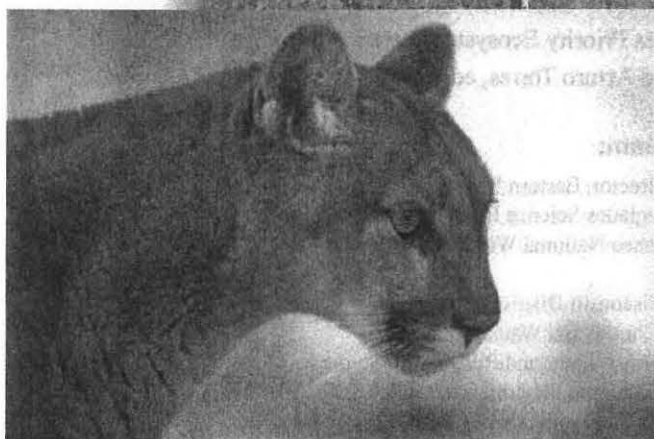
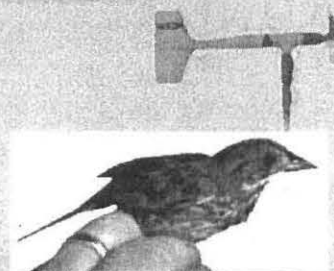


In cooperation with the U.S. Fish and Wildlife Service, National Park Service,
U.S. Army Corps of Engineers, South Florida Water Management District, and
U.S. Environmental Protection Agency

USGS Strategic Science Plan in Support of Greater Everglades Ecosystem Restoration



Series Name 0000

**This Science Plan was developed by the USGS
In consultation with other U.S. Department of the Interior Partners:**

**{YET TO BE DONE} And, in collaboration with {ONCE WE HAVE AN
'OPERATIONAL' draft}:**

The U.S. Department of the Interior USGS Science Plan in Support of Greater Everglades Ecosystem Restoration is the combined effort of a multi-agency team including:

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USGS Strategic Science Plan in Support of Greater Everglades Ecosystem Restoration

G. Ronnie Best, Jane R. Eggleston, and Arturo Torres, editors

In cooperation with the U.S. Fish and Wildlife Service,
National Park Service,
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South Florida Water Management District, and
U.S. Environmental Protection Agency

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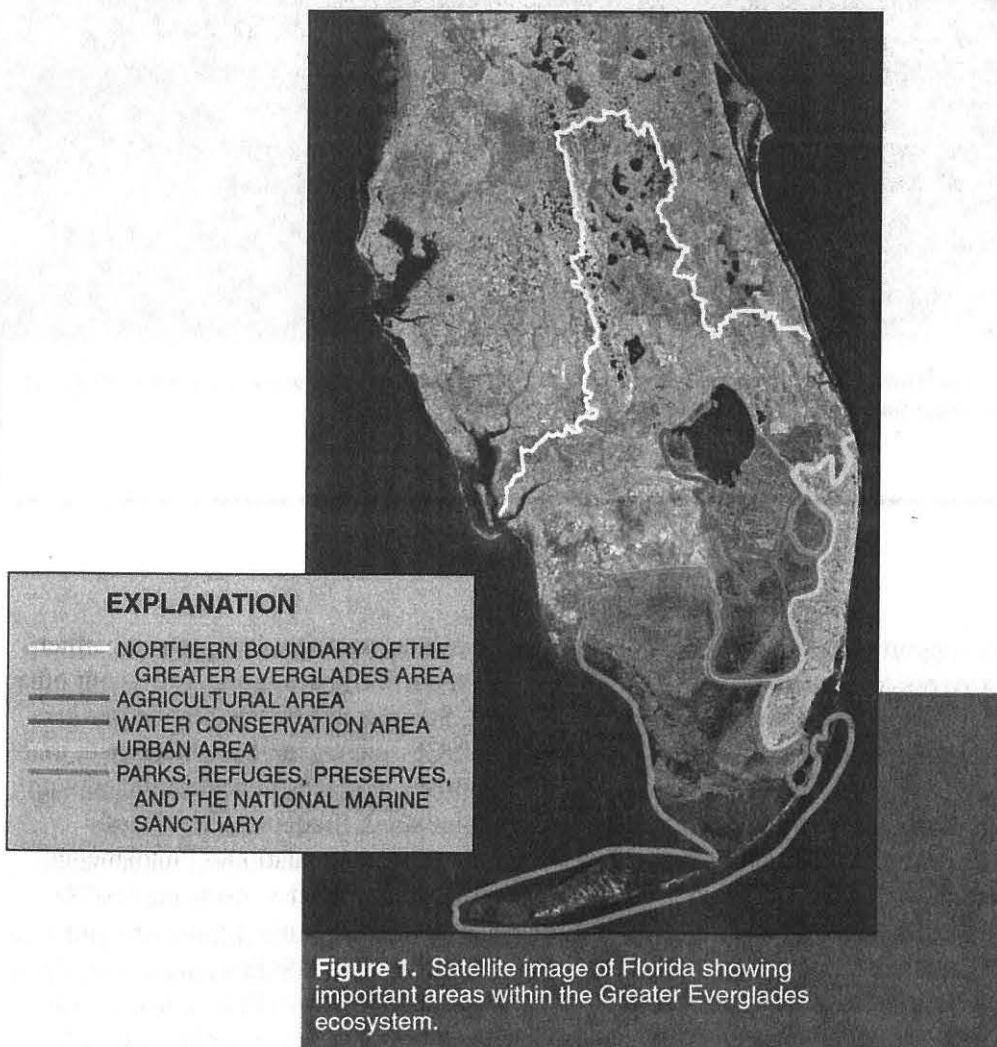
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INTRODUCTION

I

The Greater Everglades ecosystem is a unique subtropical network of diverse habitats that encompasses a large part of the southern Florida Peninsula. Part of the area—mostly publicly controlled parks, preserves, sanctuaries, and refuges managed as Department of the Interior (DOI) trust resources—remains in nearly undeveloped condition, whereas much of the area has been dramatically changed due to major urbanization and agriculture (fig. 1).

Water is the principal driving force within this system, and supplying sufficient water to support these diverse habitats is a continuing challenge for water and resource managers. The major changes to the natural hydrology of the system have had profound effects on the natural habitat and have driven a number of species, such as the Florida panther, to the brink of extinction.



Recognizing that historical and current human activities have altered the natural ecosystem of South Florida's Greater Everglades, a number of efforts have been initiated to identify and implement programs to address key information needs necessary for restoring this unique ecosystem. These efforts include the following:

- 1) The development of the Science Subgroup Report in 1993, which outlined key system-wide restoration objectives for the South Florida ecosystem (Science Subgroup, 1993);
- 2) The completion of the "Restudy" by the U.S. Army Corps of Engineers, which resulted in the Comprehensive Everglades Restoration Plan (CERP). The primary purpose of CERP is to address issues related to quantity, quality, timing and distribution of water throughout the Greater Everglades ecosystem (U.S. Army Corps of Engineers, 1999²);
- 3) The establishment of the South Florida Ecosystem Restoration Task Force (SFERTF), which identified the following restoration goals (1999):

SOUTH FLORIDA ECOSYSTEM RESTORATION TASK FORCE GREATER EVERGLADES RESTORATION GOALS*

Restoration Goal 1: Get the water right (timing, quantity, quality, and distribution). Get the water right means restoring natural hydrology functions and water quality in wetlands, estuarine, marine, and ground-water systems, while also providing for the water resource needs of urban and agricultural landscapes.

Restoration Goal 2: Restore, preserve, and protect natural habitats and species. The purpose of this goal is to restore the diversity, abundance, and behavior of native animals and plants, and halting the spread of invasive species.

Restoration Goal 3: Foster compatibility between the built and natural system.

*Adapted from: *Success in the Making — An Integrated Plan for South Florida Ecosystem Restoration*, November 1998; and *FY 1999-2000 Biennial Report of the South Florida Ecosystem Restoration Task Force*, March 2001.

In direct support of the Greater Everglades ecosystem restoration efforts, the U.S. Geological Survey (USGS) developed the Greater Everglades science initiative. USGS's Greater Everglades science initiative has had from its inception in the mid-1990s a strong emphasis on addressing the science information needs relevant to Greater Everglades restoration. During these earlier stages of CERP implementation, the USGS science initiative will more closely address the needs of the CERP and other Greater Ever-

glades restoration-related projects in partnership with our DOI partners as well as our other Federal, State, and tribal restoration partners.

USGS science includes integrated, multidisciplinary targeted studies combined with discipline-based, fundamental process research. This combination of fundamental and applied research has made the USGS a world leader in scientific information gathering for over a century. USGS's nation-wide Priority Ecosystem Science (PES) initiative was developed to focus the expertise of USGS

scientist on complex biological, chemical, geologic, hydrologic, and geographic components of an ecosystem – in this case the Greater Everglades ecosystem.

The outcomes of USGS science activities, detailed in this plan, support the present and future needs of the agencies responsible for implementing CERP and other Greater Everglades restoration projects and of the resource management agencies, including the National Park Service (NPS) and the U.S. Fish and Wildlife Service (FWS). Information on

past and present conditions of the ecosystem, and the ability to predict future responses of the system to changing conditions, form a sound scientific basis for managers to establish baseline conditions, restoration targets, and accurate predictive models. Sustainable, cost-effective, and coordinated land management decisions must be based on relevant, reliable, unbiased science that examines the myriad of complex and interconnected physical, biological, and chemical relations within the Greater Everglades ecosystem.

PHYSICAL SETTING, DRIVING FORCES, AND ENVIRONMENTAL STRESSORS

Over the last 5,500 years, the Everglades developed through succession into a spatially diverse and complex natural ecosystem (Davis and others, 1994). Within the last century, major urban and agricultural areas have developed within the system that require resources, especially freshwater, that previously supported the natural ecosystem. However, to effectively manage the health of this complex system, numerous natural and anthropogenic factors affecting the availability of freshwater must be understood. (See McPherson and Halley, 1996, for a detailed discussion of these factors.)

Natural Factors Shaping the Ecosystem

The Greater Everglades encompasses an area from Kissimmee southward, an area where surface water once flowed uninterrupted to the estuaries of South Florida. Climate, topography, and geology shaped the ecosystem; factors that continue to drive and control the environment and the supply of freshwater. Restoration requires understanding and incorporating these natural factors into plans.

South Florida is a humid environment, averaging between 40 and 65 inches of rainfall annually. The east coast usually receives the largest amount, and the Florida Keys and areas near Lake Okeechobee receive less. Approximately 70 percent of the rainfall occurs during the wet season—June through October—associated with thunderstorms, squalls, and tropical cyclones. Tropical cyclones (hurricanes and tropical storms) produce the most severe weather and storm surge in the region, often resulting in property damage due to wind and coastal and inland flooding (fig. 2).

Water levels and flows in the wetland areas of the Greater Everglades fluctuate seasonally in response to rainfall and runoff. Much of the land is inundated throughout the year; during heavy rains, all but the tree islands are flooded. In the dry season, water levels generally are close to land surface, but during droughts may be substantially below it. Historically, periods of droughts have often been accompanied by major fires, which have swept over the land burning vegetation and peat.

In recent decades, climate extremes seem to have increased and the role of global climate change, sea-surface temperatures, and El Niño/La Niña cycles on South Florida

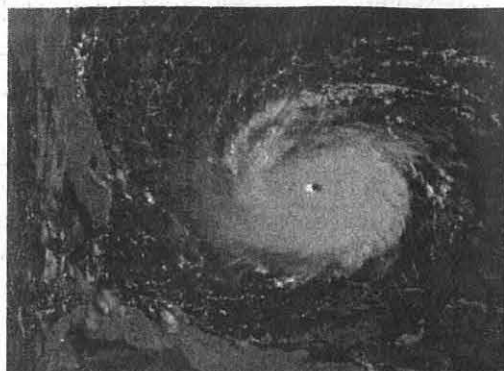


Figure 2. Hurricane Andrew (August 1992) and its impact on a South Florida wetland.



weather patterns is being investigated. For example, in South Florida, the 1997-1998 El Niño-related weather patterns produced more than twice the average dry season (November 1997 through March 1998) rainfall (see South Florida Water Management District, http://glacier.sfwmd.gov/org/omd/ops/weather/en_dist.html, accessed August 2002).

The upper 250 feet of the surficial aquifer system is the principal source of freshwater for more than 5 million people in southeastern Florida.

The Greater Everglades ecosystem is characterized by low topographic relief. Large areas are less than 20 feet above sea level. The slope from Lake Okeechobee south is almost imperceptible, changing only a few inches per mile. The nearly flat topography, proximity of hundreds of miles of coastline, and high annual rainfall has resulted in characteristic wetlands, making much of the area susceptible to flooding. In addition, subtle changes in land

elevation (for example, due to subsidence) or a slight rise in sea level can significantly affect the natural landscape due to shifts in freshwater flow resulting in saltwater intrusion and coastal flooding.

Three major aquifer systems exist within the upper part of the thick carbonate sediments and rock that lie beneath the Greater Everglades area (fig. 3). The aquifers, which are separated by confining or semi-confining layers, are the surficial, the intermediate, and the Floridan systems. The upper 250 feet of the surficial aquifer system, which includes the highly permeable Biscayne aquifer, is the principal source of freshwater for more than 5 million people in southeastern Florida. In addition, the surficial aquifer interacts directly with surface waters of the freshwater and coastal wetlands affecting plant communities and native habitats. The intermediate aquifer system, which underlies the surficial aquifer system, is a source of freshwater primarily along the Gulf Coast. The Floridan aquifer system, which is the principal source of fresh ground water in many parts of Florida, is the deepest aquifer in the Greater Everglades area; however, south of Lake Okeechobee, water in the Floridan aquifer system is too mineralized for most uses.

Human Factors Stressing the Ecosystem

The principal human factors affecting the Greater Everglades ecosystem and competing for freshwater are population growth, expanding urbanization, and agriculture; factors that did not exist a little more than 100 years ago. In the mid-1800s, South Florida was a lush,

subtropical wilderness, with few inhabitants. The Kissimmee–Okeechobee–Everglades watershed provided the freshwater that sustained high terrestrial and coastal productivity. Dade County in 1890 had a population of fewer than 1,000, but between 1894 and 1896 as the Flagler Railroad extended from West Palm southward, the city of Miami began to grow

(George, 1996). However, the new citizens of South Florida regarded area wetlands as inhospitable and without intrinsic value, and some saw the potential for development and agriculture. The conflict of human versus natural elements in South Florida began in earnest in the early 1900s when draining the wetlands was first considered essential for commerce and human safety. Loss of life due to hurricane-related flooding in the 1930s accelerated drainage projects, culminating with Congressional authorization of the Central and Southern Florida (C&SF) Project in 1948.

In 1990, 872 million gallons of water per day—94 percent of which was ground water—were used by the nearly 6 million people in the Greater Everglades area. Agriculture used 2,735 million gallons per day, divided nearly evenly between ground water and surface water. Furthermore, more than 1,400 miles of primary canals and more than 100 water-control structures provide drainage and water supply in the Greater Everglades area, and 50 percent of the original wetland areas in South Florida no longer exist. Much of the surface water flow within the Greater Everglades is now fragmented and disrupted by these canals and flood controls, changing the quantity and natural timing of delivery, as well as the quality of water in the system. Today, water flows from the Kissimmee River into Lake Okeechobee, and outflow from the

Hydrogeologic unit		Approximate thickness, in feet
SURFICIAL AQUIFER SYSTEM	Biscayne Aquifer	20-100
	Confining beds	0-60
	Water-table Aquifer	25-160
INTERMEDIATE AQUIFER SYSTEM	Confining unit	20-100
	Sandstone Aquifer	0-100
	Confining unit	10-250
	Mid-Hawthorn Aquifer	0-130
	Confining unit	100-400
FLORIDAN AQUIFER SYSTEM	Lower Hawthorn producing zone	0-300
	Upper Floridan Aquifer	700-1,200
	Middle confining unit	500-800
	Lower Floridan Aquifer Boulder zone	400
		1,400-1,800
	Sub-Floridan confining unit	1,200?

Figure 3. Hydrologic units, in increasing order of depth (and age) from top to bottom.

lake is through human-made canals. Part of the outflow passes through the Everglades Agricultural Area (EAA) and the Water Conservation Areas into Everglades National Park (ENP), and then through marshes, ridges, and sloughs to Florida Bay or the southwest coast; part flows to Biscayne Bay and Biscayne National Park (BNP). Ultimately, freshwater that enters the bays, feeds into the marine circulation system, affecting life along the Gulf Coast and within the reef tract from Key Biscayne to Dry Tortugas National Park. These changes in flow have stressed the natural system as evidenced; for example, by 50 percent reduction in original extent of the Greater Everglades, reductions in bird populations, and declines in fish and shellfish in adjacent coastal systems (South Florida Ecosystem Restoration Task Force FY1999-2000 Biennial Report, March 2001; 14 pages).

Environmental impacts of these changes, coupled with the demand for freshwater, include alteration of flow patterns; soil loss and subsidence due to agriculture and drainage; degradation of water quality including nutrient

enrichment and contamination by pesticides and mercury; fragmentation of the landscape and the loss of wetlands and wetland functions; impairment of estuarine and coastal resources; and significant declines in native plants and animals, as well as widespread invasion by exotic species.

Finding the Balance: the Future of the Ecosystem

Resource managers must serve competing needs for freshwater and, at the same time, conflicting needs for flooding (e.g., the natural system) and flood protection (e.g., the human system) within the Greater Everglades ecosystem. The large human population, concentrated near the coast (see fig. 1), requires a steady supply of high-quality freshwater for human-related use and consumption as well as protection from flooding. Similarly, agriculture, which is dominantly in the northern and southeastern rangeland and wetland areas, requires seasonal availability of water and flood protec-

tion. The natural areas—which are mostly within publicly controlled parks, preserves, aquatic and terrestrial sanctuaries, conservation areas, and refuges—requires water low in nutrients, seasonal wet and dry periods, and occasional periods of flooding, drought, and fire to remain healthy. However, upstream agricultural areas, are sources of nutrients to the natural areas.

South Florida will continue to be affected by many natural and human-induced stresses, such as sea-level rise, climate variability and climate change, and the demands of urbanization, agriculture, and the natural environment. Accommodating diverse needs for a steady water supply, enhanced flood protection, and a healthy ecosystem is the challenge of restoration.



Figure 4. Flood control structure.

USGS'S STRATEGIC SCIENCE PLAN AND GREATER EVERGLADES ECOSYSTEM RESTORATION

7

RESTORATION: GENERAL DEFINITIONS

Ecological restoration is "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed." (Society for Ecological Restoration Science & Policy Working Group, 2002, "The Society for Ecological Restoration Primer on Ecological Restoration," <http://www.ser.org/>, accessed 6/4/2002).

Ecosystem restoration is "the emulation of naturally functioning, self-regulating systems integrated with the ecological landscape." Restoration requires the reestablishment of ecosystem structure, processes and function including related biological, chemical and physical characteristics (adapted from several sources including: South Florida Everglades Restoration Task Force Science Subgroup Report (1993), and National Academy of Science, National Research Council Report entitled "Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy" (1992).

The overarching goal of the Comprehensive Everglades Restoration Plan, approved in the Water Resources Development Act of 2000, is "the restoration, preservation, and protection of the South Florida Ecosystem while providing for other water-related needs of the region, such as flood protection and water supply." That plan, led by the U.S. Army Corps of Engineers, the South Florida Water Management District, with concurrence by the Department of the Interior is the blueprint for the mechanics of Greater Everglades restoration. The South Florida Ecosystem Restoration Task Forces Science Sub-Group Report (1993) stated that the goal of Greater Everglades Ecosystem Restoration (GEER) should be to establish a healthy, sustainable ecosystem that includes humans and human activities. The report goes on to state that the idealized goal is to restore hydrologic and ecologic structure and function of the system to conditions that existed prior to significant human alteration of the environment, and to reinstate ecosystem integrity and sustainable biodiversity. A restored ecosystem would be more resilient to

stress and catastrophic events, and would require little human intervention (Science Sub-Group Report, 1993).

