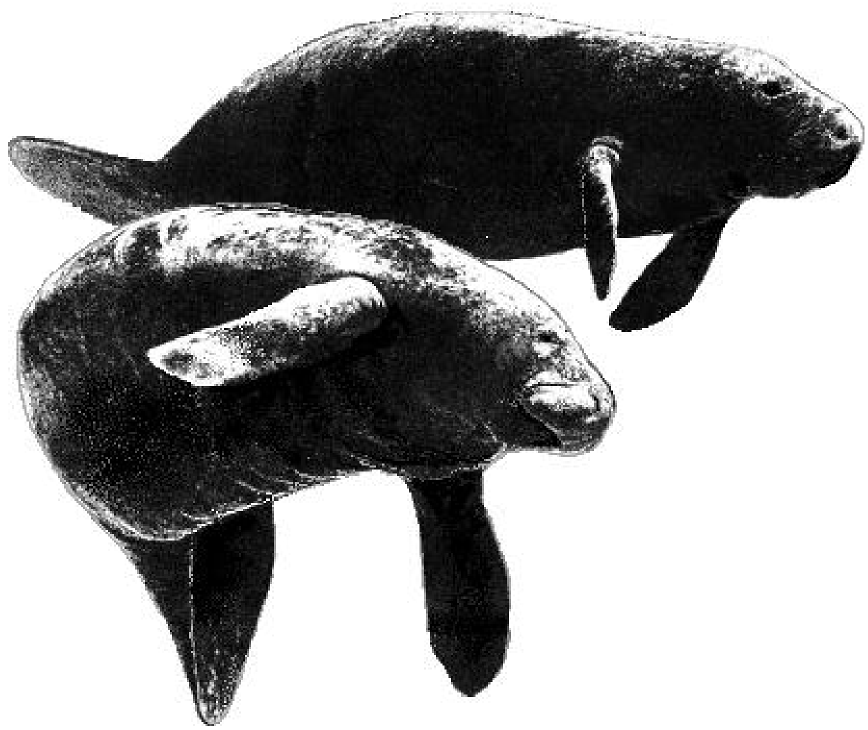
NOAA Technical Memorandum NOS NCCOS CCMA 145

National Status and Trends Program
for Marine Environmental Quality

Biscayne Bay: Environmental History and Annotated Bibliography



Silver Spring, Maryland
July 2000

US Department of Commerce

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Center for Coastal Monitoring and Assessment
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National Ocean Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce
1305 East-West Highway
Silver Spring, MD 20910

Notice

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Biscayne Bay:
Environmental History and Annotated Bibliography

A. Y. Cantillo, K. Hale, E. Collins, L. Pikula and R. Caballero

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United States Department of Commerce	National Oceanic and Atmospheric Administration	National Ocean Service
William M. Daley Secretary	D. James Baker Under Secretary	Nancy Foster Assistant Administrator

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ACRONYMS

AAF	Army Air Field
AFB	Air Force Base
AOML	Atlantic Oceanographic and Meteorological Laboratory/ERL/OAR/NOAA
ARB	Air Reserve Base
ATC	Air Transport Command
BBPI	Biscayne Bay Partnership Initiative
CAA	Clean Air Act
CCMA	Center for Coastal Monitoring and Assessment/NCCOS/NOS/NOAA
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DDTs	Dichlorophenyltrichloroethane and metabolites
ENSO	El Niño/Southern Oscillation
EPA	Environmental Protection Agency
EPCRKA	Emergency Planning and Community Right-to-Know Act
ERL	Environmental Research Laboratories/OAR/NOAA
ESA	Endangered Species Act
FAU	Florida Atlantic University
FIFRA	Federal Insecticide, Fungicide and Rodenticide Act
FIU	Florida International University
FP&L	Florida Power and Light Co.
FWCA	Fish and Wildlife Coordination Act
FWPCA	Federal Clean Water Act
MMPA	Marine Mammal Protection Act
NAS	Naval Air Station
NCCOS	National Centers for Coastal Ocean Science/NOS/NOAA
NESDIS	National Environmental Satellite, Data, and Information Service/NOAA
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service/NOAA
NPDES	National Pollutant Discharge Elimination System
OAR	Oceanic and Atmospheric Research/NOAA
PAHs	Polycyclic aromatic hydrocarbons
PCBs	Polychlorinated biphenyls
RCRA	Resource Conservation and Recovery Act
RSMAS	Rosenstiel School of Marine and Atmospheric Science/UM
SARA	Superfund Amendments and Reauthorization Act
SOI	Southern Oscillation Index
TAC	Air Transport Command
TFW	Tactical Fighter Wing
TSCA	Toxic Substances Control Act
UM	University of Miami

Biscayne Bay:
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ABSTRACT

Biscayne Bay is located along the southeast coast of the state of Florida. It is surrounded on the north by urban Dade County which includes Miami and Miami Beach, and on the south by the Homestead area, sparsely inhabited until recently, and the northern Florida Keys. Prior to the 1920s, major changes to the Biscayne Bay ecosystem were caused only by climatic events. Since then, human actions have also been the cause of major alterations. During the 1920s, there were disruptions from construction of artificial islands, bulkheading, dredging of channels and construction of cuts. Construction activities slowed considerably after 1930. Bacterial pollution due to untreated sewage discharge began during the 1920s and reached maximum levels during the 1950s. Changes to the sewer system reduced bacterial contamination after 1956. Turbidity in the water column was identified as a major problem during the 1980s and abatement measures began at that time. Environmental degradation of the Bay has slowed although areas of concern remain.

1. INTRODUCTION

"Biscayne Bay, broad and brimming with fish, was the highway on which the people moved in their small sailing craft under shifting starch-white clouds while great blue and great white herons, American egrets and roseate spoonbills dipped and wheeled and came to rest in the shallows along the shore.

"Across the Bay, Miami Beach, actually the first of the Florida keys, was preceded south in the curved march of islands by Key Biscayne which had its own history. Pedro (el) Biscaino lived there and gave the Bay its name. He was a Basque who had held the title 'Keeper of Swans' at the court of Spain."

"The thing that made the Bay country was fresh water. Calusa Indians, discoverers, pirates, seamen of all descriptions, had been sailing up the Miami River to stock up on fresh water for centuries. You could dip a tin cup in the Miami River and bring up a crystal-clear drink, and there were places in the Bay itself where fresh cold water bubbled up."

J. Muir (1953)

Biscayne Bay is located along the southeastern-most portion of the state of Florida (Figure 1). It is surrounded on the north by the growing urban areas of Dade County, which include Miami and Miami Beach, and on the south by the sparsely inhabited Homestead area and the northern Florida Keys. The environment of Biscayne Bay has changed significantly over the last one

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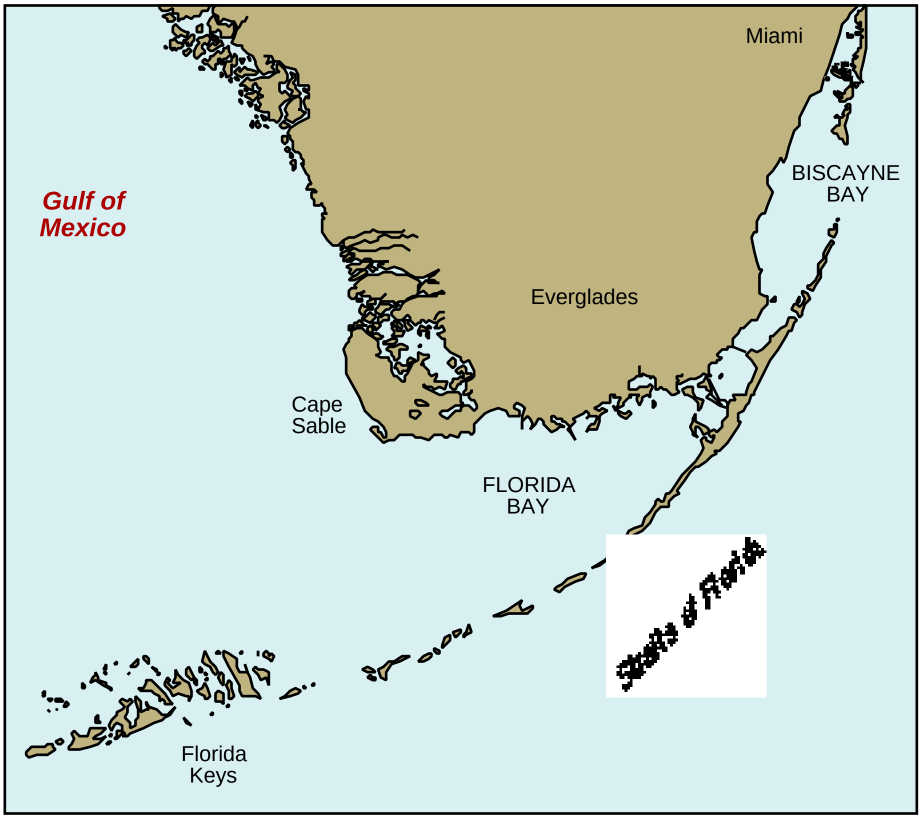

Figure 1. South Florida.

hundred years with the onset of development of Dade County, and only recently has its environmental degradation reversed. This report documents the environmental history of Biscayne Bay, which is closely tied to the history of South Florida. An annotated bibliography of material on the subject, and author and subject indices are included.

2. INFORMATION GATHERING METHODS

This document has been compiled using various sources and methods. It is based primarily on the bibliography maintained at the Marine Library of the Rosenstiel School of Marine and Atmospheric Sciences of the University of Miami (Hale, 1993 and 1996, and unpublished updates). This bibliography incorporated and updated previous bibliographic works on Biscayne Bay (Morril and Olson, 1955; Rosendahl, 1975; de Sylva, 1984; and others). Citations describing studies in which water from Biscayne Bay was used to maintain aquaria or cultures were not included. The coral reefs located east of the barrier islands and keys are not located in Biscayne Bay proper and citations concerning them were not included in this work. Only selected citations about the Miami River were included in the bibliography.

The annotated bibliography can be found in Appendix I. The subject index of the bibliography is in Appendix II and the author index is in Appendix III.

3. GENERAL DESCRIPTION

Biscayne Bay is a shallow tropical saline lagoon located on the southeast coast of the state of Florida (Figure 1). The eastern boundary of the Bay is composed of barrier islands which eventually become part of the Florida Keys. The western shore is the Florida mainland. The Bay is connected to the Atlantic Ocean by several channels and cuts, some natural and some man-made. Major tributaries (north to south) are Arch Creek, Biscayne Canal, Little River, Miami River, Coral Gables Waterway, Snapper Creek Canal, Black Creek, Goulds Canal, North Canal, Florida City Canal, and Model Land Canal. Tidal flow enters the Bay (north to south) at Bakers Haulover Cut, Government Cut, Norris Cut, Bear Cut, the Safety Valve, Sands Cut, Caesar's Creek, Broad Creek and Angelfish Creek (Figure 2 and 3). There are many islands located in Biscayne Bay, most of which are man-made.

The geology of Biscayne Bay is described in Wanless (1969). The Bay was formed as rising sea level filled a limestone depression. It is not a drowned river valley like most estuaries. Unlike other estuaries, the Bay does not receive a sediment load from major river systems. Most sediments in the Bay are produced by local biota (Wanless, 1976).

The Biscayne Bay can be divided into three major areas.

3.1. North Bay

North Bay is the heavily urbanized area extending from Broward County in the north to Rickenbacker Causeway, approximately 10% of the total Bay area (Figure 2). Five waterways drain to the northern part: the Oleta River, Arch Creek, the Biscayne Canal, Little River and Miami River. North Bay was estuarine prior to the construction of Haulover Cut. Exchange with ocean waters occurs at Bakers Haulover Cut, Government Cut and Norris Cut. There are numerous islands in North Bay. Only Belle Isle and Virginia Key are natural. A description of the construction and/or development of the islands in Biscayne Bay can be found in Kleinberg (1997). Most of the shoreline has been bulkheaded and very little remains as mangrove shoreline. Most of the bottom has been dredged and for many years lacked benthic vegetation.

3.2. Central Bay

The central area of the Bay ranges from Rickenbacker Causeway south to the boundary of Featherbed Bank just north of Sands Key (Figure 3). The Safety Valve, a series of shoals through which ocean tidal exchange occurs, serves as the eastern boundary. Three major canals, the Coral Gables Waterway, Snapper Creek and Cutler Drain, reach the Bay in this section. Moderate coastal development has occurred in the mainland portion of this area. Much of the mangrove wetlands in Central Bay remain intact. Seagrasses dominate the bottom vegetation. Chicken Key and Soldier Key are the only natural islands in this section of the Bay. A north-south area in the center of the Bay is barren but used to be vegetated by seagrasses (Harlem, 1979). Small areas of soft corals and sponges are found in the southern-most region of Central Bay.

3.3. South Bay

The southern portion of the Bay ranges from the Featherbed Bank to Card Bank (Figure 3). This section is undeveloped and fringed by mangrove wetlands. Benthic habitats are dense seagrass beds, large hard ground areas and algal communities. The main canals draining into the portion of the Bay are Black Creek, Princeton Canal, Military Canal, Mowry Canal and Model Land Canal. Ocean exchange is restricted to the tidal creeks between the islands of the northern portion of the Florida Keys. The larger creeks are Angelfish, Broad and Caesar’s Creeks. The

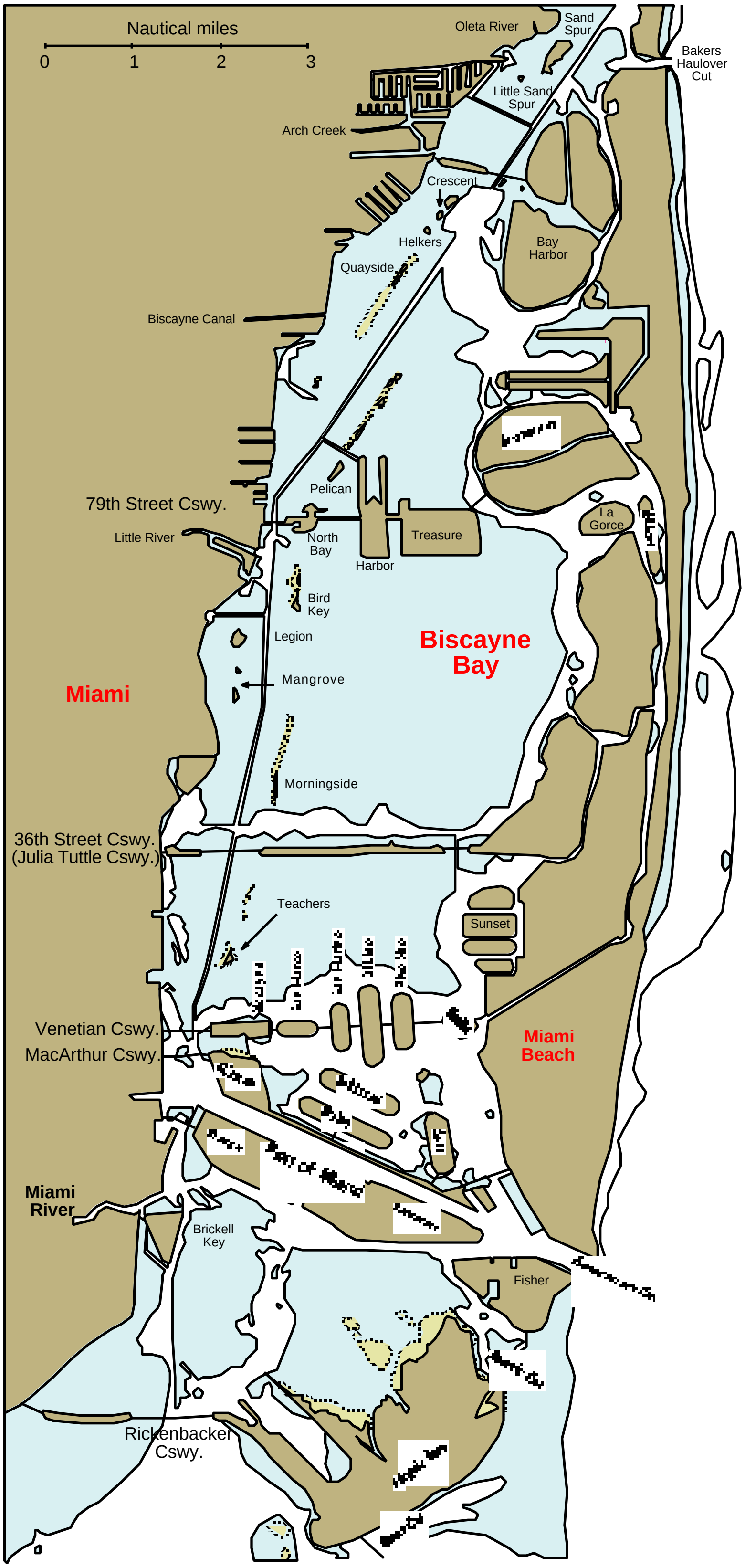

Figure 2. Northern Biscayne Bay.

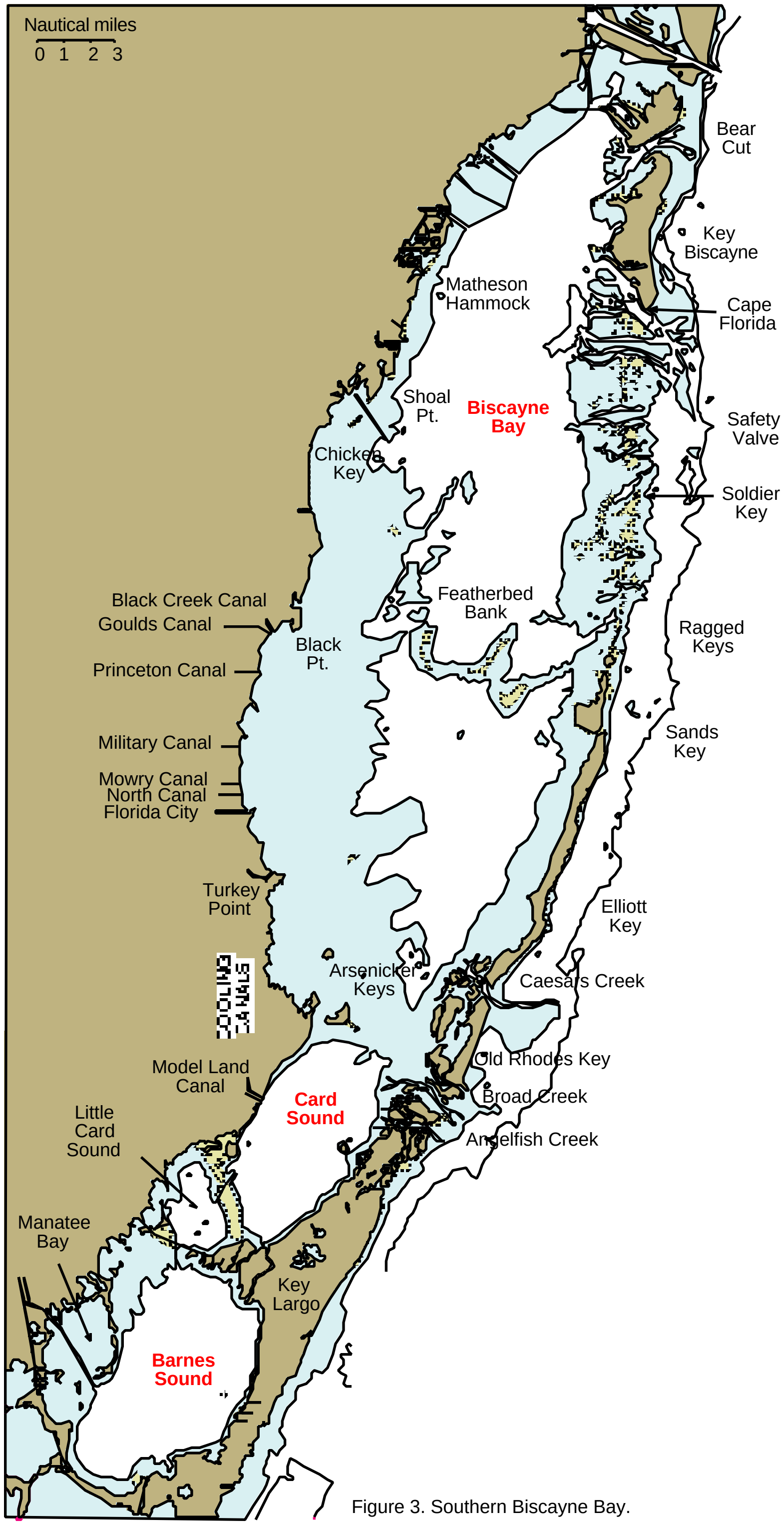

Figure 3. Southern Biscayne Bay.

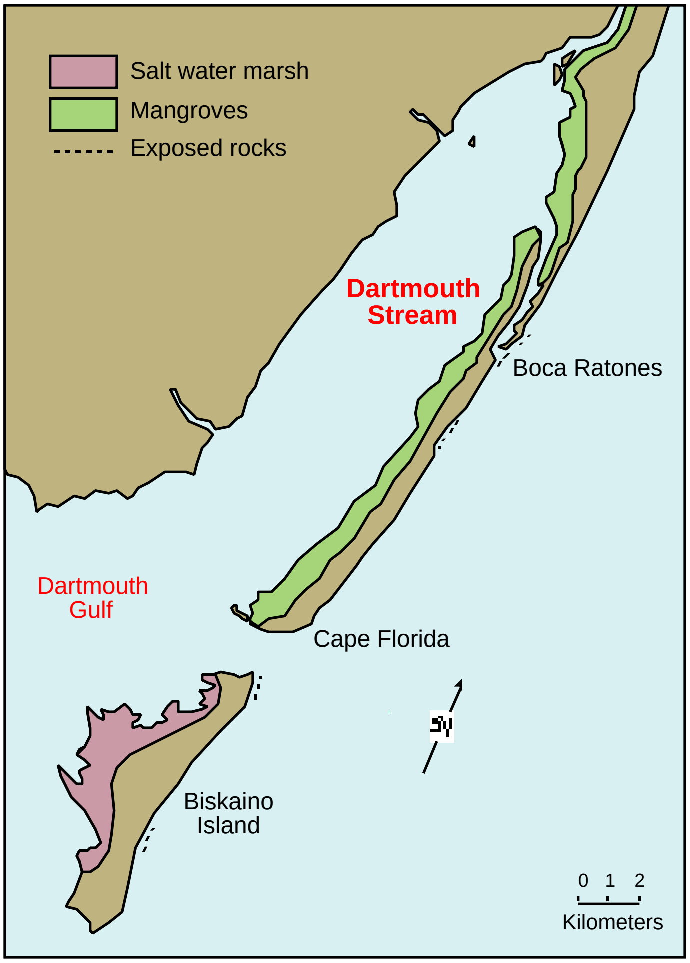

Figure 4. Northern Biscayne Bay in 1770. [Redrawn from Chardon (1978).]

southern portion of the Bay is connected to Card Sound, a small bay approximately 3 miles wide and long, and about 3 m deep. Restricted openings limit flushing and water exchange between Card Sound and Biscayne Bay. There are numerous keys in this section of Biscayne Bay and Card Sound.

4. HISTORY

Significant events related to Biscayne Bay are listed in Table 1 and shown graphically in Appendix IV.

4.1 Pre 1910s

The coastline of the barrier islands of what is now known as Biscayne Bay has changed considerably over the past 200 hundred years. Some of these changes were the result of natural processes such as hurricanes, while others were anthropogenic.

Chardon (1978 and 1982) examined pre-urban historical maps of the northern portion of Biscayne Bay. The 1770 De Brahm chart showed a continuous barrier island encompassing what is now Miami Beach to the west of the Bay, then known as Dartmouth Stream (Figure 4). Boca Ratones, a pass leading to the Atlantic Ocean, cut across the barrier island. The southern end of the barrier island was known as Cape Florida. This pass eventually became Indian Creek in Miami Beach. South of the barrier island was Biskaino Island (Key Biscayne). Dartmouth Inlet, the pass between the barrier island and Biskaino Island was eventually renamed Bear Cut. The main portion of Biscayne Bay was called Sandwich Gulf.[Δ]

During the early part of the 1900s, the population of South Florida was small, approximately 40,000 people. The largest towns in the area were Cocoanut Grove[◊] and Lemon City and the site of downtown Miami was undeveloped (Figure 5). Most of the inhabitants were dependent on the Bay for a living. There was abundant fishing in the Bay and the Miami River. Building materials and assorted items were routinely salvaged off the shores of Key Biscayne. Agriculture was not well established due to the harsh environmental conditions and swarms of mosquitoes.

[Δ] Many of the geographical names along the coast of South Florida and the Florida Keys have been in use since at least the late 1700s. Romans (1999) mentioned in the reprint of his 1775 natural history book the names Key Biscayno, Key Largo ("Cayo Largo"), Key Sal, Matacombe, Cape Sable, "Cayo Huesos" (Key West), Cape Florida, Soldier Keys (also known as "La Parida y su Figuelo"), and many others.

[◊] The spelling was later changed to Coconut Grove and coconuts planted in the area to match the name.

Table 1. Significant events in Biscayne Bay.

MAJOR TROPICAL CYCLONES PASSING CLOSE TO BISCAYNE BAY

1903	Storm 3, Sept. 9 - 16
1904	Storm 3, Oct. 12 - 21
1906	Hurricane of 1906 (Storm 8), Oct. 11 - 22
1909	Storm 9, Oct. 6 - 13
1916	Storm 14, Nov. 11 - 14
1926	Hurricane of 1926 (Storm 6), Sept. 11 - 22
1929	Storm 2, Sept. 22 - Oct. 4
1935	Storm 6, Oct. 30 - Nov. 8
1941	Storm 5, Oct. 3 - 14
1945	Storm 9, Sept. 12 - 20
1948	Storm 8, Oct. 3 - 16
1964	Hurricane Cleo (Storm 5), Aug. 10 - Sept. 5
1965	Hurricane Betsy (Storm 3), Aug. 27 - Sept. 13
1992	Hurricane Andrew (Storm 2), Aug. 16 - 28

CANALS, CUTS AND THE MIAMI RIVER

pre 1887	Norris Cut formed as the result of the passage of a hurricane (Chardon, 1977)
pre 1887	Pass at Boca Ratones was no longer observed (Chardon, 1977)
1896	Channel dug from Cape Florida to the Miami River (Harlem, 1979)
1902-1905	Construction of Government Cut (Michel, 1976)
1903	Drainage of the Everglades begun (Harlem, 1979)
1904	Salt intrusion begins
1904-1905	Government Cut (Toner, 1979; Harlem, 1979)
1908	Government Cut widened and deepened
1908	Rapids of the Miami River dynamited (Muir, 1953)
1910	4.25 mi of Miami Canal completed
1911	Miami Canal was 10 mi long
1912-1913	Other canals included Snapper Creek Canal, Cutler Canal, and the Coral Gables Waterway (Harlem, 1979)
1912	Collins Canal through part of Miami Beach
1913	Miami river dredged and material dumped on current site of Claughton Island (Gaby, 1990)
1914-1919	Channel built to Vizcaya
1924-5	Bakers Haulover completed (Toner, 1979)
1924	Haulover Cut was opened (Michel, 1976)
1925	Other smaller channels dug prior to 1925
1925?	Intracoastal Waterway (Michel, 1976)
1930s	River subjected to contamination from commercial activities and sewage
1934	Environmental concerns about the River begins.
1940s	Salt intrusion arrested but problems remain
1941	Houseboats ("shanties") removed from the River

Table 1. Significant events in Biscayne Bay (cont.).

BULKHEADING AND RELATED ACTIVITIES

1913-1914	Mangroves cut down in southern Miami Beach
1920	Large mangroves cut down in Miami Beach and swamps filled
1920s	Fisher Island shape changed by bulkheading and filling
1925	Bayview section of Miami Shores filled (Toner, 1979)
1925	Area east of Biscayne Blvd. filled to create Bayfront Park (Toner, 1979)
1950s	Southern one-fourth of Key Biscayne bulk-headed and filled
1970s	Dredge and fill activities at Fair Isle (Voss, 1974)

ISLANDS

1902	Lummus and Dodge islands (Chapman, 1993)
1905	Creation of Fisher Island (Toner, 1979)
1912	Belle Isle (Kleinberg, 1997)
1913	Miami river dredged and material dumped on current site of Claughton Island (Gaby, 1990)
1913	Flagler Monument Island when Carl Fisher merged two piles of dredge spoil (Kleinberg, 1997)
1915	Some roads built in Key Biscayne and Hurricane Harbor dredged
1916	Claughton Island purchased (Gaby, 1990)
1917	Star Island (Toner, 1979)
1918	Hibiscus Island (Toner, 1979)
1918	Palm Island (Toner, 1979)
1918-1922	Belle Isle built
1918-1922	Palm, Rivo-Alto, and Di Lido Islands (US Army Corps of Engineers, 1922)
1918-1922	Star Island (US Army Corps of Engineers, 1922)
1920s	Fisher Island shape changed by bulkheading and filling
1922-1925	Hibiscus, San Marino and San Marco
1922	Flagler monument built on spoil island
1923	Claughton Island bulkheaded and renamed Burlingame Island (Toner, 1979; Gaby, 1990)
1924	Fair Isle (Voss, 1974)
1925	Pelican Island (Isola Dilolando) outlined north of Venetian Islands (Kleinberg, 1989)
1930s	Islands of North Bay Village (Toner, 1979)
1943	Bay Harbor Islands (Toner, 1979)
1944	Pelican Island bought by the City of Miami Beach (Kleinberg, 1989)

CAUSEWAYS

1913	Collins Bridge (Toner, 1979)
1918	County Causeway (Kleinberg, 1989; Toner, 1979)
1925	Venetian Causeway replaced the old Collins Bridge (Michel, 1976; Toner, 1979; Kleinberg, 1997).
1928	79th Street Causeway (Toner, 1979)
1942	County Causeway renamed MacArthur Causeway (Kleinberg, 1989)
1943	Rickenbacker Causeway (Toner, 1979)
1951	Broad Causeway (Michel, 1976; Toner, 1979)
1960-1961	Julia Tuttle Causeway (Michel, 1976; Toner, 1979)

Table 1. Significant events in Biscayne Bay (cont.).

