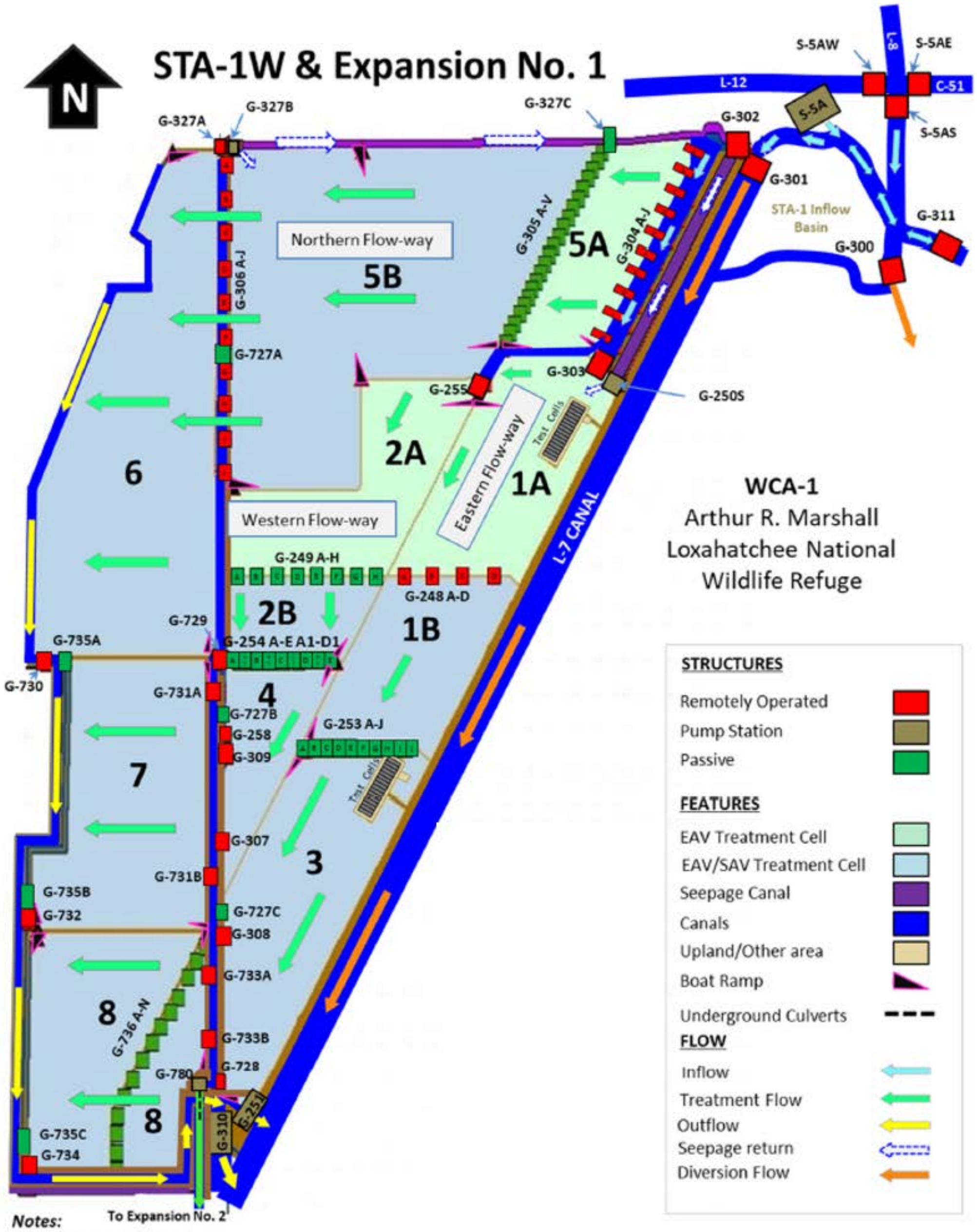
average phosphorus loading rates increased to 2.3 g/m^2-yr, with a very high phosphorus loading rate recorded during WY 2021.

