THE CARBONATE BEACHES OF FLORIDA:

AN INVENTORY OF

MONROE COUNTY BEACHES

RALPH R. CLARK

BEACHES AND SHORES TECHNICAL

AND DESIGN MEMORANDUM 90-1

FLORIDA DEPARTMENT OF NATURAL RESOURCES
Division of Beaches and Shores

March, 1990

FOREWORD

This document presents the results of a preliminary inventory of the beaches of Monroe County in advance of the preparation of a beach restoration management plan for the County. Field data acquisition was conducted during the week of October 23 - 27, 1989. The purpose of this publication is to identify the sandy beach areas of Monroe County and to identify and categorize the beach erosion problem areas. Hopefully the document provides a foundation for more detailed future investigations. The preservation and management of the beach resources of Monroe County require a far greater knowledge of their shoreline processes and of carbonate beaches in general than that knowledge which currently exists.

This document would have been impossible without the guidance and assistance of Mr. Frank Butler, Mr. Paul Wick, Mr. George Schmahl, Capt. Vicki R. Impallomeni, the Key West Seaplane Service, and the National Park Service - Fort Jefferson National Monument. Extremely helpful was the information and technical advice of Mr. Michael H. Puto, Mr. Gene Linton, Mr. Robert S. Harris, Mr. George S. Garrett, Mr. Ty Symroski, Mr. Ron Johns, Mr. Gary B. McKee, Mr. Craig Johnson, Mr. Douglas S. Rosen, Mr. Kevin McCabe, Mr. Harvey Sassa, Mr. Milton A. Chaffee, Mr. Frank Toppino, and Wild Bill of Grassy Key. The guidance of Mr. Lonnie Ryder, Mr. James H. Balsillie, and Mr. William K. Whitfield, Jr., and the expert preparation of the manuscript by Ms. Goodson is also gratefully acknowledged.

CONTENTS

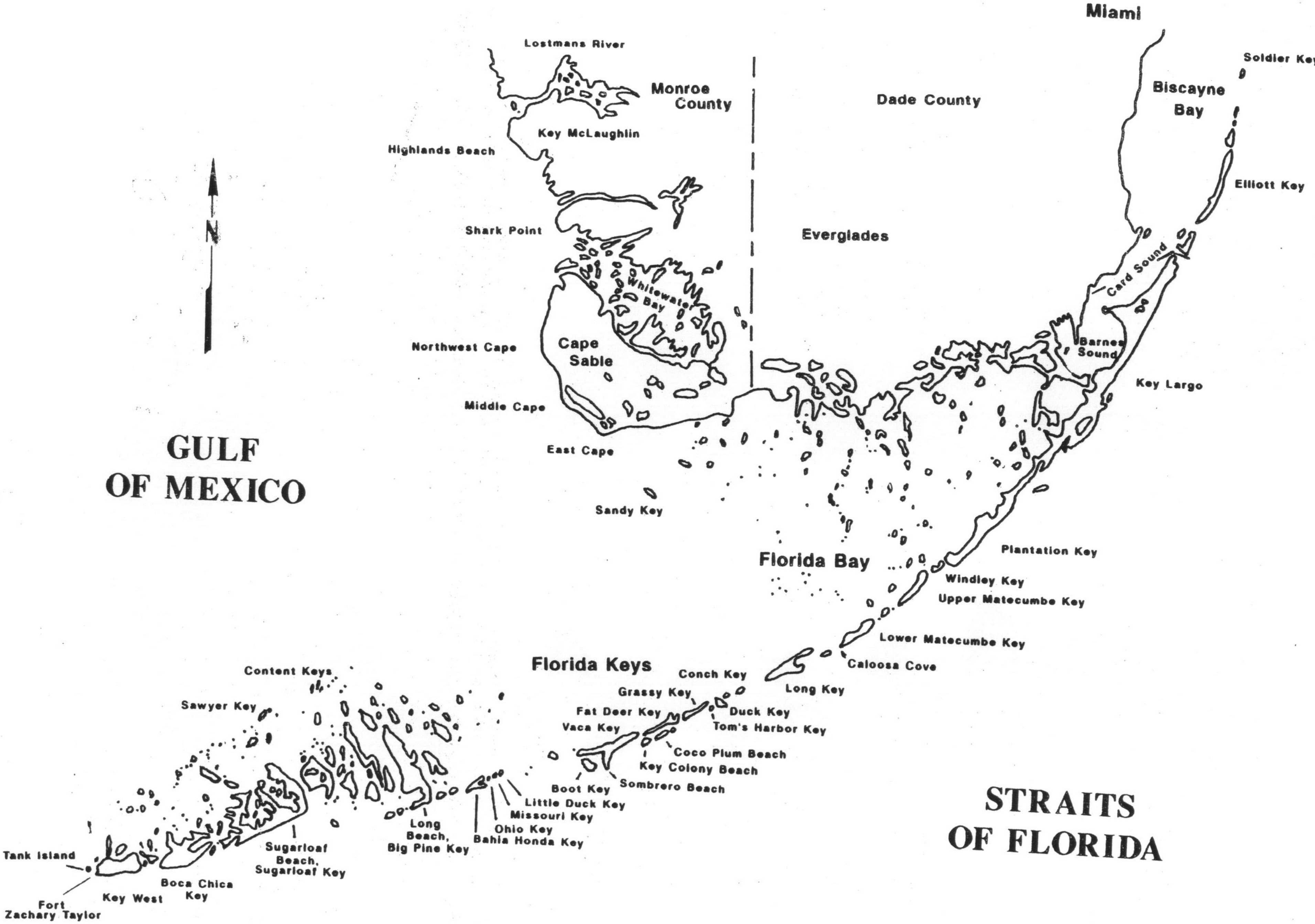

Figure 1. Monroe County

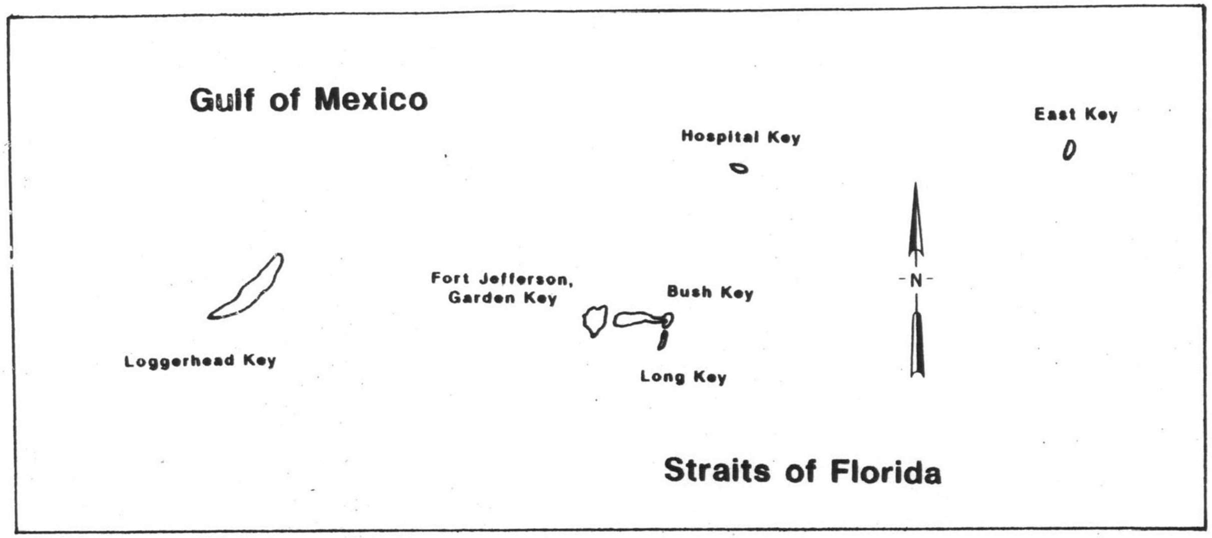

Figure 2a. Dry Tortugas

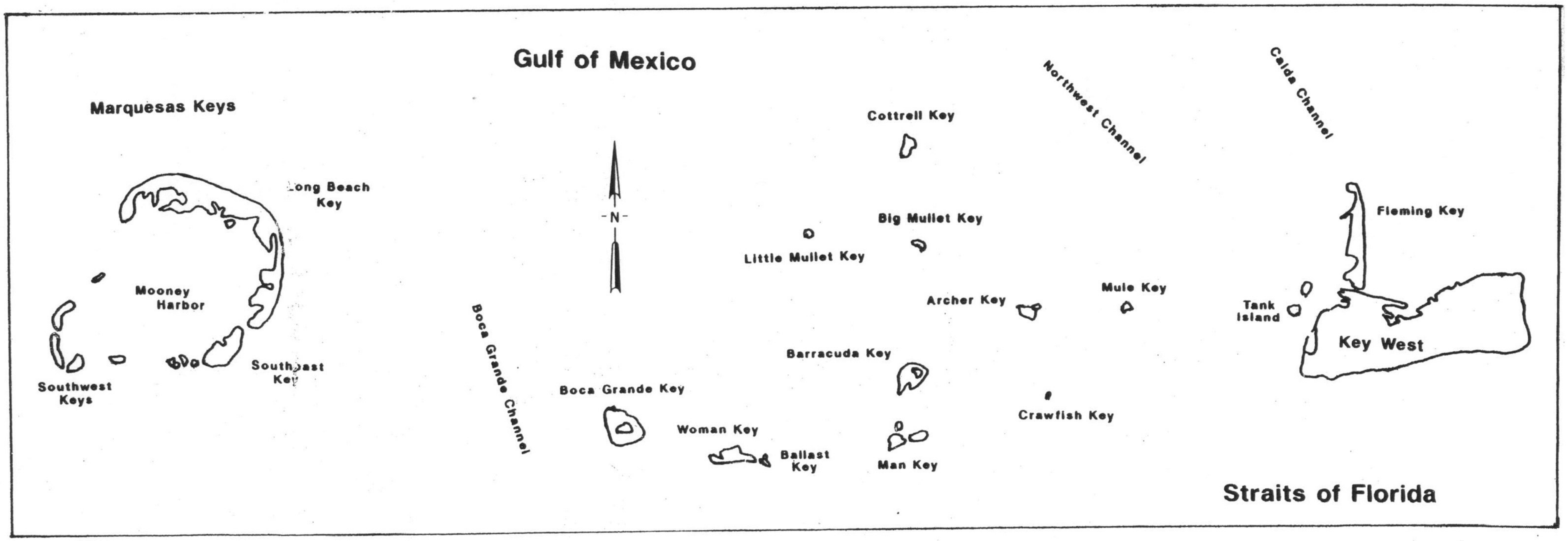

Figure 2b. Key West to the Marquesas Keys

INTRODUCTION

Monroe County is the southernmost county in Florida and comprises all of the Beach Restoration Management Planning District V. Located at the southwest tip of the Florida peninsula, that portion of the county that is located on the mainland is largely undeveloped and is mostlyincluded in the Everglades National Park. Monroe County also includes most of the Florida Keys which is an elongate, arcuate archipelago over 220 miles in length from Soldier Key at the northeast end of the chain near Miami southwest to the Dry Tortugas. The Florida Keys are separated from the mainland by Florida Bay, a broad shallow marine system which is compartmentalized by numerous carbonate mud banks.

The Gulf of Mexico mainland Coast of Monroe County extends for approximately 54 miles between the southernmost portion of the Ten Thousand Islands region to the East Cape of the Cape Sable region. The mainland shoreline of Monroe County is predominantly characterized by fringing mangrove forests which range in width from 6 to 600 feet. The dominant plant species include the red, black, and white mangroves which are distinctly zoned with red mangroves occurring on the seaward exterior of forests and with black and white mangroves occurring on forest interiors. Numerous mangrove islands and tidal creeks dot this stretch of coast. A number of major tidal channels intersect the coast north of Cape Sable including from north to south: Lopez River, Huston River, Chatham River, Charlie Creek, Lostman's River, Rodgers River, Broad River, Broad Creek, Harney River, Shark River, Little Shark River, Big Sable Creek, and Little Sable Creek.