SEWER SYSTEM	
1950s	Elimination of discharge of raw sewage into the Bay
1956	Completion of sewage disposal system (Wilson, 1995; Stone and Suman, 1995)
1974-1981	Munisport landfill operations (Florida Department of Health and Rehabilitative Services, 1998)
1983	Munisport added to EPA Superfund list
1987	Serious problems encountered with Cross Bay line
1994	Cross Bay Line replaced (Swakon *et al.*, 1995)
POWER PLANTS	
1965	Turkey Point opened (Ho, 1998)
1967-1968	Fossil Fuel units began operation (Florida Power and Light, 1994)
1972-1973	Turkey Point nuclear units (Ho, 1998; Florida Power and Light, 1994)
1972-1973	Initial cooling canal operations (Thorhaug and Bach, 1973)
PORT OF MIAMI	
1896	Port of Miami opens (Miami-Dade County, 2000)
1920s	Port is primary hub for all shipping to South Florida (Miami-Dade County, 2000)
1920s	Passenger service to Baltimore and New York begins (Miami-Dade County, 2000)
1930s	Passenger service to Havana (Miami-Dade County, 2000)
WWII	US Navy assumes control of Port (Miami-Dade County, 2000)
1960	First phase of Dodge Island Seaport (Port of Miami) (Chapman, 1993)
1964	Dodge Island Seaport opens (Chapman, 1993)
1976	First port in history to record more than one million passengers in a year (Miami-Dade County, 2000)
1981	Port expanded to Lummus Island (Miami-Dade County, 2000)
1991	A record 3.9 million tons of cargo are handled in one year (Miami-Dade County, 2000)
1999	Royal Caribbean's Voyager of the Seas, the largest cruise ship ever constructed, is based at the Port (Miami-Dade County, 2000)
PARKS	
1948	Crandon Park
1967	Cape Florida State Park opens (Blank, 1996)
1960	City of Islandia incorporates (Shroeder, 1986)
1967	Dept. of the Interior purchases keys and Bay bottom around Elliott Key (Shroeder, 1986)
1967	Biscayne National Monument established (Shroeder, 1986)
1980	Biscayne National Monument expanded and renamed National Park (Shroeder, 1986)
1993	Soldier Key sold to the National Park Service (Dewar, 1993)

Table 1. Significant events in Biscayne Bay (cont.).

ARTIFICIAL REEFS	
1982	North Bayshore Park Reef (artificial reef)
1991	San Souci Reef (artificial reef)
1979	Pelican Harbor Reef (artificial reef)
1982	Julia Tuttle Artificial Reef (artificial reef)
1991	Brickell Area Reef (artificial reef)
1986	Rickenbacker Causeway Reef (artificial reef)
1984	Mercy Hospital Reef (artificial reef)
AVIATION	
Military	
1942	Construction of Richmond Naval Air Station
1943	Construction of Homestead Army Air Field
1945	Destruction of Richmond Naval Air Station during hurricane of 1945
1945	Homestead Army Air Field rendered inactive by hurricane of 1945
1955	Homestead reactivated as an Air Force Base
1992	Destruction of Homestead Air Force Base by hurricane Andrew
1993	Homestead reactivated as an Air Reserve Base
1999	Plans to convert the Homestead facilities to civilian use
Civilian	
1917	Red Arrow Flying Service begins operation (Chalk's International Airlines, 1999)
1917	Dinner Key served as a Naval Air Station (Florida State Photo Archive)
1919	Chalk's Flying Services begins operation (Chalk's International Airlines, 1999)
1920s	Lighter than air ships begin flights over South Florida
1926	Chalk's terminal built at Watson Island (Chalk's International Airlines, 1999)
1928	Dinner Key became the first customs entry airport of the US Atlantic mainland (Florida State Photo Archive)
1930s	Pan American World Airways purchased Dinner Key to use as home base for the trans-oceanic seaplane clippers (Florida State Photo Archive)
1932	Dinner Key seaplane basin dredged
1934	Pan American terminal built at Dinner Key (Kleinberg, 1989)
1939	Embry-Riddle School of Aviation begins operations in MacArthur Causeway (Mormino, 1997)
WWII	Pan American navigators served as instructors to US Army, US Navy, British and Canadian air forces at the Dinner Key facility (Florida State Photo Archive)
1945	Pan American operations out of Dinner Key cease (Kleinberg, 1989)
1954	Dinner Key facility became the City of Miami City Hall (Kleinberg, 1989)

Table 1. Significant events in Biscayne Bay (cont.).

STILTSVILLE	
1930s-1950s	Stiltsville construction (Semple, 1997; Williams, 1990)
1964, 1965	Hurricanes Cleo and Betsy destroy all but 2 dozen houses in Stiltsville (Williams, 1990)
1992	Hurricane Andrew destroys six of the remaining 13 houses in Stiltsville
1999	Stiltsville scheduled to be removed (Morgan, 1999)
2000	Stiltsville fate to be decided (Morgan, 1999)
ENVIRONMENTAL IMPORTANCE	
1938-1939	Sponge blight
1991	Biscayne Bay closed to sponge fisheries
1992	Sponge die-off
1958	"Milk" shrimp first described (Schmale, 1998)
1970s	"Milk" shrimp infestation
1970s	Federal environmental legislation
1930-1977	PCB use
1942	DDT comes into the market (Stetler, 1983)
1970s	DDT use banned (Stetler, 1983)
MISCELLANEOUS	
1896	East Coast Railroad reaches Miami
1916	Vizcaya built
1930s	Sealevel rise begins (Wanless *et al.*, 1994a)
1980s	Baynanza begins
1983	Christo Surrounded Islands
1998	Discovery of the Miami Circle at the entrance of the Miami River

Figure 5. Miami River at Brickell Point (1897). [Photo negative, black and white, 4 x 5 in. PR09460. Print Collection, Florida State Photo Archive. <http://fpc.dos.state.fl.us/>]

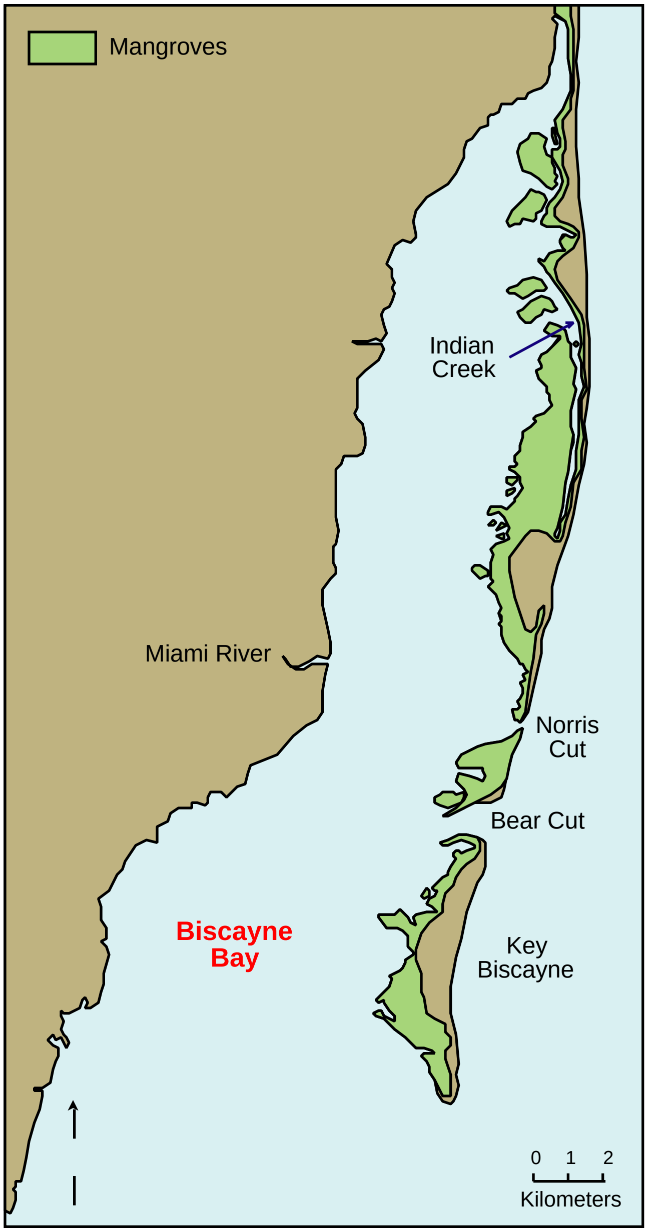

Figure 6. Northern Biscayne Bay in 1887. Adapted by Chardon (1978) from US Coast Survey charts. The area north of Norris Cut and south of Indian Creek may be evidence of a wash-over. [Redrawn from Chardon (1978).]

Chardon (1978) generated a chart of Biscayne Bay for 1887 from a series of US Coast Survey charts (Figure 6). By then, a hurricane had formed Norris Cut, probably the Hurricane of 1835 (Chardon, 1977), and the pass at Boca Ratones was no longer observed.

The Baedeker travelers guide of 1909 described Biscayne Bay as "a large sheet of clear salt water separated from the ocean by the first of the Florida Keys" (Baedeker, 1909).

James Buck visited South Florida in 1877 and wrote about his experiences (Buck, 1979 reprint). Although he did not recommend "a removal to this southeast coast" due to lack of communications and business opportunities, for an "invalid, suffer-ing from consumptive tendencies, bronchial complaints, or rheumatic affections, we think we can truly say that this bay is unsurpassed in the United States. Rheumatic troubles disappear in a surprising manner. It is a veritable Fountain of Youth."

Marjorie Stoneman Douglas recalls the Bay in 1915: "Oh, it was beautiful, so clear and clean. The color of the water changed with the nature of the bottom. It was pale green and dark blue and almost purple in spots, overflown by flocks of white birds. In the distance, the flocks wheeled and turned, flashing white in the sunshine" (Whited, 1986).

H. W. Hoover, heir to the vacuum cleaner fortune, observed in the 1920s, "Every single boat out in the ocean was escorted by three or four porpoises. I remember black clouds of mosquitoes rising out of the mangroves. I remember pulling shrimp out of the bay by the bucketful, and looking down Government Cut and seeing the sea bottom covered with what looked like a living black carpet. It was a solid carpet of lobster" (Zaneski, 1997).

Hoping to attract northerners to the mild climate and tropical conditions of the coast, Henry Flagler decided to extend his Florida East Coast Railway route to Miami. The first train arrived in the city in 1896. Flagler built the Royal Palm Hotel in 1897 on Brickell Point, between the

Figure 7. View of Royal Palm Hotel, the Miami River and Brickell Point (19--?). (View is towards the east.) [Postcard. Color (9 x 14 cm). PC2092. Postcard Collection, Florida State Photo Archive. <http://fpc.dos.state.fl.us/>]

Bay shore and the entrance to the Miami River, as a resort at the end of the railway line (Figure 7). Miami began to grow around the hotel and the City was incorporated in 1896.[Δ]

Native Americans of the Seminole tribe, who occupied much of South Florida since well before the arrival of Columbus, were familiar visitors to Miami (Rainbolt, 1924?). They frequently traveled down the Miami River to Biscayne Bay in canoes and camped by the river banks. Miami is the Seminole word for "sweet water" and it was the Seminole name for the Miami River.

One of the features of the Miami area and Biscayne Bay at this time was the presence of freshwater springs described as early as 1838. One of the best known springs was the Punch Bowl, located in the 3000 block of Brickell Avenue, very close to the Bay shore (Kleinberg, 1989).

> "Springs of good water are common and wells are to be had by a comparatively small amount of digging. This latter may often be done with axes, through the soft rock, so that the well is already stoned, when the water is reached after a few feet of cutting. Many springs burst up through the bottom of the bay, and we see fresh water boiling up through the salt."
>
> J. Buck, 1877 (Buck, reprinted 1979)

[Δ] The city was incorporated and officers elected in a failed pool room (Kleinberg, 1989). The number of votes cast exceeded the number of voters present. It was questionable that the 312 voters would have fit into the pool hall.

Freshwater flow stopped probably as the result of the lowered water table when the drainage canals were built.* The location of the former springs within the Bay proper is not known. The Punch Bowl is thought to be off what is now Peacock Park. The offshore springs were about 1.2 Km from the Cutler area (Reich, 1998). No landmarks can be identified in one (if not the only) photograph known of the site (Figure 8).

Figure 8. Mariners installed a pipe and built a platform to make water from a fresh spring in Biscayne Bay. [Photograph 117D. Munroe Collection, Historical Association of Southern Florida.]

As the population of South Florida increased at the turn of the century so did the need for dry land, and canals were built to drain the coastal wetlands beginning in 1903. The construction of the canals changed the hydrography of South Florida eventually resulting in reduced water flow to the Everglades and Florida Bay (Halley *et al.*, 1998; Reich, 1998; and others).

In 1915, E. G. Sewell advertised the City of Miami in newspapers and magazines and attracted many tourists. That season all the area hotels were filled. By the season of 1917-1918, over 10,000 people were turned away due to lack of hotel space (Rainbolt, 1924?). As tourism rose so did the number of permanent residents. The growth led to accelerated development of the Miami/Miami Beach area, that lasted until the middle of the 1920s.

Development included simultaneous destruction of natural shorelines, cutting down of mangroves (Figure 9), construction of channels, cuts and artificial islands (Figures 10-12), filling in of tidal flats (Figure 11), bulkheading of shoreline, construction of bridges and causeways (Figure 13), construction of drainage canals, and building on land. Waterfront land was created by artificial islands composed of dredged Bay bottom material, a process which removed benthic cover from large areas of the Bay bottom. There was no legislation at that time to protect the Bay's natural resources or ecosystem.

Port facilities were in the Miami River and were reached from the Atlantic Ocean via a channel south of Cape Florida and running north to the River entrance. The first channel from Cape Florida to the Miami River was dug by the Florida East Coast Railway Company. In 1897, the river dockage was abandoned and a new one built adjacent to the railroad line. There were other small channels from the Bay to the mainland, including the one built to allow ship access to Vizcaya (see Section 6.3.5).*

* Freshwater springs have been observed intermittently in Biscayne Bay since the passage of Hurricane Andrew in 1992. The springs were last seen during the 1960s. The location of the springs has not been recorded (H. Wanless, University of Miami, personal communication, 2000).

* Vizcaya is an Italian Renaissance-style villa and formal gardens built in 1916 as the winter residence of industrialist James Deering. Vizcaya is one of only two officially designated National Historic Landmarks in Miami-Dade County. The site is on the bay shore north of Dinner Key.

Figure 9. Cutting down mangrove forests (1914). [Glass transparency, black and white (3.25 x 4 in). Lc405. La Coe Collection, Florida State Photo Archive. <http://fpc.dos.state.fl.us/>]

Figure 10. Fisher Island, Terminal Island and Government Cut (1918). (View is east towards the Atlantic Ocean.) [Photograph, black and white (5 x 7 in). WE164. Wendler Collection, Florida State Photo Archive. <http://fpc.dos.state.fl.us/>]

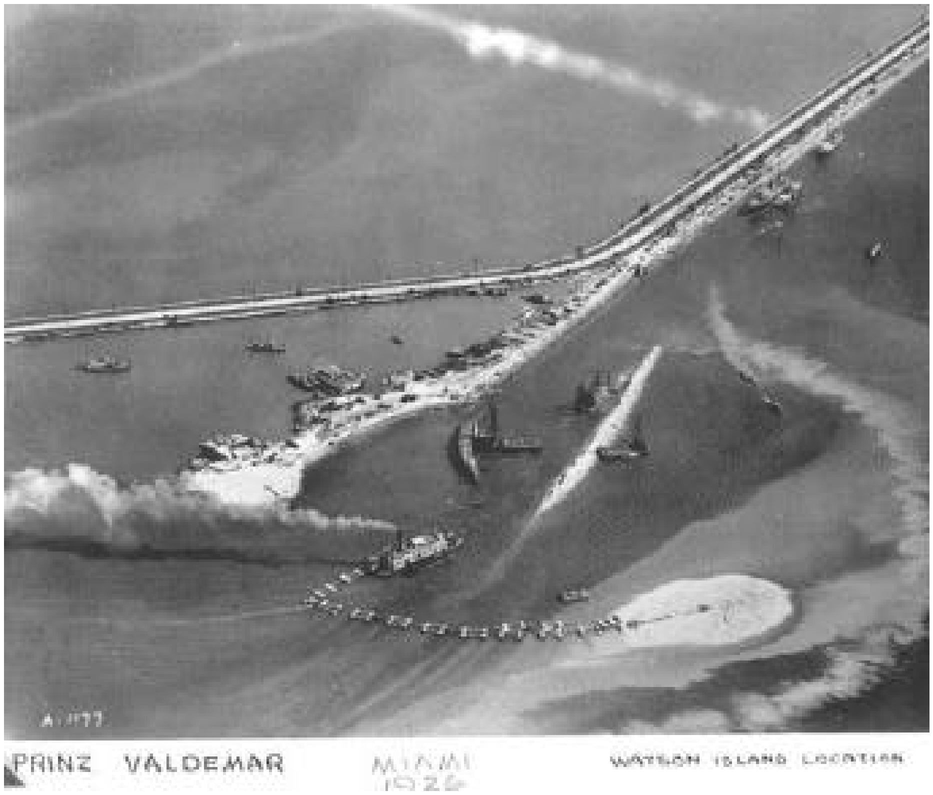

Figure 11. Prinz Valdemar capsized in the ship channel (Government Cut) (1925). (Note dredging activities in the area.) [Photo negative, black and white (4 x 5 in). N040770. General Collection, Florida State Photo Archive. <http://fpc.dos.state.fl.us/>]

Figure 12. Aerial photograph of Haulover Cut, Miami Beach (1927). (Biscayne Bay is at the top of the photograph and Atlantic Ocean is at the bottom.(Photo negative, black and white (4 x 5 in). N035204. General Collection, Florida State Photo Archive. <http://fpc.dos.state.fl.us/>]

Figure 13. Aerial view of Miami Causeway and Star Island (1922). (The Venetian Islands are to the left.) [Photograph, black and white (8 x 10 in). PR06842. Print Collections, Florida State Photo Archive. <http://fpc.dos.state.fl.us/>]

In 1902, Government Cut was constructed between Miami Beach and Norris Cut to provide access to the Miami River that avoided the lengthy trip south and around Cape Florida (Figure 10). Government cut was originally 18 ft deep and 60 ft wide, and has undergone a series of widening and deepening projects since that time.

The islands created south of the channel with dredge spoil during the construction of Government Cut were named Dodge Island and Lummus Island (Chapman, 1993). Fisher Island, the southern end of the Miami Beach barrier island, was also created at this time and was expanded with dredge spoil from the construction of the Cut. Dredged material was placed in a spoil bank on the north side of the channel, eventually becoming the MacArthur Causeway (Michel, 1976). As a result of tidal flow through the new Cut, the beaches of Fisher Island, Virginia Key and Key Biscayne experienced beach erosion (Michel, 1976).

An access channel was built to Vizcaya, the Italian Renaissance style villa built in 1916 on the mainland shore of Biscayne Bay, just south of the present day Rickenbacker Causeway Other small channels continued to be built in the Bay.

Fisher Island was once the southern-most part of Miami Beach before it was severed by the construction of Government Cut in 1905 (Hannan *et al.* 1972) (Figure 10) (see Section 6.2.5). The island was known as Rat Island or Peninsula Island. The present form of the island is the result of bulkheading and filling during the 1920s and the island was renamed after this developer, Carl Fisher. He planned to develop the island as a resort but the hurricane of 1926 brought this to an end. Since its creation, Fisher Island has undergone a series of natural and anthropogenic changes and is currently the site of high rise exclusive residential buildings. Fisher Island is only accessible by boat.

Belle Isle, one of the natural islands in North Bay and the easternmost of the Venetian Islands, was originally known as Bull's Island (Kleinberg, 1997) (see Section 6.2.7). It was little more than a muddy tidal flat when John Collins built a bridge to it in 1912. The successor to that bridge is now the Venetian Causeway The adjacent tidal flat was filled to form an island by the aforementioned Carl Fisher and renamed Belle Isle. Between 1918 and 1922, Fisher expanded the island to 32 acres and sold lots to mostly millionaires.

The first bridge to Miami Beach was built in 1913 by John Collins, and Carl Fisher began development of Miami Beach as a tourist resort. This led to the destruction of the mangrove forests of the barrier island and the bulkheading of the shoreline on the western side of the Bay.

Star Island was the first true fill island totally constructed by bulkheading a previously open water area (US Army Corps of Engineers, 1922).

Aviation has been a part of South Florida since the early part of the 20th century (Ridings, 1985). In 1917, over a million dollars were spent building the Dinner Key Aero Station. The Aero Gunners' School for the Army at Chapman Field and the Marine Aviation Station at Curtiss Field were located in the Miami area (Rainbolt, 1924?). Flying boats flew regular routes from Miami to the Caribbean and Dinner Key became the first customs entry airport of the US Atlantic mainland. Flying boats and lighter than air ships have operated in the Bay since that time. (See Section 9.1.)

Figure 14. Shipyard with trains, Biscayne Blvd. (192-). (Note seaplanes on the lower left. Biscayne Bay is to the right of the image.) [Photograph, black and white (5 x 7 in). PR06837. Print Collection, Florida State Photo Archive. <http://fpc.dos.state.fl.us/>]

Figure 15. Bayside NE 11th Street (19--). Biscayne Boulevard in the foreground. (MacArthur Causeway, Chalks Aviation, Flamingo Hotel, Miami Harbor and a lighter than air ship in the background. Biscayne Bay is towards the upper left of the image.) [Photograph by H. Wolfe. Photo negative, black and white (4 x 5 in). N038736. General Collection, Florida State Photo Archive. <http://fpc.dos.state.fl.us/>]

4.2. 1920s

The development of Miami/Miami Beach continued during the decade of the 1920s until the Hurricane of 1926, the Land Boom bust and the stock market crash of 1929.

During the 1920s Land Boom, fortunes were being made and more land was needed. "Water acreage" of Biscayne Bay was sold even before islands were built (Rainbolt, 1924?). After selecting a lot, the customer was rowed out to the appropriate location in the Bay and "shown the particular wave where his property" was located. Any disputes were soon 'washed out". When enough orders for "sea lots" accumulated, building began. Two photographs of Biscayne Bay shoreline during the mid 1920s show the degree of activity taking place in the area (Figures 14 and 15).

The Venetian Islands are artificial islands located between Belle Isle and the mainland. Their characteristic shape makes them very recognizable. San Marco, San Marino, DiLido and Rivo Alto were build in rapid succession during the 1920s and lots on these islands were quickly sold (Figure 16). The Venetian Islands were to be extended north of DiLido Island, with six additional islands to be built through the center of the Bay to Miami Shores, close to the location of the present day 79th Street Causeway (Kleinberg, 1989). However at a 1925 Miami Chamber of Commerce meeting many objected to the destruction of the beauty of the Bay and set the precedent for the Chamber to prevent further "mutilation of the waterway". Developers persuaded the Chamber to proceed with the construction plans by arguing that the Bay was "now of no utility". Sales of lots in the unbuilt islands began in 1925. Isola Dilolando, the island planned north of Di Lido Island, now known as Pelican Island, was marked out with pilings (see Section 6.2.6). The hurricane of 1926, the Land Boom Bust and the Depression ended the plans.

The removal of dredge material for the construction of islands and causeways created an 8-foot deep borrow channel on the eastern side of the Bay. There was an 8-foot limitation for

Figure 16. The newly built Venetian Islands (1925). [Photograph, black and white (5 x 7 in). WE163. Wendler Collection, Florida State Photo Archive. <http://fpc.dos.state.fl.us/>]

dredges at that time. Only a series of pits were made on the western side of the Bay since land filling activities were not continuous. The 8-foot deep Intracoastal Waterway was created at this time (Michel, 1976).

In 1923, spoil dredged from the entrance to the Miami River was used to create Burlingame Island, now known as Claughton Island (Toner, 1979).

Bakers Haulover Cut was opened in 1924 (Michel, 1976). The results were changes in the water circulation of North Bay and deterioration of the beaches of Miami Beach. It is not clear why the Haulover Cut was made (see Section 6.1.2.5).

The 79th Street Causeway was constructed at about this time. Fortuitously its location is close to the nodal point where tidal flow from the north and south meet in central Biscayne Bay so water movement was not seriously affected by construction (Michel, 1976).

Relocation of the Port of Miami created controversy. As early as the 1920s, a proposal was made to move the Port from its location on the Miami River off Biscayne Blvd. in downtown Miami to Dodge Island, an island spanning the width of the Bay (Chapman, 1993) (Figure 17). The City of Miami could not reach a decision regarding the location of the Port and it remained on Biscayne Blvd. (see Section 6.2.4). The plan re-surfaced in the 1950s and this time led to the creation of the New Port of Miami in the 1960s.

Shipping activity on the bayfront was an indicator of the intense effort required to keep up with an accelerating demand for goods and materials of the Land Boom (McIver, 1987). A photograph of the port area in Biscayne Blvd. shows several types of vessels, trains, cars and seaplanes in proximity to each other (Figure 14). In 1925, incoming railway shipments of most kinds of freight had to be stopped to repair overworked equipment and to add more track (McIver, 1987; Chapman, 1993). By winter, 7,600 southbound freight cars were sitting outside Jacksonville. By the Christmas holidays, 32 schooners, trying to help break the freight impasse, were in port, and forty more schooners were on their way to Biscayne Bay. This

Figure 17. Miami River, Royal Palm Hotel, Henrietta Towers and Granada Apartments (192-). (Biscayne Bay is to the right of the image. Port facilities are north of the Royal Palm Hotel, in the upper center of the image.) [Postcard, color (9 x 14 cm.). PC2083. Postcard Collection, Florida State Photo Archive. <http://fpc.dos.state.fl.us/>]

Figure 18. Miami Beach during the passage of the Hurricane of 1926. [Photonegative, black and white, 4 x 5 in. N045921. General Collection, Florida State Photo Archive. <http://fpc.dos.state.fl.us/>]

Figure 19. Bay Shore Drive after hurricane (1926). [Postcard, black and white (9 x 14 cm). PC2134. Print Collection, Florida State Photo Archive. <http://fpc.dos.state.fl.us/>]

bottleneck was made all the worse because the PRINZ VALDEMAR (a 241-feet Danish barkentine rigged as a floating hotel), the largest sailing vessel ever to enter the Miami Harbor, had ran aground in the late fall of 1925 in Government Cut, and overturned due to high winds on January of 1926 blocking the channel for several weeks. Several large vessels were unable to leave Biscayne Bay (Figure 11).[*]

At about this time, the Land Boom financial dealings came under scrutiny by the federal government, and the area was hit by the Hurricane of 1926, one of the most destructive hurricanes ever to affect Biscayne Bay (Figure 18).

The Hurricane of 1926 is rated four on the Saffir/Simpson scale (see Section 5.3.2). More than 300,000 people living in the affected area were unprepared for the storm and unaware of the potential danger of hurricanes. The hurricane reached South Florida September 17-18, 1926. Passage lasted approximately 11 hours. The hurricane moved several large vessels onto dry land (Figure 19). Many others were sunk, including the dredge that was supposed to deepen Government Cut (Chapman, 1993).[Δ] Damage to buildings was severe. The newly built bridge across Bakers Haulover Cut became unusable as shorelines on either side were washed away (Figure 20 and 21). Photographs and stories of the aftermath reached northern cities and destroyed the image of South Florida as a paradise and Fountain of Youth. The pace of development in the area slowed down. Photographs, newspaper articles and various government proclamations can be found in Reardon (1986).

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[*] The PRINZ VALDEMAR was eventually refloated and beached at 6th Street and Biscayne Blvd. In 1928 she was converted into a floating aquarium (Boldrick, 1975). In 1937 a steel bulkhead was placed around the vessel and it was converted into a building. It served as an Navy officer's club during World War II. It was declared an eyesore in 1949 and dismantled in 1952.

[Δ] The PRINZ VALDEMAR was one, if not the only ship to survive the hurricane with little damage (Chapman, 1993; Boldrick, 1975).

Figure 20. Remains of the bridge at Bakers Haulover Cut after the Hurricane of 1926. (See Figure 12 for aerial photograph of bridge before the hurricane.) [Photo negative, black and white 4 x 5 in. N031942. General collection, Florida State Photo Archive. <http://fpc.dos.state.fl.us/>]

Figure 21. Aerial view Bakers Haulover Cut after the Hurricane of 1926 (December 1, 1927). (See Figure 12 for aerial photograph of bridge before the hurricane. Biscayne Bay is at the top of the image and Miami Beach is at the bottom. Note erosion of the sides of the Cut. Bridge destroyed during the hurricane has been removed.) [R. B. Hoit, photographer. Photo negative, black and white, 4 x 5 in. N035203 . General Collection, Florida State Photo Archive. <http://fpc.dos.state.fl.us/>]

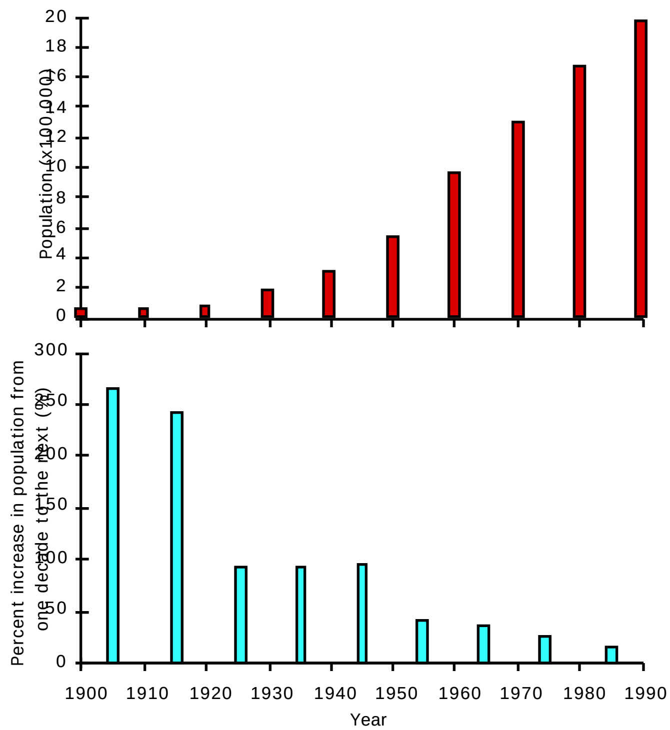


Figure 22. Numbers of persons in Dade County from 1900 to 1990 [Andriot (1983), and Bureau of the Census (1994)].