The addition of the L-8 FEB can store water so that it can be steadily delivered to the STAs, attenuating peak flows and preventing dry-downs. In addition to the construction of theL-8 FEB, the Restoration Strategies project has included earthwork in Cells 5 and 7 to level the ground elevation to improve water depths for the targeted EAV and improve hydraulics in the cells. This regrading was completed in 2022. Currently STA-1E is in transition with recovery from earthwork, vegetation establishment and management, and high phosphorus accumulation rates in upstream treatment areas due to excessive hydraulic and phosphorus loading rates. Recent refurbishment projects should help the performance of STA-1E, but there may be a lag time to achieve these benefits, because the STA cells will require time to revegetate and reach steady state following the completion of regrading activities.

Overall, STA-1E has received a much higher phosphorus loading rates than STA-2 and STA-3/4. It is critical that phosphorus loading rates to STA-1E be reduced to approximately the same level as STA-2 and STA-3/4 to improve phosphorus reduction in outflow waters. Current management projects as described above coupled with a reduction in phosphorus and hydraulic loading rates could help improve performance and place STA-1E on a positive trajectory to reduce outflow TP concentrations.

STA-1W Performance

STA-1W was started in WY 1994 as the first STA of the Everglades Nutrient Removal Project with Cells 1A-4 (Figure B-5), expanding in 1999 with Cells 5A and B, to a total of 6,554 acres (2,647 ha). In 2018, as part of Restoration Strategies an additional 4,266 acres of treatment area (Cells 6-8) were added as part of Expansion Area #1. This area was flooded in WY 2020 and became fully operational in WY 2021. At present, STA-1W has a total treatment area of 10,810 acres (4,378 ha). Targeted vegetation coverage by area includes 19 percent EAV and 81 percent EAV/SAV treatment cells. The EAV/SAV combination in each treatment cell may be an effective approach to maintain the stability of sediments.



Notes:
1. Updated 06/9/2021.
2. Drawing Not to Scale.

FIGURE B-5 A simplified schematic of STA-1W showing major inflow and outflow water control structures, the treatment area of each cell, flow direction, and dominant/target vegetation types. SOURCE: Modified from Chimney, 2022a.

A second expansion area (~1,600 acres) located south of STA-1W (see Figure 4-2) is under construction, with a goal of being operational by December 2024. This STA will be integrated with STA-1W and both facilities will be utilized in series to optimize the performance to reduce outflow TP concentrations (Shuford et al., 2022).

TABLE B-4 Summary of Select Hydrologic and Phosphorus Loading Characteristics of STA-1W During Recent Six Water Years (WY 2017-2022)

STA-1W	Treatment Area (acres)	Adjusted Effective Treatment Area (acres)	Inflow TP (conc'n) (µg/L)	Outflow TP (conc'n) (µg/L)	Phosphorus Loading Rate (g/m^2-yr)	Hydraulic Loading Rate (cm/day)	Inflow Water Volume (MAF)
WY2017	6,544	6,544	136	23	0.7	1.4	0.108
WY2018	6,544	6,544	228	39	2.1	2.5	0.195
WY2019	6,544	5,120	241	39	2.4	2.8	0.170
WY2020	6,544	5,551	146	35	1.0	2.0	0.130
WY2021	10,810	10,810	254	38	1.4	1.5	0.192
WY2022	10,810	10,810	158	24	0.3	0.4	0.057

NOTE: MAF = million acre-feet.
SOURCE: Data from Chimney, 2018, 2019, 2020, 2021, 2022a, 2022b.

Over the period of record (27 years) STA-1W has reduced flow-weighted mean inflow TP concentrations from 181 µg/L to 45 µg/L in the outflow (Chimney, 2022a). Over the recent 10 years (WY 2013-2022) in STA-1W, outflow concentrations met the upper annual average limit of the WQBEL (19 µg/L) in only 1 year (Figure 4-9; Table B-4), and average outflow TP concentrations over the 6 most recent years have remained high at 33 µg/L. Recent TP inflow loads (1.3 g/m^2-yr over WY 2017-2022) remain higher than those in the Central Flow Path, although these loads have been reduced from prior average loading rates of 2.1 g/m^2-yr during WY 2004-2012.

Recent and ongoing expansions will help reduce the phosphorus loading rate and improve STA-1W performance, and the L-8 FEB will attenuate peak flows and temporarily store water to facilitate steady delivery to the STA. Current concern of higher outflow TP concentrations of L-8 FEB during storm events needs to be addressed to reduce the load to STA. In addition, refurbishment projects to improve hydraulics and topographic issues in the three flow-ways were completed in early WY 2023. Reestablishment of vegetation is under way and scheduled to be completed later in WY 2023 (Chimney, 2022a).

