U.S. Geological Survey Science Support Strategy for Biscayne National Park and Surrounding Areas in Southeastern Florida

By Melinda A. Wolfert-Lohmann, Christian D. Langevin, Sonya A. Jones,
Chris D. Reich, Georgiana L. Wingard, Ilsa B. Kuffner, and Kevin J. Cunningham

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Conversion Factors and Vertical Datum

Multiply	By	To obtain
centimeter	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
meter per day (m/d)	3.281	foot per day (ft/d)
kilometer (km)	0.6214	mile (mi)
hectare (ha)	2.471	acre
square meter (m^2)	10.76	square foot (ft^2)
cubic meter (m^3)	264.2	gallon (gal)
cubic decimeter (dm^3)	0.2642	gallon (gal)
cubic meter (m^3)	0.0002642	million gallons (Mgal)
liter per minute (L/min)	0.2642	gallon per minute (gal/min)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows: °F = (1.8 × °C) + 32.

Vertical coordinate information is referenced to National Geodetic Vertical Datum of 1929 (NGVD 29).

Acronyms and Abbreviations

AVHRR	Advanced Very High Resolution Radiometer
CERP	Comprehensive Everglades Restoration Plan
CUES	Comprehensive Urban Ecosystems Studies
DERM	Department of Environmental Resources Management
EAARL	Experimental Advanced Airborne Research Lidar
EPOC	emerging pollutants of concern
GIS	Geographic Information System
LSI	landscape stress indicator
MAP	Monitoring and Assessment Plan
MPA	marine-protected area
MS222	Tricaine Methanesulfonate
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
ppb	parts per billion
ppm	parts per million
ppt	parts per thousand
SAV	submerged aquatic vegetation
SHARQ	Submersible Habitat for Analyzing Reef Quality
USGS	U.S. Geological Survey

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1.0 Abstract

The U.S. Geological Survey conducts a wide range of research in and around the Biscayne National Park region of southern Florida. This research encompasses the biologic, ecologic, meteorologic, geologic, and hydrologic components of the system, including water-quality analyses, ground-water modeling, hydrogeologic-data collection, ecologic-habitat evaluations, wetlands characterizations, biogeochemistry of ecosystems, and paleo-ecologic analyses. Relevant information is provided herein for researchers and managers interested in the Biscayne Bay area and about current U.S. Geological Survey efforts that address important resource protection and management issues. Specifically, managers and scientists are provided with information on current and recently completed U.S. Geological Survey projects and a sample listing of potential U.S. Geological Survey research projects addressing relevant issues that face the study area.

2.0 Introduction

The primary goal of the Comprehensive Everglades Restoration Plan (CERP) is to restore the timing, quantity, quality, and distribution of freshwater within the greater Everglades ecosystem so that the ecosystem conditions approximate predevelopment conditions as closely as possible. The changes proposed within CERP will alter the current hydrologic conditions that exist within the region, which includes Everglades National Park, Biscayne National Park, and Big Cypress National Preserve. The magnitude of the changes proposed for this highly complex, diverse, and unique ecosystem has raised concern about the long-term effects of the restoration on different components of the system. For example, restoration efforts that benefit the terrestrial parts of the Everglades may have a negative effect on the estuaries of Florida Bay and Biscayne Bay. Land-management agencies have raised questions, such as:

- How will restoration projects affect ground-water flows?
- Will restoration of wetlands result in increases in coastal aquifer heads which, in turn, may cause the return of ground-water upwelling in Biscayne Bay?
- How would the return of freshwater to Biscayne Bay affect the submerged aquatic vegetation, benthic habitats, and fauna of Biscayne Bay?
- Would increases in coastal runoff lead to the addition of nutrients and other constituents to Biscayne Bay waters and potential phytoplankton blooms?

The potential for further habitat deterioration exists in Biscayne National Park and the surrounding area in southern Florida. This threat, coupled with the numerous species of threatened and endangered animals and plants that reside

Photo 1. Red mangrove in Biscayne Bay.

Photograph courtesy of R. Alleman, South Florida Water Management District (used with permission).

in the area, resulted in a Federal mandate to prevent further habitat degradation. Additionally, the health of Biscayne Bay is an integral measure of the health of the coral reefs that lie within Biscayne National Park. These reefs constitute the northern part of an approximate 241-ha chain of reefs that extend south along the Florida Keys. This reef-tract represents the only living coral bank barrier reef in North America, and the third longest coral barrier reef in the world. Many scientists, managers, and private citizens believe that the key to preserving this unique and endangered coastal ecosystem, as well as the terrestrial Everglades wetlands, is the timing, quantity, quality, and distribution of freshwater flows into the system.

Since the passage of the Water Resources Development Act of 2000 and the approval of CERP, a substantial amount of time and effort has been spent developing management paradigms and conducting research on the location, storage, and movement of water through the greater Everglades ecosystem into Everglades National Park and Florida Bay. Comparatively little research, however, has been conducted regarding how the restoration effort affects the coastal and estuarine resources to the east and west of the axis of the restoration.

The U.S. Geological Survey (USGS) conducts a wide range of research in and around the Biscayne National Park region of southern Florida. This research encompasses the biologic, ecologic, meteorological, geologic, and hydrologic components of the system, including water-quality analyses, ground-water modeling, hydrogeologic-data collection, ecologic habitat evaluations, wetlands characterizations, biogeochemistry of ecosystems, and paleo-ecologic analyses. Summaries of the recently completed projects or projects engaged by the USGS are presented in this report. Even with the breadth of research that is performed by the USGS and other agencies and universities, more research is necessary to more fully understand the ecosystem. A primary goal of this report is to document the scope of USGS research in and near Biscayne Bay to provide others with information on current efforts and promote future collaborative research efforts with the USGS.

This report provides relevant information for researchers and managers interested in the Biscayne Bay area and about current USGS efforts that address important resource protection and management issues. Therefore, this report serves primarily as a forum to provide managers and scientists with information on USGS projects and a sample listing of potential USGS research projects addressing relevant issues that face the study area.

2.1 Partnerships

Partnerships between the USGS and Federal, State, local, and private agencies are necessary for the successful completion of research in Biscayne National Park, and all agencies involved share a concern and desire to assist in the restoration efforts. The scope of work involved requires that all agencies work together to establish common goals, most of which would not be attainable without the joint effort of all involved. These partnerships also ensure that research efforts are relevant to current issues, ensure that critical research is done in a timely fashion, and allow for further collaborative efforts among many different agencies and groups of interested parties.

One large partnership that has been formed is the Recover CERP Group (2004; 2006), consisting of Federal and State agencies, such as the South Florida Water Management District, U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, and National Oceanic and Atmospheric Administration. These agencies also have partnered with the USGS individually and together for a variety of research projects. Other USGS partnerships include those with Biscayne National Park, the University of Miami, Florida International University, Duke University, and Southern Illinois University at Carbondale.

2.2 Acknowledgments

We would like to extend our appreciation to the many USGS scientists, who provided assistance and information for the creation of this document. Additionally, we would like to extend special thanks to Gary Brewer of the USGS, who assisted in coordinating contact with individual researchers; Biscayne National Park scientists Richard Curry, Sarah Bellmund, and others; and South Florida Water Management District researchers Rick Alleman and Teresa Coley for their insight on the major issues facing Biscayne National Park.

3.0 Description of Biscayne National Park and Surrounding Areas in Southeastern Florida

Biscayne National Park (fig. 1) in southeastern Florida is the largest marine park in the National Park system, and encompasses about 172,924 ha, of which 95 percent is covered by water. The park consists of four distinct environments: (1) Biscayne Bay, (2) northern islands of the Florida Keys, (3) mangrove forest along the shoreline of Biscayne Bay, and (4) coral reef tract. The park originally was established as a national monument in 1968 and later designated as a national park by Congress in 1980, "in order to preserve and protect for the education, inspiration, recreation, and enjoyment of present and future generations a rare combination of terrestrial, marine, and amphibious life in a tropical setting of great natural beauty" (Public Law 90-606).

Biscayne National Park is bordered by a major metropolitan area with more than 2.3 million people, year-round agricultural and plant nursery communities, and the Everglades. These entities provide the park with a unique setting as well as a source of diverse issues.

3.1 Ecosystem

The four environments within Biscayne National Park provide diverse terrestrial and marine habitats for the large variety of resident animal and plant species, many of which are endangered or threatened. Hardwood hammocks are a terrestrial habitat for such animal species as the Key Largo wood rat, zebra butterflies, and rare Schaus swallowtails. Plants found in these areas include gumbo limbo, Jamaican dogwood, Strangler fig, and the rare semaphore prickly-pear cactus. Mangrove forests form the transition zone between the terrestrial and marine environments and provide habitat for a variety of bird species, such as the roseate spoonbill, snowy egret, tricolored heron, and the wood stork. Rare and endangered species, such as the American crocodile and eastern indigo snake, also inhabit these areas. Biscayne Bay is a natural habitat for more than 1,000 species of animals, including the following:

- More than 500 species of fish, such as the silver perch, hogfish, red grouper, and yellow-fin mojarra;
- More than 800 invertebrate species, including 150 species of crabs, shrimp, lobsters, and sponges;
- Sea turtles, such as the Atlantic green turtle, leatherback, and loggerhead;
- Mammals, such as the endangered West Indian manatee; and
- At least 50 different species of coral.

Photo 2. *H-alicia* shipwreck.
Photograph courtesy of R. Alleman, South Florida Water Management District (used with permission).

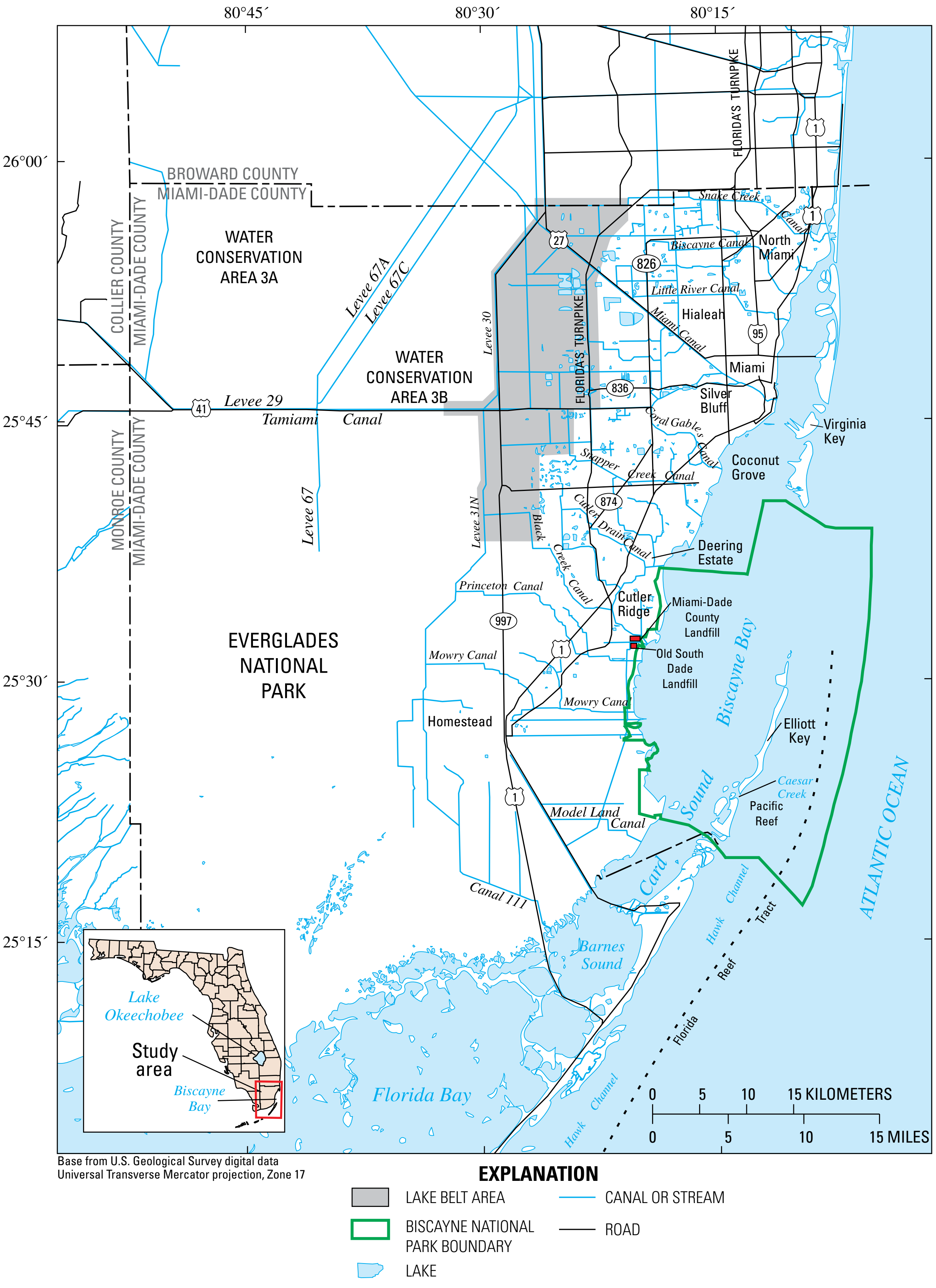


Figure 1. Location of Biscayne National Park in southeastern Florida.

3.1.1 History

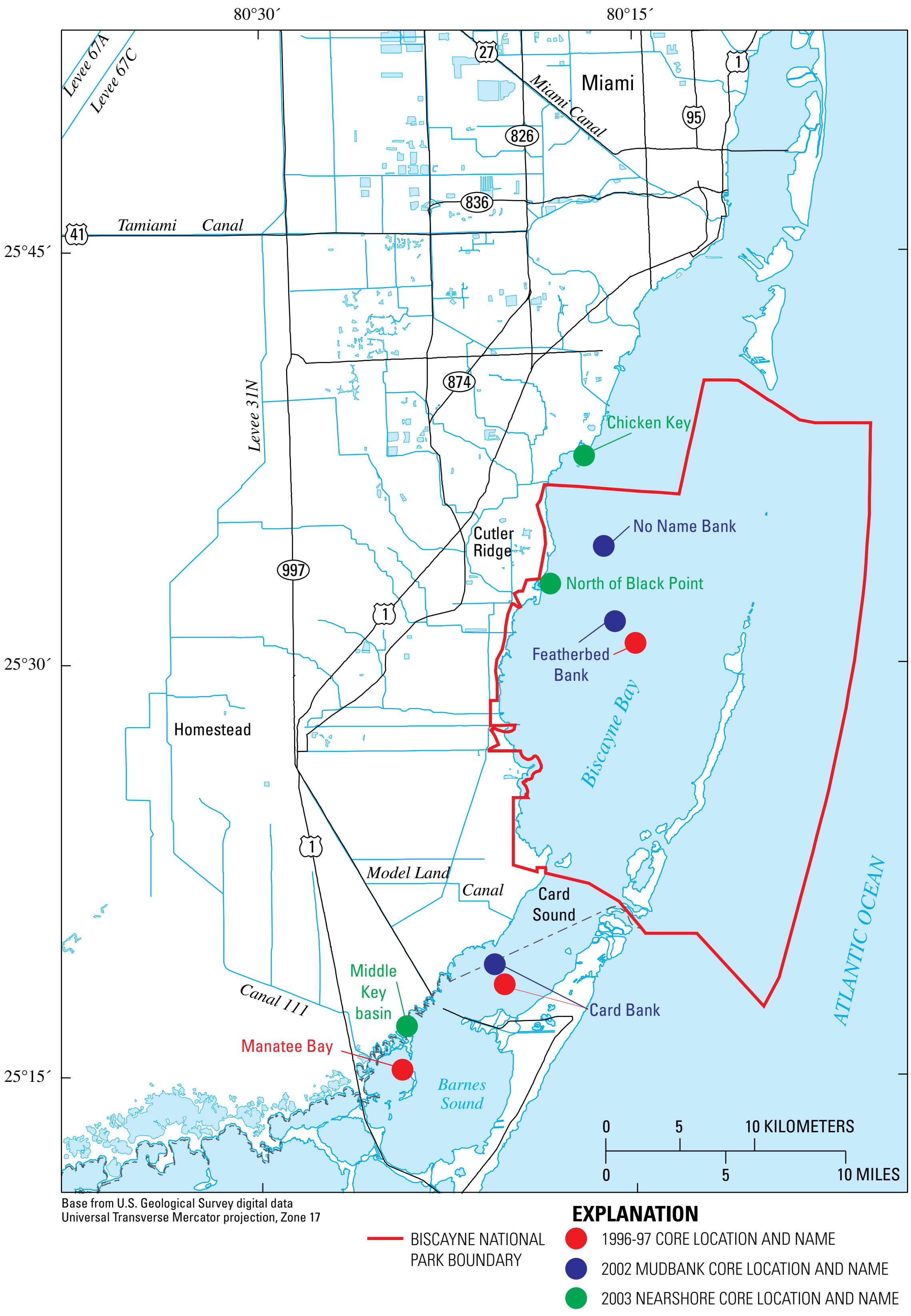
Biscayne Bay began forming between 5,000 and 3,000 years ago as sea level rose and southern Florida was flooded. Throughout most of its history, the waters of Biscayne Bay supported a rich and diverse ecosystem of marine fauna and flora, and the bay served as a nursery for the adjacent coral-reef and marine ecosystems. As Biscayne Bay evolved and formed, natural cyclical change occurred as a result of large-scale physical variation, such as sea-level and climate change, and from changes in biota living in and around the bay. Because natural ecosystems evolve over time, one needs to understand what portion of present-day change in Biscayne Bay is due to human activity and what portion is due to natural variations. To be sustainable and cost effective, restoration targets and performance measures need to be based on the natural system prior to substantial human alteration of the environment, and restoration efforts need to focus on changes associated solely with anthropogenic activity.

The USGS, in cooperation with South Florida Water Management District and Biscayne National Park, has conducted research on the history of Biscayne Bay by examining the sediments and faunal and floral remains in nine radiometric dated cores (fig. 2) from selected sites within Biscayne Bay (Ishman and others, 1998; Wingard and others, 2003; 2004). Results indicate that the Biscayne Bay ecosystem underwent many substantial changes between the last 100 and 500 years. Southern Biscayne Bay, including Card Sound and Barnes Sound, has been relatively isolated from direct marine influence for at least the last two centuries because of its enclosed configuration by barrier islands. Currently, this area is less affected by the urbanization that has occurred to the north, and few developed areas exist along the shoreline. Despite its relative isolation, however, the area has changed substantially during the last century. The three sites examined (Card Bank, Middle Key basin, and Manatee Bay) all show increasing salinity during the last 100 years. The salinity of Middle Key basin has increased steadily since the late 1800s (fig. 3). At Card Bank, salinity has varied substantially on multidecadal and centennial time scales relative to the variation observed at central Biscayne Bay sites, but marine influence at Card Bank has increased over the last century. The mud-banks of central Biscayne Bay have become increasingly marine and increasingly stable (showing less fluctuation in salinity) during the last 100 years. No indications of interdecadal salinity extremes or periods of hypersalinity have been found in cores from Featherbed and No Name Banks (figs. 4 and 5). Salinity has ranged from estuarine to marine (polyhaline to euhaline) throughout the period recorded in the sediment cores. The near-shore cores from north of Black Point and Chicken Key indicate a history of fluctuating salinity. At both sites, the oldest sediments with faunal remains show deposition under conditions of slightly elevated (mesohaline to polyhaline) salinity relative to the overlying layers, succeeded by a period of lower (mesohaline) salinity. During the last 20 to 30 years, salinity at both sites has increased to polyhaline conditions, and there is evidence of an increase in the magnitude of salinity fluctuations during the same time period.

