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FLORIDA
SEA GRANT COLLEGE

CLEARWATER PASS
GLOSSARY OF INLETS REPORT #12

Robert J. Newman

Report Number 56

April 1983

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FOREWORD

The numerous inlets and harbors connecting Florida's inner waters to the Atlantic Ocean and the Gulf of Mexico are important from the standpoint of their recreational and commercial vessel traffic as well as because they serve as harbor refuge for boats during unexpected severe weather and waves. Unfortunately, inlets and harbors also contribute significantly to the beach erosion problems that are prevalent along much of Florida's shoreline. The complexities of the hydraulic and sediment transport mechanics in the vicinity of inlets present a formidable challenge to engineers and scientists. These factors, along with the interesting historical role that inlets have played in the early development of Florida, have resulted in considerable documentation pertaining to the major inlets of the State.

This report on Clearwater Pass is one in a "Glossary of Inlets" series to be prepared under the Florida Sea Grant College project, "Glossaries of Tidal Inlets in Florida." The purpose of this series is to provide for each inlet a summary of the more significant available information and to list known documentation. It is hoped that this series will yield an improved understanding of the overall effect of each inlet on the economics, recreation, water quality, and shoreline stability of the surrounding area. The proper future management, use and control of Florida's inlets will require an appreciation of the evolution and past response of the inlets as well as considerable future study.

ACKNOWLEDGMENT

The author would like to thank the city of Clearwater, especially Mr. Andrew Nicholson, the City Oceanographer, and the Jacksonville District Corps of Engineers for providing much of the information necessary for this report. Thanks also go to Dr. A. J. Mehta, the principal investigator for the Sea Grant Glossary of Inlets Project, for his guidance during the preparation of this report and to Mr. Elias Sanchez Diaz for his assistance in compiling available reference material.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Continued)

I. INTRODUCTION

1.1 Description and Location

Clearwater Pass (formerly Little Pass) is a natural inlet on the west coast of peninsular Florida connecting the Gulf of Mexico with Clearwater Harbor (figure 1.1). Bathymetry and other pertinent navigational information appear on the National Ocean Survey Nautical Chart No. 11410, 18th Edition, 14 June 1980 (supercedes the U.S. Coast and Geodetic Survey Chart # 858). Located in Pinellas County, it is within the corporate limits of the city of Clearwater, about 24 kilometers south of the mouth of Anclote River and 40 kilometers north of the entrance to Tampa Harbor.

Historically, the inlet is believed to have been in existence during the days of the original Spanish exploration of this area (COEL/1977). Clearwater Harbor tapers towards the south to a very narrow waterway ("The Narrows") near Indian Rocks Beach and broadens to the north to eventually merge with St. Joseph's Sound. Clearwater Pass is a break between two of the barrier islands: Sand Key to the south and Clearwater Beach Island to the north. This barrier island chain extends for 72 kilometers along the Pinellas County mainland. Since as early as 1926, the pass has had a history of decreasing width and increasing depth which is closely related to construction and dredge-and-fill development within Clearwater Harbor as well as changes in the dynamic characteristics of Dunedin and Hurricane Passes, 5.6 and 12.1 kilometers to the north of Clearwater Pass, respectively.

1.2 Navigation and Other Improvements

Over the last 20 years, the U.S. Army Corps of Engineers has been dredging portions of Clearwater Pass to maintain a navigable channel 3 meters deep and 46 meters wide from the Gulf through Clearwater Pass, then 2.4 meters deep by 31 meters wide eastward to the Intracoastal Waterway, with a 2.4 meter deep by 31 meter wide channel also running northward and connecting the pass with the Clearwater Island Marina (figure 1.2).

At least as early as 1900, sand accretion on the northern tip of Sand Key was causing a reduction in the width of the inlet and increased tidal velocities. In 1975, to help eliminate such erosive velocities and maintain the structural integrity of the bascule bridge on Clearwater Pass Avenue (which traverses the pass), the City of Clearwater contracted to build a 1,220 meter long jetty at the northern tip of Sand Key. More recently the city had a 168-meter-long jetty constructed on the southern tip of Clearwater Beach Island. Construction of these jetties along with periodic dredging will effectively limit any further migration of the Pass.

The U.S. Army Corps of Engineers is currently investigating the feasibility of Federal navigation improvements at Dunedin and/or Hurricane Passes. Improvement of either of these inlets may have an impact on the size and composition of the commercial and recreational boat fleet presently using Clearwater Pass.

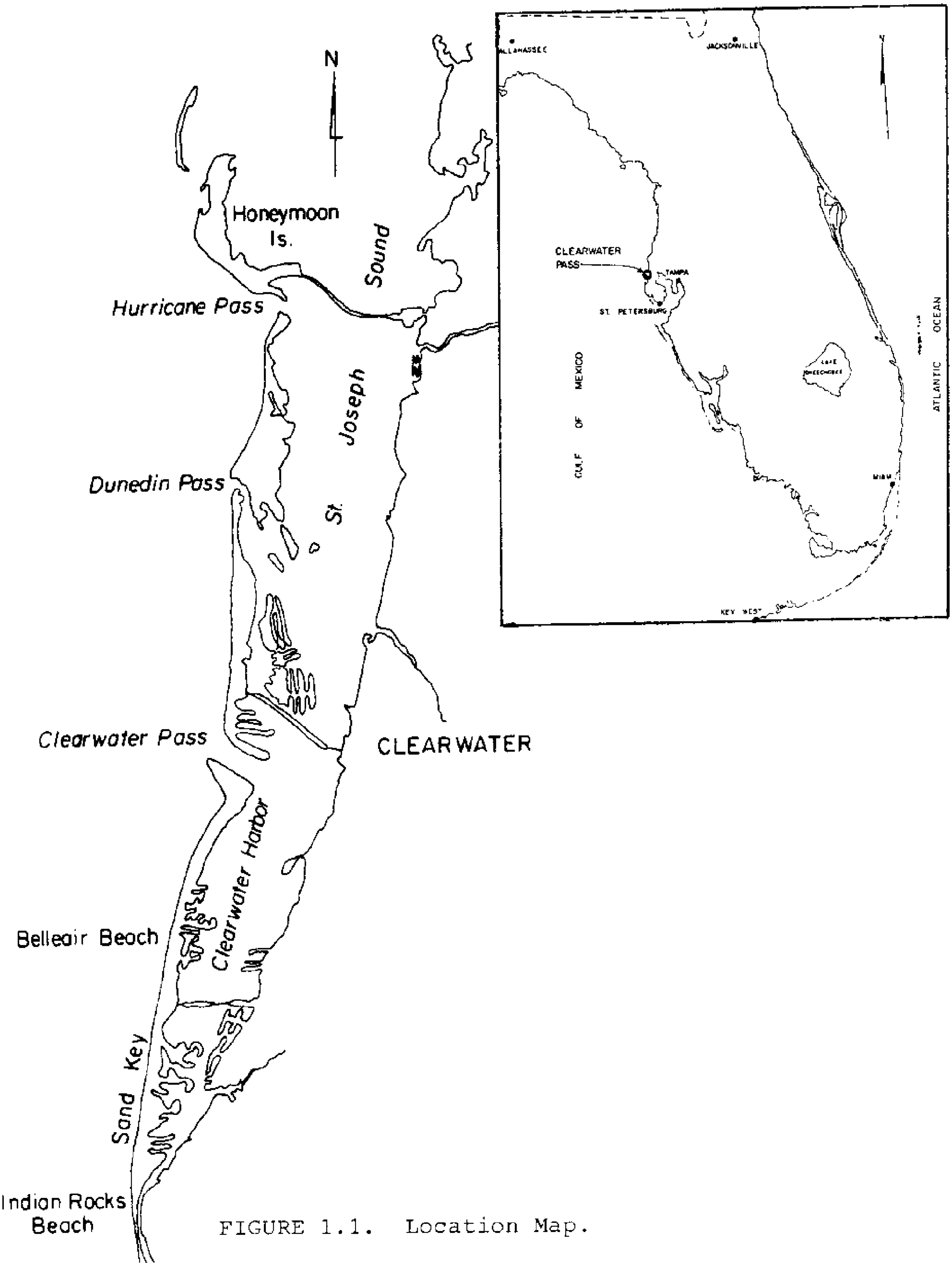
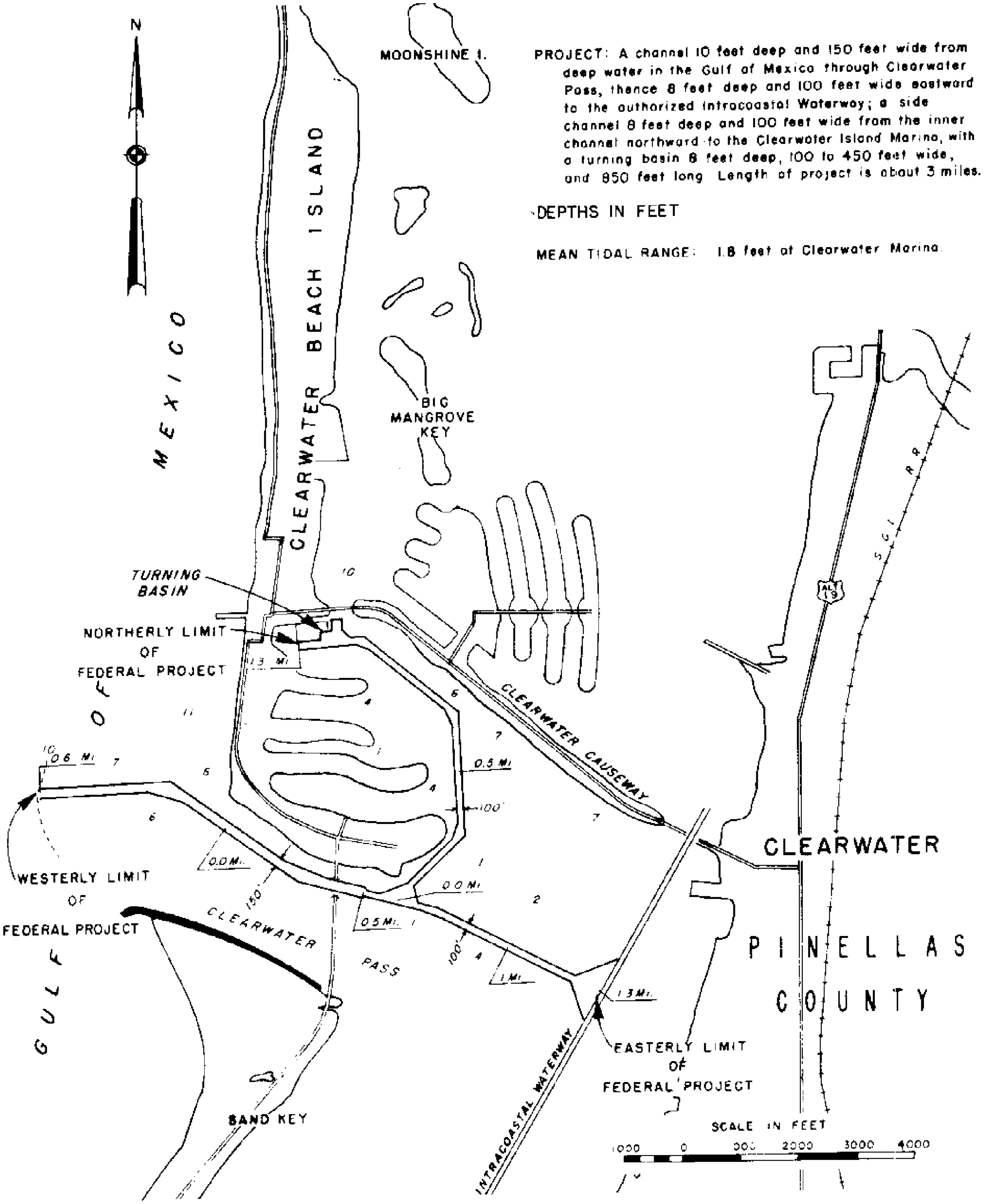


FIGURE 1.1. Location Map.



PROJECT: A channel 10 feet deep and 150 feet wide from deep water in the Gulf of Mexico through Clearwater Pass, thence 8 feet deep and 100 feet wide eastward to the authorized Intracoastal Waterway; a side channel 8 feet deep and 100 feet wide from the inner channel northward to the Clearwater Island Marina, with a turning basin 8 feet deep, 100 to 450 feet wide, and 850 feet long. Length of project is about 3 miles.

DEPTHS IN FEET

MEAN TIDAL RANGE: 1.8 feet at Clearwater Marina.

FIGURE 1.2. Federal Navigation Project(courtesy: U.S. Army Corps of Engineers, Jacksonville District).

1.3 Socioeconomic Conditions.

Pinellas County's abundant coastline has historically attracted many forms of development, from the fishing town of Tarpon Springs in the north to the urban centers of Clearwater, the county seat, and St. Petersburg to the south. Currently, over half of the entire land area of the county is in some form of urban or suburban development. The county's resident population increased 39 percent between 1960 and 1970 and 39 percent between 1970 and 1980. The resident population in 1980 was approximately 728,409 (Bureau of Economic and Business Research, 1980). Pinellas County holds the largest population within the smallest area of any county in Florida (U.S. Army Corps of Engineers, 1981). Associated with this high density are growth pressures that are expected to have a continuing impact on the remaining land available for development. Within the Clearwater area, a majority of the land is committed to low density use (U.S. Army Corps of Engineers, 1981).

The county's extensive bay and Gulf coastline combined with a moderate winter climate have made water-related recreational activities extremely popular. A 1971 study (prior to the construction of Disneyworld in Orlando) conducted by the State Department of Commerce showed that more tourists chose Pinellas County as their destination than any other Florida county. In 1970, 26 percent of the peak county population were visiting (transient) tourists. The 1980 census showed a continuing high percentage of transient population. Consequently the county's economy continues to be heavily oriented toward the tourism and service sectors.

1.4 Commercial and Recreational Fishing

In 1969 Pinellas County commercial fishermen accounted for 2,820,363 kilograms or 5.3 percent of Florida's total fish and shellfish harvest. In 1979 the county's harvest of 3,520,771 kilograms, valued at $6.7 million, was 6.5 percent of the total for the State (National Marine Fisheries, 1969 and 1978).

Pinellas County is the third largest in the State in number of registered recreational and commercial boats. During fiscal year 1978-79, over 29,000 boats were registered in the county. If 3.0 is used as a conservative estimate of the average number of persons per family, at least one in nine families would own a registered boat. The county is also ranked third in the State with at least 40 boat dealers (Bureau of Economic and Business Research, 1980). The major boating facilities which offer dockage and/or fuel and supplies are located on the bay side of Clearwater Beach Island and Sand Key, and along the mainland from Clearwater to Indian Rocks Beach. Historic records of bridge openings for the bascule bridges located on Garden Memorial Causeway and Clearwater Pass Avenue (with vertical clearances of 7.6 meters and 7.3 meters, respectively) are shown in table 1.1 (U.S. Army Corps of Engineers, 1981). The Clearwater Pass bridge is opened on demand, and as indicated, the number of larger boats using the pass has fluctuated with no significant trends in evidence. The Memorial Causeway bridge opens on a fixed schedule with no more than 30 minutes between openings. Consequently, no relationship can be obtained between b fic and bridge openings; however, large boat traffic through the apparently increasing at a steady rate. Should Federal navigation be undertaken at Dunedin or Hurricane Pass, boat traffic patterns Clearwater Harbor could be significantly altered, resulting in som tion in boat traffic through Clearwater Pass.

TABLE 1.1

Bascule Bridge Openings

Year	Clearwater Pass Draw Openings	Memorial Ca Draw Open
1972	10,079	3,432
1973	10,602	3,564
1974	12,850	3,702
1975	13,118	3,493
1976	15,243	3,743
1977	8,966	3,666
1978	9,893	3,996
1979	10,941	4,321

II. GEOLOGY AND ENVIRONMENTAL SETTING

2.1 General

Florida occupies only part of a much larger geographic division, a great continental plateau. This plateau is part of the old land continent of Applalachia which submerged in the Upper Cretaceous period. Upon the metamorphic rocks of this platform marine deposits attest to several periods of uplift and subsidence. All of the territory comprising Florida today is underlain by limestone, marl, and dolomite. Dolomite outcrops are interspersed along the upper west coast and as far south as Sarasota County. Sand material is believed to have come from the Appalachian highland, carried to the sea by rivers and streams. It drifted southward along the shoreline by the action of waves and currents. Some of it was deposited in barriers, spits, and recurved spits, while the remainder was distributed over the wave cut terrace (Per Bruun, 1958).

During Pleistocene time, the sea stood above and below its present level, submerging greater and lesser portions of the land according to its height. Whenever it remained relatively stationary for a long period (stillstand), waves and currents washing back and forth across the sea floor formed an essentially level surface called a "terrace." Upon retreat of the sea to a lower level, each terrace emerged as a level plain having a slight seaward dip. The landward margin of such a terrace is the abandoned shoreline, which is generally marked by a low scarp (Heath and Smith, 1954). Discussions of the Pleistocene history and the terraces in Florida are included in a report by Cooke (1945). Three of these terrraces, the Pamlico (sea level approximately 7.6 meters above present level), Penholoway (approximately 21 meters above present sea level), and Wicomico (approximately 30 meters above present sea level) have been recognized in Pinellas County. The locations of these terraces within Pinellas County are displayed in figure 2.1.

Geologic formations that are exposed in Pinellas County range from deposits of early Miocene Age (the Tampa formation) to undifferentiated deposits of Pliocene and Pleistocene Age. Those below the Pliocene and Pleistocene are exposed in a series of belts across the county (figure 2.2). A geologic cross section and block diagram with cross-sections displayed in figure 2.3 show the vertical extent of the different formations as well as the locations of the Pleistocene terraces.