The mainland stretch of coast also includes sandy beaches along the Key McLaughlin and Cape Sable. The 4 miles of Highlands Beach along Key McLaughlin and the 12.2 miles of beach along Cape Sable are the longest sandy beach segments in Monroe County and are as yet largely unstudied. These beaches are within the Everglades National Park and the access is difficult given their remoteness. These beaches are predominantly carbonate but their shore processes have not been well researched. The average width of these beaches is approximately SO feet and the estimated direction of net annual longshore sediment transport is to the southeast.

Sandy beaches also exist throughout the Florida Keys portion of Monroe County fronting on the Straits of Florida and the Gulf of Mexico. Beach and dune formation in the keys is not common, and compared to the Florida peninsula, there is very little quartz sand on the Keys. The sand of the Keys beaches is of carbonate origin derived from the erosion of limestone, from aragonite particles precipitated from seawater, and from the fragmented remains of corals, cast-off shells, and calcareous algae.

There are no natural beaches in the upper Keys portion of Monroe County north of the Matecumbes. The beaches generally increase in frequency to the southwest with the largest percentage of land mass composed of beach found in Bahia Honda Key, the outer islands west of Key West, the Marquesas Keys, and the Tortugas Keys.

Along the middle Keys, natural narrow beaches fronting the Straits of Florida occur on Upper Matecumbe Key, Lower Matecumbe Key, Long Key, Toms Harbor Key, Grassy Key, Crawl Key, Little Crawl Key, Vaca Key, and Boot Key. In addition, beaches were created by the dredge and fill projects of the 1950's which created the developments of Key Colony Beach and Coco Plum Beach.

In 'the lower Keys, beaches fronting the Straits of Florida occur on Little Duck Key, Missouri Key, Ohio Key, Bahia Honda Key, Spanish Harbor Key, Big Pine Key, the Newfound Harbor Keys, Ramrod Key, Sugarloaf Key, Boca Chica Key, and Key West. On the Gulf of Mexico side of the lower Keys, beaches occur on Bahia Honda Key, the Content Keys, Sawyer Key, Marvin Key, Snipe Point, and Mud Key. These Gulf beaches are all located within the Great White Heron National Wildlife Refuge, the Key Deer National Wildlife Refuge, and the Bahia Honda State Recreation Area,

To the west of Key West, three island groups have been labeled by past researchers as the Sand Keys of Florida given their origin as emergent carbonate sand bodies (Davis, 1942). Within the outer island group immediately west of Key West, natural sand beaches occur on Man Key, Ballast Key, Woman Key, and Boca Grande Key. Located over eighteen miles west of Key West are an atoll shaped group of islands known as the Marquesas Keys. Within the Marquesas Keys beaches exist on Southeast Key, the Southwest Keys, and Long Beach Key. The island group west of Key West and the Marquesas Keys are all within the Key West National Wildlife Refuge.

The most distant group of six sandy islands, located 65 to 70 miles west of Key West, are the islands of the Dry Tortugas or the Tortugas Keys. All six islands have beaches, including East Key, Hospital Key, Long Key, Bush Key, Garden Key, and Loggerhead Key. The Tortugas Keys are all within the boundaries of the Fort Jefferson National Monument.

LENGTH OF MONROE COUNTY BEACHES

Gulf of Mexico Beaches	(miles)
Key McLaughlin	4.0
Cape Sable	12.2
Lower Keys	1.3
Marquesas Keys	4.4
Tortugas Keys	4.2
	26.1

Straits of Florida Beaches	(miles)
Middle Keys	13.8
Lower Keys	6.8
Key West	3.2
Outer Islands	2.6
	26.4
Total Monroe County	52.5

STRAITS OF FLORIDA BEACHES

Beach, Key	Ownership	Total Length (ft.)	Average Width (ft.)
Upper Matecumbe Key	Private	9,800	15
Lower Matecumbe Key	Private	14,900	15
Caloosa Cove, Lower Matecumbe	State	2,200	25
Long Key State Rec. Area	State	15,800	25
West end, Long Key	Private	2,700	25
Toms Harbor Key	Private	2,400	15
Grassy Key	Private	6,800	15
Crawl Key	Private	600	15
Little Crawl Key	Private	1,200	15
Coco Plum Beach	Private	7,500	25
Key Colony Beach	Private	4,550	50
Sombrero Beach Village, Vaca Key	Private	2,000	15
Sombrero Beach, Vaca Key	County	1,600	25
Sombrero Beach, Vaca Key	Private	800	15
Boot Key	Private	180	25
Little Duck Key	County	825	25
Missouri Key	Private	500	15
Ohio Key	Private	1,600	15
Bahia Honda State Rec. Area	State	11,900	50
Spanish Harbor Key	Private	1,000	15
Southeast Point, Big Pine Key	Private	400	15
Long Beach, Big Pine Key	Private	5,400	15

Beach, Key	Ownership	Total Length (ft.)	Average Width (ft.)
Cooks Island	Private	2,400	15
Big Munson Island	Private	500	15
Munson Island	Private	600	15
Ramrod Key	Private	400	15
Sugarloaf Beach, Sugarloaf Key	Private	3,000	15
Boca Chica Key	Federal	7,300	15
South Roosevelt Blvd., Key West	State	3,000	0
George Smathers Beach, Key West	State	3,300	100
Rest Beach, Key West	Private	2,140	15
Rest Beach, Key West	City	660	15
Clarence S. Higgs Beach, Key West	County	1,250	100
Casa Marina Hotel, Key West	Private	950	50
Reach Hotel, Key West	Private	300	35
South Beach, Key West	City	300	50
Truman Annex, east of Whitehead Spit, Key West	Federal	2,000	25
Truman Annex, west of Whitehead Spit, Key West	Federal	800	100
Fort Zachary Taylor Historic Site, Key West	State	1,500	50
Truman Beach, Key West	Federal	300	25

Beach, Key	Ownership	Total Length (ft.)	Average Width (ft.)
Front Street, Key West	Private	400	25
Tank Island	Private	600	25
Man Key	Federal	250	25
Ballast Key	Private	3,000	25
Woman Key	Federal	4,960	25
Boca Grande Key	Federal	4,975	25

139,540 ft.

26.4 miles

GULF OF MEXICO BEACHES

Beach, Key	Ownership	Total Length (ft.)	Average Width (ft.)
Key McLaughlin	Federal	21,120	N.A.
Cape Sable	Federal	64,420	50
Bahia Honda Key	State	800	25
Content Keys	Federal	2,000	25
Sawyer Key	Private	2,000	25
Marvin Key, Barracuda Keys	Federal	600	25
Snipe Point, Snipe Keys	Federal	1,200	25
Mud Key	Federal	300	25
Southeast Key	Federal	1,200	25
Southwest Keys	Federal	8,250	25
Long Beach Key	Federal	14,000	25
East Key	Federal	2,625	50
Hospital Key	Federal	870	35
Long Key	Federal	1,150	25
Bush Key	Federal	6,235	25
East shore, Garden Key	Federal	1,455	25
Southwest Beach, Garden Key	Federal	380	50
Loggerhead Key	Federal	9,225	40
		137,830 ft.	
		26.1 miles	

SUMMARY OF FLORIDA KEYS BEACHES

Island Group	Total Length (ft.)	Critical Erosion (ft.)	Beach Area (acres)
Middle Keys	73,030	4,550	35.6
Lower Keys (Gulf)	6,900	0	4.0
Lower Keys (Straits)	35,825	4,100	20.2
Key West	16,900	16,200	17.5
Outer Islands	13,785	0	7.9
Marquesas Keys	23,450	0	13.5
Tortugas Keys	21,940	0	17.7
	191,830 ft.	24,850 ft.	116.4
	36.33 miles	4.7 miles	

DISCUSSION OF BEACH RESOURCES AND EFFORTS TO ADDRESS EROSION PROBLEMS

Shoreline change in Monroe County has not been well researched. Only along the south shores of Key West and Bahia Honda Key have historical studies of beach erosion been performed. Likewise, documentation of erosion control efforts is sparse. However, from aerial photography numerous erosion control and wave damage protection structures may be inventoried.

Shore processes of Monroe County's mainland beaches fronting the Gulf of Mexico are largely unstudied. These beaches are predominantly composed of carbonate sand and are of an average width of 50 feet. The estimated direction of net annual longshore sediment transport is to the southeast. Historical erosion and accretion rates have not yet been documented and there are no known erosion control efforts along these beaches.

Along the Florida Keys, beach and dune formation is not common and there exists little quartz sand. Natural sandy beaches do not exist in the upper Keys portion of Monroe County north of the Matecumbes. The southward nettransport of sand along the Atlantic barrier beaches of Florida diminishes substantially in Dade County. Key Biscayne is the southernmost barrier beachwith any significant quartz sand. Quartz sand deposits do exist in shoals south of Key Biscayne; however, little southward sand transport exists between Key Biscayne and Soldier Key adjacent southern Biscayne Bay.

There are a number of physical reasons for this lack of sand transport between the barrier islands and the Florida Keys. First, the Little Bahama Bank and the Great Bahama Bank provide substantial protection to the Dade and Monroe County shorelines from the Atlantic Ocean generated swell which dominates the wave climate along the east coast of Florida. The remaining fetch length for wave propagation is only that width across the Florida Straits where waves are generated by only the local climatic conditions which are generally quite milder than those of the North Atlantic. However, while periodic extreme tropical weather events would be expected to remove any sand from the emerged rock strata of the upper Keys, little material from the north is available for natural renourishment. In the offshore, any sand which may exist, would be influenced by the strong northward current of the Gulf Stream which blocks any southward sediment transport.

The last major drop in sea level exposed the ancient coral reefs which are presently the Florida Keys. The coral reefs which make up the Key Largo limestone formation were flourishing during the last interglacial period as a line of patch reefs in the back-reef area of a broad reef platform (Multer, 1971). As sea level fluctuated during the Pleistocene Ice Ages the Key Largo limestone accumulated up to 200 feet thick (Lane, **1986).** Intertidal erosion of the exposed Key Largo formation is a source of the sediment of the upper and middle Keys beaches. The intense erosion of carbonate rock along the Florida Keys is caused by the activities of boring and burrowing organisms (Ginsburg, 1953). Boring organisms which penetrate the rock remove calcareous material and weaken the rock to a point of breakage under wave action. The smaller fragments of rock plus the fragmented remains of corals, cast-off shells, and calcareous algae, make up the carbonate sediments of the Florida Keys.

Although the Florida Keys include several islands north of Key Largo to Soldier Key, the 28.5-mile long Key Largo is the longest and northeasternmost island of the archipelago which falls within Monroe County. Most of the northern two thirds of Key Largo is a natural rock and mangrove shoreline. However, bulkheading has been conducted at the Ocean Reef Club, a dredge and fill development at the north end of Key Largo. The southern one third of Key Largo fronting on the Straits of Florida has a mix of riprap and bulkheading as well as a natural rock and mangrove shoreline. Aerial photography reveals that at least twenty-one breakwaters (seven shoreparallel and fourteen shorenormal) and three groins exist along the southern one third of Key Largo. The breakwaters generally protect boat basins and small channel entrances from wave activity. Offshore from Key Largo, the islands of Rattlesnake Key, El Radabob Key, Dove Key and Rodriquez Key have natural mangrove shorelines.

Southwest of Key Largo, the 5.3-mile long Plantation Key has bulkheaded canals at its north end. Most of the shoreline fronting the Straits is a mix of riprap, bulkheads, and natural rock and mangrove shoreline. Aerial photography reveals nine shoreparallel and ten shorenormal breakwaters. Windley Key with the highest natural elevations in the Keys, has a mix of riprap, bulkheads, and a natural rock shoreline fronting the Straits. Six shoreparallel and six shorenormal breakwaters front the Straits shoreline of Windley Key.

The four-mile long Upper Matecumbe Key with the community of Islamorada has 9,800 feet of coarse grained sand beaches. These privately owned pocket beaches average approximately fifteen feet in width, and have an estimated direction of net annual longshore sediment transport to the southwest. Along with these beaches the Straits shoreline also includes a mix of riprap, bulkheads, and natural rock. Numerous structures extend off the shoreline including twenty-nine breakwaters (fourteen shoreparallel and fifteen shorenormal) and five groins. Although actual records of these structures are lacking it is surmised that most of the breakwaters and groins were constructed during the 1940's, 50's, and 60's. State authorizations for constructing breakwaters and groins were rarely given during the 1970's and 80's. The Matecumbes sustained severe damage by the famous hurricane of September 2, 1935 which left a reported death toll of 405 in the Keys (Dunn et al. 1967).