Currently STA-1W is in a state of transition with active management and the establishment of vegetation establishment, high phosphorus accumulation rates in the soils of upstream treatment areas, and excessive hydraulic and phosphorus loading rates. The expanded treatment areas will help reduce loading rates and improve overall performance and place STA-1W on a positive trajectory to reduce outflow TP concentrations. For example, addition of Expansion #1 (4,260 acres added to STA-1W) and Expansion # 2 (1,600 acres STA located south of STA-1W) will increase the total treatment area by 5,860 acres, which can potentially treat additional 160,000 AF of water. This will help to reduce both hydraulic and phosphorus loading rates of both STA-1W and STA-1E. However, a lag time following these improvements will be required for the STA to stabilize and reach steady-state conditions.

Key Operational Factors Affecting Performance in the Eastern Flow Path

The following operational parameters of STA-1E and STA-1W are inconsistent with the conditions observed in the best performing STAs (see also Table 4-2):

- high phosphorus loading rates (average = 1.7 g/m^2-yr for STA-1E and STA-1W, respectively, during the period of record (WY 2006-2022 for STA-1E and WY 2005-2022 for STA-1W) and 2.3 and 1.3 g/m^2-yr, respectively during recent 6 years);
- high inflow TP concentrations;
- low N/P ratios of the inflow water; and
- relatively small treatment areas.

Western Flow Path

Inflows and land use

Runoff from the C-139 Basin is the primary source of water for STA-5/6. The C-139 Basin is located west of the EAA, and historically, land in this basin was used for cattle operations, sugarcane, and winter vegetables. For the past three decades, sugarcane and winter vegetables dominated agricultural activities in the basin. Soils in this watershed are predominantly occupied by sandy Flatwood soils, and crops grown on these soils are generally fertilized at a higher rate than crops grown on EAA organic soils. A significant portion of the phosphorus added to these crops is stored in soils and subject to gradual discharge into runoff. Together, these factors result in higher phosphorus concentrations in the C-139 Basin compared to the Central Flow Path (STA-2 and STA-3/4; Figure 4-12) and implemented best management practices have been less successful in reducing phosphorus. The regulatory source control program established under the 1994 Everglades Forever Act (Fla. Sta. §373.4592) for the C-139 Basin mandates that TP loads not exceed the average annual baseline (1978-1988) conditions when adjusted for rainfall. The C-139 basin is currently judged to be in compliance (Wang et al., 2022), even though in WY2021 STA inflows were 281 μg/L. Because most of the inorganic nitrogen to added to these soils is taken by crops, runoff has discharged into STA-5/6 has low nitrogen to phosphorus ratios.

STA-5/6 Performance

STA-5[1] and STA-6[2] were started in WY 2000 and WY 1998, respectively, as two separate STAs created to address the nutrient loads from the C-139 Basin and a portion of the EAA. In 2006, the STAs were expanded with the addition of Cell 5-3A/B and Cell 6-2, and in WY 2012 additional improvements were made by combining STA-5 and STA-6 and adding Compartment C (Cells 5-4A/B, 5-5A/B, and 6-4) to create STA-5/6 (Figure B-6). The optimization period for the expanded STA-5/6 was completed in 2014. Approximately 59 percent of the treatment area is managed as EAV, and the remaining 41 percent of the area is managed as EAV/SAV (Chimney, 2022a). In this report, performance data collected for STA-5 and STA-6 prior to WY 2012 were combined into one data set for ease of comparison; from WY 2013 onward, performance data for the newly created combined STA-5/6 is reported.

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[1] Originally consisting of Cells 5-1A, 5-1B, 5-2A, and 5-2B.
[2] Originally consisting of Cell 6-3 and Cell 6-5.