The scope of GEER encompasses more than just the CERP (fig. 5). Greater Everglades restoration includes the U.S. Fish and Wildlife Services Multi-Species Recovery Plan (MSRP) and the restoration of more than 3 million acres of DOI-managed parklands, wildlife refuges, and preserves. Science in support of GEER focuses on the three major restoration goals outlined by the South Florida Ecosystem Restoration Task Force. Those goals are (South Florida Ecosystem Restoration Task Force, 2000):

Restoration Goal 1: "Get the water right;"

Restoration Goal 2: "Restore, preserve, and protect natural habitats and species;"

Restoration Goal 3: "Foster compatibility between the built and natural system."

In addition, science information as well as restoration-related science tools and technologies derived from addressing the issues of GEER provides valuable information for management

of DOI trust lands and trust species that falls outside the immediate scope of restoration (fig. 5) as well as providing valuable knowledge applicable to other similar restoration initiatives throughout the nation.

The three restoration goals address the essential components of the ecosystem—the physical-chemical, the biological, and the human. The Greater Everglades ecosystem is an interconnected mosaic of habitats, dominated by wetlands, and the life cycles of animals and plants within these habitats are dependent on the seasonal differences in the availability of freshwater. Too much or too

restore the natural patterns, timing of delivery, quantity, and quality of freshwater feeding the system. Although hydrologic restoration will take place primarily within the freshwater ecosystem, freshwater restoration will contribute to restoring the downstream estuarine and marine components of the system. Restoration Goal 1: “Get the water right” will promote restoring natural habitats, which will promote restoration of biological functions (Restoration Goal 2). However, restoring habitats and biological function likely will involve additional efforts, such as removing exotic species and reintroducing native species. Ultimately the success of

restoration will depend on the ability to find the balance between human needs and the needs of the ecosystem by fostering the compatibility of the natural and the built systems (Restoration Goal 3).

The linkage between management information needs – i.e., management-relevant *outcomes* – and basic science questions, or objectives, can best be illustrated with a “pyramid of knowledge” (see figure 6). At the *apex* of the pyramid is the specific restoration-related *outcomes* – that is, the restoration/resources management decisions in which science is a critical or key component in the decision process. At the *base* of the pyramid is the fundamental science necessary to understand the ecosystem – i.e.,

Greater Everglades Ecosystem Restoration Goals

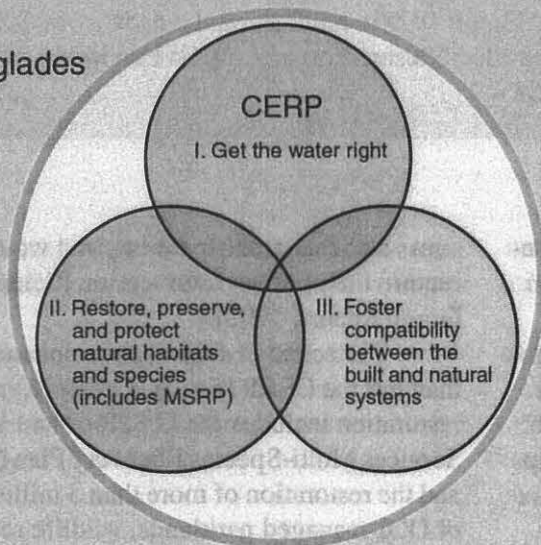


Figure 5. Goals of Greater Everglades Ecosystem Restoration.

little water at the wrong time can significantly impact recruitment success of many species. Degradation of the Greater Everglades ecosystem can be attributed to fragmentation of habitats within the system and water controls that have changed the timing and delivery of water. Therefore, the first step in restoring the Greater Everglades ecosystem is to “Get the water right” (Restoration Goal 1). Specifically,

the mission-oriented science objectives or basic science questions. This “pyramid of knowledge” builds the science from experimental and empirical science through information gathering and monitoring, to science integration and decision support tools, and ultimately relate to management questions and management decisions.

A fundamental understanding of the Greater Everglades ecosystem is required for science-based restoration and resource management decisions. The purpose of USGS's Greater Everglades Science Initiative is to ensure that, in partnership with our many South Florida restoration partners, this fundamental understanding of ecosystem process, structure, and function is developed. A significant part of USGS's research initiative is to integrate the ecosystem science through the development of decision support tools, specifically through the development of integrated models, including hydrologic models, ecological models, chemical models, and geographic and landscape models. This USGS "strategic" plan will help guide and prioritize future science and scientists working within the Greater Everglades ecosystem towards the information needs of restoration/resource managers.

Monitoring allows us to **Observe Change**
Monitoring + Experimental allows us to **Understand Change**
Monitoring + Experimental + Modeling allows us to **Predict Change**

To successfully implement and adaptively manage Greater Everglades Ecosystem Restoration, we must be able to predict the impact of our restoration actions on the natural system.

Most of the science needs listed throughout this Plan were gleaned from the DOI Science Plan (2003), from the CERP's Monitoring and Assessment Plan (2003), from recommendations in various Science Coordination reports (1998, 1999, 2003) and CROGEE reports (CROGEE is the National Academy of Sciences/National Research Councils Committee on Restoration Of Greater Everglades Ecosystem) (NRC, 2002, 2003), from NAS/NRCs report on DOI's Critical Ecosystem Studies Initiative (NRC, 2003) and from the General Accounting Offices report on science in South Florida Ecosystem Restoration (GAO, 2003).

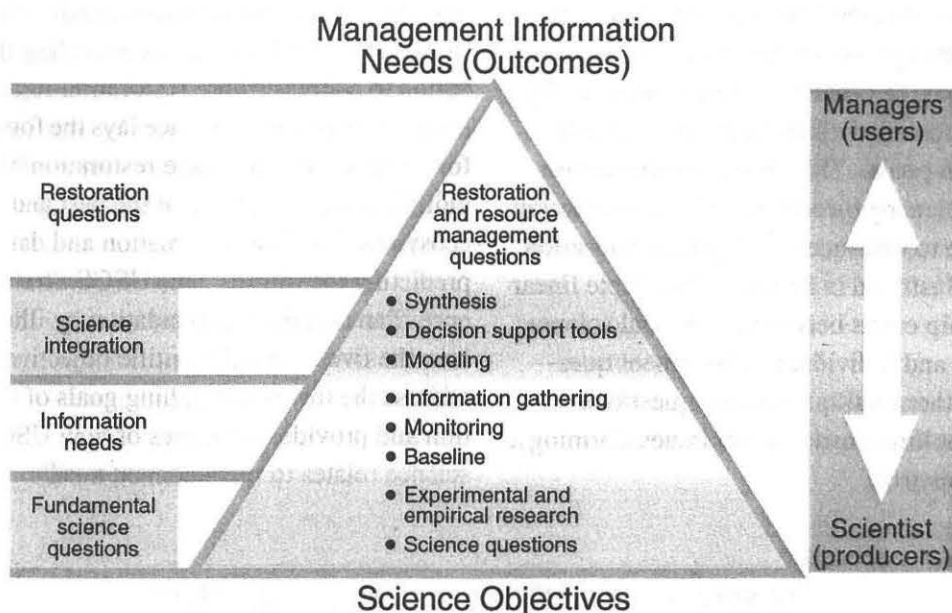


Figure 6. Linkage between management information needs and basic science questions.

The USGS, in conjunction with cooperators and collaborators, is addressing the three goals of restoration with the following science objectives. These Science Objectives can also be restated as Questions as follows:

	Science Objectives	Questions
1	Understand ecosystem structure and processes (physical, chemical, and biological).	How does the Everglades ecosystem function?
2	Determine the historical ecological setting of the Everglades.	What did the natural Everglades ecosystem look like?
3	Establish ecosystem baselines and variations for restoration targets.	What does the Everglades look like today?
4	Monitor ecosystem response to change.	How is the Everglades ecosystem changing?
5	Predict ecosystem response to anthropogenic and natural change.	What could the Everglades ecosystem look like tomorrow?

These five science objectives, or questions, encompass a broad spectrum of interrelated research topics and scientific expertise (fig. 7) that cross USGS disciplines and programmatic themes. The science objectives are interdependent—each relying on data and outcomes from the others, and each science objective may contribute information to several restoration goals. This relationship between the five science objectives and the contribution of science to the three overarching restoration goals is illustrated in figure 8. No simple linear relationship exists between individual science questions and individual management questions. Rather, multiple science questions address multiple management issues, forming a complex matrix.

Specific restoration-related management issues will naturally change in response to emerging public concerns. Restoration science, when strategically planned and implemented, addresses these management needs – both immediate needs as well as providing the foundation to address future restoration-related management needs. Science lays the foundation for successful, sustainable restoration by providing an understanding of the past and present ecosystem, and the information and data for predicting the future. This USGS Strategic Science Plan details this foundation by illustrating how the five general scientific objectives address the three overarching goals of restoration and provides examples of how USGS's science relates to management needs.

The science objectives are interdependent; each relying on data and outcomes from the others, and each science objective may contribute information to several restoration goals.

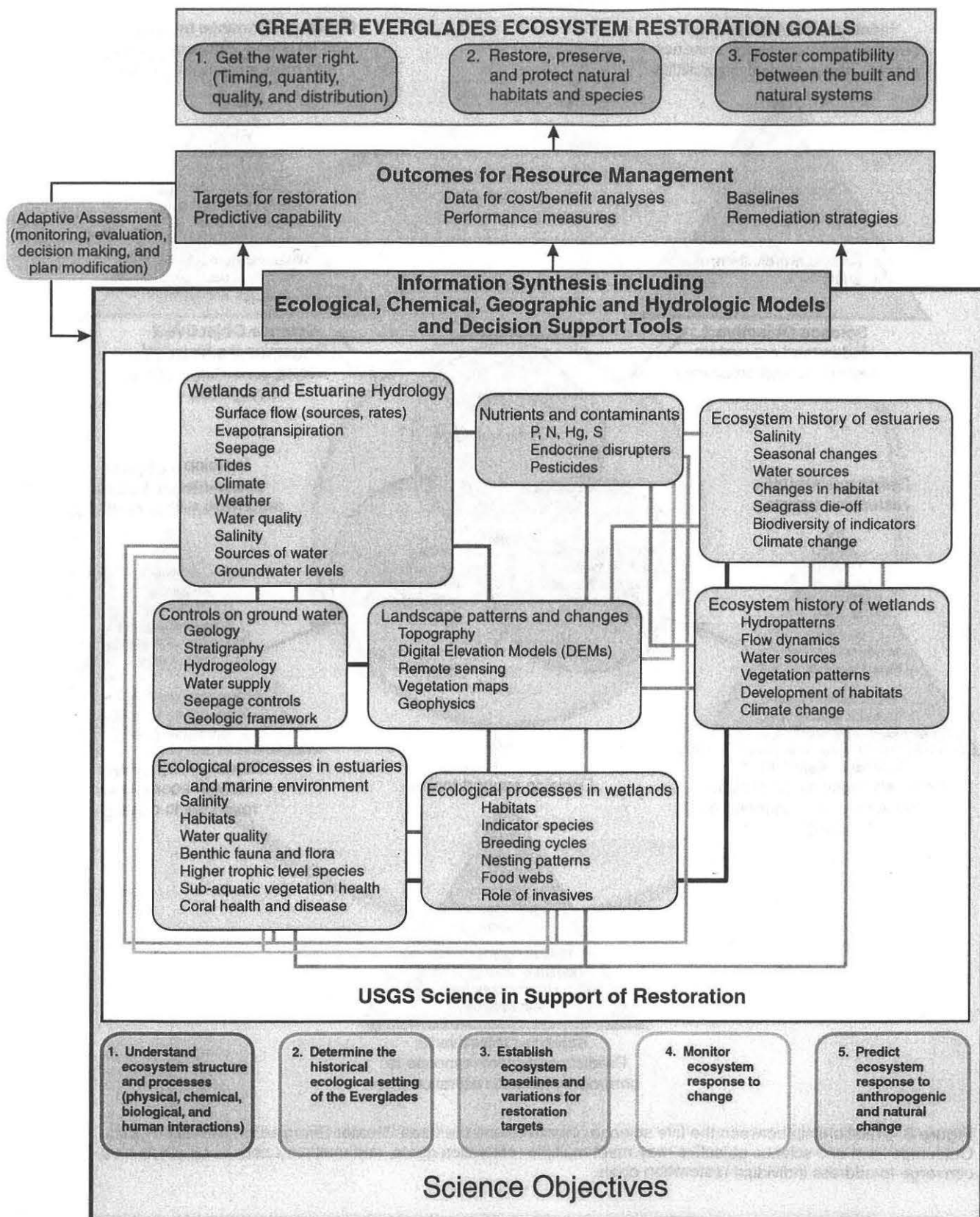


Figure 7. Role of USGS science in achieving restoration goals. The five USGS objectives are met by integration of multidisciplinary science results that address the needs of management, and restoration decision-making.

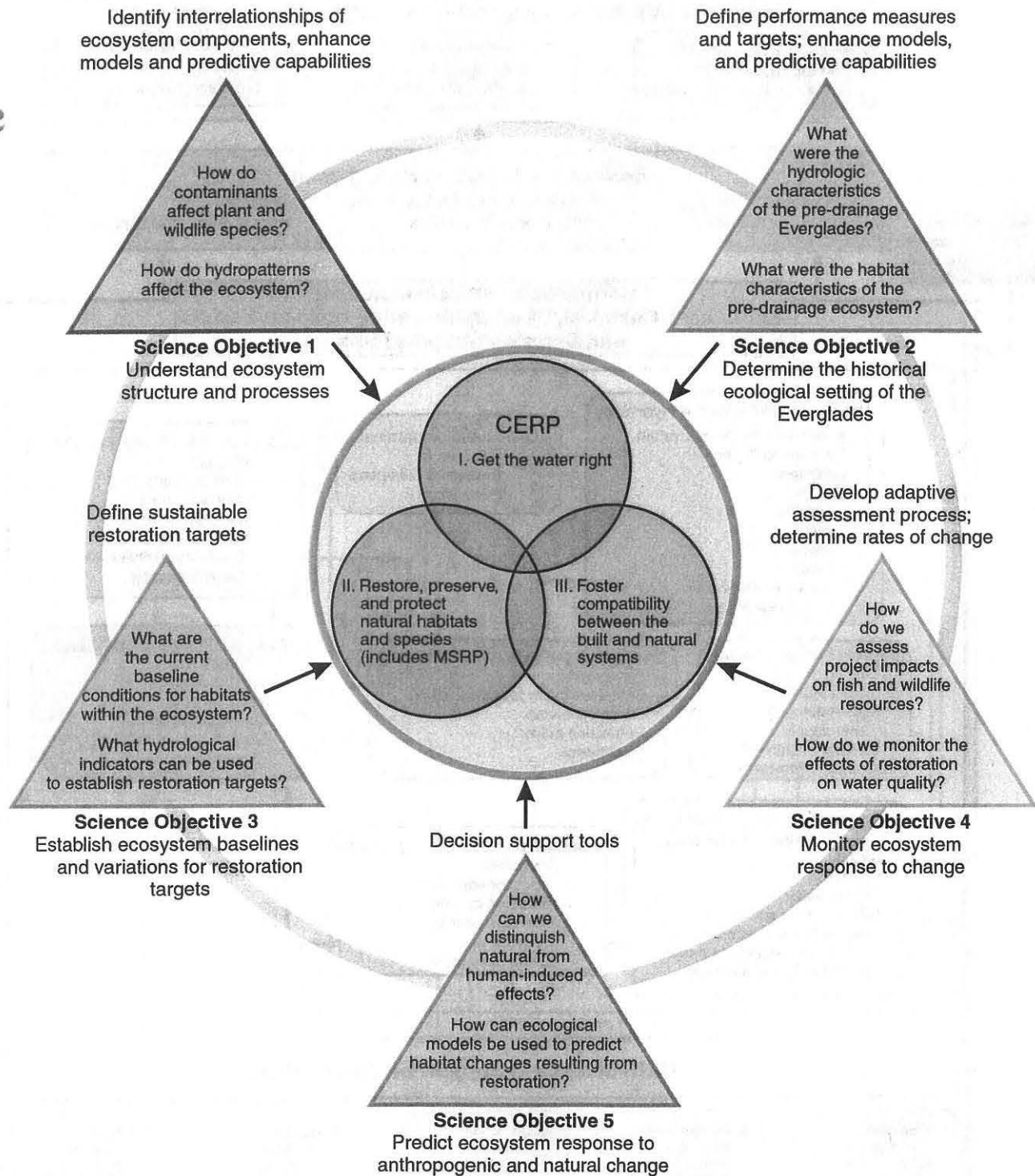


Figure 8. Relationship between the five science objectives and the three Greater Everglades restoration goals. Outcomes from one science objective may meet multiple restoration goals, and multiple science objectives may converge to address individual restoration goals.

RESTORATION GOAL 1: GET THE WATER RIGHT

13

Based on the consensus of the South Florida Ecosystem Restoration Task Force, the water will be right when the following conditions are met:

“ Natural hydrologic functions are restored in wetland, estuarine, marine, and ground water systems, while also providing for the water resource needs of urban and agricultural landscapes. Natural variations in water flows and levels are restored without diminishing essential levels of water supply or flood control. Compartmentalization is reduced, and natural patterns of sheet flow are recovered to the maximum extent possible.

Water resources accommodate the needs of natural systems, communities, and business. Safe drinking water is available for the people of South Florida. Damage caused to water quality by pollutants and contaminants (such as from agricultural nutrients or urban-related pollutants) is eliminated. Water levels and the timing of water deliveries reflect quantities resulting from natural rainfall and are distributed according to natural hydrologic patterns or patterns modified by scientific consensus. Damage to natural and human systems caused by flood and drought is minimized. Ground Water resources are protected from depletion and contamination.”

South Florida Ecosystem Restoration Task Force
Coordinating Success, 2002, pages 31-32.

RESTORATION GOAL 1.1: HYDROLOGY

Species, habitats and landscapes of the Greater Everglades are integrally linked to the hydro-pattern that drives the ecosystem. Therefore, understanding the relationship between hydro-pattern and ecosystem processes, structure and function is essential for achieving the goal of "Get the Water Right." The ultimate test for success or failure to "Get the Water Right" lies not in "hydrology" but in the restoration of species, habitats and landscapes.

Science Objectives (SO) and Questions Related to Restoration Goal 1.1: Hydrology

Science Objective 1: Understand ecosystem structure and processes (physical, chemical, biological, and human interactions).

- How do hydro-patterns and flow affect the Greater Everglades ecosystems?
- What are the sedimentation and evapotranspiration rates?
- What are the effects of sea-level changes?
- What are the effects of ground-water and surface-water interactions?
- What are the effects of vegetative resistance on flow?
- What controls circulation and flushing in coastal and estuarine ecosystems?
- What are the hydrogeologic controls on aquifer storage and recovery (ASR)?
- What are the benefits and impacts of Water Preserve Areas (WPA) to restoration?
- What effects will seepage barriers have on ground water levels and on saltwater intrusion?

Science Objective 2: Determine the historical ecological setting of the Everglades.

- What were the physical hydrologic characteristics of the pre-drainage Everglades ecosystem?
- What pre-drainage characteristics are essential to restore ecosystem health?
- What hydro-pattern frequency and dry-down durations are needed?

Science Objective 3: Establish ecosystem baselines and variations for restoration targets.

- What are sustainable restoration targets?
- What hydrological indicators can be used to establish short-term and long-term restoration targets?
- How can reasonable restoration targets be determined and their potential for success and sustainability ranked?
- How have human-made conveyances (canals) and barriers (such as levees and highways) altered historical water levels and flows?

Science Objective 4: Monitor ecosystem response to change.

- Are restoration projects and resource-management actions achieving restoration?
- How do we optimize hydrologic monitoring to assess project impacts and their effects on fish and wildlife resources?

Science Objective 5: Predict ecosystem response to anthropogenic and natural change.