2.2 Present Barrier Island and Offshore Geology

The barrier island-nearshore sediment environments of the central Florida gulf coast near Clearwater Pass demonstrate complex interrelationships between the modern coastal environments and the relict sediments of earlier Holocene coastal systems. A pre-Holocene wave-cut surface in the Miocene and Pliocene carbonate rocks, at 5 to 6 meters below sea level, flanks an erosional headland and forms a plane upon which the coastal sediments of the Holocene transgression are deposited (Riggs, 1974).

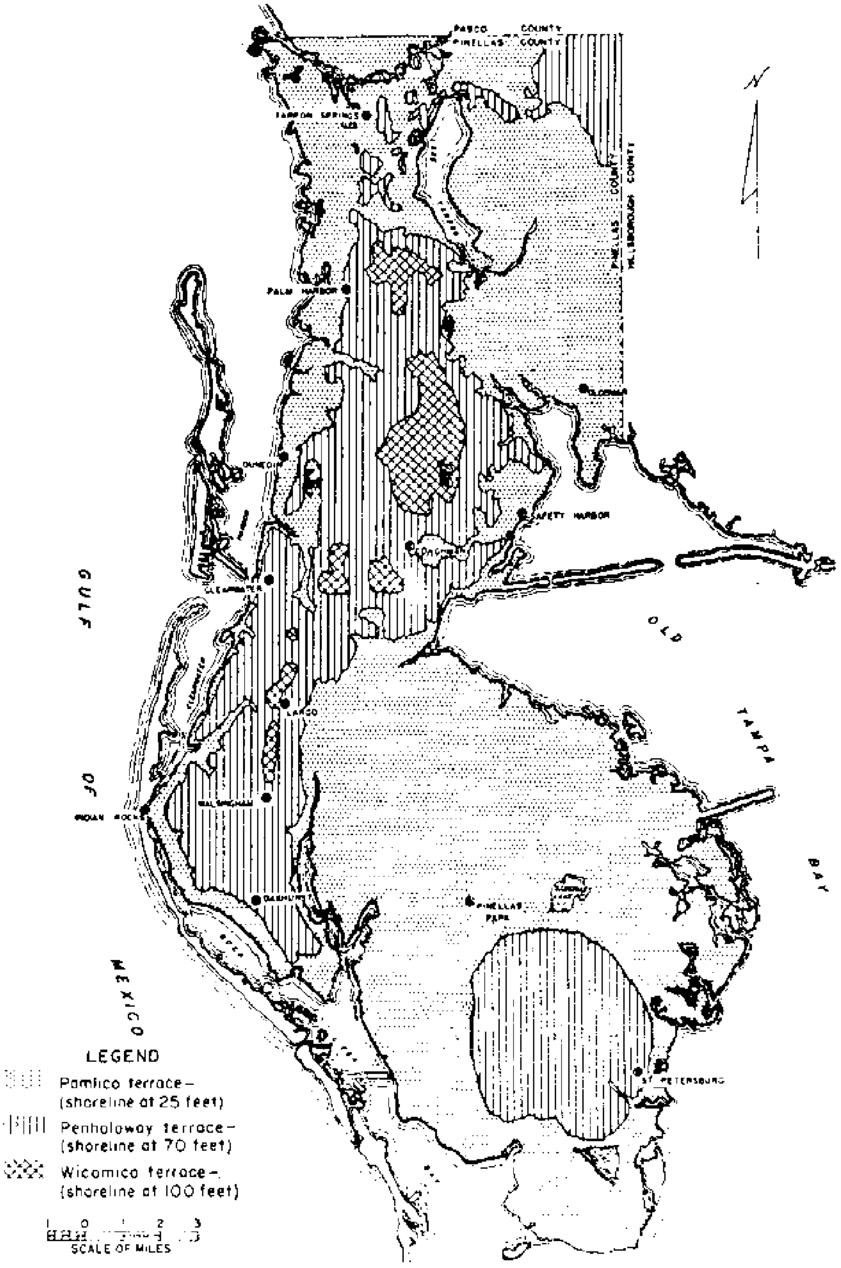


FIGURE 2.1. Pleistocene Terraces of Pinellas County (Heath and Smith, 1954).

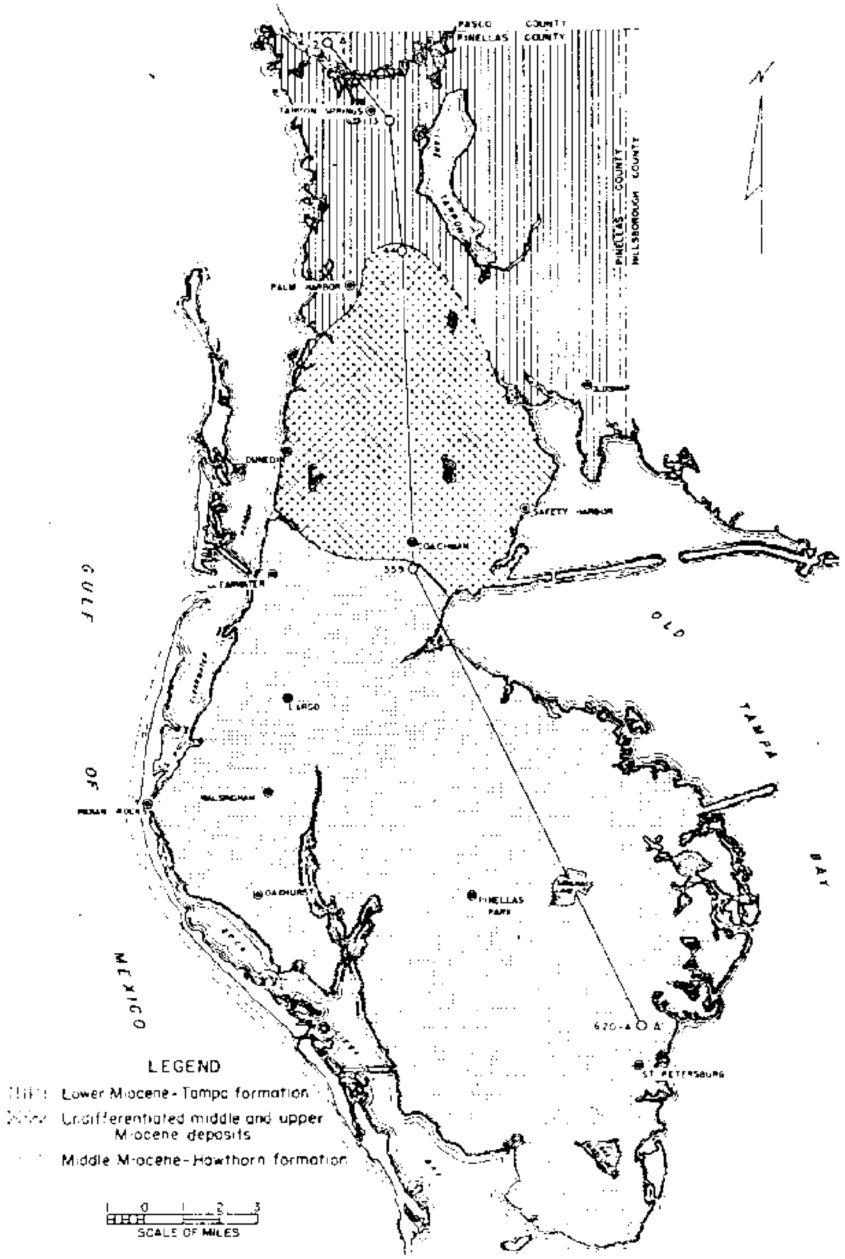


FIGURE 2.2. Geologic Map of the Miocene Deposits in Pinellas County (Heath and Smith, 1954).

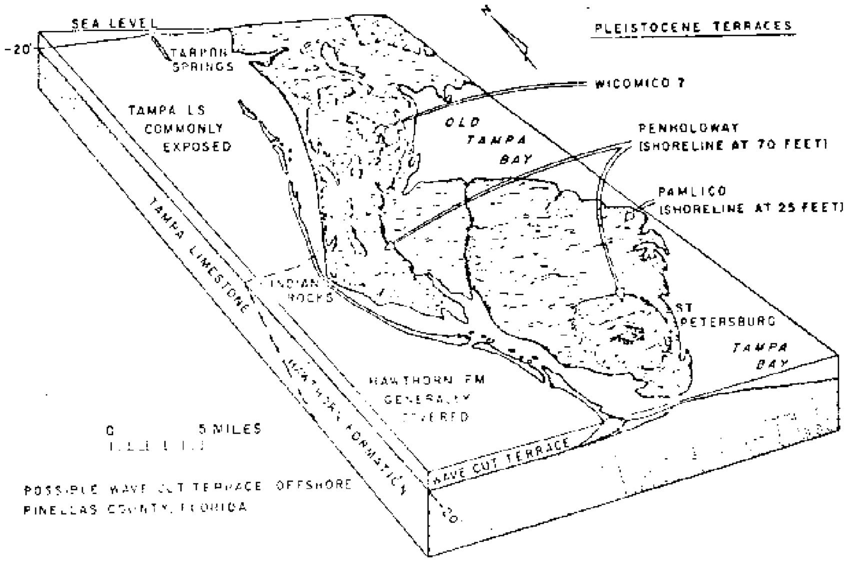


FIGURE 2.3.a. Geologic Isometric Section of Pinellas County (Riggs and O'Connor, 1974).

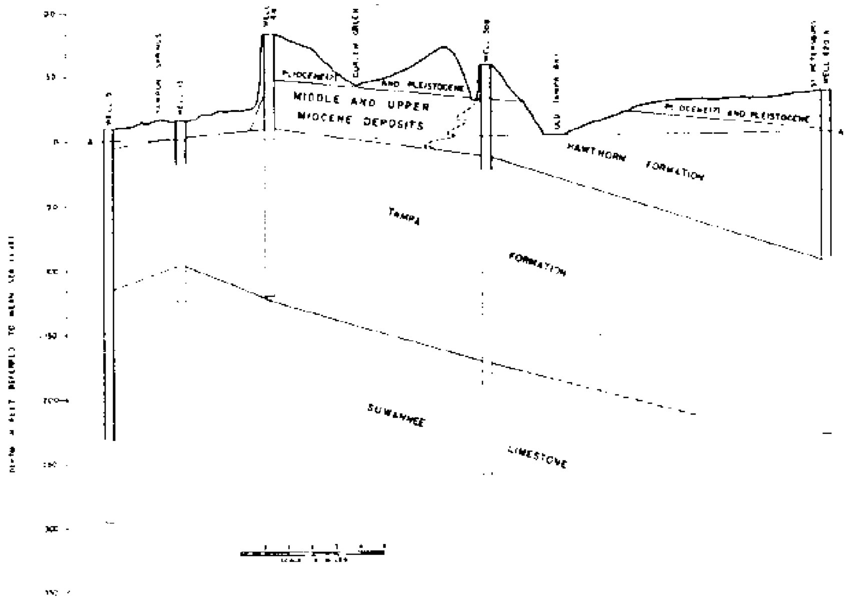


FIGURE 2.3.b. Geologic Section through Pinellas County along Line A-A' in FIGURE 2.2 (Heath and Smith, 1954).

It is believed that the barrier island-lagoon system first developed on the Miocene rock surface somewhat seaward of its present location at a lower stillstand. With continued slow rise of the sea, the barrier system has migrated up and over the lagoonal sediments and intersected the Miocene headland at Indian Rocks Beach.

The morphology of the sediment units within the Clearwater Pass coastal system are constantly being modified and the sediments redistributed by day-to-day biological and hydrological corrosion (organisms decompose and break up rock, and tides and waves move them) as well as periodic major climatic disturbances (tropical storms, hurricanes, and winter storms). At present the area has essentially no major outside source of sediments because of its very low topographic relief and lack of major rivers discharging into the area. Consequently, the day-to-day processes must now supply the bulk of the nourishing sediments which help maintain the present barrier island-lagoonal system (Riggs, 1974).

2.3 Sedimentary Rocks and Offshore Sediments

Rocks and sediments of the Pinellas County area to a depth of 3-6 meters below mean sea level can be divided into six units. From the oldest to the youngest these units are: a) Miocene carbonate rocks, sandy carbonate rocks, and greyish-green, waxy clay (M); b) Prerecent, shelly sand (A); c) Prerecent dark muddy sand (B); d) Recent beach and pass sand and shell (Rbp); e) Recent offshore bar sand and shell (Rob); and f) Recent mud and sand (Rm). The first units are ancient rocks, while the latter three are forming today (Winston, et. al, 1968). Figure 2.4 shows the distribution of these units in the vicinity of Clearwater Pass.

The offshore sedimentary units, approximately 1.6 kilometers north of Clearwater Pass, include from shore seaward: a) Recent beach and pass sand and shell; b) Prerecent muddy sand (unit B); c) Recent offshore bar sand and shell (Rob); and d) Miocene limestone (M).

The thickness of the sediments overlying bedrock is variable, increasing from nearly no-cover, 1.6 kilometers offshore, to 5.5 meters at the shoreline. Figure 2.5 shows the sediment thicknesses offshore from Clearwater Pass.

The offshore sedimentary units of north Sand Key, just 1.6 kilometers south of the pass, are the same as those occurring off Clearwater Beach Island. The distribution, however, is considerably different in that the prerecent muddy sand is much narrower and the Miocene (M) and recent offshore bar sands (Rob) are exposed very close to shore. Miocene limestone is exposed over much of the area at depths of 6 meters, rising to 5 meters or less near shore, and are covered with local, patchy accumulations of the offshore bar sands. These elongated sand bars cover considerable area but are generally less than 2 meters thick (Winston, 1968). See figure 2.6 for geologic cross sections constructed for profiles 1.6 meters north of Clearwater Pass and 1.6 and 4.8 kilometers south of the pass.