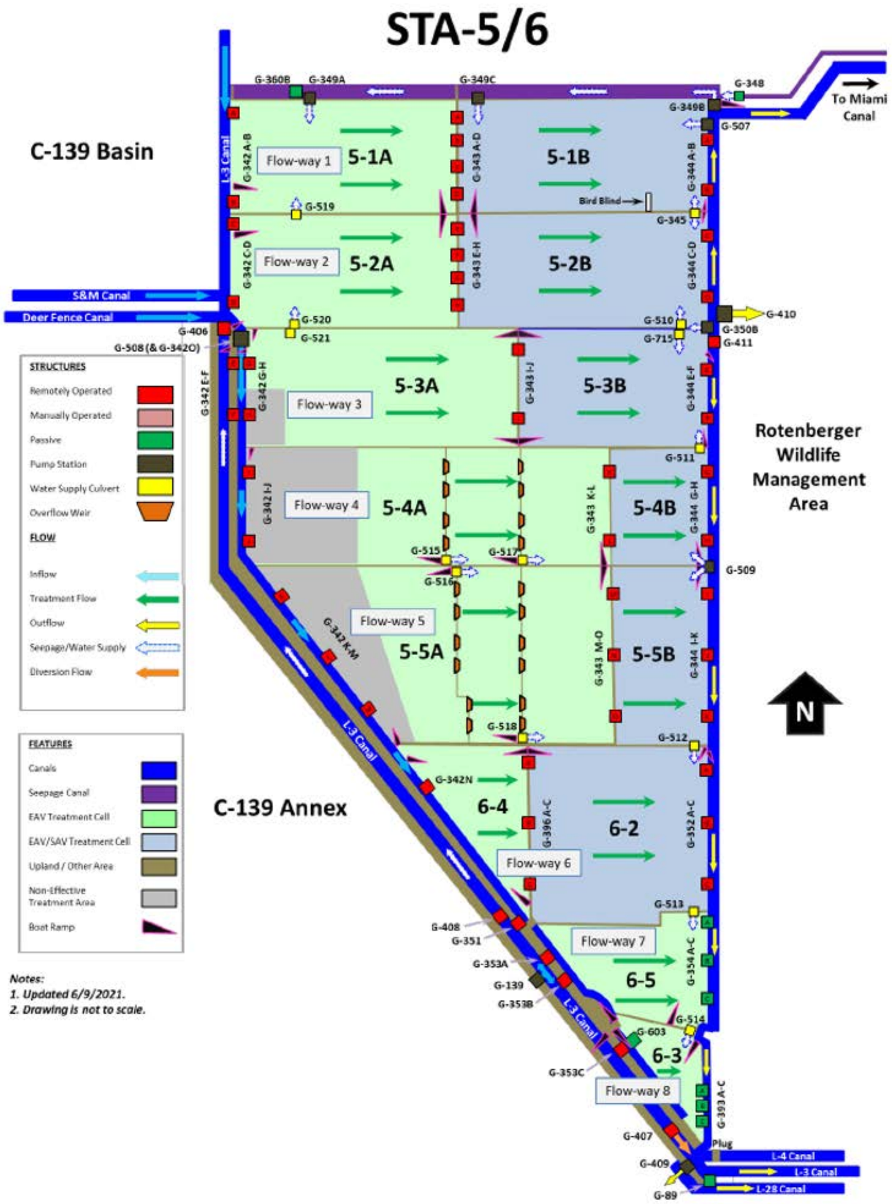

FIGURE B-6 A simplified schematic of STA-5/6 showing major inflow and outflow water control structures, the treatment area of each cell, flow direction, and dominant/target vegetation types. SOURCE: Modified from Chimney, 2022a.

Over the period of record (24 years), flow-weighted mean inflow TP concentrations to STA-5/6 were reduced from 193 µg/L to 64 µg/L in the outflow, the worst performing of the five STAs (Chimney, 2022a). Over the most recent 10 years (WY 2013-2022), STA-5/6 produced outflow TP concentrations of 17 to 80 µg/L, with 2 out of 10 years meeting the upper annual average limit of the WQBEL (19 µg/L) (Figure 4-10). Average outflow TP values during the six most recent years (WY 2017-2022) have remained high (56 µg/L). High phosphorus loading rates associated with Hurricane Irma and management interventions contributed to high annual average outflow TP concentration observed during this period (Table B-5).