. Between Upper and Lower Matecumbe Keys the small Teatable Key is bulkheaded and the Indian Key shoreline is mixed sand and gravel fill along U.S. Highway 1. The small Indian Key located offshore from the Indian Key Channel between the Matecumbes has a natural rock shoreline. The 4.5-mile long Lower Matecumbe Key has 14,900 feet of privately owned coarse grained sand pocket beaches which average fifteen feet in width. The estimated direction of net annual longshore sediment transport is to the southwest. Ragan and Smosna (1987) measured longshore current velocities which averaged 21 cm/sec (0.7 ft/sec) at Lower Matecumbe Beach. The Lower Matecumbe Key shoreline fronting the Straits also has a mix of riprap, bulkheads, and natural rock shoreline along with six groins, two shoreparallel breakwaters and two shorenormal breakwaters. The southeast end of Lower Matecumbe Key known as Calusa Cove has 2,200 feet of fine grained sandy beach averaging 25 feet wide (Figure 6). This publically owned beach which is popular for picnicking and sunbathing was leased to Monroe County by the State of Florida in 1989. Management by Monroe County will improve beach access and sanitation as well as provide improved recreational amenities for this public beach.

Southwest of Lower Matecumbe Key, the small Craig Key has a riprap shoreline along U.S. Highway 1. To the southwest is the 4.2-mile long island of Long Key. The Long Key shoreline fronting on the Straits of Florida is predominantly coarse grained sandy beach with a couple short segments of mangrove shoreline. Roughly one half of the island is within the Long Key State Recreation Area. With the longest sandy shoreline in the Keys, the State Recreation Area has approximately 15,800 feet of beach (exclusive of armoring) averaging 25 feet in width (Figure 7). There appears to be a drift divide on eastern Long Key as the eastern quarter of the island is estimated to have a northeast direction of longshore sediment transport and the western three quarters has a west direction of longshore transport. Critical erosion of 2,950 feet of shoreline exists along the camping and swimming areas within the State Recreation Area. Division of Recreation and Parks officials have estimated the shoreline recession to be as much as three feet per year since the park was opened in 1970. A 750 foot long limerock revetment was constructed in 1976 to protect the park road; however, erosion end effects are most apparent adjacent to this structure. Park officials continually remove tall Australian pines which are undermined by the erosion processes. Beach and dune restoration is needed in this area of critical erosion to protect the public facilities and replace the recreational beach which has been substantially lost due to erosion. At the west end of Long Key is an additional 2,700 feet of privately owned beach and the bridge abutment is bulkheaded to protect U.S. Highway 1.

West of the Long Key Viaduct, the small Conch Keys are protected by one shoreparallel breakwater and three groins. The adjacent Walker Island has a riprap shoreline. Duck Key has two long shoreparallel breakwaters over two miles in length protecting its dredged and fill development. The adjacent privately owned and undeveloped Toms Harbor Key has 2,400 feet of coarse grained sandy beach which averages 15 feet in width. Because of its northeast to southwest alignment and the partial sheltering effect of Duck Key, the northeast half of Toms Harbor Key has an estimated direction of net annual longshore sediment transport to the northeast and the southwest half of the island has a transport direction to the southwest. The Duck Key Channel shoals probably contribute a natural sediment source for the Toms Harbor Key beach.

West of Duck Key and Toms Harbor Key is the three mile long Grassy Key. A mangrove shoreline exists at the east end due to the sheltering effect of the islands to the southeast, but 6,800 feet of coarse grained sandy beach exists along numerous private pocket beaches of Grassy Key. Along these beaches which average 15 feet in width, the net longshore sediment transport direction is estimated to be to the southwest. As along the rest of the middle Keys beaches, the longshore transport volumes, while not quantified appear to be very small. Along this moderately developed shoreline exists six groins and three shorenormal breakwaters.

To the west of Grassy Key are the islands of Crawl Key and Little Crawl Key. The east half of Crawl Key is a mangrove shoreline. The small residential peninsula known as Valhalla Beach on Crawl Key has riprap and a bulkhead at its west end and 600 feet of coarse grained sand beach at its east point. Although sediment transport is not significant, the estimated net transport direction is northeast along this fifteen foot wide beach. The low and undeveloped Little Crawl Key has 1,200 feet of privately owned beach averaging fifteen feet wide with an estimated net transport direction to the west. The west half of Little Crawl Key, sheltered by Deer Key, has a mangrove shoreline. Deer Key to the west is a mangrove island.

In the early 1950's (most probably 1952 to 1954) two large dredge and fill developments were created east of Marathon and south of Fat Deer Key. The development to the east, Coco Plum Beach, has 7,500 feet of fine sand beach averaging 25 feet wide (Figure 8). Monroe County is considering the acquisition of 3,300 feet of Coco Plum Beach which is essential for the preservation of this area of noncritical erosion. At the east end of the area is a terminal rock groin and at the west end are two rock groins. The obvious net sediment transport direction is to the southwest as seen by the severe erosion west of the eastern groin and the accretion at the west groins. West of Coco Plum Beach is Key Colony Beach which is substantially developed (Figure 9). Also with a southwest transport direction, this 4,550-foot long and 50-foot wide beach is stabilized by fifteen limerock groins which were constructed in 1958 and have periodically been maintained.

The City of Marathon is on the 5.5-mile long Vaca Key. The east half of the Vaca Key shoreline **is** protected by bulkheads and riprap, and a shoreline segment fronting the Vaca Key Bight is predominantly a mangrove shoreline. The southern extension of Vaca Key includes small sandy beaches. Along the Somhrero Beach Village is 2000 feet of private beach averaging fifteen feet in width and having an estimated net sediment transport direction to the north. The small Tingler Island at the southern tip of Vaca Key is armored with bulkheads and riprap. To the west and sheltered from west and southwest wave activity is Sombrero Beach, a Monroe County park (Figure 10). This fine grained sandy beach is **1,600** feet long and averages **25** feet wide. The eastward transport of beach sediment off Sombrero Beach and into the adjoining canal to the east has resulted in critical erosion. At least one beach nourishment effort was conducted in **1975** when about **60** to **70** cubic yards **of** sand were brought in by truck. The construction of a terminal groin is needed at the east end of the beach to prevent continued erosion losses and to stabilize beach nourishment at this park. Northwest of the park is another 800 feet of narrow, privately owned sand beach adjacent to Sister Creek. Net sediment transport along this east shore of Vaca Key appears to be northward.

South of the west end of Vaca Key is the relatively' undeveloped and privately owned Boot Key. Having predominantly a mangrove shoreline, Boot Key has a couple narrow pocket beaches with indeterminate transport direction. Adjacent the far west end of Vaca Key with the east terminus of the Seven Mile Bridge, Knight Key's shoreline is armored with bulkheads and riprap. Along and south of the Seven Mile Bridge between the middle and lower Keys, Pigeon Key, the Molasses Keys, and Money Key all have exposed rocky shorelines.

The lower Keys are geologically different from the upper and middle Keys. Throughout the lower Keys the exposed Miami limestone formation lies atop the Key Largo limestone formation. In the lower Keys, the Miami limestone formation ***is*** an oolite facies which began forming in the late Pleistocene epoch when sea level conditions favored the accumulation of carbonate sand banks behind the outer reef. When sea level fell, the exposed ooid bank formed the lower Keys (Hoffmeister et **al 1964**; Hoffmeister and Multer, **1968**; Schomer and Drew, **1982**; Lane, **1986)**. This exposed bedrock which forms the lower Keys is covered by a veneer of recent carbonate sediments. The formation is also dissected by numerous tidal channels that extend perpendicular to the general alignment **of** these islands. Large quantities of sediments are transported through the channels forming large sand . shoal areas to the northwest and southeast. Carbonate sedimentation by tidal channels and development of carbonate banks have been studied and discussed by Ball **(1967)**, Jindrich **(1969)**, and Basan **(1973)**.

At the west end of the Seven Mile Bridge are the three small islands of Little Duck Key, Missouri Key, and Ohio Key. Little Duck Key has a 25-foot wide, 825-foot long public beach maintained by Monroe County (Figure 11). Missouri Key has, a couple narrow pocket beaches of 500 feet at its west end. The larger Ohio Key has **1,600** feet of narrow Leach along the eastern half of its shoreline and mangrove along the western half. Privately owned Ohio Key's shoreline fronting on the Straits of Florida is a property parcel on the State's land acquisition list. The estimated net annual longshore sediment transport direction along these islands is to the southwest but little volumetric transport is apparent.

The most significant carbonate beaches and dunes of the lower Keys are on Bahia Honda Key and are part of the Bahia Honda State Recreation Area. The beach and sediment processes of this island have been studied and reported by Benhan et al. (1970), Huffman et al. (1970), Ragan and Smosna (1987), and Coastal Technology Corporation (1987). The island has 11,900 feet of beach south of U.S. Highway 1 fronting on the Straits and another 800 feet of beach north of the highway fronting on the Gulf of Mexico. The estimated direction of net annual longshore transport along the Straits beaches is to the southwest at a rate estimated by Coastal Technology Corporation (1987) of 2,050 cubic yards per year. Ragan and Smosna (1987) measured longshore current velocities which averaged 24 cm/sec (0.8 ft/sec). Coastal Technology Corporation (1987) estimates a net longshore sediment transport direction to the north at a rate of 90 cubic yards per year along the 600 foot long public recreation beach between the Flagler Bridge and the U.S. Highway 1 bridge (Figure 12). This beach and the western 3,500 feet of beach fronting directly on the Straits are experiencing critical erosion. Based on a comparison of 1971 and 1986 aerial photography, Coastal Technology Corporation estimated a maximum erosion rate of -5 feet per year on the west beach.

Early efforts to mitigate erosion conditions on Bahia Honda Key include the placement of 24-inch by 36-inch concrete bridge piles near the west end of the island. In the early 1970's, riprap was placed along 400 to 500 feet of the erosion threatened roadway adjacent to the western beach. Between 1981 and 1986, the park staff planted sea oats to mitigate continued erosion in this area. This area was subsequently armored by a 1,200-foot long limerock revetment which was constructed between October, 1988 and January, 1989 to protect the park road. At the north end of the 600-foot inner beach, a 100-foot terminal groin was constructed in October, 1989. Beach sediment had been lost into the adjacent marina entrance channel. In April, 1989, 300 cubic yards of sand was excavated from the channel and placed on the beach above mean high water. An additional 240 cubic yards of sand screened from limerock aggregate at Rockland Key was placed on this beach. Currently, however, additional nourishment is critically needed at this popular beach. The eastern 7,400 feet of beach of Bahia Honda is known as Sand Spur Beach which, with prominent vegetated barrier dunes and a beach width averaging 60 feet, appears stable for most of its length (Figure 13). Only along a 650-foot eastern segment is noncritical erosion ongoing. The park staff has planted sea oats and constructed beach access structures on Sand Spur Beach.

West of Bahia Honda Key and east of Big Pine Key lie the relatively small Spanish Harbor Keys. Several bulkheads exist along the predominantly natural rock shoreline fronting the Straits. Two small pocket beaches of 1,000 feet in length exist at a private Boy Scout camp. The estimated net annual longshore sediment transport direction on the south shore pocket beach is to the southwest and on the west shore pocket beach is to the north.

The easternmost lower Keys island with the exposed Miami limestone formation is Big Pine Key. The east end of Big Pine Key adjacent to Spanish Harbor is a natural rock shoreline with this exposed geologic formation. The east shore of the Southeast Point (actually Key Largo limestone formation) on Big Pine Key is a **400-** foot long coarse grained pocket beach. The sediment of this private beach includes a large fraction of the cast-off calcareous shells of tiny mollusks. With an estimated net annual longshore sediment transport direction to the southwest, the rocky Southeast Point holds the stable pocket beach to the east and entraps large wracks of seaweed and flotsam. The west shore of the Southeast Point is a mangrove shoreline.

Much of the Straits shoreline of Big Pine Key is a coarse grained sand, perched beach. Although mollusks and coral fragments provide an available source for natural renourishment and although a prominent barrier dune backs much of the shoreline providing a feeder source of beach sediment, erosion has substantially reduced the width and quality of the beach. Long Beach extends for about 5,400 feet of Big Pine Key and has an estimated net annual longshore sediment transport direction to the west-southwest (Figure 14). The west end of Long Beach is a mangrove shoreline. Continued development pressures along the privately owned beaches of Big Pine Key can be expected to substantially impact the barrier dune. No erosion control structures exist in this area which is on the State's land acquisition list.