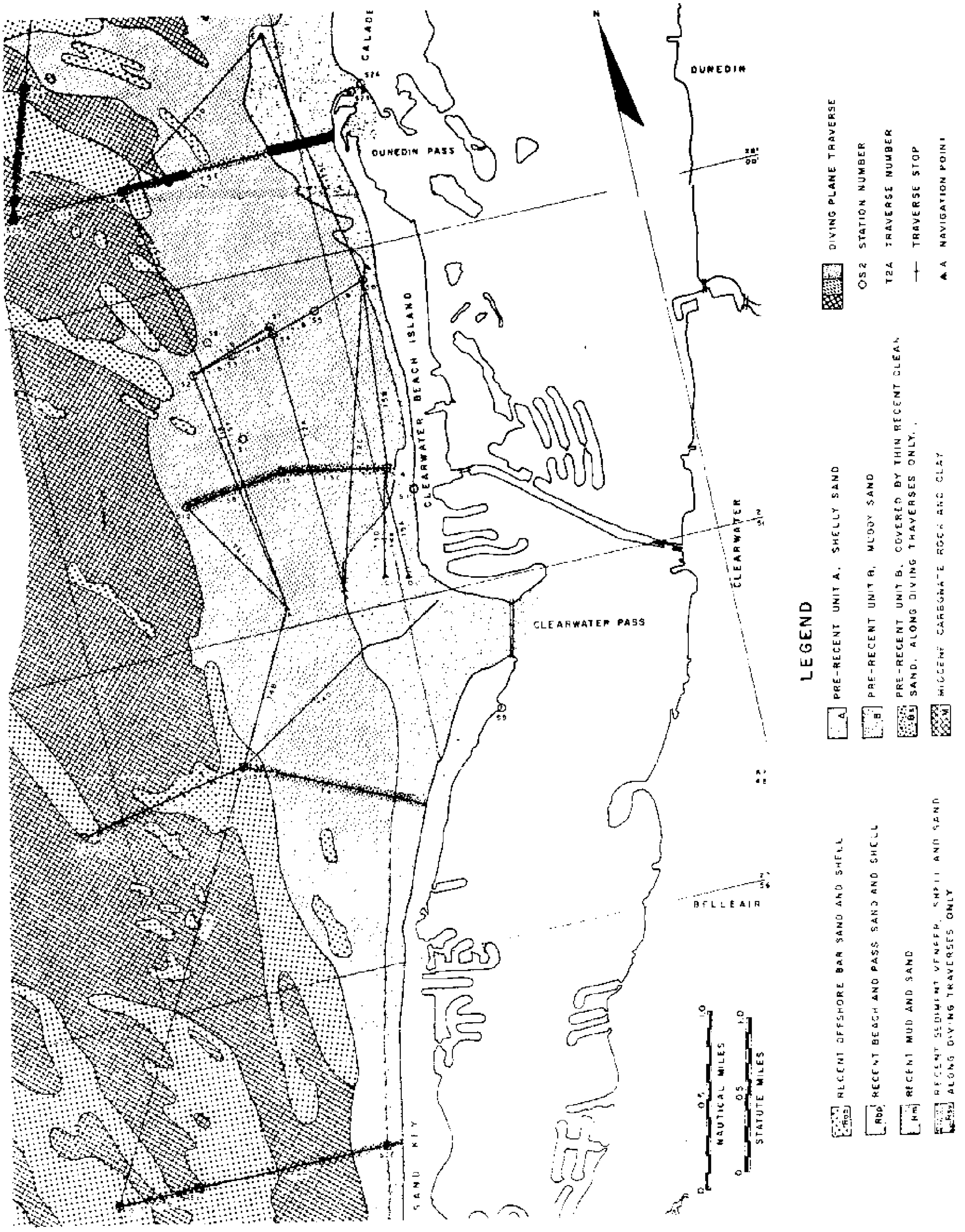
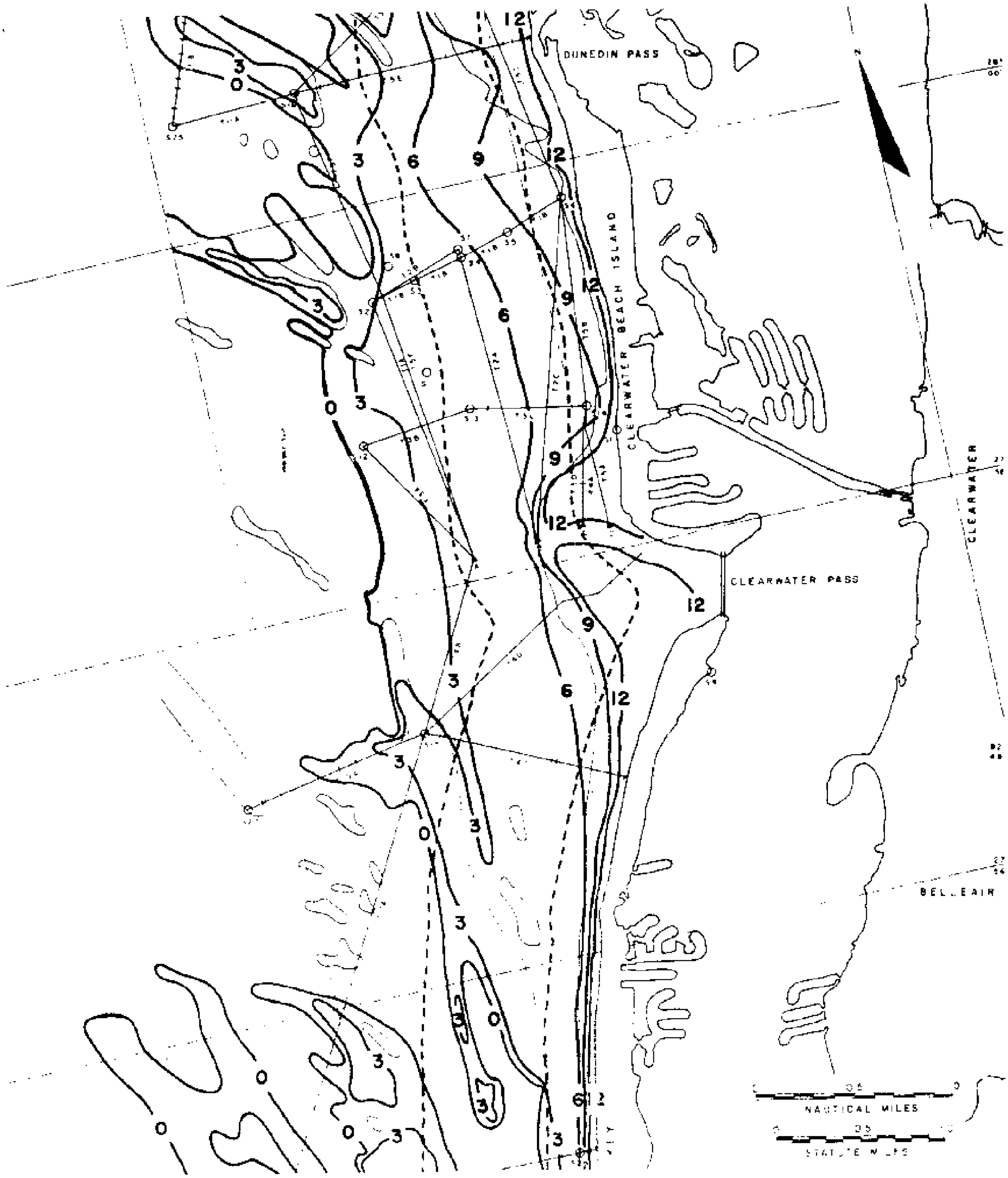


FIGURE 2.4. Distribution of Rocks and Sediments Offshore of Clearwater Pass (Winston, et. al, 1963).



THICKNESS CONTOUR INTERVAL 3 FEET

SEDIMENT INCLUDES ALL UNCONSOLIDATED MATERIAL OVERLYING MIOCENE ROCK SURFACES

A THIN VENEER OF SEDIMENT MAY OVERLIE ROCK SURFACES IN SOME AREAS ENCLOSED BY 0 FOOT CONTOURS

DASHED LINES DELINEATE 300 FOOT AND 1 MILE OFFSHORE LIMITS

FIGURE 2.5. Sediment Thickness Map Offshore of Clearwater Pass (Winston, et. al, 1968).

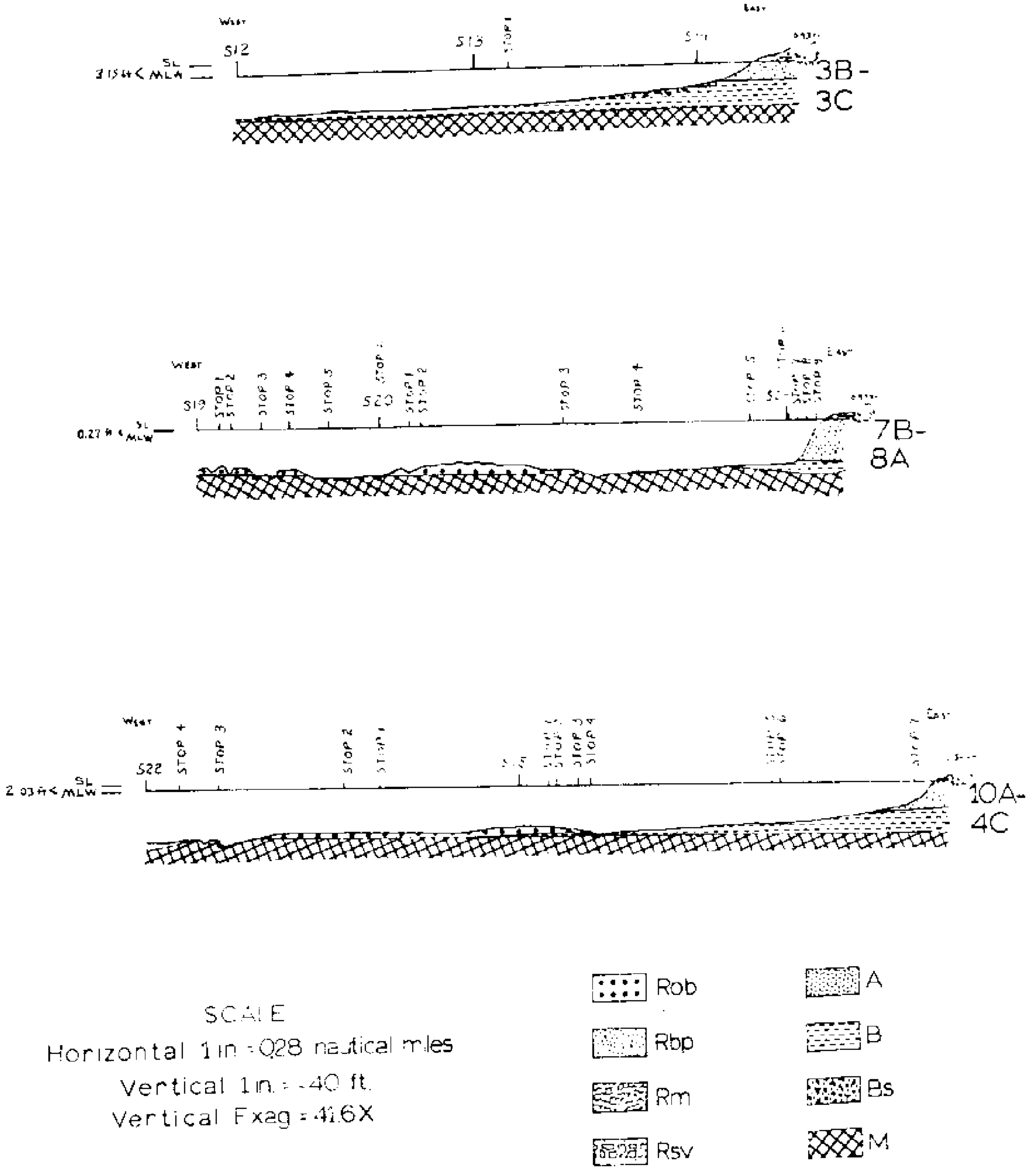


FIGURE 2.6. Geologic Cross Sections Along Profiles One Mile North and One and Three Miles South of Clearwater Pass (Winston, et. al, 1968).
*NOTE: Sections are identified in FIGURE 2.5.

2.4 Local Environment

Before man's intrusion the Clearwater Pass area was characterized by low barrier mangrove islands with shallow lagoons between them and the mainland. Most of Clearwater Beach Island and the northern end of Sand Key are now heavily developed with both private residences and commercial establishments, including many tourist facilities. Several mangrove islands east of Clearwater Beach were connected and elevated with fill dredged from the bay bottom and developed into a residential area. The fill on which the Garden Memorial Causeway was constructed was also dredged from the bay bottom. Several small emergent islands that flank the western side of the Gulf Intracoastal Waterway, and one larger island just south of the causeway (see figures 4.1 and 6.4) were originally disposal sites for construction and maintenance of the Clearwater Pass project and the Intracoastal Waterway.

In 1980, the U.S. Fish and Wildlife Service conducted an environmental assessment in the Clearwater area in conjunction with a recent Corps of Engineers navigation study (Corps of Engineers, 1981). Much of the information in the following sections was obtained from this report.

2.5 Bay Marine Environment

Natural water depths in Clearwater Harbor average from 1.5 to 2.1 meters with considerably deeper depths adjacent to finger developments. The deeper areas do not support productive aquatic habitats. The shallow bay shoals, especially adjacent to the large emergent disposal site south of the causeway, support seagrass beds. The locations of these beds can be identified by examining aerial photographs of the pass. Significant seagrass beds also occur on shoals adjacent to the mainland.

Sea grasses which occur in the area are utilized extensively by benthic algae as substrate. One of the most common algae species in the area is Enteromorpha. Copepods dominate the zooplankton; their numbers peaking in May and declining in the winter. Crabs and shrimp are important faunal components of the grass flat complex. Pink shrimp, brown shrimp, grass shrimp, blue crabs, horseshoe crabs, and mud crabs make up the greatest number.

The grass flats and other shallow areas near Clearwater Pass are important nursery and feeding areas for a number of finfish, important to the sport and commercial fishing industry. These include spotted sea trout, red and black drum, flounder, mullet, sheephead, mangrove snapper, spot, and snook. During 1976, over 2.3 million kilograms of finfish and 1.1 million kilograms of shellfish, excluding bait fish, were landed in Pinellas County. A large percentage of these animals spend at least a part of their life in shallow estuarine areas such as are found in Clearwater Harbor.

Grass flats also provide important feeding grounds for a large number of birds including grebes, loons, mergansers, scaups, pelicans, gulls, and terns. At low tides portions of the flats are exposed and shore birds can also feed on them. The high diversity of organisms associated with the dense stands of sea grass provide an important food source for many of the bird species found throughout the area.

2.6 Offshore Marine Environment

Offshore Gulf marine animal communities can be divided into four broad types based on substrate. They are: the rock community, the rippled sand community, the algae-coated sand community, and the muddy sand community. Of these, the rock communities lying on the exposed Miocene rock surfaces are by far the most luxuriant and diverse. Where well developed, they consist of a wide variety of sponges, gorgonian seawhips, abundant pelecypods, a variety of gastropods, abundant barnacles, sabellarid worms, encrusting bryozoans, worms and algae, and boring worms and pelecypods. Where rock populations are less developed, they consist of barnacles, mytilus, boring worms, pelecypods, and encrusting worms and bryozoans. Corals and sponges are rare or sparse (Winston, et. al, 1968).

2.7 Endangered Species

Several animals listed as endangered or threatened by the U.S. Fish and Wildlife Service are known to occur in the Clearwater Pass and adjacent bay and barrier island area. Atlantic loggerhead sea turtles are known to nest on Caladesi Island annually, and the Kemp's ridley and green turtles may nest there periodically. All three species are considered threatened or endangered. Although Clearwater Pass is not within the designated critical habitat for the West Indian Manatee, they are found in the area. Of course, the brown pelican is common along the entire coast.

III. CLIMATE AND STORM HISTORY

3.1 General

The Pinellas County area is favored with seasonably mild weather all year round, and this plus its proximity to the Gulf make the area very popular for tourists, especially during the winter months. The year-round average temperature is approximately 22.2° C with average high temperatures generally running 5.6 degrees higher (27.8° C), and average lows 5.6 degrees less (16.7° C). The average annual rainfall for the area is approximately 112 centimeters, and the majority of precipitation occurs during the months of June through September. Average sea temperatures range from a low in January and February of 21.1° C. to a high of 30° C in August.

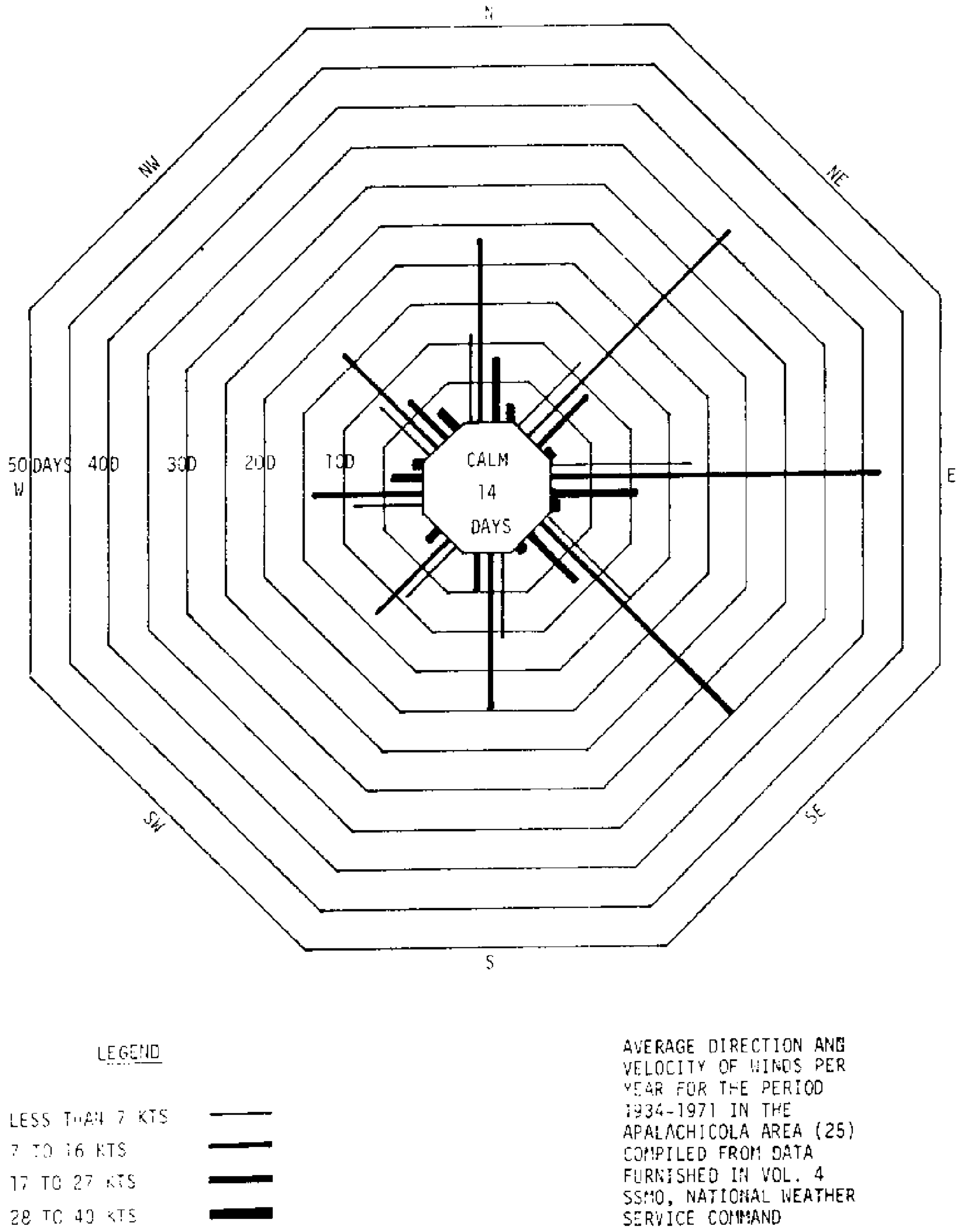
3.2 Winds

Prevailing winds are from the northeast and north during the winter months, while the remainder of the year they are predominantly from the east and south. Figure 3.1 shows a wind rose compiled from The Summary of Synoptic Meteorological Observations (SSMO) for Region 25 (central and northern Florida Gulf Coast), and cover a 9-year period from 1963 to 1971. Figure 3.2 contains the rose for the Tampa area compiled from data furnished by the U.S. Weather Bureau (now the National Weather Service) at that station and covering the years 1930 to 1936. Yearly cumulative average winds over the Gulf Coast, compiled from records of the U.S. Hydrographic Office, are shown in figure 3.3. This diagram represents the yearly average winds that have prevailed within the 5-degree square off Pinellas County (U.S. Army Corps of Engineers, 1981).