TABLE B-5 Summary of Select Hydrologic and Phosphorus Loading Characteristics of STA-5/6 During Recent Six Water Years (WY 2017-2022)

STA-5/6	Treatment area (acres)	Adjusted Effective Treatment Area (acres)	Inflow TP (conc'n) (µg/L)	Outflow TP (conc'n) (µg/L)	Phosphorus Loading Rate (g/m^2-yr)	Hydraulic Loading Rate (cm/day)	Inflow Water Volume (MAF)
WY2017	13,685	13,685	164	18	0.7	0.7	0.118
WY2018	13,685	13,685	234	74	1.4	1.7	0.271
WY2019	13,685	10,383	161	55	0.7	1.1	0.138
WY2020	13,685	11,111	226	58	0.8	0.9	0.124
WY2021	14,338	14,338	281	80	0.8	0.8	0.130
WY2022	14,338	13,841	243	50	1.0	1.1	0.178

NOTE: MAF = million acre-feet.
SOURCE: Data from Chimney, 2018, 2019, 2020, 2021, 2022a, 2022b.

STA-5/6 has historically shown poor performance (Figure B-1), and early (WY 2004-2012) phosphorus loading rates to STA-5/6 were high (1.6 g/m^2-yr). However, even though loading rates have declined sharply in the past 6 years (0.9 g/m^2-yr during WY 2017-2022), STA-5/6 average flow-weighted mean outflow TP concentrations have not declined as expected, averaging 56 µg/L. During the past 9 years (WY 2014-2022), STA-5/6 functioned at an average 65 percent efficiency in reducing the phosphorus loads. Approximately 84 percent of the phosphorus retained over the period of record was retained separately in STA-5 and STA-6 up to WY 2012.

Restoration Strategies is providing internal improvements to STA-5/6, including earthwork and regrading on more than 1,100 acres, and the construction of the new C-139 FEB, which when completed and operational in 2024, is expected to hold 11,000 AF to provide additional water to help keep the STA hydrated during dry periods, although the C-139 is substantially smaller in volume than the A-1 and L-8 FEBs.

Currently STA-5/6 is undergoing a transition with management activities including re-establishment of vegetation. The current expanded treatment area along with vegetation and soil management should help to improve overall performance and place STA-5/6 on a positive trajectory toward lower outflow TP concentrations, although there will be a lag in system performance following management activities for the STA to reach new steady state conditions.

Key Operational Factors Affecting Performance in the Western Flow Path

An analysis of key operational parameters shows that STA-5/6 faces some similar challenges as STA-1E and STA-1W and some unique challenges:

- high inflow TP concentrations;
- high early phosphorus loading rates but low loading rates (0.9 g/m^2-yr) during recent 6 years (average = 1.2 g/m^2-yr^- during the period of record, WY 2004-2022);
- frequently dryouts in the dry season; low average annual hydraulic loading rate (1.1 cm/day average for recent 6 years), which means that the STA is in dry-down conditions for significant portions of nearly every year; and

- low N/P ratios of the inflow water.

High inflow concentrations create challenges for STA 5/6 to meet the outflow concentrations of 13 µg/L. High outflow TP concentrations are likely due low hydraulic loading rates and high concentrations in STA inflows. STA 5/6 experiences recurrent dry down conditions and subsequent release of phosphorus upon rewetting, which causes very high concentration in STA discharges at the beginning of the wet season. For example in WY 2021, the SFWMD stated that dryout conditions existed in Cells 6-3 and 6-5 (Flow-ways 7 and 8; see Figure B-6) from December 2019 through April 2020 and in Flow-way 6 in April 2020, and other flow-ways were dry for part of the year (Chimney, 2021). In WY 2022, the dryout period was shorter for Flow-ways 7 and 8 (April-June 2021) but “most of the other cells partially dried out” (Chimney, 2022a).

C

Biographical Sketches of Committee Members and Staff

Denice H. Wardrop, *Chair*, is research professor of geography at The Pennsylvania State University. Her research focuses on theoretical ecology, anthropogenic disturbance and impacts on aquatic ecosystem function, ecological indicators, and ecosystem condition monitoring and assessment. Dr. Wardrop is the Executive Director of the Chesapeake Research Consortium, an association of seven institutions, each with a long-standing involvement in research on problems affecting the Chesapeake Bay and its watershed. She has served on two previous cycles of CISRERP. She has a B.S. in systems engineering from the University of Virginia, an M.S. in environmental sciences from the University of Virginia, and a Ph.D. in ecology from The Pennsylvania State University.