Off the southwest tip of Big Pine Key is a chain of three small islands, which have narrow coarse grained sandy beaches similar to those on Big Pine Key. Cooks Island has the longest beach of 2,400 feet. Big Munson Island has a 500-foot pocket beach on its predominantly natural rock and mangrove shoreline. The tiny Munson Island is completely surrounded by its sandy shore. The estimated direction of net annual longshore sediment transport for this chain of islands is to the southwest. Northwest of these islands and sheltered from the southeast swell **is** the larger Ramrod Key with its predominantly mangrove shoreline. Only at its southwest point does there exist a small coarse grained sand pocket beach.

West of Big Pine Key and east of Sugarloaf Key are two large privately developed islands with their southern tips exposed to the Straits of Florida. Summerland Key, west of Ramrod Key, has a number of groins actually fronting on Niles Channel. The south tip of Cudjoe Key is lined with bulkheads and riprap. Offshore from these two islands are the mangrove islands of Pye Key, Crab Key, Money Key, Loggerhead Key, and Gopher Key.

In the geographic center of the lower Keys lies the large island of Sugarloaf Key. The privately owned Straits shoreline of Sugarloaf Key is predominantly a mangrove shoreline; however, Sugarloaf Beach comprises 3,000 feet of sandy beach. Like Long Beach of Big Pine Key, Sugarloaf Beach **is** a narrow, severely eroded, perched beach fronting a prominent barrier dune (Figure

15). There are a couple bulkheads and one shorenormal breakwater along this shoreline which has an estimated direction of net annual longshore sediment transport to the southwest. West across the narrow tidal Sugarloaf Creek are the Saddlebunch Keys which have a mangrove shoreline. West of the Saddlebunch Keys are the mangrove shorelines of the small islands of Pelican Key and Saddlehill Key.

West of Saddlehill Key are Geiger Key and the large island of Boca Chica Key. The east and west ends of Geiger Key have mangrove shorelines with a bulkheaded development in the middle. Half of Boca Chica Key's shoreline is a natural mangrove shoreline and half is a narrow severely eroded coarse grained sandy shoreline. Boca Chica Key is under federal ownership within the U.S. Navy Air Station, and beach access and usage is restricted. According to local residents the 7,300 feet of beach was wide prior to the **1944** and **1948** hurricanes which inflicted severe erosion throughout this area. Along the critically eroded Straits shoreline of Boca Chica Key, the estimated direction of net annual longshore sediment transport is to the southwest. The transport direction at the southwest point of Boca Chica Key is to the northwest. Between Boca Chica Key and Key West, Stock Island's shoreline is characterized by fill and riprap associated with marina and port facilities. The small island of Cow Key between Stock Island and Key West has a mangrove shoreline.

The best studied sandy shoreline in Monroe County is that of Key West. The United States Army Corps of Engineers **(1957, 1958)** studied the historical shoreline conditions and factors pertinent to the beach erosion problem at Key West. In the period between **1851** to **1934**, the mean high water shoreline receded an average of **-1.5** feet per year along the stretch of shoreline identified by the Corps of Engineers to be a problem area. In the same area between **1934** and **1957** the rate ranged as high as -3 feet per year. The net annual longshore sediment transport .direction along the Key West shoreline fronting the Straits of Florida is to the west (U.S. Corps of Engineers, **1957, 1958;** Coastal Technology Corporation, **1987).** There is very little littoral material entering the area and because the erosion has resulted in the loss of all beach at the east end of the island's shoreline, the seawall fronting South Roosevelt Boulevard now defines the shoreline.

The south Roosevelt Boulevard seawall was constructed in **1926** and was repaired in **1951** after the hurricane of October, **1944** destroyed 4,000 feet of the wall and road. In **1950** a boulder mound breakwater was constructed 300 feet long and four to five feet high to entrap littoral material being transported to the west at Bertha Street. Because little sand was trapped and because the, structure collected large volumes of seaweed, it was removed in **1957.**

A more effective erosion control project was conducted by local interests in **1960** along a 3,300-foot segment of shoreline named George Smathers Beach. The project consisted of the construction of four limestone rock groins **(200** to 300 feet long) and of beach restoration involving the placement of over 30,000 cubic yards of sand screenings from crushed limerock placed over a rock core. A berm with an elevation +4 feet NGVD and a width of 100 feet was constructed. The beach had a 1:20 slope from the berm crest to sea level. Congress authorized a federal project for Smathers Beach in 1960. The project which was constructed by locals has substantially eroded over the past 30 years. In 1989 the County nourished Smathers Beach with 16,000 cubic yards of aragonite sand which was barged in from the Bahamas (Figure 16). All the material was spread above mean high water. The proposed federal project includes three segments totalling 9,400 feet and calls for the placement of 156,000 cubic yards resulting in a 100-foot wide beach at Smathers Beach, a 25-foot wide beach eastward along South Roosevelt Boulevard, and a 25-foot wide beach between Bertha Street and White Street.

In 1946, a local contractor excavated a hole adjacent to the end of Bertha Street and removed approximately 25,000 cubic yards of material (Frank Toppino, personal communication). This borrow pit subsequently filled with sediment which probably was transported along the shoreline in the area of Smathers Beach. This loss of material from the beach and the severe erosion losses caused by the 1944 hurricane had a significant impact on the beach conditions in this area. Subsequent groin construction for the Smathers Beach project prevents any significant natural longshore transport westward along the shoreline west of Bertha Street. A pending private beach nourishment project at the 1800 Atlantic condominium west of Bertha Street was permitted by the Department of Natural Resources on September 12, 1985. This project, for a 480-foot length, is proposed to create a 90-foot wide beach with the placement of 2,700 cubic yards of sand.

The westernmost 660 feet of the proposed federal project is owned by the City of Key West. This area, known as Rest Beach, had a wide natural sand beach prior to the hurricane of 1944. Adjacent the west end of Rest Beach, the White Street Pier was constructed in the mid-1960's. This structure is impermeable to longshore transport and acts as a substantial groin or shorenormal breakwater. A large seaweed and flotsam accumulation has collected east of the pier along Rest Beach and resulted in severely reduced water quality and high turbidity conditions. The County is currently proposing to open a shore-attached section of the pier to restore the natural longshore current to the west.

West of White Street is a 1,250-foot shoreline segment of County owned park known as the Clarence S. Higgs Memorial Beach (Figure 17). In 1951, the County initially improved the beach by constructing a sheet pile wall and by placing about 10,000 cubic yards of limerock screenings over exposed rock (Frank Toppino, personal communication). Later, additional sand was brought in by a small suction dredge which removed shoal material between Calda Channel and the Harbor Keys northwest of Key West. Higgs Beach is currently in need of renourishment.

West of Higgs Beach is a 50-foot wide and 950-foot long beach at the Casa Marina Hotel (Figure 18). In 1978-79, a 24-inch wide by 18-inch deep trench was cut in the rocky shoreline and lined with boulders to create a low profile retaining structure. Approximately 350 cubic yards of material was placed for nourishment including a bed of limerock screenings and a four inch cover of Ortona sand which was tucked in from near Lake Wales, Florida.

Further west at the end of Simonton Street is a 300-foot long by 35-foot wide private pocket beach at the Reach Hotel. At the end of Duval Street is another pocket beach owned by the City of Key West. This beach, known as South Beach or City Beach, is 300 feet long by 50 feet wide and is in critical need of nourishment (Figure 19). Between the City Beach and the Whitehead Spit to the west is a 2,000-foot segment of eroded sandy shoreline within the U.S. Naval Station, Truman Annex. An additional 800 feet of eroded federally owned beach exists west of Whitehead Spit. This segment has a 100-foot width.

On the southwest tip of Key West is an area which was built by dredge spoil from the ship channel dredging project (Figure 20). This fill site includes the Fort Zachary Taylor State Historical Site with its nearly 150 year old fort. A limerock revetment was constructed by the Navy around the dredge spoil in 1964. Subsequently, erosion undermined and collapsed the revetment and filtered out much of the sand along the Straits shoreline leaving an undesirable rocky beach for recreation. An investigation'by Coastal Technology Corporation (1987) compared aerial photography between 1971 and 1985 which revealed shoreline recession of up to 160 feet. Wave refraction and sediment transport studies revealed wave energy focusing in this area and sediment transport to the west by wave action and flood tidal currents into the Key West Ship Channel. As a result of these studies Coastal Technology Corporation (1987) recommended the construction of a 125-foot long terminal groin at the west end of this 1,500-foot beach and two 100-foot detached breakwaters. In October, 1989, a 110-foot long terminal groin and one 100-foot long detached breakwater were constructed of granite barged in from the Appalachians. In addition, the steep beach erosion escarpment was graded back on a 1:10 slope from the +5 ft. NGVD contour for approximately 50 feet. Approximately 2,600 cubic yards of material were removed and screened to separate the sand from the rock. Over 1,000 cubic yards of this screened sand have been stockpiled on the beach for spreading as beach fill. Approximately 9,500 cubic yards of sand were authorized to be placed as nourishment. Completion of the nourishment and breakwater construction project is needed to control the critical erosion conditions and restore this public recreation beach.

Elsewhere around the shoreline of Key West are a few other pocket beaches. A 300-foot long pocket beach known as Truman Beach exists on the island's west shore within the U.S. Naval Station, Truman Annex. Three small private beaches totalling 400 feet also exist along Front Street. One of these, a 100-foot long pocket beach at the Pier House was originally nourished in 1984 and periodically since then with over 100 cubic yards of Ortona sand (Frank Toppino, personal communication). Another pocket beach at the Hyatt was restored in the summer of 1989. Across the Key West Ship Channel on a privately owned spoil island known as Tank Island a small beach on the island's southwest shore was recently restored by only scraping the erosion escarpment landward without the placement of fill.

The lower Keys also have several significant beaches along the "back country" islands fronting on the Gulf of Mexico. Jindrich (1969) describes these islands as part of the "intertidal barrier belt" between the "interior lagoon" and the "outer plateau" in the Gulf of Mexico. The carbonate sediment accumulation in this area is due to the trapping effects of marine grass and algae. Sediments of these beaches consist primarily of the calcareous green algae, Halimeda opuntia, Pleistocene limestone fragments, and a variety of mollusks and foraminifera (Jindrich, 1969). The beaches of Mud Key, Snipe Point (Snipe Keys), Marvin Key (Barracuda Keys), Sawyer Key, and the Content Keys total approximately 6,100 feet in length and average 25 feet in width. Shoreline processes have not been documented for these beaches and the estimated direction of net annual longshore sediment transport is to the southwest.

Beaches of the three island groups west of Key West have likewise been unstudied except for their general' topographic description by Davis (1942). An investigation in October, 1989, revealed the outer islands nearest Key West and the Marquesas Keys, located over eighteen miles west of Key West, to have calcareous sand beaches averaging 25 feet in width (Figure 2b). Inspection of the beach sediment reveals a dominence of the calcareous skeletal fragments of green algae and oolitic sand. Net longshore sediment transport directions very according to the beach alignment and exposure to wave activity. Although general shoreline stability is apparent in most areas during the 50 years since Davis conducted his investigation, significant beach losses have been noted due to the "quiet invasion" of mangrove colonies. Remnant beach erosion escarpments and washovers were noted in October, 1989, along the Straits shorelines of Woman Key, Boca Grande Key, and the Marquesas Keys which probably were inflicted by recent hurricanes Elena (September, 1985), Kate (November, 1985), and Floyd (October, 1987).

Cumulatively, the length of the beaches of the outer islands nearest Key West is over 2.6 miles, The longest continuous beaches are on Boca Grande Key and Woman Key which both have nearly 5,000 feet of beach (Figures 21 and 22). Boca Grande Key, the largest of the group of islands, is thought to be the oldest and most permanent of the islands given the large areas of oolitic limerock exposure (Davis, 1942). Government charts reflect little change in shape or elevation in the past 125 years.