The changes that occurred in and around Biscayne Bay during the 1920s continued to affect the ecosystem well into the 1980s. While the largest percent increase in population took place before 1930 (Figure 22), population continued to increase well into the 1990s.

The significant changes to the bottom and shoreline of the Bay prior to 1930 were quantified by Harlem (1979) (Figures 23 and 24). More than 75% of the land from Broad Causeway to the Rickenbacker Causeway was developed by this time. Approximately 75% of the Bay bottom from Venetian Causeway to MacArthur Causeway had been dredged or disturbed by 1925, and little benthic vegetation remained in this area. The years of major dredge and fill projects in North Bay are shown in Figure 25. Most major changes occurred prior to the 1930s. The exception is the construction and expansion of the Port of Miami in the 1960s and 1970s.

4.3. 1930s

During the 1930s, few changes were noted in Biscayne Bay. Bay topography shows little change from 1920s conditions except for the presence of spoil islands next to the ship channel (Figure 26).

The first Miami cruise ship began regular service between Cuba and Miami in 1931 and passenger service between Miami and other US ports continued (Chapman, 1993). Further dredging of the ship channel began to accommodate more passenger traffic.

Commercial aviation continued to grow in the Miami area. Pan American World Airways started service in 1927 with a flight from Key West to Havana. The airline purchased Dinner Key in

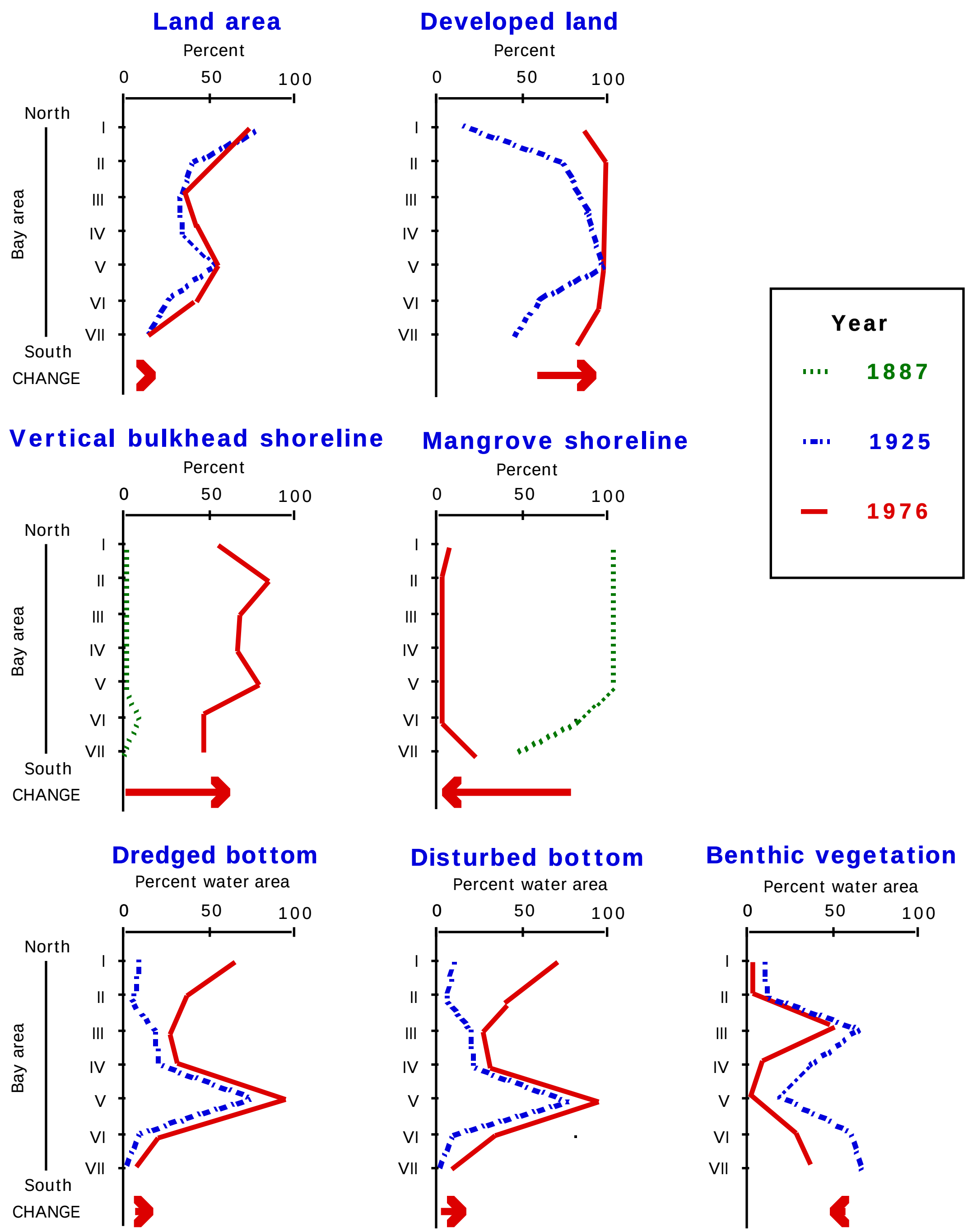


Figure 23. Percent change between 1887 or 1925 and 1976 of various characteristics of Biscayne Bay. (Redrawn from Harlem, 1976.) [Area I: North of Broad Cswy; Area II: from Broad to 79th St. Causeway; Area III: from 79th St. Causeway to Julia Tuttle Causeway; Area IV: from Julia Tuttle Causeway to Venetian Causeway; Area V: from Venetian Causeway to MacArthur Causeway; Area VI: from MacArthur Causeway to Rickenbacker Causeway; Area VII: from Rickenbacker Causeway south to the Safety Valve.]

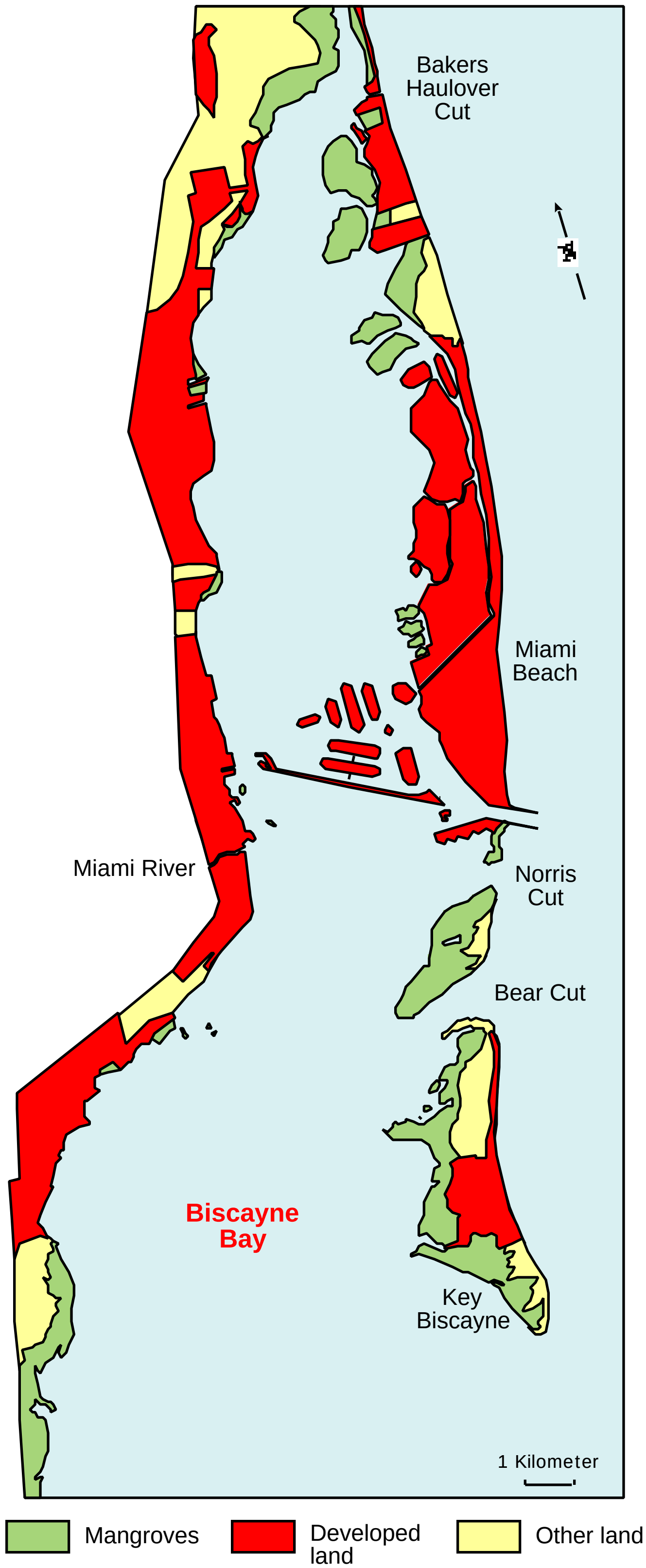


Figure 24. Developed land in northern Biscayne Bay in 1925. [Causeways not shown. Redrawn from Harlem (1979).]

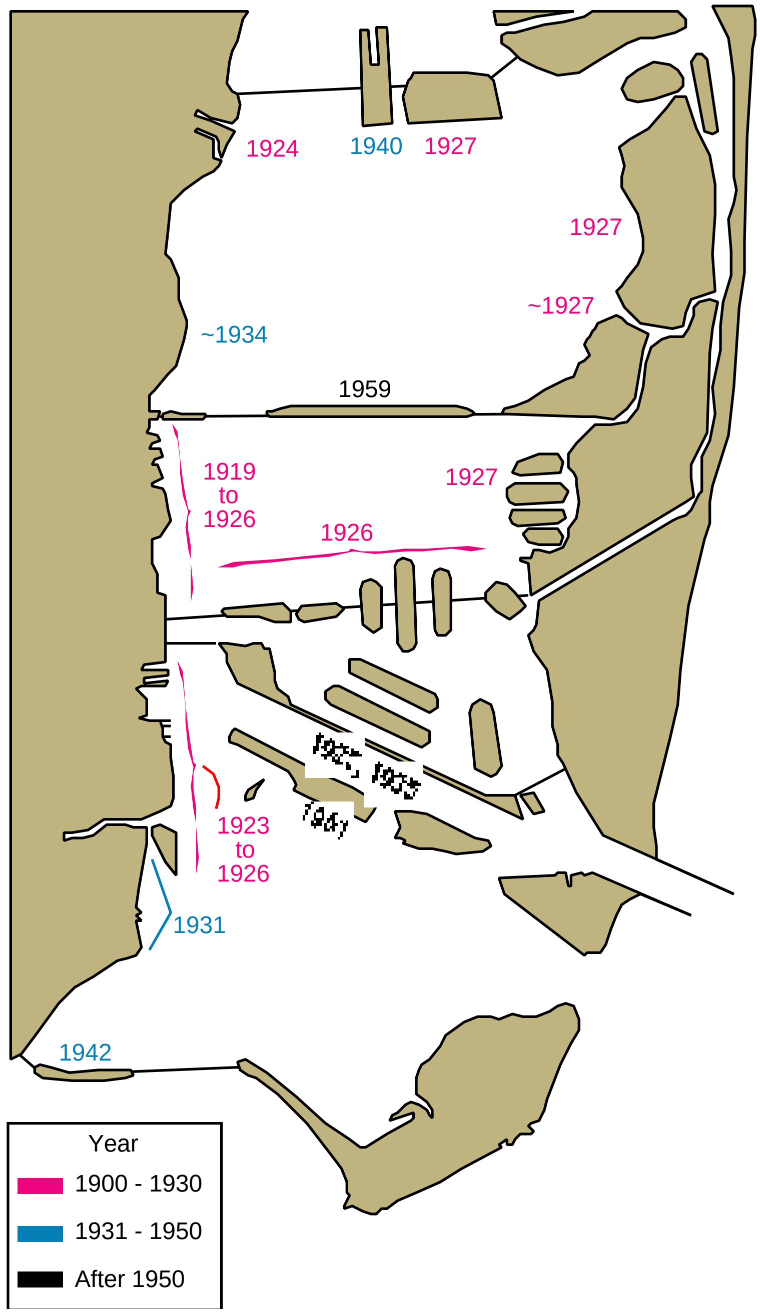


Figure 25. Years of major dredge and fill projects prior to 1970. [Redrawn from McNulty (1970).]

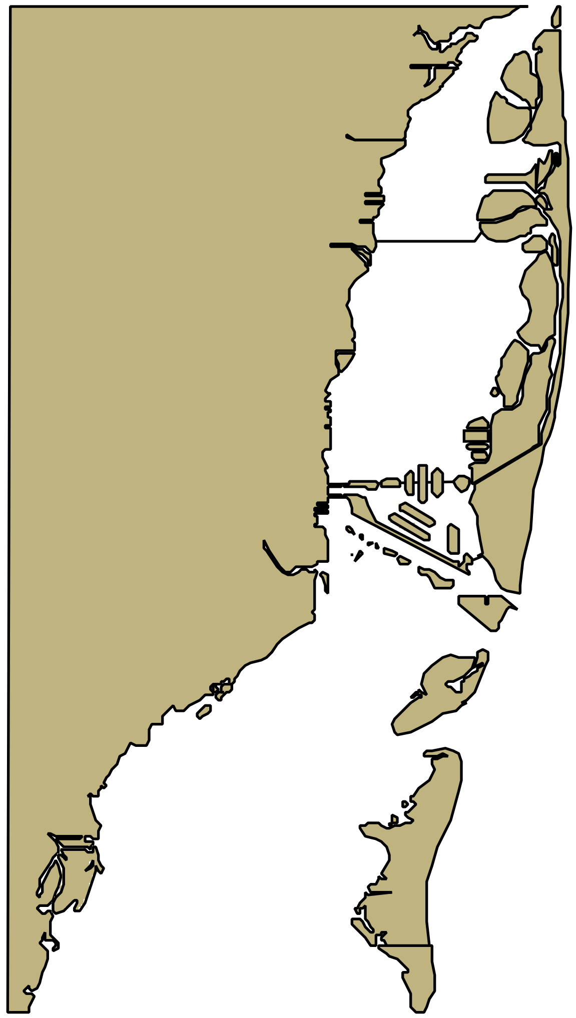


Figure 26. Biscayne Bay in the late 1930s. [Re-drawn from Wakefield (1939)].

1930 to use as home base for the trans-oceanic seaplane clippers (Figure 27). By 1935, Pan American was connecting Miami with 32 Central and South American countries. During 1938, its peak year, more than 50,000 passengers flowed through the Dinner Key facilities, making Miami the leading American city as a port of entry for international air travel at that time (Florida State Photo Archive caption for image PR00568. <http://fpc.dos.state.fl.us/>). Also during the 1930s, Eastern Airlines was flying daily between Miami, New York, Chicago and intermediate cities.

By the 1930s, sea level began to rise as evidenced by tide gauge data from Key West (Wanless *et al.*, 1994a) (Figure IV.2 Appendix IV).

In the 1930s, bacteriological pollution was found from North Bay to Tahiti Beach (located directly east across the Bay from the Safety Valve) and was traced to the City of Miami, the greater part of which had sanitary sewers discharging untreated waste (Wakefield, 1939). Twenty-eight of these sewers emptied into the Miami River. Thirty-six sewers emptied directly into the Bay and by far the greater number and the larger sewers were in the central

Figure 27. Pan American Airport at Dinner Key (193-). [Postcard, black and white (9 x 14 cm). PC2100. Postcard Collection, Florida State Photo Archive.<http://fpc.dos.state.fl.us/>]

part of the City. Between 25th Road and Northeast 55th Terrace, a distance of approximately five and one-half miles, the sewage from about 7,900 acres of densely-built city entered the Bay and Miami River through 59 separate outfalls. There were no known sanitary sewers, either private or public, entering Biscayne Bay from Miami Beach. Coral Gables had no public sewer system and depended upon private septic tanks and drainfields. Pollution from ships also contributed to the contamination. Pollution was found only close to shore and the degree of pollution decreased rapidly with distance from the Miami River or sewer outfalls. The area between 79th Street Causeway and a line between Dinner Key and Cape Florida received constant pollution which in many places reached high concentrations. Wakefield recommended that this area be closed to swimming and the citizens warned not to use the Bay in this area.

4.4. 1940s

World War II brought an economic boom to Miami, with construction, aviation and tourism as major industries. A few months after the attack of Pearl Harbor, German submarines sank several ships near the coast of Florida. In 1942, the Mexican oil tanker POTRERO DEL LLANO was torpedoed near Fowey Rocks (east of the Safety Valve) and sunk (Mormino, 1997; Kleinberg, 1989).[◊] Thirteen crew members of a total of 35 perished. The glow of the burning tanker could be seen from Miami. Due to U-boat activity just off the coast, all cruise activity and coast-wide waterborne commerce stopped (Chapman, 1993). The Port of Miami came under the control of the US Navy and used as a training camp. The Gulf Sea Frontier and Seventh Naval

[◊] Mexico was a neutral country at the time of the sinking of the LLANO. As a result of the attack, Mexico declared war on Germany two weeks later (Kleinberg, 1989).

Figure 28. Pilots in training at the Pan American World Airways facilities in Dinner Key (194-). (Note seaplanes.] [PR00559. Photograph, black and white (8 x 10 in.). Print Collection, Florida State Photo Archive.<http://fpc.dos.state.fl.us/>]

District headquarters were set up in Miami, the Submarine Chaser Training Center was established, and a U.S. Naval Air Station to house and service blimps was constructed. Many cruise ships were converted into troop transports. Miami and Miami Beach hotels were used as barracks for training and rehabilitation of service personnel. Private and fishing vessels were repainted and outfitted with .50 caliber machine guns and their owners joined the Coast Guard Reserves to assist in patrolling the waters off South Florida (Mormino, 1997). Although this Coast Guard Auxiliary was referred to as The Cockleshell Navy and the Hooligan Navy, they were credited with reducing U-boat activity.

Pan American Airways' veteran navigators served as instructors in the navigation school at Dinner Key to US Army, US Navy, British and Canadian air forces at the Dinner Key facility (Figure 28) (Florida State Photo Archive caption for image PR00559). Biscayne Bay was used to train aviation and Navy personnel.

In 1942, the County Causeway was renamed MacArthur Causeway (Kleinberg, 1989). The Rickenbacker Cswy, connecting Miami with Key Biscayne, was built in 1943 (Toner, 1979).

The Bay Harbor Islands were built in 1943 (Toner, 1979). Pelican Island was bought by the City of Miami Beach in 1944 (Kleinberg, 1989).

New parks were established including: Crandon Park, Cape Florida State Recreation Area, Biscayne National Park, and Everglades National Park.

Tourism gave birth to the cruise ship industry and today Miami is the "Cruise Ship Capital of the World" with 3.5 million passengers departing annually from The Port of Miami.

Construction of Homestead Air Force Base began during World War II to serve as a maintenance stopover point for aircraft being ferried to the Caribbean and North Africa (see Section 6.4.1.) Construction of the Richmond Naval Air Station south of Miami took place in 1942. The Station was the Navy's largest Airship Station, short of the one in Lakehurst (Friends of Naval Air Station- Richmond, 2000) (see Section 6.4.2).

The temporary residence in South Florida of thousands of service personnel introduced the area as a pleasant place to live and after the war many returned to South Florida as permanent residents.

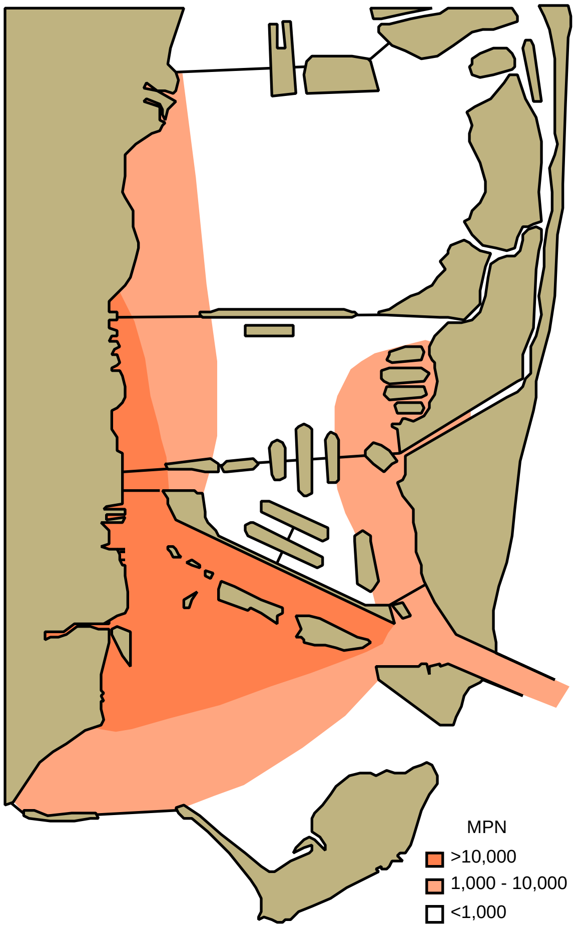
After the war, control of the Port of Miami was returned to the City of Miami. By the 1950s, the City recognized that the port site on Biscayne Blvd. could not be expanded further and another site had to be found. During the post-war era, the cruise industry based in the Port of Miami began to expand.

During the 1940s, a faunal shift occured in Manatee Bay indicating change from euhaline to polyhaline conditions present since the 1900s to a highly fluctuating annual salinity conditions with episodic periods of hypersalinity (Ishman *et al.*, 1998).

Environmental conditions in Biscayne Bay continued to deteriorate. By the mid 1940s, Hoover's idyllic Bay was in decline. Black coral sea fans, stone crabs and pompano were dying off (Zaneski, 1997). Development of Miami Beach and continued construction of man-made islands were fouling the Bay with suspended material and raw sewage. "A boat trip in the bay and out the main channel gives the visitor a chance to contrast the dark brown-gray polluted water near the city with the beautiful blue-green ocean water", a state sanitary engineer observed in 1949 (quoted in Iverson, 1979).

Up to the late 1940s, raw sewage was discharged directly into the Bay and the Miami River. The levels of contamination became so high that recommendations were made that contact with

Figure 29. View of causeway connecting Miami with Miami Beach from the Goodyear Blimp (194-). (Government Cut is on the right of the image. The spoil islands that became Dodge Island are to the left of the Cut.) [Photograph, black and white (8 x 10 in). PR06876. Print Collections, Florida State Photo Archive. <http://fpc.dos.state.fl.us/>]



Bay water be avoided thus threatening the tourist industry (Minkin, 1949; Moore *et al.*, 1955) (Figure 30). In response to public demands, the Virginia Key sewage plant was constructed, and public outfalls to the river and the Bay were sealed.

In September 1945, a massive hurricane passed through the area (Figure 31). The center passed almost directly over Homestead Army Air Base and Richmond NAS. The estimated maximum winds were approximately 275 kph on the east side of the storm (Gentry, 1974). Property damage in Dade County was $50 million. Because of destruction caused by the storm, Homestead Army Air Base was shut down in December of that year.

Salt water intrusion into the highly permeable Biscayne aquifer became significant (Figure 32). In 1945 salinity control dams were installed in most of the canals in the Miami area as barriers against further encroachment (Leach and Grantham, 1966).

Figure 30. Distribution of mean coliform bacteria in 1949 (unpublished report by Minkin (1949). [Redrawn from McNulty (1970).]

Figure 31. Wind-driven waves threaten to inundate homes. (American Red Cross, September, 1945. NOAA Photo Collection, NOAA Central Library, Silver Spring, MD. <http://www.photolib.noaa.gov/lb_images/historic/nws/wea00404.htm>.)

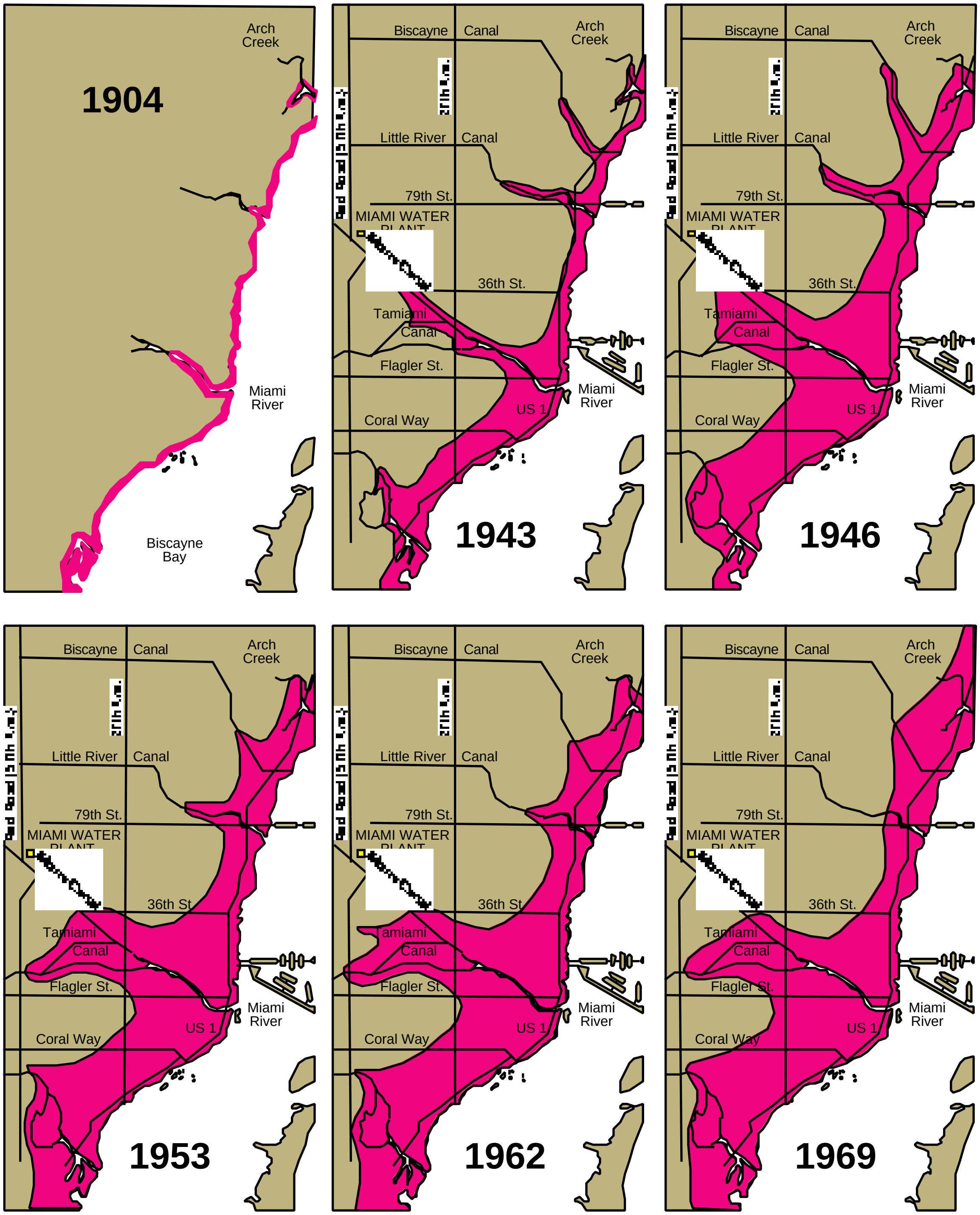


Figure 32. Seawater intrusion at the base of the Biscayne aquifer. [Redrawn from Leach and Grantham (1966) based on the work of Parker *et al.* (1955) and Kohout (1961).]

Figure 33. The newly built Rickenbacker Causeway between Key Biscayne, Virginia Key and Miami (194-). [Miami and the entrance to the causeway are at the top of the image. Key Biscayne is at the bottom. Virginia Key is the land mass in the lower middle. Presently UM/RSMAS and NOAA facilities on Virginia Key are to the left and right of the causeway in this view.] [Postcard, postmarked 1949, black and white (9 x 14 cm). PC2080. Postcard Collection, Florida State Photo Archive. <http://fpc.dos.state.fl.us/>]

4.5. 1950s

The decade of the 1950s brought a population increase and urban expansion as many servicemen who were stationed in the area during World War II returned to South Florida (Figure 22). The physical shape of Biscayne Bay did not change much during the previous decade (Figure 34).

Broad Causeway was constructed in 1951 (Michel, 1976). This causeway restricted the tidal exchange in North Bay. No significant borrow pits are associated with the construction of this causeway.

In 1959, Dodge Island was chosen as the site of the Port of Miami (Dodge Island Seaport) by Metro-Dade County. Construction began on the new facilities (Chapman, 1993).*

Over 80 ha of wetlands were destroyed in southern Key Biscayne through dredge and fill operations associated with failed developments (Milano, 2000). These wetlands were replaced with Australian pines which were destroyed by Hurricane Andrew.

The Dinner Key airport facility became the City of Miami City Hall in 1954 (Kleinberg, 1989)

* The year 1956 is listed in the Miami-Dade County web site (Miami-Dade County, 2000).