William G. Boggess is professor and executive associate dean of the College of Agricultural Sciences at Oregon State University (OSU). Prior to joining OSU, Dr. Boggess spent 16 years on the faculty at the University of Florida in the Food and Resource Economics Department. His research interests include interactions between agriculture and the environment (e.g., water allocation, groundwater contamination, surface-water pollution, sustainable systems); economic dimensions and indicators of ecosystem health; and applications of real options to environmental and natural resources. Dr. Boggess previously served on the Oregon Governor's Council of Economic Advisors and the Board of Directors of the American Agricultural Economics Association, and he currently serves on the Board of the Oregon Environmental Council. He served on the State of Oregon Environment Report Science Panel and has been active in the design and assessment of the Oregon Conservation Reserve Enhancement Program. Dr. Boggess served as a member of the National Research Council Committee on the Use of Treated Municipal Wastewater Effluents and Sludge in the Production of Crops for Human Consumption, and on the Committee on Independent Scientific Review of Everglades Restoration Progress (since 2008), serving as chair of the fourth and seventh committees. He received his Ph.D. from Iowa State University.

Casey Brown is professor in the Department of Civil and Environmental Engineering at the University of Massachusetts at Amherst and adjunct associate research scientist at Columbia University. His primary research interest is the development of analytical methods for improving the use of scientific observations and data in decision making, with a focus on climate and water resources, and he has worked extensively on projects around the world in this regard. He chairs the Water and Society Technical Committee of the American Geophysical Union Hydrology

Section and the Water Resources Planning under Climate Change Technical Committee of the American Society of Civil Engineers Environmental and Water Resources Institute Systems Committee. He earned his B.S. in civil engineering from the University of Notre Dame, his M.S. from the University of Massachusetts, Amherst, and his Ph.D. in environmental engineering science from Harvard University.

Christopher B. Burke (NAE) is the chief executive officer of Christopher B. Burke Engineering, Ltd (CBBEL), a consulting engineering and surveying firm that he founded in 1986. Over three decades in business, Dr. Burke and CBBEL have solved complex infrastructure problems for hundreds of municipal and private clients. CBBEL's water resources team, guided by Dr. Burke, has completed more than 1,700 water-related projects and has earned the reputation as a leader in water resources engineering. Dr. Burke also serves as a professor of practice at the University of Illinois Chicago, and he was elected to the National Academy of Engineering for his leadership in executing complex water resources projects. He earned B.S. and M.S. in civil engineering and a Ph.D. in hydraulics and hydrology from Purdue University. He also received the Honorary Doctorates in Engineering from Purdue University and the University of Illinois.

Philip M. Dixon is university professor in the Department of Statistics at Iowa State University. His research centers on developing and evaluating statistical methods to answer biological questions, and his research interests include ecological and environmental statistics, mathematical biology, and computational modeling. He previously worked as a biostatistician at the Savannah River Ecology Lab administered by the University of Georgia. He earned his A.B. in biology from the University of California, Berkeley, an M.S. in statistics from Cornell University, and a Ph.D. in ecology and evolutionary biology from Cornell University.

Charles T. Driscoll, Jr. (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 an 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 has served on several National Academy committees. He has also served on the Committee on Independent Scientific Review of Everglades Restoration Progress since 2006. He is a fellow of the American Academy for the Advancement of Science. 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.

K. Ramesh Reddy is graduate research professor and director at the School of Natural Resources and Environment at the University of Florida. His research areas include biogeochemistry, soil and water quality, ecological indicators, and restoration of wetlands, and aquatic systems. Dr. Reddy investigates biogeochemical cycling of macro-nutrients in natural ecosystems, including wetlands, shallow lakes, estuaries, and constructed wetlands, as related to soil and water quality, carbon sequestration, and greenhouse gas emissions. He served as a member of the U.S. National Committee for Soil Sciences in the National Academies' Policy and Global Affairs Division. He served on the U.S. Environmental Protection Agency's Science

Advisory Board Panel. Dr. Reddy served as a member of the second and third Committees on Independent Scientific Review of Everglades Restoration Progress. Dr. Reddy earned his Ph.D. in agronomy and soil science from Louisiana State University in 1976.

Denise J. Reed is an expert in coastal marsh sustainability and the role of human activities in modifying coastal systems with more than 35 years of experience studying coastal issues in the United States and abroad. Dr. Reed has served as a Distinguished Research Professor in the University of New Orleans' Department of Earth and Environmental Sciences, and spent 5 years as Chief Scientists at The Water Institute of the Gulf. 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 National Research Council Committee on Sustainable Water and Environmental Management in the California Bay-Delta, and has been a member of the U.S. Army Corps of Engineers Environmental Advisory Board and the National Oceanic and Atmospheric Administration Science Advisory Board. Dr. Reed received her B.S. in geography from Sidney Sussex College and her M.A. and Ph.D. from the University of Cambridge.