- What natural changes will impact restoration and how can we distinguish natural from human-induced effects?
- What are the predicted impacts and benefits of restoration projects on the Greater Everglades ecosystem?
- What are the predicted effects of changes in water management?
- What are the predicted effects of specific structures and (or) projects?
- How should the water management system be operated to achieve restoration?
- How can we accurately forecast the impacts of proposed changes to the system?
- How do we obtain the best science and hydrologic models to support restoration?
- How have human-made conveyances (canals) and barriers (such as levees and highways) altered historical water levels and flows?

Ecosystem History: Clues in the Sediments

The layers of sediments that accumulate on the earth's surface over time contain clues about what the environment was like in the past. Paleocologists, sedimentologists, geochemists, geochronologists and biochemists are working together to recreate the prior history of the ecosystem using the sedimentary record. By improving our understanding of that earlier environment, land managers can make more knowledgeable decisions regarding south Florida's restoration.

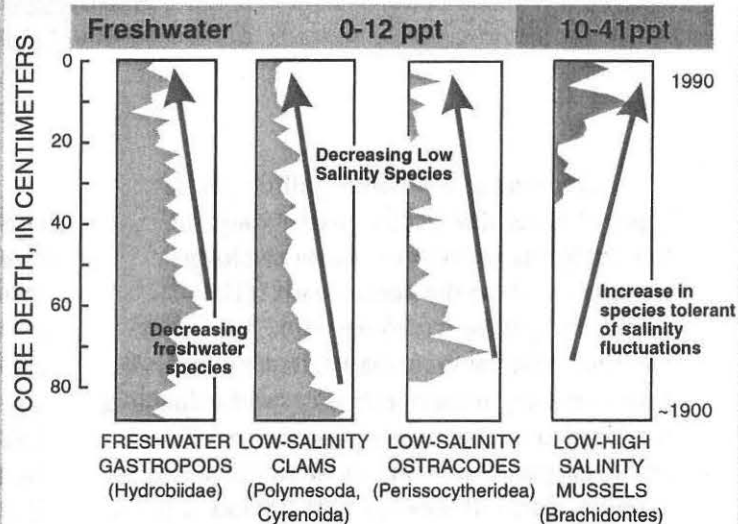
In south Florida shallow cores (see illustration) have been collected throughout the ecosystem in different environments. The cores are examined for signs of disruption by storm erosion, bioturbation, or human activities. If the cores look relatively free of disruption, they are cut into thin slices, each representing an increment of time, which is determined by the geochronologist using radiometric dating methods. The geochemist looks at changes in sediment composition over time, for example increases in nitrogen or phosphorus that may be important environmental indicators of change.

The paleocologists remove plant and animal remains from the core samples to reconstruct what environmental conditions existed at the site in the past. Their interpretations are based on a thorough understanding of the ecology of the modern organisms and follow a basic principle in paleoecology—the present is the key to the past. For example, if a gastropod is known to live in Florida Bay today in waters ranging from 18-35 ppt (parts per thousand salinity) and to live on seagrass, it is assumed that it existed under those same conditions in the past. The presence of that gastropod in a segment of a core then provides information that the water may have been 18-35 ppt and seagrass may have been present at the time the sediment was deposited. The information from this single gastropod is combined with information from multiple species and multiple groups of animals and plants to increase confidence in the interpretations, and these data are compared to the geochemical data. A picture develops of what the environment was like at the core site at different points in time (see illustration). This historical information illustrates natural ranges of variability in the ecosystem over time, and allows land managers to set realistic targets for restoration.



Note: Scale is approximate due to oblique projection of the x-ray source on film.

X-rays of two sediment cores from Featherbed Bank, Biscayne Bay, collected in 2002. Scale is in centimeters.



Plots show fluctuations in salinity indicator species in a core from near the mouth of Taylor Creek, Florida Bay. Core depth is shown on the left vertical axis in centimeters, approximate year of deposition on the right. Percent abundance of the individual species increases from left to right on the horizontal axis. During the 20th Century freshwater influx decreased, raising the salinity, and increasing fluctuations in salinity.

Drainage of the Everglades, beginning in 1880 and accelerated by the 1948 Congressionally authorized C&SF Project, has changed South Florida from a subtropical wetland to a human-dominated landscape (see Science Information Box A – Ecosystem History). At present (2003), the Everglades is half its

original size, water tables have dropped, hydro-patterns have been altered, flows have been diverted, wetlands have been impounded, wildlife has been reduced, water quality has been degraded, and habitats have been invaded by nonindigenous plants and animals (Sklar and others, 2002).

"Today, the C&SF Project is the backbone of South Florida's system of water management. But because of an unpredictably high increase in population and, until recently, a lack of understanding of the natural systems, the project has had unforeseen environmental effects. Compartmentalization of the remaining Everglades into a series of Water Conservation Areas (WCAs) has disrupted sheetflow patterns throughout the Everglades, and has caused an artificial pattern of impoundment. As a result, there are unnaturally large releases during the wet season and a reduction of total flow of freshwater into the mainland estuaries and Florida Bay during the dry season (Fennema and others, 1994; Van Lent and Johnson 1993; Ogden and others, 1999). In many regions, slow moving sheet flow has been replaced by faster moving canal flows."

Total System Conceptual Ecological Model
Ogden, J., Barnes, T., and Davis, S., 2003.

On average 1.7 billion gallons per day (gpd) of water that once flowed through the South Florida ecosystem is now discharged through canals to the ocean or gulf (USACE, 1999). To "get the hydrology right," the CERP and other restoration initiatives include projects for recapturing most of this water and redirecting it to sustain natural system functioning (fig. 9) and to supplement urban and agricultural water supplies. Some of these projects include aquifer storage and recovery, in-ground reservoirs and seepage controls, and water preserve areas (WPAs).

Regional aquifer storage and recovery (ASR) is proposed by CERP as a cost-effective means of meeting future water-supply needs for South Florida. The proposed project includes about 330 ASR wells (fig. 10), each having a capacity to inject or recover 5 million gallons per day, to be constructed in inland areas around Lake Okeechobee, central Palm Beach County, along the Caloosahatchee River in Hendry County, and possibly in other areas of the system. Recovered water will be used to: maintain optimal water levels in Lake Okeechobee (for improved lake management) and wetland areas;

replace evaporative losses and reduce seepage from reservoirs; minimize land needed for surface storage; and reduce surface-water flows to estuaries and bays during storms.

Another proposed CERP project for retaining surplus wet-season water is to develop in-ground reservoirs. In-ground reservoirs (reservoirs where the bottom is significantly deeper than land surface), varying in size from

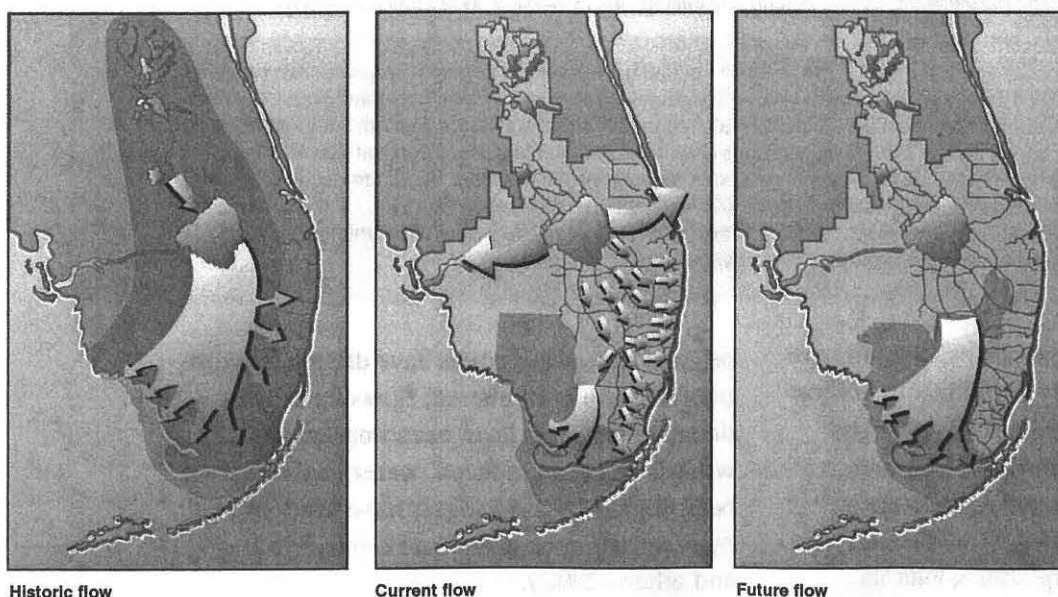


Figure 9. Historical, current and future water flows in the Greater Everglades and adjacent coastal ecosystems.

WHAT IS ASR?

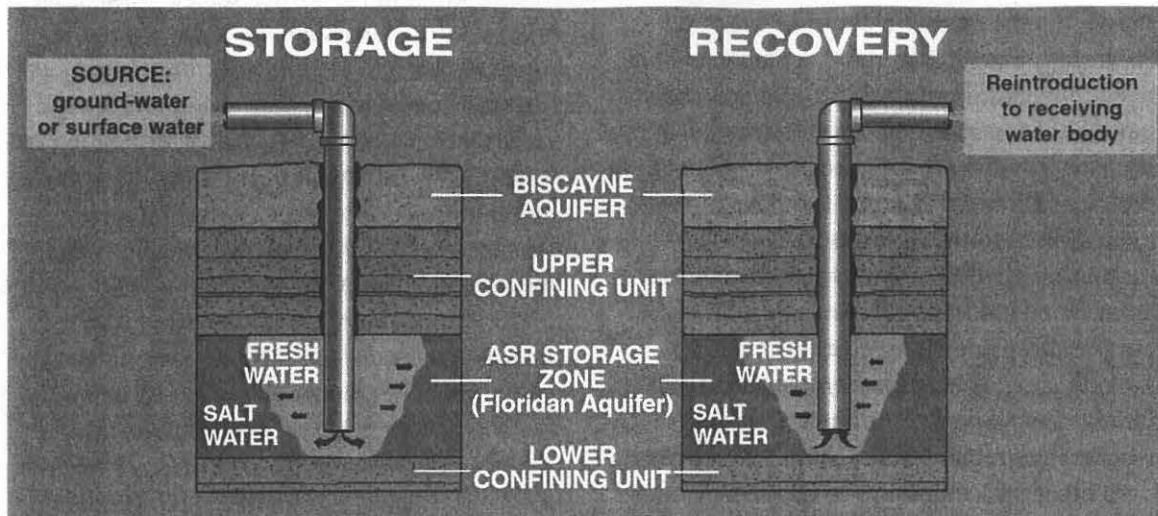


Figure 10. Aquifer storage and recovery wells.

1,200 to 5,200 acres, will include above-ground storage of up to 16 feet for the wet season and sufficient capacity to be drawn down as much as 30 feet below land surface in the dry season.

One of the goals of Greater Everglades restoration is to increase flows and water levels in Northeast Shark River Slough of ENP. Currently, water is lost from the slough by seepage into L-31N. The proposed CERP project, L-31N seepage management control, will use a barrier wall to reduce seepage from the slough into and across L-31N. This project will also increase flows and water levels in the slough during the wet season by capturing water with a series of ground-water wells adjacent to L-31N, then back-pumping that water into the slough.

The concept of water preserve areas (WPAs) was initially proposed by the National Audubon Society (1994) to capture and store surface water normally discharged to the coast through the Central and Southern Florida Project canal system (USACE, 1999, 2001). Today, water preserve areas are a series of marshes, reservoirs, and ground-water recharge areas along the east side of the Water Conservation Areas within Palm Beach, Broward, and Dade Counties and generally west of existing developed areas. Components of the WPAs include (or could include) marshes, step-down

water levels, recharge areas, reservoirs, seepage collection systems, curtain walls (impervious underground barriers), and stormwater treatment systems (marsh or filtering facilities). Water Preserve Areas should enhance regional capabilities for meeting environmental, urban, and agricultural water demands, while providing protection of certain designated wetlands outside the Water Conservation Areas and ENP.

Linking Science and Restoration Goals

The South Florida ecosystem evolved under hydrologic conditions that included flooding and sheetflow across broad expanses of the southern peninsula of Florida. Vegetative assemblages formed in response to the flooding depths, seasonal period of flooding (hydropatterns), and flows. Subtle differences in topography determined these flooding characteristics and ultimately the types of biological communities that developed. The flow of water across the landscape eventually entered the coastal environment where the mixing of fresh and salt waters created estuarine conditions characteristic of the coastal Everglades ecosystems. Urban and agricultural development in South Florida has resulted in changes in the hydrologic regime, including changes in hydropatterns and flows in wetland and estuarine systems, and changes in ground- and surface-water interactions.

To achieve Greater Everglades restoration, science must be linked to restoration, as shown in the example pyramid, "Get the Hydrology Right" (fig. 11). A science objective to meet this restoration goal generates a number of interdisciplinary science questions, such as: What were the predevelopment hydrologic conditions? What are the rates of sedimentation? sediment transport? evapotranspiration? How do hydropatterns determine landscape patterns and flows? To answer these questions, scientific studies including ecosystem history, baseline studies, monitoring, experiments and empirical research are required, and these studies along with other information provide the basis for developing integrated models that help managers to meet restoration goals.

Science Information Needs

Although extensive data and research exists on the hydrologic environment in the Greater Everglades, additional information is needed to better understand and predict how specific restoration projects will affect the ecosystem. This information is needed to develop and monitor restoration targets, to track changes in the hydrology, and to record and understand how specific CERP and other restoration projects affect the ecosystem. Most of the science needs listed below were gleaned from the DOI Science Plan (2003), from the CERP's Monitoring and Assessment Plan (2003), and from recommendations in various CROGEE reports (CROGEE is the National Academy of Sciences Committee on Restoration Of Greater Everglades Ecosystem). The

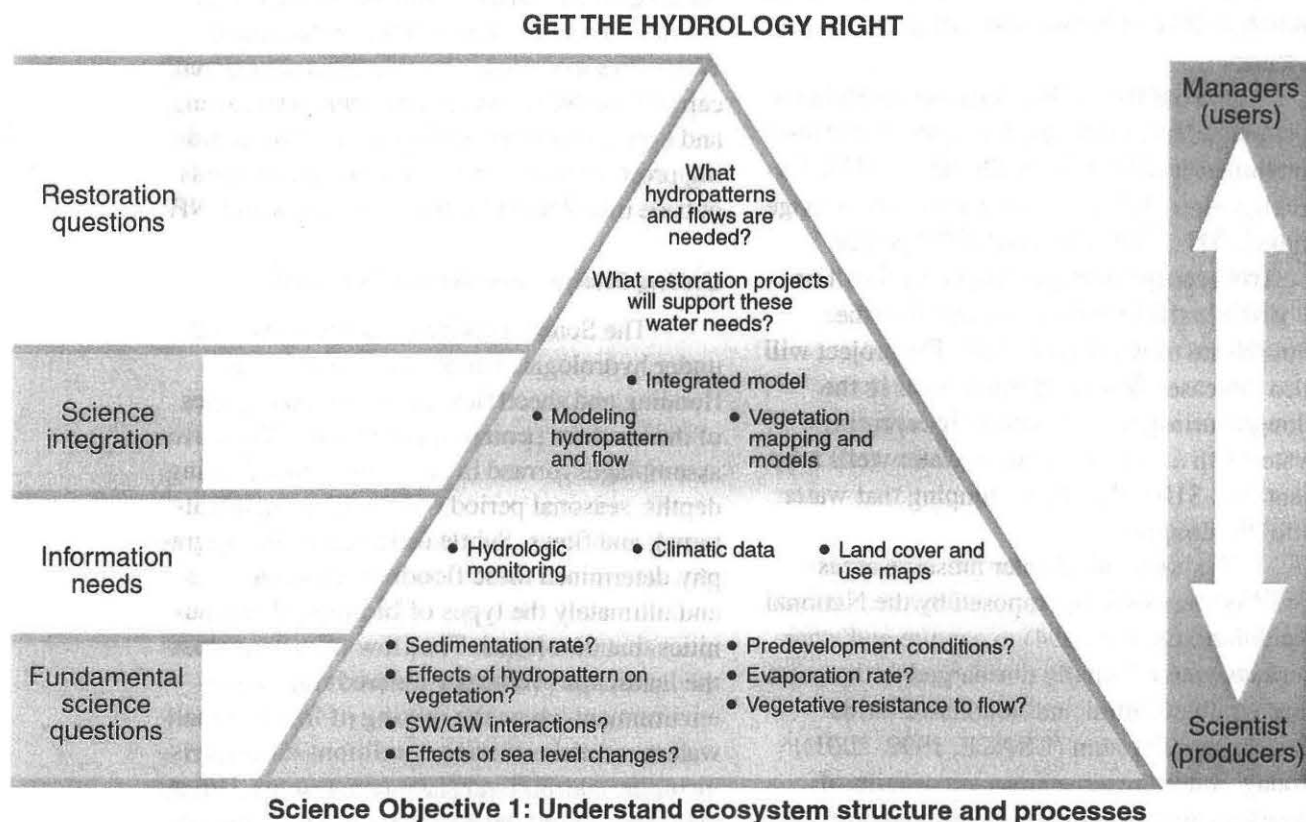


Figure 11. Relation between Restoration Goal 1: Water - Get the Hydrology Right, and the Science Objective 1: Understand ecosystem structure and processes.

.... additional information is needed to better understand and predict how specific restoration projects will affect the ecosystem.

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science needs are organized around major linking themes such as "process," "habitat," "coastal," "modeling," and CERP "projects." In addition, many of the science needs address more than one Science Objective (SO) and related questions (see, for example, fig. 12), showing the linkages between Science Objective 1 and Science Objective 2. The specific science objective(s) addressed by each science need is noted.