3.3 Swells and Waves

Waves generated in distant storms that have advanced into areas of weaker winds or calm are called swells, and they are characterized by more regular and longer period wave motion. A yearly ocean swell rose for deep water off Tampa Bay is illustrated in figure 3.4. It can be seen that the largest percentage of onshore swell is from the southwest. Waves generated by local wind conditions are in general agreement with the offshore wind rose for Tampa. The yearly wind wave rose for deep water off of Tampa Harbor is presented in figure 3.5. The wind wave and ocean swell data represent statistical summaries of wave data for a 3-year period developed by hindcast techniques in 1945. The deep water location for the hindcast is about 161 kilometers offshore, west of Tampa Harbor (U.S. Army Corps of Engineers, 1945).

The hindcast ocean swell and wind wave information indicates that waves affecting the Clearwater Pass study area rarely exceed a height of 1.8 meters and generally average less than 1 meter with a period of about 5 seconds. It should be noted that the wave swell data is compiled from figure 3.6. Offshore observations and statistical summaries will vary considerably for areas with dissimilar bathymetry due to wave refraction, diffraction, shoaling, etc.



AVERAGE DIRECTION AND
VELOCITY OF WINDS PER
YEAR FOR THE PERIOD
1934-1971 IN THE
APALACHICOLA AREA (25)
COMPILED FROM DATA
FURNISHED IN VOL. 4
SSMO, NATIONAL WEATHER
SERVICE COMMAND

FIGURE 3.1. SSMO Area 25, Apalachicola, Wind Rose (courtesy: U.S. Army Corps of Engineers, 1981).

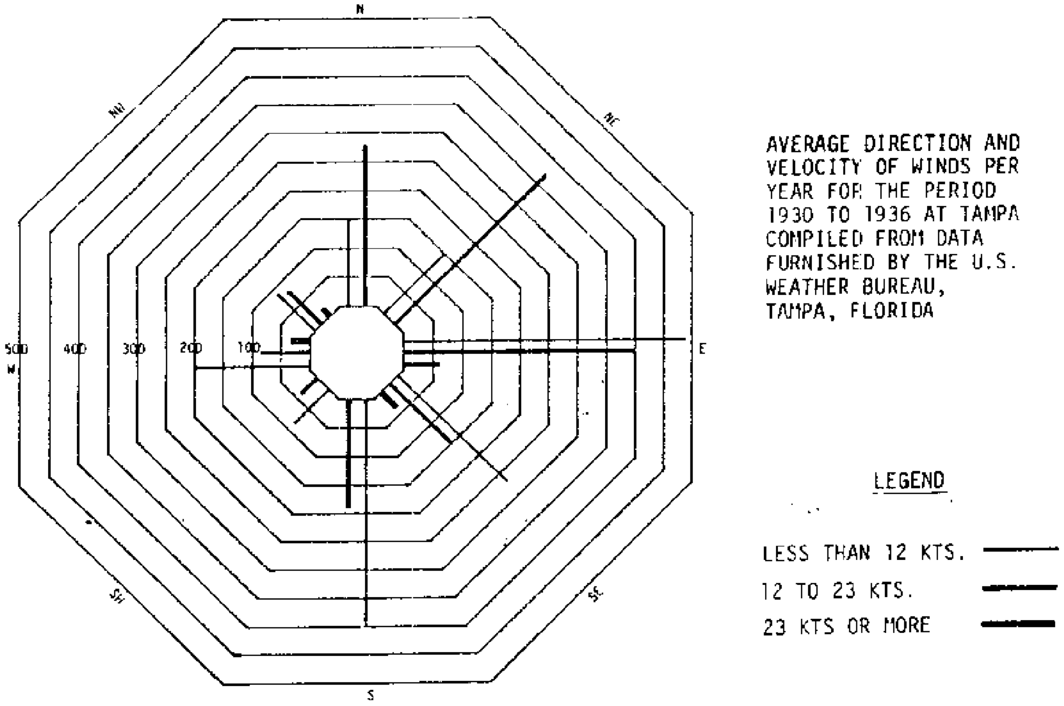


FIGURE 3.2. Tampa Area Wind Rose (courtesy: U.S. Army Corps of Engineers, 1981).

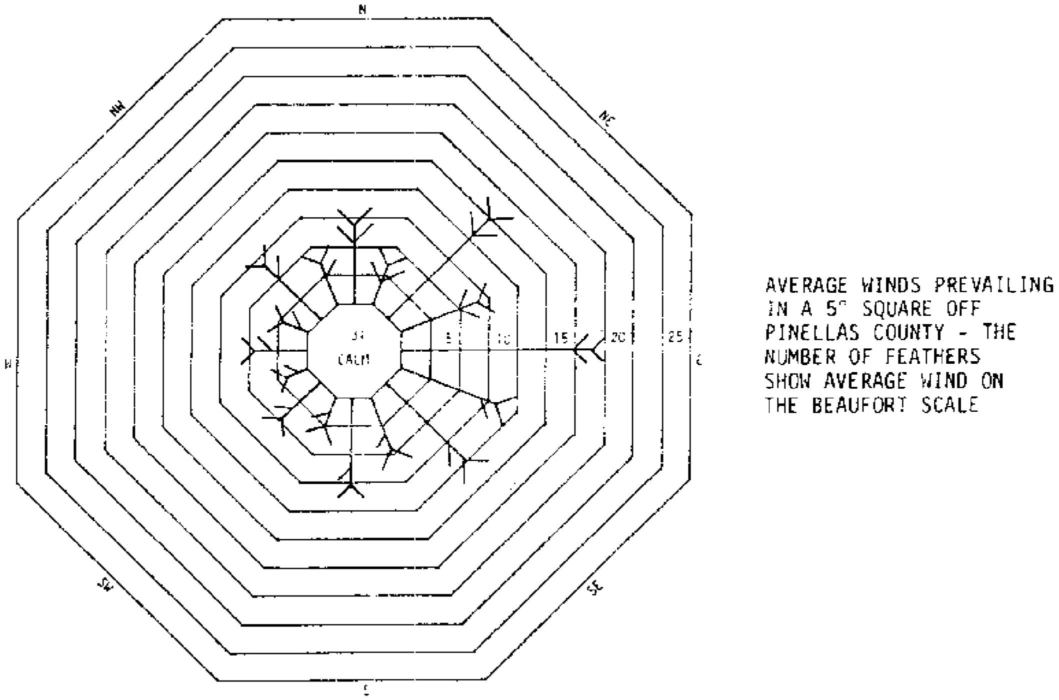


FIGURE 3.3. Pinellas County Wind Rose (courtesy: U.S. Army Corps of Engineers, 1981).

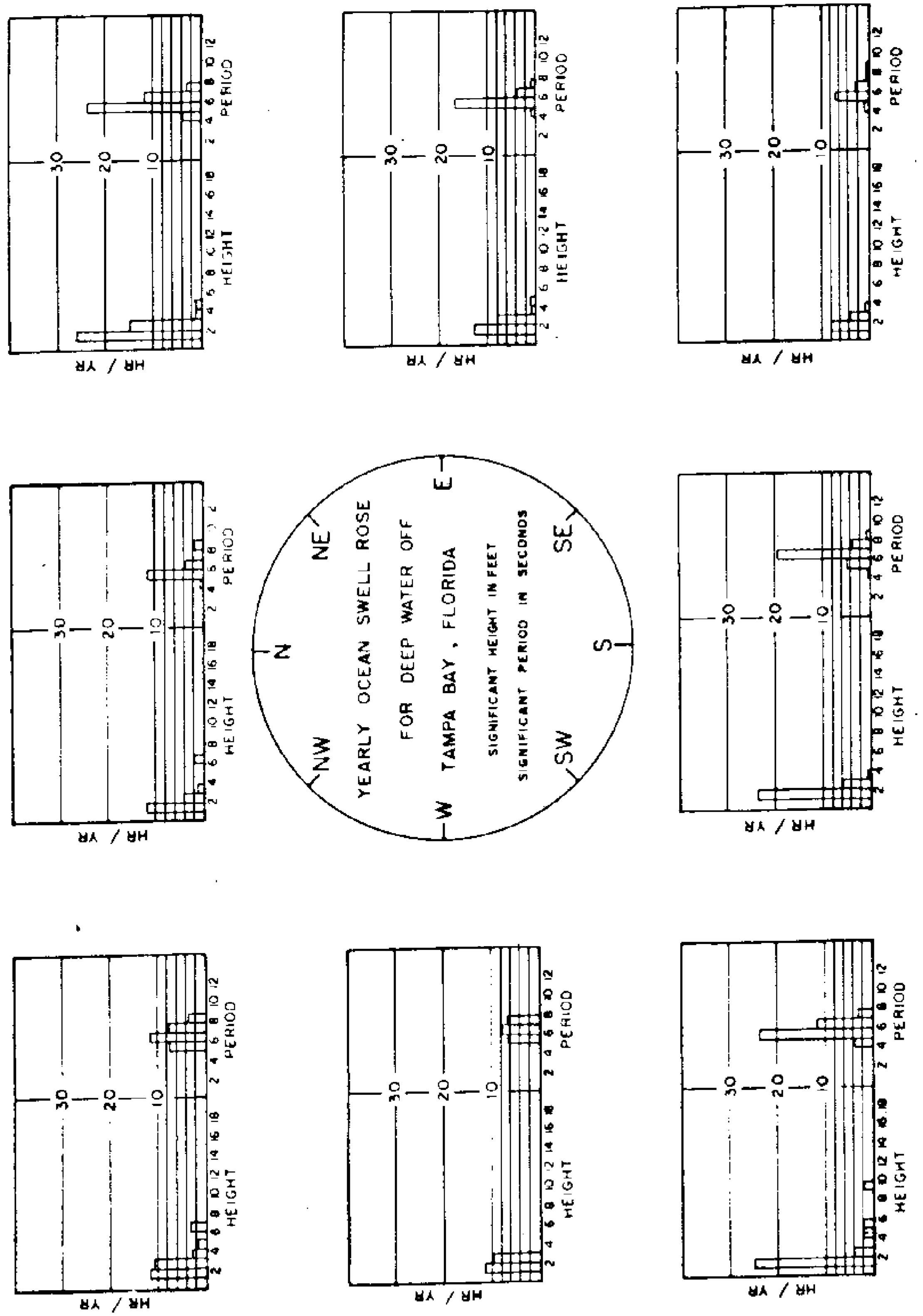


FIGURE 3.4. Yearly Swell Rose Deep Water Offshore of Tampa Bay, 1950, 1951, & 1954 (courtesy: U.S. Army Corps of Engineers, 1955).

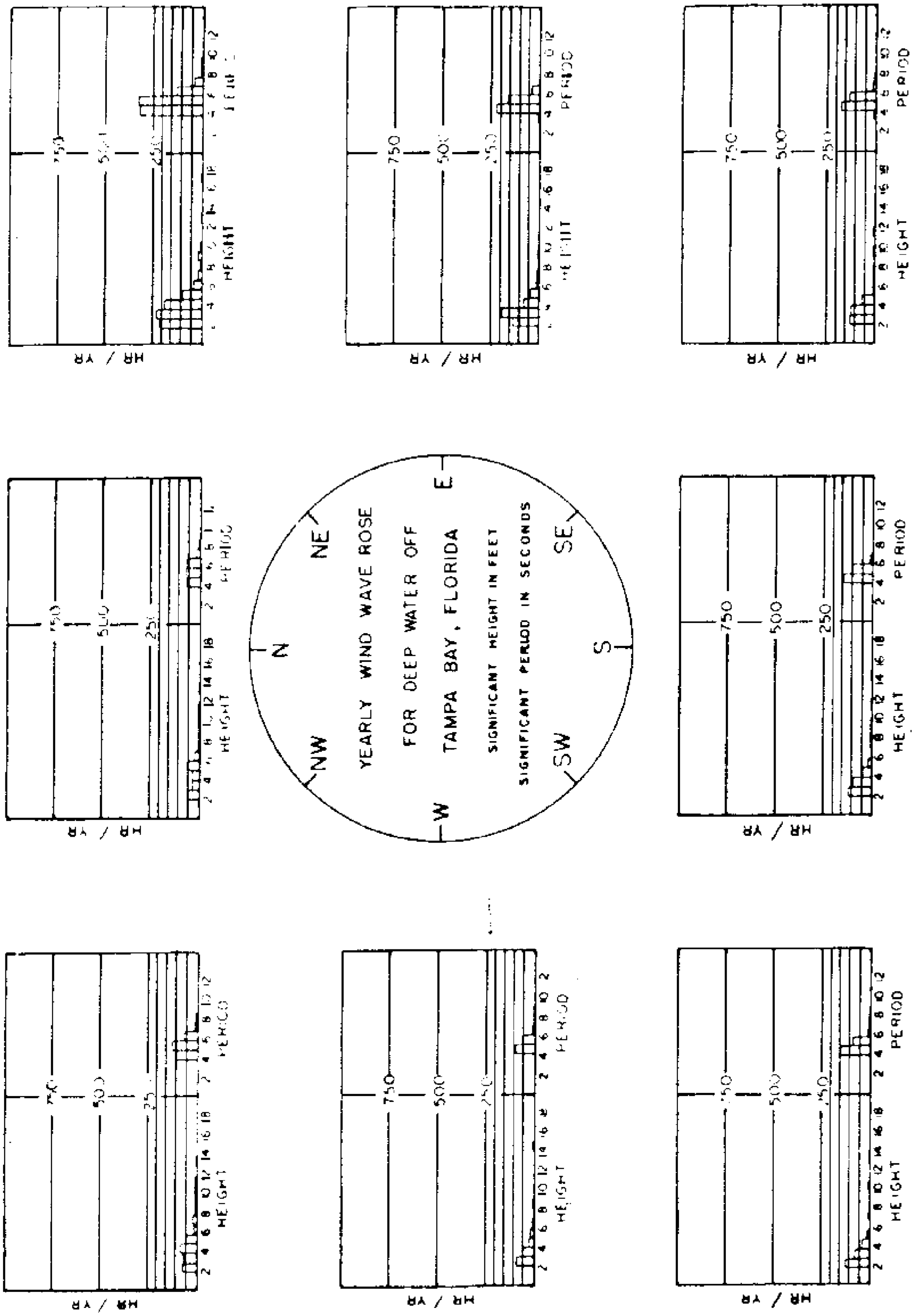


FIGURE 3.5. Yearly Wind Wave Rose Deep Water Offshore Tampa Bay, 1950, 1952, & 1954 (courtesy: U.S. Army Corps of Engineers, 1955).

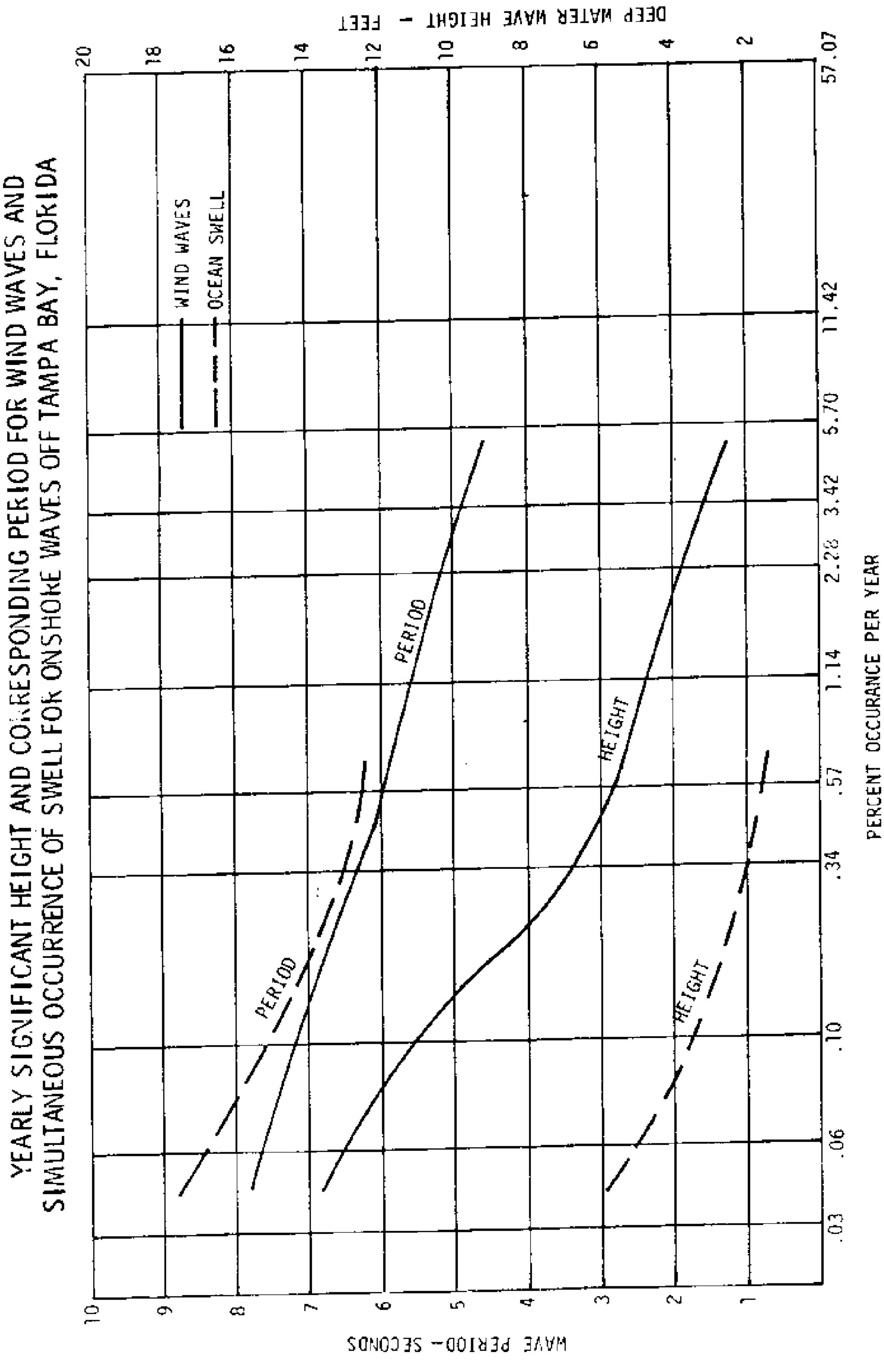


FIGURE 3.6. Statistical Summary of Deep Water Wave Data Offshore of Tampa Bay (courtesy: U.S. Army Corps of Engineers, 1955).