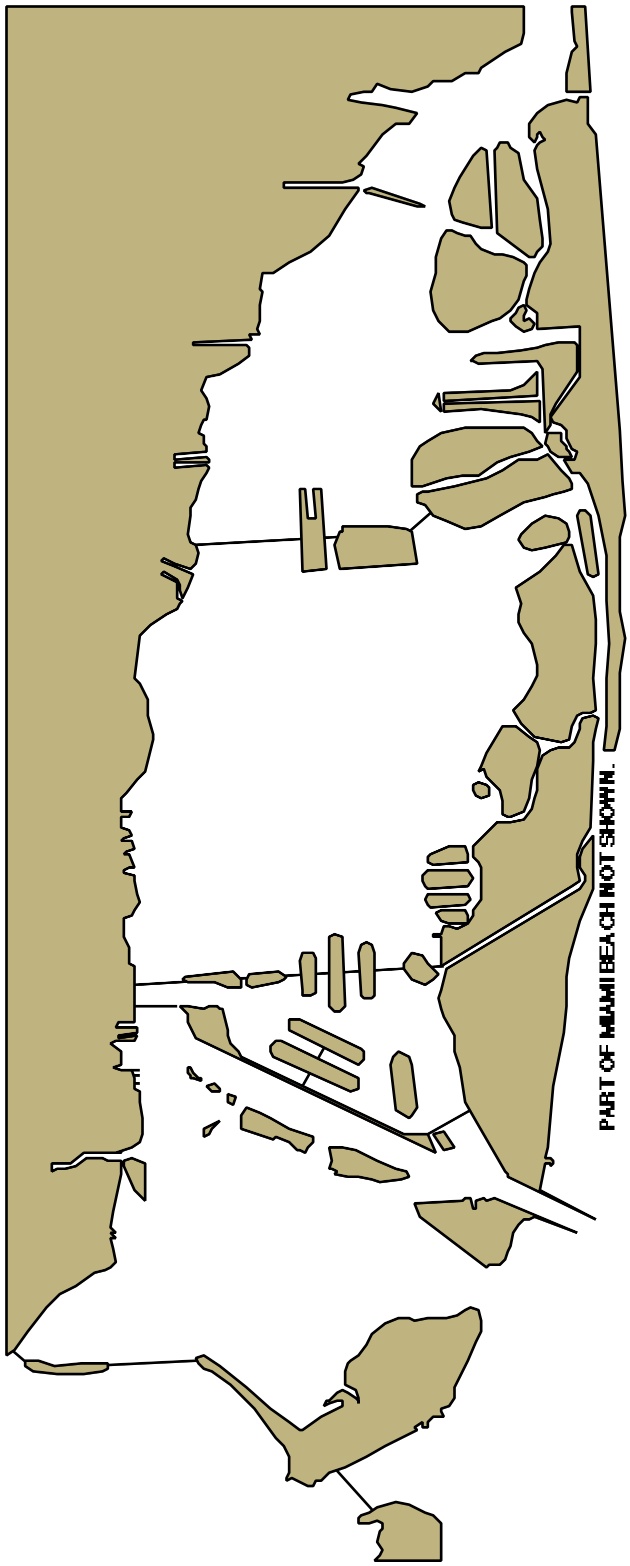


Figure 34. Biscayne Bay in the 1950s. [Redrawn from Moore *at al.* (1955).]

During the 1950s, the number of outfalls was reduced and the level of coliform bacteria in Biscayne Bay waters declined. McNulty (1970) compared the benthos, sediment, plankton, and fouling organisms of northern Biscayne Bay before (1956) and after (1960-1961) pollution abatement. Care was taken to use the same sampling techniques at many of the same stations sampled in 1956 before pollution abatement measures were instituted. Pollution came from the 136 to 227 million liters per day of untreated domestic sewage. Four years after abatement certain changes were noted. Populations of benthic macro invertebrates in the area near the City of Miami and the Miami River declined from abnormally large numbers of species and individuals to normal numbers of each. In hard sandy bottoms adjacent to outfalls, numbers of species and numbers of individuals increased. In poorly flushed waters, volumes of zooplankton decreased to about one-half the pre-abatement values. Abundance of amphipod tubes declined. Populations of other fouling organisms remained about the same. There was no evidence of improved commercial and sports fishing.

Due to abnormally high river water discharge in 1954, the pollution situation was comparable to that of 1949. Pollution was less severe than expected (Hela *et al.,* 1957).

The area from the mouth of the Miami River north to the west end of the MacArthur Causeway was expected to remain polluted until major changes were made to contaminant input to the Bay from the Miami River (Voss, 1972). The waters of the area were turbid, reducing illumination and limiting growth of marine plants. Bottom sediments were very fine grained. There were indications of eutrophication. Surveys in 1954-57 and 1959 showed the area to be almost totally devoid of attached benthic life. Fishing in the area was minimal.

Figure 35. Aerial view of Miami (1969). (The Port of Miami at the upper left of the image. Cloughton Island is the triangular-shaped island to the left. The entrance to the Miami River is just past the island. The shoreline between Cloughton Island and Rickenbacker Causeway (just off the image) remained undeveloped and was known as Millionaire's Row.) [Photograph, black and white (8 x 10 in). PR06844. Print Collection, Florida State Photo Archive. <http://fpc.dos.state.fl.us/>]

The waters of the ship basins were found to be traps for the collection and sinking of debris and garbage.

4.6. 1960s

Urban development in South Florida continued during the 1960s with the influx of Cuban refugees.

The Julia Tuttle Causeway was built in 1961 (Michel, 1976). Fill was obtained from an area just north of the new causeway. The resulting borrow pit is 29 feet deep. This causeway further restricted circulation in North Bay.

The Dodge Island Seaport officially opened in 1964 when port operations were moved from the old site in Biscayne Blvd. Port activity continued to increase as cruise lines used the Port as a base of operation (Chapman, 1993) (Figure 35). Several NOAA vessels including the DISCOVERER and the RESEARCHER, and University of Miami vessels including the R/V COLUMBUS ISELIN were based at the port.

During the 1960s Hurricanes Donna, Cleo and Betsy passed near or over Biscayne Bay. These storms were less devastating than the 1926 storm (see Section 5.3.4).

4.7. 1970s

The environmental movement, begun in the 1970s, brought public attention to the growing environmental problems in the US. In 1974, the Biscayne Bay Ecology Committee organized a symposium on the status of the Bay and the papers published in the proceedings are a synthesis of the physical, geological and biological processes, and man's uses and interaction with the Bay (Thorhaug and Volker, 1976).

The last major change to North Bay took place with the expansion of the Port of Miami onto Lummus Island (Figure 36).

In 1974, the Florida State Legislature enacted a law designating Biscayne Bay as an aquatic preserve thus placing stringent controls on further development of the Bay (Michel, 1976; Dade County, 1984; Florida Department of Environmental Protection, 2000a). The Preserve consists of two separate areas of the Bay: North Bay south to a line connecting Cape Florida to Chicken Key; and Card Sound. The two areas are separated by Biscayne National Park.

The nuclear units of the Florida Power and Light Turkey Point Power Plant in South Bay began operations in 1972 (see Section 6.3.1.1). The effect of thermal pollution on the fauna and flora of southern Biscayne Bay and Card Sound were extensively studied during the 1970s before and after the cooling canals were put into use.

Pollution inputs to the Bay during the 1970s were attributed to runoff from the metropolitan areas introduced via the canals and rivers (Waite, 1976). Sewage pollution continued to occur and further monitoring of Bay conditions was recommended.

Teas *et al.* (1976) studied changes in shore vegetation up to the 1970s at five sites: Interama, Cocoplum, Saga, a section south of Black Point, and Card Point. The shoreline vegetation of Biscayne Bay changed significantly since the turn of the century. Shore vegetation was eliminated in most of the northern Bay and seriously impacted elsewhere. Anthropogenic effects on the shore vegetation were of two types: physical (land fill, vegetation removal, erosion by boat wakes) and water quality- and quantity-related (reduction of freshwater and changes in salinity). There is evidence that vegetational changes took place in the shores of the Bay prior to human settlement. The authors recommended revegetation using mangroves to stabilize shorelines.

Walter Kandrashoff began to catch sick and deformed fish in Biscayne Bay, and brought this problem to the attention of local scientists to determine the reason for the emaciated condition of the animals. A description of the problem is found in Section 7.2.4.

A cyanobacterium Synechococcus sp. was isolated from an area of Biscayne Bay where a massive fish kill occurred in the 1970s (Reyes-Vazques, 1985). Hemolytic compounds are produced by this strain.

4.8. 1980s

During the 1980s, fine suspended material was identified as a major problem in Biscayne Bay (Wanless *et al.*, 1984). Fine bottom sediment became suspended in the water column through several mechanisms, such as wind events, cold fronts, wave action, and boat traffic. Fine

Figure 36. Central Biscayne Bay. [Some of the channels, such as the one between the Miami River and the Virginia Key Sewage Treatment Plant can be observed. The left-most rectangular indentation in the Port of Miami was home base to NOAA and University of Miami research vessels. The deep area north of the 36th Street Causeway is the dark colored area. Note seagrass bed at the top left of the image.] [Aerial photograph 5WGQ2987, 1992. Scale 1:48000, azimuth 191.1, 25.76833° N, 80.14556° W. (Coastal Aerial Photography, NOAA/National Ocean Service, <http://mapfinder.nos.noaa.gov:80/mapfinderhtml3/surround/photos/photos.html>, <http://mfproducts.nos.noaa.gov/images/Photos/5WGQ2987.gif>. Black areas are artifacts in original photograph. See Figure 2 for identification details.] *See color version on p. 119.*

material can also enter the Bay waters via runoff. The suspended material can smother bottom communities thus destabilizing additional areas of Bay bottom. During the passage of cold fronts, there is a southward longshore drift of sand along the beaches and southward transport of unstable sands along the Bay bottom (Warzeski, 1976). Sediment is stirred into suspension and is redeposited elsewhere in the Bay, carried out to form tidal deltas and bars, or taken out of the Bay. It is well documented that higher levels of trace metals and organic contaminants are found in fine sediments than in coarse ones. Steps were taken to reduce the amount of suspended material, including installation of natural sediment traps, such as restored mangrove wetlands, planting of native trees and shrubs in the mid-Bay islands, placing limestone boulders along shorelines, and creating reefs in silty depressions in the Bay bottom (Zaneski, 1995). As the amount of suspended material in the water column was reduced, light penetration increased, and bottom communities, including seagrasses, showed signs of recovery and expansion.

The amount of suspended solids decreased in the Bay from 1979 to 1983 (Dade County, 1985). Nonetheless, initial efforts to restore seagrasses failed due to high turbidity. The only sections in North Bay that appeared healthy were flushed with ocean water from Bakers Haulover Cut, and the seagrass bed north of the Julia Tuttle Cswy (Figure 37). The most turbid water was found between the 79th Street and Broad Cswys., probably the result of the dredge pits created during waterfront development in the 1920s.

Corcoran *et al.* (1983) conducted a survey of hydrocarbon concentrations in Biscayne Bay sediments in 1982-1983. High concentrations were found in Little River, the Miami River, Black Creek/Goulds Canal and Military Canal. The Miami River, with its shipping activity and urban runoff, had the highest concentrations. Military Canal drains Homestead Air Force Base (see Section 6.1.3.2). Black Creek merges with Goulds Canal before emptying in to Biscayne Bay. It has small boat traffic and two marinas. Little River has minimal boat traffic but receives high amounts of urban runoff.

Development of Cloughton Island, renamed Brickell Key, began at this time.

During the 1980s, there were many events centered on Biscayne Bay that helped raise awareness of its environmental condition and importance to South Florida. These events included Christo's Surrounded Islands (see Section 9.2), the annual Baynanza boat races (see Section 9.3), and the use of Biscayne Bay in film, television and print media (see Section 7.3.4).

4.9. 1990s

Restoration efforts continued during the 1990s. The passage of Hurricane Andrew resulted in damage to the Bay ecosystem as well as new restoration opportunities.

Hurricane Andrew, a category 4 storm, passed directly over Biscayne Bay in August 1992 (see Section 5.3.5). Homestead and towns nearby suffered severe damage. Homestead Air Force Base was virtually destroyed and the Air Force decided not to re-open the facility (see Section 6.4.1). Hurricane Andrew literally removed tons of vegetation from the mainland and Bay islands. Most of the plant species lost, such as the Australian pine, were foreign to Florida. The removal of the vegetation provided a unique opportunity to restore many sites to conditions as close as possible to those found in the 1900s. Planting of native species, such as mangroves, sea oats and gumbo limbo, stabilizes shorelines and reduces runoff of fine sedimentary material (Maass, 1992). As of 1995, one million mangrove trees were planted on the shores of Biscayne Bay, 100 acres of wetlands were restored or created, and twelve artificial reefs were created (Zaneski, 1995). The eight “spoil” islands created during the dredging of the Intracoastal Waterway have been transformed into beaches and picnic areas, surrounded by rock boulders to

Figure 37. North Biscayne Bay. [Note seagrass bed north of 36th Street Causeway (Julia Tuttle Causeway).] [Aerial photograph 5WPA1338, 1999. Scale 1:39800, azimuth 186.1, 25.82484° N, 80.14796° W. (Coastal Aerial Photography, NOAA/National Ocean Service, <http://mapfinder.nos.noaa.gov:80/mapfinderhtml3/surround/photos/photos.html>, <http://mfproducts.nos.noaa.gov/images/Photos/5WPA1338.gif>. See Figure 2 for identification details.] *See color version on p. 120.*

reduce fine material runoff and protect mangrove plantings. The underwater craters in North Bay are being filled with concrete rubble to create artificial reefs. Restoration efforts continue at present.

Hook and line, and crab trap surveys were used to determine the nature and distribution of abnormalities and diseases in fish and blue crabs from sites throughout Biscayne Bay during the 1990s (Gassman *et al.*, 1994). Missing or deformed dorsal fin rays were the most common abnormalities observed in gray snapper. Scale disorientations were most common in pinfish while sea bream exhibited both types of abnormalities. The highest prevalence rates for these three species were found at Sunset Harbor Marina and at Miami Beach Marina. Blue striped grunt had a low frequency of a variety of abnormalities. The prevalence of abnormalities for all fish surveyed was correlated with the concentration of total and aromatic hydrocarbons in sediment samples from sites within 2 km of the faunal survey sites. However, no correlations were found with sediment concentrations of aliphatic hydrocarbons, polychlorinated biphenyls, or five metals (Cd, Cu, Pb, Hg, and Zn). No correlations were found between contaminant concentrations and the distribution of abnormalities in the individual fish species or blue crab except between sediment Cu levels and abnormalities in the blue striped grunt.

Contamination hot spots were identified at Biscayne Canal, Arch Creek, Little River and the Miami River in North Bay. Shoreline dumpsites were identified and targeted for clean up, while damage to the ecosystem from boating activities continues.

Military Canal was identified as a potential source of contamination to South Bay (see Section 6.1.3.2.). Conversion of Homestead Air Reserve Base to civilian use may pose other environmental problems (see Section 6.4.1.).

The initial Surface Water Improvement and Management (SWIM) Plan for Biscayne Bay was prepared and adopted by the South Florida Water Management District in 1988 and modified in 1989 and 1995 (South Florida Water Management District, 1995). The 1995 plan addressed the issues identified in the previous plan and the effectiveness of the initial strategies, as well as new issues and problems.

In 1999, the Florida Legislature and the South Florida Water Management District funded the Biscayne Bay Partnership Initiative (BBPI), coordinated by the Biscayne Bay Foundation and the FAU/FIU Joint Center for Environmental and Urban Problems (Biscayne Bay Partnership Initiative, 2000). BBPI will foster a management forum and program incorporating federal, state, county and local governments, as well as marine industries, tourism and business development interests, members of the conservation community, recreational organizations, and citizens of South Florida. BBPI Survey teams were formed to identify and discuss issues in management, social and economic values, science, and regulations. The Science Team is currently preparing a document on past and current research efforts in Biscayne Bay, information gaps, and priorities.

Fishing improved in Biscayne Bay during the 1990s perhaps due to reduction of contaminant input, above-average rainfall reducing the salinity, and the statewide ban on coastal net fishing protecting game-fish and bait established in 1995 (Cocking, 1997). Fishermen reported clearer waters in the northern Bay.

5. METEOROLOGY

5.1. Solar cycles

The sun provides all of the energy that fuels the atmosphere and oceans, and changes in solar output can affect planetary weather. Sunspots are dark (cool) areas on the Sun's surface that interrupt the regular pattern of solar emissions (NOAA, 1991). Sunspot frequency rises and falls with the 11-yr solar cycle. Monthly mean sunspot values are shown in Figure IV.1 (Appendix IV) (NOAA, 2000a). It has been found recently that the solar radius is variable, with variations on an ~80 yr time scale, and that these variations may result in large changes in solar luminosity (Gilliland, 1982). This ~80 yr cycle, as well as the shorter 11-yr solar sunspot cycle and 22-yr Hale cycle of solar magnetic reversals, may explain hemispheric temperature trends. A third possible cycle is the 18.6-yr lunar nodal cycle in which tidal influences may also play a role.

5.2. El Niño Southern Oscillation

The El Niño/Southern Oscillation (ENSO) is the largest single source of interannual climatic variability on a global scale and its effects are wide ranging (Diaz and Markgraf, 1992). The Southern Oscillation is a large scale sea level pressure "seesaw" across the tropical Pacific Ocean. The anomalous oceanic and atmospheric conditions that occur periodically along the upwelling zone of the Equatorial Pacific along the coast of Ecuador and Peru are known as El Niño and are a manifestation of coupled ocean-atmosphere processes. The warm phase of this coupling is known as El Niño and the cold phase as La Niña. Winter *et al.* (1994) found a very good correspondence between low $\delta^{13}C$ values (indicative of cloud cover) in a core taken from a specimen of *Montastrea annularis* and strong El Niño events indicating that the Caribbean is sensitive to ENSO activity.

The Southern Oscillation Index (SOI) is defined as the normalized difference in surface pressure between Tahiti, French Polynesia and Darwin, Australia, and it is a measure of the strength of the trade winds, which have a component of flow from regions of high to low pressure (NOAA, 2000b). High SOI (large pressure difference) values are associated with stronger than normal trade winds and La Niña conditions, and low SOI (small pressure difference) values are associated with weaker than normal trade winds and El Niño conditions. El Niño and La Niña years as defined by SOI values are shown in Figure IV.1.

Hanson and Maul (1991) identified rainfall anomalies associated with major El Niño events in the climate record of the seven climatic divisions of Florida. Only El Niño events that were strong enough to persist over two successive years were examined in this study. Therefore only "moderate" and "strong" events as defined by Quinn *et al.* (1987) were used. An additional requirement was that the year prior to the two-year event must be a non-El Niño year. The two-year events that met this criteria were: 1911-12, 1917-18, 1925-26, 1930-31, 1939-40, 1957-58, 1972-73, and 1982-83 (other events have been identified since 1991). The most significant anomalies were: below normal rainfall over the State of Florida during winter (December, January and February) and spring (March, April and May) of the year prior to an El Niño event; and above normal rainfall over the State during the winter and spring of the second year of an El Niño event. The largest rainfall anomalies occurred in the southern climatic divisions of Florida (the Everglades and southeast coast, lower east coast, and the Keys).

5.3. Hurricanes

Hurricanes are tropical cyclones with wind speeds of 119 km per hour (Table 2) or higher that occur over the Atlantic Ocean, Caribbean Sea and Gulf of Mexico usually during summer and fall. These storms originate in warm waters in areas of low pressure and with wind circulation counterclockwise around the center. The annual number of hurricanes is greater in South Florida than in any other place in the US and hurricanes have struck in half the years during the past century (Gentry, 1984). The annual numbers of all hurricanes in the Atlantic was below average from 1894 through 1930, and was especially low from 1911 through 1921. During the 1930s, the numbers increased above average and remained so through 1982, with the exception of a few years around 1940. In Florida, the frequency was above average from 1933 - 1938, 1945 - 1952, and 1964 - 1966. Frequencies were below average until the onset of El Niño. Tropical cyclones passing over or within a radius of approximately 50 mi of Biscayne Bay from 1910 to 1999 are listed in Table 3 and are shown graphically in Figure IV.1. Meteorological information about tropical cyclones from 1921 to 1999 can be found in the NOAA National Hurricane Center internet site (<http://www.nhc.noaa.gov/pastall.html>), and information about cyclones from 1886 to 1998 can be found at the Unisys internet site (<http://weather.unisys.com/hurricane/atlantic/ index.html>).

5.3.1. Hurricane of 1906

In October 1906 Miami was hit by a minimal strength hurricane (Kleinberg, 1989). Few of the approximately 5000 residents had experienced a hurricane and none of the buildings in the area had been through such a storm. The city suffered considerable damage. Eyewitness accounts report the sinking of the paddle wheeler St. Lucie, and of survivors clinging to mangroves in an effort to survive the storm surge.

5.3.2. Hurricane of 1926

The Hurricane of 1926 struck South Florida in the morning of September 18. High winds and storm surges of 3 - 4 m caused severe destruction to Miami and Miami Beach (Figures 18 - 21) (see Section 4.2). Recorded winds were 132 mph before the anemometer was blown away. The storm surge destroyed many buildings and carried large vessels into Bayfront Park. Damage in Florida was estimated at $100M (Gentry, 1974) and more than 100 lives were lost in Miami (Kleinberg, 1989). This hurricane severely reduced the rate of urban development in South Florida.

5.3.3. Hurricane of 1945

The Hurricane of 1945, a category 4 storm, passed directly over Homestead Air Force Base on September 15 (Figure 31). Maximum sustained winds of 177 Kph were recorded at Carysford Reef Light, a few miles west of the point of entry to the coast but on the weak side of

Table 2. Saffir/Simpson hurricane intensity scale (Morgan and Morgan, 1989).

Category	Central pressure (mb)	Central pressure (in)	Wind speed (mph)	Wind speed (km/hr)	Storm surge (ft)	Storm surge (m)	Damage
1	>980	>28.94	74-95	121-154	4-5	1-2	Minimal
2	965-979	28.50-28.91	96-110	155-178	6-8	2-3	Moderate
3	945-964	27.91-28.47	111-130	179-210	9-12	3-4	Extensive
4	920-944	27.17-27.88	131-155	211-250	13-18	4-6	Extreme
5	<920	<27.17	>155	>250	>18	>6	Catastrophic

Table 3. Tropical cyclones passing over or near Biscayne Bay from 1900 to 1999 (Neumann *et al.*, 1993; NOAA, 2000d; Unisys 2000).

Year	Category (when nearest to the Bay)		Storm name	Date
1901	TS		Storm 4	Aug. 4 - 18
1903	2		Storm 3	Sept. 9 - 16
1904	1		Storm 3	Oct. 12 - 21
1906	3		Storm 8	Oct. 11 - 22
1909	1		Storm 9	Oct. 6 - 13
1916	TD	(off shore)	Storm 5	Aug. 21- 25
1916	1		Storm 14	Nov. 11 - 14
1924	TS	(north of Bay)	Storm 7	Oct. 14 - 23
1926	4		Storm 6	Sept. 11 - 22
1926	2	(south of Bay)	Storm 10	Oct. 14 - 24
1929	3		Storm 2	Sept. 22 - Oct. 4
1932	TS	(Florida Bay/Florida Keys)	Storm 3	Aug. 26 - Sept. 4
1935	1		Storm 6	Oct. 30 - Nov. 8
1936	TS		Storm 1	June 12 - 17
1936	TS		Storm 5	July 27 - Aug. 1
1941	3		Storm 5	Oct. 3 - 14
1945	4		Storm 9	Sept. 12 - 20
1947	5	(north of Bay)	Storm 4	Sept. 4 - 21
1947	1	(Florida Bay/Florida Keys)	Storm 8	Oct. 9 - 16
1948	2		Storm 8	Oct. 3 - 16
1950	2	(north of Bay)	Storm 11 (King)	Oct. 13 - 19
1960	4	(Florida Bay/Florida Keys)	Storm 5 (Donna)	Aug. 29 - Sept. 14
1964	2	(Florida Bay/Florida Keys)	Storm 5 (Cleo)	Aug. 10 - Sept. 5
1965	3	(Florida Bay/Florida Keys)	Storm 3 (Betsy)	Aug. 27 - Sept. 13
1966	1	(Florida Bay/Florida Keys)	Storm 9 (Inez)	Sept. 21 - Oct. 11
1968	TD	(Florida Bay/Florida Keys)	Storm 4 (Dolly)	Aug. 10 - 17
1970	TD	(Florida Bay/Florida Keys)	Storm 7 (Felice)	Sept. 12 - 17
1972	TD		Storm 5 (Dawn)	Sept. 5 - 14
1987	1	(Florida Bay/Florida Keys)	Storm 7 (Floyd)	Oct. 9 - 14
1992	4		Storm 2 (Andrew)	Aug. 16 - 28
1999	TS	(north of Bay)	Storm 8 (Harvey)	Sept. 19-22
1999	TS	(Florida Bay/Florida Keys)	Storm 9 (Irene)	Oct. 13 - 19

TS - Tropical storm. : A tropical cyclone in which the maximum sustained surface wind speed from 39 mph (63 kph) to 73 mph (118 kph).
TD - Tropical depression: A tropical cyclone in which the maximum sustained surface wind speed 38 mph (62 kph) or less.

275 Kph. Richmond Naval Air Station, one of the largest lighter than air ship bases in the US, was destroyed by fire during the passage of this storm (Gentry, 1974) (see Section 6.4.2). Homestead Army Air Field suffered severe damage and was closed for several months (see Section 6.4.1).

5.3.4. Hurricanes Donna, Cleo and Betsy

Hurricane Donna reached South Florida in September 1960. The storm moved across the Florida Keys and Florida Bay on a northwesterly course. Winds of 80 mph were recorded in the northern part of Biscayne Bay, and of 100 mph in the southern portion. Storm surge on southern Biscayne Bay was 5 - 6 feet above mean sea level (Perkins and Enos, 1968). Hurricane damage to vegetation was generally most severe in the mangrove belt and on the Florida Keys. Hurricane Donna caused storm effects in an area where detailed data on prestorm sea floor conditions existed (Ball *et al.*, 1967). The amount of boulder-sized rubble formed by hurricane surf on platform-edged reefs far exceeded the amount produced by day-to-day processes, and death and deterioration. Donna was considered the most destructive hurricane ever to affect the US up to that time (Gentry, 1974).

Hurricane Betsy was a slow-moving storm that reached South Florida in September 1965 passing over the Florida Keys on a westerly course (Perkins and Enos, 1968). Sustained winds of between 120 and 140 mph were recorded. Winds from the north brought high tides of up to 10 feet above mean sea level to southern Biscayne Bay. The water spilled over the narrow bank into Florida Bay washing out two sections of US Highway 1.

The effects of hurricanes Donna (1960) and Betsy (1965) were compared (Perkins and Enos, 1968). These hurricanes were of comparable size and intensity but their effects differed. Both caused extensive damage to the outer reefs but Betsy acted essentially on fauna from which Donna had already removed the weaker elements.

Hurricane Cleo approached the South Florida coast from Cuba on August 26, 1964. As the center approached Miami, winds intensified to approximately 105 mph with gusts of approximately 135 mph resulting in a category 2 storm. The eye of the hurricane moved over Key Biscayne August 27 (Dunn *et al.*, 1965). The geometric center of the eye passed over Virginia Key and reached the west side of Biscayne Bay at about the 36th Street Causeway There was minimal damage to buildings in Dade County. Principal damages were uprooted trees, disrupted communications and power, sand blasting of buildings and automobiles, overturned parked aircraft and agricultural losses. Cleo was the first hurricane to strike South Florida since 1950.

5.3.5. Hurricane Andrew

Hurricane Andrew passed directly over Biscayne Bay August 24, 1992 and moved rapidly west. Andrew was a relatively dry hurricane, with strongest sustained winds of 144 mph (Rappaport and Sheets, 1993). The effects of this storm on Biscayne Bay and the northern Florida Keys have been well documented (Tilmant *et al.*, 1994). Its effect has been described as that of a 25-mile wide tornado. The major environmental impact occurred in South Bay. Homestead Air Force Base, which was sevely damaged by hurricanes in 1926 and 1945, was again nearly destroyed (see Section 6.4.1).

The most evident impact of Andrew on coastal ecosystems was uprooted and defoliated mangroves. Many of the small keys in the Bay and most of Cape Florida were denuded of vegetation or severely damaged. Hurricane Andrew flattened over 70,000 acres of mangrove forest on the east and west coasts of south Florida (Gelsanliter, 1993). This flattening was primarily caused by high winds The areas of severe mangrove destruction in Biscayne Bay were Soldier Key to Caesar's Creek, and south of Matheson Hammock. The catastrophic modification by Hurricane Andrew is a normal part of the geological dynamics of these mangrove wetlands. Mangrove environments contain well-preserved storm layers from previous storms. These storm layers are capped by a coarse charcoal layer which represents burning of the mangrove forest that had been flattened. Sediments were disturbed and organic material from coastal areas entered the Bay resulting in discolored waters and low oxygen conditions. Seagrasses did not appear to suffer much damage since Andrew was a fast moving storm. Since Andrew, vegetation of many keys and coastal areas has begun to recover to natural conditions. The effects of the storm on the ecosystem of Biscayne Bay continue to be studied.

5.4. Rainfall and temperature

The cycles of rainfall and temperature for South Florida can be found in NOAA (2000c). The Palmer Index was developed in the 1960s and uses temperature and rainfall information in a formula to determine dryness. The Palmer Index is most effective in determining long term drought and is standardized to local climate. The Palmer Index for South Florida is shown in Figure IV.1 (Appendix IV). From the 1940s to the present, correlations can be observed in drought conditions in South Florida and the presence of El Niño or La Niña in the Pacific. Data prior to the 1940s may not be as abundant or of the same quality as recent data.

5.5. Sea level change

Global sea level has been rising since the last glacial maximum approximately 18,000 yrs ago and this rise has not been at a uniform rate. Wanless *et al*. (1994b) has shown that the sea level rise for the past few thousand years has been about 0.04 cm/yr compared to that of the Holocene, approximately 0.25 cm/yr. Maul and Martin (1993) have determined the sea level rise at Key West using instrument records from 1846 - 1987. The linear sea level rise has been about 30 cm and there is a statistically weak but consistent indication that the rate of rise has increased slightly since the 1920s (Figure IV.2, Appendix IV). Should the sea level rise continue, changes to the coastal ecosystem are expected as more land is submerged. The changes include an increased level of coastal turbidity and nutrients; storm driven loss of coastal wetlands; storm driven modification and migration of coastal levees, mud and sand banks, and barrier islands; deepening of coastal bays; and breaching of low areas along the Keys to create new tidal passes.

5.6. Soil subsidence

A review of subsidence of organic soils in the Everglades can be found in Stephens (1984) and is abstracted in this section. The Everglades, adjacent to Biscayne Bay, contains the largest single tract of organic soils in the world, over 3,100 square miles. These soils, formed under marshy conditions, subsided when drained. Subsidence is caused by compaction due to: dessication, consolidation, and tillage; biochemical oxidation; wind erosion; and/or burning. Biochemical oxidation accounted for approximately two thirds of the total loss of arable soils in the region. Subsidence has had serious environmental effects on agriculture, water supplies and wildlife. The sequence of observed subsidence of organic soils at three sites in the Everglades is shown in Figure IV.2. The sites are the North River Canal, just below old South Bay Lock; the Bolles Canal, a major drain at Okeelanta; and the Everglades Experiment Station. Ground surface elevation has decreased by approximately 9 ft at all three sites. Soil losses have been greatest near the original drainage canals and "subsidence valleys" several miles wide were formed along both sides. Valley depths were greatest where drainage was best.