An increasing salinity trend is evident in the Biscayne Bay system (fig. 5) over the past decades (Wingard and others, 2004), although the timing and onset of the salinity increase varies. At the near-shore sites, average salinity has increased and been accompanied by increased variability. In contrast, salinity has increased and become increasingly stable over the last century at the central Biscayne Bay sites. These trends could be a result of rising sea level, of changes to the natural flow of freshwater, or both; however, the timing of changes at some of the near-shore sites may indicate that both factors are involved. These results have several implications for restoration planning. First, sea-level rise and the recognition that Biscayne Bay appears to be evolving toward a more marine environment must be factored into the planning process. Second, generalized performance measures (goals established by CERP) and targets for the near-shore and wetland areas may not reflect the natural variability seen at these sites. Examining decadal to centennial trends in a variety of habitats within the Biscayne Bay ecosystem provides a realistic means to: (1) set performance measures, (2) predict system response to changes invoked by restoration efforts, and (3) better inform the public about predevelopment conditions of the system.

3.1.2 Function

Substantial portions of Biscayne National Park include three major habitats characteristic of subtropical continental shelves: mangrove forests, seagrass beds, and coral reefs. Of these, coral reefs have been studied most extensively by the USGS. The connectivity between these habitats is widely recognized (Ogden and Gladfelter, 1983), and a number of ecologically and economically important species spend part of their life histories in more than one habitat. Seagrass beds and mangrove forests are nursery grounds for a variety of popular edible fish (snappers, grunts, and groupers), as well as *Panulirus argus*, the spiny lobster. Many coral reef fish (yellowtail snapper, French grunt, striped parrotfish, and the rainbow parrotfish) along reefs with mangrove habitat nearby show greater biomass than those found along reefs where mangroves have been removed (Mumby and others, 2004). Additionally, mangroves benefit associated marine ecosystems by buffering sedimentation and other land effects, filtering contaminants from runoff, and preventing shoreline scour (Ogden and Gladfelter, 1983). Seagrass beds stabilize sediments and provide foraging habitat for many commercially important reef species. Additionally, seagrass beds and mangroves serve detrital food webs by processing dissolved and particulate organic matter.



Base from U.S. Geological Survey digital data
Universal Transverse Mercator projection, Zone 17

Figure 2. Location of core sites in Biscayne Bay, Florida.

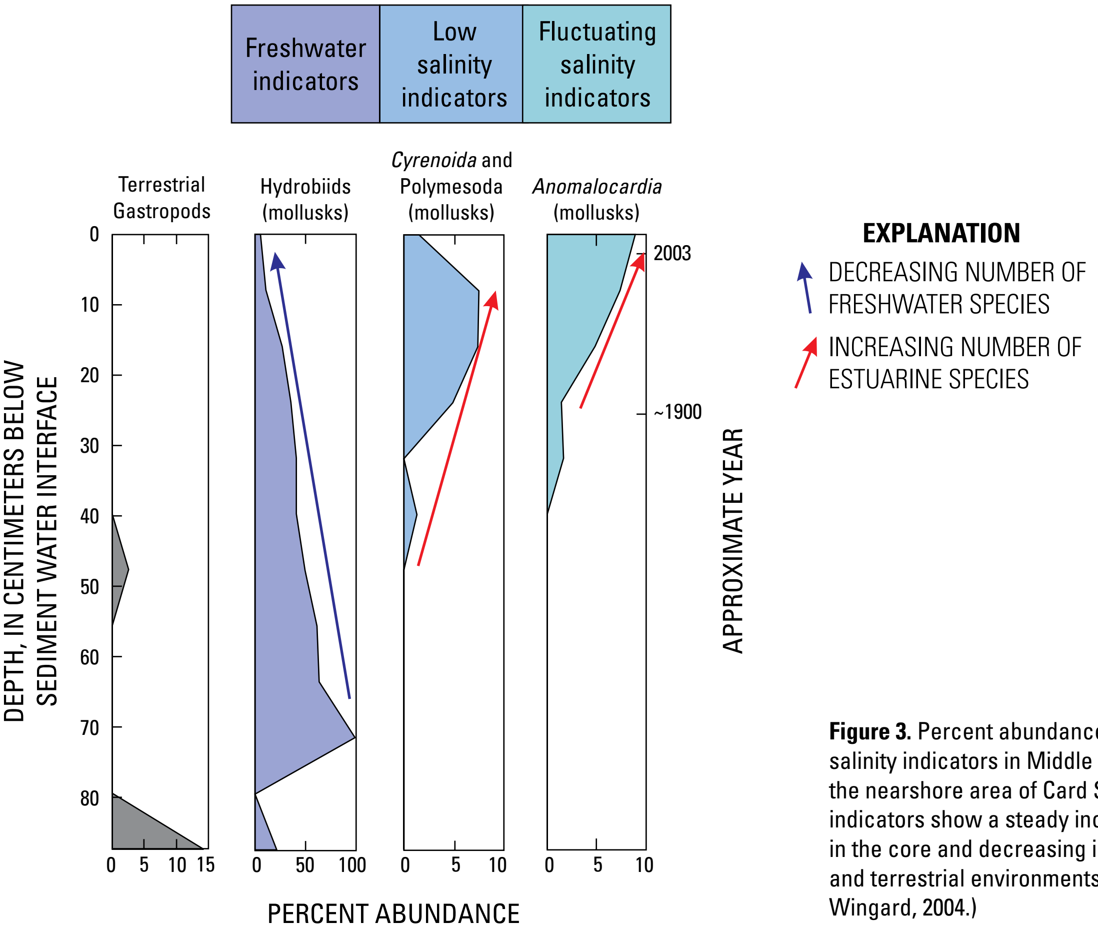


Figure 3. Percent abundance of key molluscan salinity indicators in Middle Key core segments from the nearshore area of Card Sound. Combined, the indicators show a steady increase in salinity upward in the core and decreasing influx from freshwater and terrestrial environments. (Modified from fig. 18, Wingard, 2004.)

The mangrove forests in Biscayne National Park consist of three mangrove species: the red mangrove (*Rhizophora mangle*), black mangrove (*Avicennia germinans*), and white mangrove (*Laguncularia racemosa*) (Smith, and others, 1994; Odum and others, 1982). The band of tall mangroves present along the shoreline of Biscayne Bay occasionally exceeds 15 m in height, and in certain areas, extends up to 200 m inland. Mangrove height decreases further inland, averaging about 1.5 m (Smith, and others, 1994). Within these forests, the majority of the trees are red mangroves. Bands of mixed mangrove forests are also present on the keys that surround Biscayne Bay. The mangrove forests benefit the local ecosystem and nearby population by providing (1) habitat for various types of wildlife, (2) protection from storm-related winds and flooding, (3) protection from soil erosion, (4) natural water filtration that helps improve water quality and clarity, and (5) a source of food for marine organisms that, in turn, are a food source for larger organisms (Odum and others, 1982).

Mangroves are susceptible to a variety of anthropogenic and environmental threats. In recent decades, the high demand for bayside housing has resulted in the destruction of extensive tracts of mangrove forest, although State and local ordinances now help protect mangroves from removal. Mangroves are also affected by chemicals and contaminants (such as herbicides) in the water. Because mangroves are a coastal tropical species, they are susceptible to hurricanes, as well as changes in salinity, tides, water temperature, and soil characteristics.

Photo 3. Biscayne Bay mangroves near Black Point (from Wingard, 2004).

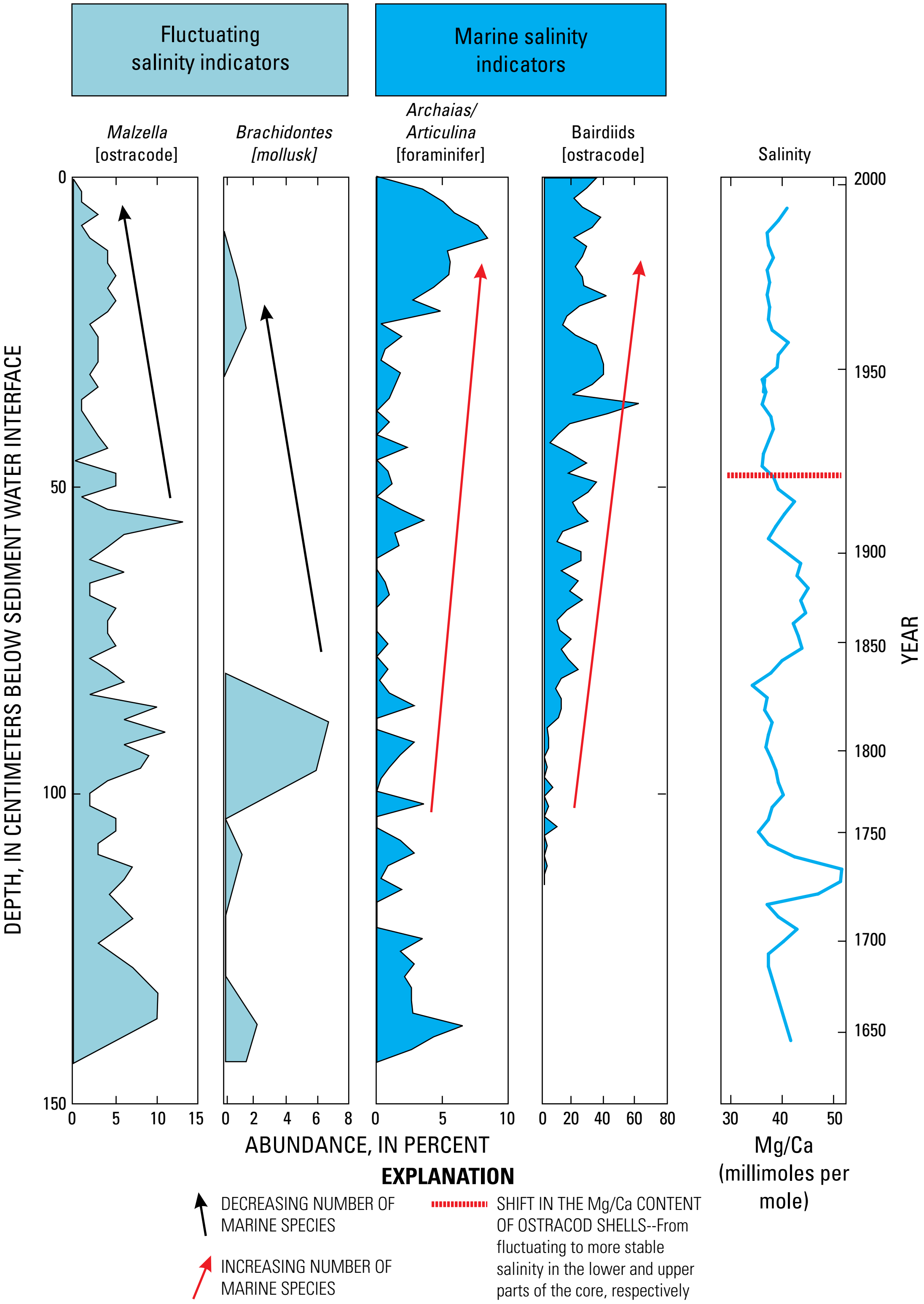


Figure 4. Percent abundance of key salinity indicator species in No Name Bank core segment from central Biscayne Bay and magnesium-calcium (Mg/Ca) ratios derived from ostracod shells.

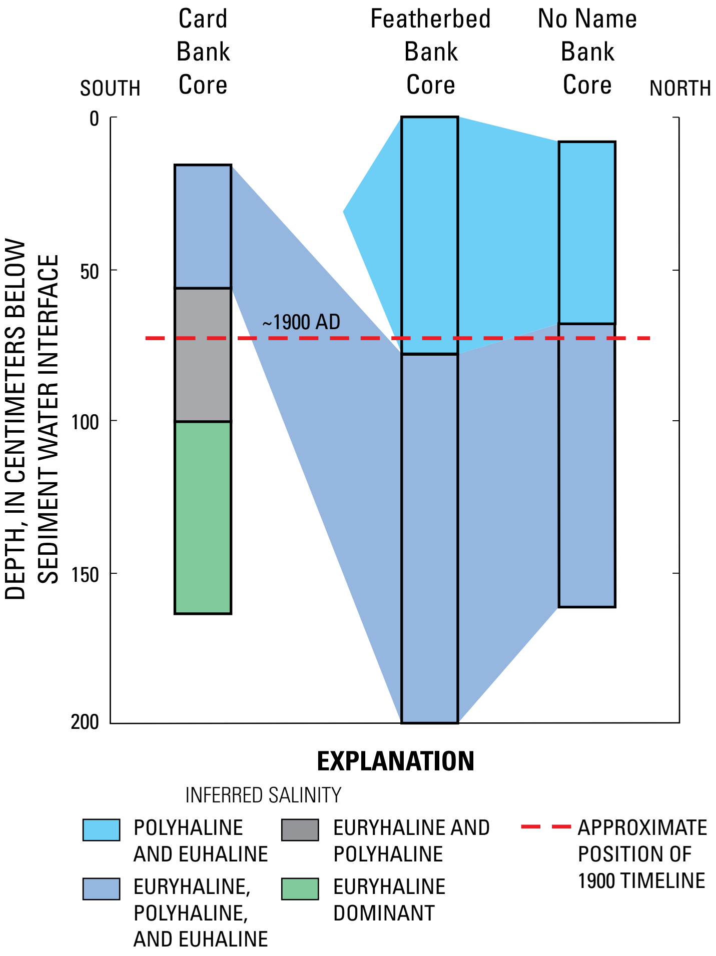


Figure 5. Infrared changes in Biscayne Bay salinity in recent centuries based on indicators from cores between Card Bank and central Biscayne Bay.

Seagrasses are marine plants that are considered to be essential components of coastal ecosystems. The Smithsonian Marine Station at Fort Pierce (2003) noted that seagrasses support high biodiversity, and “because of their sensitivity to changes in water quality, they have become recognized as important indicator species that reflect the overall health of coastal ecosystems.” Seagrasses provide habitat for many different species of marine life, including several endangered species, such as the West Indian Manatee. Additionally, they help provide sediment stabilization, and contribute to the carbon budget (Lirman and Cropper, 2003).

In Biscayne Bay, seagrass beds cover up to 64 percent of the seafloor (Department of Environmental Resources Management, 1985) and consist of seven species: turtle grass (*Thalassia testudinum*), shoal grass (*Halodule wrightii*), manatee grass (*Syringodium filiforme*), three types of Halophilia, and Ruppia maritime (Browder and others, 2005). Of these species, *Thalassia testudinum*, *Halodule wrightii*, and *Syringodium filiforme* make up over 70 percent of the coverage (Lirman and Cropper, 2003).

Photo 4. Seagrass in Biscayne Bay (from Wingard, 2004).

It has been estimated that Biscayne Bay has lost about 43 percent of its seagrass coverage since the 1940s (Florida Department of Fish and Wildlife, 2003). Seagrass communities are sensitive to several anthropogenic and natural environmental threats, especially changes in water quality, as noted earlier. Canal outflows are a major source of water-quality degradation, because they can contain high nutrient and chemical loads, such as sulfides and modified dissolved oxygen levels. In addition, large freshwater outflows occur that substantially change salinities in Biscayne Bay. Natural environmental threats include temperature increases, disease, and hurricanes (Lirman and Cropper, 2003).

The coral reef habitat in Biscayne National Park varies widely in form and function. Within Biscayne Bay, temperature, sedimentation, and salinity seem to limit coral abundance and diversity, particularly to the west (Lirman and others, 2003). A comprehensive survey of hard-bottom habitat within the bay revealed 12 species of hard corals, with the density of coral colonies inversely related to mean sediment depth (Lirman and others, 2003). Expansive and shallow seagrass beds are present between the outer shoreline of the Biscayne National Park keys and about 4 km seaward where the water deepens. At about 3 to 7 km from the shoreline, seagrass beds surround patch reefs with depths between about 1 and 6 m. Deeper fore reef habitat is present about 7 km from the shoreline of the keys.

Coral reefs around the world have experienced marked degradation over the past three decades due to a number of global and local scale stressors (Hoegh-Guldberg, 1999; Hallock, 2001; Hughes and others, 2003; Pandolfi and others, 2005). Within Biscayne National Park, research shows a gradual decline in the average annual growth of an important reef-building coral *Montastrea annularis* (Hudson, and others, 1994). Fisheries stocks in Biscayne National Park show signs of heavy exploitation: 77 percent of 35 species of fish that could be analyzed are over fished, and stock biomass is critically low (Ault and others, 2001). Fishing pressure (mainly skilled recreational) is particularly high in readily accessible areas directly seaward of Caesar's Creek (Harper and others, 2000).

Photo 5. Biscayne National Park patch reef.

Photograph by Mark Bonito.

Photo 6. *Montstrea cavernosa* infected with black band disease.

Photograph by Ilsa Kuffner, U.S. Geological Survey.

In general, the lagoon patch reefs inside Biscayne National Park show greater coral cover, biodiversity (Miller and others, 2000), and topographic complexity (Brock and others, 2004) than the adjacent outer fore reefs. Densities of coral recruits were consistent across the shelf (Miller and others, 2000) and seem to be comparable with other areas in the Caribbean (Edmunds, 2000). One study found higher recruit densities on patch reefs in the lower keys than in the upper keys (Moulding, 2005), whereas another study found no latitudinal gradient (Tougas and Porter, 2002). In another study, two inshore patch reefs showed lower rates of herbivory compared to two offshore reefs, but algal biomass (which is seasonally dynamic) did not correlate with the pattern (Lirman and Biber, 2000). The patch reefs in Biscayne National Park showed better resistance to Hurricane Andrew compared to the outer fore reefs (Blair and others, 1994), although the damage spatially was inconsistent (Tilmant and others, 1994). Evidence is lacking to determine whether inshore patch reefs are subject to greater anthropogenic stress than outer reefs due to their closer proximity to land-based sources. The few studies that address this topic, however, do not support the hypothesis because patch reefs studied seem to be in better condition than the offshore reefs (Glynn and others, 1989; Szmant and Forrester, 1996; Miller and others, 2000).