In 1980 the University of Florida's Coastal and Oceanographic Engineering Laboratory began monitoring wave data from a pressure transducer installed about 2 kilometers off the coast of Clearwater Beach Island. Statistical information obtained from this offshore wave data, as well as estimates of nearshore wave climate, longshore sediment transport rates, etc., would be more reliable than earlier approximations derived from hindcast techniques.

3.4 Storms and their Effects

Tropical storms with wind velocities ranging from 32 kilometers per hour to hurricane force are the chief generators of the larger waves and wind tides in the study area. Local frontal storms of unusual intensity are also generators but their effects are comparatively less (Corps of Engineers, 1966).

The paths of hurricanes which have passed within 80 kilometer and 240 kilometer radii of Pinellas County between 1830 and 1980 are shown in figure 3.7 for the period 1830 to 1964 inclusively. Since 1830 a total of 60 known hurricanes and tropical disturbances have influenced the Pinellas County coast. Of that total, 26 were classified as being of hurricane intensity and 34 of less-than-hurricane force. Data on major hurricanes that have affected the area and, to the extent available, on local frontal storms that have caused considerable erosion and damage are presented below (U.S. Army Corps of Engineers, 1966).

a. Hurricane of October 1-18, 1910. Originating in the western Caribbean Sea, this hurricane passed over Cuba and moved northward in the Gulf for 3 days, passing inland approximately 80 kilometers south of Tampa. As the storm passed southeast of Tampa Bay, water levels at the mouth of Hillsborough River were lowered to minus 2 meters by northeast winds, and when the wind shifted to south some 14 hours later, they rose to plus 1 meter, a total differential of 3 meters. Losses were not considered severe.

b. Hurricane of October 21-31, 1921. This storm was considered one of the most severe to strike the Gulf Coast of Florida in the present century. It originated in the Caribbean Sea, followed a northerly path, and crossed inland in northern Pinellas County. Almost all coastal communities along a 240 kilometer reach from Tarpon Springs southward reported flooding conditions which were prolonged by the slow forward movement of the storm. Along the coast of Pinellas County, full hurricane intensity winds were estimated to be between 130 and 160 kilometers an hour. At Tampa, where peak winds of 121 kilometers per hour were reported, high tides and wave action were the major causes of damage. A peak tide of 3.2 meters was the maximum since the 1848 hurricane.

c. Hurricane of September 6-22, 1926. According to local residents, damages resulting from the hurricane were exceeded only by those caused by the hurricanes of October 1921 and September 1950. It originated in the South Atlantic Ocean and passed across Florida from Miami to Punta Rassa,

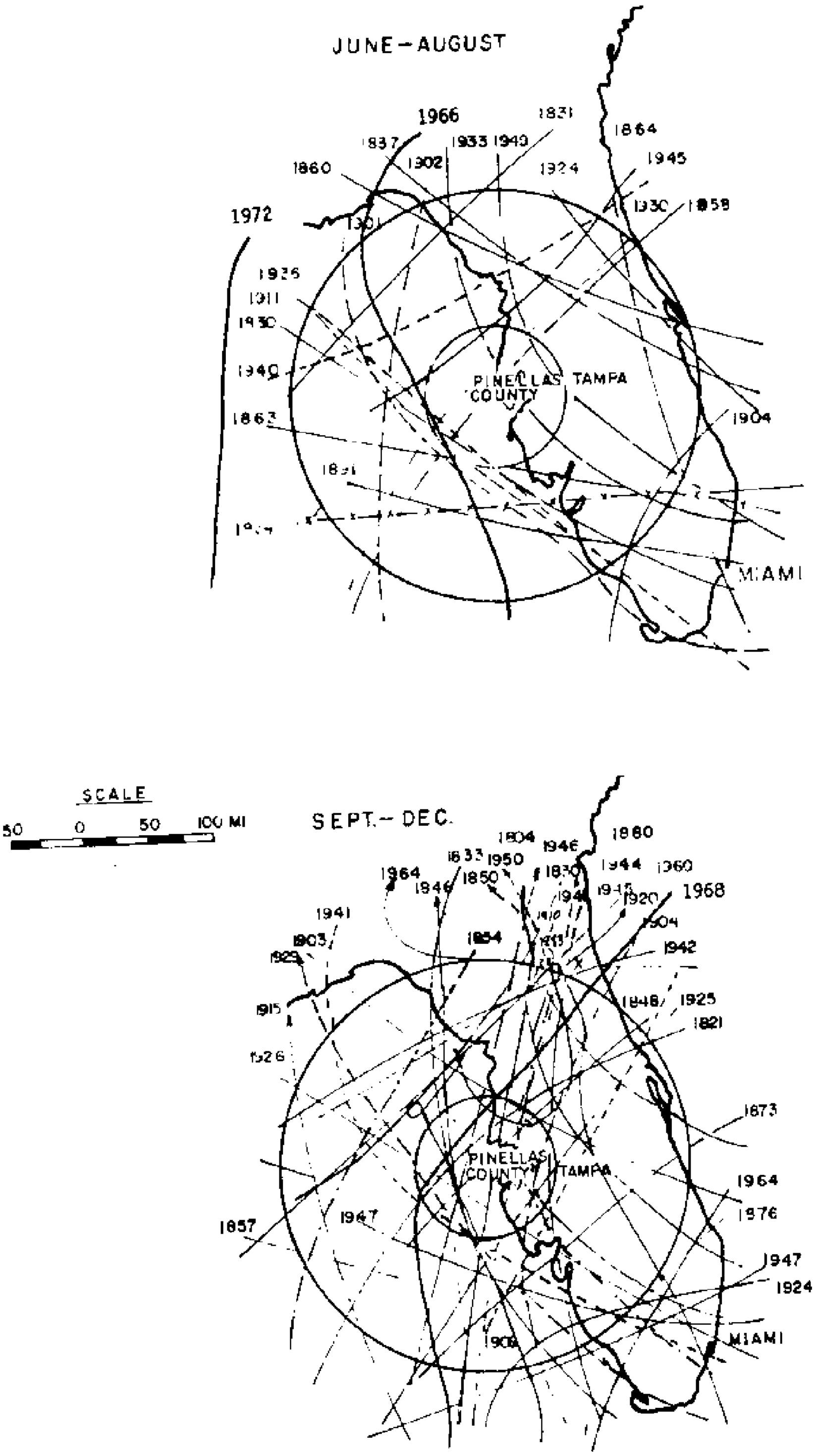


FIGURE 3.7. Paths of Pinellas County Hurricanes (courtesy: National Oceanographic and Atmospheric Administration).

about 200 kilometers northwest of Miami. The maximum wind velocity recorded at Tampa was 80 kilometers per hour. The hurricane produced a tide of 1.4 meters at Tampa, and local residents reported that storm waves reached about 3 meters in height at Clearwater Beach and about 1.8 meters in height at Indian Rocks Beach. Such waves were reported to have caused considerable erosion damage along some sections of the beaches.

d. Hurricane of March 1932. This storm was of short duration and was caused by a low pressure system of considerable intensity which moved eastward over Florida from the Gulf of Mexico. The maximum wind velocity recorded at Tampa was 64 kilometers per hour from the northwest. It was reported that several islands off St. Petersburg were inundated. Waves were reported to have broken over the city pier at Clearwater Beach during the height of the storm. At that location, fifteen cottages, two amusement pavilions, and a hotel were reported to have been severely damaged. Property damage along other sections of the beaches was reported to have been heavy.

e. Hurricane of August 31-September 8, 1935. First observed east of Turks Island in the Bahama Islands, and traveling toward the Florida Straits, this hurricane soon passed up the west coast of Florida and crossed inland approximately 160 kilometers northwest of Tampa. Maximum wind velocity at Tampa was 120 kilometers per hour from the southeast. Some flooding occurred in the Tampa area as tides rose to 1.6 meters above normal. It was reported that many sections of the beaches were covered with water.

f. Hurricane of October 13-21, 1944. This storm originated in the western Caribbean Sea south of Grand Cayman Island, moved across Cuba, entered the west coast of Florida about 80 kilometers south of Tampa, and swept northeastward almost directly over Tampa. The maximum 5 minute average wind at Tampa was 90 kilometers per hour from the northeast, with gusts up to 160 kilometers per hour. Considerable erosion damage was reported and several beach protective structures were destroyed.

g. Hurricane of June 19-27, 1945. Developing near British Honduras and moving directly northward into the gulf, this storm curved northeast and crossed Florida at a point about 121 kilometers north of Tampa. The hurricane was accompanied by winds of 79 kilometers per hour, recorded at Tampa. At Sunset Beach (Treasure Island), a 0.8 kilometer section of seawall was destroyed and an entire colony of cottages collapsed due to failure of the wall and undermining of the cottage foundations.

h. Hurricane of August 24-29, 1949. This storm formed northeast of the Leeward Islands and reached full hurricane intensity as it passed north of the Bahamas, crossing inland from West Palm Beach to a point on the gulf coast about 16 kilometers north of Tampa. Southwest winds of 80 kilometers per hour were reported at Tampa, with gusts up to 108 kilometers per hour. A tide of 1.5 meters was recorded at Tampa. At Clearwater Beach it was reported that the high tide caused water to flow across the island a short distance north of Causeway Boulevard. It was also reported that several hectares of beach along the south part of Clearwater Beach Island were washed away.

i. Hurricane of September 1-7, 1950. Forming over the western Caribbean Sea and passing over Cuba and into the Gulf of Mexico, this storm paralleled the Florida coastline, described two loops near the Gulf Coast approximately 160 kilometers north of Tampa before curving southeastward to within 43 kilometers north of Tampa, at which point it recurved and traveled northward into Georgia. Pinellas County beaches were exposed to wind-driven waves for more than 48 hours. Along Pinellas County beaches homes, buildings, seawalls, streets, and sidewalks were damaged. In places, the shoreline receded as much as 21 meters. Serious flooding from tides, estimated as being between 1.8 to 2.4 meters, resulted in damage to homes along the beachfront. At Blind Pass, water was reported to have been within 0.6 meters of the bridge decking; at Sunset Beach, on Treasure Island, 2.4 to 3.0 meter high waves were reported. Tides were highest in Tampa since the 1921 hurricane.

j. Hurricane of September 3-13, 1960. "Donna" ranked as one of the great storms of the century. After forming in the Cape Verde area, "Donna" traveled west past Puerto Rico and Cuba and crossed directly over the central keys. From there it curved northward along the gulf coast to a point approximately 120 kilometers south of Tampa, where it moved inland to emerge on the Atlantic Coast at a point about 112 kilometers southeast of Jacksonville. In the Tampa area, offshore winds in the first phase lowered water levels. Second phase winds of 105 kilometers per hour were onshore but greatly diminished as the hurricane center moved inland over Florida. Peak tides were below 1.2 meters.

k. Storm of September 29, 1963. An intense low pressure area over the Gulf, lasting almost a week, produced winds gusting up to 112 kilometers per hour, and caused considerable damage to Pinellas County beaches. Although the storm was not a hurricane, tides were reported to be the highest in 13 years, washing over all causeways between Pinellas and Hillsborough Counties. Winds, together with spring tides, caused water levels to increase 1.2 to 2.4 meters above normal. Damage was particularly severe at Sunset Beach on Treasure Island where many homeowners reported flood waters 0.6 meters deep. Some seawall failures occurred at Treasure Island.

l. Hurricane of June 4-14, 1966. "Alma" caused some serious erosion problems along Treasure Island, Sand Key, and Clearwater Beach Island. Tides were 1.2 meters above normal (St. Petersburg Times, June 10, 1966).

m. Hurricane of October 20-29, 1968. "Gladys" originated in the west Caribbean Sea and made land fall approximately 37 kilometers north of Clearwater. This hurricane was termed the worst in 15 years and caused extensive damage to sea walls and beach erosion (St. Petersburg Times, Oct 19-20, 1968).

n. Hurricane of June 15-22, 1972. Although "Agnes" passed 260 kilometers west of Pinellas County, it caused damage to structures along the coast and beach erosion. Tides were reported to be 1.5 to 1.8 meters above normal (St. Petersburg Times, June 21, 1972).

3.5 Hurricane and Tropical Storm Summary

Since 1830, a total of 45 known hurricanes and tropical disturbances have passed within a 80 kilometer radius of Pinellas County; of this total, 20 were classifed as being of hurricane intensity and 25 of less than hurricane force. Since 1900, 13 hurricanes and 16 tropical disturbances have passed within a 80 kilometer radius of the area. The accuracy of data prior to 1900 is questionable. The relative frequencies of major storm occurances passing within a 80 kilometer radius of the area for specific time intervals is given below:

	HURRICANES PASSING WITH AN 80 Km RADIUS		HURRICANES AND TROPICAL DISTURBANCES	
PERIOD	Number	Relative Frequency	Number	Relative Frequency
1830-1900	7	1 in 10 yrs	16	1 in 4 1/2 yrs
1900-1964	13	1 in 5 yrs	29	1 in 2 1/4 yrs
1830-1964	20	1 in 6 1/2 yrs	45	1 in 3 yrs

If it is assumed that these hurricane events occur randomly and the simultaneous occurrence of these events has a negligible probability, then the random variable (the occurrence of a hurricane) can be approximated by a Poisson distribution (Miller and Freund, 1965). The probability of having k number of events within a specified time interval t (years) is given by the following relation:

$$P_r [x = k] = e^{-\lambda} \frac{\lambda^k}{k!} \qquad (3.1)$$

where $\lambda = vt$ the average number of occurrences in time t

Using the hurricane data for the 81 year period between 1900 and 1980, the probability that no hurricane will pass within an 80 kilometer radius of Pinellas County during any given year is 0.82 or 82 percent, while the probability that no tropical storms will pass within this radius is 67 percent. This means that the probability of at least one hurricane passing within an 80 kilometer radius of Pinellas County during a 1 year period is 12 percent. Likewise, in any 1 year the probability of at least one tropical storm passing within this radius 33 percent. Using the same data, the probability of at least one hurricane passing within an 80 kilometer radius within the next 5 years is 63 percent.

3.6 Storm Flood Plain

According to the Federal Insurance Administration's Flood Hazard Boundary Map H 01-15 (Community No. 125096A), Clearwater Beach Island to the north of the pass and Sand Key to the south lie within the V13 zone. This means that they are within the designated 100 year coastal flood plain. The 100 year or base flood describes the statistical chance or probability of 1 percent that a flood of designated magnitude (in this case elevation +3.7 meters MSL) will occur within any given year. During the 100 year flood, these islands would be inundated and subjected to wave action. With the exception of a narrow band along the mainland and areas adjacent to drainage channels, the majority of land within the city of Clearwater is above the 500 year flood plain. This is because the city is located on the Penholoway terrace formed during the Pleistocene epoch.

IV. HISTORY

4.1 General

Information regarding Government land grants on file with the U.S. Public Land Sales Office reveals that Clearwater Beach Island, approximately 65 hectares, was originally purchased by a Mr. Ernest Tate for $200.00 in 1898. Shortly afterwards it was resold for approximately $2,000.00 and so began the speculative coastal land sale business. Today $2,000 per front foot of beachfront property would be considered a conservative estimate.

4.2 Chronology of Events

Clearwater Pass is believed to have been in existence during the times of early Spanish exploration, and is probably the oldest pass in the area. The earliest available map (1879 USC and GS Coast Chart # 177) shows Little Pass, as it was formerly called, as a rather narrow break in the barrier island. Over the past 100 years inlet and bay system has been subjected to frequent alterations both man-made (development and construction) as well as natural (ocean swell, windwaves, storms, wind, etc.). The following is a chronologic listing of most of the significant man-made alterations. These events, in conjunction with historic storm information, provide a description of the influences of the forces that have been at work in shaping and making the Clearwater Pass Inlet and bay system as it is today.

YEAR	EVENT
1898	Federal land grant for the sale of Clearwater Beach Island.
1921	Hurricane caused a break-through in Hog Island (now Caladesi and Honeymoon Islands). After the storm, it remained opened and stable and was named, appropriately enough, Hurricane Pass.