James E. Saiers is the Clifton R. Musser Professor of Hydrology at the Yale School of Forestry and Environmental Studies. Dr. Saiers studies how human activities and natural processes affect the quality of drinking-water resources and alter freshwater flows within aquifers, wetlands, and river basins. His recent research projects address water-quality impacts of fossil-fuel development, carbon and nutrient transport through watersheds, radionuclide migration in groundwater, and climate-change effects on water resources in Africa. Dr. Saiers has served on the Committee on Independent Scientific Review of Everglades Restoration Progress since 2012, and he 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 Environmental Protection Agency 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.

Alan D. Steinman is the Allen and Helen Hunting Director and Professor of Water Resources at the Annis Water Resources Institute, Grand Valley State University. Previously, he was director of the Lake Okeechobee Restoration Program at the South Florida Water Management District. Dr. Steinman's research interests include aquatic ecosystem restoration, harmful algal blooms, phosphorus cycling, and water resources policy. He is a fellow of the Society of Freshwater Science. Dr. Steinman was awarded a postdoctoral fellowship from Oak Ridge National Laboratory and earned a Ph.D. in botany/aquatic ecology from Oregon State University, an M.S. in botany from the University of Rhode Island, and a B.S. in botany from the University of Vermont.

Martha A. Sutula is a principal scientist and head of the Biogeochemistry Department of the Southern California Coastal Water Research Project Authority, where she oversees projects related to the effects of climate change and anthropogenic pollution on acidification, hypoxia, harmful algal blooms, and eutrophication. Her research group combines the use of observations, experiments, and numerical models to understand drivers and ecological impacts of these phenomena in streams, lakes, estuaries, and coastal waters. Beyond her research activities, she focuses on linking science to management. Examples of this research include her work as lead scientist to the California State Water Resources Control Board, providing technical support to develop eutrophication water quality objectives for California's waters. She has served on several boards and panels addressing the effects of anthropogenic activities on inland and coastal habitats and the role of science in guiding management actions, including the Southern California Wetland Recovery Project and the Expert Panel on Sediment Diversion Plan to Restore Louisiana Coastal Wetlands. She received her B.S. in chemistry from Purdue University, M.S. in public health from Tulane University, and Ph.D. in coastal oceanography from Louisiana State University.

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 to 1994. Dr. Walters has done extensive research and published many articles on the red-cockaded woodpeckers in North Carolina and Florida, and he chaired an American Ornithologists' Union Conservation Committee Review that looked at the biology, status, and management of the Cape Sable Seaside Sparrow, a bird endemic to the Everglades. His research interests are in the behavioral ecology, population biology, and conservation of birds, and his recent work has focused on cooperative breeding, dispersal behavior, and endangered species issues. Dr. Walters served on two panels of the Sustainable Ecosystems Institute that addressed issues with endangered birds in the Everglades restoration in addition to previously serving as a member of the National Academies' Committee on Restoration of the Greater Everglades Ecosystem and five previous terms of the Committee on Independent Scientific Review of Everglades Restoration Progress. He holds a B.A. from West Virginia University and a Ph.D. from the University of Chicago.

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 many studies, including the Panel to Review the Critical Ecosystem Studies Initiative and all nine 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.

Jonathan M. Tucker is an associate program officer with the Water Science and Technology Board and the Board on Earth Sciences and Resources. Prior to joining the National Academies in July 2022, he worked as a postdoctoral researcher studying volcanology, mantle geochemistry, and deep Earth volatile cycles. He received his B.A. in chemistry and astronomy from Amherst College and his Ph.D. in Earth and planetary sciences from Harvard University.

Padraigh Hardin, program assistant, is a staff member with the Water Science and Technology Board and Board on Earth Sciences and Resources. They joined the National Academies in May 2022. During their last year of undergraduate study at George Mason University (GMU), they conducted research on cloud type and forecast model simulations, which was showcased at the GMU College of Science Research Colloquium. They earned their B.S. in atmospheric sciences from GMU.