Although global stressors (for example, increases in water-surface temperature and sea level rise) are largely beyond the control of local resource managers, local-scale stressors can be understood and mitigated. For example, the occurrence of coral diseases in the Florida Keys is increasing (Porter and others, 2002), but evidence is unclear whether the increase is related directly to anthropogenic factors. Disease outbreaks have caused major changes in the coral community structure in many areas of the Caribbean and Florida in the recent past (Aronson and Precht, 2001), and evidence suggests that elevated nutrient levels potentially could increase the severity of coral diseases (Bruno and others, 2003). Because of the potential changes to Biscayne National Park water quality that may result from CERP, it is prudent to make research in this area a priority. At this juncture in CERP, it is important to understand the relation between nutrient (both dissolved and particulate) input and community structure in all of the major marine habitats represented within Biscayne National Park boundaries.

3.2 Hydrology

The hydrology of southeastern Florida is complex because of the dynamic interaction between ground water and surface water. The surface-water component consists of a managed system of canals, control structures, levees, and a small portion of overland flow. The underlying ground-water network in this area is characterized by a shallow surficial aquifer system and the deeper Floridan aquifer system. Parker and others (1955) and Kohout (1960) have suggested that the ground water discharging into Biscayne Bay originates from the Biscayne aquifer, which is part of the surficial aquifer system.

Prior to dredging and construction of the surface-water canal and levee system throughout the Everglades and southeastern Florida, the water level was about 1.8 m higher (Thorhaug and others, 1976) than it is today. This loss of upland water pressure has decreased fresh ground-water discharge to Biscayne Bay. The replumbing of the predevelopment system reduced the seaward hydraulic gradient that supplied freshwater to offshore submarine springs throughout Biscayne Bay, and lowered ground-water levels throughout the area (Buchanan and Klein, 1976). The lowering of inland water levels has caused substantial reductions in submarine spring flows.

3.2.1 Surface Water

The dynamics of the surface-water system are governed by both natural and anthropogenic features. The Atlantic Coastal Ridge, a physiographic feature, separates the Everglades from the Atlantic Ocean and Biscayne Bay. This ridge is between 5 and 15 km wide and roughly parallels the coast in the northern half of Miami-Dade County. In southern Miami-Dade County, the ridge is located farther inland, and low-lying coastal marshes and mangrove swamps adjoin Biscayne Bay. Historically, the transverse glades (low-lying areas that cut through the ridge) allowed high-standing surface water in the Everglades to drain into Biscayne Bay. Throughout much of the area, a complex network of levees, canals, and water-control structures is now used to manage the water resources. The major canals, operated and maintained by the South Florida Water Management District, were constructed to prevent low-lying areas from flooding and prevent saltwater intrusion into the Biscayne aquifer. These canals are mostly within the low-lying transverse glades to more effectively route surface water toward Biscayne Bay.

3.2.2 Ground Water

In Miami-Dade County, the surficial aquifer system includes all rocks and sediments from land surface downward to the top of the intermediate confining unit, defined by a substantial decrease in permeability (fig. 6). The rocks and sediments are composed mostly of limestone, sandstone, sand, shell, and clayey sand and range in age from Holocene to Pliocene (Causaras, 1987). The permeability of rock and sediment within the surficial aquifer system is variable, allowing the system to be divided into one or more aquifers separated by less-permeable or semiconfining units. The uppermost part of these water-bearing units is the Biscayne aquifer (Parker, 1951; Parker and others, 1955), and the lowermost water-bearing unit is the gray limestone aquifer (Fish and Stewart, 1991; Reese and Cunningham, 2000). The geology and hydrology of the Biscayne aquifer in Miami-Dade County have been the subject of numerous studies (Parker and Cooke, 1944; Parker and others, 1955; Kohout, 1964; Perkins, 1977; Causaras, 1987; Labowski, 1988; Shinn and Corcoran, 1988; Fish and

Photo 7. Sea fan (*Gorgonia* sp.) in Biscayne Bay.

Photograph courtesy of R. Alleman, South Florida Water Management District (used with permission).

Photo 8. Sponge (unidentified) in Biscayne Bay.

Photograph courtesy of R. Alleman, South Florida Water Management District (used with permission).

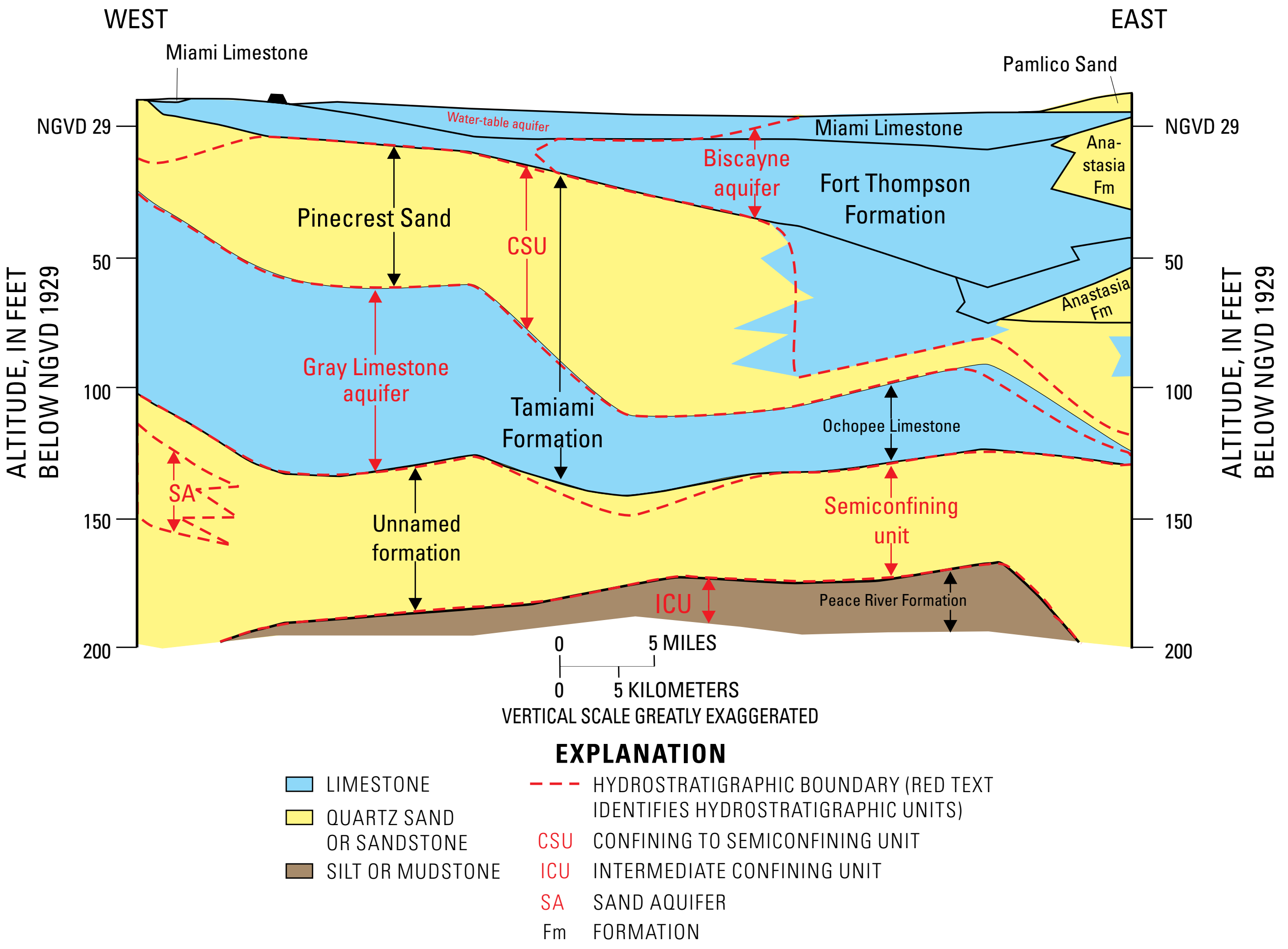


Figure 6. Relations of geologic formations, aquifers, and semipermeable units of the surficial aquifer system across central Miami-Dade County (from Reese and Cunningham, 2000).

Stewart, 1991; Galli, 1991; Solo-Gabriele and Sternberg, 1998; Nemeth and others, 2000; Langevin, 2001; Sonenshein, 2001; Cunningham and others, 2004a,b; 2006a,b).

The Biscayne aquifer is the primary aquifer in southeastern Florida and has been declared a sole-source aquifer (Federal Register Notice, 1979). Parker (1951) named and defined the Biscayne aquifer as a hydrologic unit of water-bearing rocks that carries unconfined ground water in southeastern Florida. Later, Fish (1988), defined the Biscayne aquifer more completely as:

> That part of the surficial aquifer system in southeastern Florida composed of (from land surface downward) the Pamlico Sand, Miami Oolite [Limestone], Anastasia Formation, Key Largo Limestone, and Fort Thompson Formation (all of Pleistocene age) and contiguous, highly permeable beds of the Tamiami Formation of Pliocene and late Miocene age where at least 10 ft (about 3 m) of section is highly permeable, with a horizontal hydraulic conductivity of at least 1,000 ft/d (about 305 m/d).

Fish (1988) provided further definition of the base of the Biscayne aquifer:

> If there are contiguous, highly permeable (having hydraulic conductivities of about 100 ft/d [about 30.5 m/d] or more) limestone or calcareous sandstone beds of the Tamiami Formation, the lower boundary is the transition from these beds to subjacent sands or clayey sands. Where the contiguous beds of the Tamiami Formation do not have sufficiently high permeability, the base of highly permeable limestone or sandstones in the Fort Thompson Formation, Anastasia Formation, or Key Largo Limestone is the base of the Biscayne aquifer.

The Biscayne aquifer recently has been described as a karst aquifer (Cunningham and Aviantara, 2001; Vacher and Mylroie, 2002; Cunningham and others, 2004a,b and 2006a,b; Renken and others, 2005). This revised view has implications that may fundamentally alter the definition of the hydrogeologic framework needed for reliable simulation of ground-water movement and solute transport. Karst aquifers traditionally are characterized by three types of porosity: interparticle matrix porosity, fracture porosity, and large cavernous porosity (Martin and Screaton, 2001). This has led many researchers to view karst aquifers as two component systems, where much of the ground-water storage occurs in the matrix porosity, fractures, or both, and much of the ground-water flow and transport takes place in large dissolutional conduits (Martin and Screaton, 2001). However, in the young eogenetic karst that defines the Pleistocene limestone of the Biscayne aquifer, a fourth porosity type—touching-vug porosity—is especially important for ground-water transport (Vacher and Mylroie, 2002; Cunningham and others, 2006a,b). The triple porosity of the Biscayne aquifer is typically: (1) a matrix of interparticle and separate vug porosity, providing much of the storage; (2) touching-vug porosity, creating stratiform ground-water flow passageways; and (3) less common conduit porosity composed mainly of bedding plane vugs, thin solution pipes, and cavernous vugs—these three conduit porosity types are all pathways for conduit ground-water flow (figs. 7- 9). Stratiform refers to the three-dimensional aspects of porosity; that is, it is constrained to a layer, bed, or stratum with lateral continuity (Jackson, 1997).

In the 246-km^2 (95-mi^2) Lake Belt area west of Biscayne Bay, Cunningham and others (2004a,b; 2006a,b) have shown that porosity and permeability of the Biscayne aquifer are related to past depositional environments and how sediments were deposited during repeated past sea-level changes. In the Lake Belt area, six depositional environments containing major lithologic components of the Biscayne aquifer—the Tamiami Formation, the Fort Thompson Formation, and the Miami Limestone—include: (1) middle ramp, (2) platform margin-to-outer platform, (3) open-marine platform interior, (4) restricted platform interior, (5) brackish platform interior, and (6) freshwater terrestrial environments. High-frequency cycles form the fundamental building blocks of the rocks of the Biscayne aquifer. Vertical lithofacies assemblages, which have stacking patterns that reoccur, fit within the high-frequency cycles. Upward-shallowing subtidal cycles, upward-shallowing paralic cycles, and aggradational subtidal cycles define three types of ideal high-frequency cycles that occur within the Fort Thompson Formation and Miami Limestone. Based on vertical cycle patterns, high-frequency cycles group into two cycle sets: an older progradational cycle set, and an overlying, younger aggradational cycle.

The geologic framework of Biscayne National Park has been investigated by core drilling along a northwest to southeast transect from Black Point to Pacific Reef. Seven sites were core drilled and monitoring wells installed as part of a ground-water characterization project (Reich and others, 2006). The cores were described and used to extend the onshore geologic framework of the aquifer (Fish and Stewart, 1991; Cunningham and others, 2004a,b) seaward into Biscayne Bay. The Miami Limestone and Fort Thompson Formation extend into the bay, and a facies change occurs at Elliott Key to a more reefal limestone as the Miami Limestone grades laterally into the Key Largo Limestone. The Key Largo Limestone is buried to the east under modern sediments within Hawk Channel and a Holocene reef cap out on the Florida Reef Tract. Age-dated coral within the cores indicates the Pleistocene-Holocene boundary is about 10 m below NGVD 29 along the shelf edge at Pacific Reef.

3.2.3 Water Quality

There are numerous sources of potential ground-water and surface-water contaminants in the terrestrial areas adjacent to Biscayne National Park. The shoreline and nearby upland areas have been extensively developed. The upland areas contain numerous deeply dredged pits (rock mines), lakes, and water storage sites that collect and hold urban surface-water runoff. The highly permeable limestone substrate of the region makes the ground-water system highly susceptible to the infiltration and spread of nonpoint-source pollutants from surface-water runoff and the dredged sites. In addition, a large Class I landfill (the South Dade Landfill at Black Point) was established in 1978 in an area directly adjacent to Biscayne Bay and Biscayne National Park. It replaced an earlier, privately owned Class I landfill, that was unlined and sited about 1-3 ft (0.3-0.9 m) into the local water table in southern Miami-Dade County, and was operated between 1950 and 1978 (McKenzie, 1983; Shinn and Corcoran, 1988). The newer facility has resulted in the creation of a large mound of municipal waste (the older landfill material has largely decomposed and now forms a low-profile hill), with a strong potential for ground-water contamination, which could be transported into Biscayne National Park through ground-water flow paths. Some ground-water infiltration of nutrients and contaminants from the urban developments and the municipal waste facility have been documented; the concentration of ammonia nitrogen in local ground water, including that of Biscayne National Park, has increased by more than 40 ppm above normal background levels of 10 ppb.

The question of whether nutrients from human sources reach the outer reef tract in southern Florida remains unresolved. Some researchers contend that anthropogenic nutrients are the key factor responsible for the increase in fleshy macroalgae observed on Florida (and many other)

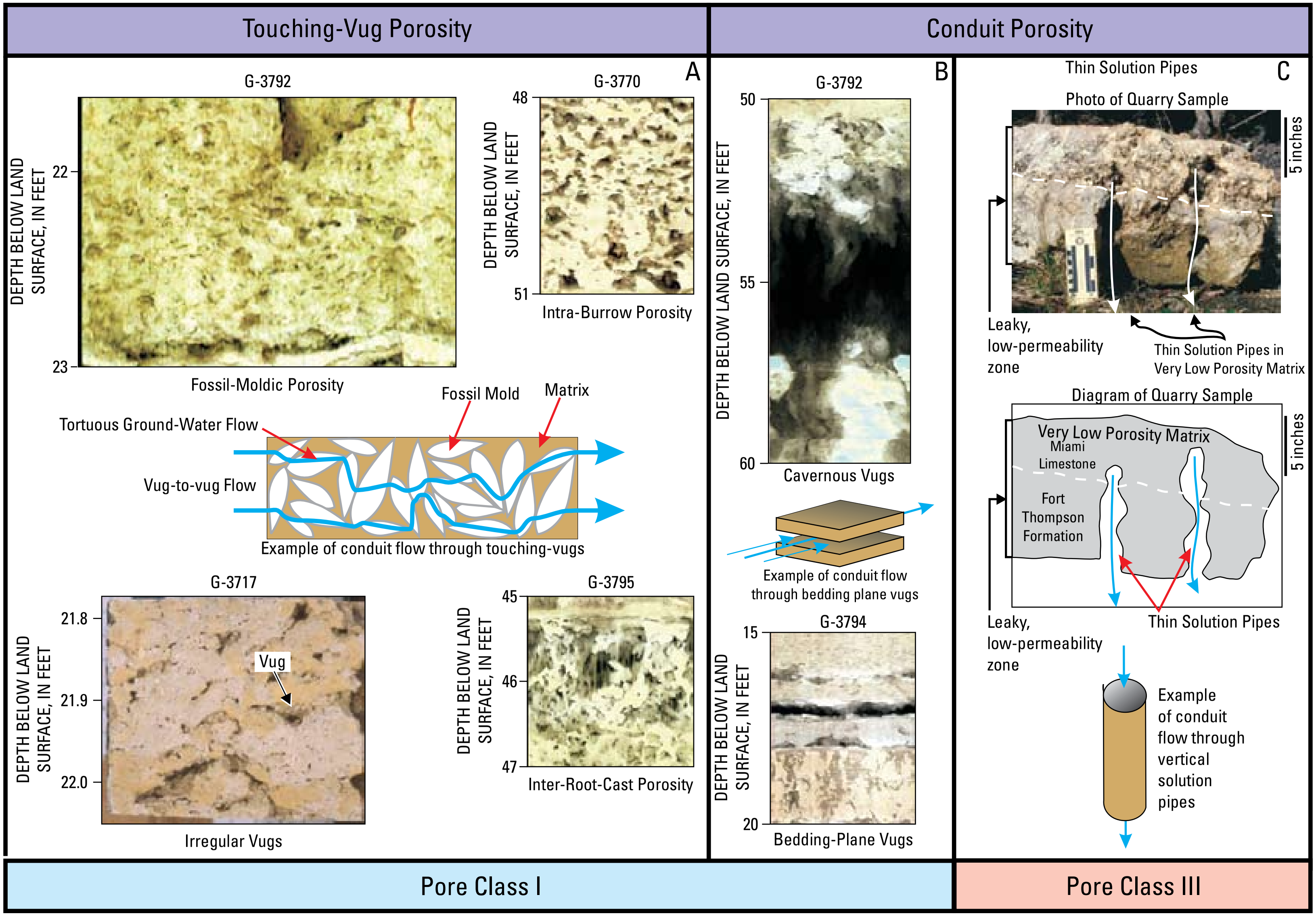


Figure 7. Relation between pore classes I and III and touching-vug and conduit-pore types, respectively, for the Fort Thompson Formation and Miami Limestone in the Lake Belt area of Miami-Dade County. (A) Four common types of touching-vug porosity: fossil moldic, intra-burrow, irregular vugs, and inter-root-cast porosity for pore class I. (B) Two types of conduit porosity (cavernous and bedding-plane vugs) that are rather untypical for pore class I. (C) Thin, vertical conduits that are a typical pore type of pore class III. From Cunningham and others, 2006a.