1924	Clearwater Beach Island was christened by a real estate development company as "Mandalay" and advertised widely in popular magazines as "The isle of a thousand palms." This was the beginning of the development boom.
1925-27	The construction of the Garden Memorial Causeway was initiated and completed. This causeway replaced an old pile bridge and created a significant barrier to flow between Clearwater Harbor and St. Joseph's Sound. Although it improved the flow regime through Dunedin Pass, it reduced the effective bay area for Clearwater Pass.
1950	1) The first phase of construction on the Island Estates residential area was initiated. Much of the land mass for this residential development was pumped up from the adjacent lagoon bottom, thus further reducing the bay area; 2) Approximately 115,000 cubic meters of beach fill were placed on the southern end of Clearwater Beach Island. Of that amount, 23,000 cubic meters were placed by the city on the south end of Clearwater Island Public Beach. The remainder was placed on private property further south; 3) The city of Clearwater also constructed two groins at the southern end of the public beach to help stabilize the eroding shoreline.
1952	A 150 meter long concrete pier groin, 91 meters of which consisted of concrete slab baffles, was constructed, near the southern end of Clearwater Beach Island to help reduce erosion.
1957	A storm caused a small break-through in Sand Key south of Clearwater Pass, but it closed shortly thereafter.
1960	Congress authorized a Federal navigation project at Clearwater Pass, and the U.S. Army Corps of Engineers dredged a navigation channel 3 meters by 46 meters from the Gulf through the inlet with two branch bay channels 2.4 meters deep by 31 meters wide. One of these turns north ending at the Clearwater Municipal Marina, while the other continues eastward to intersect with the Gulf Intracoastal Waterway. (See figure 4.1).
1961-1963	1) The Federal Government constructed the portion of the Gulf Intracoastal Waterway that passes through St. Joseph's Sound and Clearwater Harbor. Dredged material was pumped into disposal areas (now islands) paralleling the waterway; 2) The city of Clearwater constructed an additional seven groins to help protect the southern Clearwater Beach Island shoreline; 3) the Clearwater Pass bascule bridge was constructed with 7.3 meter clearance. The southern bridge

abutments caused an eddy pattern with low velocity flow where sediment could fall out of suspension. Consequently the area near the abutments eventually accreted enough sand to become high and dry; 4) Another concrete baffel-type pier groin was constructed by the city. In addition, the city began an annual program of placing large quantities of rubble and fill at the southern limit of public property near the pass.

1964 Construction of Honeymoon Causeway connecting Honeymoon Island with the mainland was completed, adding an additional restriction to the tidal flow in and through St. Joseph's Sound. This boxed in the lagoonal area east of Clearwater Beach Island, and had a considerable impact on the dynamics of Dunedin and Hurricane Passes. This, no doubt, had some impact on Clearwater Pass' flow regime also, although the change was not as significant.

1965 The Corps of Engineers performed maintenance dredging of the Intracoastal Waterway south of the Garden Causeway. Approximately 23,000 cubic meters were removed from the channel and placed in existing disposal islands.

1967 The first maintenance dredging of Clearwater Pass (navigation project) was conducted, removing shoals in the pass and bay project channels. Dredged material was pumped into four submerged disposal areas, one south of the entrance channel, and three flanking the bay channel.

1969 The Corps of Engineers performed the second maintenance dredging at the Clearwater Pass. Shoal areas were removed from the entrance channel and along the intersection of the two bay channels (just inside the pass). These two locations proved to have shoaling problems. The dredged material was pumped to Gulf and bay disposal areas.

1970 The conclusions of a University of Florida Coastal and Oceanographic Laboratory Study indicated that due to sand accretion on the northern tip of Sand Key, the pass was becoming narrower and deeper. This deepening trend posed a threat to the structural safety of the Clearwater Pass bridge.

1973 The U.S. Army Corps of Engineers performed the third maintenance dredging of the Clearwater Pass entrance channel and branch intersection of the bay channels. All material was placed in an upland disposal site at the northern end of Sand Key.

1973	Completion of a University of Florida Coastal and Oceanographic Engineering Laboratory study, recommending the construction of a 1,200 meter long south jetty and an 244 meter long north jetty. The study results indicated that this work in conjunction with periodic dredging in the inlet (to maintain the cross-sectional area of flow) would improve the navigational safety of the pass and decrease maximum flow velocities around the bridge piles.
1975	The city of Clearwater fixed the southern limit of the inlet by constructing a 1,280 meter long jetty (including seawall and rubble mound) at the northern end of Sand Key.
1977	The U.S. Army Corps of Engineers performed the fourth maintenance dredging of the Clearwater Pass (entrance channel only). All material was placed as beach fill on the northern tip of Sand Key behind the jetty.
1980	The University of Florida's Coastal and Oceanographic Engineering Laboratory began monitoring wave data from a pressure transducer installed about 2 kilometers off the coast of Clearwater Beach Island.
1981	The city of Clearwater fixed the northern limit of the pass by constructing a 168-meter-long jetty on the southern tip of Clearwater Beach Island.
1981	The city of Clearwater purchased an hydraulic dredge plant and began dredging operations in the pass. Material was used to nourish eroded beaches on the northern end of Sand Key, widen city beaches on Sand Key and Clearwater Beach Island, and to fill in the scour hole around several of the Clearwater Pass Bridge piers.

4.3 Dredging Records

The initial construction and maintenance dredging of the Clearwater Pass project was accomplished with hydraulic dredge plant. Table 4.1 (courtesy of Jacksonville District, U.S. Army Corps of Engineers) gives the dredging record for all work on the project channels from 1960 (initial construction) to 1977. The letters correspond to disposal sites and their locations are displayed in figure 4.1.

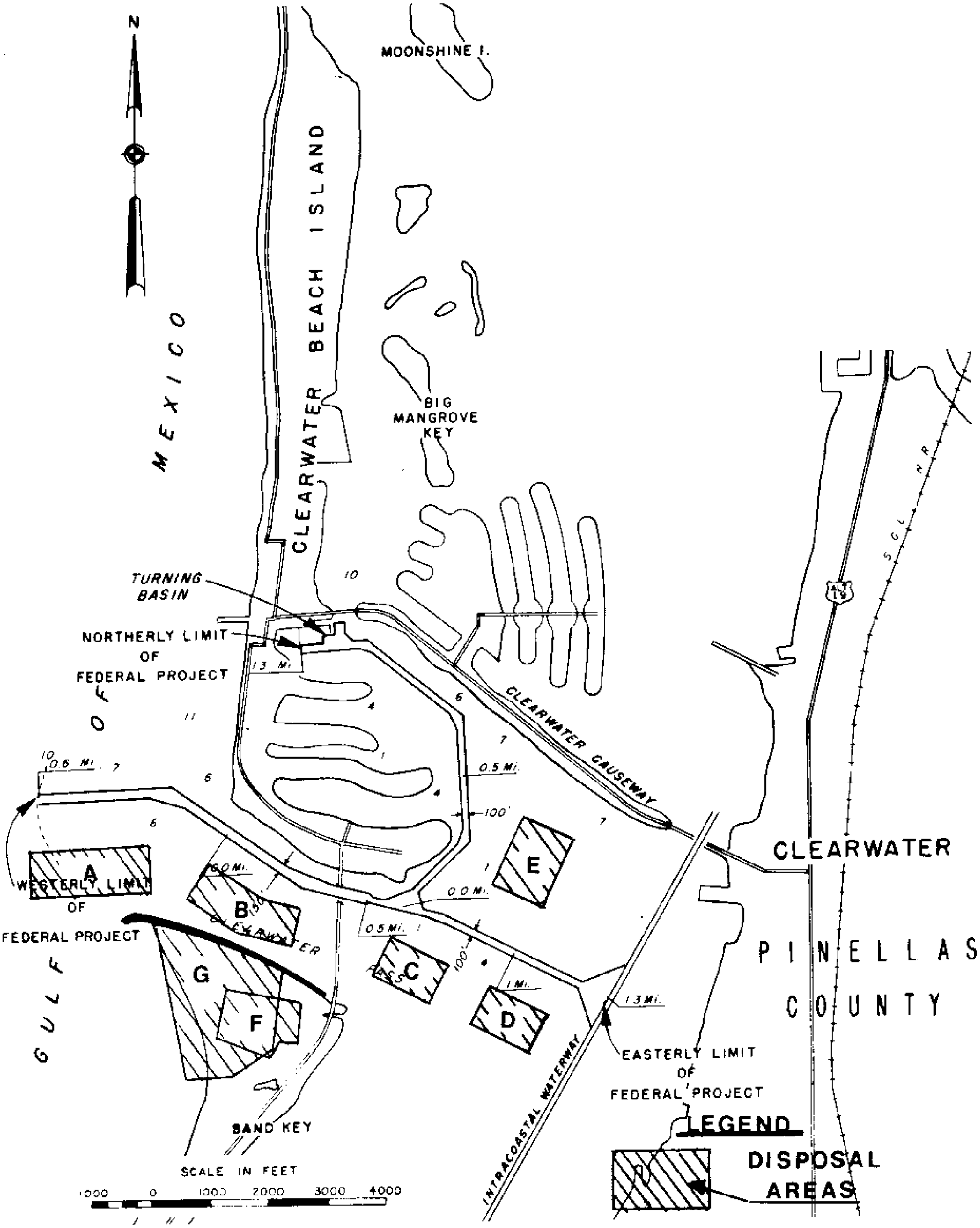


FIGURE 4.1. Location of Disposal Areas for Initial Construction and Subsequent Maintenance of Federal Navigation Project (courtesy: U.S. Army Corps of Engineers).

TABLE 4.1
Dredging Records for Clearwater Pass, Florida 1960 to 1977 (inclusive)

Contract Plan Drawing Sheet No.	Year	Amount Dredged (Pay Quantity) Cubic Meters	Cost	Disposal Sites
57-26, 827-11	1960*	127,700 (nw)*	$ 68,489	A, B, C, D, E
57-29, 948	1967	61,885 (m)	53,184	A, B, C, D, E
57-30, 598	1969	55,701 (m)	62,255	A, E **
57-36, 857	1973	96,241 (m)	340,256	F **
57-32, 335	1977	142,016 (m)	311,439	G
	TOTAL	483,543 cu. mtrs.	$835,623	

*(nw) refers to initial construction, (m) refers to maintenance dredging
** diked disposal areas

4.4 Inlet Dredging and Beach Nourishment

In 1979 the city of Clearwater purchased a dredge plant with 36 cm suction and 30 cm discharge pipes. Appropriately named "Clearwater Pass," the dredge began its first project excavating material from the pass in February, 1981. The purpose of this project was two-fold: 1) widen the inlet cross-section to reduce maximum tidal velocities and prevent additional scour around the Clearwater Pass Bridge piers, and 2) use the excavated material to nourish eroding beaches on the northern end of Sand Key, widen city beaches, and fill in the inlet scour hole. Approximately 840,000 cubic meters of material will be removed from the pass during the project.

On Sand Key, beach nourishment will extend approximately 3.2 kilometers south of the pass and include 2.3 kilometers along privately owned land and 0.9 kilometers of public beach. Property owners along the 0.4 kilometers of shoreline immediately south of the public beach do not have an erosion problem and are not participating in the project. From the southernmost limit of the project, the first 460 meters of beach will have a 90 meter width, while the remaining project beach will have a 45 meter width (to mean high water). The wider beach is intended to provide a reserve of littoral material. The beach will have a +2 meter (MSL) elevation at its landward limit and include a small berm with a maximum elevation of +3 meters. A total of 570,000 cubic meters will be placed on Sand Key beaches, 230,000 of which will be pumped on the public beach. Of the remaining material, approximately 80,000 cubic meters will be pumped along 910 meters of public beach on Clearwater Beach Island, while 190,000 cubic meters will be pumped into the scour hole.

The city anticipates completing nourishment of the private portions along Sand Key by late 1982, and the Sand Key city beach should require an additional 6 months.

V. MORPHOLOGY

5.1 Maps, Surveys, and Photographs

Clearwater Pass originally appeared on the 1879 USC&GS Coast Chart # 177. This chart is reproduced in figure 5.1. The pass now appears on National Ocean Survey's nautical chart # 11410, 14 June 1980, (the latest edition). It also appears on the "Clearwater, Fla." topographic quadrangle map, containing hydrographic data compiled from Nos. 858 (1974) and 1257 (1973).

Clearwater Pass and its adjacent land areas were first surveyed by the USC & GS in 1883 (Topographic Sheet No. 1301a) as part of a more extensive survey of the Florida coastline. This agency again performed bathymetric and high water shoreline surveys of the area in 1924 (Topographic Sheet No. T4214) and 1939 (Topographic Sheet T5823). Similar surveys have been performed by the U.S. Army Corps of Engineers in 1950 and 1964-5. In 1974 the Florida State Department of Natural Resources (DNR), in connection with the coastal construction setback line study, conducted a survey of coastal beaches along the barrier islands adjacent to Clearwater Pass. Beach profiles were taken at approximately 305-meter intervals, with a permanent reference monument set for each profile location. The profiles at every third monument were extended 914 meters offshore, with mean sea level depths of greater than 6 meters. The remaining profiles were taken to wading depth.

Before and after dredging, surveys were conducted within the federally authorized project limits by the U.S. Army Corps of Engineers in 1960-61, 1967, 1969, 1973-74, and 1977. The reference numbers for these maps are given in table 4.1.

A summary table of the known aerial photography of Clearwater Pass that was taken prior to 1975 is contained in U.S. Army Corps of Engineers GITI Report 75-2 (Barwis, 1975), "Catalog of Tidal Inlet Aerial Photography." The references to aerial photography for Clearwater Pass are listed in table 5.1.

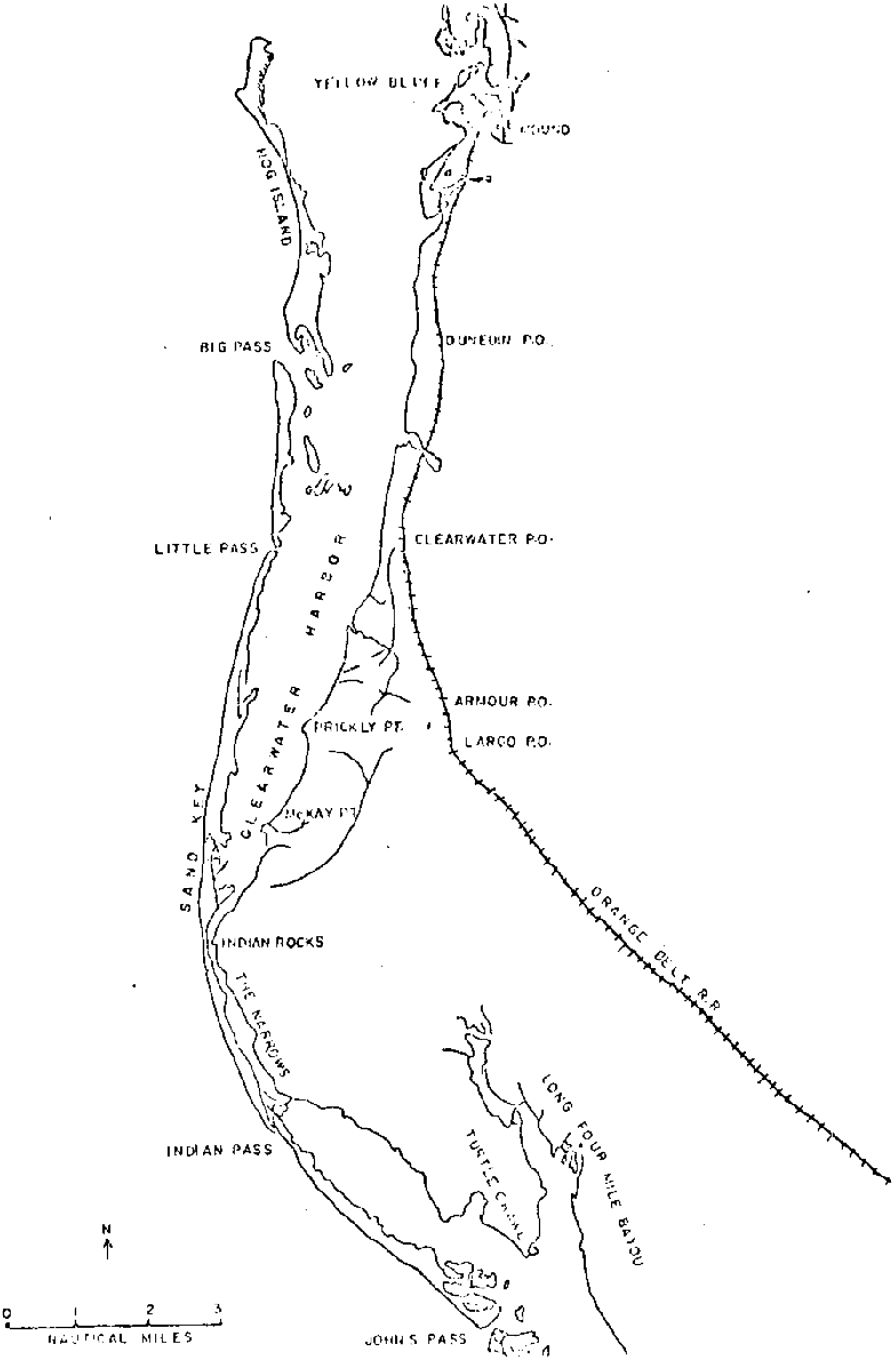


FIGURE 5.1. First USC&GS Coast Chart of Little Pass (now Clearwater Pass), 1879.

TABLE 5.1

Aerial Photography of Clearwater Pass, Florida

DATE	AGENCY	PROJECT [1]	EXPOSURE	SCALE
1924 [2]	Hamilton Maxwell, Inc. New York City, NY	Pinellas County	Sheet South - No. 22 Sheet North - No. 21 Sheet South - No. 18	1" = 800 ft
1942	Tobin Research, Inc. P.O. Box 2101 San Antonio, TX 78297	Unknown	17S138E	1:20,000
April 1942	Cartographic Archives Div. National Archives General Services Adm. Washington, DC 20418	CYY	1c/43,45	1:20,000
Dec. 1942	Department of Defense Central Film Library U.S. Geological Survey National Cartographic Info. Ctr. National Ctr., Mail Stop 507 Reston, VA 22092	MISS23514	VV2 (Roll 549)	1:20,000
Sept. 1944	USGS Same as Dec. 1942	4M-454	82 (3501 BU)	1:41,000
May 1945	USGS	5M-142	18 (16 RSA)	1:20,000
Nov. 1951	U.S. Dept. of Agriculture Agricultural Stabilization and Conservation Service Programs for Performance Div., 14th & Independence Ave. SW, Washington, DC 20250	CCY	2H/16, 18, 20 2H/40, 42, 44	1:20,000
Dec. 1954	U.S. Air Force [4] Film held by Defense Intelligence Agency 1221 South Fern St. Arlington, VA 20301	54AM89	VV/94-97	1:20,000
Nov. 1956	USGS	USN/VaP62	M11/23/5	1:30,000
Mar. 1957	USDA Agricultural Stabilization and Conservation Service Programs for Performance Div. 14th & Independence Ave. SW Washington, DC 20250	CCI	IT/16, 18, 38, 40	1:20,000
1959	USGS	PMG58-I	4/55, 3A/102	1:10,000

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[1] Designation assigned to the photographic mission by the agency responsible.