6. GEOGRAPHICAL FEATURES

6.1. Rivers, channels, cuts and canals

6.1.1. Rivers

6.1.1.1. Miami River

> "The mouth of the Miami River, which we were about entering, was before us, flanked by high banks, well-built houses (the best on the bay) were on either shore, in fact the river's brim was fringed with really handsome and stately rows of fruitful cocoa-palms, while back of them could be seen the dense and vivid foliage of sweet-orange trees, royal bananas, lemons, limes, guavas, and the graceful, unsurpassed crowns of delightful maumees.
>
> The Miami River, like all others on this coast, has a course of but a few miles, but is a full-grown stream at its source, bursting, as though propelled from a hydrant, out of the vast and accumulation reservoir of the Everglades, and forcing its widening way to the Bay. Indeed, at times, in the rainy season, so much fresh water is driven into this salt bay of thirty miles in length, from the various streams, that the entire body becomes freshened, and salt-water fish are obliged to leave for the time or die."
>
> J. Buck, 1877 (Buck, reprinted 1979)

The Miami river is the major river flowing into Biscayne Bay, flowing west to east through the center of the city of Miami (Austin, 1971). The River ranks fifth largest among Florida's international seaports, handling $1.7 billion of cargo, approximately 9% of Florida's port cargo value and 18% of total cargo from the Miami Custom District. Approximately 80% of all river cargo is containerized, and the rest is bulk (Beacon Council, 1991) The major exporting partners are Haiti, the Bahamas, the West Indies and Mexico. Industrial facilities along the Miami River include seafood processing and metal recycling. The navigable portion of the River is currently from the Miami International Airport through congested commercial and residential areas to Brickell Point, just south of downtown Miami.

The river varies in width from 150 to 250 ft, and navigable depths range from 15 ft at high water to 13 ft at low. The natural river extended only four miles west from Biscayne Bay into the Everglades (Gaby, 1990). It was fed by numerous fresh water springs. The major tributary of the natural Miami River was Wagner Creek which joined the river at about 8th Avenue. The rapids of the Miami River that were located near today's 27th Ave. were dynamited in 1908. In 1913, the river was dredged and the material removed was dumped on the current site of Cloughton Island (now named Brickell Key) (Figure 38). In 1918, John Seybold dug the Seybold Canal from the Miami River north along 7th Avenue and northwest to a turning basin, and widened Wagner Creek. During the 1930s, the Army Corps of Engineers widened the Miami River and Canal and deepened them to 15 feet.

By the 1930s, the river was receiving contamination from commercial activities and sewage from the Miami area. In 1934 the first targets of an environmental campaign were cheaply built barge housing called "shanties". These houseboats were removed in 1941.

The inflow of salt water into the River is the result of tidal action from Biscayne Bay and changes in the water table resulting from the construction of the drainage canal system. Salt water intrusion and fresh water discharges in the River and canal system are controlled through a series of dams.

Figure 38. Miami River, Port of Miami. and Brickell Key (Note Miami river sediment plume. Some of the old channels are still visible to the east of Brickell Key.) [Aerial photograph 5WG68412, 1992. Scale 1:15000, azimuth 189.7, 25.77778° N, 80.17917° W. (Coastal Aerial Photography, NOAA/National Ocean Service, <http://mapfinder.nos.noaa.gov:80/mapfinderhtml3/surround/photos/photos.html>, <http://mfproducts.nos.noaa.gov/images/Photos/5WG68412.gif>. Black areas are artifacts in original photograph. Figures 38 and newb through newe were reduced to the same scale. See Figure 2 for identification details.] *See color version on p. 121.*

The Miami river is currently a slow moving body of water, still contaminated by untreated sewage effluents and urban runoff. Acute coliform bacteria contamination events are characterized by coliform concentrations hundreds of thousands of times higher than water quality standards (Markley *et al.,* 1990). These episodes affect widespread areas of the River itself, its tributaries and adjacent portions of the Bay, and are the result of raw sewage discharge from emergency overflows and from manholes during flow conditions that exceed pump station capacity. Chronic contamination of the River is characterized by coliform levels tens of times higher than standards and is primarily caused by contamination of storm drains by raw sewage.

The sediments of the Miami River are contaminated. Arsenic, Cd Hg, Pb and Ag are above natural levels (Ryan *et al.*, 1985; Ryan and Cox, 1985). In general, contaminant concentrations at the two farthest upstream (at the salinity barrier) locations were lower than those downriver. Corcoran *et al.* (1984) found similar trends for organic contaminants. Results indicated that there is considerable input of pollutants from the river into adjacent areas of Biscayne Bay. Compared to other Florida navigation system studies, sediments from the Port of Miami and the Intracoastal Waterway were in general the most contaminated of all samples analyzed. Particle bound pollutants appeared to be accumulating in deep dredge holes.

6.1.1.2. Oleta River

The Oleta River State Recreation Area is the largest urban park in Florida, occupying almost 1000 acres (Florida Department of Environmental Protection, 2000b). The most prominent natural feature of the park is the Oleta River. Tequesta* sites dating as far back as 500 BC have been found along the river. When Spaniards first visited the area they encountered bear, deer, panthers, bobcats, wolves, alligators, manatees and numerous birds and small animals. In 1841, the river was named Big Snake Creek and was used by southern-moving Federal troops during the Second Seminole War. In 1881, Captain William Hawkins Fulford explored the river and settled further inland in the area known today as North Miami Beach. Once "discovered", other settlers ventured north from Miami and by the 1890s, pineapple and vegetable farms had sprung up along the river. An Indian trading post was established at what is now Greynolds Park. In 1922, Big Snake Creek was renamed the Oleta River. Waterbirds feed along the mangrove-lined shoreline and West Indian manatees find refuge in the area. The Phase I of the wetlands enhancement effort at the Oleta River State Recreation Area, completed in 1990, was funded by Miami-Dade with matching funds from the Dade County Seaport Dept. Phase II is ongoing. The mangrove enhancement effort in the area was also completed in 1990 and was funded by Miami-Dade with matching funds from the South Florida Water Management District. The restoration effort is described in Milano (1999).

6.1.1.3. Arch Creek

Arch Creek was an underground stream carrying water from the Everglades into Biscayne Bay that eventually became exposed (Kleinberg, 1989). It was well known for a natural bridge, which was part of the road from Fort Dallas (present day Miami) to Fort Lauderdale in the 1850s. It is an archeological site of Tequesta Native People. Chrysler Corporation bought the property in 1972 and planned to build an auto dealership on the site. The State of Florida bought the site from Chrysler in 1973. Within hours of the purchase, the natural bridge collapsed. The site is currently a state park.

* The Tequestas were part of the Calusa Nation that dominated the Florida peninsula between fifteen hundred and two thousand years ago (Blank, 1996).

6.1.2. Channels and cuts

6.1.2.1. Safety Valve

The Safety Valve is a complex carbonate tidal bar belt extending approximately 10 miles southward of Key Biscayne to Soldier Key (Figures 39 and 40). The belt is composed of about 10 east-west trending bars separated by tidal channels. Sediment thickness varies from 4-5 m in the north to 1 m in the southern end. Carbon dating indicates that the northern section began forming in the northern end about 3600 BP at about the time Biscayne Bay was reflooded by the rise in sea level (Plescia and Stipp, 1975). Stiltsville, a cluster of homes set on pilings, is located at the northern end of the Safety Valve.

6.1.2.2. Bear Cut

Bear Cut is a natural channel connecting the northern part of Biscayne Bay to the Atlantic Ocean (Figure 3). There is strong tidal flow through this channel. The University of Miami's Rosenstiel School of Marine and Atmospheric Science is located on the northern side of the Cut and some of the School's research vessels are docked on the Cut. The bridge across Bear Cut is the only connection between Key Biscayne and the mainland.

6.1.2.3. Norris Cut

Norris Cut was apparently formed by the passage of a hurricane prior to 1887, probably the storm of 1835 (Chardon, 1977) (Figure 6). Norris Cut is not open to large vessel traffic.

6.1.2.4. Government Cut

Government Cut is a man-made channel providing access to the Port of Miami from the ocean (Figure 10). Construction of Government Cut began in 1902 when the Port was still in the Miami River (Michel, 1976). Since then, a series of deepening and widening projects have taken place as the size of the vessels using port facilities increased. Material dredged during the construction of the Cut was used to create the MacArthur Causeway and Dodge and Lummus Islands, the current site of the Port of Miami.

6.1.2.5. Bakers Haulover Cut

Bakers Haulover Cut, built in 1924 - 1925, connects North Bay with the Atlantic Ocean (Figure 41) (Michel, 1976; Toner, 1979). Prior to opening of the Cut, North Bay was estuarine. Reasons for construction of the Cut included decrease in the residence time of water in North Bay thereby decreasing bacterial contamination and faster access to the Atlantic Ocean.

6.1.2.6. Caesar's Creek, Broad Creek, and Angelfish Creek

Caesar's Creek, Broad Creek, and Angelfish Creek provide tidal exchange for South Bay and Card Sound (Figures 42 and 43). These channels are shallow passages through the upper islands of the Florida Keys chain. Caesar's Creek was named after Black Caesar, an escaped African slave, who became a pirate and operated out of Elliott Key (Atkinson, 1970).

Figure 39. The Safety Valve. (The southern end of Key Biscayne is at the top. Soldier Key is at the bottom right.) [Aerial photograph 5WGS3280, Jan. 2, 1992. Scale 1:48000, azimuth 208.8, 25.62889° N, 80.17889° W. (Coastal Aerial Photography, NOAA/National Ocean Service, <http://mapfinder.nos.noaa.gov:80/mapfinderhtml3/surround/photos/photos.html>, <http://mfproducts.nos.noaa.gov/images/Photos/5WGQ2991.gif>. Black area at the top of the image is an artifact in original photograph. See Figure 3 for identification details.] *See color version on p. 122.*

Figure 40. Ragged Keys, Sands Key and the northern end of Elliott Key. (The southern end of the Safety Valve is north of the Ragged Keys.) [Aerial photograph 5WGN2919, Jan. 17, 1992. Scale 1:48000, azimuth 11.3, 25.52917° N, 80.14528° W. (Coastal Aerial Photography, NOAA/National Ocean Service, <http://mapfinder.nos.noaa.gov:80/mapfinderhtml3/surround/photos/photos.html>, <http://mfproducts.nos.noaa.gov/images/Photos /5WGN2919.gif>. See Figure 3 for identification details.] *See color version on p. 123.*

Figure 41. Bakers Haulover Cut. (The Oleta River is just off the image at the upper right. The Munisport Landfill site is almost directly east of Bakers Haulover Cut. Note sediment deltas on either side of the cut. Delta inside the Bay appears to have formed prior to dredging of the Intercoastal Waterway.) [Aerial photograph 5WPA1416, 1999. Scale 1:40000, azimuth 31.1, 25.88965° N, 80.16151° W. (Coastal Aerial Photography, NOAA/National Ocean Service, <http://mapfinder.nos.noaa.gov:80/mapfinderhtml3/surround/photos/photos.html>, <http:// mfproducts.nos.noaa.gov/images/Photos/5WPA1416.gif>. See Figure 2 for identification details.] *See color version on p. 124.*

Figure 42. Elliott Key, Caesar's Creek and Old Rhodes Key. (Biscayne Bay and Card Sound are to the right of the image.) [Aerial photograph 5WGN2887, 1992. Scale 1:48000, azimuth 209.2, 25.37861° N, 80.23139° W. (Coastal Aerial Photography, NOAA/National Ocean Service, <http://mapfinder.nos.noaa.gov:80/mapfinderhtml3/surround/photos/photos.html>, <http://mfproducts.nos.noaa.gov/images/Photos/5WGN2887.gif>. See Figure 2 for identification details.] *See color version on p. 125.*

Figure 43. Broad Creek and Angelfish Creek. (Biscayne Bay and Card Sound are to the right of the image.) [Aerial photograph 5WGN2889, 1992. Scale 1:48000, azimuth 209.2, 25.34333° N, 80.25306° W. (Coastal Aerial Photography, NOAA/National Ocean Service, <http://mapfinder.nos.noaa.gov:80/mapfinderhtml3/surround/photos/photos.html>, <http://mfproducts.nos.noaa.gov/images/Photos/5WGN2889.gif>. See Figure 2 for identification details.] *See color version on p. 126.*

6.1.3. Canals and the Biscayne Aquifer

The canal drainage system of South Florida is managed by the South Florida Water Management District and the US Army Corps of Engineers (Figure 44). Construction of canals to drain land for urban and agricultural uses began during the 1900s. The canal system encompasses most of South Florida. No chronological record of construction of the canal system could be found as of this writing.

The Biscayne Aquifer is a highly permeable unconfined aquifer more than 200 feet thick in north Broward County, that thins to an edge 40 miles inland in the Everglades (Klein and Hull, 1978) (Figure 40). The aquifer is composed of limestone, sandstone and sand. Generally the sand proportion increases as the aquifer thickens to the north and east. The Biscayne Aquifer is primarily independent of the Everglades and recharges by local rainfall. Discharge is by evaporation, canal drainage, coastal seepage and pumping. Prior to 1900, discharge into Biscayne Bay occurred through well-known solution holes in the Miami oolite and this flow produced numerous freshwater springs (Figure 8) (see Section 4.1). Since then, anthropogenic changes to the natural flow reduced or eliminated spring flow. Recent changes to the drainage canal system may have reversed this effect.

Saltwater intrusion along the southeastern boundary of the Biscayne Aquifer has been documented since 1904, shortly after the construction of drainage canals began in the area (Halley *et al.*, 1998; and others) (Figure 32). Since the 1940s, the salt intrusion has been regionally arrested although localized problems exist (Halley *et al.*, 1998). Willard *et al.* (1999) investigated hydrologic changes over the past century using floral and faunal assemblages in sediment cores as proxies for vegetation and environmental parameters and found indications that the major, system-wide biotic changes occurred by 1940. This date coincides with the construction of the major canals in the area. Several authors have suggested that the increased salinity in Florida Bay, the salt water intrusion into the Biscayne Aquifer and the reduction of the offshore freshwater springs are the result of the drainage canals. The greater head potential of the Biscayne Aquifer acted as a salinity barrier (Reich, 1998).

Contaminants can enter the aquifer by direct infiltration from land surface or controlled canals, septic tanks and other drainfields, drainage wells, and solid waste dumps. Most of the contamination is concentrated in the upper 20 to 30 feet of the aquifer.

6.1.3.1. Mowry Canal

The Mowry Canal (C-103) is located approximately 25 mi south of Miami and plays an important role in flood protection and the salt water intrusion control network. It is one of the major canals draining into Biscayne Bay.

6.1.3.2. Military Canal

Military Canal connects Homestead Air Reserve Base (ARB) to Biscayne Bay providing a conduit for storm water drainage (US Air Force, 1998). A series of small canals and ditches in the base drain into Boundary Canal and flow into a reservoir that discharges into Military Canal via natural flow or pumping. Military Canal and Boundary Canal were constructed before 1942 and modified in 1942. Military Canal is managed by the South Florida Water Management District.

EPA conducted sediment analysis, toxicity tests and ecological risk assessments of Military Canal and found no significant contamination or ecological risk (US Air Force, 1998). EPA and the US Air Force have drafted plans to clean up the canal (Zaneski, 1999). Yet, polycyclic aromatic hydrocarbons (PAHs) in the sediment of the Canal may be the result of illicit dumping

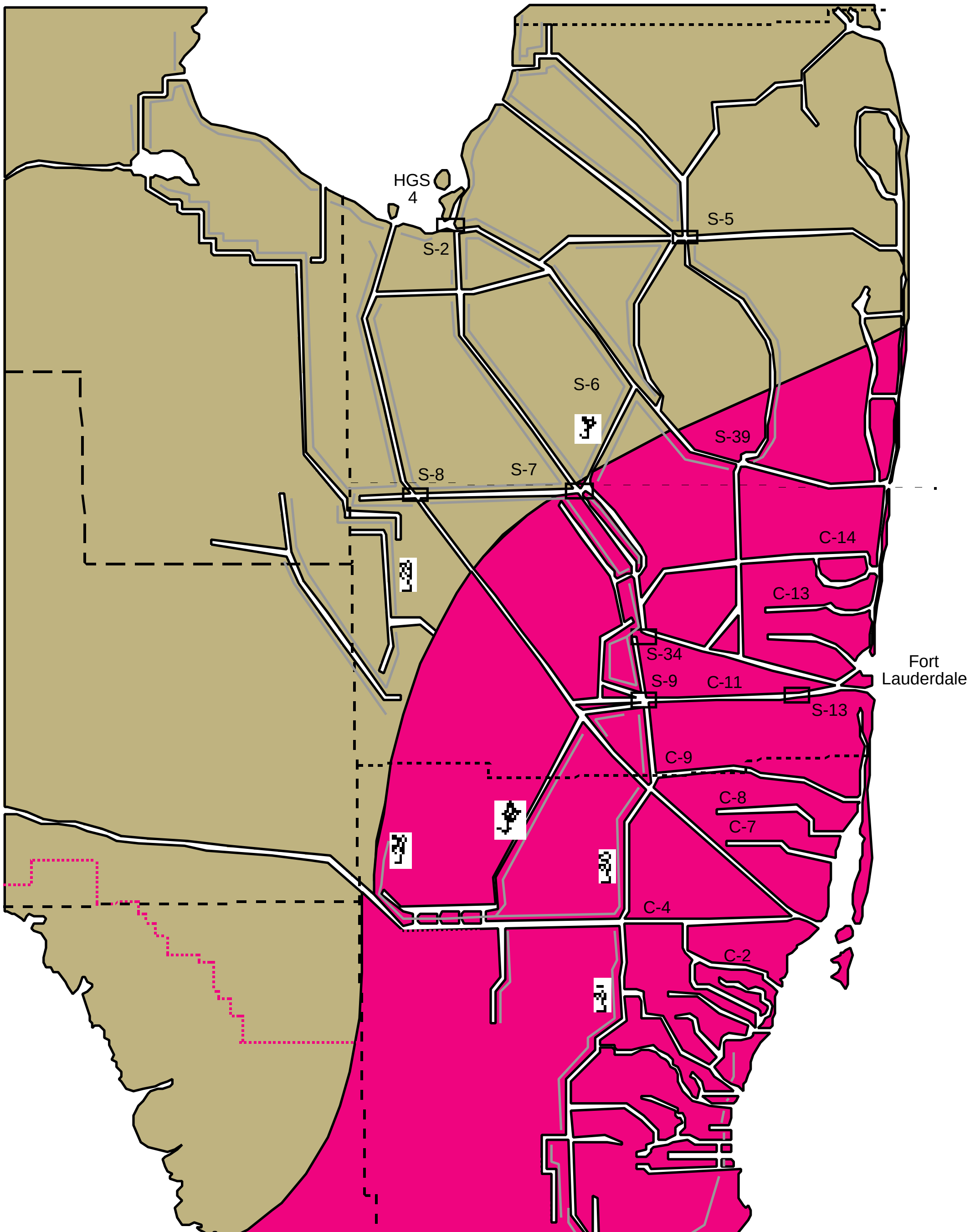


Figure 44. Hydrologic structures and hydrologic features of the South Florida Water Management District. [Redrawn from Klein and Hull (1978).]

activities of organic debris, an old boat, and asphalt shingles. Pesticides and petroleum products were commonly mixed before application to open water bodies to control human disease vectors such as mosquitoes and may be the source for the pesticides detected in the sediment of the Canal. The anomalous trace metal concentrations in the sediment can be linked to recreational fishing (lead sinkers), illicit solid waste dumping and car disposals.

6.1.3.3. Miami Canal

The Miami Canal is a part of the canal system of South Florida. The Miami Canal ran from Lake Okeechobee in the north, through the Everglades, to the Miami river between 1916 and 1923. At that time, there was shallow draft boat traffic through the canal. After a flood in 1923, a dam was constructed across the canal east of the South New River Canal thus ending water traffic.

6.2. Islands

6.2.1. Miami Beach

Miami Beach was a barrier island between Biscayne Bay and the Atlantic Ocean. There were natural channels between the Atlantic and Biscayne Bay across Miami Beach. These channels were probably opened and closed as the result of tropical storms. In 1904, Government Cut was built to provide fast access to the Port of Miami (see Section 6.1.2.4). Government Cut separated the southern end of the barrier islands from the rest thus creating Fisher Island (see Section 6.2.5). During the 1920s, development of the barrier islands began and as a result the mangrove forests covering the islands were removed beginning in 1913 (Figure 9). The Collins Canal through part of Miami Beach was built in 1912. In 1924, a channel was cut across a narrow section of the barrier island to provide access between the Atlantic and North Bay thus avoiding the trip south to exit the Bay via Government Cut. This channel is Bakers Haulover Cut (see Section 6.1.2.5). Miami Beach is now completely urban and very few areas of vegetation remain.

6.2.2. Key Biscayne

Key Biscayne is the largest natural island in Biscayne Bay. It is the southern-most of the sand keys, and for a greater part of its length a sand bar lies off shore about 1500 ft. This sand bar affects the beach by reducing the heavy surf and undertow. During the 1940s, seagrasses took root along various sections of Crandon Park beach and it was decided to dredge the fine silt of the seagrass beds and replace it with clean sand.

There have been settlements in Key Biscayne since the 1700s and evidence of occupation of the island by Native Peoples before that. An account of the history of Key Biscayne from the Spanish Conquista to the date of publication can be found in Blank (1996).

The Bill Baggs Cape Florida Recreation Area is located at the southern portion of Key Biscayne (see Section 6.3.2). Crandon Park is located on the Atlantic coast of Key Biscayne (see Section 6.3.2).

Hurricane Andrew destroyed the forest of Australian pines (*Causarina*) that covered Cape Florida and the northeast end of the island. These areas have been revegetated with native plants (Figures 45 and 46). The restoration effort in the Cape Florida area is described in Section 6.3.2. The Bear Cut Preserve Wetlands Restoration, completed in 1996, was funded by

Figure 45. Virginia Key and Key Biscayne prior to Hurricane Andrew. (Note extensive Australian pine cover at the southern end of Key Biscayne.) [Aerial photograph 5WGQ2991, Jan. 17, 1992. Scale 1:48000, azimuth 191.1, 25.70722° N, 80.15889° W. (Coastal Aerial Photography, NOAA/National Ocean Service, <http://mapfinder.nos.noaa.gov:80/mapfinderhtml3/surround/photos/photos.html>, <http://mfproducts.nos.noaa.gov/images/Photos/5WGQ2991.gif>. Black area at the bottom of the image is an artifact in original photograph. See Figure 3 for identification details.] *See color version on p. 127.*

Figure 46. Key Biscayne after Hurricane Andrew. (Note difference in plant cover at the southern end of Key Biscayne. Restoration sites are the light colored areas on the Atlantic site just south of Bear Cut and the area to the south on the Bay side.) [Aerial photograph 5WPA1342, 1999. Scale 1:40000, azimuth 187.6, 25.70489° N, 80.16356° W. (Coastal Aerial Photography, NOAA/National Ocean Service, <http://mapfinder.nos.noaa.gov:80/mapfinderhtml3/surround/photos/photos.html>, <http://mfproducts.nos.noaa.gov/images/Photos/5WPA1342.gif>. See Figure 3 for identification details.] *See color version on p. 128.*

Miami-Dade County with matching funds from Miami-Dade Water and Sewer and the Biscayne Bay Environmental Enhancement Trust Fund. The effort is described in Milano (1999 and 2000).

6.2.2.1. Fossil mangrove forest

Along the southern shore and northeastern shore of Key Biscayne there is a small rock reef approximately 400 yds long and extending out for 115 yds seaward (Hoffmeister and Multer, 1965) (Figure 45). This reef is composed of a framework of fossilized black mangrove (*Avicennia nitida*) roots. The mangrove swamp probably extended seaward beyond the present edge of the reef and landward over at least the northern part of what is now Key Biscayne. The reef is barely awash at high tide and it is exposed at low tide. The roots turned into calcareous rods and are embedded in a friable calcareous-quartzitic sand which can be washed away by wave action thus exposing the lattice work of the root systems. Part of the reef has been hardened and protected by coatings of barnacles. Marine algae also cover part of the reef but it is not as effective as the barnacle coating in protecting the area from erosion. Radiocarbon dating indicates the age of the rods to be between 1000 and 2000 yrs old. This is believed to be the first reported occurrence of fossilization of mangrove roots.

6.2.2.2. Biscayne Nature Center

The site of the new Biscayne Nature Center is in the northeast corner of Crandon Park. The Center is sponsored by Dade County Public Schools, the Marjorie Stoneman Douglas Biscayne Nature Center organization (a private non-profit organization), and the Miami-Dade County Parks and Recreation Department. Part of the project’s program includes replanting native plants to repair the extensive damage suffered from Hurricane Andrew. The sand dunes nearby are an evolving natural community which will become a living interpretive display. The Center will also act as a park visitor center and as a gateway to the Bear Cut Preserve to the north, currently under restoration.

6.2.3. Virginia Key

Virginia Key, one of the three natural islands in North Bay, was created in the 19th Century when a hurricane formed the channel now known as Norris Cut (Figures 4 and 5). Until then, Virginia Key was the southern tip of the barrier islands that is now Miami Beach. Virginia Key is separated from Key Biscayne by Bear Cut, another of the natural channels of Biscayne Bay.

In 1945, Virginia Beach, on the Bear Cut side of Virginia Key, was designated as the county's only beach for African Americans (Bragg, 1999). It was accessible only by ferry until 1947 when the Rickenbacker Causeway was built. A hurricane in the mid 1960s destroyed many of the buildings. Virginia Beach is not open to the public at this time.

Facilities on the island are Virginia Key Sewage Treatment Plant (see Section 6.3.2.1), the Miami Seaquarium, the Miami Marine Stadium (severely damaged by Hurricane Andrew and currently unusable), the NOAA Atlantic Oceanographic and Meteorological Laboratory, the NOAA National Marine Fisheries Southeast Fisheries Science Center, and the University of Miami Rosenstiel School of Marine and Atmospheric Science (RSMAS) and the Maritime and Science Technology High School.

RSMAS maintains private docking facilities for research vessels on Bear Cut south of Rickenbacker Causeway The Seaquarium Flats are located south of the Rickenbacker Causeway and across from the Miami Marine Stadium. This area has been the subject of several research projects by RSMAS faculty and students.

There have been numerous plans to use the land between the treatment plant and Virginia Beach (City of Miami, 1987). None have been put into effect. The area is used as training facilities for law enforcement agencies and a common location for movie making.

The Virginia Key Dune/Wetland Restoration project is ongoing and is funded by Miami-Dade with matching funds from City of Miami, Biscayne Bay Environmental Enhancement Trust Fund, and the Florida Dept. of Environmental Protection. The effort is described in Milano (1999).

6.2.4. Port of Miami

At the turn of the century, port activities in the Miami area were centered in the Miami River. Henry Flagler funded construction of the Port and began collecting dockage fees in 1896 (Miami-Dade County, 2000). A shallow channel was dredged between Cape Florida and the river to provide access to larger vessels. In 1915, Government Cut was constructed through Miami Beach, providing port access to larger vessels and creating Fisher Island and spoils banks on the side of the cut. In 1918, the County Cswy, later known as MacArthur Causeway, linking Miami and Miami Beach, was built parallel to Government Cut.

During the 1920s, the Port of Miami became the primary hub for all shipping to South Florida. Passenger service to Baltimore and New York began at this time (Miami-Dade County, 2000).

Burlingame Island was built with dredge material from deepening of the Miami River port site in 1923. In 1925 the western edge of the Bay was dredged to provide fill for Bayfront Park, the area on the east side of the City of Miami (Figure 47). In this same year, Government Cut was deepened and broadened. Port facilities moved to a site north of Bayfront Park. The Port remained at that location until the construction of the Dodge Island Seaport in the 1960s. Shipping activities declined after the Land Boom, Stock Market Crash and Hurricane of 1926. Cruise service to Havana began during the 1930s (Miami-Dade County, 2000). During World War II, the US Navy assumed control of the Port (see Section 4.4 for wartime activities in Biscayne Bay). In 1956, the Port selected Dodge Island for future expansion. The City of Miami transferred port administration to Dade County in 1960 and work began on the Dodge Island Seaport in 1962. Port operations at the new site began in 1963. By 1968, a cruise port record was set with four maiden voyages in one month (Miami-Dade County, 2000). The Port of Miami was the first in history to record more than one million passengers in a year. Oceanographic research vessels of NOAA and the University of Miami Rosenstiel Institute of Marine Sciences used the Port of Miami as home. The Seaport was expanded in the 1980s by joining Dodge and Lummus Islands (Miami-Dade County, 2000). Passenger and cargo records continued to be set. In 1991, a record 3.9 million tons of cargo were handled in one year. One of the last modifications to the Port was the infilling of small ship basins on the perimeter of Dodge-Lummus Islands (Figure 48).

The area around the Biscayne Blvd. port facilities was one of the most heavily polluted with coliform bacteria in the Bay (Voss, 1972). McNulty repeated the pollution study of the area after pollution abatement measures began in the late 1950s. Little change was noted in the port facility area. Organic matter was present in large amount and benthic animals were few. High turbidity, water depth, lack of mixing and flushing, and input from the Miami River were also reported (Voss, 1972). The aesthetic quality of the Biscayne Blvd. port facilities was poor.

The various stages of Port construction since the turn of the century increasingly constricted water flow in the Bay, and dredging operations resulted in a severely impacted bottom ecosystem (Voss, 1972).

Figure 47. Aerial view of the Port of Miami off Biscayne Blvd. (1928). (The city of Miami is at the center of the image. The Miami River entrance is beyond the city and to the left of the image. The spoil island that became Cloughton Island is just beyond the river entrance. [Photo negative, black and white, 8 x 10 in. PR06894. Print Collection, Florida State Photo Archive. <http://fpc.dos.state.fl.us/>]

6.2.5. Fisher Island

Fisher Island, once the southern-most part of Miami Beach before it was severed by the construction of Government Cut in 1905, covered 33 acres before it was expanded with sediment from the Cut (Figures 10 and 36). Its first name was Rat Island and then Peninsula Island. The present form of the island is the result of bulkheading and filling during the 1920s. It is now 200-plus acres. The geological history of the island can be found in Hannan *et al.* (1972). Fisher Island is currently the site of high-end residential housing.

6.2.6. Venetian Islands and Pelican Island

The Venetian Islands are man-made islands with a characteristic elongated oval shape located between the mainland and Miami Beach (Figures 16, 29 and 36). Real estate on the Venetian Islands sold quickly and plans to build an additional series of islands north of Di Lido Island were proposed. Isola Dilolando was supposed to be part of the northward extension of the Venetian Islands. Today it is known as Pelican Island, located between the Julia Tuttle Causeway and the Venetian Causeway It is not a true island but a network of pillings outlining a rectangular area of the Bay bottom about 3 feet deep. In 1944, the City of Miami Beach purchased the land inside the pillings (Kleinberg, 1989). Although several plans were considered for the site, no further development took place.