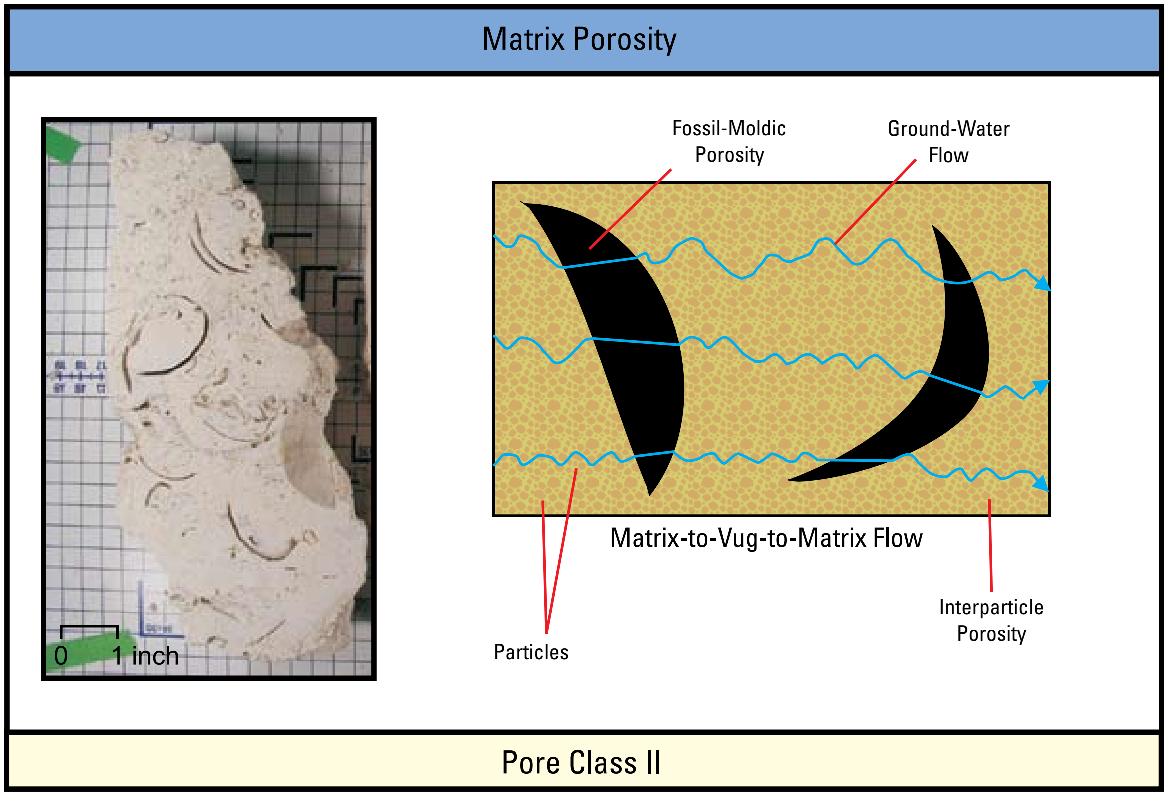


Figure 8. Relation between pore class II and matrix porosity. Ground-water flow through the matrix is generally matrix-to-vug-to matrix flow. Core sample of pelecypod floatstone and rudstone lithofacies shown in photograph is from the Fort Thompson Formation. From Cunningham and others, 2006a.

Photo 9. Alina's Reef drilling in Biscayne National Park.

Photograph by Chris Reich, U.S. Geological Survey.

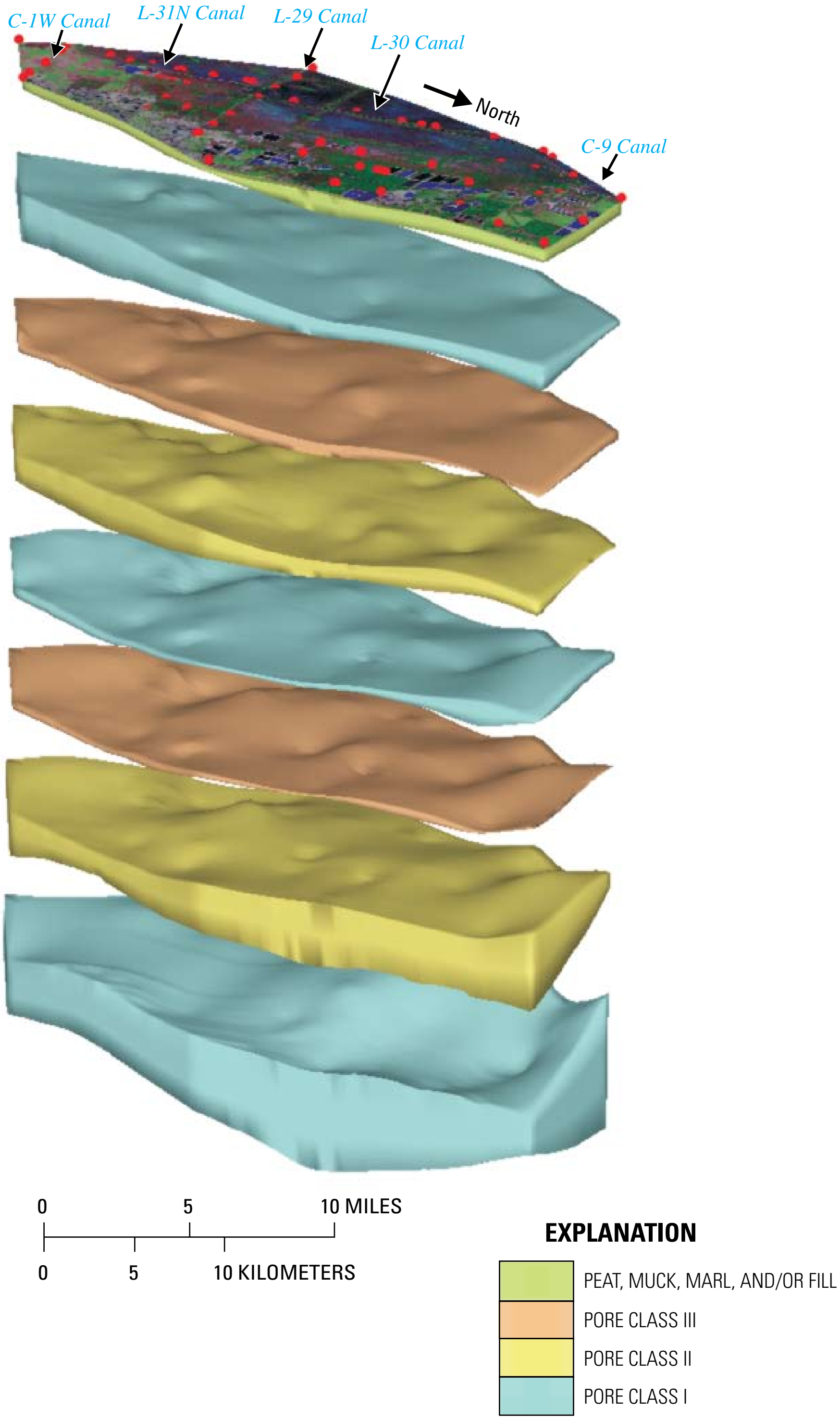


Figure 9. Three-dimensional conceptual hydrogeologic model of the Biscayne aquifer for the Lake Belt area in north-central Miami-Dade County (modified from Cunningham and others, 2006b).

Photo 10. Scientist/diver collecting pore-water samples at Alina's Reef, Biscayne National Park.

Photograph by Chris Reich, U.S. Geological Survey.

reefs (Lapointe, 1997; Lapointe and others, 2002), whereas others believe that a combination of hurricanes and declines in herbivory caused by overfishing and disease (*Diadema antillarum* die-off) are the main causes, and nutrients play a much smaller role (Hughes, 1994; Szmant and Forrester, 1996; Lirman, 2001; Szmant, 2002). Although preliminary research shows that ground water beneath reefs does contain nutrients, a USGS study (Reich and others, 2006) indicates that "ground water beneath the reefs do contain nutrients, principally ammonium (Shinn, 1993) and soluble silicates, at levels many times higher (10 to 300) than that of normal seawater, and evidence for a direct linkage to coral reef degradation is lacking." Discharge of treated wastewater into the Lower Floridan aquifer (about 800 m [2,600 ft] below land surface) is another possible source of contamination for Biscayne National Park. Additional surface-water pollutants enter Biscayne National Park from the Miami River, Turkey Point Nuclear Power Plant, and from heavy metals and petroleum from several coastal marinas (Lidz, 2002). With the projected changes outlined in CERP, additional research is needed to adequately determine the connection among nutrients, contaminants, and coral reef health, particularly in areas such as Biscayne National Park where a number of potential eutrophication sources exist. Resource managers in Florida have expressed a considerable need for scientific research to address the issue (Keller and Causey, 2005).

3.3 Socioeconomic Conditions

Population growth and development in southeastern Florida place considerable anthropogenic stress upon the natural resources of the area. In 2000, the population of Miami-Dade County (which includes Biscayne National Park) was about 2,250,000 (U.S. Census Bureau, 2000) and has since increased to more than 2,350,000. The population is expected to grow even further in the coming years, increasing the demand for agriculture, water supply, and sewage treatment, as well as increasing air pollution, land pollution, and developed areas. Water inflow to Biscayne National Park occurs primarily through a series of canals and levees operated by the South Florida Water Management District. The possibility of additional pollution through these waterways caused by future population growth is of concern; however, a larger issue is CERP, signed into law in 2000. One goal of CERP is to remove canal and levee infrastructures in the watershed to restore the predevelopment southward flow of water into Everglades National Park. If research on the effects of changing the quantity, quality, timing, and distribution of water is not performed before CERP is fully implemented, the planned modifications may create additional problems for Biscayne National Park in the future.

The increasing population in the region also may increase park visitation and consequent stress to the Biscayne National Park ecosystem. Increased recreational activities within the park may result in overfishing, additional boat damage to threatened seagrass beds and coral reefs, and increased trash and pollutants. Additionally, invasive nonnative species have been introduced into the park ecosystem. These species compete for resources, and in some instances (for example the snail *Melanoides tuberculatus*), introduce diseases that can threaten the health of park visitors and native animal populations.

4.0 U.S. Geological Survey Research Issues and Needs

USGS scientists working in Biscayne National Park and surrounding areas have identified several environmental resource issues where substantial gaps in information exist and further research is needed. The research needs have been grouped into four major categories: (1) ecosystem stresses; (2) water deliveries; (3) contaminants; and (4) database and Geographic Information System (GIS) issues. Selected potential USGS projects that address many of these issues are described later.

4.1 Ecosystem Stresses

Rapid population growth and associated development during the 20th century have resulted in aquatic habitat loss at an unprecedented rate. This is especially true in coastal wetland areas of the Nation where at least one-third of threatened and endangered species reside (Murdock, 1994). Brackish coastal wetlands are being developed or otherwise degraded and destroyed at an accelerating rate as a direct and indirect effect of urbanization. These problems make it essential to identify and study the different indicator species in the region to determine how urbanization affects them and their associated habitats.

As described earlier, Biscayne National Park is bordered by developed areas within Miami-Dade County and includes a substantial amount of sensitive estuarine areas and fragile ecosystems within its boundaries, such as the coral reef and reef-associated habitat. As with most other reefs in the region, those within Biscayne National Park have experienced substantial declines in coral cover and fish biomass/abundance, as well as increased algal cover and incidence of coral disease. Despite the semiprotected status of these resources within Biscayne National Park, reef habitats have not shown any signs of recovery since the protection laws were established. Water-quality issues, including increased levels of nutrients and water-borne pathogens, are hypothesized to be a primary cause of these observed changes. Although the previously described modifications under CERP are pending, baseline community structure data are unavailable for many areas throughout the park. These data are needed to: (1) accurately assess and document the positive or negative effects associated with changes in freshwater delivery patterns, and (2) determine the effects of terrestrially derived contaminants upon the Biscayne National Park estuary and ecosystem.

In the future, it is also important to know, not only what is currently in Biscayne Bay, but to develop models that can describe the potential habitat suitability for these different flora and fauna. This will provide managers and others with a method to assess how potential changes to the system may alter the habitat and affect the populations of different species that reside in these habitats.

In addition to habitat stress, there are major stresses to the many different species of flora and fauna in Biscayne National Park and Biscayne Bay. The shoreline of Biscayne Bay is highly developed and is considered one of the 10 most endangered parks in the national park system (National Parks Conservation Association, 2001). Pollutants can potentially enter Biscayne Bay from multiple point and nonpoint sources including boats, canals, quarrying operations, the Class 1 landfill described earlier, several C and D landfills, military operations, a sewage-treatment plant, urban and agricultural runoff, and submarine ground-water springs. Additional studies are needed to determine which of these, if any or all, directly affect Biscayne Bay. Because the effects of these sources on the fauna and flora (including the microbial component) of Biscayne National Park have not been characterized fully, additional study is needed to address the following questions:

- Are anthropogenic chemicals changing bay microbial community compositions, resulting in modulation of nutrient cycling or increases in opportunistic pathogens?
- Do pollutants entering Biscayne Bay ultimately reach the reef tract, or are they remediated by other natural or anthropogenic factors within the bay?
- How severe are the effects of these pollutant stressors on the fauna and flora of Biscayne Bay?

To fully determine the threats to the Biscayne National Park ecosystem, studies in addition to those listed above would be necessary. These studies may involve the use of models, field-data collection, or both to determine or extrapolate the following:

- Past and/or future ecological conditions in Biscayne Bay,
- Relation between the distribution of bay organisms and freshwater flows and contaminants,
- Relation between salinity and the Biscayne National Park ecosystem or its components,
- Critical ranges for ecological species targets, and
- Present floral and faunal species distributions.

Photo 11. Alina's Reef in Biscayne Bay.

Photograph by G.L. Wingard, U.S. Geological Survey.

4.2 Water Deliveries

During the last century, Biscayne Bay has been affected greatly by anthropogenic alteration of the environment through urbanization of the Miami-Dade County area and alteration of predevelopment surface-water flow. The alterations of historical quantity, quality, timing, and distribution of freshwater flow into the bay have changed the shoreline and associated submerged aquatic vegetation (SAV). Current CERP goals are to restore predevelopment flows of freshwater into Biscayne Bay that would ultimately begin the restoration of the natural fauna and flora. Predevelopment baseline conditions first need to be determined to establish targets and performance measures for restoration. To accomplish this task, it is necessary to examine patterns of temporal change in salinity, water quality, vegetation, and benthic fauna in Biscayne Bay between the last 100 and 300 years and examine the causes of change. These historical data also can be applied to help predict system characteristics in the future with and without CERP. Additionally, it is necessary to understand the geologic framework of the aquifer and the general patterns of surface-water flow that existed prior to the construction of the canal systems to create a better approximation of the predevelopment flow system.

Currently, CERP plans to reestablish flows in the Everglades system and surrounding areas, including Biscayne Bay. The changes proposed within this plan may substantially alter current hydrologic conditions in the park, and may even cause offshore springs in Biscayne Bay to once again become sites of freshwater discharge. Additionally, these activities that reestablish ground-water flow may create the potential for "flushing" stagnant and possibly contaminated ground water into the offshore marine ecosystem. If this scenario were to occur, there is a large potential for the deterioration of habitat for the many different threatened or endangered species of plants and animals that reside along the coastline of Biscayne Bay, in the bay, and on the coral reef tract. Therefore, it is essential that these hydrologic conditions are determined prior to any water-delivery changes made by CERP in order to protect these sensitive ecosystems.

Collective knowledge of the subsurface hydrogeology beneath Biscayne Bay and offshore reef areas is limited, but necessary for connecting the better known onshore hydrogeology to the offshore. The current hydrogeology of the bay is based mainly on lithologic data from shallow coreholes that have not been linked to the context of the new karst hydrostratigraphic conceptual model that has been developed onshore by Cunningham and others (2006a,b). A cost effective means of linking the onshore hydrogeologic model is through acquisition and interpretation of high-resolution marine-reflection seismic data throughout the bay. The seismic data could be combined with new offshore coreholes that fully penetrate the Biscayne aquifer, thus providing critical data for mapping a much improved hydrologic framework that is needed for development of more accurate ground-water flow simulations. The new modeling could be used to quantify rates and flows of freshwater to Biscayne Bay for managing the bay ecosystems and improve delineation of coastal saltwater intrusion.

In addition to the subsurface characteristics of Biscayne Bay, it is necessary to determine sediment thickness and the hydraulic characteristics within Biscayne Bay. This information serves as model input and is necessary to accurately determine how closely surface water and ground water interact within the bay.

Biscayne National Park has a vested interest in better understanding how submarine ground-water discharge has affected Biscayne Bay during the past and present, and how CERP modifications will affect future ground-water and surface-water flows. New technologies recently have been used to successfully identify and quantify submarine ground-water discharge in Biscayne Bay (Swarzenski and others, 2004a,b). Geophysical tools, such as direct-current continuous resistivity profiling, have been used in several marine and estuarine areas to discern the subsurface freshwater-saltwater interface and freshened ground-water masses. Monitoring wells within the bay were used as controls in matching *in-situ* ground-water salinity and values obtained using continuous resistivity profiling. Other means used to delineate ground-water discharge are electromagnetic seepage meters and *in-situ* radon-222. Radon-222 is particularly well suited as a submarine ground-water discharge tracer in southern Florida because: (1) radon-222 concentrations in ground water are several orders of magnitude greater than those measured in surface waters (Swarzenski and others, 2006), and (2) radon-222 is a chemically inert noble gas, and also has a short half-life ($t_{1/2} = 3.8$ days). Surface waters where radon-222 is elevated typically coincide with areas of enhanced submarine ground-water discharge. These technologies could be used in Biscayne Bay and surrounding waters to increase current knowledge of subsurface ground-water flow patterns; the results could then be placed in the context of potential ecological effects (Kim and Swarzenski, 2005).

Photo 12. Water sampling syringe and mini-piezometer used for collection of reef sediment pore waters.

Photograph by Chris Reich, U.S. Geological Survey.

As mentioned above, monitoring wells have been installed within Biscayne National Park and along the coastline in northern Biscayne Bay. During the installation of these monitoring wells, rock cores were collected to obtain lithologic and hydrostratigraphic information about the rocks beneath Biscayne Bay and the reef tract. Additional coring sites may be necessary if modeling efforts require additional information about permeability, porosity, or chemistry that can be obtained from monitoring wells. The installation of pressure sensors in wells may be useful for understanding hydraulic gradients across Biscayne National Park. Dye and isotope tracers, as well as monitoring of springs and their associated benthic communities along coastal Biscayne Bay, would allow better management of minimum flows and levels.

4.3 Contaminants

A better understanding of ground-water chemistry (for example, nutrients, pathogens, and emerging contaminants) is needed throughout Biscayne Bay for several reasons. In combination with much needed seepage estimates, knowing certain constituents may help explain spatial and temporal variations in SAV. Greater knowledge of fluxes at different locations, for example, along the western shoreline of Biscayne Bay, shoreline of upper Keys (for example, Elliott Key), or along the coral reef tract, will enhance current knowledge about how ground water may affect various benthic and pelagic biota.

Photo 13. Monitoring wells located on Alina's Reef. Wells are installed with screens at different depths below reef cap.

Photograph by Chris Reich, U.S. Geological Survey.