The cumulative length of the beaches of the Marquesas Keys is nearly **4.5** miles. A 1,200-foot beach exists on Southeast Key and **8,250** feet of beach exists on the three islands which make up the Southwest Keys (Figure 23). In **1904** the Southwest Keys were one island but a storm after **1910** probably truncated the southern island. The northern two islands were also breached but reattached by the late **1930's** (Davis, **1942).** Any of the several hurricanes of the **1940's, 50's**, or **60's** which crossed this area could have created the current breach between the northern two islands. Long Beach Key with over 2.5 miles of continuous beach fronting on the Gulf of Mexico is the longest and largest of all the islands west of Key West (Figure **24).** The beach/dune system of Long Beach Key characterizes the high energy conditions which may be expected associated with winter frontal systems crossing the Gulf. The beach sediments are predominantly Halimeda fragments and a vast source of this material is readily produced in the adjacent waters. The wide dune ridge along Long Beach Key is well stabilized by one of the densest communities of sea oats found along Florida's beaches.

Perhaps the most remote beaches of Florida are those of the Dry Tortugas or Tortugas Keys, which are located 65 to 70 miles west of Key West (Figure 2a). All six islands of this group have beaches which cumulatively measure **4.5** miles. Coral fragments comprise a large fraction of the sediments of these islands. The **9,225** feet of beach on Loggerhead Key characterizes perhaps the highest wave energy conditions in Monroe County (Figure 26). The steeply sloping beaches are fronted by a developing beach rock of indurated calcareous sand. Examination of the beachrock reveals aragonite cement as coatings around and fillings between individual sediment particles. Beach processes of the Dry Tortugas are generally unresearched and in need of further study to determine erosion/accretion patterns and longshore transport processes. Erosion control efforts are not apparent on any of the three distal island groups west of Key West.

ESTIMATED DIRECTION OF NET ANNUAL LONGHORE SEDIMENT TRANSPORT

STRAITS OF FLORIDA BEACHES

Beach, Key	Net Transport Direction
Upper Matecumbe Key	Southwest
Lower Matecumbe Key	Southwest
East quarter of Long Key	Northeast
West three quarters of Long Key	West
Northeast half of Toms Harbor Key	Northeast
Southwest half of Toms Harbor Key	Southwest
Grassy Key	Southwest
East end of Crawl Key	Northeast
Little Crawl Key	West
Coco Plum Beach	Southwest
Key Colony Beach	Southwest
Sombrero Beach Village, Vaca Key	North
Sombrero Beach, Vaca Key	East
East shore Vaca Key (Sister Creek)	North
Boot Key pocket beaches	Indeterminate
Little Duck Key	Southwest
Missouri Key pocket beaches	Indeterminate
Ohio Key	Southwest
Bahia Honda Key	Southwest
Inner pocket beach, Bahia Honda Key	Indeterminate
Spanish Harbor Key pocket beach	Southwest
West shore Spanish Harbor Key	North
Southeast Point, Big Pine Key	Southwest
Long Beach, Big Pine Key	West-Southwest

Beach, Key	Net Transport Direction
Cooks Island	Southwest
Big Munson Island	Southwest
Munson Island	Southwest
Southwest point of Ramrod Key	Indeterminate
Sugarloaf Beach, Sugarloaf Key	Southwest
Boca Chica Key	Southwest
Southwest point of Boca Chica Key	Northwest
Smathers Beach, Key West	West
Rest Beach, Key West	West
Higgs Beach, Key West	West
Casa Marina Hotel, Key West	West
Reach Hotel pocket beach, Key West	Indeterminate
Key West City Beach, pocket beach	Indeterminate
Truman Annex, east of Whitehead Spit	West-Southwest
Truman Annex, west of Whitehead Spit	West
Fort Zachary Taylor Historic Site	West
Truman Beach, Key West	North
Front Street pocket beaches, Key West	Indeterminate
Tank Island pocket beach	Indeterminate
East end of Man Key	North
South shore of Ballast Key	Southwest
East shore of Ballast Key	North
Woman Key	West
West shore of Woman Key	North
South shore of Boca Grande Key	West
West shore of Boca Grande Key	North

ESTIMATED DIRECTION OF NET ANNUAL LONGSHORE SEDIMENT TRANSPORT

GULF OF MEXICO BEACHES

Beach, Key	Net Transport Direction
Key McLaughlin	Southeast
Cape Sable	Southeast
North shore of Bahia Honda Key	Southwest
Content Keys	Southwest
Sawyer Key	Southwest
Marvin Key, Barracuda Keys	Indeterminate
Snipe Point, Snipe Keys	Southwest
Mud Key	Indeterminate
Southeast Key	Southwest
East half of southeast island of Southwest Keys	Northeast
West half of southeast island of Southwest Keys	West
West shore of southeast island of Southwest Keys	North
West shore of southwest island of Southwest Keys	Southeast
North shore of southwest island of Southwest Keys	East
West shore of north island of Southwest Keys	South
North shore of Long Beach Key	West
Southeast shore of Long Beach Key	Southwest
East Key	Indeterminate
Hospital Key	Indeterminate
Bush Key	Indeterminate
Long Key	Southwest

Beach, Key	Net Transport Direction
East shore of Garden Key	**South**
Southwest beach of Garden Key	**South**
Loggerhead Key	**Needs Further Study**

CHARACTERISTICS OF BEACH SEDIMENTS

During the week of October 23 to 27, **1989**, beach, dune, and nearshore sediment samples were randomly collected from beach sites throughout the Keys between Lower Matecumbe Key and the Dry Tortugas. The locations of all samples are detailed in the following table and shown in Figures 3, 4a, and 4b. **A** subsequent table qualitatively identifies the beach sediment composition by texture and predominant constituents.

The greatest material constituent of the beach sediments was the skeletal components of calcareous algae. Mitchell-Tapping **(1978)** studied sediments of the reef shoal environment throughout the lower Keys and the Dry Tortugas and determined the main algal constituent consists of the genera Halimeda, Penicillus, and Goniolithon. However, he found that the percent volume composition of Penicillus and Goniolithon is less than five percent of the total algal component and is generally only common in the less than 3.0 phi size sediment. Goniolithon strictum, the branching coralline red algae, with brittle branches **1** to **5mm** in diameter fractures into stick-like particles or rods creating a coarse sandy sediment of high magnesium calcite. Goniolithon was a dominant constituent in the sediment samples of the intertidal zones on Missouri Key and Big Pine Key, but was also noted in the sediment samples from Little Duck Key, Sugarloaf Key, and Long Key. Penicillus, a lightly calcified green algae, fractures upon death into triangular plate-like particles of aragonite crystals. Though relatively common, Penicillus disintegrates to the fine sand size to silt size particles and may not be a particularly important constituent in the beach sediments.

The most abundant constituent of the beach sediments collected is the calcareous green algae, Halimeda sp., which is the major sediment producer throughout the Keys. Halimeda consists of articulated calcified segments or joints of aragonite. Upon death of the plant, individual segments or plates separate and may occur whole in the sediment or be broken down by biological activity to sand and smaller size particles. Mitchell-Tapping **(1978)** found the Halimeda plate sizes range from **-1.125** to **-0.875** phi. Halimeda plates were the predominant constituent in all the sediment samples obtained in this investigation west of Key West and were detected in most of the samples taken from the middle and lower Keys. The Marquesas Keys appear to have completely evolved from Halimeda banks.

Among the major contributors of carbonate sediment in Monroe County are the coelenterates The most important coelenterates in forming the sediment are the octocorals, hydrocorals, and scleractinians. Numerous species of the stony corals are prominent sediment producers. Hurricanes and other major storms have very destructive effects on coral reefs, and biological breakdown of coral fragments by fish, mollusks, sponges, crustaceans, annelid worms, echinoids, and starfish contribute to the production of sand size coralline sediments. Coarse sand to gravel size coral fragments were noted in the sediment samples of Bahia Honda Key, Big Pine Key, Key West, Boca Grande Key, and throughout the Dry Tortugas. Mitchell-Tapping (1978) noted that if a coral skeletal element had been reduced below a limiting size by fracturing and abrasion, shape recognition would not be possible. Size reduction of the skeletal grains is both dependant on the physical stress exerted against a grain and on the strength of the grain.

Calcareous forms of foraminifera are also found in the carbonate sediments. Among the common species, Homotrema rubrum is recognized by its red color and dense fibrous walls of cubical shape. This sediment may be of value in tracing the direction of transport of sandy sediment. Also abundant in most of the sediment samples obtained were mollusks. Although there are six major classes of mollusks, the Gastropoda and the Pelecypoda are the important sediment producers. The composition of pelecypods is predominantly aragonite with a small amount of calcite. There are also numerous species of gastropods which are found in the sediment. Abrasion and bioerosion reduces mollusks to sediment sizes. In his study of sediments throughout the lower Keys and Dry Tortugas, Mitchell-Tapping (1978) found that less than one percent of the sediment volume was made up of skeletal particles of sponge and tunicate spicules, bryozoa, crustacean skeletal fragments, serpulid tubes, ostracods, fish skeletal fragments, fecal pellets, and diatoms. Organic material was also commonly found in the dune sediment samples obtained this investigation.

BEACH SEDIMENT SAMPLES

Sample No.		Texture		Predomin	
1	10-23	4:20	P.M.	Fort Zachary Taylor	0.0
2	10-23	4:45	P.M.	South Beach, Key West	+2.0
3	10-23	6:00	P.M.	Smathers Beach, Key West	+4.0
4	10-24	4:30	P.M.	Woman Key	+0.5
5	10-24	4:30	P.M.	Woman Key	+3.0
6	10-24	3:30	P.M.	Boca Grande Key (100 ft. off west shore)	-1.0
7	10-24	3:30	P.M.	Boca Grande Key (west shore)	0.0
8	10-24	1:30	P.M.	Boca Grande Key (west beach)	+2.0
9	10-24	3:30	P.M.	Boca Grande Key (westshore dune)	+6.0
10A	10-24	11:30	A.M.	Southwest Keys(southeast island)	+5.0
10B	10-24	11:30	A.M.	Southwest Keys(southeast island)	+1.5
11	10-24	11:30	A.M.	Southwest Keys(southeast island)	+1.5
12	10-24	12:00	P.M.	Southwest Keys (middle island)	+5.0
13	10-24	12:00	P.M.	Southwest Keys (middle island)	+1.0
14	10-24	1:00	P.M.	Southwest Keys (north island)	+3.0
15	10-24	1:30	P.M.	Long Beach Key	+10.0
16	10-24	1:30	P.M.	Long Beach Key	+3.0
17	10-24	1:30	P.M.	Long Beach Key	-0.5
18	10-24	2:30	P.M.	Long Beach Key	-2.0
19	10-24	10:30	A.M.	Long Beach Key (southern horn)	+1.0
20	10-24	10:30	A.M.	Long Beach Key (southern horn)	+5.0
21	10-25	9:00	A.M.	Boca Chica Key	+2.0
22	10-25	10:00	A.M.	Sugarloaf Beach, Sugarloaf Key	+0.5
23	10-25	11:15	A.M.	Long Beach, Big Pine Key	+2.0

BEACH SEDIMENT SAMPLES

Sample No.		Texture		Predomin	
24	10-25	11:30	A.M.	Long Beach, Big Pine Key	+0.5
25	10-25	11:45	A.M.	Southeast Point, Big Pine Key	+3.0
26	10-25	12:.40	P.M.	Bahia Honda Key (inner beach)	0.0
27	10-25	12:45	P.M.	Bahia Honda Key (inner beach)	-2.5
28	10-25	1:10	P.M.	Bahia Honda Key (west beach)	0.0
29	10-25	1:40	P.M.	Sandspur Beach, Bahia Honda Key	+2.0
30	10-25	1:45	P.M.	Sandspur Beach, Bahia Honda Key	-2.5
31	10-25	2:25	P.M.	Missouri Key	+1.0
32	10-25	2:45	P.M.	Little Duck Key	+0.5
33	10-25	4:00	P.M.	Sombrero Beach, Vaca Key	0.0
34	10-25	4:30	P.M.	Key Colony Beach	+1.9
35	10-25	5:00	P.M.	Coco Plum Beach	+0.5
36	10-26	3:45	P.M.	Long Key (west end)	0.0
37	10-26	4:20	P.M.	Long Key (eroded shore)	+0.5
38	10-26	5:10	P.M.	Calusa Cove, Lower Matecumbe	+0.5
39	10-27	10:45	A.M.	Bush Key	0.0
40	10-27	10:45	A.M.	Bush Key (dune crest)	+3.0
41	10-27	11:15	A.M.	Garden Key (northeast shore)	0.0
42	10-27	11:00	A.M.	Garden Key (southwest shore)	0.0
43	10-27	11:00	A.M.	Garden Key (southwest shore)	+8.0
44	10-27	10:15	A.M.	Loggerhead Key (east beach)	0.0
45	10-27	10:15	A.M.	Loggerhead Key (east beach)	+8.0
46	10-27	10:00	A.M.	Loggerhead Key (mid-island)	+10.0
47	10-27	10:00	A.M.	Loggerhead Key (west beach)	
48	10-27	10:00	A.M.	Loggerhead Key (west beach)	0.0