Processes:

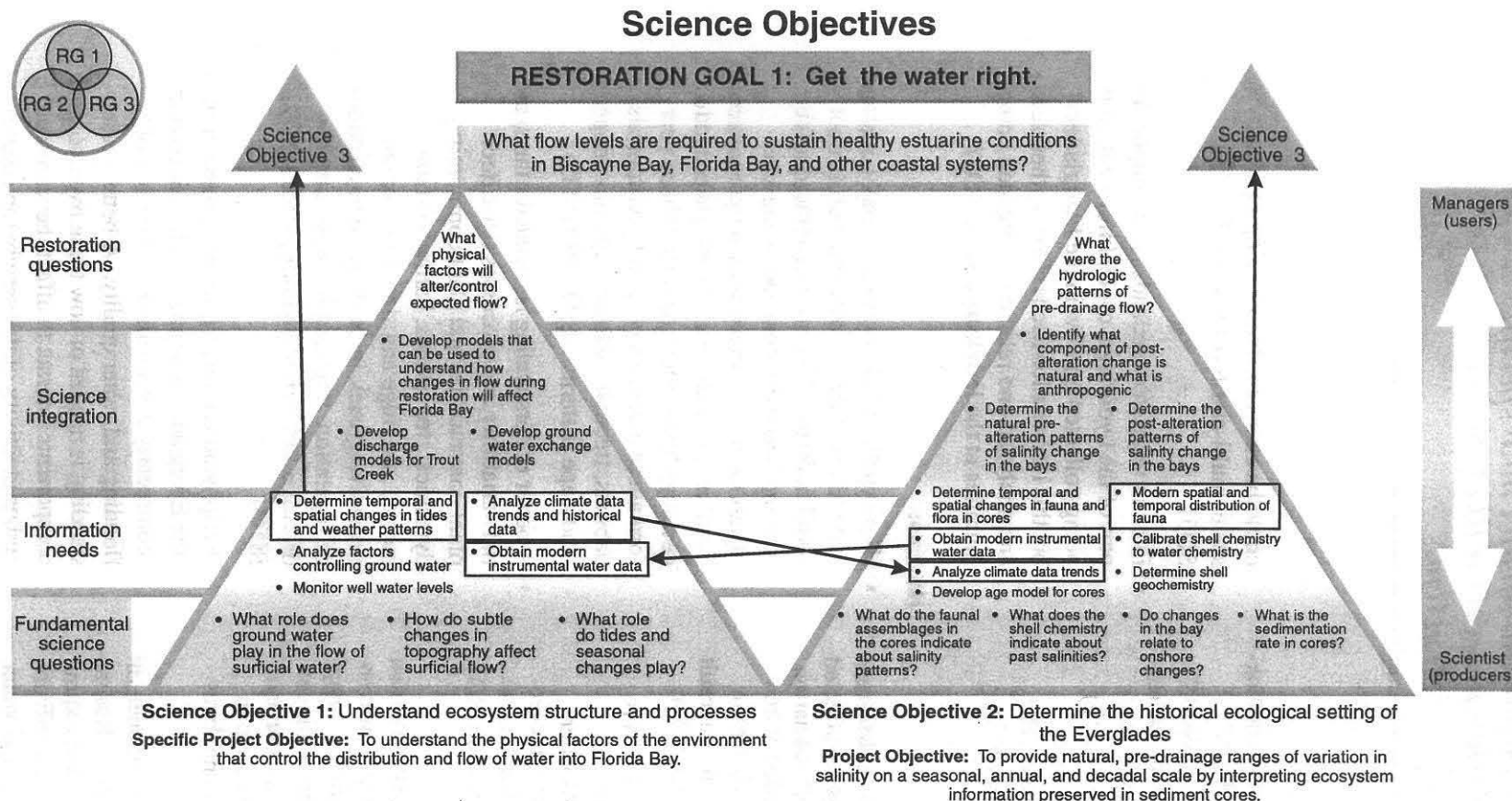
- Peat deposition, oxidation, and subsidence rates throughout the Everglades are affected by water depths and periods of inundation. A better understanding is needed of how these rates will be affected if changes in water depth and inundation occur as a result of restoration efforts. (SO1, SO3, SO4)
- Marl soil formation occurs in the Everglades where suitable geologic and hydrologic conditions exist. A better understanding is needed of what the geologic, hydrologic, and biological requirements are for the marl soil formation. (SO1, SO3, SO4)
- Water flow, inundation, and peat deposition and oxidation in the predevelopment Everglades were controlled primarily by topography. A comprehensive understanding of predevelopment topography, peat deposition and subsidence will be required to maximize restoration efforts in the Everglades. (SO2)
- Ground water is an essential component of the Everglades hydrologic budget. Restoration of the Greater Everglades will require an understanding of the predrainage Everglades hydrology, including ground-water fluxes. Predrainage ground-water fluxes

could be estimated by developing a fine-scale, multi-aquifer model. (SO1, SO2, SO5)

- Flow in vegetated wetlands is an important part of the hydrologic cycle. Information is being collected on flow in the Everglades, but this information needs to be synthesized and analyzed and related to vegetated communities at the landscape scale. (SO3)

Habitats:

- Hydropattern and flow exert a major control on the Everglades landscape, but it is not well understood how they interact to affect the landscape. Restoration of the Everglades will result in changes in hydropattern and flow, so additional research is needed to develop hydropattern and flow-based performance measures for plant communities, habitats, tree islands and ridge-and-slough landscape patterns. (SO1, SO4, SO5)
- A better understanding is needed of the spatial variability and processes that affect plant communities and plant community dynamics, tree islands, hardwood hammocks, and ridge and slough communities in the Everglades, including the interactions of vegetation, topography, soils, and pre-drainage and current hydrology. (SO1, SO2, SO4)
- Periphyton is a major primary producer in the Everglades ecosystem. The periphyton community is controlled by duration of flooding and water quality. A better understanding is needed of how these hydrologic components interact to affect the structure and productivity of the periphyton community. (SO1)



Over forty USGS projects are addressing restoration goals and management questions, but there is not a simple linear relationship between a science question and a management question. As figure 5 illustrated, each science goal contributes to multiple restoration goals, and the science goals themselves are interrelated. The pyramids shown here provide a detailed look at two very different science projects - a hydrologic project primarily focused on addressing science objective 1 and an ecosystem history project primarily focused on science objective 2

Each project begins with a specific objective. In order to achieve that objective, multiple scientific questions must be answered. Answering the science questions involves gathering a broad spectrum of data. In the process of gathering these data, the projects contribute to other science goals, as illustrated by the arrows linking between the pyramids. The outcomes of each project contribute information to the management agents and potentially to other research projects.

In the examples provided here, the hydrologic project develops models that can be used by South Florida Water Management District (SFWMD) and the Army Corps of Engineers (ACOE), as well as other USGS projects, to test and predict how changes in water control structures will affect flow. The ecosystem history project provides information on the pre-drainage ecosystem that can be used by SFWMD and ACOE to set performance measures and restoration targets. Together, these two projects along with many others, address the issue of freshwater flow into the estuaries, and ultimately contribute to restoration goal 1 - getting the water right.

Figure 12. "Pyramids of knowledge" showing linkage between two Science Objectives and related, yet different, restoration-related management questions.

Coastal:

- Everglades restoration may alter flows of freshwater into the coastal ecosystem and thus alter salinity and circulation patterns. We need to better predict the spatial and temporal variations in salinity and circulation in coastal ecosystems that may occur with specific CERP and other restoration projects. (SO1, SO3, SO4, SO5)
- Salinity of estuaries and bays varies with climatic changes and freshwater runoff. A better understanding is needed of how the salinity in estuaries and bays of South Florida has changed over historical periods, and to what degree these changes are related to natural cycles or to human activities. (SO2, SO4)

CERP Projects and Monitoring:

- ASR is proposed as a primary technology to be used to better manage water for both the natural system and human systems. A much better understanding is needed of the effects of ASR on subsurface hydrology and geology to effectively evaluate the regional potential of ASR. (SO1, SO4, SO5)
- Predictive hydrologic models are needed to evaluate the functioning of WPAs. To develop these hydrologic models, more information is needed on ground-water level data, interaction of ground water and surface water, stormwater runoff, evapotranspiration, and seepage. (SO1, SO3, SO4, SO5)
- Restoration will require regionwide hydrologic monitoring that currently is incomplete. The regionwide monitoring network in the Greater Everglades, including areas such as A.R.M./Loxahatchee NWR, the Water Conservation Areas, Big Cypress National Preserve, Everglades National Park, and Biscayne Bay National Parks coastal wetlands, should be expanded to document spatial and temporal variations in hydrologic parameters used in ecological and hydrologic models. (SO4, SO5)

Models:

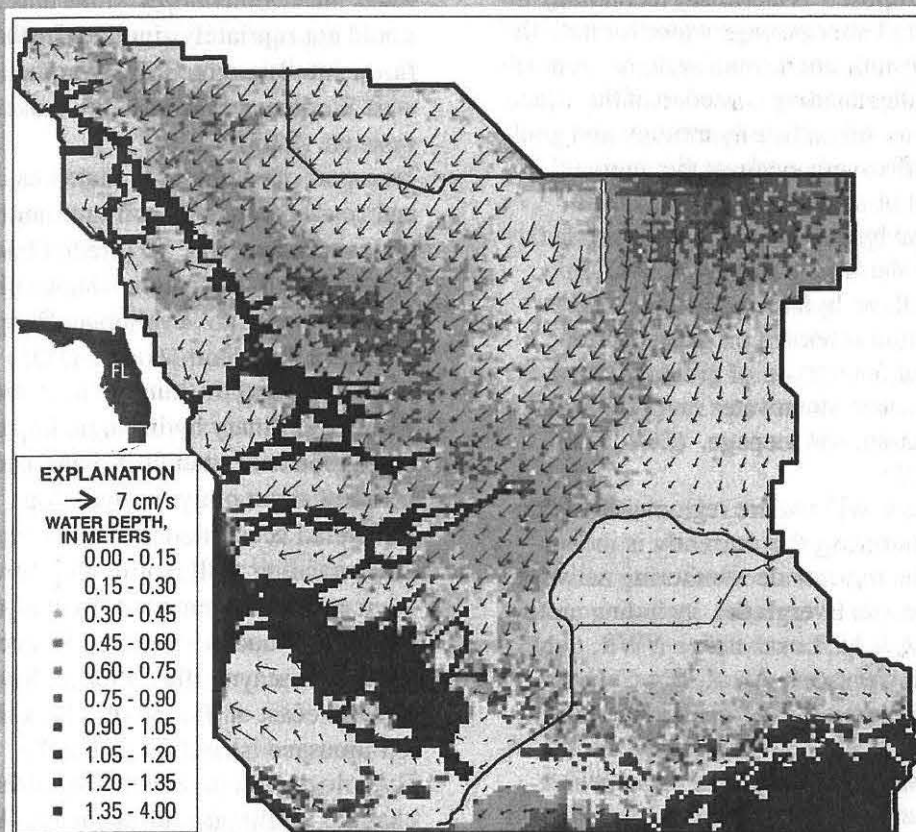
- The Natural System Model (NSM) is used to evaluate predevelopment conditions in the Everglades. Additional calibration and

verification of the model is needed using historical soils maps, photographs, and accounts by early naturalists that visited the region. The NSM can help provide performance measures and habitat suitability indices needed for restoration. (SO2, SO5)

- Restoration will result in changes in the quantity, timing, and distribution of water. There is a need to enhance existing physics-based hydrologic flow models (see Science Information Box B – Hydrologic Models) and to incorporate chemical and sediment transport into these flow models. (SO3, SO4, SO5)
- Freshwater flows of surface- and ground-water to the coast are a major part of the overall hydrologic budget. We need to develop integrated surface/ground-water density dependent models that incorporate water management operations and that could appropriately simulate freshwater flows into Biscayne Bay, Everglades, southwest Florida and Florida Bay coastal ecosystems. (SO5)
- Transport of sediment in marshes, canals, and coastal waters is an important hydrologic consideration. To predict how sediment transport might change with restoration, we need to develop an Everglades Sediment Transport Model. (SO5)
- Circulation and flushing of bays and estuaries are of primary hydrologic importance, and a good understanding of these processes is essential not only for hydrology, but also for overall ecosystem understanding. This understanding will require that development and improvement of hydrodynamic circulation models continue for coastal areas of Biscayne Bay, Florida Bay, southwestern coast of Everglades Park and the ten-thousand island areas. (SO5)
- Hydrology will be affected by global changes in climate and sea level. A better understanding is needed of how these global changes will affect coastal and freshwater ecosystems in the Everglades. This understanding will entail, in part, the development of hydrologic models that simulate changes forced by global climate cycles and changes. (SO5)

Numerical Simulation Hydrologic Models

Numerical simulation models are invaluable predictive tools for use in planning and evaluating ecosystem restoration initiatives in south Florida. USGS's hydrologic models integrate physical and landscape processes to simulate hydrologic conditions likely for various restoration scenarios. Application of the models requires a knowledge of the spatial and temporal behavior of factors that affect flow of water through heavily vegetated low-gradient wetlands. To effectively investigate the mixing of freshwater and salt water in adjacent coastal ecosystems, the models account for inputs from seasonably variable precipitation and structure releases, losses through evapotranspiration and canal diversions, and hydraulic interactions with surficial aquifers. Additionally, the models include the flow-forcing mechanisms of vegetative resistance, bottom and surface stresses, and tidal dynamics. Information about the model and related hydrologic process studies can be obtained from the website <http://time.er.usgs.gov>.



Flow depths and velocity vectors simulated by a numerical model covering the south Florida Everglades from Tamiami Trail to Florida Bay and the Gulf coast.

Restoration Goal 1.2: Water Quality

Runoff from agriculture and stormwater from urban areas has polluted much of the Everglades and Lake Okeechobee and impaired ecological conditions. Phosphorus is a major concern, but it is not the only pollution problem. The water quality of the Caloosahatchee River, St. Lucie Estuary, Biscayne Bay, Florida Bay, the Florida Keys, and the nearshore waters off the coasts already show signs of significant degradation, including eutrophication, excessive salinity range, and short term variability and introduction of anthropogenic agricultural or industrial pollutants. In marine systems, exogenous nitrogen and mercury appear to be of particular concern.

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South Florida Ecosystem
Restoration Task Force
Coordinating Success, 2002, page 36.

High quality water is an essential element of a properly functioning ecosystem. One of the primary goals of the South Florida restoration plan is to improve water-quality conditions in impacted areas, and to design systems that will ensure good water quality in the future. The USGS science objectives below (see text box on page 24) will aid in achieving these restoration goals.

Changes to the hydrology and land-use patterns in southern Florida over the past 100 years have resulted in dramatic changes to water quality in the South Florida environment. This cause-and-effect relationship between ecosystem alterations and water quality underscores the hydrologic, chemical, and biological linkages throughout the Greater Everglades ecosystem and the need for science to aid the restoration decision-making process. What was once almost exclusively an oligotrophic (nutrient limited) wetland with water quality and water levels closely tied to rainfall is now dramatically altered. Water-quality impacts from a variety of human-related activities can be widely demonstrated across South Florida, and as a result, many of the fundamental biogeochemical processes that sustain the unique characteristic of the ecosystem have been modified or completely changed.

Presently, the restoration goal to restore (or at least improve) water quality in the Everglades, and the means by which the restoration plan proposes to achieve that goal, do not appear to be in harmony. Restoration Goal 1: Get the Water Right prescribes actions to restore the hydrology of the Everglades to a more natural condition of sheet flow and a more natural hydroperiod fluctuations. On the other hand, increased flows may likely enhance the transport of many chemical constituents (including contaminants) in the water. Without thorough consideration of how the structure of the ecosystem, internal biogeochemical processes, external driving factors, and the resulting water quality all interrelate, prescribing effective restoration activities that will yield a desirable long-term water quality for the Everglades will be difficult to achieve. Restoring, preserving, and protecting the water quality of the Everglades are essential elements of a successful restoration program that will lead to high-quality natural habitats and abundant species. Water-quality science activities conducted by the USGS will continue to be central toward achieving these overall restoration goals.

Changes to the hydrology and land-use patterns in southern Florida over the past 100 years have resulted in dramatic changes to water quality in the South Florida environment.

Science Objectives (SO) and Questions Related to Restoration Goal 1:2: Water Quality

Science Objective 1: Understand ecosystem structure and processes (physical, chemical, biological, and human interactions).

- What are the water-quality characteristics of a "healthy" Everglades?
- How does water quality relate to the major biogeochemical processes, and current land use and management activities?
- How do we restore and protect water quality in the ecosystem?
- What contaminants ("contaminants" include excess nutrients) are currently present, and what contaminants (and their distribution) might we expect to see after restoration?
- What are ecosystem risks associated with current water quality?
- How do freshwater inflows affect water quality in the coastal ecosystem?
- How do contaminants affect plant and wildlife species?
- Will recovered ASR waters be compatible with receiving environments and aquatic and terrestrial biota?

Science Objective 2: Determine the historical ecological setting of the Everglades.

- What were the water-quality characteristics of the predrainage ecosystem?
- Are there identifiable trends in patterns and timing of water quality changes in the Greater Everglades?

Science Objective 3: Establish ecosystem baselines and variations for restoration targets.

- What are current water quality conditions across the South Florida environment?
- What are current contaminant burdens in plants and wildlife in the Everglades?
- How do we determine reasonable water quality restoration targets and rank their potential for success and sustainability?
- How can we protect those areas currently with good water quality, and can we restore or improve conditions where significant impacts have been observed?
- What contaminants are currently present, and what contaminants (and their distribution) might we expect to see after restoration?

Science Objective 4: Monitor ecosystem response to change.

- What are the relative impacts of the various restoration activities on water quality at the ecosystem scale?
- Do we have the adequate monitoring systems in place to detect changes to water quality in response to restoration activities; and, if not, what systems are necessary?
- How (spatial and temporal scales) do we monitor the effects of restoration activities and water management on water quality?

Science Objective 5: Predict ecosystem response to anthropogenic and natural changes.

- Do we have the necessary tools presently to predict water quality changes? And, if not, what tools are needed?
- What are the predicted impacts and benefits to water quality from restoration efforts:
 - o Impacts or benefits of changes in water supply?
 - o Impacts of specific structures?
 - o Impacts of altered flows on estuary and marine ecosystems?

Plans to implement total maximum daily loads (TMDLs) in the Greater Everglades basin will be an important consideration for "get the water quality right." The TMDLs are the maximum loading of a pollutant (contaminant or excess nutrient) that a water body can assimilate and still meet water-quality standards. TMDLs were established by the 1972 Clean Water Act, which requires states to identify water bodies that do not meet Federal standards. In 1998, there were 712 impaired water bodies listed in Florida and 2,000 segments require TMDLs assessments. The Florida Department of Environmental Protection (FDEP) must conduct TMDL assessments within the Lake Okeechobee and the west coast watersheds of the Greater Everglades, where impaired water bodies or segments exist. To meet the science objectives of the FDEP TMDL program in the Lake Okeechobee and the Greater Everglades west coast watersheds, several tasks must be completed including: physical, chemical, and ecological characterization of the watersheds; identification of

specific parameters of concern (biological/chemical) required to develop TMDLs in these watersheds; establishment of surface water, ground water, and biological monitoring networks to collect additional data in support of the TMDL program; and development of water-quality modeling to help establish TMDLs.

Linking Science and Restoration Goals

To achieve meaningful Everglades restoration, science must be linked to restoration, as shown in this example, Get the Water Quality Right (fig. 13). To meet this restoration goal, one of the science objectives is to Understand Ecosystem Structure and Processes. This science goal generates a number of interdisciplinary science questions, including: What is the occurrence, fate, and transport of nutrients and contaminants? How do contaminants enter the food web? What are the linkages between ecosystem structure and biogeochemistry? And, What is the role of risk assessments in science

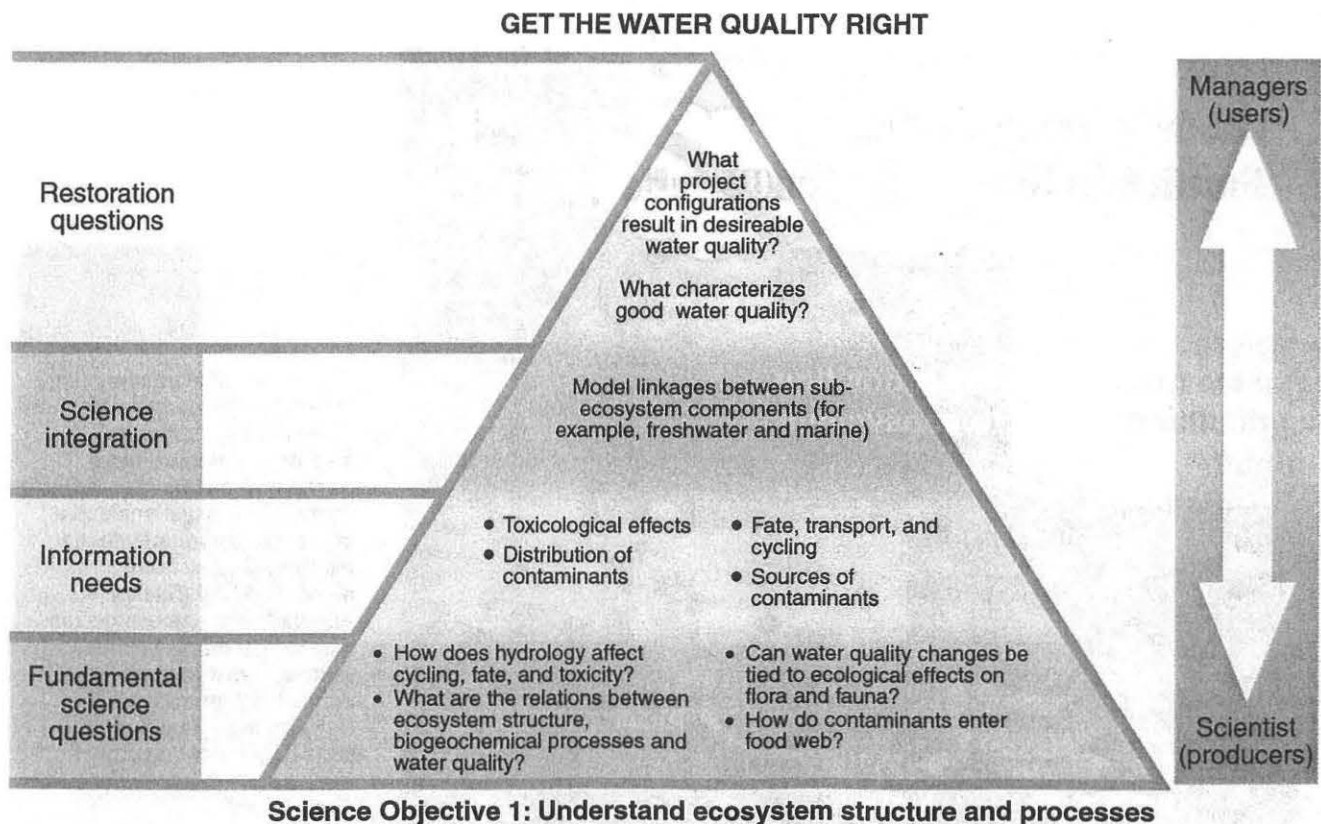


Figure 13. Relation between Restoration Goal 1.2: Water Quality, and Science Objective 1: Understand ecosystem structure and processes.

planning? To answer these questions, scientific studies are required, and these studies along with other information provide the basis for developing integrated models that allow managers to meet the restoration goals.