Various potential sources of contaminants to Biscayne Bay and Biscayne National Park exist, but quantifying their threat to the bay is difficult. For example, a current study of the effects of the Old South-Dade Landfill and the Miami-Dade County landfill and water-treatment plant on nearshore and offshore ground water has been undertaken. High ammonium concentrations have been found in nearshore surface- and ground-water samples; however, the levels are not high enough to indicate that either landfill is a source. Additional monitoring wells would be needed between the nearshore Biscayne Bay wells and the landfill to understand nitrogen processes as well as other chemical variations along onshore to offshore flowpaths.

One potential source of pollution is the Florida Power and Light nuclear powerplant. The 270-km-long array of canals used in the process of discharging high temperature water from the powerplant and reusing the cooler canal water may affect nearshore communities. The effects of elevated water temperature on nearshore communities are not fully quantified. One question that may need to be addressed is whether natural microbial communities in the subsurface or surface waters will be affected in a way that alters the quality of water delivered to Biscayne Bay.

The growth, persistence, and spatial distribution of bacteria in aquatic and sediment systems are directly influenced by the quantity and quality of nutrients and organic matter. The rates at which native (autochthonous) and foreign (allochthonous) microbes assimilate these nutrients are affected by temperature and salinity. The potential sources of pollution in the coastal waters of Biscayne National Park contribute nutrients as well as thermal energy that increases the temperature of the receiving ground waters. The occurrence and persistence of microbial indicators, such as fecal coliform bacteria, enterococci, coliphage, and *Clostridium perfringens*, and pathogens, such as *Escherichia coli* and *Serratia marcescens*, and human enteroviruses, in the water column and sediments of marine systems may be enhanced by increased nutrient concentrations and *in-situ* temperatures. The increased occurrence and persistence of the indicators thereby increase the risk of disease in humans, marine mammals, invertebrates, and possibly coral reefs that come in contact with these contaminated waters.

4.4 Database and Geographic Information System Issues

Over the past 50 years, a large amount of data collection and research has taken place in Biscayne National Park. Large portions of the data have been transferred into a digital database, which includes raster and vector coverages of the park and the surrounding areas. To serve the data to all interested parties, there is a need to create a geodatabase of all the available data. Some examples of the information available are topology, land use, vegetation, and bathymetry. The database would include an inventory of current data-collection activities in and around the park from all involved agencies, such as the USGS, Biscayne National Park, Miami-Dade Department of Environmental Resource Management, U.S. Army Corps of Engineers, South Florida Water Management District, U.S. Fish and Wildlife Service, and local universities. It would include long-term network activities as well as project-oriented activities, such as multidisciplinary data from biology, hydrology, geology, hydrogeology, ecology, and so forth. This database can function as a tool for researchers who are (1) interested in contributing their data for other researchers to use, (2) trying to locate and fill gaps in research needs, and (3) working closely with park managers in identifying concerns that affect their park.

The ability to compile and use the data collected from a variety of sources is essential to all current and future researchers as well as to local and regional managers. Once the data are compiled into a centralized database, the database can be utilized to create a large host of evaluation tools, such as models and GIS coverages. One important issue that can be addressed using these GIS maps is land use and preservation/restoration. Land use and preservation/restoration decisions have substantial but highly uncertain effects on water quality and quantity, flow patterns, and ecosystem health in the Greater Everglades Ecosystem. These environmental and ecological factors, however, have economic value that currently is being ignored (or only partially considered) in these decisions. To address these issues successfully, a research program is needed that involves: (1) estimating the economic value of environmental and ecological resources affected by development and preservation/restoration decisions, (2) aggregating and quantifying the substantial uncertainties associated with these decisions, and (3) creating a decision support system that will provide land managers and local officials with a clearer idea of the economic consequences of various courses of action.

5.0 Current or Recently Completed Studies in and around Biscayne National Park

To show how the USGS is assisting and/or supplementing needed research in Biscayne National Park and Biscayne Bay, several USGS scientists have composed descriptions of their current or recently completed research projects. These projects are examples of studies that are supplying managers with the information they need to address the problems that face Biscayne Bay.

Project Description Index

Biscayne Bay Coastal Wetlands

K. Cunningham and M. Wacker, USGS Florida Integrated Science Center—Ft. Lauderdale, Fla.

The objective of the CERP Biscayne Bay Coastal Wetlands Project is to rehydrate wetlands and reduce point-source discharge to Biscayne Bay. The project will replace lost overland flow and partially compensate for the reduction in ground-water seepage by redistributing, through a spreader system, available surface water entering the area from regional canals. The proposed redistribution of freshwater flow across a broad front is expected to restore or enhance freshwater wetlands, tidal wetlands, and nearshore bay habitat. A primary goal of the project is to develop a realistic representation of ground-water flow within the karst Biscayne aquifer.

Recently, Cunningham and others (2004a) demonstrated that a dual-porosity conceptual model is appropriate for this karst aquifer system consisting of a series of interlayered diffuse-carbonate and conduit flow zones that are arranged vertically within the context of a high frequency sequence stratigraphy. Mapping these ground-water flow units is key to the development of models that simulate ground-water flow from the Everglades and urban areas through the coastal wetlands to Biscayne Bay.

As participants in this pilot project, the South Florida Water Management District, the U.S. Army Corps of Engineers, and the USGS are working together to better understand the hydrogeologic framework of the surficial aquifer system in the Biscayne Bay coastal wetlands in Miami-Dade County.

Because little detailed hydrogeologic data exist for the surficial aquifer system (to depth) in this area, the Biscayne Bay Coastal Wetlands Project Delivery Team proposes to install two monitoring well sites and collect the necessary detailed hydrogeologic data.

Historical Changes in Salinity, Water Quality, and Vegetation in Biscayne Bay

G.L. Wingard, T. M. Cronin, D. Willard, W. Orem, P. Swart, G. Dwyer, S. Ishman and E. Gaiser, USGS Reston, VA; and C. W. Holmes, USGS Florida Integrated Science Center—St. Petersburg, Fla.

During the last century, Biscayne Bay has been greatly affected by anthropogenic alteration of the environment through urbanization of the Miami-Dade County area, and alteration of natural flow. The sources, timing, delivery, and quality of freshwater flow into the bay, and the shoreline and subaquatic vegetation have changed. Current restoration efforts are directed toward restoring “natural” flow of freshwater into Biscayne and Florida Bays and to restore the natural vegetation, but first the predevelopment conditions prior to substantial human alteration must be determined to establish targets for restoration. This project examines the predevelopment patterns of temporal change in salinity, water quality, vegetation, and benthic fauna in Biscayne Bay during the last 100 to 300 years and examines the causes of change.

The objectives of this project are to: (1) examine, in broad context, historical changes that have occurred within the Biscayne Bay ecosystem at selected sites on a decadal-centennial scale, and (2) correlate these changes with natural events and anthropogenic alterations in southern Florida. Specific emphasis will be placed on historical changes to the (1) amount, timing, and sources of freshwater influx and the resulting effects on salinity and water quality; (2) shoreline and subaquatic vegetation; and (3) relation between sea-level change, onshore vegetation, and salinity. In addition, a detailed examination of historical seasonal salinity patterns will be derived from biochemical analyses of mollusks, ostracods, foraminifera, and corals. The coral data will allow comparison of marine and estuarine trends, examination of the linkage between the two systems, and will provide precise chronological control. Land-management agencies (principally, the South Florida Water Management District, U.S. Army Corps of Engineers, and Biscayne National Park) can use the data obtained from this project to establish performance criteria for restoring predevelopment flow, and to understand the consequences of altered flow. These data also can be used to forecast potential problems as upstream changes in water delivery are made during restoration.

Ground-Water Discharge to Biscayne Bay

C.D. Langevin, USGS Florida Integrated Science Center—Ft. Lauderdale, Fla.

The goal of Everglades restoration is to restore the ecosystem of southern Florida to conditions that closely resemble predevelopment conditions. Much of the restoration will occur by making substantial changes to the structures and operational procedures of the existing water-management system. These changes, however, must not harm the ecosystem of Biscayne Bay, which is already threatened by reductions in fresh ground-water flow caused by development.

Prior to the construction of the extensive canal network in southern Florida, offshore springs discharged large quantities of fresh ground water into Biscayne Bay. During this time, most of the freshwater flow to Biscayne Bay occurred either as spring flow or continuous seepage of fresh ground water along the coast of the bay. When drainage canals were constructed to reduce flooding in the area, the mechanism for transporting water to the bay was altered substantially. Rather than receiving a continuous supply of fresh ground water, Biscayne Bay received wet-season pulses of canal discharge. Biologists have confirmed that the change in timing and location of freshwater flow to the bay has harmed the Biscayne Bay ecosystem. Seagrass beds, and the juvenile fish that use them as refuge, no longer receive a continuous supply of freshwater—a requirement for their survival.

The purpose of this project, better known as the "Ground-Water Flows to Biscayne Bay," is to determine how planned restoration alternatives will affect the bay by providing answers to the following questions:

- How much fresh ground water is currently discharging to Biscayne Bay?
- How will south Florida restoration efforts affect the quantity of fresh ground-water flow to Biscayne Bay?

To answer these questions, ground-water flow to Biscayne Bay is being simulated with a computer model. The model will help identify which of the restoration alternatives will result in fresh ground-water flows to the bay that are most beneficial to its ecosystem.

Development of an Integrated Surface Water and Ground-Water Model of Biscayne Bay and Analysis of the Hypersalinity Events in Southwestern Biscayne Bay

M.A. Wolfert and C.D. Langevin, USGS Florida Integrated Science Center—Ft. Lauderdale, Fla., and J.D. Wang, University of Miami, Miami, Fla.

Throughout the last century, Biscayne Bay has been impacted by human alteration of the natural environment through urbanization of the Miami-Dade County area and modifications of natural freshwater flows to the bay. The altered hydrology of the natural system has reduced the seaward ground-water gradient that historically supplied freshwater by way of submarine springs throughout Biscayne Bay to offshore areas of the bay. The absence of this gradient has reduced or eliminated flow from these springs. Data collected in recent years in Biscayne National Park indicate that hypersalinity (for example, salinity greater than 35 ppt) events are occurring every few years in nearshore regions of the bay.

The primary objective of this project is to investigate the cause or causes of the hypersalinity events observed in recent years in south-central Biscayne Bay. This objective will be addressed using the following approach:

- Existing empirical data and output from other numerical models will be evaluated to identify the methods needed to determine causes of hypersalinity in Biscayne Bay;
- A computer model will be developed to describe the effect of surface-water flows on salinity in the bay;
- The completed surface-water flow model will be coupled with a completed ground-water model, which is currently in the calibration stage of development; and
- The integrated surface-water and ground-water model for Biscayne Bay and the surrounding areas will be used to perform hydrogeologic investigations to determine if and how changes in shallow ground-water flow are affecting Biscayne Bay salinities.

Ground- and Surface-Water Impacts on Water Quality and Ecology: Science to Assist Resource Management at Biscayne National Park

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CERP aims to reestablish predevelopment natural flows in the Everglades system and surrounding areas including Biscayne Bay. The changes proposed within this plan may substantially alter the hydrologic conditions that exist in Everglades National Park and Biscayne National Park. There are system-wide management issues and environmental and water-supply concerns about how restoration efforts will affect ground-water flows, including those between Everglades National Park and Biscayne National Park, and along the L-31N and C-111 canals. For example, restoration of wetlands may lead to increases in coastal aquifer heads and cause offshore springs in Biscayne Bay to once again become sites of substantial freshwater discharge in Biscayne National Park. Accordingly, CERP restoration activities may more rapidly flush ground water and any associated contaminants into the offshore marine ecosystem. If this scenario were to occur, there is considerable potential for the deterioration of habitat for many different threatened or endangered species of plants and animals that reside along the coastline of Biscayne Bay, within the bay, or along the coral reef tract. Unlike the surface-water system, which has been extensively compartmentalized and channelized, ground-water flow in the aquifers beneath Everglades National Park and Biscayne National Park is interconnected and not as amenable to partial domain simulation. A comprehensive model is needed to reliably and credibly assess simultaneous ground-water effects to both parks.

The goal of this project is to determine how freshwater deliveries, which are believed to be critical to the perpetuation of ecologically sensitive coastal habitats, have changed, and will change, as the various State and Federal land-management agencies implement different portions of the restoration plan for the southern Florida/Everglades ecosystem. During the past 5 years, a substantial amount of time and effort was spent developing different management paradigms to locate, store, and move water through the Everglades ecosystem into Everglades National Park and Florida Bay. Although there was some effort to project how the altered hydrology may affect the resources of the Florida Keys and the coral reef areas closely associated with Florida Bay, there was much less effort to determine how the alterations may affect the coastal and estuarine resources to the east and west of the axis of the restoration. This project will supply the scientific information and understanding needed to make informed ecosystem restoration decisions in these other areas.

The primary objective of this project is to develop a numerical model to characterize detailed ground-water flow patterns and discharge rates to the Biscayne Bay estuary, and to examine the migration paths of contaminants to the estuaries, bay, and coral reef. This will require the development of numerical surface water and ground-water models of Biscayne National Park. A substantial amount of uncertainty remains, however, in simulating and predicting patterns and rates of submarine ground-water discharge.

A primary science objective of this project is to improve the accuracy of modeling submarine ground-water discharge to a coastal marine estuary. This objective will be achieved by applying the latest numerical modeling techniques and developing new techniques for the simulation of density dependent ground-water flow. Results from the carbonate hydrostratigraphy component and other field studies in the bay will provide information about preferential flow paths within the aquifer and possible submarine discharge locations.

With an improved scientific understanding and a reliable numerical tool, this project will address many of the scientific questions posed by Biscayne National Park restoration issues. For example, the surface- and ground-water models will be used to estimate predevelopment rates of overland flow and submarine ground-water discharge, and predict the effects of Everglades restoration on future freshwater inflows to the bay. It is expected that simulated flow patterns will correlate with ecological indicators of stressed communities, providing insight into the causes of ecosystem degradation.

Remote Sensing of Water Turbidity and Sedimentation in Florida Bay and Biscayne Bay

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A decline in water clarity in Florida Bay has been observed following the seagrass dieoffs that have occurred since the late 1980's. Algal blooms and discolored water have been reported in Florida Bay over the last several years and factors such as the resuspension of material and nutrients from the bottom have been suggested as a potential cause. Monthly monitoring programs by Florida International University and the Florida Department of Environmental Protection have documented blooms through chlorophyll measurements.

The current project uses remote sensing to examine resuspension events, the distribution of turbid water, and changes in the patterns of water clarity in the bay. The project also is conducting comparisons between chlorophyll values collected from the shipboard monitoring programs and pre-cruise reflectances to assess whether there is a link between resuspension events and algal blooms. The next step is to extend the Advanced Very High Resolution Radiometer (AVHRR) dataset further back by compiling data collected prior to the seagrass dieoffs and to incorporate Landsat data for limited high resolution analysis.

Contaminant Effects on Biological Resources: Sediment Quality in Canals that Discharge into Biscayne Bay, Miami-Dade County, Florida

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A study of sediment quality was conducted in the freshwater canals of Miami-Dade County to aid in understanding the effects of stormwater runoff to Biscayne Bay. This study coincided with an assessment by the National Oceanic and Atmospheric Administration (NOAA) of sediment quality within the Biscayne Bay estuary. Using a weight-of-evidence approach, surficial sediment samples were collected at 178 sites along 23 canals. The samples were analyzed for a comprehensive suite of chemical contaminant concentrations, and a battery of toxicity tests was performed that included: (1) chronic toxicity testing of solid-phase sediments using *Hyalella azteca*, (2) acute toxicity testing of pore water using *H. azteca*, and (3) Microtox bioassay using *Vibrio fischeri* of dichloromethane extracts of solid-phase sediments. Samples were collected during two time periods: 1995-96 and 2001-02. The data from both time periods were merged for evaluation, because they showed no large systematic changes in chemical concentrations or toxicity between periods.

A total of 178 samples were collected from 178 sites. Only 30 of these samples (collected from 11 sites scattered across the study area) did not contain toxins. A total of 71 sites were classified as slightly degraded, because samples taken from these sites had slightly elevated concentrations of contaminants or toxicity, but not both. The slightly degraded conditions were distributed among most of the canals (19 of 23), and therefore, represented the most widespread classification. Moderately degraded sediments were identified at 63 sites and were the predominant condition in 8 canals. The moderately degraded conditions were characterized by elevated chemical contamination and/or severe toxicity. Fourteen sites located along eight canals were classified as being the most degraded, because samples contained excessive concentrations of contaminants and had high toxicity.

The incidence of chemical contamination in Miami-Dade County canals was approximately equivalent to that in nationwide databases and in several large estuaries, considerably less than in industrialized bays and harbors of other regions of the United States, but slightly higher than in the adjoining saltwater of Biscayne Bay. Overall, the incidence and level of toxicity observed in the Miami-Dade County freshwater canals was comparable to levels observed in other southeastern study areas, but lower than in several national databases which included results of surveys conducted in the more industrialized regions.

Temporal and Spatial Variation in Seagrass-Associated Fish and Invertebrates in South Florida: Nearshore Seagrass Community of Biscayne Bay, Florida

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Loss and/or degradation of coastal wetlands and nearshore estuarine habitat is a long-term threat to the ecosystem of Biscayne Bay and its associated productivity. These habitats are dependent upon restoring a more natural quantity, quality, timing, and distribution of freshwater flow to Biscayne Bay. CERP and the Lower East Coast Regional Water Supply Plan could substantially affect freshwater flow to Biscayne Bay. Special projects in CERP will be designed to restore estuarine habitat in Biscayne Bay that has been diminished by past and current water-management practices. Both CERP and Lower East Coast Regional Water Supply Plan require periodic assessments to evaluate the effect of new CERP projects as they are implemented. Science-based performance measures are needed to quantify change, and targets are needed to indicate whether restoration is succeeding. Scientific workshops have revealed a lack of essential information about coastal wetlands and nearshore biological communities with which to develop performance measures and guide the design of the Biscayne Coastal Wetland Restoration Project. It is important to start acquiring this information.

Because of its clear, shallow waters, Biscayne Bay's benthic community is a primary source of its productivity and diversity. The benthic animal community, consisting of small forage fish, juvenile game fish, and invertebrates such as pink shrimp, is particularly well developed in the shallow nearshore zone adjacent to the mainland and may be dependent upon freshwater inflow. The pink shrimp is an important commercial and recreational species in Biscayne Bay, as is the blue crab. Gray snapper is highly sought recreationally, both in the bay and on the nearshore reef. These species are linked to nearshore environments, but their relationships in these areas with freshwater inflow have received minimal investigative attention. Scientific information on this topic is needed to develop performance measures based on these species and their community.

The proposed study has four elements: (1) characterization of the spatial and temporal patterns of density and diversity of fish and macro-invertebrates (emphasis on caridean and penaeid shrimps including the pink shrimp, Farfantepenaeus duorarum) in seagrass habitats of the mainland nearshore zone, as well as in the deeper water commercial fishing zone; (2) evaluation of the relationship of variability in shrimp catch rates of commercial vessels operating in the commercial fishing zone with shrimp densities in fished versus unfished seagrass habitats; (3) examination of trends in commercial pink shrimp fisheries in relation to freshwater inflow and salinity; and (4) evaluation of relationships between fishes utilizing mangrove fringe habitats and the abundance and diversity of fish and macro-invertebrates in adjacent seagrass habitats.