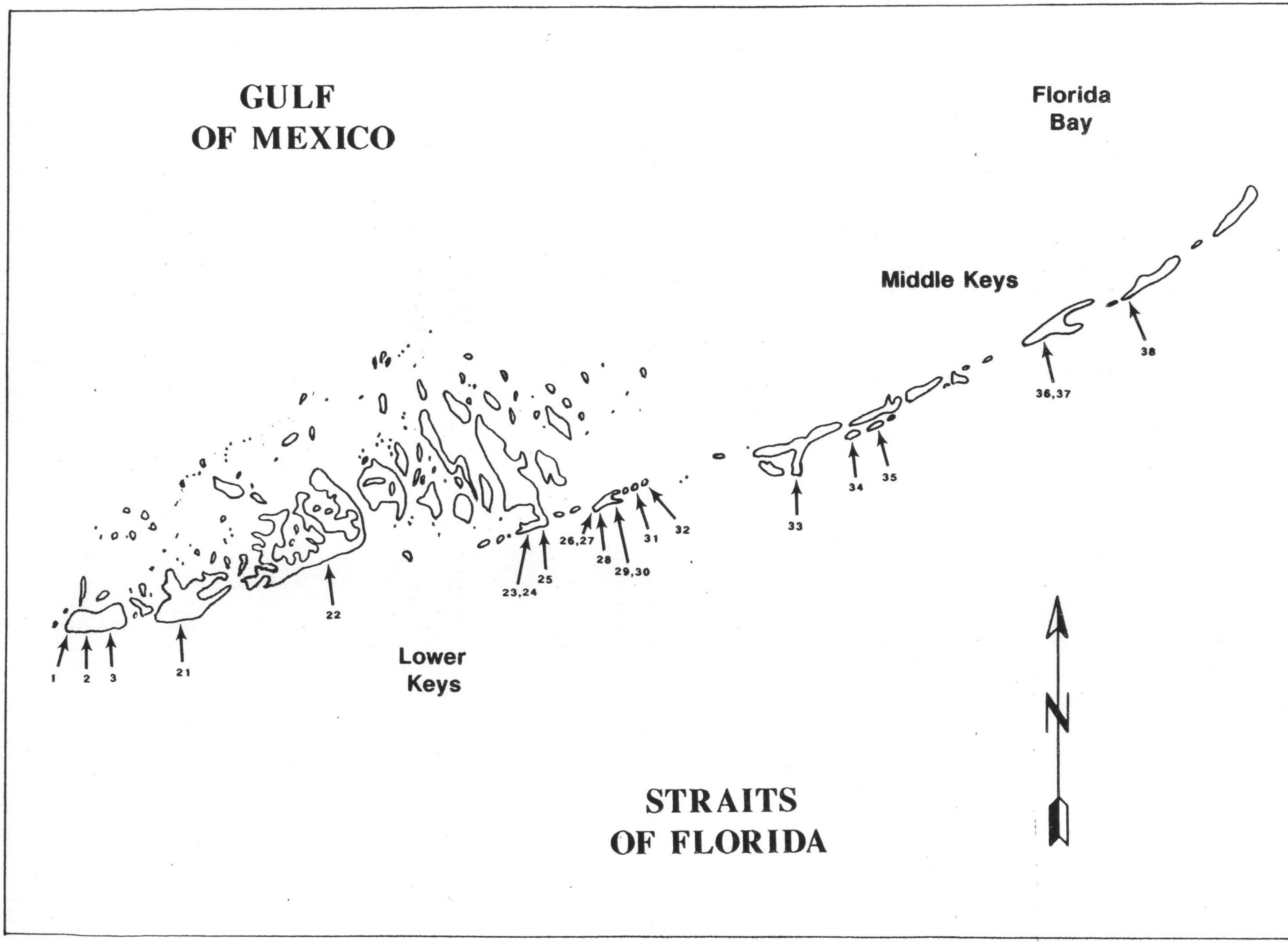

Figure 3. Sediment sample locations from beaches of lower and middle Keys

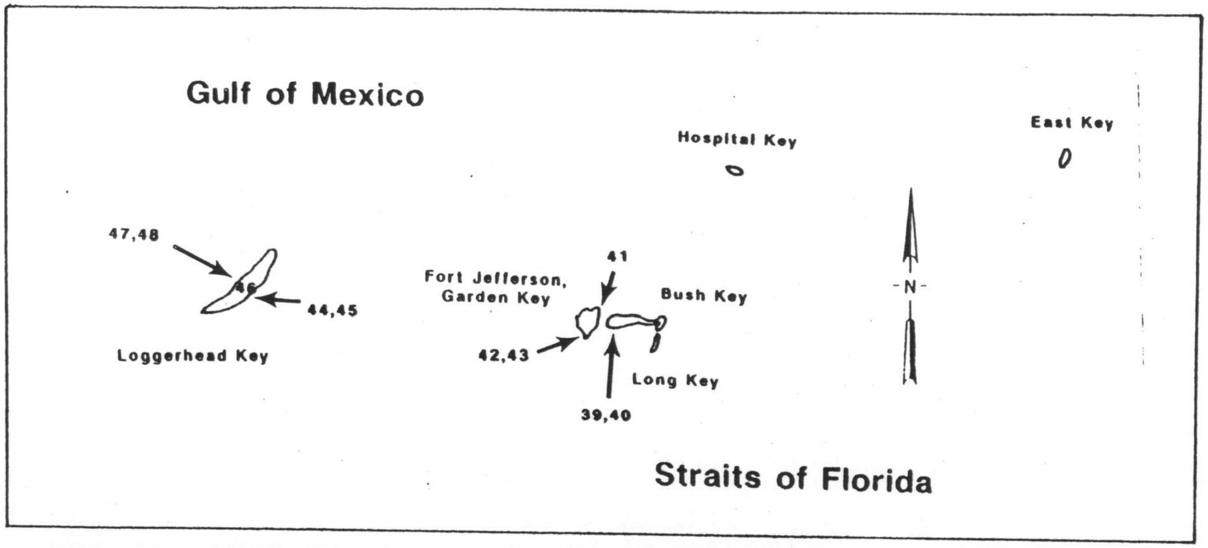

Figure 4a. Sediment sample locations in Dry Tortugas

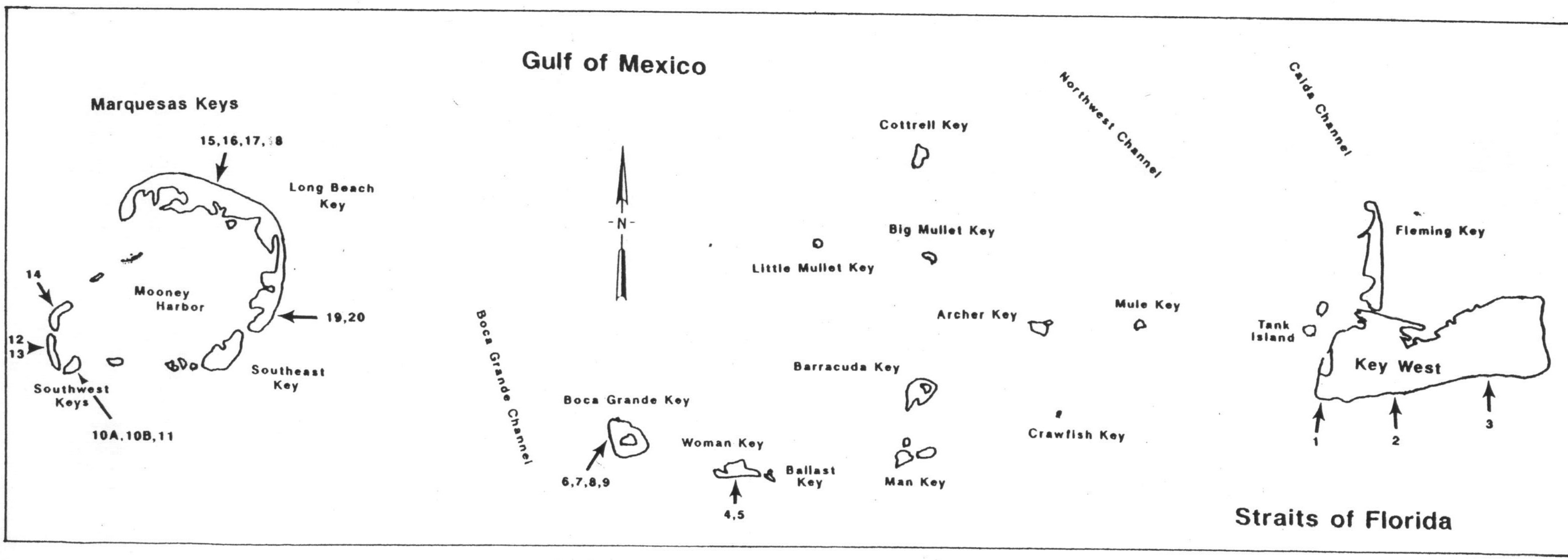

Figure 4b. Sediment sample locations from Key West to the Marquesas Keys

BEACH SEDIMENT COMPOSITION

Sample No.	Texture	Predominiant Constituents
1	fine	oolite, coral, mollusk
2	very fine	oolite with large coral & mollusk fragments
3	fine & coarse	oolite, coral, mollusk
4	fine	Halimeda, mollusk
5	fine	Halimeda, mollusk
6	very fine	Halimeda
7	coarse	Halimeda, mollusk
8	fine & coarse	Halimeda, coral, mollusk
9	coarse	Halimeda, mollusk, organics
10A	very coarse	Halimeda, mollusk, organics
10B	very coarse	Halimeda
11	algae mat	unfragmented Halimeda
12	coarse	Halimeda, organics
13	coarse	Halimeda
14	very coarse	Halimeda
15	medium to coarse	Halimeda, black organic silt
16	medium to coarse	Halimeda
17	coarse	Halimeda, mollusk
18	very coarse	Halimeda & mud conglomerates
19	fine & coarse	Halimeda
20	fine & coarse	Halimeda, organics
21	fine	oolite, mollusk
22	fine	oolite, Goniolithon, mollusk
23	coarse	Goniolithon, mollusk, coral

BEACH SEDIMENT COMPOSITION

Sample No.	Texture	Predominiant Constituents
24	coarse	Goniolithon, mollusk, coral
25	very coarse	mollusk, Goniolithon, coral
26	coarse & fine	Halimeda, mollusk, coral
27	coarse & fine	Halimeda, large mollusk & coral fragments
28	coarse & fine	coral, mollusk, oolite
29	very fine	oolite, Halimeda
30	coarse & fine	oolite, Halimeda, mollusk
31	coarse	Goniolithon, mollusk
32	coarse	oolite, Goniolithon
33	fine	oolite, Halimeda
34	coarse	Halimeda, mollusk, oolite
35	very fine	oolite with large mollusk fragments
36	coarse	oolite, mollusk, Goniolithon, Halimeda
37	coarse & fine	oolite, mollusk, Goniolithon, Halimeda
38	fine	oolite, mollusk, Halimeda
39	fine	Halimeda, coral
40	coarse & fine	Halimeda, coral
41	fine	Halimeda, coral
42	Eine & coarse	Halimeda, coral, mollusk
43	fine & coarse	Halimeda, coral, mollusk
44	coarse	Halimeda, coral, mollusk
45	coarse	Halimeda, mollusk, coral
46	coarse	Halimeda, organics
47	coarse	Halimeda, coral, mollusk
48	coarse	Halimeda, coral, mollusk

TIDAL CHANNELS

Unlike the barrier island coasts of Florida which have coastal barrier inlets that affect longshore sediment transport along the beaches, Monroe County has numerous tidal channels throughout the Florida Keys as well as tidal creek entrances along the mainland coast. The tidal flow and sediment transport characteristics of the tidal creeks of the mainland coast are generally unstudied; however, these entrances do not appear to have a major influence on the long term stability of the adjacent beaches.