The first restoration goal of Get the Water Right has elements of quantity, timing, and quality; however, the quality aspects to date have essentially been focused on controlling excess nutrient (primarily phosphorus) inputs in runoff from the Everglades Agricultural Area (EAA). Despite this focus on phosphorus, other water-quality alterations are expected (such as other nutrients, conductivity, pH, and contaminants—mercury, sulfur, and pesticides) and the intended restoration goal may be compromised. The primary mechanism to abate excess phosphorus loading into the Everglades prescribed by the restoration plan is the construction of over 45,000 acres of stormwater treatment areas (STAs). STAs will probably not be effective for many other contaminants of concern including the following:

- (1) runoff-transported contaminants not retained by STA soils and plants (sulfate);
- (2) contaminants that are already present in the soils upon which STAs have been constructed (organochlorine pesticides, trace metals, and metalloids) and may be released to overlying water and accumulated by aquatic biota; and,
- (3) those contaminants that enter the South Florida ecosystem by other pathways (mercury from atmospheric deposition). In the case of mercury, complex biogeochemical processes operating in aquatic ecosystems serve to greatly increase the net toxicity through the formation of methylmercury (fig. 14), which is a potent neurotoxin that bioaccumulates in aquatic-based food webs to levels of toxicological concern. Occurrence and distribution of methylmercury in South Florida's Greater Everglades ecosystems is controlled by many factors including in significant part the external loading of sulfate, which is primarily derived from EAA runoff and is one of the necessary elements for mercury methylation (fig. 14).

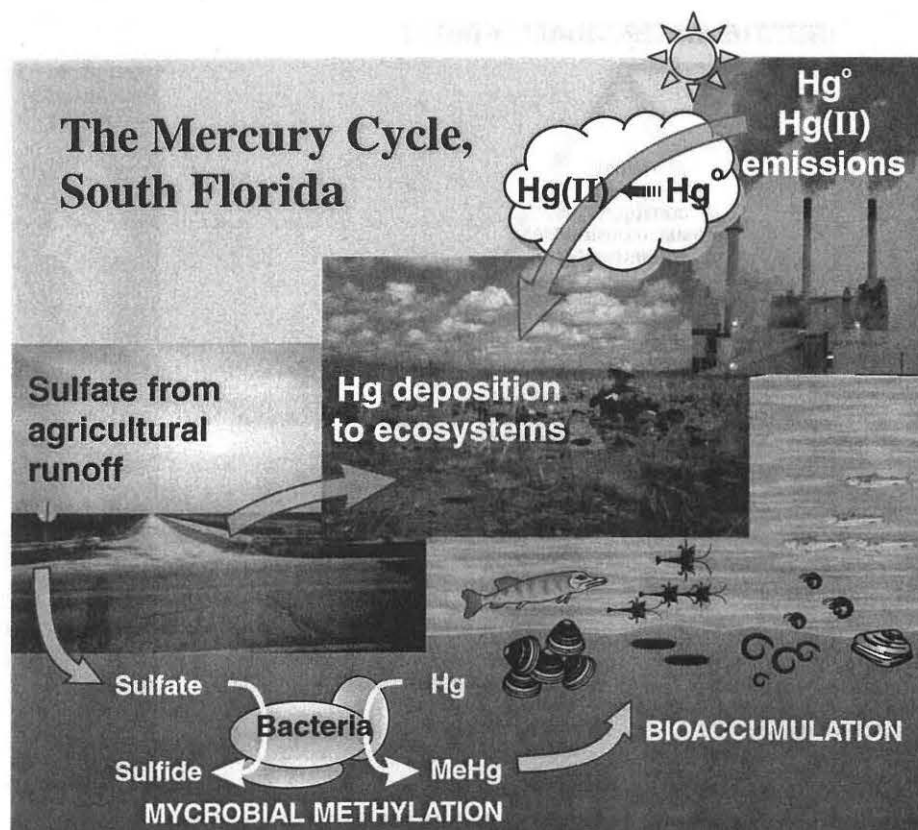


Figure 14. The mercury (Hg) cycle generally originates at an air-emission source and becomes of toxicological concern when mercury deposits in aquatic ecosystems and a portion is converted into the much more toxic form methylmercury (MeHg). Although this process occurs naturally in many wetland systems, sulfate from agricultural practices in the Everglades Agriculture Area (EAA) stimulate mercury methylation in the Greater Everglades.

In addition, drying and rewetting cycles in the Greater Everglades have been shown to substantially increase methylmercury production, thus since hydrologic restoration targets will include wider ranges in hydroperiod we need to better understand the natural process related to biogeochemical processes and methylmercury generation. Methylmercury formation is a good example of how USGS science has aided South Florida land managers to understand the synergistic relationship of two contaminants (mercury and sulfur), place their cycling and fate in the context of ecosystem-scale processes, and relate the findings to present restoration activities that may affect their future impacts on the Everglades.

Other critically needed information regarding the STAs is presently unavailable, but should be part of a robust science plan that supports Greater Everglades restoration. For example, while the STAs in use to date have partly achieved their goal of reducing phosphorus loading to the downstream ecosystem, it remains unclear how long (or if) these engineered systems can maintain this function, or if there are ecologically engineered alternatives or ecologically based management practices that could "reset" their effectiveness. In addition, while the first operational STA yielded no net additional methylmercury in its discharged waters, STA2, on the other hand, has responded in the opposite extreme by yielding some of the highest methylmercury concentrations ever observed. Although previous research provides good clues as to the reasons behind this response, additional research is needed to identify the mechanisms and help prescribe corrective management actions. Finally, when fully implemented, the STAs themselves will comprise a substantial land area in the Greater Everglades, and will likely serve as foraging habitat for waterfowl and other aquatic wildlife. STAs were specifically designed to retain many chemicals; however, STAs may evolve over the long term into areas of elevated contaminant exposure, and unintended risks may result.

Science Information Needs

Additional information is needed in the areas described below for "get the water quality

right." Some of the science needs listed herein address more than one Science Objective (SO). The specific science objective(s) addressed by each science need is noted.

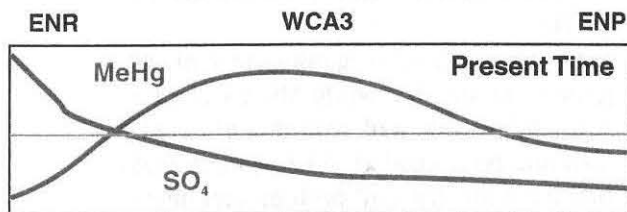
- Refine our understanding of what water quality will sustain desirable ecosystem characteristics and functions. (SO1)
- Fully understand the sources, cycling and fate of critical chemical constituents. Although considerable effort has been put toward understanding phosphorus sources, effects on the ecosystem, and methods for controlling its impact, essentially no effort has been ascribed to evaluating mitigation strategies for other known contaminants. (SO1)
- Some areas of the Everglades presently have good water quality, while other areas are substantially affected. Additional scientific information is needed to describe restoration methods that will both protect unaffected areas while improving impacted areas. (SO3)
- The overall South Florida restoration projects have primarily focused on restoring hydrologic characteristics of the predrainage ecosystem and controlling phosphorus inputs. While current grossly impacted areas may receive benefit from these activities, will the restoration process have a net overall benefit to the Greater Everglades ecosystem? (SO4)
- To monitor changes in response to the restoration projects, water-quality targets need to first be identified, and then adequate spatial and temporal water-quality databases developed to "detect" deviations from baseline (+/- natural variability) conditions. (SO4)
- Can water-quality targets be prescribed that are achievable, indicative of restoration success, and that can be sustained? (SO3, SO4) Although changes to water quality can reliably be expected to occur in response to restoration activities (fig. 15), additional information is needed in order to predict the timing and magnitude of the response. (SO5)
- Understand contaminant linkages from terrestrial and freshwater systems to estuarine and marine systems (Florida Bay, Biscayne Bay, Mangroves, southwest Everglades estuaries, Ten Thousand Islands area).

There are high methylmercury levels in eastern Florida Bay and its biota, which have resulted in the issuance of health advisories. However, the source of methylmercury in Florida Bay is unknown, and it may be affected by restoration activities. (SO1)

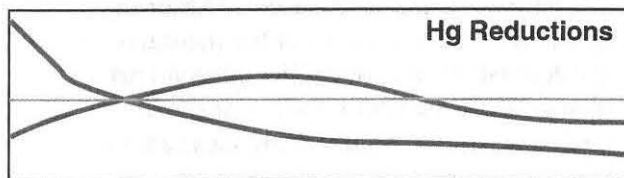
- The sources, abundance, and distribution of several contaminants in South Florida ecosystems (mercury and sulfate) have been relatively well established; however, there is a lack of good appreciation for their ecological impacts and risks (see Science Information Box C – Mercury and Sulfate). (SO1)
- The coexistence of multiple contaminants is known to have both synergistic and antago-

nistic effects (mercury and selenium, sulfur and mercury, various pesticides). Additional information is needed so that the most effective restoration projects can be implemented, while not exacerbating risks associated with multiple contaminant stressors. (SO1)

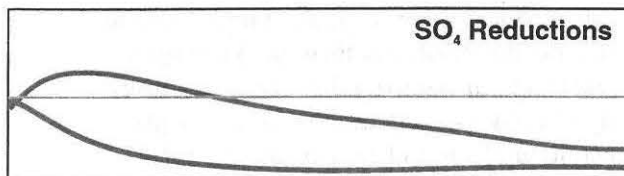
- Tools to evaluate historical water quality patterns for South Florida ecosystems are still under development. These tools are necessary to provide a fundamental understanding of the historical Everglades, and to help bound restoration targets and establish baseline variability. (SO2, SO3)
- Determine the long-term effectiveness of STAs for retaining phosphorus, how they will respond to natural perturbations (for example, wetting and drying cycles), how these systems can be managed to maintain their maximal positive benefit, and if they are concentrating other contaminants (metals, fungicides, insecticides, herbicides, PCBs, and PAHs) to high levels and present a risk to resident wildlife. (SO3, SO4, SO5)
- Aquifer storage and recovery (ASR) is critical to restoration of water to the natural system. However, many interactions between surface water and the ground-water system are not well understood, including water quality. Critical issues that have not been addressed include the fate and potential effects of low concentrations of contaminants, especially those that are known to have endocrine activity in wildlife, or those that can exacerbate contaminant toxicity, such as sulfate and mercury in recovered water. (SO1, SO3, SO4, SO5)
- To address the science objectives related to the establishment of TMDLs in South Florida, information is needed on: stream discharges to define assimilative capacities; ground-water level data (historical and new) and aquifer characteristics to quantify ground-water flows; rainfall and evapotranspiration data to quantify water budgets; biological and ecological data to define ecosystem variations owing to changes in land use; and historical water-quality data of parameters that will be targeted under the TMDL program. (SO1, SO3, SO4)



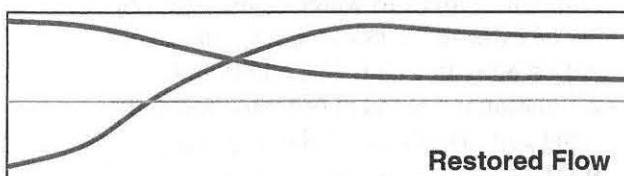
Hypotheses: High sulfate loading limits MeHg in the north, and low sulfate limits MeHg in the south.



Hypotheses: Hg reductions will lower MeHg levels ecosystem-wide proportionally.



Hypotheses: Decreases in the S load will decrease MeHg production, and shift the hot spot to the north.



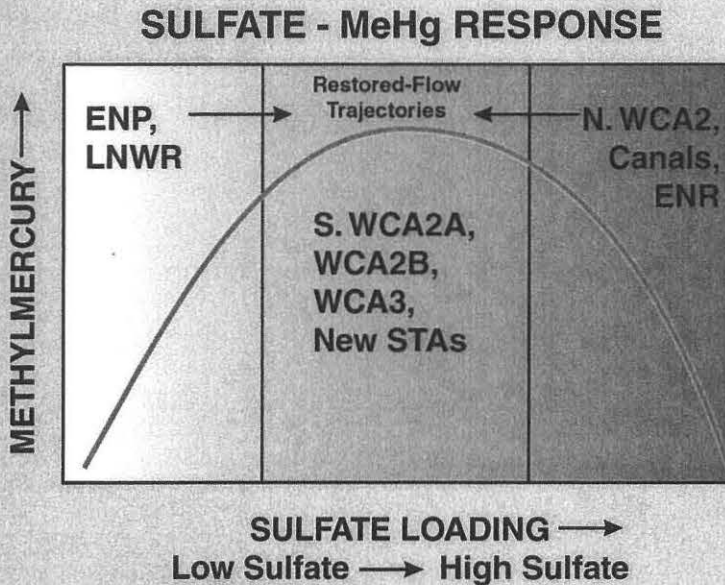
Hypotheses: Increased flow would serve to deliver SO_4 to currently SO_4 limited parts of the Everglades.

Figure 15. Postulated changes to distribution of methylmercury in the Everglades in response to Everglades restoration activities and mercury abatement regulations.

Mercury and Sulfate: Co-Contaminants in the Everglades

Mercury (Hg) is a global contaminant that exhibits high exposure levels in food webs of the Everglades. Once in the environment, natural processes can increase its toxicity by conversion from the inorganic form that is emitted from industrial sources to the organic (methylated) form, which is a neurological toxin and bioaccumulates.

Methylmercury (MeHg) is principally produced by sulfate-reducing bacteria that thrive in anoxic (oxygen-free) sediments and where sulfate availability is not limiting. The use of sulfur as a soil amendment in agriculture land subsequent transport to the Everglades as sulfate in canal water discharge results in stimulation of these microbial communities and net increases in the amount of MeHg. However, in some areas of the Greater Everglades, sulfate loading is so high that levels of porewater sulfide (a byproduct of sulfate reduction) reach concentrations that inhibit methylation. Because of the dual stimulation-inhibition response of sulfate on mercury methylation, plots of MeHg production versus sulfate loading exhibit a bell-shaped curve.



The Hg, MeHg, and sulfate data collected in the Everglades indicates that the highest MeHg levels occur in the central regions of the ecosystem; lower levels occur in the sulfate starved regions of the National Park and in the highly sulfidic areas near the canals draining the EAA. The question is, will Everglades restoration increase the extent or distribution of the optimal MeHg production zone over present conditions? Studies continue in an attempt to address this question, including the use of experimental chambers (mesocosms) and isotope tracer studies.

RESTORATION GOAL 2: RESTORE, PRESERVE,
AND PROTECT NATURAL HABITATS AND SPECIES
(RESTORE THE NATURAL SYSTEM)

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Considerable science is required to satisfy the second goal of the Task Force: Restore, Preserve, and Protect Natural Habitats and Species. Based on the consensus of the Task Force this requires:

"The diversity, abundance, and behavior of native South Florida animals and plants and their terrestrial and aquatic habitats are characteristic of predrainage conditions. The spatial extent of wetlands and other natural systems is sufficient to support the historic functions of the Greater Everglades ecosystem. Important wildlife corridors are identified, enhanced, and preserved. Endangered and other Federal and state listed species recover self-sustaining levels, and sufficient habitats for maintaining healthy numbers are restored and protected. Invasive exotic plant and animal species are substantially eliminated or reduced to manageable levels."

South Florida Ecosystem Restoration Task Force
Coordinating Success, 2002, page 41.

RESTORATION GOAL 2.1: HABITATS, LANDSCAPES, AND ECOLOGICAL PROCESSES

Habitat and landscape patterns in the Everglades mosaic are indicative of the geology, hydrology, biology, and climate that shaped them and, therefore, understanding these characteristics directly benefits all other restoration research. For example, information on past landscapes provides insight into past hydrologic and ecologic processes in the Everglades, and current habitat patterns strengthens investigation of species/habitat relations.

Science Objectives (SO) and Questions Related to Goal 2.2: Habitats, Landscapes, and Ecological Processes

Science Objective 1: Understand ecosystem structure and processes (physical, chemical, biological, and human interactions).

- What ecological processes determine the relation between hydrology, fire, habitats, and distribution and abundance of native flora and fauna?
- What natural changes in habitats and landscapes will influence restoration?

Science Objective 2: Determine the historical ecological setting of the Everglades.

- What were the habitat and landscape characteristics of the predrainage Greater Everglades ecosystem?
- What were the natural patterns of change in the habitats in the predrainage Greater Everglades ecosystem?

Science Objective 3: Establish ecosystem baselines and variations for restoration targets.

- How can we determine reasonable habitat and landscape restoration targets and rank their potential for success and sustainability?
- What is the current baseline condition for habitats and landscapes within the ecosystem?

Science Objective 4: Monitor ecosystem response to change.

- What tools and methodologies are needed to monitor and assess habitat, landscape, and ecological process responses to support adaptive management and ensure restoration.

Science Objective 5: Predict ecosystem response to anthropogenic and natural change.

- How can ecological models be used to predict and evaluate habitat and landscape changes due to restoration?

Linking Science and Restoration Goals

The Greater Everglades ecosystem functions as an interconnected mosaic of wetlands, uplands, coastal areas, and marine systems. Predrainage landscapes consisted of swamp forest; saw grass plains; mosaics of saw grass, tree islands, and ponds; marl-forming prairies; wet prairies; cypress strands; pine flatwoods; pine rocklands; tropical hardwood hammocks; and xeric hammocks. Natural seascapes of South Florida's Greater Everglades included shallow sea grass beds, river and fringe mangrove forests, intertidal flats, coral reefs, hard bottom communities, mud banks, and shallow, open inshore waters. Historically, these communities were interconnected within a topographic area that graded from about 20 feet above sea level at Lake Okeechobee to below sea level at Florida Bay (Science Sub-Group Report, 1993).

Urban and agricultural development in South Florida have resulted in changes in landscape and plant communities including loss of spatial extent of habitats, changes in community composition, and led to loss of ecosystem function including:

- Reduction in spatial extent of aquatic productivity,
- Reduction in aquatic productivity due to shortened hydroperiods and interrupted flows,
- Reduction in cover of wet prairie and slough and related aquatic productivity in the remaining system, and
- Loss of habitat diversity at landscape and community levels.

To meet the restoration objective of recapturing the defining characteristics of the diverse ecosystems of the Everglades, these science objectives focus on identifying ecological processes that support sustainability of

landscapes and habitats. Figure 16 depicts how this science should relate to the restoration goal to restore, preserve, and protect natural habitat species. Inherent in these scientific questions is the development of the monitoring and modeling tools necessary to evaluate and assess changes.

Science Information Needs

The science information and the set of tools necessary for evaluation and assessment of restoration success is not complete. Additional information is needed in the areas described below. Many of the science needs listed herein address more than one Science Objective (SO). The specific science objectives(s) addressed by each science need is noted.