This study focuses largely on characterizing the animal communities present in seagrass habitats in Biscayne Bay. Existing commercial catch data (Pamela Eyo, National Marine Fisheries Service, written commun. 2006) and supplemented USGS data will be analyzed in relation to the new data on shrimp densities in seagrass beds to address the second and third elements of this study. Close collaboration with a related study (J. Serafy, University of Miami, oral commun., 2006) documenting fish usage of mangrove fringe habitats in our study area will address the fourth element.

Inventory of the Amphibians and Reptiles of Big Cypress National Preserve, Biscayne National Park, and Buck Island Reef National Monument

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In response to concerns about the lack of basic knowledge of the amphibians and reptiles inhabiting U.S. Department of the Interior lands, inventory programs are being instituted nationwide. This study describes the goals and objectives, sampling methods, complicating factors, and the expected outcomes of proposed amphibian and reptile surveys in Big Cypress National Preserve, Biscayne National Park, and Buck Island National Monument.

The primary goal of this project is to inventory the amphibians and reptiles of Big Cypress National Preserve, Biscayne National Park, and Buck Island National Monument. The inventories will provide information about the status and distribution of the species of amphibians and reptiles on these Department of the Interior lands. Sampling at these parks will involve a multitiered approach that involves data collection for three specific models:

- *Species Richness*—To use this model, many plots will be used that may be visited only once during the study.
- *Proportion of Area Occupied*—For this model, some of the plots used for species richness will be visited several times within a given season.
- *Detection Probability*—On a subsample of the plots that are visited repeatedly, we will also gather data that will allow us to estimate the detection probability of some species using models like dual observer and mark and recapture.

Application of Landscape Ecology to the Design of Marine Protected Areas

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Coral reef ecosystems and associated fisheries are experiencing declines throughout the Caribbean. Marine-protected areas (MPAs), one of the most highly advocated forms of ecosystem-based management, are intended in most cases to provide a spatial refuge for intensely exploited species and also may help alleviate threats to marine biodiversity. To design new ecosystem-based MPAs and set realistic expectations about the performance of existing MPAs, it is necessary to determine whether large-scale measures of habitat are correlated with reef fish assemblage parameters of interest to resource managers; for example, abundance of targeted fishes and species diversity.

To date, most MPAs focus on single habitats, potentially neglecting functional linkages among habitats (that is, juvenile settlement and adult foraging areas) that benefit reef fishes at critical times during their life history (St. Mary and others, 2000). The opportunity still exists, however, to design and manage MPAs as entire ecosystems, based on habitat requirements of important reef-associated fishes. Recent advances in marine mapping technologies provide the opportunity to ascertain whether MPAs can be cited today based on available scientific knowledge.

The purpose of the current project is to determine whether landscape indices, such as habitat diversity and total area of specific habitats that have proven valuable in terrestrial systems, can be used to predict reef fish assemblage parameters of interest to resource managers, including species diversity and abundance of exploited species. Empirical datasets from three protected areas with differing levels of reef fish protection—Virgin Islands National Park, Florida Keys National Marine Sanctuary, and Biscayne National Park—will help determine how applicable this new technology is for addressing conservation science questions.

Research for the current study is conducted within the three MPAs described above, with the following four objectives:

***Objective 1**: Develop landscape metrics using benthic maps and geospatial analysis (Virgin Islands National Park)*—Metrics commonly used in terrestrial systems will be calculated for 16 reef sections using benthic habitat maps. Principal components analysis will be used to determine whether a large set of the original correlated landscape habitat metrics can be reduced to a small number of transformed uncorrelated variables.

***Objective 2:** Determine the relations between landscape metrics and fish assemblage parameters*—The relation of landscape metrics and reef fish assemblage structure will be explored in Virgin Islands National Park as preexisting reef fish census data are available. Census data collected in 1994 and 2001 using a point-count method at a total of 16 reef sections will be coupled with the calculated landscape metrics and analyzed using linear regression and multivariate statistical procedures. A total of at least 16 reef fish censuses per 25,000-m^2 reef provide sufficient sampling effort to determine mean values for each assemblage parameter. Landscape-level metrics will be correlated with reef fish assemblage parameters using linear regression, with landscape metrics as independent variables and entire assemblage parameters as dependent variables. Step-wise multiple regression analysis will be used with metrics at each distance (100, 250, 500, and 1,000 m) as independent variables and entire assemblage parameters (for example, species richness, total abundance, and abundance of particular trophic guilds) as dependent variables. Principal components analysis, an unconstrained ordination technique, will be used to summarize data redundancy to describe the relation between various landscape metrics and individual reef fish assemblage parameters, such as species richness. If principal components can be identified, these will be used as variables in a step-wise multiple regression model.

***Objective 3:** Test hypothesis that proximity to, and/or total area of, seagrass predicts abundance of specific fishes within Virgin Islands National Park and Biscayne National Park*—Using existing habitat maps from the Virgin Islands National Park, 20 reefs will be selected based on specific criteria. Landscape metrics of proximity and area of seagrass will be calculated at various spatial extents. Randomly generated sampling stations will be identified in ArcView using a random point script. Linear regression will be used to test the prediction that species diversity, total abundance, and abundance of adult and juvenile grouper, snapper and grunts will be greatest at sites with the greatest seagrass coverage. ANOVA will be used to determine if there is a significant difference in total species richness and abundance of adult and juvenile snappers, grunts, and groupers between seagrass and non-seagrass reefs. Benthic habitat maps will be generated using recent (2002) aerial photos of Biscayne National Park using IMAGINE and ArcView 8.1. A total of 20 small (less than 3,000 m^2) discrete reef patches (of similar size and shape) on a gradient of low to high seagrass area will be selected. Linear regressions will be performed using total seagrass area as the independent variable and fish assemblage parameters as dependent variables. Standard ANOVA procedures will be used to examine differences between reefs with and without seagrass.

***Objective 4:** Compare results between fished and unfished areas in the Florida Keys National Marine Sanctuary*—Eighteen special protected areas within the Florida Keys National Marine Sanctuary and their reference (fished) sites will serve as study locations. Landscape metrics (seagrass areal coverage and habitat diversity) will be calculated using existing benthic habitat maps developed by functional magnetic resonance imaging. Reef fish censuses will be used to determine average values for reef fish assemblage parameters such as total species richness, abundance, mean abundance of adult and juvenile grouper, snapper and grunts. Linear regression will be used to determine the relations between the reef fish assemblage parameters and the seagrass metrics for MPAs and control sites.

Environmental Assessment of Effects of Rotenone on Seagrass Beds

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The National Park Service, though the Natural Resource Challenge action plan, has initiated a program of biological inventories for vertebrates and vascular plants within 270 National Park units that have significant natural resources. These inventories are 1 of 12 data layers that the National Park Service is in the process of compiling to assist park management based on sound scientific information about the natural resources managed by the park.

The majority of these inventories use non-destructive techniques for species identification, such as visual counts, acoustic signature matching, field observations, and tracking. For most of these techniques, the National Environmental Protection Act provides a categorical exclusion that allows for this type of field work.

By nature, cryptic fish are difficult, if not impossible, to see with the naked eye because they have a well-developed mimicry of their surrounding habitats. These fish in complex environments, such as coral reefs, mangrove roots, or dense aquatic vegetation, and because of their visual mimicry, remain largely unstudied. The role of these cryptic fish, therefore, is uncertain in the ecosystems they inhabit, and some may remain unknown to the scientific world.

The primary objective of the National Park Service Vertebrate and Vascular Plant Inventories program is to document the presence of more than 90 percent of the species living within National Park lands. The southern Florida/Caribbean network developed a study plan in December 2000 that identifies these cryptic fish as a priority dataset that should be funded for comprehensive inventories in many of the network parks. The Network Science and Technical Committee have identified the need for an environmental assessment of rotenone effects on the ecosystem when used for cryptic reef fish sampling.

The National Park Service units involved would include Big Cypress National Preserve, Biscayne National Park, Buck Island Reef National Monument, Everglades National Park, Dry Tortugas National Park, Salt River National Historic Site and Ecological Preserve, and Virgin Islands National Park. The ecosystems to be sampled with this technique include seagrass meadows and sand bottoms. Because inventories will be conducted infrequently, this is not to be considered a monitoring technique. Rotenone will be used within contained areas to ensure that only a targeted habitat is sampled and to minimize bykill. Alternatives to be explored include no-action, use of Tricaine Methanesulfonate (MS222), use of clove oil, and mechanical methods if applicable.

Assessment of Emerging Pollutants of Concern (EPOCs) in Wastewater Influent and Effluent at the South Miami-Dade Wastewater Treatment Plant and Biscayne Bay Coastal Environment

A. C. Lietz (retired), USGS Florida Integrated Science Center—Ft. Lauderdale, Fla.

A primary goal of CERP is the restoration of natural water flows and historical hydroperiods in the southern Florida ecosystem, including the Biscayne Bay Coastal Wetlands adjacent to Biscayne National Park. In the original Central and Southern Florida Project Comprehensive Review Study Final Integrated Feasibility Report and Programmatic Environmental Impact Statement (Restudy) it was determined that Biscayne Bay and Biscayne National Park were not receiving an adequate supply of freshwater to ensure adequate restoration. The Restudy team evaluated the use of reclaimed water as a viable source of additional water to accomplish these goals. Highly treated wastewater then was identified as a potential source of additional water supply. A critical question, however, that must be addressed in the application of reused water to the Biscayne Bay Coastal Wetlands is the degree to which certain constituents in reclaimed water may adversely affect the aquatic biota of the ecosystem in question. This is especially true for constituents identified as emerging pollutants of concern (EPOCs) that could adversely affect the sensitive biota of Biscayne National Park.

CERP proposes to develop one of two advanced wastewater treatment pilot facilities at the current South District Wastewater Treatment Plant in southern Miami-Dade County. Superior, advanced treated reuse wastewater from this facility will be used to replace and augment freshwater flows to the sensitive Biscayne Bay and Biscayne National Park ecosystems as well as restore more natural hydroperiods to the Biscayne Bay Coastal Wetlands. As part of a current CERP project, the USGS is examining the presence and concentration of EPOCs in wastewater influent and effluent at the wastewater treatment plant.

Marine activities in Biscayne National Park, as well as urban and agricultural activities in the adjacent coastal areas, may also contribute contaminants (including EPOCs) to the park environment. This situation underscores the need to assess the possible occurrence, distribution, and probable sources of EPOCs in Biscayne National Park and the adjacent coastal environment prior to using advanced treated wastewater to restore natural flow and hydroperiods to the Biscayne Bay Coastal Wetlands.

Biogeochemistry of Ecosystems in Biscayne Bay

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Baseline ecosystem status and pollution data for Biscayne Bay are lacking. Biscayne National Park contains the southern part of the bay, as well as (1) the longest stretch of mangrove forest remaining on Florida's east coast, (2) 14 threatened or endangered wildlife species, and (3) the northernmost coral reefs in the continental United States. The bay acts as a buffer zone for these reefs. Human activity affects the coastal marine environment of southern Florida through urban development; air, land, and water pollution; intense recreational and commercial use; introduction of pathogens and nutrients from sewage-disposal injection wells and shoreline landfills; and physical damage to coral reefs and other bottom communities caused by derelict fishing gear, boat anchors and ship groundings. Nutrient enrichment increases oxygen depletion in coastal waters, which can stress or kill biota. Coastal land-use practices (marina, agricultural and industrial development) cause contamination by chemical pollutants, pesticides, petroleum products, fertilizers, and heavy metals. Each effect alters the coastal ecosystems and has important implications for human issues, including the health of swimmers, fishery nurseries and resources, and management of coastal land development.

The USGS and University of Southern Florida, in cooperation with the National Park Service and Biscayne National Park, are assessing environmental quality in Biscayne Bay to provide pre-Everglades restoration baseline data and decision products that will facilitate restoration and/or preservation of ecosystems within the bay. Surface-sediment data will be used to construct contour maps of grain size, heavy-metal distribution and concentration, foraminiferal assemblages diagnostic of pristine to heavily polluted waters, and dominant types of skeletal sand grains. These products will characterize present conditions in the bay and can be applied to monitor future changes in biota (due to environment, water quality, and pollution) as well as document past changes by comparison of the sediment data with historical records determined from analogous studies of sediment cores.

In general, overall results of the Phase I pilot study along the western bay margin indicate that: (1) the highest concentrations of heavy metals are near densely urbanized areas, (2) most abnormalities in foraminiferal shells are near the Black Point landfill, and nearshore ecosystems within the bay are under stress. The stress is probably due both to natural causes (such as rising sea level) and anthropogenic causes (such as increased pollution). Phase II bay-wide geochemical, sedimentary, and microfaunal analyses are designed to delineate more precise trends in pollution, and will include the origin of biogenic sand grains that will identify the biotic structure of benthic communities.

Biogeochemical Measurements of Reef Health

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Community scale measurements of reef metabolic processes will be taken during 24-hour time periods over different benthic bottom types using the Submersible Habitat for Analyzing Reef Quality (SHARQ). This incubation chamber, constructed of an anodized aluminum frame and clear vinyl sheeting, isolates water over the substrate and accentuates changes in water chemistry that reflect key biogeochemical parameters. The large size of SHARQ (11 m^2) allows areas of study to be identified on aerial photographs. Analytical results, therefore, can be used to help characterize the benthic community of Biscayne National Park. We propose that measurements of rates of calcification, photosynthesis, and respiration will provide important baseline information and serve as a basis for evaluating long-term change years to decades in the future. Identical measurements are being made in Hawaii and Florida Bay, with further study planned in the U.S. Virgin Islands to make inter-regional comparisons and evaluate contrasting benthic settings.

The short-term objectives of this project are to: (1) collect continuous biogeochemical data for 24-hour periods from four well-characterized bottom types; (2) use the data to calculate rates of calcification, dissolution, photosynthesis, and respiration; and (3) place the metabolism rates for Biscayne National Park in context with other reef study sites. The long-term objectives are to characterize metabolism rates at four sites in Biscayne National Park and re-occupy sites to identify trends.

For this project, SHARQ is used to examine the response of reef biogeochemical processes to elevated partial pressure of carbon dioxide (pCO_2) in the water column. An internal circulation system (260 L/min) generates turbulent water flow and is aided by the flexibility of the chamber, which enables oscillatory water motion to be translated through the structure. The chamber isolates about 7.0 m^3 of water over 12 m^2 of seafloor so that gas exchange, seawater circulation, and changes in water chemistry can be controlled and quantified. A closed-loop, flow-through system is employed to continuously measure dissolved oxygen, pH (on the free scale), salinity, and temperature. Filtered water samples for total alkalinity and nutrient measurements were removed from a sampling port in the flow-through system at 4-hour intervals.

During July 2002, we began to examine the effects of elevated atmospheric carbon dioxide on the health of coral reefs. An early observation was that reef sand partially dissolves as carbon dioxide increases and partially buffers corals from adverse effects. To examine the dissolution process, we conducted two experiments on sand.

A SHARQ was deployed at a 5-m depth over reef sand and allowed to stabilize for 24 hours. During the first experiment, two additions of carbon dioxide were made at noon on July 13 and 14, 2002, and monitored until July 15. The SHARQ was opened and surface sediments were mixed and allowed to equilibrate with ambient water for 24 hours. On July 16, the second experiment began with three injections of carbon dioxide during the afternoon. The second experiment was monitored until noon July 18. A second SHARQ, identical to the first but with a vinyl floor, was deployed near the first as a control.

We are currently evaluating the data and planning follow-up experiments in the near future. Preliminary evaluation of the data indicates that more sediment dissolution occurs than had been expected, and results indicate that sediment dissolution may provide a mechanism for buffering Biscayne coral reefs from pH changes associated with elevated atmospheric carbon dioxide.

Ground Water Characterization in Marine Areas of Biscayne National Park

R.B. Halley, P.W. Swarzenski , Christopher Reich, and Don Hickey, USGS Florida Integrated Science Center—St. Petersburg, Fla., and R. Curry, Biscayne National Park

Biscayne National Park is a marine park that is bordered by a metropolitan area consisting of more than one million people. Extensive development has occurred along the shoreline and nearby upland areas, and natural upland water flow has been altered substantially through a complex network of drainage canals and dredged waterways. In addition, numerous deeply dredged ponds, lakes and water-storage sites that collect and hold urban surface run-off also are present in these upland areas.

The infiltration and dispersion of nonpoint source pollutants into the ground-water system from the surface runoff and dredged sites is likely to be substantial for a number of reasons. The highly porous limestone substrate of the region, known as the Biscayne aquifer, flows directly into Biscayne Bay. In addition, Class 1 municipal landfill was established during the 1970s adjacent to southern Biscayne Bay and Biscayne National Park. This landfill consists of municipal waste that has considerable potential to affect local ground-water and the subsurface flow of contaminants into the park. Previous studies have documented some infiltration of nutrients and contaminants from urban developments and the municipal waste facility. The extent, however, to which these contaminants flow beneath and resurface within Biscayne Bay and offshore reef-area waters has not been determined. According to McNeill (2000), 10 of the 17 injection wells at the Miami-Dade Water and Sewer South District plant were constructed improperly, creating a relatively open pathway for upward migration of injected effluent. As a result, ammonia was detected in shallow monitoring wells within 11 years of first injection. This differs substantially from the initial 343-year estimate for upward migration of effluents.

Recent declines in offshore coral reef health may be linked to declines in ground-water or surface-water quality, or possibly other ecosystem stress factors. For park managers to make informed management decisions concerning the loss of park marine resources, the park needs additional information about the current extent of ground-water pollution and its possible effects on park resources. The current project uses geochemical and hydrogeologic information to determine whether ground water enters Biscayne Bay and the nearby coral reef tract through coastal aquifers; the approach has two objectives.

The first objective is to use water quality (geochemistry) to identify water mass signatures. Geochemical tracers, including isotopes of radon and radium or cations and anions (for example, calcium, and magnesium), will be used to help identify specific water masses. Other water-quality parameters will be used to identify potential sources of contamination to the ecosystem. Air and surface-water sources are relatively easy to investigate but ground water beneath a marine system is much more difficult to access. This project will quantify four field constituents (pH, dissolved oxygen, salinity, and temperature) and water-quality parameters that include nutrients (primarily nitrogen and phosphorus species), trace elements (zinc, copper, and arsenic), waste-water compounds (17-beta-estradiols, coprostanol, caffeine, and surfactants), pesticides (Lindane, Endosulfan, and DDT). These constituents will help characterize the ground water beneath Biscayne Bay and provide some index of their potential threat to surface-water quality within Biscayne National Park.

The second objective of this project is to characterize the flow regime beneath Biscayne Bay and within Biscayne National Park. Ground-water flow is driven by changes in water level (the potentiometric surface gradient) in the adjacent Biscayne aquifer. In southern Florida, potentiometric ground-water surfaces have been investigated extensively in inland areas, and along the coastline to some extent, but no information exists for offshore areas. Offshore natural flow gradients are complicated by tidal pumping, which creates flow patterns in marine ground waters. Although tidal pumping has been investigated using seepage meters, it is quantified most accurately by observation wells. Determining the pressure gradients produced between ground water and surface water through tidal pumping potentially can provide data about vertical and horizontal ground-water movement.