Over seventy tidal channels exist throughout the Florida Keys between Key Largo and Key West. The tidal creeks and canal entrances of Key Largo have no influence on the shore stability of Key Largo given the rock character of the shoreline. The twenty-eight tidal channels which separate the islands of the middle Keys carry sediment which is transported on both the flood and ebb tides. The characteristic narrow pocket beaches of the middle Keys fronting the Straits may be influenced by the distribution of sediments transported by these tidal channels and their shoals; however, the sediment transport patterns have not been identified. Throughout the lower Keys, the Miami limestone formation is dissected by at least seventeen tidal channels extending perpendicular to the general alignment of the islands. Along the intertidal barrier belt group of islands fronting on the Gulf of Mexico are at least fifteen more channels which extend into the interior lagoon. A number of the channels connecting with the Straits are on the same general alignment with the channels connecting with the Gulf.

The astronomical tide provides the forcing function for the hydraulic flow which created these channels. The tides of the Keys are chiefly semidiurnal but generally are mixed with a diurnal phase. The tide amplitudes trend to dominantly semidiurnal nearest the neap tides and are most notably mixed nearest the spring tides. The mean range and spring range of the tides vary from 2.3 feet and 2.8 feet respectively at the Ocean Reef Club on north Key Largo, 1.6 feet and 2 feet at Marathon, 1.3 feet and 1.8 feet at Key West, to 1.1 feet and 1.7 feet at Fort Jefferson, Dry Tortugas. Mainland tides of Monroe County are among the highest on the Gulf of Mexico, with the mean range and diurnal range varying from 2.9 feet and 3.8 feet respectively at East Cape, Cape Sable to 3.5 feet and 4.9 feet at Pavilion Key near the north Monroe County line.

In the lower Keys, tidal currents transport large quantities of sediment through the channels forming large sand shoals to the northwest and southeast. The ebb tide dominant channels which dissect the intertidal barrier belt north of Key West transport sediments Gulfward to develop large tidal deltas on the shallow plateau. Jindrich **(1969)** researched one of these channels, Bluefish Channel, and described the ebb tidal current velocities as greatly exceeding flood tidal current velocities, because as the ebb tide waters retreat toward the Gulf and the barrier belt emerges, the ebb flow is constricted in the channels. At the northern termini of these channels of the western intertidal barrier belt are large deltas of calcareous sand composed largely of Halimeda (Jindrich, 1969; Basan, 1973). Although quite large in grain size, the platy and porous Halimeda material possesses a hydraulic behavior comparable to much smaller sand grains due to its low settling velocity and ease of resuspension. In a 1985 sand source investigation for a Key West beach restoration project, the United States Army Corps of Engineers, Jacksonville District, identified a large shoal system at the northwest mouth of Calda Channel containing an estimated 400,000 cubic yards of beach quality sand.

The tide channels of the eastern intertidal barrier belt lack the prominent ebb tide deltas of those to the west, either because of higher wave activity which prevents ebb tide sediment accumulation or because of erosive flood tide velocities (Jindrich, 1969). Basan (1973) investigated sedimentation and carbonate bank development in the Barracuda Keys and noted that sediment transport is affected mainly by the flood tide and secondarily by wind waves generated by the east to southeast trade winds. On these banks, as on those to the west, the disintegration of indigenous Halimeda skeletons provides the greatest volumetric constituent of the sediment.

Although the tidal channels throughout Monroe County probably do not have as significant an impact on adjacent beaches as those coastal barrier inlets along the remainder of Florida's coast, local distribution of sediments by nearby tidal channels should be investigated whenever evaluating specific shoreline erosion problem areas.

TIDAL CHANNELS ON THE FLORIDA STRAITS

UPPER KEYS STRAITS CHANNELS	TO SOUTH	TO NORTH
Broad Creek	Broad Key, Palo Alto Key	Swan Key, Dade Co.
Anglefish Creek	Anglefish Key	Palo Alto Key
Little Anglefish Creek	Anglefish Key	Anglefish Key
Pumpkin Creek	Key Largo	Anglefish Key
3 tidal channels, Ocean Reef Club	Key Largo	Key Largo
Little Dispatch Creek	Key Largo	Key Largo
North Sound Creek	El Radabob Key	Key Largo
South Sound Creek	Key Largo	El Radabob Key
Rock Harbor Entrance	Key Largo	Key Largo

MIDDLE KEYS STRAITS CHANNELS	TO SOUTHWEST	TO NORTHEAST
Tavernier Creek	Plantation Key	Key Largo
Snake Creek	Windley Key	Plantation Key
Whale Harbor Channel	Upper Matecumbe Key	Windley Key
unnamed dredged channel	Teatable Key	Upper Matecumbe Key
Teatable Key Channel	Indian Key	Teatable Key
Indian Key Channel	Indian Key	Teatable Key
Lignumvitae Channel	Lower Matecumbe Key	Indian Key
Channel Two	Craig Key	Lower Matecumbe Key
Channel Five	Long Key	Craig Key
unnamed open water at Long Key Viaduct	Conch Keys	Long Key

Toms Harbor Cut	Duck Key	Conch Keys
Duck Key Channel	Toms Harbor Keys	Duck Key
Toms Harbor Channel	Grassy Key	Toms Harbor Keys
Coco Plum Canal Entrance	Coco Plum Beach	Deer Key
unnamed dredged channel	Key Colony Beach	Coco Plum Beach
unnamed pass	Vaca Key	Fat Deer Key
Sister Creek	Boot Key	Sombrero Beach, Vaca
Boot Key Harbor Entrance	Knight Key	Boot Key
Knight Key Channel	Pidgeon Key	Knight Key
Moser Channel	Molasess Keys	Pidgeon Key
Molasses Key Channel	Money Key	Molasses Keys
Money Key Channel	Money Key	Molasses Keys
Pacet Channel	Little Money Key	Money Key
unnamed channel	Little Duck Key	Little Money Key
Missouri Little Duck Key Channel	Missouri Key	Little Duck Key
Ohio Missouri Channel	Ohio Key	Missouri Key
Ohio Bahia Honda Channel	Bahia Honda Key	Ohio Key
Bahia Honda Channel	Spanish Harbor Keys	Bahia Honda Keys

TIDAL CHANNELS ON THE FLORIDA STRAITS

LOWER KEYS STRAITS CHANNELS	TO WEST	TO EAST
Bahia Honda Channel	Spanish Harbor Keys	Bahia Honda Keys
Spanish Harbor Channel	Big Pine Key	Spanish Harbor Keys
Pine Channel	Little Torch Key	Big Pine Key
Newfound Harbor Channel	Torch Keys & Ramrod Keys	Newfound Harbor Keys
Torch Channel	Middle Torch Key	Little Torch Key
Torch Ramrod Channel	Ramrod Key	Middle Torch Key
Niles Channel	Summerland Key	Big Torch Key & Ramrod Key
Kemp Channel	Cudjoe Key	Knockemdown Keys & Summerland Key
Bow (Sugarloaf) Channel	Sugarloaf Key	Cudjoe Key
Sugarloaf Creek	Saddlebunch Keys	Sugarloaf Key
Saddlebunch Harbor	Bird Key, Pelican Keys	Saddlebunch Keys
Shark Channel	Shark Key	O'Hara Key & Saddlebunch Keys
unnamed channel	Geiger Key	Saddlehill Key
Geiger Creek	Boca Chica Key	Geiger Key
Boca Chica Channel	Stock Island	Boca Chica Key
Cow Key Channel	Key West	Stock Island
Main Ship Channel	Kingfish Shoals	Key West

TIDAL CHANNELS ON THE GULF OF MEXICO

LOWER KEYS GULF CHANNELS	TO WEST	TO EAST
Northwest Channel	The Lakes	Calda Bank
Jack Channel	Calda Bank	---
Calda Channel	Calda Bank	---
Man of War Harbor	Frankfort Bank	Fleming Key
Bluefish Channel	----	----
West Harbor Key Channel	----	West Harbor Key
East Harbor Key Channel	West Harbor Key	East Harbor Keys
Jewfish Channel	East Harbor Keys	Mud Keys
Mud Key Channel	Mud Keys	Snipe Keys
Barracuda Key Channel	Snipe Keys	Barracuda Keys
Johnson Key Channel	Johnson Key	Sawyer Key
Cudjoe Channel	Sawyer Key	Crane Key
Content Passage	Content Keys	Content Keys
Harbor Channel	Upper Harbor Key	Cutoe Banks
Rocky Channel	Spanish Banks	Bullfrog Banks

EROSION PROBLEM AREAS - FLORIDA KEYS

Beach/Key	Erosion Length, miles	Critical, miles	Noncritical, miles
Long Key State Recreation Area	0.6	0.6	0.0
COCO Plum Beach	0.6	0.0	0.6
Sombrero Beach, Vaca Key	0.3	0.3	0.0
Bahia Honda State Recreation Area	1.0	0.8	0.2
Long Beach, Big Pine Key	1.0	0.0	1.0
Sugarloaf Beach, Sugarloaf Key	0.6	0.0	0.6
Boca Chica Key	1.3	0.0	1.3
Key West	2.8	2.8	0.0
Ft. Zachary Taylor State Historical Site	0.3	0.3	0.0
	8.5	4.8	3.7

Figure 5. Erosion problem areas, Florida Keys

IDENTIFIED BEACH EROSION PROBLEM AREAS

The primary causative factors for beach and dune erosion in Monroe County include periodic major storm events, onshore and longshore sediment budget deficits, historical development trends, and long term sea level rise. Because of the nature of the carbonate sediment of the beaches in Monroe County the sediment supply is affected by the chemical and biological processes of adjacent waters. Not well understood are the environmental influences of changing salinity, hydrostatic pressure, temperature, turbidity, organic and inorganic pollutants, and other marine environmental factors on the chemical and biological production of sediments for the natural nourishment of the beaches.

Long Key State Recreation Area - The net annual longshore sediment transport direction along the western three quarters of Long Key is to the west. Small tidal creeks, tidal lagoons, and a mangrove dominant shoreline fronting on the Straits near the center of the island create a sediment budget deficit to the west affecting the shoreline campgrounds of the State Recreation Area. A 750-foot limerock revetment was constructed to protect the park road from erosion. This structure also contributes to the sediment budget deficit to the west where approximately 0.6 mile of beach is eroding at a rate as high as -3 feet per year. This erosion is critical due to the threat to the campground facilities. The erosion problem is exacerbated by the existing exotic plants which are dominant along the eroding segment of shoreline. From a beach/dune preservation perspective, beach and dune restoration is needed in this critically eroded area to replace the natural storm erosion protection to the public facilities and to replace the recreational beach which has been substantially lost due to erosion. Shoreline monitoring is necessary for the future management of the beach resources of this State Recreation Area.

Coco Plum Beach - The net annual longshore sediment transport direction along Coco Plum Beach is to the southwest. The eastern 0.6-mile of beach is eroding and the western 0.8-mile of beach is stable or accreting. At the east end of Coco Plum Beach is a terminal limerock groin with a dredged navigation channel to the east. The erosion along the undeveloped eastern segment of Coco Plum Beach is a result of a longshore sediment transport deficit as no material is being introduced to the east end. Given the lack of threat to any development or recreation interest in this area the erosion is considered noncritical. Public ownership and management of this eroding area is essential for the preservation of the beach system. Development within this area may be expected to substantially impact the beach system.

Sombrero Beach, Vaca Key - The net annual longshore sediment transport direction along Sombrero Beach is to the east. This 0.3-mile public beach is sheltered from west and southwest wave activity. The eastward transport of beach sediment off Sombrero Beach and into an adjoining canal to the east has resulted in critical erosion. To prevent continued beach losses into the canal, a terminal groin is necessary at the east end of the public beach. Beach restoration is needed to replace the eroded public beach.