- Many relations between hydrology and populations have been established that are critical for guiding restoration and providing measures for evaluating success. Further

development and refinement of our knowledge of hydrological effects on the Greater Everglades is necessary for communities (sawgrass and cattail, tree island, estuaries) and physical processes (fire, water flow). (SO1)

- Hydrological restoration has been the focus for most efforts in the Everglades. However, other impacts of human activities can be measured in populations and communities. Questions regarding invasive species, impacts of recreational activities, habitat loss, and other physical processes, such as fire, salinity, and nutrients need evaluation. (SO1)
- Information on the historical mosaic of habitats in the Greater Everglades is required to establish restoration targets and develop ecological models. (SO2, SO3, SO5)
- Restoration targets are important for evaluating success. These targets need to be established for many habitats and communities. (SO3, SO5)

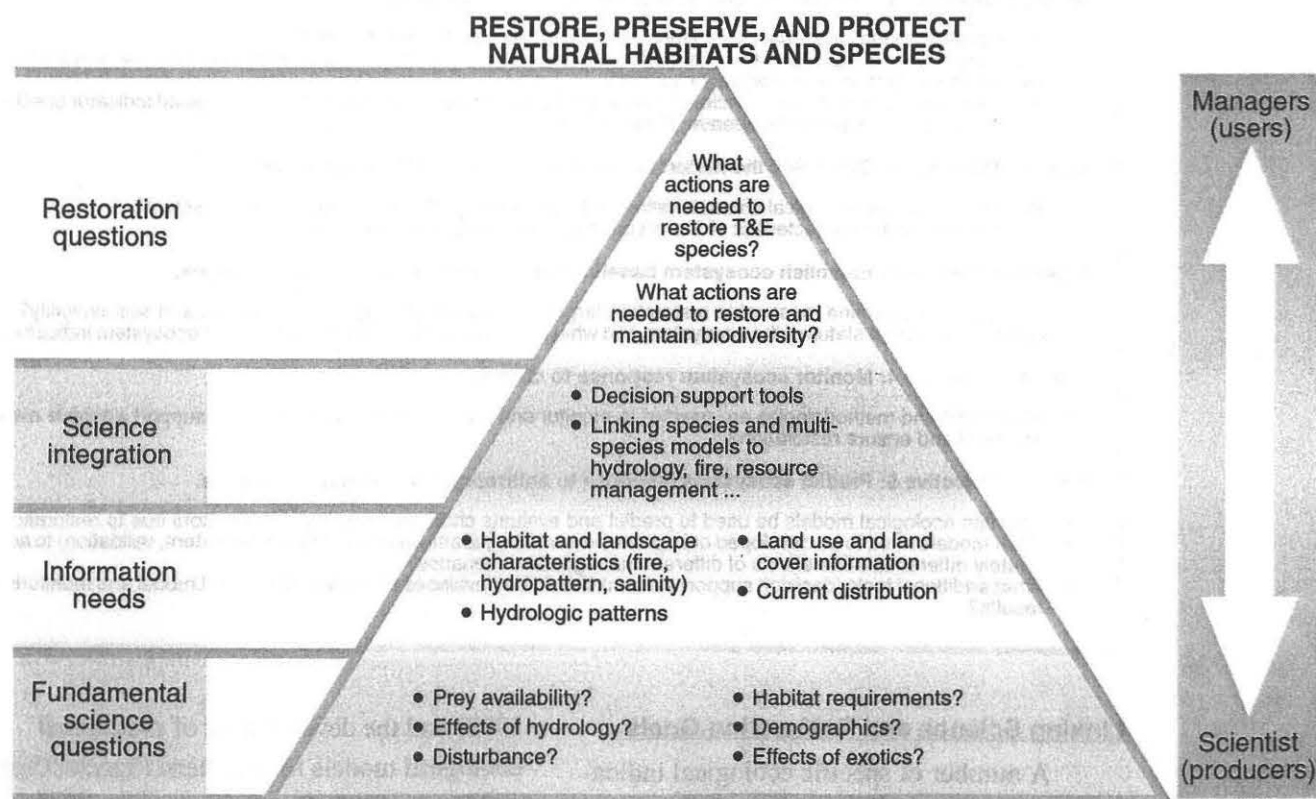


Figure 16. Relation between the Restoration Goal 2: Restore the Natural System – threatened and endangered species and Science Objective 1: Understand ecosystem structure and processes.

- Tools must be developed and implemented to evaluate, assess, and monitor restoration effects, especially for baseline information and initial model development. Apply a variety and perhaps a combination of remote-sensing and field technologies to generate specific information important in habitat modeling (corridors, solution hole mapping and monitoring for aquatic refuge habitat study and channel morphology characterization for hydrologic modeling and restoration impact assessment). (SO4, SO5)
- Ecological models have been important tools for guiding management decisions.

However, existing models require more information for validation and refinement, and new models require baseline data and parameter estimates. Specific needs include:

- o Expand the range of several models. (SO5)
- o Develop more complete information on key processes including disturbance. (SO1, SO5)
- o Improve existing models and develop new models. (SO5)
- o Improve user-friendliness of ecological models and other model-related decision support tools. (SO1, SO4, SO5)

RESTORATION GOAL 2.2: ECOLOGICAL INDICATORS

The Greater Everglades are characterized by complex patterns of spatial heterogeneity and temporal variability. Due to this complexity, a subset of ecological indicators must be chosen for concentrated study. Understanding processes that control ecological indicators are critical to restoration.

Science Objectives (SO) and Questions Related to Restoration Goal 2.2: Ecological Indicators

Science Objective 1: Understand ecosystem structure and processes.

- What ecological indicators can be reliably used to establish restoration targets?
- What important habitat characteristics such as hydropattern (amount, timing, and distribution), fire, and salinity will permit restoration of ecological indicators?
- Are there ecosystem indicator species, keystone indicator species or threatened or endangered indicator species that can help characterize the Greater Everglades?

Science Objective 2: Determine the historical ecological setting of the Everglades.

- What were the key ecological characteristics of the predrainage Greater Everglades ecosystem?
- What species were characteristic of the predrainage Greater Everglades ecosystem?

Science Objective 3: Establish ecosystem baselines and variations for restoration targets.

- How can we determine reasonable restoration targets and rank their potential for success and sustainability?
- What is the current status of the ecosystem and what are trends and variability of important ecosystem indicators?

Science Objective 4: Monitor ecosystem response to change.

- What tools and methodologies are needed to monitor and assess indicator responses to support adaptive management and ensure restoration?

Science Objective 5: Predict ecosystem response to anthropogenic and natural change.

- How can ecological models be used to predict and evaluate changes to ecological indicators due to restoration?
- What models need to be developed or improved (new data, parameter estimates, spatial extent, validation) to adequately differentiate the effects of different management scenarios?
- What additional tools (decision support system) should be developed to apply and interpret model and monitoring results?

Linking Science and Restoration Goals

A number of specific ecological indicators have been identified for Everglades restoration through identification of science information needs (Science Sub-Group Report

1993) and the development of conceptual ecological models for southern Florida (Ogden and Davis, 1999; Gentile and others, 2001). A subset of these is being used specifically to monitor and assess the system-wide impacts of

CERP activities (RECOVER 2003). However, reliability and applicability to specific restoration actions have not been tested. Continued evaluation of the set of ecological indicators is required for monitoring changes in response to restoration activities. If selected effectively, these ecological indicators can provide cost-effective information for evaluating ecosystem response to restoration activities.

Indicators should:

- Have relatively high abundance in the physiographic area of interest,
- Be easy to reliably measure and monitor,
- Be ecologically relevant to management decisions,
- Be sensitive to a specific stressor (for example, wetland hydrologic regime), and
- Have dynamics that are relatively well understood.

Planning restoration and evaluating its success in the Greater Everglades ecosystem require measuring changes in current ecological function and indicators. Science objectives must focus on identifying the ecological processes important to the Everglades ecosystem, key indicators, and the science to evaluate changes.

Science Information Needs

Although historical data and current research and modeling have provided information on indicator populations and communities, additional information is needed for some, and restoration targets are needed for many others. Many of the science needs listed herein address more than one Science Objective (SO). The specific science objective addressed by each science need is noted.

- For some potential indicator species, relationships between hydrology and populations have been established and have guided restoration and provided measures of success. Development and refinement of our knowledge of hydrological and other effects such as fire and salinity on the Everglades is necessary for:
 - Populations such as roseate spoonbill, apple snail, otters, limpkin, and others. (SO1)
 - Communities such as ridge and slough, tree island, marl prairies, and others. (SO1)
- Predrainage information on status and distribution of ecological indicators must be compiled. (SO2)
- Targets and information is needed on the effects of hydrology on:
 - Populations such as American crocodile, alligator, long and shortlegged wading birds, snail kite. (SO1, SO3)
 - Communities such as amphibians, freshwater and estuarine fish, and aquatic insects. (SO1, SO3)
- Other impacts of human activities should be measured in populations and communities, including effects of stressors such as invasive species, off-road vehicles, habitat loss, physical processes (fire, salinity, and nutrients). (SO4)
- There is a need for vegetative performance measures, which are critical for evaluating restoration success include developing:
 - Comprehensive lists of vascular plant species occurring in various hydropatterns and in early and late succession. Measures of plant diversities and abundance will help identify appropriate species as indicators of hydrologic regimes. (SO3, SO4)
 - Indicators that demonstrate disturbance, succession, or other factors relevant to the hydrologic regimes of communities. (SO3, SO4)
- Tools (such as ecological models, habitat suitability index models, GIS overlays and models) for developing restoration targets, where historical information does not exist, as well as tools for evaluating, assessing, and monitoring restoration effects, must be developed and implemented (see Science Information Box D – Alligator Model). Monitoring design and deployment is needed immediately for key indicators:
 - Populations, including alligators, wading birds, crocodile, crayfish limpkin. (SO3, SO4, SO5)
 - Communities, including amphibians, freshwater fish, crayfish, copepods, tree islands, and mangroves. (SO3, SO4, SO5)

ATLSS Alligator Population Model

USGS's ATLSS (Across Trophic Level System Simulation) project is generating a set of species and habitat predictive models of the effects of planned restoration activities in South Florida's Greater Everglades on animal and plant species living there. Over the past 3 years, a module has been developed which simulates alligator populations in and around the Everglades. Using this model and data from the South Florida Water Management District, the Florida GAP project, and ATLSS, the likely population densities that would occur across the Everglades landscape under various restoration scenarios are being evaluated. A validation regimen has also been developed to check the accuracy of the predicted output by comparing nighttime spotlighting surveys along georeferenced trails with a virtual survey performed along the same paths using the simulation output. Preliminary tests indicate that the model has a close fit to actual survey counts.

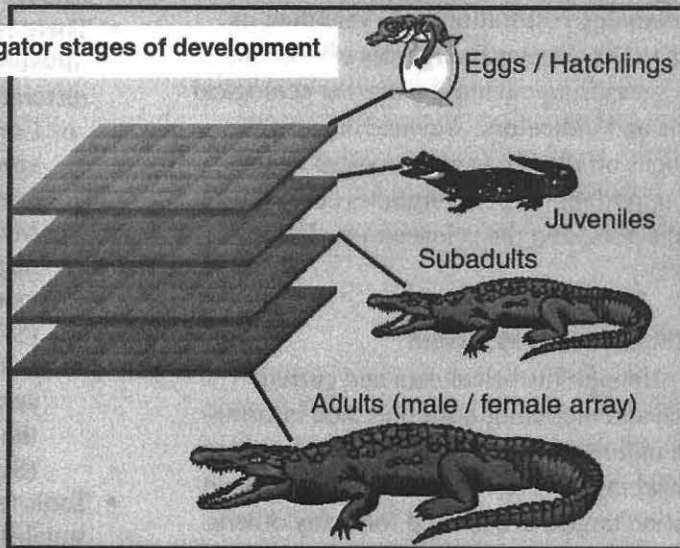
The core model component is a 3-D matrix that records the density of alligators at each developmental stage in each 500x500m spatial location. This structure is manipulated in its entirety with 3-D matrix operations, and interacts with survival and condition 3-D matrices, each in turn calculated for each time step based on water level, crowding, etc.

Alligators either survive and grow to the next stage of development, survive but don't grow, or die. The proportion of each stage that falls into the three categories depends on water levels and alligator condition throughout the year, and the density of adult alligators at each spatial location. Adult female alligators produce offspring at each spatial location, depending on water levels during the nesting period, habitat type, and the age and condition of

the female over the previous season. The nesting potential of each cell is predicted by the ATLSS American Alligator Production Index which incorporates local habitat data and hydrological dynamics to predict the probability of producing nests and offspring successfully in each cell, if a healthy female is present.

Many important questions concerning the effects of Greater Everglades restoration on alligator populations remain unanswered such as the impacts of decompartmentalization, the role of alligator holes as aquatic refugia, and the effects of hydrology on population growth and condition. Additionally, new restoration scenarios are being proposed, for which alligator population responses will be needed. Through simulation modeling, these questions can be prioritized and targeted monitoring plans can be developed to predict the success of each restoration scenario.

Alligator stages of development



RESTORATION GOAL 2.3: THREATENED AND ENDANGERED SPECIES

Restoration of native biological diversity, including the protection and recovery of threatened and endangered species and their habitats, will be an important part of Everglades restoration. This effort will require management based on sound science.

Science Objectives (SO) and Questions Related to Restoration Goal 2.3: Threatened and Endangered Species

Science Objective 1: Understand ecosystem structure and processes (physical, chemical, biological, and human interactions).

- What are the habitat requirements (amount, composition, configuration, and prey availability) for the recovery of threatened and endangered species?
- What important habitat characteristics such as hydroperiod (amount, timing, and distribution), fire and salinity will permit recovery of threatened and endangered species?

Science Objective 2: Determine the historical ecological setting of the Everglades.

- What were the distribution and abundance of threatened and endangered species and their habitats in the pre-drainage Greater Everglades ecosystem?

Science Objective 3: Establish ecosystem baselines and variations for restoration targets.

- What are the current status, trends, and variability of threatened and endangered species populations and habitats?
- What information is needed to determine reasonable recovery targets?

Science Objective 4: Monitor ecosystem response to change.

- What tools and methodologies are needed to monitor and assess threatened and endangered species responses to support adaptive management and ensure recovery?

Science Objective 5: Predict ecosystem response to anthropogenic and natural change.

- How can ecological models be used to predict and evaluate changes to threatened and endangered species due to restoration?
- What models need to be developed or improved (new data, parameter estimates, spatial extent, validation) to adequately differentiate the effects of different management scenarios?
- What additional tools (decision support system) should be developed to apply and interpret model and monitoring results?
- How can recovery for the greatest number of threatened and endangered species be accomplished simultaneously?

Linking Science and Restoration Goals

The large number of threatened and endangered species in South Florida reflects both loss of habitat owing to land conversion and development, and the alteration of ecological processes within the remaining natural ecosystems. Changes in the quantity, distribution and quality of water in South Florida, in particular, has altered habitats both in wetlands, such as the Everglades, and in uplands where lowered water tables alter vegetation, fire frequency, and availability of isolated or ephemeral wetland habitats.

In the Multi-Species Recovery Plan, the USFWS provides an ecosystem based approach to ensure a viable future for all Federally listed species as well as other native species in South Florida. The MSRP aims to fulfill major objectives of the South Florida Ecosystem Restoration initiative including recovery of threatened and endangered species and restoration and maintenance of biodiversity of native plants and animals. This multifaceted approach focuses on these goals:

- Maintaining viable populations of all native species within a defined area,
- Maintaining representation of all native community types across the landscape,
- Maintaining evolutionary and ecological processes,
- Incorporating monitoring and/or management over sufficient time to maintain the evolutionary potential of species and communities, and
- Accommodating human use.

An integration of basic biological information with a landscape or ecosystem-based approach is ideal for simultaneously addressing the needs of the majority of these species due to the complexity of human impacts and ecological processes in the Everglades.

Science Information Needs

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The MSRP has compiled existing information related to threatened and endangered species and highlights deficiencies in our scientific knowledge needed for recovery. Areas where additional information or tools are needed to implement the MSRP are listed below. Many of the science needs listed herein address more than one Science Objective (SO). We will specifically note the science objective(s) addressed by each science need.

- Specific recovery studies are needed to provide information on and monitor life history characteristics, species distribution, habitat use, and population size. (SO1, SO3, SO4)
- Ecosystem and community level studies that help us to understand the linkages between ecosystem- and community-level factors and the ecological requirements of threatened and endangered species. (SO1)
- Ecosystem and community level studies that help us to understand the effects of habitat loss, fragmentation, and degradation on threatened and endangered species due to factors such as contaminants, water and air quality, exotic species, fire suppression, land subsidence, and changes in hydrology. (SO1)
- Predrainage information on status and distribution of ecological indicators must be interpreted and modeled. (SO2, SO5)
- Ecological modeling and decision support tools to:
 - o Evaluate the viability of focal species (see for example Science Information Box E – Cape Sable Sparrow) over periods of up to a few decades including the effects of landscape fragmentation, life history characteristics of species, as well as physiological capabilities and behavioral responses to landscape configurations and temporal variability of environmental conditions. (SO5)
 - o Incorporate demographic stochasticity and genetic variation into models. (SO5)
 - o Develop a decision support system to assist model users, including user-friendly model interfaces and GIS-based analytical tools for landscape- and ecosystem-level evaluations and assessments. (SO5)

Adapted from DOI's Science Plan in Support of Everglades Restoration:

The fundamental question to be answered for habitat and species recovery projects is, What are the highest priority management actions needed to achieve multi-species recovery? Science needed includes:

- Comprehensive information and modeling to predict changes in overall landscape patterns related to broad-scale hydrologic change.
- More detailed local/community information, modeling, and monitoring to first predict, then track ecological changes within specific communities related to Greater Everglades restoration.
- Specific species information, modeling, and monitoring to predict and track individual species responses to specific habitat changes resulting from Greater Everglades restoration.



A Model to Evaluate the Impact of Hydrology on the Cape Sable Seaside Sparrow

The Cape Sable seaside sparrow (*Ammodramus maritima mirabilis*) is an ecologically distinct subspecies of the seaside sparrow, and is restricted to a few hundred square kilometers within the marl prairie of south Florida. Although historically the marl prairie has been subject to only limited periodic flooding, more recently this habitat has experienced frequent flooding. The sparrow subspecies population has declined by 50% since the early 1990's, to approximately 3,000 individuals in 2002.



Changes to the hydrology of the southern Everglades, which are planned as part of the Comprehensive Ecosystem Restoration Plan, will affect the water levels in parts of the sparrow's range. The Cape Sable seaside sparrow model, as well as additional subspecies-specific data collected, will provide managers with a valuable tool in implementing the Restoration Plan so that the preservation of the Cape Sable Seaside Sparrow is assured.

The Cape Sable seaside sparrow population was modeled to determine the effects of the hydrologic regime on various measurements of the population, and model results were compared to long-term sparrow census data. Results indicate that the model accurately predicts the census data, and that the population is extremely sensitive to temporal hydrologic patterns. The hydrologic regime impacts the population directly by affecting the spatial extent of the annual breeding success of the sparrow, and indirectly by controlling vegetative patterns which comprise the sparrow habitat.

RESTORATION GOAL 2.4: NON-INDIGENOUS INVASIVE SPECIES

Non-indigenous invasive species are a significant component of human-induced environmental change in the Everglades. They may have significant impacts on species, habitats, and landscapes and understanding these relationships will be necessary for restoration.

Science Objectives (SO) and Questions Related to Restoration Goal 2: Restore the Natural System 2-4. Non-indigenous Invasive Species

SO1. Understand ecosystem structure and processes (physical, chemical, biological, and human interactions).

- What ecological processes determine the relation between hydrology, fire, habitats, and distribution and abundance of invasive species?
- How do invasive species affect natural ecological processes?
- What natural changes will impact the spread of invasive species?
- What are the characteristics of species that make them invasive?
- What methods (biological, chemical, fire, mechanical) can be used to control invasive and exotic species?

SO2. Determine the historical ecological setting of the Everglades.

SO3. Establish ecosystem baselines and variations for restoration targets.

- What is the current distribution of exotic and invasive species within the ecosystem?

SO4. Monitor ecosystem response to change.

- What tools and methodologies are needed to monitor and assess the distribution and spread of invasive species?

SO5. Predict ecosystem response to anthropogenic and natural change.

- How can ecological models be used to predict and evaluate habitat changes due to exotic species?
- How can we predict which species will become invasive and where?
- How can we optimize control of invasive species?