Figure 48. Belle Isle, the Venetian Islands, Watson Island, and the Port of Miami. [Miami Beach is at the top left of the image, and Fisher Island is at the top right. Note that the rectangular ship berthing basins have been filled in (see Figure 38).] [Aerial photograph 5WPB1537, 1999. Scale 1:20000, azimuth 290.2, 25.78139° N, 80.15513° W. (Coastal Aerial Photography, NOAA/National Ocean Service, <http://mapfinder.nos.noaa.gov:80/mapfinderhtml3/surround/photos/photos.html>, <http://mfproducts.nos.noaa.gov/images/Photos/5WPB1537.gif>. Black areas are artifacts in original photograph. See Figure 2 for identification details.] *See color version on p. 129.*

Figure 49. Aerial view of Belle Isle (193-). (Miami Beach is to the left of the image.) [Photonegative, black and white, 8 x 10 in. PR09460. Print Collection, Florida State Photo Archive. <http://fpc.dos.state.fl.us/>]

Figure 50. Aerial view of Belle Isle and the Venetian Causeway (196-). (Miami Beach is to the left of the image.) [Photonegative, black and white, 8 x 10 in. PR07001. Print Collection, Florida State Photo Archive. <http://fpc.dos.state.fl.us/>]

6.2.7. Watson Island

Watson Island is located at the western end of the MacArthur Causeway and was constructed during dredging operations (Figure 36). The island has been the site of Chalks Airlines, the Goodyear blimp facilities, a helicopter charter service, and the Japanese garden. Voss (1973) found that the area from the mouth of the Miami River north to the west end of the MacArthur Causeway was contaminated and was expected to remain so until major changes were made in the Miami River. The waters of the area were turbid, reducing illumination and limiting the growth of marine plants. Bottom sediments were very fine grained. There were indications of eutrophication. Surveys in 1954-57 and 1959 showed the area to be almost totally devoid of attached benthic life. Fishing in the area is minimal. The waters of the ship basins are traps for the collection and sinking of debris and garbage.

6.2.8. Belle Isle

Belle Isle, one of the three natural islands in North Bay, is the eastern most of the Venetian Islands and was so named by Carl Fisher. Belle Isle was originally known as Bull's Island. It was a tidal flat, mucky at low tide, when John Collins built the bridge to it in 1912 as part of the causeway connecting Miami to Miami Beach. The bridge was eventually rebuilt as the Venetian Causeway and the tidal flat was filled forming an island. During the 1920s, Fisher extended it to 32 acres and sold lots to millionaires. The shape of the island has changed little since the 1930s (Figures 49 and 50).

6.2.9. Fair Isle

Fair Isle is a man-made island south of the Mercy Hospital grounds. The major and initial dredge and fill damage occurred in 1924 when seagrass beds were covered by the spoil bank (Voss, 1974). Possible damage may have occurred in the area due to dredge and fill since the 1970s.

6.2.10. Elliott Key

Elliott Key is the northernmost of the Florida Keys. Pioneering families settled on Elliott Key by the beginning of the 20th century (Niemiec, 1996; Niedhauk, 1969 and 1973) (Figures 40 and

42). Charles Brookfield built the Ledbury Lodge on Elliott Key in 1936 using primarily driftwood and cypress washed up on the island. Many notable people stayed at the Lodge (Shroeder, 1986). After World War II, it became derelict.

During the 1960s, Elliott Key became the focus of developers and conservationists since the proposed Islandia development centered on the northern part of the Key. Islandia was conceived as the "last sparkling jewel of the ocean", a city in the style of Miami Beach. Extensive development of Elliott Key and the smaller keys in the area and a causeway connecting Cape Florida with Elliott Key were planned. As a first step, Islandia was incorporated as a city in 1960 (Shroder, 1986). In opposition to the development, the US Department of the Interior recommended Federal purchase of the island and the Bay bottom in 1967 for preservation as a natural area. The Mayor of Islandia vowed to continue development and proceeded to build Elliott Key Blvd. which would eventually connect with the planned causeway between Key Biscayne and Elliott Key. In 1968 bulldozers cut through the vegetation and construction began. Opposition to Islandia increased and discussions became heated.[Δ] Islandia was declared a "National Monument", a designation just short of that of National Park. In 1980, Biscayne National Monument was expanded from 104,700 to 175,000 acres and designated a National Park. The City of Islandia still exists but development never occurred.

The eye of Hurricane Andrew passed very close to Elliott Key. The effects of the storm are discussed in Section 5.3.5.

6.2.11. Chicken Key

Chicken Key is one of the six natural islands in the Central Bay. Legend has it that it was thus named because sailors trying to escape pirates and too "chicken" to confront their foes would hide in this small island (Rabin, 1996). Most of the island's vegetation was destroyed in the 1940s when the government dredged a channel just north of the island so military barges would reach Chapman Field. More than 30,000 cubic yards of fill were pumped onto the Key, and this material eventually eroded and reached the Bay. Australian pines and Brazilian pepper trees invaded the key displacing native vegetation. Hurricane Andrew destroyed the vegetation of the Key and provided an opportunity to restore the Key. Chicken Key will be managed by the Deering Estate for the Metro Parks and Recreation Department. The Chicken Key Bird Rookery Restoration effort, completed in 1997, was funded by Miami-Dade with matching funds from the Florida Dept. of Environmental Protection, the South Florida Water Management District and the Biscayne Bay Environmental Enhancement Trust Fund. The effort is described in Milano (1999).

6.2.12. Ragged Keys

The Ragged Keys are five small islands located north of Elliott Key (Figure 40). These keys are the northern-most end of the Florida Keys. During the 1950s, it was proposed that the Ragged Keys be consolidated as part of a bulkhead and fill project (Tabb, 1958). The project was not put into effect. The Ragged Keys were also part of the planned Islandia development (see Section 6.2.9).

6.2.13. Soldier Key

Soldier Key is a very small island located in the Safety Valve (Figure 39). The key was so named because, according to legend, a soldier was stranded there. Soldier Key was devastated by Hurricane Andrew. All vegetation and the caretakers house were razed from the key. The

[Δ] A newspaper account described the result of one of the public meetings: "The wife of an Islandia property owner ended a discussion with a conservationist by clobbering the bird watcher on the head with her purse" (Shroeder, 1986).

National Park Service bought the key in 1993 after plans to develop the property into a resort fell through (Dewar, 1993). Restoration of the key is underway.

6.2.14. Spoil islands

The spoil islands created during the construction of the Intercoastal Waterway have been or are currently undergoing restoration. These islands in North Bay are: Flagler Memorial Island, Teachers Island, Morningside Island*, Mangrove Islands (two islands), Legion Island, Pelican Island, Quayside Island, Helkers Island, Crescent Islands (two islands), Little Sandspur Island, and Sandspur Island (Figures 51 - 54) (Milano, 2000). These islands were used by the environmental artist Christo Javacheff for his <u>Surrounded Islands: project for Biscayne Bay, Greater Miami, Florida, 1980-1983</u> (see Section 9.2).

6.3. Parks and reserves

6.3.1. Biscayne National Park

Biscayne National Monument was established in 1968 (Markley and Milano, 1985; Flik, 1993). Park boundaries expanded in 1974 and 1980, changing its name to Biscayne National Park. The Park encompasses most of southern Biscayne Bay and extends seaward to the 10 fathom line, encompassing 49 acres of keys and 20 miles of reef (Voss *et al.,* 1969). The largest keys are Elliott Key, Old Rhodes Key, Sands Key, Totten Key, Long Arsenicker Key, Swan Key and Adams Key. Biscayne National Park has 47 documented resource sites. The Park is unique in that it is 95% water.

6.3.2. Bill Baggs Cape Florida Recreation Area

The Bill Baggs Cape Florida State Recreation Area is located on the southern part of Key Biscayne and was named after the late Miami newspaper editor who championed this area for a state park.

Ponce de Leon visited the Biscayne Bay area in 1513 and named the southern end of Key Biscayne "Cape of Florida" (Hurley, 1989; Florida Department of Environmental Protection, 2000c). When Florida became a U.S. Territory in 1821 the national network of lighthouses was extended and in 1825 the Cape Florida Lighthouse was built. The lighthouse is still there and is the oldest building in south Florida. In 1836 during the Second Seminole War the lighthouse was attacked and damaged by fire. It was restored in 1846 and placed back in service in 1847. In 1861, Confederate sympathizers removed the lamps and burners and smashed the crucial center prism so it could not be used by the Union sailors. The lighthouse was repaired and re-lit again in 1866. When the Fowey Rocks Light was placed into service in 1878, the lens and illuminating apparatus atop the Cape Florida lighthouse were removed and shipped to Staten Island, NY. A century passed and in 1978, the light was reinstalled by the U. S. Coast Guard to again serve as a navigational aid.

Hurricane Andrew destroyed the Australian pines that once covered the area thus providing an opportunity to restore the natural plant communities and systems historically associated with the island (Figures 45 and 46)) (Colon, 1998; Florida Department of Environmental Protection, 2000c). Seventy five acres of mangroves, beach dunes, the maritime hammock and the freshwater wetland are also being restored. The Bill Baggs Cape Florida State Recreation Area

* Morningside Key, previously known as Spoil Island No. 2, was cleaned and converted into a recreation area during Baynanza 1997 (Tomb, 1997).

Figure 51. North Bay, Harbor and Treasure Islands. [Note spoil islands and Intercoastal Waterway.] [Aerial photograph 5WJ68404, 1992. Scale 1:15000, azimuth 189.7, 25.87195° N, 80.16028° W. (Coastal Aerial Photography, NOAA/National Ocean Service, <http://mapfinder.nos.noaa.gov:80/mapfinderhtml3/surround/photos/photos.html>, <http://mfproducts.nos.noaa.gov/images/Photos/ 5WJ68404.gif>. Black areas are artifacts in original photograph. Figures 38 and newb through newe were reduced to the same scale. See Figure 2 for identification details.] *See color version on p. 130.*

Figure 52. Bird, Legion, Mangrove and Morningside Keys. [North Bay, Harbor and Treasure Islands are at the top of the image. Note channels cutting across seagrass bed.] [Aerial photograph 5WJ68406, 1992. Scale 1:15000, azimuth 189.7, 25.84833° N, 80.165° W. (Coastal Aerial Photography, NOAA/National Ocean Service, <http://mapfinder.nos.noaa.gov:80/mapfinderhtml3/surround/photos/photos.html>, <http://mfproducts.nos.noaa.gov/images/Photos/5WJ68406.gif>. Black areas are artifacts in original photograph. Figures 38 and newb through newe were reduced to the same scale. See Figure 2 for identification details.] *See color version on p. 131.*

Figure 53. Morningside Key and 36th Street Causeway [Teachers Key is at the bottom of the image.] [Aerial photograph 5WJ68408, 1992. Scale 1:15000, azimuth 189.5, 25.825° N, 80.16672° W. (Coastal Aerial Photography, NOAA/National Ocean Service, <http://mapfinder.nos.noaa.gov:80/mapfinderhtml3/surround/photos/photos.html>, <http://mfproducts.nos.noaa.gov/images/Photos/5WJ68408.gif>. Black areas are artifacts in original photograph. Figures 38 and newb through newe were reduced to the same scale. See Figure 2 for identification details.] *See color version on p. 132.*

Figure 54. Teachers, Biscayne, San Marco, and Watson Islands, and Port of Miami. [Oblong shapes on the north side of the Port are cruise ships.] [Aerial photograph 5WJ68410, 1992. Scale 1:15000, azimuth 189.7, 25.80139° N, 80.17445° W. (Coastal Aerial Photography, NOAA/National Ocean Service, <http://mapfinder.nos.noaa.gov:80/ mapfinderhtml3/surround/photos/photos.html>, <http://mfproducts. nos.noaa.gov/images/Photos/5WJ68410.gif>. Black areas are artifacts in original photograph. Figures 38 and newb through newe were reduced to the same scale. See Figure 2 for identification details.] *See color version on p. 133.*

Wetlands Restoration, completed in 1999 was funded by Miami-Dade County with matching funds from the Florida Inland Navigation District, South Florida Water Management District, Miami-Dade Water and Sewer, Biscayne Bay Environmental Enhancement Trust Fund, US Department of Agriculture/Forest Service and the Village of Key Biscayne. The effort is described in Milano (1999).

6.3.3. Crandon Park

Crandon Park opened in 1948 and is located along the northeastern shore of Key Biscayne, between the fossil mangrove forest and the Bill Baggs Cape Florida Recreation Area. Crandon Park was the last public beach development in the Metropolitan Dade County area. Bonds for initial development were sold in 1940 but active construction did not take place until the end of World War II. Rickenbacker Causeway connecting the mainland to Virginia Key and Key Biscayne was started early in 1942. Construction was delayed due to the war. The causeway was opened in 1949 providing access to the Park.

In 1948, a one-truck traveling menagerie in financial difficulties consisting of a couple of bears, some monkeys, ocelots and a goat became the nucleus of the Crandon Park Zoo, the predecessor of the current Metrozoo. The animals were housed in Key Biscayne until they were moved to the mainland facility in 1978.

6.3.4. Matheson Hammock Park

Matheson Hammock Park* , the oldest in Miami-Dade County, is a man-made Atoll Pool which is flushed naturally with the tidal action of Biscayne Bay (Figure 55). The Park was named after Commodore W. J. Matheson, a New York chemical and dye manufacturer, who arrived in Dade County in 1902. Upon his death in 1930, 100 acres of mangrove and hammock were willed to Dade County and became the basis of the Park, built during the 1930s by the Civilian Conservation Corps. The Atoll Pool is fed from Biscayne Bay through four aluminum-grated gates and aerated to reduce bacterial levels.

6.3.5. Deering Estate and Vizcaya

The Deering Estate is located on the shore of Biscayne Bay and some of South Florida's earliest buildings, dating to 1896, are found in the site (Miami-Dade County, 2000) (Figure 55). Fossil bones have been found in the area dating as far back as 50,000 years. Tequesta Indians lived on the site from about 2000 years ago to the late 1700s. In 1838, the US awarded a provisional land grant, the Perrine Grant, to Dr. Henry Perrine for the propagation of commercially valuable tropical plants, in what is currently the Deering Estate. Perrine was killed during the Second Seminole War and never settled in the area. After the Second and Third Seminole Wars, several settlers established home sites in the area. By the 1890s, the area became known as "Cutler". In 1900, the Richmond family added a structure to their 1896 house and opened the "Richmond Cottage," the first hotel between Coconut Grove and Key West. The Richmond family home and the Richmond Cottage are two of the most significant historic buildings on the Estate. Industrialist Charles Deering bought the Richmond property in 1913 and remodeled it into his private winter residence. His brother, James Deering, built Vizcaya in 1916, an Italian Renaissance-style villa and formal gardens as a winter residence (Figure 56).*

* Information from upublished material provided by Matheson Hammock Park (2000).

* Vizcaya is just south of the present day Rickenbacker Cswy.

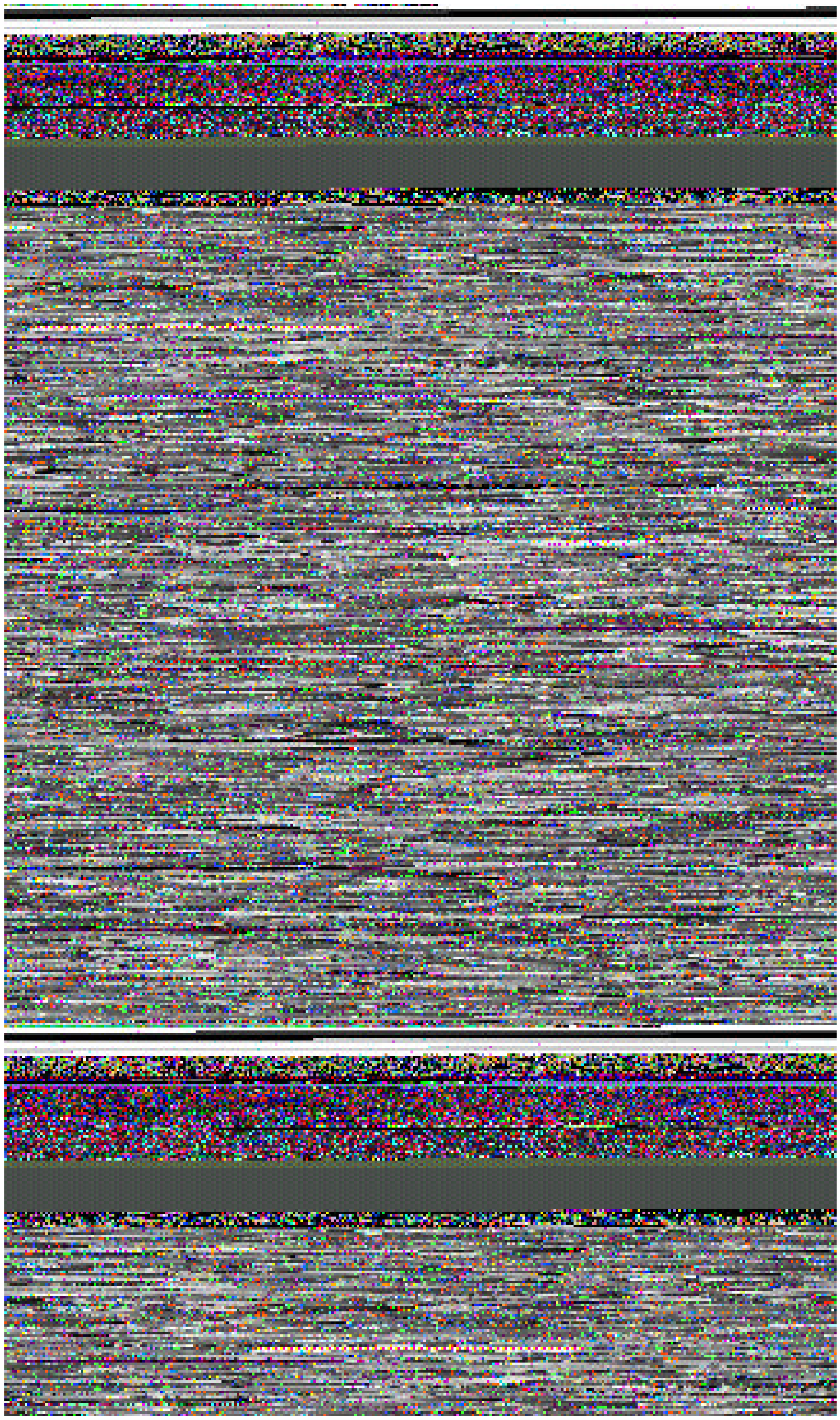


Figure 55. Matheson Hammock, ITT Hammock, the Deering Estate and Chicken Key. [The Matheson Hammock Atoll Pool is the circular feature at the top left of the image. The Snapper Creek Canal (C-2) passes through the ITT Hammock. The Deering Estate is to the right (west) of Chicken Key at the bottom left of the image.] [Aerial photograph 5WGQ2977, 1992. Scale 1:48000, azimuth 11.2, 25.65028° N, 80.29361° W. (Coastal Aerial Photography, NOAA/National Ocean Service, <http://mapfinder.nos.noaa.gov:80/mapfinderhtml3/surround/photos/photos.html>, <http://mfproducts.nos.noaa.gov/images/Photos/5WGQ2977.gif>. See Figure 2 for identification details.] *See color version on p. 134.*

Figure 56. Vizcaya and Mercy Hospital. [Vizcaya is near the top center of the image. The old access channel leading to the stone "boat" (the small oval-shaped island) built on the water at the back of the house can be seen. The Mercy Hospital complex is south of Vizcaya. The Rickenbacker Causeway is at the top left of the image.] [Aerial photograph 5WJ68378, 1992. Scale 1:15000, azimuth 9.5, 25.73583° N, 80.21333° W. (Coastal Aerial Photography, NOAA/National Ocean Service, <http://mapfinder.nos.noaa.gov:80/mapfinderhtml3/surround/photos/photos.html>, <http://mfproducts.nos.noaa.gov/images/Photos/5WJ68378.gif>. See Figure 2 for identification details.] *See color version on p. 135.*

Construction of the Estate's keyhole-shaped Boat Basin began in 1916 and was completed in 1918. The Boat Basin was built directly on an axis with the Richmond Cottage, as a focal point for the arrival of his yacht, the "Barbee," schooners bringing construction materials, and other vessels. Deering descendants inhabited the property until 1980. The Estate was purchased by the State of Florida and Miami-Dade County in 1985. The Estate is managed by the Miami-Dade Park & Recreation Department, in partnership with the Deering Estate Foundation.

The Estate contains over 115 acres of coastal tropical hardwood hammocks and 150 acres of globally endangered pine rockland forests. A variety of wildlife such as grey foxes, spotted skunks, squirrels, bobcats and birds inhabit the area. Mangroves, salt marshes and the offshore island of Chicken Key occupy 130 acres of the Estate and are accessible by canoe.

The Deering Estate was seriously damaged by Hurricane Andrew in 1992 and restoration efforts are in progress.

6.3. Municipal facilities

6.3.1. Power plants

6.3.1.1. Turkey Point Nuclear Power Plant

The Florida Power and Light Turkey Point Nuclear Power Plant is located in Homestead and covers 22,295 acres (Ho, 1998). The facility is a combination of two fossil fuel and two nuclear units, and it is linked to the statewide electrical power transmission system. The fossil fuel units began operation in 1967 and 1968, and the nuclear units in 1972 and 1973. The fossil fuel storage units hold 554,000 barrels of low sulfur oil. The fossil fuel units consume 20,000 barrels of oil and 4,000 barrels of natural gas daily. Approximately 300 tons of uranium are required to produce a year's supply of fuel for both nuclear units.

The effect of thermal pollution on the fauna and flora of southern Biscayne Bay and Card Sound were extensively studied during the 1970s before and after cooling canals were installed. In 1972, a 2700 ft/min thermal effluent flowed directly into Card Sound at a point 6 miles south of the Florida Power and Light Company's Turkey Point site (Thorhaug and Bach, 1973). In March 1973, a self-circulating canal system was opened and effluent stopped entering Card Sound (Figure 57).

During the period when effluent was discharged into Card Sound, the maximum temperature rise was about 1° C over ambient in an area of about one acre directly in front of the canal mouth. This same area was covered to about 30 cm depth with suspended matter from the canal. A two-year study of attached algae in Card Sound revealed no significant changes in the normal seasonal pattern of productivity and standing crops of four major calcareous macro-algae (*Penicillus, Halimeda, Udotea,* and *Rhipocephalus)* and green algae except in the area of deposition of suspended matter directly in front of the canal mouth where the plants were apparently smothered (Thorhaug *et al.*, 1979). The distribution of the red algal macrophyte association was affected by flow from the canal since this group, predominantly *Laurencia poitei,* forms large rolling mats that are subject to influence by currents.

The self-circulating cooling canal system has affected the fauna and flora of the area. About 64% of the system is water and about 36% is spoil berm (Gaby *et al.*, 1985). The berms were created from material dredged during the construction of the canals and support a variety of vegetation. While vegetation of the surroundings is dominated by mangrove swamp, the dominant vegetation of the cooling canals is Widgeon grass (*Ruppia maritima*).

Figure 57. Turkey Point cooling canals. [Composite image prepared from aerial photographs 5WGS3233 and 5WGS3235, Jan. 2, 1992. Scale 1:48000; azimuth 191 and 192.1; 25.40778° N, 80.31194° W and 25.37195° N, 80.31972° W. (Coastal Aerial Photography, NOAA/National Ocean Service, <http://mapfinder.nos.noaa.gov:80/mapfinderhtml3/surround/photos/photos.html>, <http://mfproducts.nos.noaa.gov/images/Photos/5WGS3235.gif> and <http://mfproducts.nos.noaa.gov/images/Photos/5WGS3233.gif>. Black areas on the left of the image are artifacts in original photographs. See Figure 3 for identification details.] *See color version on p. 136.*

Chemistry studies of Biscayne Bay were non existent prior to the building of Turkey Point (Roessler and Tabb, 1974). The construction of the canal system and potential thermal pollution resulted in comprehensive studies of southern Biscayne Bay and Card Sound (e.g., Bader, 1969; Bader and Tabb, 1970; Gerchakov *et al.*, 1971; Gilio and Segar, 1976; Segar *et al.*, 1971; and others).

No changes were observed in salinity, nutrients, dissolved oxygen, Fe, Cu, and alkalinity of the cooling water itself during a two-year monitoring effort (Gerchakov *et al.*, 1971).

Gaby *et al.* (1985) found that the American crocodile used the berms of the cooling canals as nesting sites. The Turkey Point population contributes 10% of the annual production of hatchlings in south Florida. The resident population exhibits differential habitat preference according to size class, and shows seasonal changes in distribution. Salinity was a factor in these trends. Ecology and population structure were similar to those of the population residing in the more pristine habitat of Everglades National Park.

6.3.1.2. Cutler Ridge Power Plant

The Cutler Ridge Plant is a fossil fuel power plant that discharges heated water into a small, shallow, partially enclosed portion of central Biscayne Bay. A study was conducted of water and sediment temperatures, sediment character and benthic plants (Smith and Teas, 1977). Analysis of aerial photographs showed that there had been an increase in the area of denuded seafloor near the thermal discharge point from 8.5 ha in 1956 to 35 ha in 1973, when full capacity of the plant was reached. Ground truth checks indicated that the bare region at the effluent canal was an area of macrophyte loss, which corresponded to the highest temperatures of the thermal effluent.

Cutler Bay has considerable protection from the wave action of Biscayne Bay and thus appears to be a sump for fine sediments. Some of the fine material could be the result of materials in the water that are precipitated or coagulated by passage through the power plant cooling condensers. Aerial photographs show an increase in macrophyte cover in Cutler Bay since 1938 probably associated with the deposition of sediment associated with deepening the boat channel and dredging of the power plant effluent canal. Macrophyte standing crop in Cutler Bay is positively correlated with sediment depth.

In 1963, Florida Power and Light (FP&L) proposed to expand the Cutler Plant by adding two conventional units (Atkinson, 1970). Miami refused to grant the license. In 1964, FP&L proposed building a new plant at Turkey Point. In 1966, FP&L applied to the Atomic Energy Commission to build two nuclear units to supplement the existing two conventional units. In 1967, the Dept. of the Interior Fish and Wildlife Service voiced concern about thermal pollution generated by the cooling system needed for the nuclear units.

6.3.2. Sewage treatment plants and waste disposal sites

6.3.2.1. Virginia Key Sewage Treatment Plant and the Cross Bay Line

During the 1950s, discharge of raw sewage into the Bay was eliminated or reduced by collecting sewage at large pumping stations and sending it under pressure through the Cross Bay Line to a treatment plant in Virginia Key. This system was completed in 1956 (Stone and Suman, 1995). Currently there are three wastewater collection zones (North, Central and South Districts) in Dade County. The North and South Districts have regional wastewater treatment plants that provide secondary treatment of the sewage before it is discharged into the ocean via outfalls. The sewage from the Central District continues to be sent to the Virginia Key facility through the Cross Bay Line.

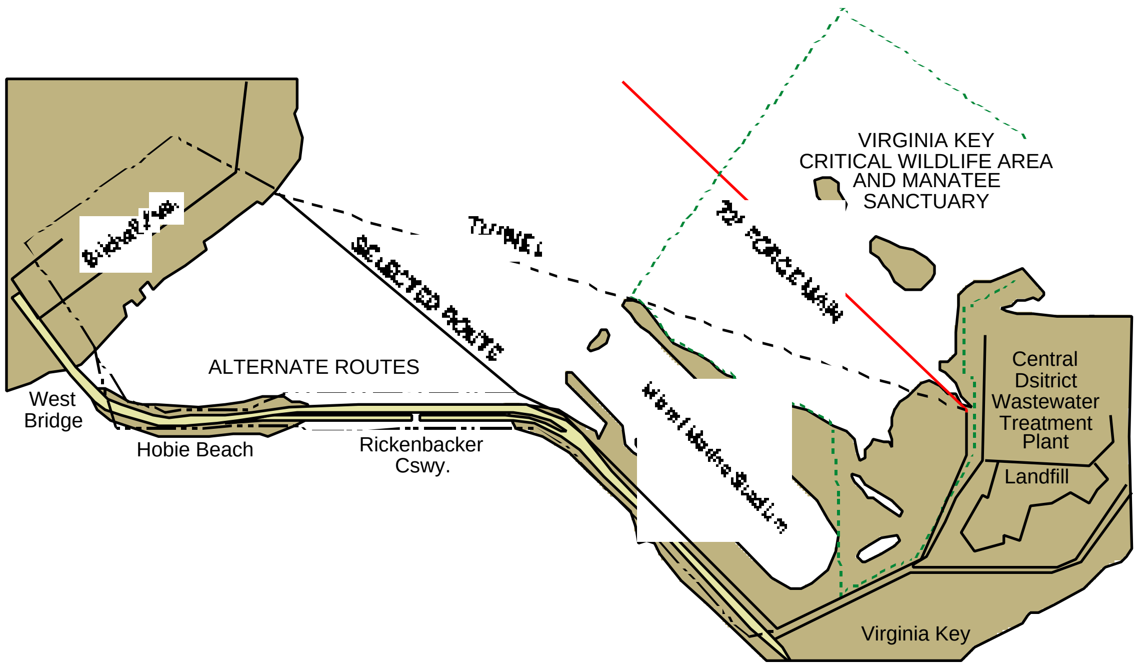


Figure 58. Alternate and final routes for the Cross Bay sewer line. [Redrawn from Swakon *et al.* (1995).]

The Cross Bay Line, in operation since 1956, is a 72-in diameter reinforced concrete cylinder pipe (Figure 58) (Wilson, 1993; Miami-Dade Water and Sewer Department, 1994; Stone and Suman, 1995). The line crosses under Biscayne Bay from Bayside to the shore of Virginia Key, a distance of approximately 14,400 ft. Building specifications required the pipe to be buried below the bottom to a minimum cover of 5 ft. The invert elevation at Bayside is 28 ft below mean sea level and rises to a depth of 15.5 ft at Virginia Key. There are nine manhole covers along the crossing. The manholes rise from the pipe to the top of the sediment. Additionally, there is a 16-in sludge force main from the North District Plant paralleling the Cross Bay Line.