Bahia Honda State Recreation Area - There are three erosion segments along the beaches of Bahia Honda Key. The 600-foot long public recreation beach, between the Flagler Bridge and the U.S. Highway 1 bridge, is critically eroded due to both onshore and longshore sediment budget deficits. The beach losses due to the northward sediment transport may have been arrested by the 100-foot terminal groin at the north end of this beach. Although minor nourishment has been conducted, additional nourishment is needed to completely restore the recreation beach which has been lost. The western 3,500 feet of beach which fronts on the Straits is also critically eroding. The shoreline retreat of up to -5 feet per year threatens the park road and various park facilities. A more detailed investigation to include a wave refraction analysis and shoreline erosion monitoring is needed to determine the most viable solution to the critical erosion along this segment. The eastern 7,400 feet of beach on Bahia Honda Key, known as Sand Spur Beach, has a 600-foot segment near the east end which is experiencing erosion. This erosion is noncritical given the lack of threat to any park facilities. Beach monitoring along all the sand beaches of Bahia Honda Key is crucial to the resolution of the critical erosion problems and to the management of the beach resources in this State Recreation Area.

Long Beach, Big Pine Key - Approximately one mile of sandy shore along Big Pine Key experiences noncritical erosion. Abundant mollusks and coral fragments provide an available source for natural beach renourishment and a prominent barrier dune backs much of the shoreline providing a feeder source of beach sediment; however, erosion has substantially reduced the width and quality of the beach. Dune preservation is needed to maintain the natural source of beach nourishment material.

Sugarloaf Beach, Sugarloaf Key - Approximately 0.6 mile of sandy shore along the predominantly mangrove lined Sugarloaf Key experiences noncritical erosion. Like Long Beach of Big Pine Key, Sugarloaf Beach is a narrow, severely eroded, perched beach fronting a prominent barrier dune. Dune preservation is needed to maintain the natural source of beach nourishment material.

Boca Chica Key - Periodic major storm events have rendered the 1.3-mile beach of Boca Chica Key severely eroded. The erosion has undermined and damaged segments of a paved road which is now closed. Given the lack of development or threatened facilities within the U.S. Navy Air Station the erosion conditions are noncritical.

Key West - The net annual long shore sediment transport direction along the Straits shoreline of Key West is to the west (U.S. Army, 1957, 1958; Coastal Technology Corporation, 1987). The lack of littoral material entering the area has resulted in the loss of all beach at the east end of the island. Between 1851 and **1934**, the mean high water shoreline receded an average of -1.5 feet per year in the area studied by the Corps of Engineers. From **1934** to **1957** the shoreline erosion rate ranged as high as **-3** feet per year. Periodic major storm events have inflicted severe erosion losses and structural damages requiring erosion control efforts including seawalls, groins, breakwaters, and beach nourishment. The beach restoration project at Smathers Beach has substantially eroded over the past **30** years and is in need of renourishment. The project's groins and dredged holes which entrap littoral material have accelerated erosion to the west along Rest Beach; The pocket beaches and perched beaches to the west suffer erosion losses from major storms and require periodic minor nourishment. The erosion along Key West is critical for 2.8 miles.

Fort Zachary Tayor State Historic Site - On the southwest tip of Key West, the State Historic Site is an area built by dredge spoil from the ship channel. A revetment constructed around the dredge spoil was undermined by erosion and sand losses left an undesirable rocky beach for recreation. The shoreline receded up to 160 feet between **1971** and 1985 (CoastalTechnology Corporation, **1987)**. Wave refraction and sediment transport studies have revealed wave energy focusing in this area and sediment transport to the west by wave action.and flood tidal currents into the Key West Ship Channel. With the completion of beach nourishment and the construction of a terminal groin and breakwater, a monitoring program is necessary for the future management of the beach resources of this State Historic Site.

REFERENCES

Ball, M. M., June, 1967, Carbonate sand bodies of Florida and the Bahamas: Journal of Sedimentary Petrology, volume 37, pages 556-591.

Ball, M. M., E. A. Shinn, and K. W. Stockman, 1967, The geologic effects of hurricane Donna in south Florida: Journal of Geology, volume 75, number 5, pages 583-597.

Balsillie, James H., Robert S., Wilkerson, and John D. Wilson, May, 1980, Analysis of the hurricane emergency response capabilities in the Florida Keys: Florida Bureau of Disaster Preparedness.

Basan, P., 1973, Aspects of sedimentation and development of a carbonate bank in the Barracuda Keys, South Florida: Journal of Sedimentary Petrology, volume 43, pages 42-53.

Benham, S. R., et al., 1970, A carbonate sand beach, Bahia Honda, Florida: Geological Society of America Abstracts with Programs, volume 2, pages 194.

Blanton, J. O., J. B. Opdyke, and M. Stuiver, September, 1965, Report on damage survey along southeast coast of Florida after hurricane Betsy: Coastal Engineering Laboratory, University of Florida (65/005).

Bond, Paulette A., 1986, Carbonate rock environments of south Florida: Southeastern Section Geological Society of America centennial field guide, volume 6, pages 345-349.

Carballo, Jose D., Lynton S. Land, and Donald E. Miser, January, 1987, Holocene dolomitization of supratidal sediments by active tidal pumping, Sugarloaf Key, Florida: Journal of Sedimentary Petrology, volume 57, number 1, pages 153-165.

Case, Robert A., and Harold P. Gerrish, 1986, North Atlantic tropical cyclones, 1985: National Hurricane Center, National Oceanic and Atmospheric Administration.

Case, Robert A., 1988, North Atlantic tropical cyclones, 1987: National Hurricane Center, National Oceanic and Atmospheric Administration.

Clark, Ralph R., March, 1986, Hurricane Kate, November 15-23, 1985: Beaches and shores poststorm report number 86-1.

Coastal Engineering Laboratory, University of Florida, 1959, Report on construction of a 1025 foot pier in the Straits of Florida, 'KeyWest (59/019).

Coastal Technology Corporation, October, 1987, Shoreline andmarina channel renovation alternatives at Bahia Honda State Recreation Area, Monroe County, Florida.

Coastal Technology Corporation, October, **1987**, Shoreline renovation alternatives at Fort Zachary Taylor State Historic Site, Key West, Florida.

Davis, John H., Jr., November, **1942**, The ecology of the vegetation and topography of the Sand Keys of Florida: Carnegie Institute of Washington, Papers from Tortugas Laboratory, publication 524, volume **33**, pages **113-195.**

Falls, Darryl L., and Daniel **A**. Textoris, **1970**, Size, grain type, and mineralogical relationships in recent marine calcareous beach sands: Geological Society of America Abstracts, page 208.

Fleece, James B., **1962**, The carbonate geochemistry and sedimentology of the Keys of Florida Bay, Florida: Florida State University, masters thesis.

Fowler, Michael L., et al., **1970**, Biota and sediment in a small lagoon on Big Pine Key, Florida: Geological Society of America Abstracts, page **210.**

Fowler, T. **A**., **1977**, Local variations in the modern carbonate depositional environment, Bahia Honda Key, Florida: University of Texas at Arlington, masters thesis.

Ginsberg, R. N., **1953**, Intertidal erosion on the Florida Keys: Bulletin of Marine Science, volume **3**, number 1, pages 55- 69.

Hoffmeister, J. E., et al., November, **1964**, Living and fossil reef types of south Florida: a guidebook for the Geological Society of America Convention, field trip number 3.

Hoffmeister, J. E., and H. G. Multer, **1968**, Geology and origin of the Florida Keys: Geological Society of America Bulletin, volume **79**, number 11, pages **1487-1502.**

Huffman, S. F., et al., **1970**, A carbonate sand bar near Bahia Honda Key, Florida: Geological Society of America Abstracts with Programs, volume 2, pages **219-220.**

Hurricane Damage Study Committee, **1961**, Florida hurricane report, concerning hurricane Donna.

Hursky, M. J., **1977**, Grain size distribution and constituent particle analysis of nearshore carbonate sediment of Lower Matecumbe Key, Florida: University of Texas at Arlington, masters thesis.

Jindrich, V., **1969**, Recent carbonate sedimentation by tidal channels in the lower Florida Keys: Journal of Sedimentary Petrology, volume **39**, pages **531-553.**

Lane, Ed, **1986**, Geology of the state parks in the Florida Keys: Florida Department of Natural Resources, Bureau of Geology, leaflet number **14.**

Malloy, R. J., and R. J. Hurley, **1970**, Geomorphology and geologic structure **-** Straits of Florida: United States Department of Commerce, National Oceanic and Atmospheric Administration, NOAA reprints, volume 1, number **25.**

Milligan, Donald B., **1962,** Marine geology of the Florida Straits: Florida State University, masters thesis.

Mitchell-Tapping, Hugh J., August, **1978,** The mechanical breakdown of recent carbonate sediment in the coral reef environment: Florida State University, Department of Geology, dissertation.

Multer, H. Gray (editor), **1971,** Field guide to some carbonate rock environments, Florida Keys and western Bahamas: Department of Earth Sciences, Fairleigh Dickinson University.

National Climatic Center, National Oceanic and Atmospheric Administration, October **1987**, Storm data: volume 29, number 10.

Perkins, R. D., and P, Enos, **1968,** Hurricane Betsy in the Florida-Bahama area, geologic effects and comparison with hurricane Donna: Journal of Geology, volume **76**, pages **710-717.**

Pray, L. C., **1966,** Hurricane Betsy **(1965)** and nearshore carbonate sediments of the Florida Keys: Geological Societies **of** America Annual Meeting, pages **168-169.**

Price, W. Armstrong, **1953,** The low energy coast and its new shoreline types on the Gulf of Mexico: Department of Oceanography, Texas A & M University, contribution number 44.

Ragan, John, and Richard Smosna, **1987,** Sedimentary characteristics **of** low-energy carbonate beaches, Florida Keys: Journal of Coastal Research, volume 3, pages 15-28.

Research Planning Institute, Inc., **1984,** Atlas **-** the sensitivity of coastal environments and wildlife to spilled oil in the south Florida region,

Roberts, Harry H., Thomas Whelan, and William G. Smith, **1977,** Holocene sedimentation at Cape Sable, south Florida: Coastal Studies Institute, Louisiana State University.

Ross, Bernard E., and Melvin W. Anderson, December; **1972,** Hurricanes.

Sasso, R. Harvey, Chung-Po Lin, and Michael P. Walther, March, **1988**, a numerical model for the prediction of shoreline change: Proceedings of the National Beach Preservation Technology Conference, pages **99-106.**

Scholl, David W., July ,**1964,** Recent sedimentary record inmangrove swamps and rise in sea level overthe southwestern coast of Florida, part 1: Journal of Marine Geology, volume 1, number **4**, pages **344-366**.

Schomer, N. Scott, and Richard D. Drew, September, 1982, An ecological characterization of the lower Everglades, Florida Bay and the Florida Keys: United States Fish and Wildlife Service, Office of Biological Services (EWS/OBS-82/58.1).

Stehli, Francis G., and John Hower, September, 1961, Mineralogy and early diagenesis of carbonate sediments: Journal of Sedimentary Petrology, volume 31, number 3, pages 358-371.

Stockman, K. W., R. N. Ginsburg, and E. A. Shinn, June, 1967, The production of lime mud by algae in south Florida: Journal of Sedimentary Petrology, volume 37, number 2, pages 633-648.

Stoddart, D. R., and F. R. Fosberg, July, 1981, Topographic and floristic change, Dry Tortugas, Florida, 1904 - 1977: Atoll Research Bulletin, the Smithsonian Institution.

United States Army Corps of Engineers, Jacksonville District, 1957, Beach erosion control report on cooperative study of Key West, Florida.

United States Army Corps of Engineers, Jacksonville District, June 1958, Key West, Florida, beach erosion control study: House document number 413, 85th Congress, 2nd Session.

United States Army Corps of Engineers, Jacksonville District, November, 1961, Survey review report on Key West Harbor, Florida.

United States Army Corps of Engineers, Jacksonville District, October 1965, Report on flood of 7-9 September, 165 in central and southern Florida (hurricane Betsy).

United States Army Corps of Engineers, Jacksonville District, February, 1982, (revised April 1983), Feasibility report for beach erosion control with accompanying environmental impact statement for Monroe County, Florida.

Wanless, Harold R., and Randall W. Parkinson, March, 1989, Late Holocene sealevel history of southern Florida: control on coastal stability: Proceedings of the Eighth Symposium on Coastal Sedimentology, pages 197 - 213.

Warnke, Detlef A., V. Goldsmith, P. Grose, and J. J. Holt, April, 1966, Drastic beach changes in a low-energy environment caused by hurricane Betsy: Journal of Geophysical Research, volume 72, number 6, pages 2013-2016.