Linking Science and Restoration Goals

Some invasive species affect the structure and function of ecosystems, as well as the preservation and restoration of native biological diversity. While economic losses due to invasive species may be possible, the loss of natural ecosystems and native biodiversity is seldom measured and often considered an unfortunate byproduct of economic growth. More than 500 introduced species are known to occur in South Florida of which about 60 have been documented as serious invaders of natural areas causing loss of native habitat, ecosystem alterations, and threats to native species. An additional 40-50 introduced species are identified as potentially serious invaders in South Florida. Invasive exotic species must be successfully managed to ensure successful restoration. The effective management and control of invasive species will require additional science information to be integrated with the set of possible management alternatives (fig. 17).

Science Information Needs

The South Florida Ecosystem Restoration Task Force has established the management of invasive pest plants as one of its priorities. The specific science objectives addressed by each science need is noted.

- Develop a biological and ecological understanding of the individual species that threaten natural areas and ecosystem restoration. (SO1)
- Develop the relationships between invasive species and the native species, habitats, and landscapes they affect. (SO1)
- Develop methods to detect, assess, and predict what species may become invasive and where they may invade (biological risk assessment, early detection). (SO3, SO4, SO5)
- Develop methods and techniques to manage and control invasive exotic species that are threats to natural areas and to restoration. (SO1, SO5)

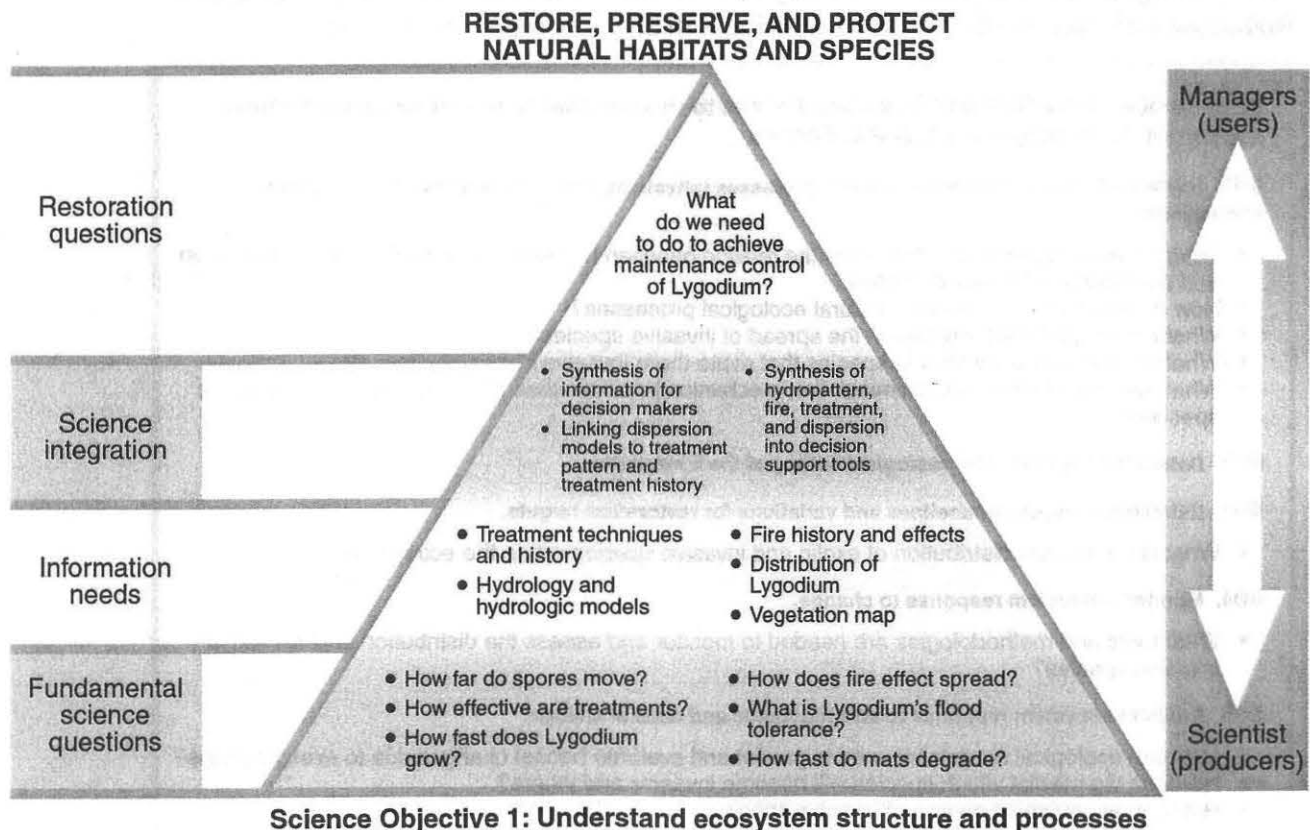


Figure 17. Relation between the restoration goal, "Restore, preserve, and protect natural habitats and species (non-indigenous invasive species)," and the science object, "Understanding ecosystem structure and processes."

RESTORATION GOAL 3: FOSTER COMPATIBILITY OF THE BUILT AND NATURAL SYSTEMS

"Compatibility of the built and natural systems will be realized when the built environment is compatible with ecosystem restoration and preservation goals."

"The compatibility of the built and natural systems will be achieved when the following conditions are met: (1) The people of South Florida understand the connection between a healthy environment and a healthy community. (2) Development patterns—development, redevelopment, and infrastructure—are complementary to ecosystem restoration and compatible with a restored natural system. (3) Development practices support conservation of significant and special natural areas and reduce habitat fragmentation. (4) Flood-protection level of service and water supply are maintained at existing levels, or augmented where appropriate. (5) The quality of life of people in South Florida is enhanced through the ability to reside in areas with fishable, drinkable, and swimmable water and clean air. (6) Park, open space and recreation lands, blueways, greenways, and roadways are compatible with and complementary to getting the water right and enhancing and preserving the natural system. (7) Land, water, wastewater, and transportation planning are coordinated and supportive of ecosystem restoration. (8) Agriculture is an environmentally and economically sound component of the landscape, consistent with ecosystem restoration. (9) In agricultural and urban areas stormwater and wastewater are reclaimed when possible. The ecosystem is not damaged by improper disposal of wastes."

South Florida Ecosystem Restoration Task Force
Coordinating Success, 2002, pages 31-32.

A primary requirement to meet the overall goals of ecosystem restoration identified in this plan is to Foster the compatibility of the built and natural systems. To achieve this compatibility, implementation plans/restoration projects will have to be linked to the following specific science objectives and questions.

Science Objectives (SO) and Questions Related to Restoration Goal 3: Foster Compatibility of the Built and Natural Systems

Science Objective 1: Understand ecosystem structure and processes (physical, chemical, biological, and human interactions).

- How can flood protection efforts be made compatible with the natural system?
- What factors concerning saltwater intrusion need to be considered before restoration projects are implemented?
- What are the appropriate hydrologic linkages between compartmentalized areas?
- How will the ASR program affect freshwater marshes, estuarine zones, and aquifer productivity?
- What effects do recreational uses (boating, fishing) have on the natural system?

Science Objective 2: Determine the historical ecological setting of the Everglades.

- What were the historical populations of species used for recreation (bass, pig frogs)? What were their distributions?
- What were the predrainage ecological conditions in the Everglades?
- How have climate and sea-level change affected freshwater availability in the Everglades in the past?

Science Objective 3: Establish ecosystem baselines and variations for restoration targets.

- What are the spatial and temporal variations in seepage between compartmentalized areas?
- How are current structures and water management practices affecting the species and habitats of the Greater Everglades ecosystem?

Science Objective 4: Monitor ecosystem response to change.

- As restoration proceeds and built systems are added, removed, or altered, what responses are seen in the natural system?
- How will water storage and recovery periods for ASR affect hydropattern and water quality reliant processes and functions in the South Florida ecosystem?

Science Objective 5: Predict ecosystem response to anthropogenic and natural change.

- What project configurations (design, operation, and sequencing) best support restoration and minimize detrimental effects on ecological indicators and threatened and endangered species?
- What land acquisition best support restoration?
- Should water from flood protection (water discharges to the ocean through canals) be minimized and made available for water supply?
- How will individual and cumulative Everglades Restoration projects affect saltwater intrusion?
- How will sea-level rise affect coastal restoration projects?
- How will climate change affect restoration projects?
- How will ASR affect the water quality of the freshwater marshes and estuarine zones?
- How can we best restore the natural system while maintaining recreational opportunities (boating, hunting, and fishing)?

During the second half of the last century, and especially following congressional approval of the Central and Southern Florida (C&SF) project in 1948, the lack of compatibility between the built and natural systems caused major disruptions in the Greater Everglades ecosystem. Human population growth and the subsequent need for public services

have resulted in changes to natural ecological systems in South Florida. These changes include loss of marine, wetland, and upland habitat, fragmentation of ecosystems, spread of invasive species, severe drawdown of freshwater resources, intrusion of saltwater into freshwater aquifers, loss of open space, and degradation of water quality.

The built environment, driven by a growing population, has caused widespread changes throughout south Florida and Greater Everglades ecosystems. Drainage systems, flood control structures, and management practices constructed and implemented during and after completion of the C&SF Project initiated in 1948, altered the entire hydrologic regime within the Greater Everglades ecosystems. Likewise, urban sprawl, construction of public facilities, road infrastructures, and agricultural development has reduced the spatial extent and character of the natural system.

Greater Everglades restoration must mitigate the effects of the current built environment and help plan for future development compatible with the natural environment. However, natural and built environments compete for water and available land, and have hydrologic and land-use conflicts including requirements for draining, flooding, and flood control, and water-quality.

South Florida geology presents special obstacles in making the natural and built environments compatible. Shallow aquifers beneath the Greater Everglades region are often in direct hydraulic contact with canals, rivers, wetlands, bays and estuaries, effectively making surface water (including wetlands) and some aquifers a single hydrologic resource. Further, deeper aquifers, although partly separated from overlying systems by low-permeability layers, play a role in Everglades restoration because of their potential to serve as reservoirs for water currently discharged to the coast during the rainy season, which is the premise for the proposed ASR program.

Effects of Built Systems on South Florida Ecosystems

Drainage, land and water management practices, well pumpage, flood protection, and water resources development are all essential for agricultural and urban activities. In South Florida, these activities have been underway for more than 100 years; during much of this time little regard has been given to the effects of these actions on the natural systems of the region. However, in recent years more and more emphasis has been placed on measures

that create and sustain the built system in such a way that the change to the natural system is minimized.

Land Management

"In order to maintain a high quality of life for South Florida's residents, the built environment must be planned and managed in a manner that both supports the social and economic needs of communities and is compatible with the restoration, preservation, and protection of natural habitats and species. This will require development patterns, policies, and practices that serve both built and natural systems. Urban, suburban, and rural development utilizes lands that would otherwise be available to support natural system functioning. To the extent that development patterns in these areas are sensitive to the critical needs of both community residents and the natural system, South Floridas communities can be a sustainable part of a healthy ecosystem.

South Florida Ecosystem
Restoration Task Force
Coordinating Success,
2002, pages 50-51.

Management of land is an essential component in the effort to foster compatibility between the built system and the natural system. Early in the 20th century, land in South Florida was managed primarily for the benefit of human activities. Swamps, marshes and coastal wetlands were drained to make land suitable for homes, cities, and farms. A few small areas of land were set aside for wildlife refuges, but generally little thought was given to the declining natural ecosystem. Everglades National Park was established in 1947, but over subsequent years it became increasingly recognized that the health of the Park was dependent on lands outside its boundaries. Today, it has become obvious that land management to foster compatibility must include not only acquiring new lands that have remained relatively natural, but also active management of lands within the built-up system to minimize effects of human activities on the natural system.

Drainage, Water Management Practices, Well Pumpage, and Flood Protection

"Providing the land for suitable development and human habitation will continue to require considerable flood protection, since without such protection most of South Florida would be unsuitable for existing urban and agricultural uses. Given the population growth projections for South Florida, there will be ongoing need for monitoring and balancing the flood-protection needs of urban, natural, and agricultural lands as part of restoration."

South Florida Ecosystem
Restoration Task Force
Coordinating Success, 2002,
page 51.

As a result of the C&SF project and water management practices over the last 50 years, the South Florida ecosystem is now highly fragmented and has diminished habitat diversity. Channelization and impoundment have disrupted the annual pattern of rising and falling water levels in the remaining wetlands (Science Sub-Group, 1993). Furthermore, the reduction in flow from upstream areas has reduced the maximum area covered by water each year and the duration of flooding. Controls on water also have enhanced the spread of invasive, non-native plant species that are changing the landscape, hydrologic conditions, and ecosystem function. The water conveyance system also may be a conduit for the transport of contaminants, including pesticides and excess nutrients. Additionally, water control and drainage of the Greater Everglades during the last 50 years has lowered the water table beneath the Atlantic coastal ridge, reduced water flow to interior wetlands and to estuaries, affected plant communities, increased saltwater intrusion of aquifers, and reduced available water supplies (Science Sub-Group, 1993).

The main challenge of restoration is to improve water quality and optimize water management by delivering water in a more

timely manner that mimics natural hydrologic fluctuations to the natural system and at the same time by preserving the function of the flood control and water supply systems in South Florida. Hydrologic restoration is the starting point critical to ecological restoration.

One objective of Everglades restoration is increase flow through the historical Everglades, including North East Shark River Slough, by retaining water flowing to the coast through coastal canals and the South Dade Conveyance system (Science Sub-Group, 1993). However, the retention of water flowing to the coast along canals will not only affect canal stages, but will also affect water levels in the surficial aquifers because the canals are in direct hydraulic connection with the aquifers. Changes in canal stages and aquifer heads, and well pumpage from urban well fields can induce saltwater intrusion in coastal aquifers, which is a long-standing problem for communities on both the east and west coast of South Florida.

Although saltwater intrusion has been studied extensively in South Florida and elsewhere, additional, more-detailed studies are needed to address the dynamic changes that may occur as a result of development and restoration activities and natural processes. Earlier studies used different criteria to define saltwater intrusion, and most studies produced a synoptic snapshot of the present-day location of the saltwater/freshwater interface. However, the interface likely has not come into equilibrium with water level fluctuations. Water-level changes continue as a result of development, restoration, global climate changes and sea-level rise.

Providing the land for suitable development and human habitation will continue to require flood protection, since without such protection most of South Florida would be unsuitable for existing urban and agricultural uses. Given the population growth projections for South Florida, there will be an ongoing need for monitoring and balancing the flood-protection needs of urban, natural, and agricultural lands as part of restoration.

Sustainability of Water Resources for Built and Natural Systems

"The same issues that are critical to the natural system "getting the water right and restoring, preserving, and protecting diverse habitats and species" are equally critical to maintaining a high quality of life for South Floridas residents. Like the future of South Floridas natural systems, the future of its human communities is dependent on getting the water right. The appropriate quantity, quality, timing, and distribution of water is essential to meeting the future water supply needs generated by projected population growth and by continuing economic productivity, most notably in tourism and agriculture (the two largest sectors of the economy). The overriding issue is not who gets the water, the natural system or the built system, but how to fulfill all water needs by ensuring that what is built can be adequately supported within the parameters of a healthy natural system. Failure to achieve this compatibility would likely be detrimental for both future residents and the environment.

"Providing sufficient water resources, using and managing land, and maintaining and improving flood protection—all in a manner compatible with restoration of the Greater Everglades ecosystem—are important subgoals for fostering compatibility of the built and natural systems."

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pages 50-51.

Public supply, agriculture, and the ecosystem compete for water that, even at current usage, inadequately meets the needs of the area. Ground water from the surficial aquifer system, which includes the highly permeable Biscayne aquifer, is the principal source of potable water and provides much of the water used by agriculture in South Florida. During periods of drought and during the dry season, the surficial aquifer system has been the most overtaxed.

Providing water for public supply and agriculture in South Florida and, at the same time, restoring flows to Everglades wetlands presents a significant challenge. The population of South Florida is expected to double by the year 2030, and present water supplies will not satisfy these combined needs. Ground water that has been pumped from inland well fields to coastal areas will be insufficient to supply the increasing demands and will require developing new, more expensive supplies. Alternative sources, including water of marginal quality and that currently discharged to the coast (1.7 billion gallons per day) must be tapped. More freshwater must be stored during the rainy season for use in the dry season. Storage means being considered include aquifer storage and recovery (ASR), constructed above ground and subsurface reservoirs (in-ground reservoirs), and barrier walls to prevent seepage losses from the Everglades.

Linking Science to Restoration Goals

To achieve Restoration Goal 1: Foster Compatibility of the Built and Natural Systems requires a linkage between science and restoration. A significant scientific contribution towards achieving compatibility will be to predict the ecosystem response to human and natural changes (fig. 18).

Science objectives needed to address the restoration goal Foster Compatibility of the Built and Natural Systems will generate questions such as how will restoration projects affect salt water intrusion along the coast and could this threaten public water supply from intrusion into well fields? How can freshwater flow to the ocean be minimized, so that maximum amounts are available to protect well fields without flooding urban and residential lands? How can freshwaters be managed so as to provide for urban needs without altering desired hydropatterns in natural areas? To answer these questions, scientific studies are required, and these studies, along with other information, provide the basis for developing integrated models that will allow managers to meet restoration goals.

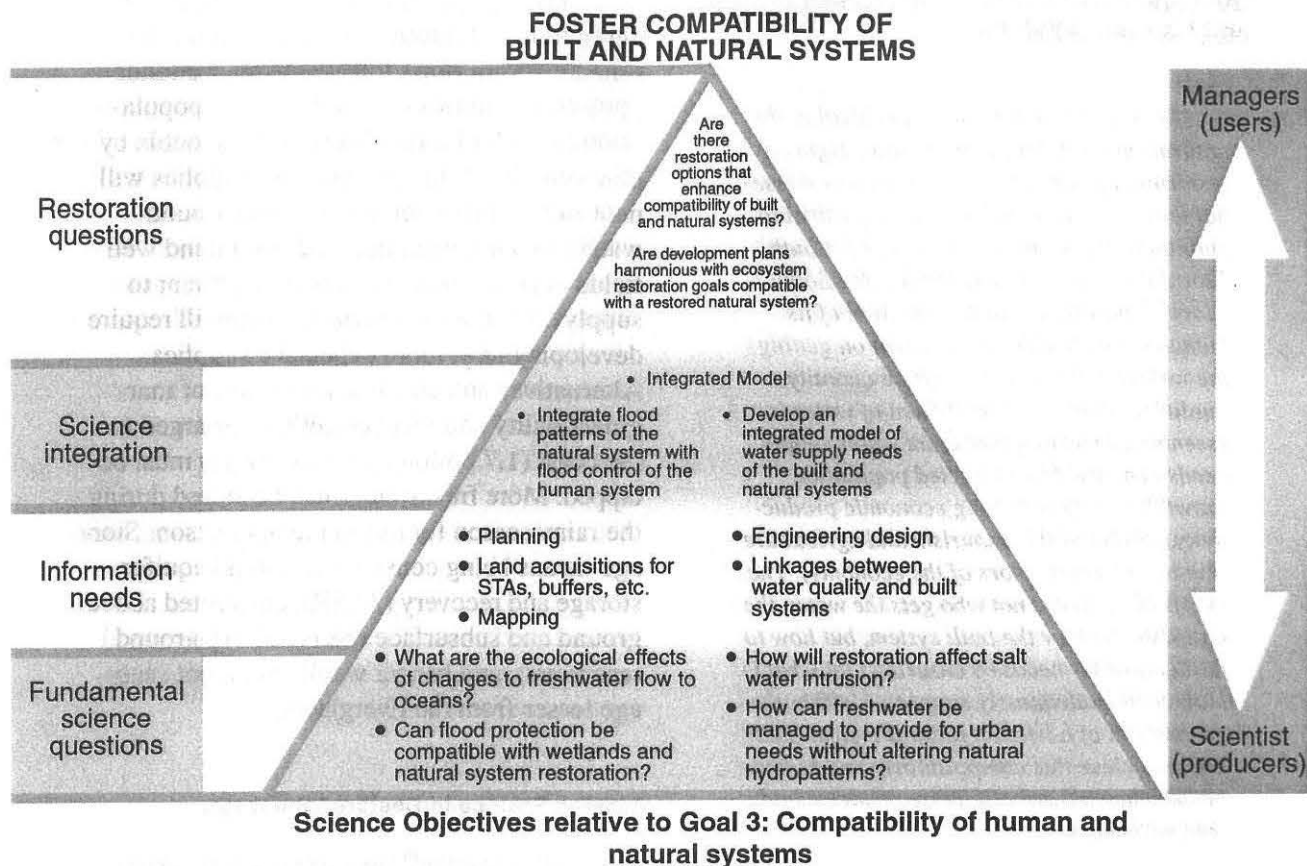


Figure 18. Relation between Restoration Goal 3: Foster compatibility of built and natural systems and several of the restoration-related Science Objectives.