In recent years, leaks have developed in the Cross Bay Line due to corrosion* /scouring, joint leaks, and pipe segment break. Pipe and manhole failures can occur independently or in combination and may result from internal or external events. Contingency plans are in place in case of line rupture, but 90 million gallons of raw sewage could flow into the Bay every day for at least two weeks resulting in severe damage to the ecosystem (Wilson, 1995). There were several years of ongoing discussions to replace the Cross Bay Line before failure. The options considered for replacement of the pipe had severe environmental restrictions since Biscayne Bay is now a protected Aquatic Preserve. Permits for replacement of the pipe were issued in 1993 and the in-water portion of pipeline replacement was completed in 1994. By 1995, some natural re-growth of seagrasses was noted in the disturbed bottoms area (Swakon *et al.*, 1995).

The Cross Bay Line Contingency Plan Update detailed the course of action for the Miami-Dade Water and Sewer Department in the event of a Cross Bay Line failure resulting in the discharge of pollutants to Biscayne Bay (Miami-Dade Water and Sewer Department, 1994). Of primary importance was the minimization of adverse effects on human health and welfare by users of

* Corrosion can occur from the formation of sulfuric acid from the hydrogen sulfide in the saw sewage.

the Bay and the beaches. Preservation of water quality and protection of environmentally sensitive areas were also essential concerns.

6.3.2.2. Munisport

Munisport is 290-acre inactive municipal landfill owned by the City of North Miami. A detailed description of the site can be found in Florida Department of Health and Rehabilitative Services (1998) (Figure 41). The landfill operated from 1974 through 1981. The site received several million cubic yards of solid waste including clean fill, construction debris, municipal and hospital refuse and drums containing tricresol phosphate, ethyl cyanoacetate and acetate (Hicks, 1989). Groundwater associated with the landfill is contaminated with high concentrations of ammonia and low levels of trace metals, pesticides and volatile organics. Movement of the groundwater is towards a residential canal, a Florida State Mangrove Preserve and Biscayne Bay. The Florida Mangrove Preserve is approximately 130 acres and is subjected to daily tidal exchange with North Bay. Tidal exchange takes place through two culverts. A dike separates the landfill from the mangrove preserve. In 1983, the Environmental Protection Agency (EPA) added this site to the Superfund National Priorities List. There has been no remediation at this site since landfill operations ceased in 1980. EPA is considering removing the Munisport landfill site from the Superfund list (Park, 1998).

Despite its contamination, Interama, an international business concern, proposed to locate at the site. It did not but the site became the Bay Vista Campus Florida International University. The Bay Vista Campus Wetland Restoration project, completed in 1995, was funded by Miami-Dade with matching funds from the Dade County Public Works Dept. The effort is described in Milano (1999).

6.4. Defense facilities

6.4.1. Homestead Air Force Base

During the 1940s, Pan American Ferries, Inc. constructed a landing strip in rural Dade County that was turned over to the US Government before the beginning of World War II. Shortly after the attack on Pearl Harbor, Army Air Corps officials decided the site would serve defense needs as a maintenance stopover point for aircraft being ferried to the Caribbean and North Africa and construction of a fully operational military base, the Homestead Army Air Field (AAF), began. By 1943, the base assumed a more vital role with the activation of the 2nd Operational Training Unit that provided advance training for air crews. As the need for trained transport pilots grew, the entire base was transferred to Air Transport Command's (ATC) Ferrying Division, with the sole mission of preparing C-54 air crews to fly from Burma to China.

After World War II in September 1945, a massive hurricane passed through the area causing such destruction the base was shut down in December of that year (see Section 5.1.3). The base property was then turned over to Dade County and was managed by the Dade County Port Authority for the next eight years. During this period, the runways were used by crop dusters and the buildings housed a few small industrial and commercial operations.

In the early 1950's, as the Korean conflict was winding down, defense officials once again looked toward Homestead as a key site in continental defense. In mid-1954, an advance party arrived at the old base to begin clean up, and in February 1955, it was reactivated as Homestead AFB. The base quickly became home for the 823rd Air Division, an umbrella organization encompassing the 379th and the 19th Bomber Wings. By this time, Homestead AFB represented the largest four-engine transport training operation in the entire ATC. In 1962, the 31st Tactical Fighter Wing (TFW), a tactical air fighter unit, was moved from George AFB, CA, to Homestead in response to the growing Communist threat from Cuba. In October of that year, it was discovered that the Soviet Union was placing medium-range missiles on the island. Troops and aircraft were sent to Homestead, swelling its population to tens of thousands. Though still nominally a Strategic Air Command base, Homestead then had the dual mission to stand ready to project air power around the world, and to maintain an operationally ready tactical air force. With the presence of the 31st TFW made permanent, the role of the Tactical Air Command (TAC) at Homestead AFB increased rapidly throughout the 1960s. In late 1966, the 31st TFW was deployed to Vietnam, and the 4531st TFW was activated to maintain TAC's presence at Homestead. In 1968, TAC officially took control of the base. In 1970, the 31st TFW returned from Vietnam and became the host unit. In 1981, the 31st TFW became the 31st Tactical Training Wing and took the task of training F-4 air crews. Training remained the Base's primary mission until 1985, when the first F-16 arrived. With that event, the host unit again reclaimed the designation of the 31st TFW.

Hurricane Andrew struck Homestead AFB in 1992, the base was home to the 31st and the 482nd Fighter Wings. Both units flew F-16s. Other units in the base were the 301st Rescue Squadron, Air Force Reserve; the Det 1, 125th Fighter Interceptor Group, Florida Air National Guard; and the US Customs Miami Air Branch. The storm caused such severe damage that all these units were relocated during the salvage and recovery phase. Even though the 301st Rescue Squadron along with the Coast Guard provided the only emergency medical rescue capability in south Dade County immediately after the hurricane, it too was removed.

In 1993, the Department of Defense Base Realignment and Closure Commission recommended the conversion of the base to a military/civilian joint use airfield. The Commission recommended that the host unit, the 31st Fighter Wing, be activated and that the 482nd Fighter Wing, the 301st Rescue Squadron, and the 125th Fighter Interceptor Group be returned to the base. The US Customs unit was scheduled to return. Other units were transferred elsewhere. Approximately one third of the base was to remain a military installation, the Homestead Air Reserve Base (ARB), and the rest will eventually be transferred to Dade County.

It has been proposed that the Homestead ARB be converted into an international airport ten times the size of the original base. The proposed action is to transfer the 1,632 acres of now surplus property, including the runway, to Miami-Dade County for use as a commercial airport. Alternative plans, including a commercial spaceport, are under consideration (US Air Force and Federal Aviation Administration, 1999).

Biscayne National Park is directly connected to the Homestead ARB by Military Canal, which carries storm run-off from the base into the Bay (Zaneski, 1999; Heinrich, 1997) (see Section 6.1.3.2). The canal is considered a Superfund site. Additional run-off from the airport could include jet fuel, solvents and other hazardous materials which could result in harmful effects on the Bay's ecosystem.

There are concerns about the impact of increasing aircraft noise from initial activity level up to the maximum capacity of the existing one runway (Heinrich, 1997; Mackay, 1998; Landrum and Brown, 1999). Alternative traffic routing has been proposed to modify or reduce noise within properties owned and operated by the National Park Service and the Fish and Wildlife Service.

6.4.2. Richmond Naval Air Station

The Richmond Naval Air Station (NAS) was the Navy's largest Airship Station, short of the one in Lakehurst (Friends of Naval Air Station - Richmond, 2000; Atwood, 1996). It was built in 1942, 20 miles south of Miami. Three large airship hangars and all of an active navy base's support buildings and barracks were built quickly and by the summer of 1942 the first airship arrived at the base. Richmond NAS was home to ZP-21, the largest squadron of airships in the Navy. Five more squadrons and a dozen smaller K-Ship bases reported to NAS Richmond. Its three hangars were the largest wooden buildings on earth at that time (16 stories). The Navy's first giant M-Class Airships were assigned to NAS Richmond for testing and deployment. From its headquarters, NAS Richmond oversaw the defense of the Panama Canal, and anti-submarine warfare in the Battle of the Atlantic and the Gulf Sea Frontier. PBYs, fighters, and other HTAs (Heavier than Air aircraft) routinely landed at NAS Richmond's airstrip.

As the Hurricane of 1945 approached, 14 K-Ships stood moored in the cavernous hangars. Another 11 airships were deflated and crated for space. Aircraft from NAS Fort Lauderdale, NAS Opa Locka, and NAS Key West, and TBMs, F-4 Hellcats, Widgeons, patrol and cargo planes arrived at NAS Richmond and were brought into the hangars totalling in all 213 naval aircraft. Eastern Air Lines requested hangar space for its aircraft. Embry-Riddle Aviation School, which had trained thousands of military aviators, also appealed for safe haven for its fleet of Steerman trainer biplanes. The Base granted permission and 152 more planes joined the Navy blimps and aircraft in the hangars. One hundred automobiles and trucks were also stored in the hangars. About mid afternoon the hurricane came ashore and NAS Richmond was directly in its path. Shortly after 5 PM, a fire broke out in Hangar One. High winds spread the fire to the other hangars and within minutes, all three hangars were ablaze. The hangars and their contents were a total loss. It was the largest fire of 1945, assessed at $30 million (in 1945 dollars). The damage constitutes the largest peacetime loss of federal property, in the shortest time, on record.

6.7. Artificial reefs

Florida is the leading state in number of artificial reefs (Pybas, 1997). The first artificial reef permit on file is dated 1918. Heaviest reef construction took place from 1987 to 1991. Within the boundaries of Dade County, there are 21 artificial reef sites, most with more than one structure and located outside the barrier islands. The seven artificial reefs located within Biscayne Bay proper are listed in Table 4. Additional reefs have been constructed since 1997.

Table 4. Artificial reefs within Biscayne Bay (Pybas, 1997).

Year	Name	Depth (ft.)	Location [Latitude (N), longitude (W)]	Composition
1982	North Bayshore Park Reef	7	25° 53.2', 80° 9.0'	Concrete rubble, pipe
1991	San Souci Reef	25	25° 52.9', 80° 8.5'	3611 tons limerock boulders
1979	Pelican Harbor Reef	7	25° 50.5', 80° 10.0'	Concrete culvert
1982	Julia Tuttle Artificial Reef	28	25° 48.8', 80° 10.2'	133 Autos, 12 vessels, 27 tanks, 2540 tons concrete
1991	Brickell Area Reef	12	25° 44.9, 80° 11.2'	3370 Tons limerock boulders
1986	Rickenbacker Causeway Reef	10	25° 44.8, 80° 10.9'	Concrete piles, limestone boulders
1984	Mercy Hospital Reef	10	25° 44.3', 80° 12.7'	Concrete rubble, bicycle racks, vessels, habitats

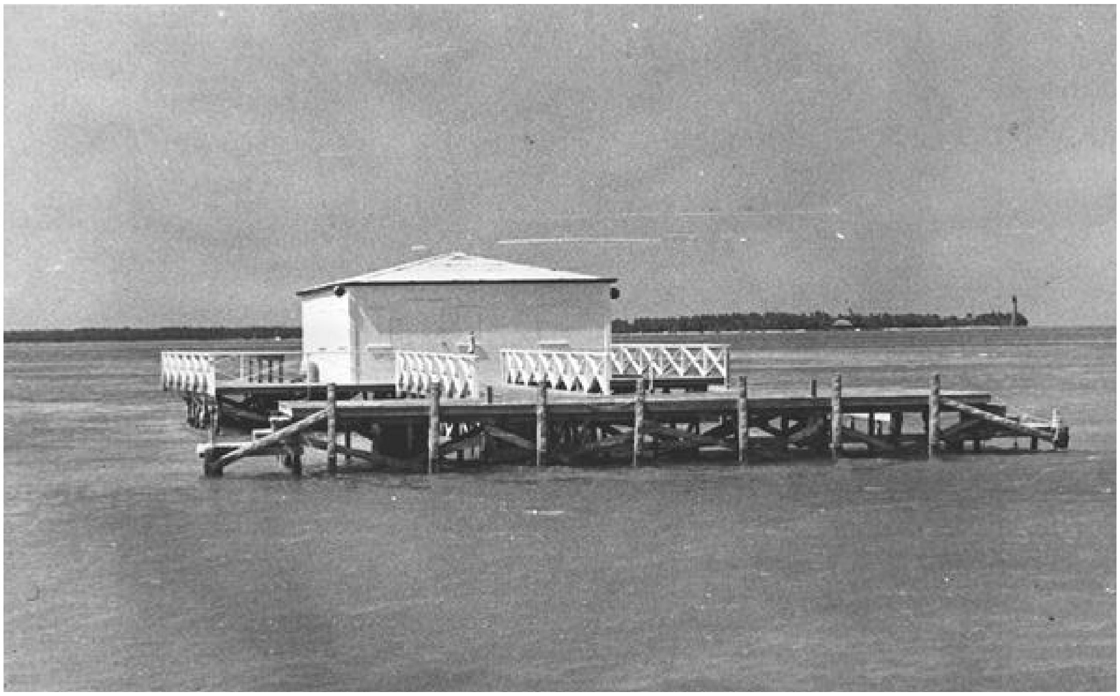


Figure 59. Second fishing shack that belonged to the Ruskin and Orovitz families (194-). [The Cape Florida Lighthouse is on the far right of the photograph.] [Photonegative, black and white (4 x 5 in). ms25975. MOSAIC Collection, Florida State Photo Archive. <http://fpc.dos.state.fl.us/>]

6.6. Stiltsville

Stiltsville is the local name for a group of houses built on pilings approximately a mile offshore in Biscayne Bay. The first structure was Crawfish Eddie's bait shack built in the 1930s on a barge that had run aground about one mile south of the Cape Florida lighthouse (Semple, 1997). During the 1930s and 1940s, houseboats and barges were towed to the sand flats and either moored or sunk and houses built atop (Williams, 1990). Later on, these structures were replaced by more permanent houses on stilts (Figure 59). Stiltsville's heyday was in the 1950s with 25 or so residences and two nightclubs. Regulars of the two nightclubs could sit on a barstool and fish right through the floor. The lack of liquor licenses and outhouse sanitation resulted in regular raids by the Police, and the clubs closed in the 1960s. Soon after that hurricanes Cleo and Betsy destroyed all but thirteen structures. Hurricane Andrew destroyed six of the remaining thirteen houses in 1992.

Stiltsville has seven surviving houses. No new houses are permitted on the site. It is currently within the jurisdiction of the Biscayne Bay National Park. Stiltsville could be demolished, preserved, or left as is until the houses are destroyed by natural causes. Under Park rules, all structures were scheduled to be removed by July 1, 1999. As of this writing, negotiations regarding the fate of Stiltsville will continue until December 2000 (Morgan, 1999).

Stiltsville has served as an unofficial navigation aid to the inexperienced boater: "No body of water in North America attracts more certifiable morons in high powered yachts and speedboats than Biscayne Bay. Most of them don't know the difference between a channel marker and a lobster pot, but they do know a double-decker house when they see one looming off their bow" (Hiaasen, 1999) (Figure 60).

Figure 60. Vessel aground, Biscayne Channel, Biscayne National Park (1998). [Note prop scarring in the seagrass bed. One of the houses of Stiltsville is seen at the upper left of the image.] (Photo by Karen Battle, Biscayne National Park.) *See color version on p. 137.*

6.7. Archeological sites and the Miami Circle

During routine excavations in June 1998 prior to construction of a planned apartment building, the Miami-Dade County Historic Preservation Division uncovered a 38-foot diameter circle of holes cut into the limestone of Brickell Point (Milanich, 1999; Miami-Dade Parks, 2000). The site is known as the Miami Circle. Brickell Point is the southern side of the Miami River where it flows into Biscayne Bay (see Figures 6, 7 and 17 for site location). The Circle site is part of the village of Tequesta, once located on both the north and south banks of the Miami River in what is now downtown Miami. Shell middens, Glades pottery, shell, stone and bone artifacts, and human and animal remains have been uncovered at the site. Archeological activities in the area prior to the discovery of the Miami Circle can be found in Laxon (1959 and 1968). The discovery of the site halted construction and triggered a complex legal and media battle between the County, the City of Miami, the builders and the public. Controversy about the site continues. A detailed description of the site can be found in Miami-Dade Parks (2000).

7. ECOSYSTEM CHANGES

The rare, endangered and species of special concern found in the Biscayne Bay Aquatic Preserve are listed in Table 5 (Florida Department of Environmental Protection, 2000a).

7.1. Flora

7.1.1. Seagrasses

The major vascular plants found in Biscayne Bay are *Thalassia testudinum* (turtle grass), *Halodule wrightii* (Cuban shoal grass), and *Syringodium filiforme* (manatee grass). *Thalassia* is dominant in many areas of the Bay and *Thalassia* beds support a rich animal community (Zieman, 1982). These plants function as a food source, provide shelter and protection, stabilize sediments, and act as a chemical sink (Thorhaug, 1976). There is a progression of these seagrasses with distance from shore in non-disturbed areas of Biscayne Bay. Intertidally, there is a band of *Halodule*. From sublittoral, there is a band of *Thalassia* interspersed with *Halodule* and *Syringodium*. This thins out into green alga and a sand bottom towards mid-Bay. Seagrasses in the northern part of the Bay have been heavily impacted by man's activities and the normal *Thalassia* community is not observed north of the Port of Miami.

Sediment is generated by *Thalassia* communities and major disruptions to the seagrass beds result in modifications to the sediments.

Attempts were made in 1982 and 1984 to rehabilitate approximately 110 ha of barren sea bed with seagrass (Thorhaug, 1977; Thorhaug, 1980; Thorhaug, 1987; and others). Efforts have been carried out to revegetate areas of Biscayne Bay with seagrasses and currents, wave action and turbidity difficulties in these efforts.

The effect of the thermal effluent released by the Turkey Point Nuclear Power Plant on *Thalassia* beds has been studied extensively. *Thalassia* disappeared in areas of water 5° C above ambient, and declined by 50% in waters 3-4° C above ambient temperature (Thorhaug *et al.*, 1973). Environmental stress caused by temperature or salinity changes may make *Thalassia* more susceptible to disease.

An increasing problem in Biscayne Bay is the scarring of seagrass beds, commonly made when a boat's propeller tears and cuts up roots, stems and leaves (Sargent *et al.*, 1995; Zaneski, 1998). The greatest acreage of moderate to severe scarring occurred in areas of dense human population and a large number of registered boats. An assessment of the degree of seagrass bed scarring statewide indicated that approximately 8% of the seagrass beds in Dade County were scarred, and approximately 6% were rated with moderate/severe scarring (Figures 61 and 62).

7.1.2. Mangroves

The information in this section was found in Hanlon *et al.* (1975). A thorough discussion of mangrove forest ecology can be found in Odum *et al.* (1982).

The most common mangrove species in the tropical coastlines of North America are: the red mangrove (*Rhizophora mangle*); the black mangrove (*Avicennia germinans*); the white mangrove (*Laguncularia racemosa*); and the buttonwood (*Conocarpus erectus*). The mangroves characterize and dominate a large portion of the world's tropical coastal margins and their

Table 5. Rare (R), endangered (E) and species of special concern (SSC) found in Biscayne Bay (Florida Department of Environmental Protection, 2000a).

		State designation	Federal designation
FISH			
Common snook	*Centropomus undecimalis*	SSC	
Mangrove rivulus	*Rivulus marmoratus*	SSC	
REPTILES			
American alligator	*Alligator mississippiensis*	SSC	
American crocodile	*Crocodylus acutus*	E	E
Atlantic green turtle	*Chelonia mydas mydas*	E	E
Atlantic hawksbill turtle	*Eretmochelys imbricata imbricata*	E	E
Atlantic loggerhead turtle	*Caretta caretta caretta*	T	
Atlantic ridley turtle	*Lepidochelys kempi*	E	
Eastern indigo snake	*Drymarchon corais couperi*	T	T
Gopher tortoise	*Gopherus polyphemus*	SSC	
Miami black-headed snake	*Tantilla oolitica*	T	
BIRDS			
Arctic peregrine falcon	*Falco peregrinus tundrius*	E	T
American oystercatcher	*Haematopus palliatus*	SSC	
Bald eagle	*Haliaeetus leucocephalus*	T	E
Brown pelican	*Pelecanus occidentalis*	SSC	
Burrowing owl	*Speotyto cunicularia*	SSC	
Cape Sable seaside sparrow	*Ammodramus maritimus mirabilis*	E	E
Least tern	*Sterna antillarum*	T	
Little blue heron	*Egretta caerulea*	SSC	
Limpkin	*Aramus guarauna*	SSC	
Osprey	*Pandion haliaetus*	SSC	
Piping plover	*Charadrius melodus*	T	T
Red-cockaded woodpecker	*Picoides borealis*	T	E
Reddish egret	*Egretta rufescens*	SSC	
Roseate spoonbill	*Ajaia ajaja*	SSC	
Snowy egret	*Egretta thula*	SSC	
Tricolored heron	*Egretta tricolor*	SSC	
White-crowned pigeon	*Columba leucocephala*	T	
Wood stork	*Mycteria americana*	E	E
MAMMALS			
Florida panther	*Felis concolor coryi*	E	E
West Indian manatee	*Trichechus manatus latirostris*	E	E

Figure 61. Grounding and prop scars, Featherbed Shoal, Biscayne National Park (1996). (Photo by Karen Battle, Biscayne National Park.) *See color version on p. 137.*

Figure 62. Grounding trench, Pelican Bank (1994). (Photo by Mark Nicholas, Gulf Islands National Seashore.) *See color version on p. 138.*

habitat is a unique blend of land and aquatic ecosystems. There is a natural succession of mangroves from seaward to landward. The red mangrove occurs at the seaward edge, the black mangrove occurs further landward, and the white mangrove occurs farthest from the shore.

The red mangrove, with its thick mass of prop roots, is particularly well established in the substrate, and only the most violent of hurricanes can disturb it. It forms a protective barrier along the coast, behind which the other mangroves and associated flora take root. The accumulation of sand, leaves, and debris which is caught in this web of roots eventually decomposes and raises soil levels. At the same time, red mangrove seedlings take root farther seaward as the soil level increases. In time, the result is a gradual seaward extension of the coastline. The landbuilding quality of the red mangrove is important. It does well on nearly all types of soil or substrate provided they are wet. The black mangrove does well on all soils, including some dry and salty ones. The white mangrove does best in sandy and drier soil, thus explaining its general occurrence on higher ground.

Until recently, mangrove forests in Florida were regarded as a wasteland suited only for development. However, these forests contribute in many ways to man's economic betterment. Ninety-five percent of the annual mangrove leaf production eventually enters the aquatic system. The fallen leaves from the mangroves collect between the roots and begin to be decomposed bacteria and fungi, which turn the leaves into detritus. The detritus, or plant debris, of mangrove origin accounts for 35-60% of the suspended material in estuarine waters. Most of the other detrital material comes from the sea grasses. This detritus is the basis of the estuarine food chain, contrary to previous thought which maintained that all estuarine food chains were based upon phytoplankton.

A host of small invertebrate animals, ranging from nematodes to small crabs and shrimp, feed on this detritus. They in turn are eaten by the larger predators, including commercial and game fish. It has been pointed out that the commercial shrimp of the Dry Tortugas are dependent upon the mangrove swamp as a nursery ground. Equally important is the fact that several other commercially valuable species, including mullet, gray snapper, red drum, blue crabs, tarpon, snook, and spotted sea trout, also rely on the mangrove swamp as a nursery and feeding ground. It is therefore evident that the destruction of mangroves would be tantamount to the removal of the primary food source upon which many animals of commercial and recreational importance depend.

The role of the mangroves in landbuilding, shore protection and stabilization, and reforestation is of paramount importance. The tropical belts of the world are subjected annually to tropical depressions and hurricanes and mangrove forests are well suited to protect the coastline against the force of these storms.

Mangroves along Biscayne Bay can be classified into five communities: Coastal Band, Dense Scrub, Sparse Scrub, White and Mixed, and Black Marsh (Teas, 1974). The Coastal Band of mature mangroves along the shore is the most productive, and the dwarfed Sparse Scrub the least. Red mangroves along Biscayne Bay suffer from infestation by the marine isopod *Sphaeroma* and from tumors, and all mangrove species suffer from lightning damage and storm erosion.

During the last few years, mangrove dieoffs have been observed. There is no evidence of seasonality. The dieoffs were first observed in black mangrove at higher elevations but are currently observed in red mangrove at lower elevations. There is a rough correlation with seagrass dieoffs suggesting possible correlation to high salinities (Brown and Ortner, 1994).

Davis (1940) reported that, in numerous instances, fishermen and guides pointed out changes they observed during the past 20 to 40 yrs in mangrove forests, and some of these observations, when checked against maps, were found to be reliable. Snedaker (1994) suggests that changes in precipitation and runoff are the most important factors concerning mangrove survival. Reduced rainfall and runoff would result in higher salinity and greater seawater exposure. This change would likely be associated with decreased primary production and increased sediment organic matter decomposition leading to subsidence. Higher rainfall and runoff would result in reduced salinity and exposure to sulfate, and also increase delivery of terrigeneous nutrients. Consequently, mangrove production would increase and sediment elevations would be maintained. Support for this scenario derives from studies of the high production in saline mangrove impoundments which are depleted in seawater sulfate.

In addition to changes in mangrove ecosystems due to climatic factors, mangrove forests along the shores of Biscayne Bay were destroyed beginning in the 1910s as the result of urbanization (Figures 9 and 23). The construction of the drainage canal system changed the hydrology of the area further changing the mangrove ecosystem.

7.2. Fauna

7.2.1. Sponges

The information in this section was found in Stevely *et al.* (1978). A historical account of the sponge fishery along the east coast of Florida can also be found in Shubow (1969).

Up until the 1940s, the sponge fishery was one of the most valuable fisheries in Florida. However, a combination of disease, heavy harvesting, and the introduction of synthetic sponges reduced the industry to a small fraction of its former importance. Low level sponging activities in Florida for the last 30 yrs indicates that the sponge industry, as it is currently structured, will probably never return to its former production levels. Production in the Tarpon Springs area, the traditional center for sponging in Florida, declined to extremely low levels and Dade County emerged as the center of the now much smaller industry.

In the 1880s, schooners harvested the sponge beds of Elliott Key, Soldiers Key and other parts of Biscayne Bay as far north as Miami. During the early part of the century, the sponges of Biscayne Bay were evaluated for commercial purposes and found to be of excellent quality. Sponge industry activities, however, remained low key as the main centers of the fisheries were in Tarpon Springs and Key West. During 1938 - 1939 sponge beds on both coasts of Florida were affected by a blight. The disease first appeared in the Bahama Islands and rapidly spread throughout the West Indies and the Gulf of Mexico. The progress of the mortality was recorded in a detailed manner and transmission of the disease was attributed to water currents. This disease has been attributed to the fungus *Spongiophaga communis*.

During 1947 - 1948, a disease affecting the commercial sponges along the west coast of Florida was reported. Investigation of this phenomenon by members of the Marine Laboratory, University of Miami, did not identify the cause of this sponge mortality. No evidence of fungal disease was found. Mortality of sponges due to the outbreak of red tide has been noted. Sponge fishermen have reported that sponges in shallow water are occasionally killed off by a phenomenon they call "mallee". This "mallee" is a heavy growth of fine algae that usually smothers sponges.

The sponge population recovered and during the 1960s, fishermen who had engaged in the sponge business in Cuba began to harvest the sponge beds of Biscayne Bay.

Sponge dieoffs were observed in 1992 in central Florida Bay to the southeast, adjacent to the Keys (Brown and Ortner, 1994). They were apparently related to microalgal blooms, with a time lag of 5-7 days after blooms.

Currently, highest sponge densities occur in Biscayne Bay in hard bottom areas with moderate currents, constant salinity, low sedimentation, shallow, coarse sediments and sparse vegetation (DiResta *et al.*, 1995). The highest densities are in a north-south cluster in Central Bay. To preserve the populations, Biscayne Bay was closed to commercial sponging in 1991.

Widespread mortality occurred during the passage of Hurricane Andrew in 1992 (DiResta *et al.*, 1995). Mortality was highest for the smaller sponges. Recovery of sponge populations has been noted at some sites in the Bay. It was recommended that Biscayne Bay remain closed to commercial sponge harvesting.

7.2.2. "Milk" shrimp syndrome

The dominant shrimp species in Biscayne Bay is the pink shrimp (*Penaeus duorarum*). Specimens have occasionally been observed with an opaque abdomen and thorax resulting from infection by the microsporidian species *Thelohania duorara* and Pleistophora spp. *Thelohania* were first observed in pink shrimp in 1958 (Schmale, 1998). In a 1998 study, less than 3% of the shrimp studied exhibited gross microsporidian infection. No conclusion can be made as to whether the percent of infected shrimp has changed since the problem was first noted in the 1950s. No regional differences were observed in the Bay.

7.2.3. Lobsters

The importance of Biscayne Bay to juvenile spiny lobster (*Panulirus argus*) has resulted in a large portion of the Bay (roughly from Cape Florida south through Card Sound) having been designated as a Lobster Sanctuary.

7.2.4. Abnormal fish

In 1968, Walter Kandrashoff moved to Miami from his native New York and started fishing commercially in Biscayne Bay. The fish were abundant and well formed (Wright, 1977; Skinner and Kandrashoff, 1988; Browder, 1990; Browder *et al.*, 1993; and others). By 1969, he began to take emaciated croakers and his concern about the state of the Bay began. By 1970 he was taking hundreds of fish that were just "skin and bones". Kandrashoff brought some of the abnormal fish to the biologists at the University of Miami Rosenstiel School of Marine and Atmospheric Science (UM/RSMAS), who were not able to assert that the emaciated condition of the fish as abnormal since no baseline data was available. By the following year, Kandrashoff began to find fish with tumors and deformities, and his efforts to determine what was causing the problem in fish began in earnest. By 1971, a croaker collected by Kandrashoff was diagnosed with lymphoblastoma, a form of leukemia. In 1973, UM/RSMAS received funding to study the abnormal fish.

Many of the fish collected by Kandrashoff were stored frozen at the NOAA/NMFS Southeast Fisheries Science Center in Virginia Key, and the documentation by Kandrashoff is kept at the UM/RSMAS Library.