Analysis of Historical Water-Quality Data in Southern Florida

B.F. McPherson (retired), USGS Florida Integrated Science Center—Tampa, Fla.

This project provides a review and analysis of historical water-quality data in Everglades National Park, Big Cypress National Preserve, Loxahatchee National Wildlife Refuge, and nearby coastal waters of southern Florida. This information will help establish water-quality standards and baseline conditions in the parks, and will help agencies evaluate how CERP hydrologic modifications will affect regional water quality. The objectives of this study are to: (1) compile, review, and edit water-quality data and construct a working database; and (2) analyze and evaluate the compiled data to describe historical water-quality conditions and trends in Big Cypress National Preserve, Everglades National Park, Loxahatchee National Wildlife Refuge, and Department of the Interior coastal waters. These analyses will provide a baseline for evaluating how CERP-related modifications may affect water quality in the parks and refuge.

This study supports several projects listed in the U.S. Department of the Interior science plan, including the following:

- *Loxahatchee National Wildlife Refuge Internal Canal Structure*—This study provides data and analysis of historical hydrologic and water-quality conditions in the refuge needed to develop the specific hydrologic and ecological targets for the project.
- *Water Conservation Area 3 Decompartmentalization and Sheetflow Enhancement*,
- *Additional Water for Everglades National Park and Biscayne Bay Feasibility Study*—This study provides data and analyses of historical hydrologic, land use, and water-management changes, and water-quality conditions in Big Cypress National Preserve, Everglades National Park and Loxahatchee National Wildlife Refuge. These data and analyses complement ongoing hydrologic, paleoecological, and modeling investigations in these Department of the Interior lands; clarify linkages between geologic, hydrologic, chemical and biological processes in the Everglades; and support the development of hydrologic targets for the restoration projects.

Principal findings of the current project are as follows:

- Major physical alterations of the landscape and associated water-management practices in the greater Everglades have altered water quality over the last 40 years.
- Water quality in canals that drain agricultural lands is characterized by relatively high concentrations of dissolved solids, nutrients, and pesticides compared with background levels.
- Canal-water inflow has altered the water quality of Everglades National Park and Loxahatchee National Wildlife Refuge marshes.
- Water quality in marshes away from canals is affected by seasonal changes in rainfall and water levels, as well as variation in geology, hydrology, and vegetation.

During phase 2 of the study, water quality and flow data for Shark River and Trout Creek were compiled. Currently, the data are being organized and arranged for computing nutrient fluxes.

Remotely Sensed Rugosity Measurements and Patch Reef Community Structure in Biscayne National Park

I.B. Kuffner, J.C. Brock, Rikki Grober-Dunsmore, V.E. Bonito, T.D. Hickey, and M.S. Harris, USGS Florida Integrated Science Center—St. Petersburg, Fla.

With the realization of the need for coral reef ecosystem management across large spatial scales, scientists and resource managers currently are seeking variables that are easily measured over large areas and correlate well with the status of reef resources. In this study, we investigate the ability of new technology in airborne laser surveying (National Aeronautics and Space Administration [NASA] Experimental Advanced Airborne Research Lidar [EAARL]) to predict the status of shallow (less than 15 m) coral reef ecosystems. After large portions of Biscayne National Park were surveyed remotely using EAARL, reef fish and benthic community structure variables were measured using traditional methods *in situ* on 12 patch reefs. At independent, randomly selected stations ($n = 16$ per reef), we measured rugosity (topographic complexity of the benthos) and the abundance and species richness of macroalgae, reef fish, gorgonians, and other sessile invertebrates. EAARL submarine topography data were used to quantify rugosity at spatial scales unobtainable using traditional *in situ* methods.

Rugosity, important in providing information about surface area and shelter availability for reef organisms, has been shown to correlate positively with reef-fish species richness, abundance, and biomass. Previously, the inability to measure rugosity on spatial scales appropriate to the organisms of interest had constrained research efforts. We conducted correlation, ANOVA, and linear regression analyses to elucidate the predictive power of EAARL rugosity measurements in describing the variance in reef community structure. EAARL rugosity indices were significantly correlated with *in situ* rugosity measurements and with species richness of fishes. Additionally, relations were found between benthic cover variables and herbivorous fish abundance. The EAARL shows promise as a technique to predict coral reef community structure over large areas, and may be a useful tool for managers that inventory and protect coral reef resources.

Comprehensive Urban Ecosystems Studies (CUES): Activities Planned for the Miami Urban Area and Adjacent Portions of the Greater Everglades Ecosystem

Paul Hearn, USGS, Reston, Va.

Working within the geospatial framework of the USGS National Map, the Comprehensive Urban Ecosystems Studies (CUES) initiative is intended to develop web-based science applications to address key issues in the urban areas of the Nation. CUES will integrate data from *The National Map* with thematic data and web-based tools to apply USGS science expertise to critical issues including security, vulnerability of water resources, natural hazards, urban sprawl, and the conservation and protection of parklands and other natural resources.

Work began in fiscal year 2005 to design and develop a CUES website for the greater Miami area (Miami-Dade County) and adjacent portions of the greater Everglades ecosystem (Loxahatchee National Wildlife Refuge, Biscayne National Park, and Everglades National Park). The initial stages of this effort, which is expected to continue for the next 3 to 5 years, involve:

- Gathering and integrating the best-available foundation-layer datasets for *The National Map*, including imagery, land-cover, transportation, hydrology, elevation, geographic names, boundaries, and structures;

- Developing a web interface and map viewer to support the display and download of both base mapping and thematic data, and the web deployment of selected science applications for decision support; and

- Communicating with other U.S. Department of the Interior agencies, such as the National Park Service and U.S. Fish and Wildlife Service, as well as local government agencies and local universities to identify key issues and potential science applications for deployment on the CUES/Miami website.

6.0 Potential U.S. Geological Survey Research Projects in and around Biscayne National Park

To better describe how the USGS can assist and/or supplement needed research in Biscayne National Park and Biscayne Bay, several USGS scientists have composed descriptions of potential research projects. These projects are examples of studies that could supply managers with needed information to address the problems that face Biscayne Bay in the near future. Each of the projects address important independent issues, but additionally most of them also address specific CERP Monitoring and Assessment Plan issues, which can be found in the Monitoring and Assessment Plan (MAP) Part 1 chapter 3 and MAP Part 2 section 9 Southern Estuaries Module documentation (RECOVER, 2004; RECOVER, 2006) and topics from the National Park Service's "Vital Signs" network. The topics of research include ecosystem stresses, water deliveries, contaminants, and database and GIS issues.

Research Project Description Index

6.1 Ecosystem Stresses

Ecosystem History of Biscayne Bay

G. Lynn Wingard, Thomas M. Cronin, Debra A. Willard, Charles W. Holmes, William Orem, and W. Bane Schill

During the last century, Biscayne Bay has been greatly affected by anthropogenic alteration of the environment through urbanization of the Miami-Dade County area and alteration of natural flow. The sources, timing, delivery, and quality of freshwater flow into the bay, as well as the shoreline and subaquatic vegetation have changed. The goal of current restoration efforts is to restore natural flow of freshwater into Biscayne Bay and restore the natural fauna and flora. To accomplish this, however, pre-alteration baseline conditions need to be determined to establish targets and performance measures for restoration.

This project examines the natural patterns of temporal change in salinity, water quality, vegetation, and benthic fauna in Biscayne Bay over the last 100 to 300 years and examines the causes of change. The work will answer the following questions:

- What were the natural patterns of change and the range of variation within the system, particularly the supply of freshwater and salinity, prior to substantial anthropogenic alteration?
- What component of the changes seen in Biscayne Bay during the 20th century is due to anthropogenic alteration and what is due to natural change?
- How have past changes in climate and sea level altered the system in terms of changes to the water mass, and corresponding changes to the biota?

Once the natural cycles of change and the patterns of the system response to those changes are determined, the next step is to predict what the system will look like in the future. In addition, the ecosystem history data can be used to test the hydrologic and biologic models.

Shallow sediment cores will be collected from areas within the ecosystem that have been targeted as areas of interest, for example, areas located near historical ground-water upwelling. This work will build on and fill in gaps from previous project work (Wingard and others, 2003; 2004). Cores are collected, x-rayed, and described, and then cut into 1- to 2-cm-thick samples. Age models are developed for the cores using Pb-210 and C-14 radioisotopes, and the first-occurrence horizon of *Casuarina* pollen. Core samples will be evaluated for any biotic remains, sediment geochemistry, and shell geochemistry. Biotic assemblages are compared to modern assemblages to interpret environmental characteristics at the time of deposition of each sample.

Determining Relationships between Remotely Sensed Measures of Reef Habitat Complexity, Reef Fish Assemblages, and Benthic Community Structure

John C. Brock, G. Todd Kellison, and Ilsa B. Kuffner

As anthropogenic activities degrade coral reef ecosystems worldwide, resource managers are in an increasing need of methods to identify target areas for conservation and management actions. Studies in coral reef ecosystems have documented relationships between levels of habitat complexity (for example, rugosity) and reef fish and benthic community structure. Methods that would enable (1) accurate determination of habitat complexity measures over large spatial scales and with minor in-water effort, and (2) subsequent prediction of spatially explicit reef fish and benthic community structure would be of great benefit to resource managers. Such methods are currently lacking.

Building on recent research (Brock and others, 2003; I.B. Kuffner, U.S. Geological Survey, written commun., 2007), we will assess relationships between remotely sensed measures of reef habitat complexity (for example, rugosity and elevational change; measured with National Aeronautics and Space Administration [NASA] Experimental Advanced Airborne Research Lidar [EAARL]) and reef fish and invertebrate community structure (for example, species richness and intra-species abundance). This project will address four main research questions:

- Are there predictive relationships between lidar-measured values of habitat complexity and measures of reef fish and benthic community structure? If so,
- At what spatial scales do these predictive relationships exist?
- What species groupings (for example, taxonomic or trophic) are most responsive to changes in habitat complexity?
- Do these relationships differ between patch and continuous-reef environments?

Initial studies will focus on a portion of the northern Florida Keys reef tract (Biscayne National Park), using both patch reefs and continuous reef habitat. We will calculate scale-specific habitat complexity measures from LIDAR data, and collect reef fish and benthic community structure data from scuba visual censuses. We will utilize statistical approaches such as linear regression, MANOVA, and principal component analysis to assess relationships between habitat measures and fish and invertebrate community structure. Subsequent work will expand to other areas (for example, Dry Tortugas National Park) to determine if habitat-species relationships are consistent across larger spatial scales.

Results will demonstrate a novel technique to assess measures of habitat complexity over large spatial scales, and provide: (1) insight about the ecological processes governing species distribution in coral reef ecosystems, (2) predictive tools for managers to determine areas that should be targeted for management and conservation, and (3) information to resource managers in Biscayne National Park for the purpose of developing a General Management Plan and a Fisheries Management Plan.

Characterization of the Histopathology of White Diseases of Corals at Biscayne National Park

Lou Sileo and Valerie Bochsler

An issue that is currently important at Biscayne National Park is characterizing the microbial communities that are associated with diseased and healthy corals and sea grasses, as well as providing a rapid diagnosis of disease and identification of pathogenic microbes in tissues, coral mucus, sediments, the benthic boundary layer, and the water column.

Diseases with unknown or equivocal contributing factors are an important cause of mortality in corals. The National Wildlife Health Center has a long institutional history of determining the cause of coral diseases. Few studies of diseased corals have been multidisciplinary; the National Wildlife Health Center, in cooperation with other institutions, can collect matching companion samples of diseased corals and do multidisciplinary diagnostic procedures in histopathology, microbiology, virology, parasitology, ultrastructure and molecular biology. Various “white” diseases of coral have been attributed to infections by *Serratia marcescens*, *Aurantimonas coralicida*, and unidentified vibrios; these reports need repetitive confirmation. Published descriptions of the histopathology of the various white diseases are inadequate, and management of these diseases is not feasible until their cause or causes are identified.

This project will determine (1) whether the histopathology of white diseases of corals at Biscayne National Park is the same as at the U.S. Virgin Islands, and (2) whether *Serratia marcescens*, *Aurantimonas coralicida*, and vibrios are the causes. Field work in Biscayne National Park will include collection of samples from diseased and reference corals for laboratory tests at the National Wildlife Health Center and other collaborating institutions.

Distribution of Non-Native Gastropod *Melanoides tuberculatus* (Red-Rimmed Melania) and Potential Associated Parasites in Biscayne National Park

G. Lynn Wingard, W. Bane Schill, and James B. Murray

A non-native gastropod, *Melanoides tuberculatus* (Family Thiaridae; common name Red-Rimmed Melania), has been found in relatively large numbers in samples collected from Biscayne National Park in 2003. The presence of this species raises several issues of concern to local resource managers: (1) the role of the species as an intermediate host to human parasites, *Clonorchis sinensis* (liver fluke) and *Paragonimus westermani* (lung fluke); (2) the potential displacement of native species; and (3) the potential effect on the health of animals within the park. The Thiaridae reproduce by means of parthenogenesis; therefore, a single individual can start a new colony and their reproductive rates are extremely high. A previous study documented as many as 23,000 per square meter near Coral Gables, Florida (Roessler and others, 1977). *M. tuberculatus* is an intermediate host for several parasitic organisms that potentially affect animals: (1) *Philophthalmus megalurus*—an avian parasite that affects the eyelids of waterfowl; (2) *Centrocestus formosanus*—a trematode that burrows into the gills of fish, and then enters mammals or birds that consume the fish; and (3) *Haplorchis*—a parasite that infects the muscle tissue of fish. In addition, there is some documentation of *Paragonimus* affecting mammals that eat raw crustaceans.

The primary objective of this project is to provide information about *Melanoides tuberculatus* that will enable Biscayne National Park managers to determine whether the species poses a substantial threat to human or animal health within the park. To address this issue, the following questions need to be answered:

- How widespread is *M. tuberculatus* and what is its distribution within southern Florida?
- What factors control its distribution? (Potential controlling factors include salinity, pH, water temperature, and nutrient levels.)
- Have there been multiple and/or continual introductions of the species, or are the individuals present the result of a single introduction that established a colony?
- Do the populations currently present in the parks contain any harmful parasites that might be a threat to humans or to native animal populations?

Live individuals will be collected from selected sites to be tested for the presence of parasites. Samples will be sent to Leetown, West Virginia, following established protocols for microbiology/parasitology analyses. A minimum of 60 individual *M. tuberculatus* collected at each site will provide a 95-percent probability of detection of the parasites if the incidence of infection is greater than 5 percent of the population. Field surveys will be conducted at various sites in Biscayne National Park to determine distribution and densities of *M. tuberculatus*. Collections will be made along salinity transects, moving from freshwater out into polyhaline to euhaline conditions. Water chemistry and other environmental parameter data will be collected as well as native mollusk population data. Individuals from the *M. tuberculatus* populations identified in the distribution study will be sampled to determine genetic diversity. If limited introductions of the species are occurring into the estuaries, low genetic diversity is expected at each site because of parthenogenesis; however, higher genetic diversity is expected if multiple or continual introductions are occurring.

Resolving Boundaries of Management Units for a Broadly Distributed Indicator Species, the Diamondback Terrapin (*Malaclemys terrapin*), in Biscayne National Park, Florida

Kristen Hart, Tim L. King, and Carole C. McIvor

Human population expansion during the 20th century has resulted in aquatic habitat disappearance at an unprecedented rate. Perhaps no habitat (and its associated species) illustrates this trend more conclusively than coastal wetlands in the United States, where at least one-third of the threatened and endangered species of the Nation reside (Murdock 1994). Brackish coastal wetlands are being developed, and otherwise degraded, and destroyed at an accelerating rate as a direct and indirect effect of human development through urbanization.

Diamondback terrapins (*Malaclemys terrapin*) exist as geographic populations that occupy brackish waters along the Atlantic and Gulf coasts of North America (Ernst and others, 1994). Diamondback terrapins once supported a multimillion dollar restaurant trade, before overharvesting and habitat degradation severely affected populations. Currently, the terrapin is listed as a Threatened Species in Massachusetts and a Species of Special Concern in several other states that have conducted inventory and monitoring efforts. The status of this species is unknown for other areas.

Effective conservation and restoration plans require clearly definable units of management. Diamondback terrapins are restricted to the brackish coastal waters of North America along the Atlantic Ocean and Gulf of Mexico. This presumably continuous distribution would seem to provide a mechanism to facilitate gene, exchange, and thus prevent the development of distinct evolutionary lineages. Terrapin populations, however, have been shown to exhibit extensive morphological differentiation with seven subspecies recognized (Ernst and others, 1994). This distribution and the observed morphological differentiation seem contradictory, suggesting that the distribution may not be continuous but instead consist of discrete populations. Until now, no genetic information was available concerning the fine-scale population structure, levels of gene flow, or relatedness of any geographic collection of *M. terrapin*.

To develop management strategies for maintaining evolutionarily important terrapin lineages that will ensure long-term population stability and reduce the need for protection through regulatory processes, we undertook a study to develop a thorough understanding of the evolutionary relationships (for example, gene exchange) among geographically proximate and distal collections of *M. terrapin*. During 2001-05, we conducted both range-wide and fine-scale studies of *M. terrapin* microsatellite DNA variation to quantify population structure and define population boundaries for the species. In southern Florida, we analyzed samples from Key Largo, the Everglades (Gulf Coast), and Tampa. Samples from the east coast of Florida or Biscayne Bay, however, were lacking.

By examining the genetic makeup of individuals from Biscayne National Park, we will determine whether terrapins living in this bay in southern Florida are unique or instead part of a single large population. We will also determine whether Biscayne Bay terrapins are exchanging genes with turtles from the Florida Keys and the Everglades, thus effectively moving across greater distances than individuals would be expected to travel (based on ecological studies).

The specific objectives of the current study are to:

- Define the genetic population structure among multiple geographic collections of diamondback terrapins from southern Florida;
- Delineate management units and evolutionarily important lineages among geographic collections of diamondback terrapins from southern Florida;
- Compare results from genetic analysis of southern Florida terrapin samples with those obtained from analysis of samples collected throughout the entire range of the species; and
- Promptly report the findings of this research to all the State and Federal stakeholders.

This project will involve sampling geographically separate collections of diamondback terrapins (*M. terrapin*) in southern Florida and examining levels of gene flow among populations to clearly define populations and management units. The Biscayne Bay *M. terrapin* samples will be used in the current project to determine effective population size, relatedness of individuals, and fine-scale population structure for terrapins residing within park boundaries.

This project will provide State and Federal resources managers with information on the boundaries of the southern Florida metapopulations of the *M. terrapin*. Summarized information about genetic variability at each polymorphic marker and the portioning of genetic variability among diamondback terrapin populations sampled also will be made available to interested Federal, State, or local agencies as well as universities and interested user groups.