Science Information Needs

To foster compatibility of the built and natural systems, additional information is needed in the areas described below. Some of the science needs listed herein address more than one Science Objective (SO). The specific science objective(s) addressed by each of the science needs is noted.

- Water control and drainage of the Greater Everglades during the last 50 years has altered the hydrology and ecology in South Florida by (1) lowering the water table in the coastal surficial aquifer, (2) reducing water flow to interior wetlands and estuaries, (3) affecting plant communities, (4) increasing saltwater intrusion of aquifers, and (5) reducing available water supplies. A thorough understanding is needed of the effects of water controls on the distribution of surface and ground-water flows and on ways to reestablish sheet flow in part of the Greater Everglades. (SO1, SO3, SO4, SO5)
- Water management practices in South Florida have enhanced the spread of invasive, non-native plant species; some of these species are changing the landscape, hydrologic conditions, and ecosystem function. The water conveyance system also serves as a conduit for the transport of contaminants, including pesticides and nutrients. We need to thoroughly understand and document the impact of these water management practices and conveyance systems on the ecosystem so as to minimize potential adverse effects of proposed restoration projects. (SO1, SO3, SO4, SO5)
- A quantitative understanding of the hydrologic linkages between compartmentalized areas is needed, including the degree of surface-water/ground-water interconnectivity, and the variability of seepage between adjacent areas. (SO1, SO3, SO4, SO5)
- Flood protection is crucial for human habitation and for urban and agricultural development in South Florida. Given the

population growth projections for South Florida, there will be an ongoing need for monitoring and balancing the flood-protection needs of urban, natural, and agricultural lands as part of restoration. (SO3, SO4, SO5)

- Surface and ground-water data-collection networks in South Florida should be expanded to improve our knowledge of flows, both spatially and temporally, throughout the Greater Everglades ecosystem, and to provide a basis to compare current flows with predrainage flows. (SO2, SO4)
- Saltwater intrusion into South Florida coastal aquifers increases with declines in surface water levels that result from drainage, lower canal stages, and well pumpage. In addition, saltwater intrusion is more prevalent along canals and along preferential karst flow zones in the limestone aquifers. A better understanding of coastal stratigraphy is needed to determine preferential flow zones of saltwater migration (SO1, SO4, SO5)
- To monitor the movement of the freshwater-saltwater interface and the extent of saltwater intrusion along coastal aquifers, additional monitoring wells within saltwater intruded zones are needed to determine the extent and shape of the freshwater-saltwater mixing zone and the rate of movement of saline water. (SO3, SO4, SO5)
- Saltwater moves inland along canals and through coastal aquifers intruding laterally or by up-coning as a result of well pumping. There is a need to collect and interpret isotopic and other data to determine the sources of saline water in coastal surficial aquifers. (SO3, SO4)
- Variable-density transport models are needed to evaluate locally and regionally important processes in saltwater intrusion. Likewise, effects of restoration alternatives

on saltwater intrusion must be simulated using variable-density transport models. (SO5)

- Global climate change and sea-level rise will have long-term consequences for south Florida, both for the natural ecosystem and the built-up system. Studies are needed to determine the long-term consequences of these changes and how they will affect restoration; specifically how they will affect saltwater intrusion. (SO2, SO3, SO4, SO5)
- Aquifer storage and recovery (ASR) is being considered as an alternative water supply planning tool to support water needs for anticipated rapid population growth and the natural system. There is a need to improve the understanding of how the ASR program proposed by CERP will affect water quality, flows, hydropattern, and ecosystem functions. (SO1, SO3, SO4, SO5)
- Recreational uses (boating, fishing) have impacts on the natural system; however, a better understanding is needed of the cause and effect relation between these uses and ecosystem degradation. At the same time, public land use of the South Florida ecosystem is important to protect. How can the natural system best be restored while maintaining recreational opportunities (boating, hunting, and fishing)? (SO1, SO4, SO5)
- It has become obvious that land management to foster compatibility in South Florida must include not only acquiring new lands that have remained relatively natural, but also active management of lands within the built-up system to minimize effects of human activities on the natural system. Land acquisition in support of Everglades ecosystem restoration is a major topic of discussion among urban planners, water managers and restoration scientists. There is major need for determining what land acquisition best support restoration efforts in South Florida. (SO5)

PLAN IMPLEMENTATION

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LINKING USGSS GREATER EVERGLADES STRATEGIC SCIENCE PLAN WITH DOIS PROJECT-SPECIFIC SCIENCE INFORMATION NEEDS

The Department of the Interiors (DOI) United States Geological Survey (USGS) developed the Greater Everglades Ecosystem Restoration (GEER) Science Initiative (part of USGSs national Priority Ecosystem Science (PES) initiative) in direct support of South Florida ecosystem restoration efforts, including the Restudy and CERP. A solid foundation in ecosystem and restoration-related multiple science objectives needs to be met in order to achieve the restoration goals outlined by the South Florida Ecosystem Restoration Task Force (SFERTF): "Restoration Goal 1: Get the Water Right," "Restoration Goal 2: Restore, Preserve, and Protect Natural Habitats and Species," and "Restoration Goal 3: Foster Compatibility between the Built and Natural Systems." Appendix I includes the detailed science objectives and questions addressed by the GEER science initiative. DOI's Science Plan in Support of Everglades Restoration was developed as a tactical plan to help meet project-specific science information needs of DOIs resource management agencies. This DOI tactical science plan describes a number of CERP projects and other restoration-related projects that will be implemented to achieve many of the goals Greater Everglades Ecosystem Restoration (GEER).

USGS developed this strategic science plan to complement DOIs tactical science needs. A thorough understanding of baseline conditions, ecosystem history, physical and landscape setting, as well as a basic understanding of the hydrologic, biologic, chemical and physical dynamics of the Greater Everglades ecosystem is necessary before restoration can be planned, implemented and

evaluated. USGSs research is dedicated to understanding the Greater Everglades ecosystem with the ultimate target of synthesizing that understanding into predictive hydrologic, ecological, chemical and geographic models and decisions support tools to aid restoration and resource management staff in their critical decisions.

Table 1 shows the relation between USGSs Science Objectives and DOIs resource management agencies (FWS and NPS) GEER projects, and provides a linkage between USGSs Strategic Science Plan and DOIs Science Prioritization Strategy.

{{ Reviewers: Please note, the DOI Greater Everglades Restoration Science Prioritization Strategy is still undergoing development. Therefore, this section cannot be completed until the DOI Plan is complete. However, as you can see from the attached spreadsheet, we are trying to provide a table/spreadsheet/diagram that provides a linkage between the Science Objective and Questions in USGSs Strategic Science Plan In Support of Greater Everglades Ecosystem Restoration and the Science Information Needs in DOIs Greater Everglades Ecosystem Restoration Science Prioritization Strategy. Any recommendations on how to best achieve this goal would be much appreciated. Thanks, Ronnie Best } }

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SO4 = Monitor ecosystem response to change:

SO5 = Predict ecosystem response to anthropogenic and natural change]

[illegible]

Table 1. Linkage Between DOI and USGS Science Plans (Continued)

SO1 = Understand ecosystem structure and processes;

SO2 = Determine the historical ecological setting of the Everglades;

SO3 = Establish ecosystem baselines and variations for restoration targets;

SO4 = Monitor ecosystem response to change;

SO5 = Predict ecosystem response to anthropogenic and natural change]

DOI Science Plan	Goal 1: Get the Water Right										Goal 2: Restore, Preserve, and Protect Natural Habitats and Species																				Goal 3: Foster Compatibility				
	1.2: Hydrology					1.2: Water Quality					2.1: Habitats, Landscapes, & Ecological Processes					2.2: Ecological Indicators					2.3: Threatened & Endangered Species					2.4: Invasive Species									
	SO1	SO2	SO3	SO4	SO5	SO1	SO2	SO3	SO4	SO5	SO1	SO2	SO3	SO4	SO5	SO1	SO2	SO3	SO4	SO5	SO1	SO2	SO3	SO4	SO5	SO1	SO2	SO3	SO4	SO5	SO1	SO2	SO3	SO4	SO5
Everglades National Park, Biscayne Bay, and the Florida Keys																																			
Water Conservation Area 3 Decompartmentalization and Sheetflow Enhancement	•	•	•	•	•	•	•		•	•						•			•		•			•											
Combined Structural and Operational Plan (CSOP), Including the C111 Spreader Canal	•	•	•	•	•	•	•			•	•	•		•		•		•	•	•															
Biscayne Bay Coastal Wetlands	•	•	•	•	•																														
Additional Water for Everglades National Park and Biscayne Bay Feasibility Study	•	•	•	•	•	•	•			•	•	•		•																					
Wastewater Reuse Pilot Project						•				•	•																								
Florida Bay and Florida Keys Feasibility Study	•	•	•	•	•	•				•	•					•			•																
Landscape-Scale Science Needed to Support Multiple CERP Projects																																			
Landscape-Scale Modeling																																			
Comprehensive Integrated Water Quality Feasibility Study						•	•	•	•	•						•																			
Studies to Support Fish and Wildlife Friendly Siting and Operation of Reservoirs, STAs, and ASR Structures						•	•	•	•	•																									
Risks to Fish and Wildlife from Soil-Borne Contaminants						•	•	•	•	•																									
Landscape-Scale Monitoring and Assessment	•	•	•	•	•	•	•	•	•	•									•																

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SO4 = Monitor ecosystem response to change;

SO5 = Predict ecosystem response to anthropogenic and natural change]

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Appendix

Appendix I. SCIENCE OBJECTIVES AND QUESTIONS

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1. GET THE WATER RIGHT

1.1. Hydrology

SO1 Understand ecosystem structure and processes

How do hydropatterns and flow affect the Greater Everglades ecosystems?

What are the sedimentation and evapotranspiration rates?

What are the effects of sea-level changes?

What are the effects of ground-water and surface-water interactions?

What are the effects of vegetative resistance on flow?

What controls circulation and flushing in coastal and estuarine ecosystems?

What are the hydrogeologic controls on ASR?

What are the benefits and impacts of Water Preserve Areas (WPA) to restoration?

What effects will seepage barriers have on ground water levels and on saltwater intrusion?

SO2 Determine the historical ecological setting of the Everglades

What were the physical hydrologic characteristics of the pre-drainage Everglades ecosystem?

What pre-drainage characteristics are essential to restore ecosystem health?

What hydroperiod frequency and dry-down durations are needed?

SO3 Establish ecosystem baselines and variations for restoration targets

What are sustainable restoration targets?

What hydrological indicators can be used to establish short-term and long-term restoration targets?

How can reasonable restoration targets be determined and their potential for success and sustainability ranked?

How have manmade conveyances (canals) and barriers (such as highways) altered historical water levels and flows?

SO4 Monitor ecosystem response to change

Are restoration projects and resource-management actions achieving restoration goals?

How do we optimize hydrologic monitoring to assess project impacts and the status and trends of fish and wildlife resources?

SO5 Predict ecosystem response to anthropogenic and natural change

What natural changes will impact restoration and how can we distinguish natural from human-induced effects?

What are the predicted impacts and benefits of restoration projects on the Greater Everglades ecosystem?

What are the predicted effects of changes in water management?

What are the predicted effects of specific structures and (or) projects?

How should the water management system be operated to achieve restoration?

How can we accurately forecast the impacts of proposed changes to the system?

How do we obtain the best science and hydrologic models to support restoration?

How have manmade conveyances (canals) and barriers (such as highways) altered historical water levels and flows?

1.2. Water Quality

SO1 Understand ecosystem structure and processes

What are the water-quality characteristics of a healthy Everglades?

How does water quality relate to the major biogeochemical processes, and current land use and management activities?

How do we restore and protect water quality in the ecosystem?

What contaminants are currently present, and what contaminants (and their distribution) might we expect to see after restoration?

What are the ecosystem risks associated with current water quality?

How do freshwater inflows affect water quality in the coastal ecosystem?

How do contaminants affect plant and wildlife species?

Will recovered ASR waters be compatible with receiving environments and aquatic and terrestrial biota?

SO2 Determine the historical ecological setting of the Everglades

What were the water-quality characteristics of the pre-drainage ecosystem?

SO3 Establish ecosystem baselines and variations for restoration targets

What are current water quality conditions across the South Florida environment?

What are current contaminant burdens in plants and wildlife in the Everglades?

How do we determine reasonable water quality restoration targets and rank their potential for success and sustainability?

How can we protect those areas currently with good water quality, and can we restore or improve conditions where significant impacts have been observed?

What contaminants are currently present, and what contaminants (and their distribution) might we expect to see after restoration?

SO4 Monitor ecosystem response to change

What are the relative impacts of the various restoration activities on water quality at the ecosystem scale?

Do we have the adequate monitoring systems in place to detect changes to water quality in response to restoration activities; and, if not, what systems are necessary?

How (spatial and temporal scales) do we monitor the effects of restoration activities and water management on water quality?

SO5 Predict ecosystem response to anthropogenic and natural change

Do we have the necessary tools presently to predict water quality changes? And, if not, what tools are needed?

What are the predicted impacts and benefits to water quality from restoration efforts:

Impacts or benefits of changes in water supply?

Impacts of specific structures?

Impacts of altered flows on estuary and marine ecosystems?

2. RESTORE, PRESERVE, AND PROTECT NATURAL HABITATS AND SPECIES

2.1. Habitats, Landscapes, and Ecological Processes

SO1 Understand ecosystem structure and processes

What ecological processes determine the relation between hydrology, fire, habitats, and distribution and abundance of native flora and fauna?

What natural changes in habitats and landscapes will impact restoration?

SO2 Determine the historical ecological setting of the Everglades

What were the habitat and landscape characteristics of the pre-drainage Greater Everglades ecosystem?

What were the natural patterns of change in the habitats in the pre-drainage Greater Everglades ecosystem?

SO3 Establish ecosystem baselines and variations for restoration targets

How can we determine reasonable habitat and landscape restoration targets and rank their potential for success and sustainability?

What is the current baseline condition for habitats and landscapes within the ecosystem?

SO4 Monitor ecosystem response to change

What tools and methodologies are needed to monitor and assess habitat, landscape, and ecological process responses to support adaptive management and ensure restoration.

SO5 Predict ecosystem response to anthropogenic and natural change

How can ecological models be used to predict and evaluate habitat and landscape changes due to restoration?

2.2. Ecological Indicators

SO1 Understand ecosystem structure and processes

What ecological indicators can be reliably used to establish restoration targets?

What important habitat characteristics such as hydropattern (amount, timing, and distribution), fire, and salinity will permit restoration of ecological indicators?

SO2 Determine the historical ecological setting of the Everglades

What were the key ecological characteristics of the pre-drainage Greater Everglades ecosystem?

SO3 Establish ecosystem baselines and variations for restoration targets

How can we determine reasonable restoration targets and rank their potential for success and sustainability?

What is the current status of the ecosystem and what are trends and variability of important ecosystem indicators?

SO4 Monitor ecosystem response to change

What tools and methodologies are needed to monitor and assess indicator responses to support adaptive management and ensure restoration?

SO5 Predict ecosystem response to anthropogenic and natural change

How can ecological models be used to predict and evaluate changes to ecological indicators due to restoration?

What models need to be developed or improved (new data, parameter estimates, spatial extent, validation) to adequately differentiate the effects of different management scenarios?

What additional tools (decision support system) should be developed to apply and interpret model and monitoring results?

2.3 Threatened and Endangered Species

SO1 Understand ecosystem structure and processes

What are the habitat requirements (amount, composition, configuration, and prey availability) for the recovery of threatened and endangered species?

What important habitat characteristics such as hydropattern (amount, timing, and distribution), fire and salinity will permit recovery of threatened and endangered species?

SO2 Determine the historical ecological setting of the Everglades

What were the distribution and abundance of threatened and endangered species and their habitats in the pre-drainage Greater Everglades ecosystem?

SO3 Establish ecosystem baselines and variations for restoration targets

What are the current status, trends, and variability of threatened and endangered species populations and habitats?

What information is needed to determine reasonable recovery targets?

SO4 Monitor ecosystem response to change

What tools and methodologies are needed to monitor and assess threatened and endangered species responses to support adaptive management and ensure recovery.

SO5 Predict ecosystem response to anthropogenic and natural change

How can ecological models be used to predict and evaluate changes to threatened and endangered species due to restoration?

What models need to be developed or improved (new data, parameter estimates, spatial extent, validation) to adequately differentiate the effects of different management scenarios?

What additional tools (decision support system) should be developed to apply and interpret model and monitoring results?

How can recovery for the greatest number of threatened and endangered species be accomplished simultaneously?

2.4 Non-indigenous Invasive Species

SO1 Understand ecosystem structure and processes

What ecological processes determine the relation between hydrology, fire, habitats, and distribution and abundance of invasive species?

How do invasive species affect natural ecological processes?

What natural changes will impact the spread of invasive species?

What are the characteristics of species that make them invasive?

What methods (biological, chemical, fire, mechanical) can be used to control invasive and exotic species?

SO2 Determine the historical ecological setting of the Everglades

SO3 Establish ecosystem baselines and variations for restoration targets

What is the current distribution of exotic and invasive species within the ecosystem?

SO4 Monitor ecosystem response to change

What tools and methodologies are needed to monitor and assess the distribution and spread of invasive species?

SO5 Predict ecosystem response to anthropogenic and natural change

How can ecological models be used to predict and evaluate habitat changes due to exotic species?

How can we predict which species will become invasive and where?

How can we optimize control of invasive species?

3. FOSTER COMPATIBILITY BETWEEN THE BUILT AND NATURAL SYSTEMS

SO1 Understand ecosystem structure and processes

How can flood protection efforts be made compatible with the natural system?

What factors concerning saltwater intrusion need to be considered before restoration projects are implemented?

What are the hydrologic linkages between compartmentalized areas?

How will the ASR program affect freshwater marshes, estuarine zones, and aquifer productivity?

What effects do recreational uses (boating, fishing) have on the natural system?

SO2 Determine the historical ecological setting of the Everglades

What were the historical populations of species used for recreation (bass, pig frogs)? What were their distributions?

What were the pre-drainage ecological conditions in the Everglades?

How have climate and sea-level change affected freshwater availability in the Everglades in the past?

SO3 Establish ecosystem baselines and variations for restoration targets

What are the spatial and temporal variations in seepage between compartmentalized areas?

How are current structures and water management practices affecting the species and habitats of the Greater Everglades ecosystem?

SO4 Monitor ecosystem response to change

As restoration proceeds and built systems are added, removed, or altered, what responses are seen in the natural system?

How will water storage and recovery periods for ASR affect hydroperiod and water quality reliant processes and functions in the south Florida ecosystem?

SO5 Predict ecosystem response to anthropogenic and natural change

What project configurations (design, operation, and sequencing) best support restoration and minimize detrimental effects on ecological indicators and threatened and endangered species?

What land acquisition best support restoration?

Should water from flood protection (water discharges to the ocean through canals) be minimized and made available for water supply?

How will individual and cumulative Everglades Restoration projects affect saltwater intrusion?

How will sea-level rise affect coastal restoration projects?

How will climate change affect restoration projects?

How will ASR affect the water quality of the freshwater marshes and estuarine zones?

How can we best restore the natural system while maintaining recreational opportunities (boating, hunting, and fishing)?