[2] Cronaflex on file at the city of Clearwater Engineering Department.

[3] Abbreviations are made when the full address has been printed earlier in the table.

[4] Photography not for sale or general use, but available for loan on a limited basis.

TABLE 5.1 (Continued)

Aerial Photography of Clearwater Pass, Florida

DATE	AGENCY	PROJECT	EXPOSURE	SCALE
Nov. 1960	Photo Map and Imagery Information Section NOAA Department of Commerce Washington Science Center Rockville, MD 20352	60-W	4530	1:36,000
Feb. 1962	NOAA	62-3	901	1:40,000
May 1963	NOAA	63-M	007	1:20,000
May 1966	Research Data Facility NASA, Johnson Space Flight Center, Houston, TX 77058 (All NASA photography must be purchased from: U.S. Dept. of Interior, EROS Data Center, Sioux Falls, SD 57198)	23/106	3/8475-8477	1:30,000
Nov. 1970	NOAA	70-L (C)	230A,23IA	1:40,000
Mar. 1971	NOAA	71-E (C)	9707, 9708	1:20,000
Mar. 1971[5]	Hamrick & Vogeney			1" = 100 ft.
Dec. 1971	USGS	GS-SWFM	3/65, 66	1:20,000
Feb. 1973 [5]	Mark Hurd Aerial Surveys 345 Pennsylvania Ave. South Minneapolis, MN 55426	Unknown	1225, 1224 [5]	1:20,000
Apr. 1976 [5]	City of Clearwater City Engineering Office Clearwater, FL	Unknown		1" = 400 ft.
April 1976 [5]	Hamrick & Vogeney			1" = 100 ft.
Sept. 1976	NOAA		0265	1:40,000
Dec. 1979 [5]	Hamrick & Vogeney			1" = 100 ft.
Oct. 1980 [5]	Florida Department of Transportation		Range 15E/TWP 29S Sec. 5, 6, 7, 8, 17, 18, 19, 20, 29, 30	1" = 200 ft.

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[5] Recent photography included with cronaflex copies on file with City Engineer, city of Clearwater Beach, Florida.

5.2 Changes in Inlet Dimensions

According to the USC&GS Coast Guard Chart # 177, figure 5.1, in 1879 the inlet was about 107 meters wide, thus the name Little Pass. By the 1924 USC&GS survey, the inlet had grown to a width of about 1,370 meters. There are little data available between these dates; however, it is noted that the 1921 hurricane, considered to be one of the most severe to strike the Gulf Coast of Florida in the present century, causing storm surge elevations in excess of 3 meters (MSL), may have been a significant factor in the enlargement of the pass. Historic changes in the minimum width of the pass as measured from available surveys and aerial photography are listed in table 5.2 and figures 5.2 through 5.5 shows a visual comparison of 1924, 1942, 1971, and 1976 aerial photography of the pass. After the construction of the Memorial Causeway bridge (1925-27), the northern tip of Sand Key began accreting, thus steadily reducing the width of the pass. Figure 5.6 shows the historical variation in the minimum controlling widths for Clearwater, Dunedin, and Hurricane Passes, including the dates of major climatic and manmade alterations to the tidal regime (COEL, 1973). As indicated, there seems to be a correlation between Clearwater Pass' narrowing trend and the combined effects of the formation of Hurricane Pass and the construction of Clearwater Causeway. Figure 5.7 shows comparative inlet cross-sections along the Clearwater Pass bridge, from which it is observed that the narrowing was accompanied by a deepening trend, with the formation of a well-defined trench along the north side of the pass. This deepening trend which jeopardized the structural integrity of the bridge, ultimately led to the construction of the 1,220 meter south jetty to define the northerly limit of Sand Key migration. The city of Clearwater is presently increasing the inlet cross-section by hydraulic dredging, and pumping the material on eroded beaches south of the pass. According to the city oceanographer, this has reduced tidal velocities and prevented further scour around the bridge pilings.

TABLE 5.2

History of Inlet Width

Year	Clearwater Pass, Minimum Width (meters)
1879	110
1926	1,390
1939	1,070
1942	930
1950	770
1957	760
1964-65	700
1971	380
1973	340
1976*	420

* Approximate minimum width from seawalls north of pass to south jetty.

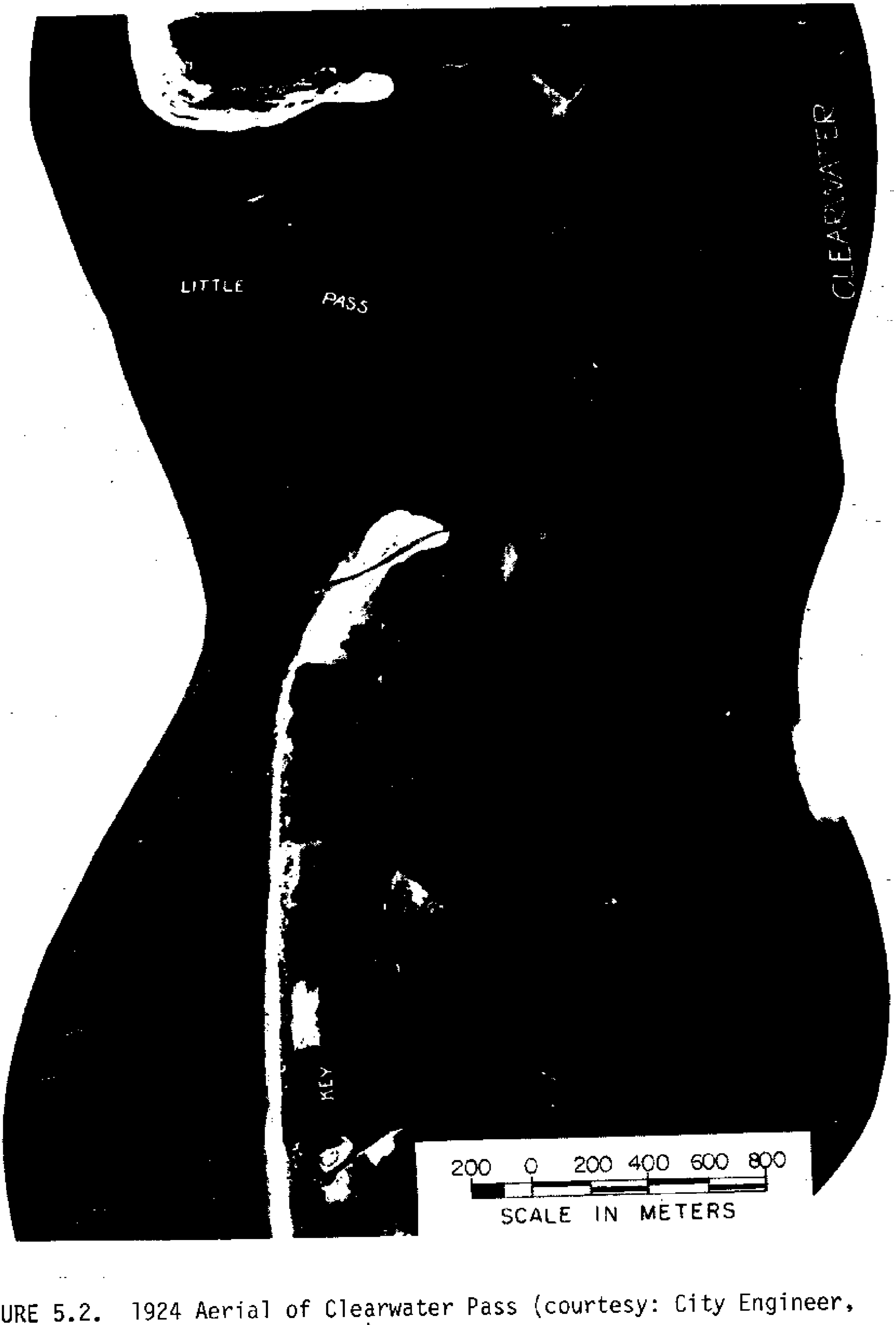

FIGURE 5.2. 1924 Aerial of Clearwater Pass (courtesy: City Engineer, City of Clearwater).

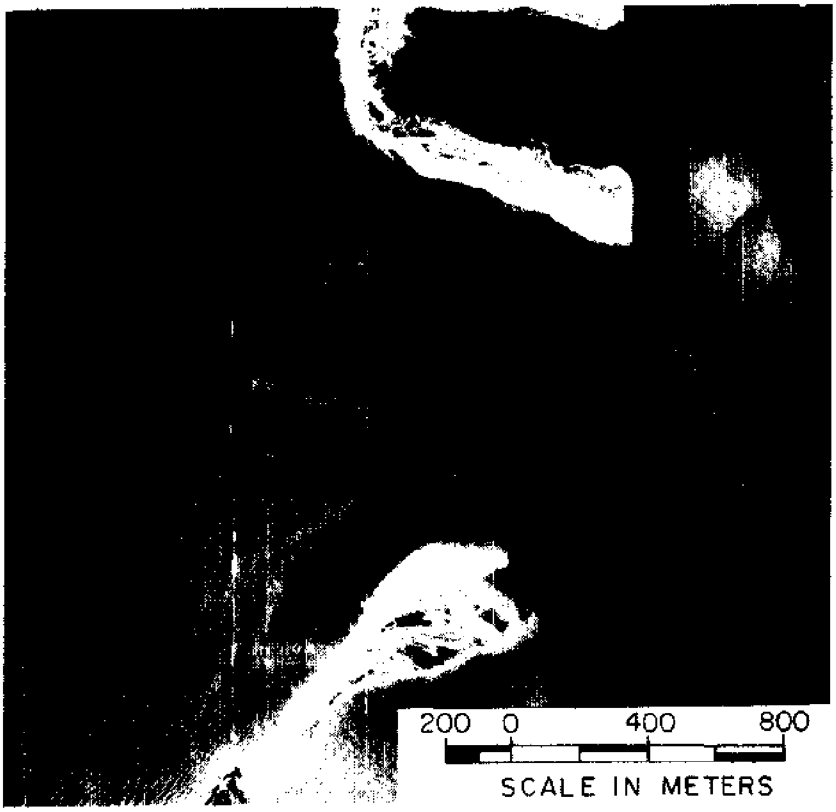

FIGURE 5.3. 1942 Aerial of Clearwater Pass (courtesy: National Archives U.S. General Services Administration).

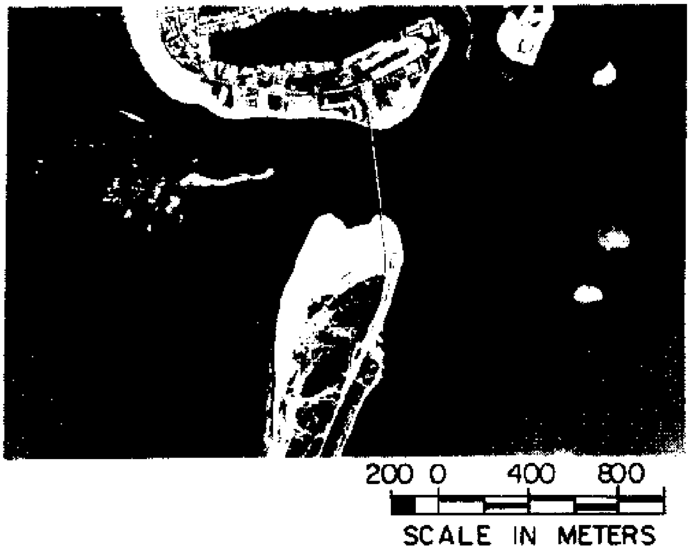

FIGURE 5.4. 1971 Aerial of Clearwater Pass (courtesy: National Oceanographic and Atmospheric Administration).

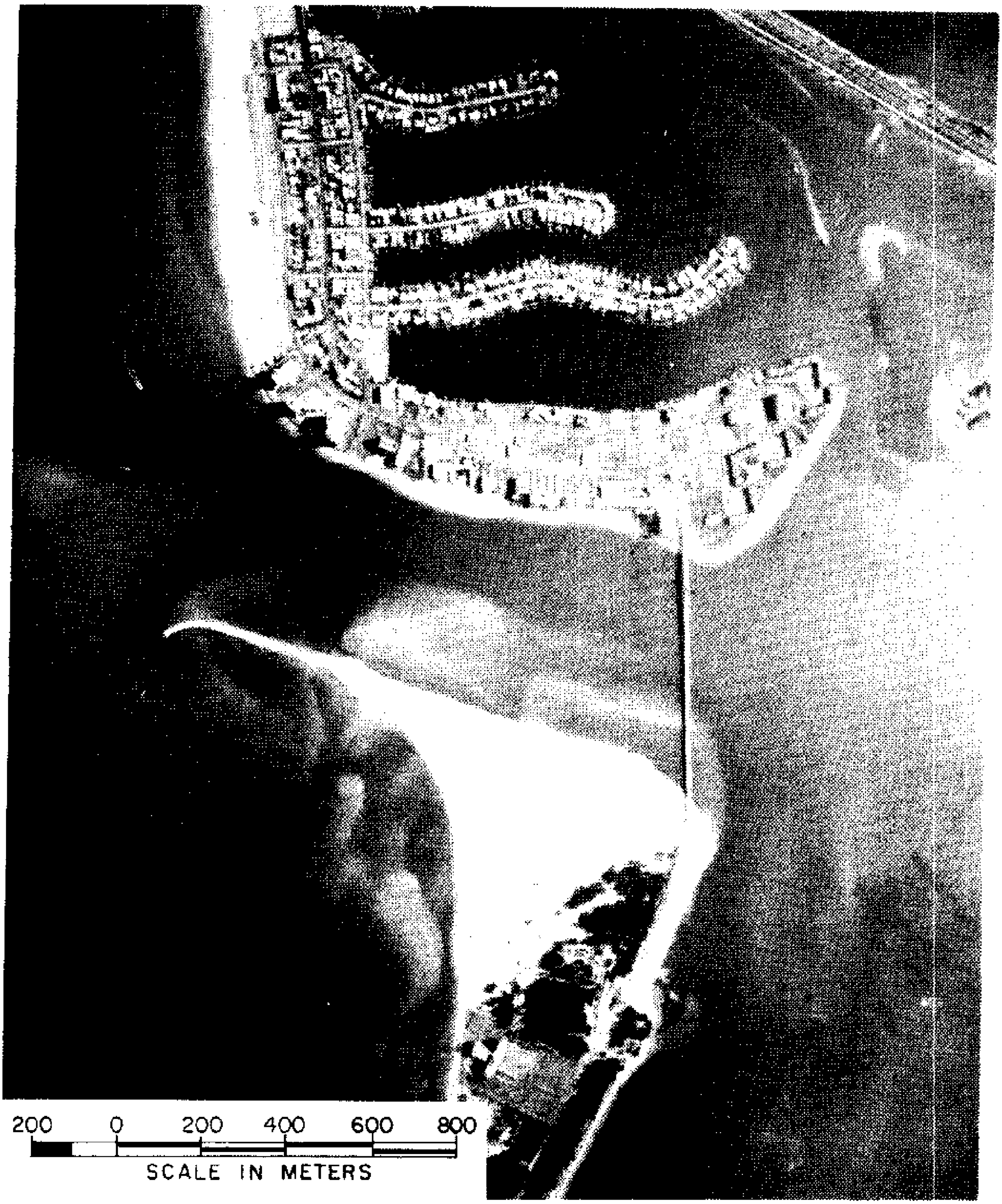

FIGURE 5.5. 1976 Aerial of Clearwater Pass (courtesy: National Oceanographic and Atmospheric Administration).