Effects of Altered Fresh Water Delivery to Biscayne National Park: Consequences to Reefs and Reef-Associated Macro and Microbial Communities

Ilsa Kuffner, John Lisle, Chris Reich, and Peter Swarzenski

Coral-reef community structure is affected continually by anthropogenic factors, particularly in reef areas adjoining populous, highly developed coastlines. Biscayne National Park is bordered by an urban metropolis of 2.3 million people within Miami-Dade County, and includes a substantial amount of coral reef and reef-associated habitat within its boundaries. As with other reefs in the region, these areas within Biscayne National Park have experienced substantial declines in coral cover and fish biomass/abundance, and increases in algal cover and incidence of coral disease. Despite the semiprotected status of these resources within Biscayne National Park, reef habitats are not showing signs of recovery. Water-quality issues, including increased levels of nutrients and water-borne pathogens, are hypothesized to have played a key role in these observed changes. With the impending alteration of the water-management system as part of CERP, it is important to collect baseline data on community structure throughout Biscayne National Park so that positive or negative effects associated with changing patterns of freshwater delivery to the area can be assessed and documented.

The objectives of the project are as follows:

- Collect baseline algal community structure data in areas where nutrient-laden submarine ground-water discharge is suspected to be measurably increased due to CERP.
- Collect baseline microbial community structure, diversity, and physiological function data in areas where nutrient-laden submarine ground-water discharge is suspected to be measurably increased due to CERP.
- Evaluate areas to determine if cascading effects of algal community change, including reduced coral cover, coral recruitment, and recruit survival, are not apparent.
- Evaluate areas to determine if cascading effects of microbial community change are not affecting key processes such as sediment dissolution, nitrogen fixation, nutrient remineralization, sulfide production, and nutrient fluxes from sediments to the reefs.
- Evaluate to determine if microbial indicators of coral pathogens found in human fecal wastes are not being transported by way of submarine ground-water discharge or surface waters affected by submarine ground-water discharges to the reefs.

Based upon existing knowledge of freshwater delivery derived from observational and modeling studies (Szwarzenski, 2004a, Langevin, 2001), sites will be selected for quarterly monitoring of benthic and microbial communities and processes therein. The goal will be to select sites within Biscayne National Park along a gradient of existing and predicted freshwater delivery levels.

6.2 Water Deliveries

Conceptual Hydrogeologic Model of the Karst Biscayne Aquifer in Support of Ground-Water Flow Simulations from Everglades National Park to Biscayne National Park

Kevin J. Cunningham

Water diversions and excessive nutrients and contaminants within the Everglades wetlands have decimated populations of wading birds and other animals to near extinction levels. In Biscayne Bay, the degradation of estuarine and marine waters has caused declines in the marine community. Because of the inextricable link between surface-water levels in the wetlands and underlying fresh ground-water flows to the coast, "getting the water levels right" in the Everglades wetlands is an important aspect of ecologic restoration in both the terrestrial wetlands and coastal marine environments. The best water-management strategy includes managing the relation between hydrology and biological community components, including wading birds, coral reefs, and vegetation, by managing optimal timing and distribution of freshwater flows. Critical to the management of the hydrologic component is accurate simulation of ground-water flow from the Everglades wetlands to the coast of Biscayne Bay. It has been realized recently, however, that current conceptual representations of the Biscayne aquifer in ground-water flow simulations are not realistic, especially as they relate to nutrient and contaminant transport, thus decisions based on them are suspect.

Current ground-water models for the Biscayne aquifer assume that the aquifer is a porous medium with essentially homogeneous hydraulic properties (for example, Wilsnack and others, 2000). The Biscayne aquifer, however, is actually a heterogeneous, dual-porosity, karst system characterized by intergranular matrix porosity and well-connected, larger scale secondary cavities (Cunningham and others, 2004a). These different types of porosity create a heterogeneous distribution of permeability, and consequently, flow rates in a given area depend on whether ground-water flow is through matrix, cavities, or a combination of both. Diffuse and non-laminar flow occurs predominately within the intergranular porosity, whereas turbulent flow may occur within the conduit-pore system of connected cavities. Rates of flow within the conduit-pore system clearly are more rapid than within the matrix, as demonstrated by a USGS tracer test at the Northwest Well Field in Miami-Dade County (Renken and others, 2005). During the test, the apparent mean advective flow velocity of the tracer was one order of magnitude or greater than the rate predicted by simulations that assume diffuse flow. A critical consideration to modeling contaminant and nutrient distribution and flow rates within the karst Biscayne aquifer is that the contaminants are influenced by the relative proportion and spatial arrangement of matrix and conduit porosity. The conceptual karst hydrogeologic model to be developed in this study is intended to provide a framework that accurately represents the distribution of matrix and conduit porosity for numerical simulations of ground-water flow and nutrient and contaminant transport on a regional scale.

The objectives of the project are to:

- Provide information about changes in ground-water flow to Biscayne National Park resulting from Everglades restoration;
- Develop a karst hydrogeologic conceptual model based on cyclostratigraphic concepts for use in simulation of ground-water flows from Everglades National Park to offshore Biscayne National Park;
- Provide information about freshwater flow from Everglades National Park to offshore Biscayne National Park; and
- Develop modeling procedures for simulation of flow in dual-porosity karst aquifers.

This project will involve the following tasks:

- Drill and install onshore and offshore well clusters in Biscayne National Park, each including a shallow, intermediate, and deep ground-water monitoring well;
- Collect cores and advanced geophysical logs;
- Instrument wells and collect water level, salinity, and temperature data;
- Produce a karst hydrogeologic conceptual model by integrating analyses of cores, borehole geophysical logs, cyclostratigraphy, and hydrologic data; and
- Provide data to the Flows to Coral Reefs U.S. Department of the Interior Landscape Project for development of modeling procedures to integrate the karst hydrogeologic conceptual model in simulations of ground-water flow and solution transport.

Ground-Water Inputs to Biscayne National Park: Impacts on the Estuary and Coral Reef

Robert Halley, Christian Langevin, and Chris Reich

Biscayne National Park and Biscayne Bay receive ground- and surface-water flow from the Everglades. Surface water flows through numerous canals that transect highly developed lands (urban and agricultural) and can potentially transport high loads of nutrients and other contaminants to the bay. In addition, ground water that is recharged in these onshore areas is transported through the highly transmissive Biscayne aquifer and discharged along the coastline. Additional research to quantify ground-water flux to the bay is needed to further characterize chemical transport from ground to surface waters as well as validate current (and future) ground-water flow models.

The purpose of this project is to determine whether freshwater presently is seeping into the bay. If so,

- Determine where, and what known or identifiable pollutants are being delivered with it, and
- Predict how Everglades restoration (CERP) and installation of 300 aquifer storage wells farther inland may affect offshore reefs.

The activities for this project will involve collecting pressure measurements in existing monitoring wells to determine onshore to offshore hydraulic gradients. Hydraulic gradients will be utilized to refine the ground-water flow model for Biscayne Bay. Water samples also will be collected from existing wells to complement existing water-quality data. Selected sites where identified springs may occur will be monitored using seepage meters to obtain flux measurements during varying dry and wet periods throughout the year.

Quality of Surface-Water Discharge into Biscayne Bay

P.V. Winger and P.J. Lasier

Surface-water discharge to Biscayne Bay occurs primarily through canal inflows; these have the potential to be affected adversely by stormwater runoff and point and nonpoint-source discharges associated with extensive municipal and industrial development within the Biscayne Bay watershed. Potential impairment of the estuarine resources of Biscayne Bay from these freshwater inflows is high, and an evaluation of them is needed to provide information of sufficient accuracy to develop management plans that can protect and preserve this unique and valuable estuarine system over the long term. Previous studies have indicated that a number of the canal inflows to Biscayne Bay have degraded water quality, as demonstrated by elevated concentrations of contaminants and toxicity to test organisms.

Because the quality of sediment reflects the quality of the surface water, the weight of evidence approach will be used to determine the quality of freshwater in canals discharging into Biscayne Bay. Specifically, inflow water quality will be determined by measuring contaminants in the sediments and toxicity of solid-phase sediment and sediment porewater.

The objective of this study is to determine the quality of water that discharges into Biscayne Bay and identify sources that are degraded. Areas that are identified as having degraded conditions can then be targeted by the appropriate management agency, such as the Department of Environmental Resources Management (DERM), for cleanup and/or remediation.

Completion of this study will involve the following tasks:

- Select study sites in the canals that discharge into Biscayne Bay,
- Collect sediments to analyze in the laboratory,
- Measure contaminant residues in the sediments,
- Determine chronic toxicity of solid-phase sediments,
- Determine acute toxicity of pore water,
- Determine physical characteristics of the sediments, and
- Determine sediment quality using the weight-of-evidence approach.

6.3 Contaminants

Reconnaissance for Emerging Pollutants of Concern (EPOCs) in Biscayne National Park and the Adjacent Biscayne Bay Coastal Environment

A.C. Lietz (Retired)

A primary purpose of the CERP is the restoration of natural water flows and historical hydroperiods in the ecosystem of southern Florida, including the Biscayne Bay Coastal Wetlands adjacent to Biscayne National Park. As part of the plan, reclaimed wastewater will be used from the South District Wastewater Treatment Plant, and of particular concern is the presence of emerging pollutants of concern (EPOCs) in reused wastewater. In a recent study, the presence of EPOCs in wastewater influent and effluent was detected at the wastewater treatment plant (Lietz and Meyer, 2006). An additional and necessary step is to document the possible occurrence and concentration of EPOCs in Biscayne National Park and the adjacent coastal environment prior to using reclaimed wastewater so that a baseline of EPOC concentration levels will be available for future studies.

The objective of this project is to develop a reconnaissance of EPOCs by documenting their occurrence, concentrations, and possible sources in Biscayne National Park and the adjacent coastal environment. This reconnaissance will develop an EPOC database to be used as a baseline for comparison of contamination levels after the implementation of the use of reclaimed wastewater to establish historical hydroperiods and more natural flow to the Biscayne Bay Coastal Wetlands. The scope of this project will involve (1) selection of critical Biscayne National Park and adjacent coastal canal sites for reconnaissance sampling, and (2) sampling and analysis at the above-mentioned sites for the EPOCs identified by Koplin and others (2002).

Anthropogenic Influences on Biota and Biogeochemistry of Biscayne Bay: Integration of Chemical, Geological, and Molecular Genetic Data

G. Lynn Wingard, W. Bane Schill, and James B. Murray

The Biscayne Bay shoreline is highly developed and has been listed as one of the 10 most endangered coastal parks of the 389 park units in the National park system. Pollutants enter Biscayne Bay from multiple point and non-point sources, including boats, canals, quarrying operations, a Class I landfill, several C and D landfills, military operations, a sewage treatment plant, urban and agricultural runoff, and submarine ground-water springs. Large tracts of seagrass, primarily *Thalassia testudinum*, colonize the shallow areas of western Biscayne Bay and provide habitat (including nurseries) for many aquatic organisms as well as biofiltration for the marine ecosystem. The extensive surface area of *Thalassia* plants as well as the sediments underlying *Thalassia* beds harbor microbes capable of performing a number of important ecosystem functions including nitrogen cycling, sulfur and metal reduction, and metabolism of organic pollutants. Increased research is required to better characterize the types of pollutants entering the bay waters, their fate in the environment, and how life in the bay is affected by the interactions of multiple stressors. Because water circulation patterns (as seen in satellite images) indicate that many inputs to Biscayne Bay are swept southward and out to the coral reef tracts (with an estimated residence time of 7-10 days), additional research is required to determine the spatial extent of pollutant effects.

The primary objective of this project is to determine the effects of anthropogenic activities on the fauna and flora (including the microbial component) of Biscayne National Park. Specific questions to be addressed include:

- What are the sources of pollution (for example, metals, agrochemicals, and endocrine disrupters) entering Biscayne Bay and are there synergistic effects with other forms of pollutants such as thermal input? How severe are the effects of these pollutant stressors on the fauna and flora of Biscayne Bay?
- Do pollutants entering Biscayne Bay ultimately reach the reef tract, or are they remediated by other natural or anthropogenic factors within the bay?
- Are anthropogenic chemicals changing bay microbial community compositions resulting in modulation of nutrient cycling or increases in opportunistic pathogens?

Samples will be collected at sites that extend from Coral Gables in northern Biscayne Bay to the C-111 Canal in southern Barnes Sound. Multiple sites are located in the vicinity of Black Point near a landfill, sewage treatment plant, quarrying operations, and three power plants (one nuclear and two oil burning). Four types of analyses will be performed on the samples:

- *Metal Analysis:* Organisms that secrete biogenic carbonate (for example, *Porites* sp.) and are representative of multiple trophic levels will be analyzed to determine the type and amount of anthropogenic chemicals sequestered within the carbonate matrix. *Porites* make an ideal study organism because they are found from within the bay out to the reef tract.

- *Organic Analysis:* Water samples will be quantified for a suite of organic compounds (for example, atrazine, metalochlor, glyphosate, bisphenol A, alkylphenols, and total steroids).
- *Microbial Analysis:* Several key groups of microbes will be monitored using advanced molecular methods, including quantitative (real-time) polymerase chain reaction, laser scanning cytometry, terminal restriction fragment length polymorphism, and fluidized microarray to detect their presence, species composition, and reaction to environmental conditions.
- *Genetic Analysis:* Microbial samples from specimens of *Porites* collected across the system from bay to reef tract will be genetically identified to determine a typical microbial community.

Occurrence, Survival, and Risk Assessment of Microbial Indicators and Pathogens in Ground Waters and Marine Waters and Sediments within Biscayne National Park

John Lisle, Chris Reich, and Robert Halley

Biscayne National Park is the largest marine park in the national park system. Four distinct ecosystems have been identified within the park and include Biscayne Bay, the northern islands of the Florida Keys, mangrove forest along the shoreline of the park, and a coral reef tract. All of these ecosystems have experienced some degree of decline in their respective productivity during the recent past. Two contributing factors are: (1) increased volumes of terrestrial runoff (non-point discharge) into Biscayne National Park that contain elevated concentrations of nutrients, organics and microbials; and (2) substantial reductions in the volume of fresh submarine ground water discharge from the coastline within Biscayne National Park due to flood control projects within the Everglades. The karst geology of this area increases the complexity of these problems because it allows relatively rapid infiltration of surface waters, point and non-point septic discharges, and subsurface septic waste injection into the surficial aquifer system, a major contributor to submarine ground-water discharge.

Ongoing efforts to monitor the effect of submarine ground-water discharge and point and non-point discharges on the water quality of Biscayne National Park have focused on nutrients, physical constituents, and trophic levels at or above that of phytoplankton. To date, there has been no organized effort to determine the concentrations of microbial indicators (that is, fecal coliforms, enterococci, *Clostridium perfringens*, and coliphage) and known pathogens of environmental interest (that is, *Escherichia coli*, *Serratia marcescens*, and human enterovirus) in surface runoff, shoreline submarine ground-water discharge, and ground water from an inland-to-reef tract vector within Biscayne National Park.

We are proposing a project that will use existing USGS monitoring wells within Biscayne National Park, along with identified sites of point and non-point discharges and zones of confirmed submarine ground-water discharge, to determine the abundances of selected microbial indicators and pathogens in the respective sample types. Environmental diffusion chambers, designed by the USGS, also will be used to determine the survival rates of selected microbial indicators and pathogens in sediments, surface waters (marine and fresh), and ground waters within Biscayne National Park.

The proposed project is designed to address the following questions:

- What are the abundances of microbial indicators and pathogens in surface-water runoff, submarine ground-water discharge, ground water, and waters at the reef tract within Biscayne National Park?
- Which factors in each of the sample types inhibit/enhance the survival rates of microbial indicators and pathogens?
- Is there an increased risk to humans and other mammals that come in contact with these waters based on microbial risk assessment modeling?

The proposed project will involve the following four activities:

- Collection of water samples from (1) fresh surface-water discharges into Biscayne National Park, (2) sites identified as having substantial submarine ground-water discharge, (3) USGS monitoring wells that are located within Biscayne National Park; and collection of sediment cores from selected sites including the reef tract;
- Analysis of these samples for fecal coliforms, enterococci, *E. coli*, *Clostridium perfringens*, coliphage, *Serratia marcescens,* and enterovirus;
- Use of the data obtained from the analyses, to calculate the human health risk, if any, associated with contact with these waters; and
- Determination of survival rates for selected microbial indicators and pathogens using *in situ* environmental diffusion chambers.

6.4 Database and Geographic Information System Issues

A GIS-Based Decision Support System for the Greater Everglades Ecosystem Restoration

Richard L. Bernknopf and Paul Hearn, Jr.

Land use and preservation/restoration decisions have substantial, but highly uncertain, effects on water quality and quantity, flow patterns, and ecosystem health in the greater Everglades ecosystem. These environmental and ecological factors, however, have economic values that currently are not being (or only partially) considered in these decisions. A program of research is needed to: (1) estimate the economic value of environmental and ecological resources affected by development and preservation/restoration decisions, (2) aggregate and quantify the large uncertainties associated with these decisions, and (3) develop a decision support system that will provide land managers and local officials with a clearer idea of the economic consequences of various courses of action.

The objectives of this project are to:

- Develop and test a method to estimate the benefits and costs of ecosystem restoration projects in the greater Everglades ecosystem;
- Develop, estimate, and test integrated ecological and economic indicators that measure the effect of restoration efforts on natural and anthropogenically altered environments—test areas will include Loxahatchee National Wildlife Refuge, Biscayne National Park, and Everglades National Park;
- Provide U.S. Department of the Interior land managers with a GIS-based decision support system that is capable of estimating the socioeconomic implications of land-use decisions, and provide a method to assess land allocations and their economic values that includes the consideration of uncertainty. (Test areas include the Miami-Dade County urban development boundary and Everglades Agricultural Area.)

The proposed project includes two primary components, a cost-benefit analysis and decision support system development.

Cost-Benefit Analysis

Conduct a cost-benefit analysis of an investment project intended to increase ecosystem sustainability. The application would be designed to estimate the benefits and costs of the construction of a multi-mile bridge along the Tamiami Trail to improve water flow. Benefit estimation will include the willingness to pay for environmental services.

Decision Support System Development

- *Task 1*—Gather and integrate required base and thematic data and build GIS with integrated decision support system software, using cost share with the Comprehensive Urban Ecosystem Systems (CUES) project for the greater Everglades ecosystem.
- *Task 2*—Develop, estimate, and test a landscape stress indicator (LSI) for Loxahatchee National Wildlife Refuge, Biscayne National Park, and Everglades National Park. Stressors are severe storms, agrochemicals, mining, and human encroachment. The landscape stress indicator will be a spatial vulnerability metric in the decision support system that is used to assess the relative ecological and economic sustainability of a given land area.
- *Task 3*—Develop and implement a land allocation and land valuation model that includes explicit consideration of associated uncertainties in the Miami-Dade County urban development boundary or the Everglades Agricultural Area.
- *Task 4*—Develop and test a Bayesian (probabilistic) network as a decision framework for tasks 2 and 3.

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