7.2.5. Avifauna

Many species of birds are found in Biscayne Bay. Many are permanent residents while others use the Bay as a resting area during migration. Major bird rookeries include Bird Key and Chicken Key, the mangrove shoreline south of Matheson Hammock, Biscayne National Park, Key Biscayne, Virginia Key, and the mangrove islands in North Bay.

7.2.6. Crocodiles

Crocodiles are an endangered species throughout their range in South Florida which includes Biscayne Bay, Card Sound and Barnes Sound (South Florida Water Management District, 1995). The South Florida crocodile population represents a large part of the breeding population in the US. Currently, crocodiles are mostly found in South Bay and the Sounds. Nesting distribution in southern Biscayne Bay and northeastern Florida Bay is discussed in Kushlan and Mazzotti (1989). Nesting sites in Miami Beach and the upper Florida Keys have been lost to development. This loss has been compensated by the creation of artificial nesting sites on spoil banks along the cooling canals of southern Biscayne Bay. The general distribution of the crocodile in Florida is the same as that historically documented.

7.2.7. Manatees

The Florida manatee (*Trichechus manatus latirostris*), also known as the West Indian manatee, is regarded as a regional subspecies. Manatees are herbivores requiring access to vascular aquatic plants, freshwater sources, proximity to channels 1 to 2 m deep, and access to warm water during the winter. Manatees are found along most of the coast of Florida (Ashton, 1992). Their geographical distribution is seasonal. During the summer, they migrate to warmer waters and are known to aggregate in natural or industrial warm water sources. Man is the only predator of the manatee, and the greatest threat to these animals is collision with boats.

Concern for the survival of the manatee in Florida was recognized as early as the 1700s when the English Crown established all of Florida as a manatee refuge (Gimble 1986). By 1893, the State of Florida passed laws prohibiting the capture or killing of a manatee without a permit. In 1907, a $500 fine and three months in jail were added as penalties. The manatee was listed an endangered species in 1967 and thus came under the protection of the Endangered Species Preservation Act of 1966. A series of subsequent legislative actions to protect endangered species, including the manatee, took place and by the 1970s US Fish and Wildlife Service organized a Recovery Team to prepare an overall recovery plan for manatee. During this decade, further measures for manatee protection in Florida came into effect and the first manatee conceived in captivity was born at the Miami Seaquarium in 1975. Public education to increase awareness of manatee conservation increased during the 1980s and continues.

An important factor in conservation efforts has been the successful marketing of the manatee image. It has been said that manatees are so ugly they are cute. They evoke sympathy and support from the legislators, the media and the public.

Manatees continue to suffer a high degree of human induced mortality and injury. The latter are usually the result of wounds caused by boat propellers.

Biscayne Bay is a Federally Designated Critical Habitat for the Florida manatee (South Florida Water Management District, 1995). Surveys indicate a winter population of 80 to 100 animals in open waters and tributaries of the Bay. More than 100 manatees have been found dead in Dade County between 1974 and 1993, and more than 80 of these mortalities were directly caused by human activities (29 deaths were caused by boating activities and 41 were due to crushing or drowning in water control structures). The two major causes of manatee deaths have been addressed in order to reduce mortalities.

Table 6. Population of Dade County from 1900 to 1990 (Andriot, 1983; and Bureau of the Census, 1994).

Year	Dade
1900	4955
1910	11933
1920	42753
1930	142955
1940	267739
1950	495084
1960	936047
1970	1267792
1980	1629701
1990	1937094

7.3. Human population and corresponding pressures

7.3.1. Human population

The population of the southeast United States has increased in recent decades and is projected to continue to do so at the highest rate of all regions in the Nation (Culliton *et al.*, 1990) further stressing ecosystems within the Southeast. Eastern Florida counties are expected to grow at the fastest rate, and are projected to have the highest population density in the Southeast United States by 2010. The population in Dade County from 1900 to the present is listed in Table 6 and shown graphically in Figure 15.

7.3.2. Agriculture

Agricultural activities in and around the Everglades, south of Lake Okeechobee, began after the drainage projects of 1906 - 1927, and intensified after the water control projects of the early 1950s, which created the Everglades Agricultural Area (Snyder and Davidson, 1994). Currently, more than $750 million is earned annually from production of sugarcane, vegetables, sod, and rice and over 20,000 full-time equivalent jobs are provided by the agricultural industry of South Florida. The future of this industry is uncertain since the loss of organic soils, concerns over nutrients and pesticides drainage, and possible flooding of lands as part of the South Florida Ecosystem Restoration Project may result in a reduction of agricultural activities.

7.3.3. Boating

Boating activities by residents and tourists are an increasing problem in Biscayne Bay resulting in conflicts between recreational use and ecosystem health (Austin, 1976). There is competition for the same resource as, for example, between recreational and commercial fishermen, land developers and conservationists. Marinas occupy space along the shoreline that used to provide breeding and nursery habitats but are now sources of contaminants, especially petroleum-derived chemicals. Scarring of seagrass beds by boat propellers is significant in Biscayne Bay and the rest of Florida (Sargent *et al.*, 1995). Of the estimated 145,000 acres of seagrass beds in Dade County, almost 8% show scarring, and 5.8% show moderate to severe scarring.

7.3.4. Motion pictures, television and popular literature

Biscayne Bay has been featured in still photography, feature films, commercial production and television, and music videos. The motion picture "Moon Over Miami" (1941) was shot in South Florida during World War II and was instrumental in showing the attractions of Miami and Miami Beach to a wide audience. Recent motion pictures such as "The Birdcage" (1996)* were filmed in and around Biscayne Bay. Virginia Key Beach is often used as a set for generic tropical island scenes. The film industry is very active in South Florida.

During the 1960s, the television series "Flipper" was filmed in Biscayne Bay, and images of the Bay were thus shown worldwide. During the 1980s, the popular television series "Miami Vice" opened each episode with an aerial shot of a motor boat speeding past the city of Miami.

The restoration of South Beach in Miami Beach into a world class tourist attraction has brought the area to international attention through such diverse media activities as music videos and fashion photography.

During the past decade, there have been many popular literature works set in Biscayne Bay and South Florida. These include the works of C. Hiaasen, E. Buchanan, C. Garcia-Aguilera and many others.

8. LEGISLATION

8.1. Federal legislation

[Some of the information in this section is condensed from NOAA (1981), Hildreth and Johnson (1983), McClain (1991), and Wolf (1988) and checked in the 1999 General Index, United States Code Annotated (Anonymous, 1999).]

8.1.1. Clean Water Act

The Federal Water Pollution Control Act (FWPCA), originally enacted on June 30, 1948 (Publication 845, 62 Stat. 1155), is also called the Clean Water Act. It has been amended many times. The Act was enacted in 1972 to restore and maintain the chemical, physical and biological integrity of the nation's waters. The three objectives of the Act were: to eliminate the discharge of pollutants into navigable waters by 1985; to attain, whenever possible, water quality that allows for fishing and recreational use by 1983; and to prohibit the discharge of toxic pollutants in toxic amounts. The FWPCA also established a national policy for providing financial assistance to construct publicly owned waste water treatment plants. EPA was given the principal responsibility for administering the FWPCA. The National Pollutant Discharge Elimination System (NPDES) is part of the FWPCA. The FWPCA prohibits discharges into navigable waters unless authorized by an NPDES permit.

8.1.2. Clean Air Act

The Clean Air Act (CAA), also called the Air Pollution Control Act, was enacted on July 14, 1955 (Public Law 159, 69 Stat. 322) and extended and substantially amended in 1977. The

* Several scenes were filmed on MacArhur Cswy. facing Government Cut and the Port of Miami.

purpose of this act is to protect and enhance the quality of the nation's air resources in order to promote public health and welfare and the productive capacity of the population. The CAA provides for two principal ways of controlling air pollution: national ambient air standards, and point source emission limitations. EPA is required to publish a list of air pollutants which are subjected to ambient air standards.

8.1.3. Toxic Substances Control Act

The Toxic Substances Control Act (TSCA) (Public Law 94-469, 90 Stat. 2003) was enacted on October 11, 1978 and its primary purpose is to regulate the chemical substances that present a hazard to human health or to the environment. This act greatly expanded regulation of chemicals. It is intended to control chemical hazards at the source. TSCA applies not only to pure chemical substances but also to the impurities contained in these materials.

8.1.4. Federal Insecticide, Fungicide and Rodenticide Act

The Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) (Public Law 102, 61 Stat. 163) was originally enacted on June 25, 1947 and was amended significantly in 1972, 1978 and 1988. When first enacted, FIFRA was primarily a pesticide labeling law. The 1972 legislation required registration of all pesticides, constituting a premarket clearance for these substances. In order to approve registration of a pesticide, EPA must ensure that the substance will not affect the environment or the population. EPA must also determine that the benefits of using the pesticide outweigh the risks associated with its use.

8.1.5. Resource Conservation and Recovery Act

The Resource Conservation and Recovery Act of 1976 (RCRA) (Public Law 94-580, 90 Stat. 2795), also known as the Solid Waste Disposal Act, was enacted on October 21, 1976. The Act substantially changed the Federal regulations for solid waste disposal and control of hazardous waste.

8.1.6. Comprehensive Environmental Response, Compensation, and Liability Act

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (Public Law 96-510, 94 Stat. 2767), also known as the Superfund Act, was enacted on December 11, 1980. It established a federally-directed program to clean up the nation's most hazardous waste and chemical contamination sites. CERCLA enabled the federal government to respond to actual or threatened releases of hazardous substances and to recover damages for the destruction or harm to natural resources. The original Superfund legislation was disappointing because EPA, which was responsible for the administration of the Act, was only able to begin clean up of a few sites of the thousands identified nationwide. The Superfund Amendments and Reauthorization Act (SARA) (Public Law 99-499, 100 Stat. 1613) of 1986 amended CERCLA and expanded and toughened the cleanup authority of the Federal government.

8.1.7. Emergency Planning and Community Right-to-Know Act

The Emergency Planning and Community Right-to-Know Act of 1986 (EPCRKA) (Public Law 99-499, Title III, 100 Stat. 1728) established emergency planning, reporting and notification requirements that were meant to protect the public in the event of a release of hazardous substances.

8.1.8. The Endangered Species Act

The Endangered Species Act (ESA) (Public Law 93-205, 87 Stat. 884) was approved on December 28, 1973 and last amended in 1988 (Public Law 100-707, Title I, 102 Stat. 3835). The purpose of this Act is to provide a program for the conservation of threatened and endangered species of plants and animals, and the habitats in which they are found. The Act provides the legislative authority to implement the treaties and conventions on endangered species to which the US is signatory. The endangered and threatened species found in Biscayne Bay are listed in Table 2.

8.1.9. National Marine Sanctuaries Act

The National Marine Sanctuaries Act (Public Law 95-532, Title III, 86 Stat. 1061) was approved on October 23, 1972 and last amended on October 11, 1996 (Public Law 104-283, 110 Stat. 3363). The purposes and policies of this Act are to identify marine areas of special significance, provide for their management, support research, enhance public awareness, and promote all public and private uses of the marine environment to the extent that these issues are compatible with resource protection. The Florida Keys National Marine Sanctuary was established in 1990 under this Act and implemented in 1994.

8.1.10. Marine Mammal Protection Act

The Marine Mammal Protection Act (MMPA) of 1972 (Public Law 92-522, 86 Stat. 1027) was last amended in 1998 (Public Law 105-277, 112 Stat. 2681). The purpose of this Act is to protect, conserve, and encourage international research on marine mammals.

8.1.11. Coastal Zone Management Act

Congress passed the Federal Coastal Zone Management Act in 1972 (Public Law 92-583, 86 Stat. 1280) to further a national interest in the effective management, beneficial use, protection, and development of the coastal zone.

8.1.12. Magnuson-Stevens Fishery Conservation and Management Act

The Magnuson-Stevens Fishery Conservation and Management Act of 1976 (Public Law 94-265, 90 Stat. 331) authorizes the Federal government to conserve and manage all fishery resources, except tuna, within the US fishery conservation zone which extends from the seaward boundary of the territorial sea to 200 nmi from shore NOAA, 1981). The Act also provides for exclusive management authority over Continental Shelf fishery resources and over anadromous species beyond the US fishery conservation zone. The Act has been amended many times.

8.1.13. Fish and Wildlife Coordination Act

The Fish and Wildlife Coordination Act (FWCA) was enacted on March 10, 1934 (Public Law 121, 48 Stat. 401) and subsequently broadened and modified by amendments in 1948, 1958, and 1965. The Act was originally named the Conservation of Wildlife, Fish and Game Act, and later renamed the Wild Life Conservation Act. Sections of this Act deal specifically with wildlife resources in relation to Federal water resource development actions. FWCA recognizes the importance of wildlife resources and mandates that wildlife conservation shall receive equal consideration and treatment as other features of water resources development.

8.1.14. Lead in gasoline ban

Use of alkyl lead in gasoline began after 1940 and ended in the early 1970s. Shen and Boyle (1987) used a sample of the coral *Montastrea annularis* collected 1 km from shore at 4 m depth at the Hens and Chickens Reef in 1978 and 1983, respectively, to reconstruct historical industrial Pb fluxes to the ocean surface. The Florida Keys maintained a surface water concentration of 38 pM Pb until about 1930, which was probably supported by shelf/resuspended Pb inputs. Levels grew gradually to a peak of 190 pM in 1977, followed by a decline to 142 pM in 1982. Relative to the Bermuda records, the Florida coral lacks a strong industrial revolution signal and exhibits a moderated post-World War II Pb increase and muted maximum. These patterns reflect dilution of US Pb sources and delayed response due to long-range horizontal transport.

8.1.15. DDT and metabolites

DDT (4,4'-DDT), or 1,1'-(2,2,2-trichloroethylidene)bis[4-chlorobenzene], was first described early in the century and resynthesized during the late 1930s as part of a research program at Geigy (Stetler, 1983). This program was a search for a contact insecticide characterized by a long duration of activity. Following the discovery of the pronounced insecticidal properties of the new agent and the registration of the first patents in 1940, the product, formulated in Switzerland, was introduced to the market in the spring of 1942 for use in crop protection and hygiene. The epidemic-promoting circumstances of World War II and the post-war years brought about increased and effective use of DDT in the field of medicinal hygiene. Malaria, typhus, typhoid fever, and cholera were drastically reduced by the effective control of *Anopheles* mosquitoes, lice, and flies of all types or, as in the case of malaria, were virtually eradicated in many countries. It has been estimated that almost 1 billion people in all parts of the world have been saved from malaria by the use of DDT. 4,4'-DDT is metabolized by the loss of a chlorine to yield the non-insecticidal 4,4'-DDE {(1,1'-(dichloroethylidene)bis[4-chlorobenzene]}, and by the substitution of a chlorine by a hydrogen to yield 4,4'-DDD {(1,1'-(2,2-dichloroethylidene)bis[4-chlorobenzene]}. DDT and some of its metabolites are toxicants, with long-term persistence in soil and water. They are widely dispersed by erosion, runoff, and volatilization, and accumulate in adipose tissue in wildlife and humans.

Restrictions introduced by most Western industrialized countries on the production of DDT and other chlorohydrocarbons at the start of the 1970s have reduced use of these chemicals to a fraction of the original quantities. The use of DDT was banned in the US in 1972. The special situation of the Third World countries, however, resulted in production peaks (on a worldwide basis) as late as the mid-1970s. Without sufficient quantities of DDT and dieldrin, the World Health Organization is unable to fulfill its vector-control programs.

8.1.16. Polychlorinated biphenyls ban

Polychlorinated biphenyls (PCBs) are widely distributed in the environment, and have no known natural source. PCBs were manufactured by Monsanto and were available in the US from 1930 to 1977 as a series of mixtures of congeners called Aroclors, having different average compositions of congeners. PCB concentrations have also been reported as Aroclors (EPA, 1993). There are 209 congeners, having from one to ten chlorines. Twenty of these congeners have non-ortho chlorine substitutions and so can attain a planar structure which makes them similar in structure to the highly toxic polychlorinated dibenzo-*p*-dioxins and dibenzofurans (McKinney *et al.*, 1985; Sericano *et al.*, 1991).

Figure 63. Chalks Flying Service on Biscayne Boulevard (19--). [Photoprint, black and white (8 x 10 in). Rc06653. Reference Collection, Florida State Photo Archive. <http://fpc.dos.state.fl.us/>]

9. OTHER ACTIVITIES AND EVENTS

9.1. Aviation

9.1.1. Chalk's International Airlines

Red Arrow Flying Service began service from Biscayne Bay to Tampa and St. Petersburg in 1917, the first scheduled air service in the US (Chalk's International Airlines, 1999). The airline operated off the dock of the Royal Palm Hotel near the entrance to the Miami River. During World War I, the owner of Red Arrow, A. B. Chalk, joined the Air Corps and after the war returned to Miami and resumed the business under the name of Chalk's Flying Services in 1919. During prohibition, Chalk expanded service to the Bahamas. In 1926, Chalk built a small terminal on Watson Island, a newly built landfill island at that time (Figure 63). The airline has been sold several times since the 1920s and the seaplane fleet modernized as technology improved. Service continues to the present making it one of the oldest, continuously operating airlines in the world (Smith, 1982).

9.1.2. Pan American Airways

When Pan American Airways received the contract to fly US Mail between US and Cuba it was stipulated that operations begin no later than 1927 (Smith, 1982; Pan American World Airways Historical Foundation, 2000). Due to equipment limitations at that time, the base of operations had to be situated in Key West, the closest US airport to Havana. The flight to Havana was the first scheduled international flight by a United States airline. Once the airline received the longer range Fokker F-10 Trimotors, operations were moved to a barge off Dinner Key in Miami in 1928. In 1939, the barge was replaced by the Pan American flying boat terminal which is currently used as the Miami City Hall (Figure 27). During World War II, Pan American navigators served as instructors for pilots and navigators (see Section 4.4) (Figure 28). Airline operations ceased at Dinner Key when use of flying boats ended after World War II.

Figure 64 The Goodyear airship 'Mayflower' over Biscayne Bay (19--). (The Venetian Islands are to the left of the image. View is towards Miami Beach.) [C. Hansen, photographer. Photoprint, black and white, 8 x 10 in. WE054. Wendler collection, Florida State Photo Archive. <http://fpc.dos.state.fl.us/>]

9.1.3. Embry-Riddle School of Aviation

The Embry-Riddle School of Aviation opened in 1939 in response to concerns about US entry into World War II (Mormino, 1997). The school operated from a site in MacArthur Causeway It is estimated that one tenth of all American World War II pilots were trained at Embry-Riddle. Aviation mechanics were also trained at the school. In 1965, the school moved to Daytona Beach and continues operations to this day as Embry-Riddle Aeronautical University (Embry-Riddle Aeronautical University, 2000).

9.1.4. Lighter than air ships

Lighter than air craft have been seen in the skies over Biscayne Bay since at least the 1920s (Figures 64 - 66). For many years, the Goodyear blimp terminal was located on Watson Island next to Chalks Airlines. The German "Graf Zeppelin" visited Miami in October 23, 1933 (caption for image Rc06268, Florida State Photo Archive. <http://fpc.dos.state.fl.us/>). Lighter than air ships based in South Florida were used in anti-submarine warfare in the Atlantic Ocean and the Gulf of Mexico during World War II.

The Richmond Naval Air Station (NAS) contained the largest aircraft hangars in the world in order to house and service the large dirigibles that patrolled the Atlantic Ocean (Mormino, 1997; Friends of Naval Air Station - Richmond, 2000) (see Section 6.4.2). Richmond NAS was destroyed during the Hurricane of 1945 (see Section 5.3.3).

9.2. Christo's Surrounded Islands

Christo Javacheff is an environmental artist whose well-known works include Running Fence, Sonoma and Marin Counties Coast, 1972 - 1976, Wrapped Coast, Little Bay, Australia 1969, and Wrapped Walk Ways, Loose Park, Kansas City, Missouri, 1977 - 1978. Christo's work is temporary and leaves no mark upon the earth, and is public in that the community is involved in the plans from the beginning (Christo, 1986; Stewart, 1990). Surrounded Islands: project for Biscayne Bay, Greater Miami, Florida, 1980-1983 consisted of surrounding eleven small islands spread over 7 mi of Biscayne Bay with pink woven plastic fabric floating on the surface of the water for a period of two weeks, a work reminiscent of Monet's Water Lilies.* As with previous art projects, Surrounded Islands was entirely financed by the artist through the sale of the preparatory pastel and charcoal drawings, collages, lithographs and early works, and a $700,000 personal loan.

The eleven islands and the submerged lands that were used in the project were leased to the artist by the State of Florida for approximately $12,000. Three communities had to give their consent: the City of Miami, the Village of Miami Shores and North Miami City. State approval was given in 1982. Opposition reached critical proportions by 1983. Jurisdiction over the project was eventually given to Federal Court thus no other authority could touch Surrounded

* Photographs of Surrounded Islands can be seen at the Internet site <http://www.beakman.com/christo/xtojc/xtojc.html>.

Figure 65 Airship USN 'Los Angeles' over Biscayne Bay (January 13, 1929). (Downtown Miami is at the center of the image.) [Photoprint, black and white, 8 x 10 in. Rc09329. Reference collection, Florida State Photo Archive. <http://fpc.dos.state.fl.us/>]

Figure 66. US Navy airship 'Akron' over Biscayne Bay (January 4, 1933). (The 'Akron', built by Goodyear, was based west of Opa Locka and was destroyed next spring in a storm off the coast of New Jersey.) [Photoprint, black and white, 8 x 10 in. Rc15158. Reference collection, Florida State Photo Archive. <http://fpc.dos.state.fl.us/>]

Islands. Only the Justice of the Federal Supreme Court could stop the project. Permits were obtained from the following governmental agencies: The Governor of Florida and the Cabinet; the Dade County Commission; the Department of Environmental Regulation; the City of Miami Commission; the City of North Miami; the Village of Miami Shores; the U.S. Army Corps of Engineers; and the Dade County Department of Environmental Resources Management.

More than 40 tons of garbage including refrigerator doors, tires, kitchen sinks, plastic, bottles, cans, dead animals and an abandoned boat were removed from the islands prior to deployment of the pink fabric. Studies were carried out to determine if the placement of the fabric along the shoreline of the islands would have any adverse environmental effects especially on seagrasses (Thorhaug)*, algae, birds (Owre and Cummings)* and marine mammals (Odell)* . To determine if manatees would be affected by the project, Odell covered a tank at Orlando Sea World containing five manatees with the pink fabric. The US Fish and Wildlife Service was invited to observe that the manatees were neither panic stricken nor driven neurotic by the pink sky above them. The biologists were interested in observing that these mammals showed a predilection for seeking shelter in the new ambiance created by the fabric and once there were roused to sexual behavior.

Detailed surveys of the shape of each island were used to determine how the 6.5 million sq. ft of woven propylene mesh-like pink fabric were to be cut and sewn. Cutting and sewing of the 79 sections of fabric that followed the outline of the islands were done at the Opa Locka Blimp Hangar. A flotation strip was sewn in each seam. The fabric sections were accordion folded for transport to the Bay. Anchors were placed under the trees on the islands and 200 ft away on the Bay bottom, approximately 50 ft apart. A series of radial lines were deployed between the anchors forming a circle around each island. The folded fabric sections were towed to the sites and the sections hooked to the radial lines forming a pink ring around the islands. Blossoming Day, the day in which the folded fabric was unfurled, was May 4, 1983. Each fabric section was unfolded, the fabric pulled towards the anchors set in each island, and secured. The fabric covered the surface of the island beaches so only the dark green vegetation surrounded by bright pink could be seen. Fabric sections were laced together through grommets on the edge of the overlapping sections. By May 7, all eleven islands were completely surrounded by pink fabric and remained thus for two weeks. Surrounded Islands was tended by monitors in inflatable boats during that time. Surrounded Islands was best viewed from the air and the work focused world attention on South Florida and Biscayne Bay.

9.3. Baynanza

Baynanza is a public awareness effort begun in the 1980s to bring attention to the Biscayne Bay ecosystem. The event is sponsored by the Miami-Dade County Department of Environmental Resources Management and many organizations and businesses in South Florida including the Biscayne National Park, the Everglades National Park, the Florida Department of Environmental Protection, the Florida Marine Patrol, the Zoological Society of Florida and Florida Power and Light. Baynanza 2000 included teacher workshops on the marine environment, clean-ups of urban areas and shore lines, restoration work, and field trips to various places in the Bay such as the Fossil Reef in Key Biscayne and Boca Chita Key.

10. DISCUSSION

There exist significant numbers of documents and data related to the environment that for various reasons remain unpublished or are only available as internal reports. Such material is

* The reports produced by these investigators are unpublished (K. Hale, UM/RSMAS/ personal communication, 1999).

extremely difficult to obtain and is thus mostly unavailable to the scientific community and the public. These unique documents and data are important because they define the state of the marine environment in the past, and they are essential for estimating rate of change of ecosystems.

During the preparation of this document, many documents related to Biscayne Bay were available solely through the efforts of South Florida-based faculty and librarians, who saw the value of this material and stored copies in libraries or in their private files. Due to the nature of the materials on which they are printed and in some cases the conditions in which they are housed, they are in jeopardy of being lost.

An effort should be made to search for unpublished data and documents related to the Biscayne Bay and prepare a metadata file of the material. Information judged valuable to current activities can be converted to electronic and printed form, and archived and distributed electronically. Preliminary data and document rescue of Biscayne Bay-related materials has been done and the results are available on the Internet, at the NOAA/Miami Regional Library and at the Marine Library of the University of Miami Rosenstiel School of Marine and Atmospheric Science.*

Photographs proved extremely valuable in this work and in others. Efforts should continue to search, archive and make available images of the South Florida marine environment for future use.

Maps and charts of the area are also invaluable and old versions should be archived and made accessible through libraries or the Internet.

11. CONCLUSIONS

The changes observed in Biscayne Bay since the 1900s are the result of natural and anthropogenic factors. Over the past 200 years, Florida Bay and Biscayne Bay have been driven primarily by climatic and oceanographic factors and these factors were disrupted early in the 20th century by man's influence (Willard *et al.,* 1998). The anthropogenic disruptions resulted in changing salinity patterns, water circulation, benthic fauna and flora, levels of suspended particulates, and salt water intrusion. Recognition of the serious effects of the ecosystem disruption resulted in remediation efforts in the 1980s. There are indications that the Biscayne Bay ecosystem is recovering although conditions are not expected to return to those of the 1900s (Figure 67).

Briefly, major events related to the environment of Biscayne Bay are:

Prior to the 1920s, major changes to the Biscayne Bay ecosystem were caused by climatic events and changes (hurricanes, sea level changes, rainfall, etc).

During the 1920s, there were major changes in North Bay due to construction of artificial islands, bulkheading, dredging of channels and construction of Government Cut and Haulover Cut. Construction activities in and around the Bay slowed considerably after 1930.

Construction of drainage canals beginning at the turn of the century resulted in system-wide ecological changes.

* Coastal and Estuarine Data Rescue and Archeology (CEDAR) web site at <http://www.aoml.noaa.gov/general/lib/CEDAR.html>.

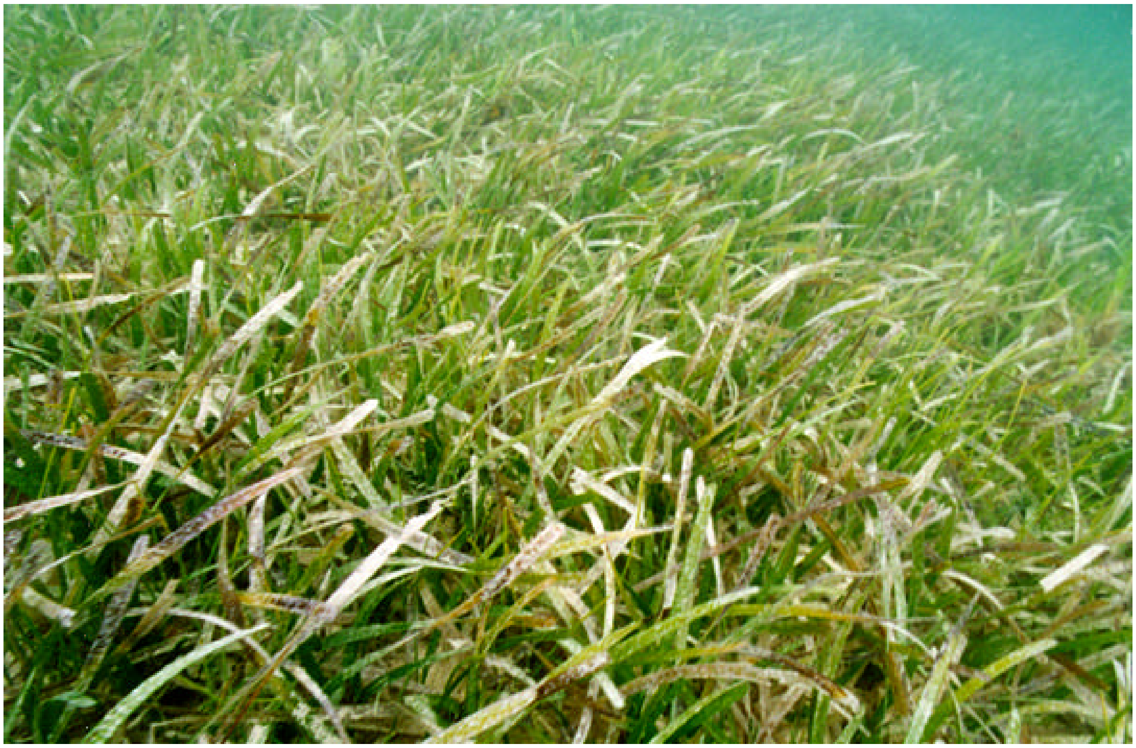


Figure 67. Healthy seagrass bed, Featherbed Shoal, Biscayne National Park (1997). (Photo by Karen Battle, Biscayne National Park.) *See color version on p. 138.*

Bacterial pollution due to untreated sewage discharge into the Bay began during the 1920s.

Bacterial pollution and turbidity reached maximum levels during the middle 1950s.

Major sewers discharging directly into the Bay were closed in the late 1950s.

Construction of Dodge Island in the 1970s and subsequent expansion of the Port of Miami again changed circulation patterns of North Bay.

Abatement measures to decrease turbidity began in the 1980s with changes in bulkheading practices and planting of mangroves.

Turbidity in the Bay decreased by the 1990s. Bottom communities returned. Sports fisheries improved.

Effects of hurricanes are localized and part of the South Florida ecosystem.

The Miami River remains polluted with sewage outfalls, hydrocarbons and trace metals.

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