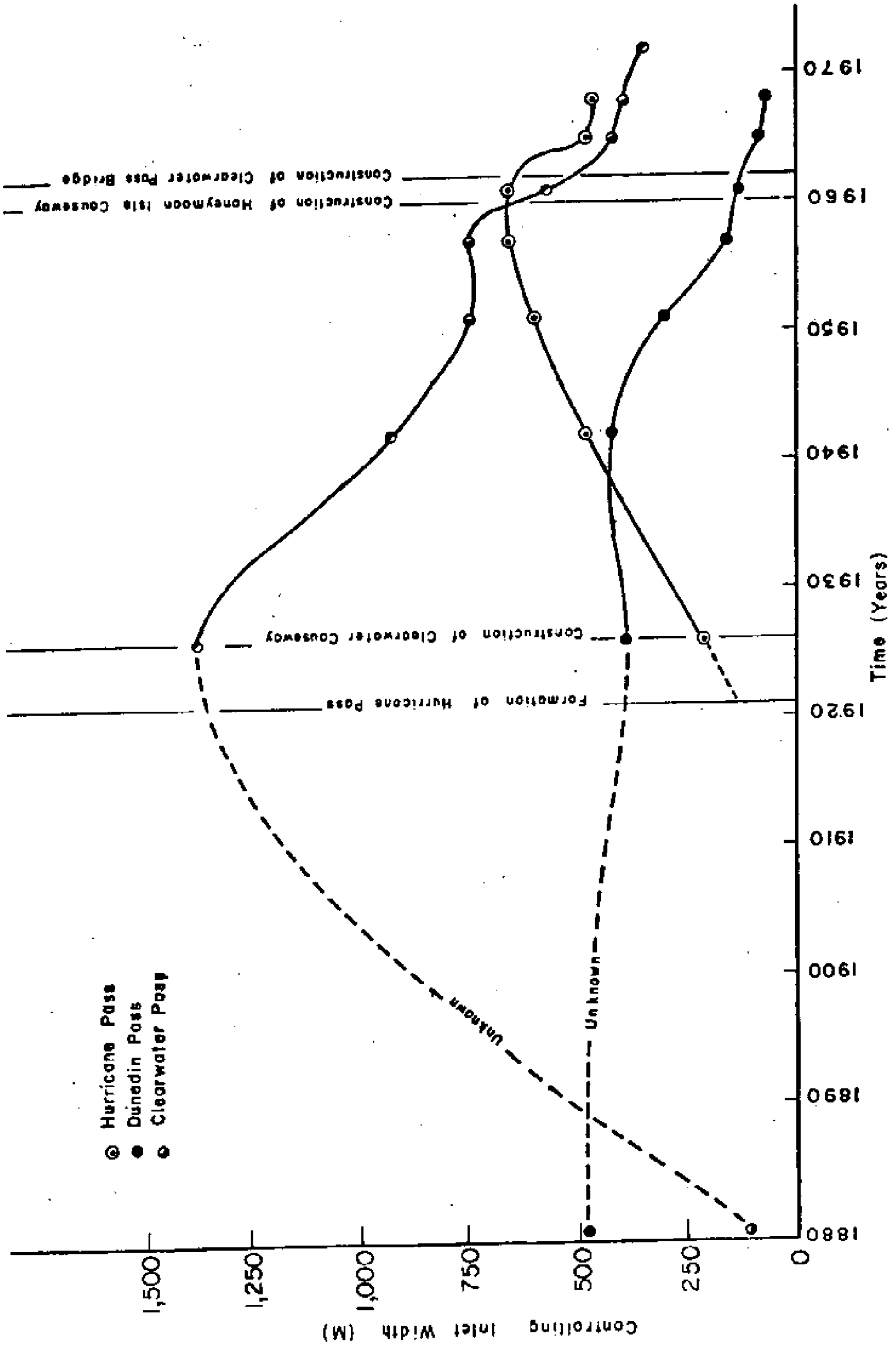

FIGURE 5.6. Minimum Controlling Width for Clearwater, Dunedin, and Hurricane Passes, Historic Variation (COEL, 1970).

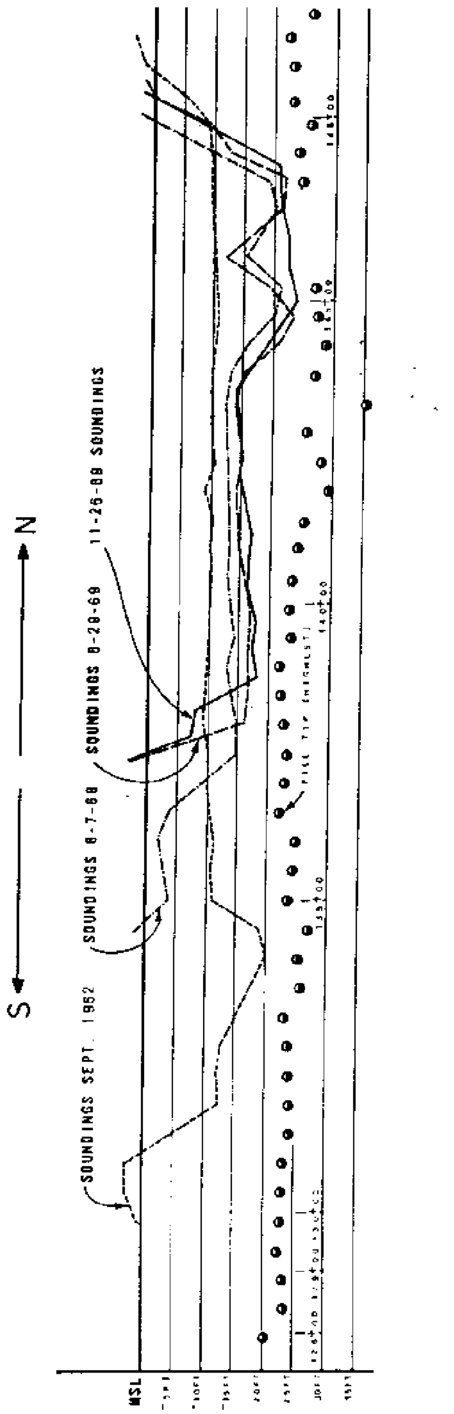

FIGURE 5.7. Historic Comparison of Cross Sections Taken along Axis of Clearwater Pass Bridge (COEL, 1970).

5.3 Outer Coast Shoreline Changes

The comparative positions of the mean high water shoreline for the period from 1873 to 1965 are shown in figure 5.8 (Corps of Engineers, 1966). The mean high water shoreline changes for the same period are outlined in table 5.3. The profile numbers correspond to the lines in figure 5.5.

TABLE 5.3

Mean High Water Shoreline Changes
(Horizontal Distance in Meters)

	Period					
	1873 to 1950			1950 to 1964-65		
Profile	Advance	Recession		Advance	Recession	
	-- Clearwater Beach Island --					
2	NA			21		
3	55			137		
4		122		128		
5		15		21		
6		61		-	(1)	
8		85	(2) 37	15		
10	(1)			43	(2) 41	
13	24	37		30		
15	(1)			61		
16				24		
17/20					24	
	-- Sand Key --					
20/17	NA			152		
20A		533		91	(2) 97	
21		518		46		
22		183			61	
23		107			43	
24		55			12	
25		15			15	
26		12			6	
27	(1)				12	
28	(1)				6	(2) 15
29	(1)				3	
30		30			6	
31		55			(1)	
32		18			6	
33	(1)				3	

---

(1) No change.
(2) Average change for bracketed reach.
* Pinellas County Beach Erosion Control Study 1966, U.S. Army Corps of Engineers.

The data show that the Clearwater Beach Island shoreline receded an average of 37 meters between 1873 and 1950, and advanced an average of 41 meters (per profile line) between 1950 and 1964-65, thus indicating an overall net advance of 4 meters (per profile line) for the period of record. This advance is an average for the island, and there are reaches where the shoreline has receded or not changed in position. Part of the advance reflects a corrective action (structures and fill) undertaken by local interests. As indicated in figure 5.8, the shoreline at the southern end of the island has receded (U.S. Army Corps of Engineers, 1966).

The Sand Key shoreline receded over almost its entire length between 1873 and 1950. What is indicated as extreme recession at the northern tip of the key was due primarily to an easterly shift in island alinement. The northern limit of the key has been advancing northward since 1939 which is probably the result of net accretion including deposition around the Clearwater Pass bridge abutments.

5.4 Offshore Depth Changes

The 3.7 meter (12 foot) depth contour for 1981-83, 1926, and 1950 surveys are plotted in figure 5.8. Figure 5.9 gives the 1.8 meter (6 foot) and 5.5 meter (18 foot) contours for these survey dates. In the reach off Clearwater Beach Island for the period of record, the 1.8 and 5.5 meter contours receded net averages of 127 meters and 163 meters, respectively. Off Sand Key the 3.7 and 5.5 meter depth contours receded net averages of 123 meters and 230 meters, respectively. The 1.8 meter contour receded about 91 meters (U.S. Army Corps of Engineers, 1966).

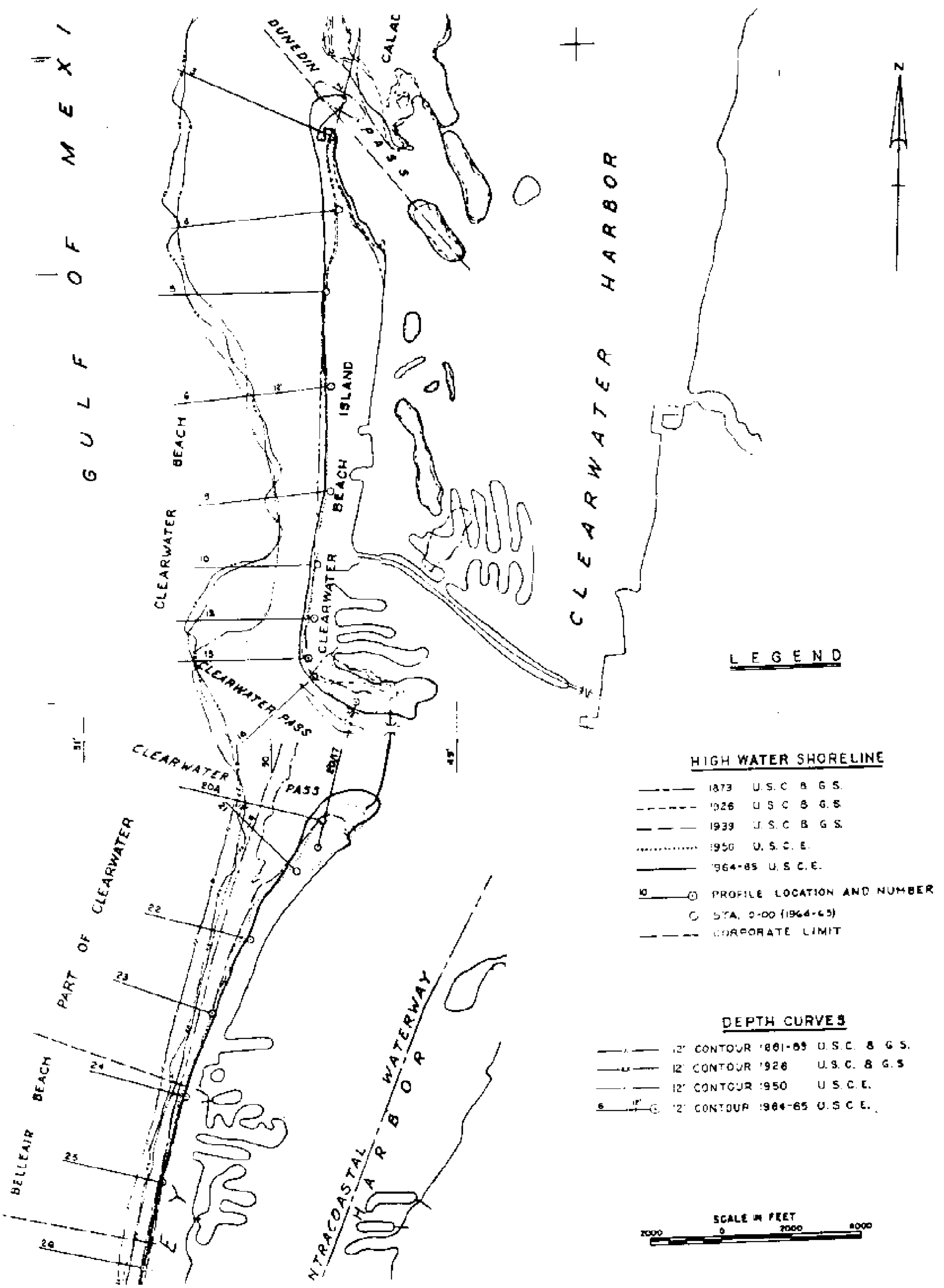

FIGURE 5.8. Comparative Positions of the Mean High-water Shoreline (courtesy: U.S. Army Corps of Engineers, 1966).

1/ Representation of the 1873 highwater shoreline in the vicinity of the pass is questionable and the 1879 USC&GS Coast Chart, Figure 5.1, should be referred to.

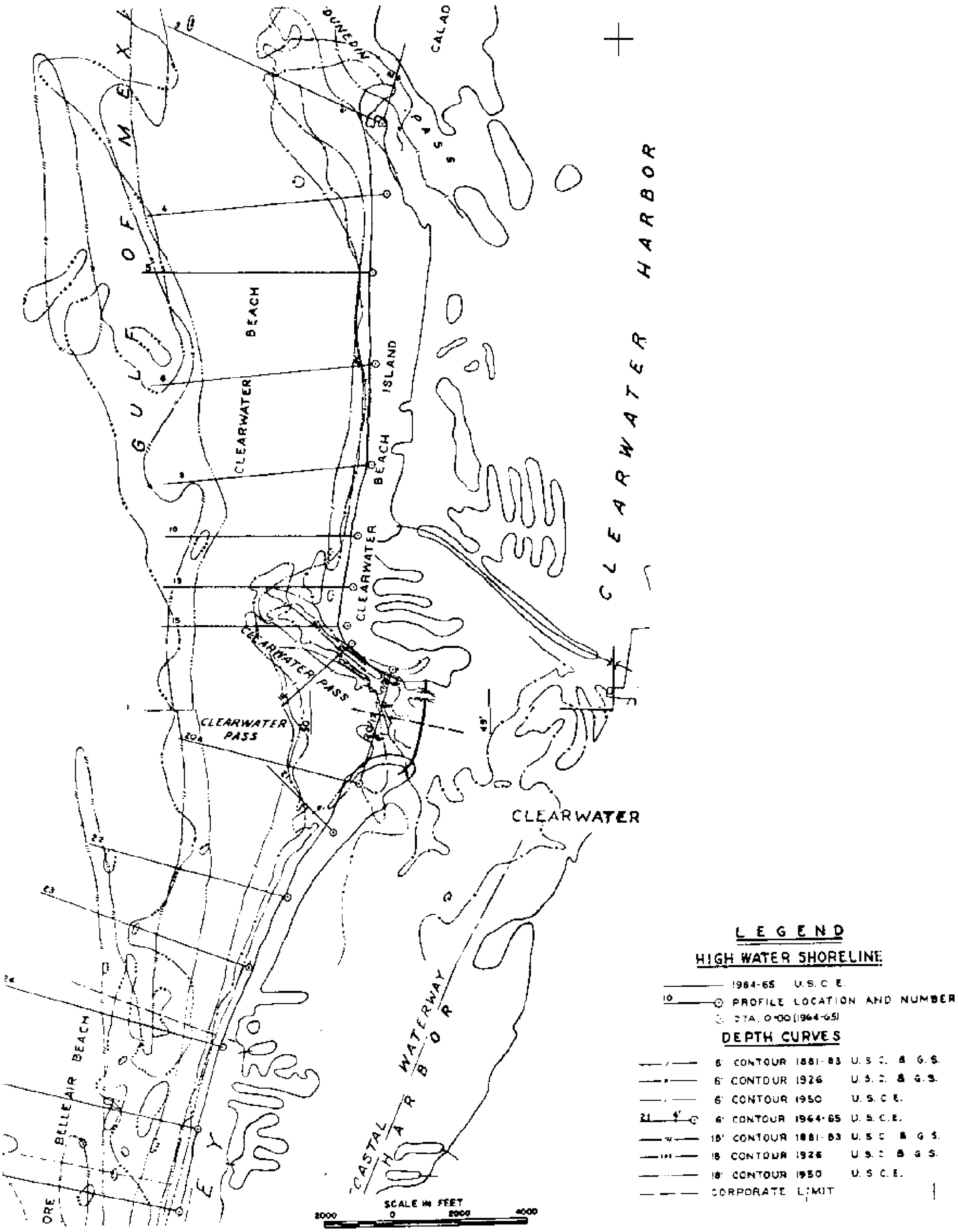

FIGURE 5.9. Comparative Positions of the Six and Eighteen-foot Depth Contours off Clearwater Pass (courtesy: U.S. Army Corps of Engineers, 1966).

VI. HYDRAULICS

6.1 Tides

Tides in the vicinity of Clearwater Pass are a mixture of semi-diurnal and diurnal types, with the semi-diurnal component dominating (COEL, 1973). The weaker diurnal component produces a noted inequality in successive tides; consequently, on an average of 22 days each month, two high and two low waters of varying magnitudes are predicted from the National Ocean Survey's tide station at St. Marks, Florida. During the remainder of the month only one high and one low water occur per lunar day. According to the NOS Tide Tables, the mean range of bay tide near the city of Clearwater is 0.55 meters, and the spring range is 0.79 meters. A two day plot of six recording tide gages placed in the Gulf and harbor area in conjunction with the 1973 model study conducted by the Coastal and Oceanographic Engineering Laboratory, University of Florida, on 26 and 27 September 1972 is shown in figure 6.1. The measurements were made during a spring tide and, as indicated, the phase lag between gulf and bay slack waters was small. Consequently the bay spring range was only slightly less than that for the Gulf. The nearest Gulf tide reported in the Tide Tables is 21 kilometers north of the pass on the southern tip of Anclote Key, and the tide at this location has a mean range of 0.64 m and a spring range of 0.91 m. The measured spring range (26 to 27 September 1972) off Sand Key just South of Clearwater Pass was also 0.91 m.

NOS presently maintains a tide gauge on a pier off Clearwater Beach Island that is approximately 1 kilometer north of the pass. NOS' last evaluated the tidal components for this station in 1975 from a 330 day record. The amplitudes of four important frequency components were: K_1(Luni-solar diurnal) = 0.499, O_1(Principal lunar diurnal) = 0.479, M_2(Principal lunar) = 0.787, and S_2(Principal solar) = 0.301.

The ratio of the amplitudes of the principal diurnal constituents to the principal semi-diurnal constituents, R_1, is defined as:

$$R_1 = \frac{K_1 + O_1}{M_2 + S_2} \qquad (6.1)$$

The computed R_1 value at NOS' Clearwater Beach Station is 0.90, which is within the mixed range as described by Marmer (1951).

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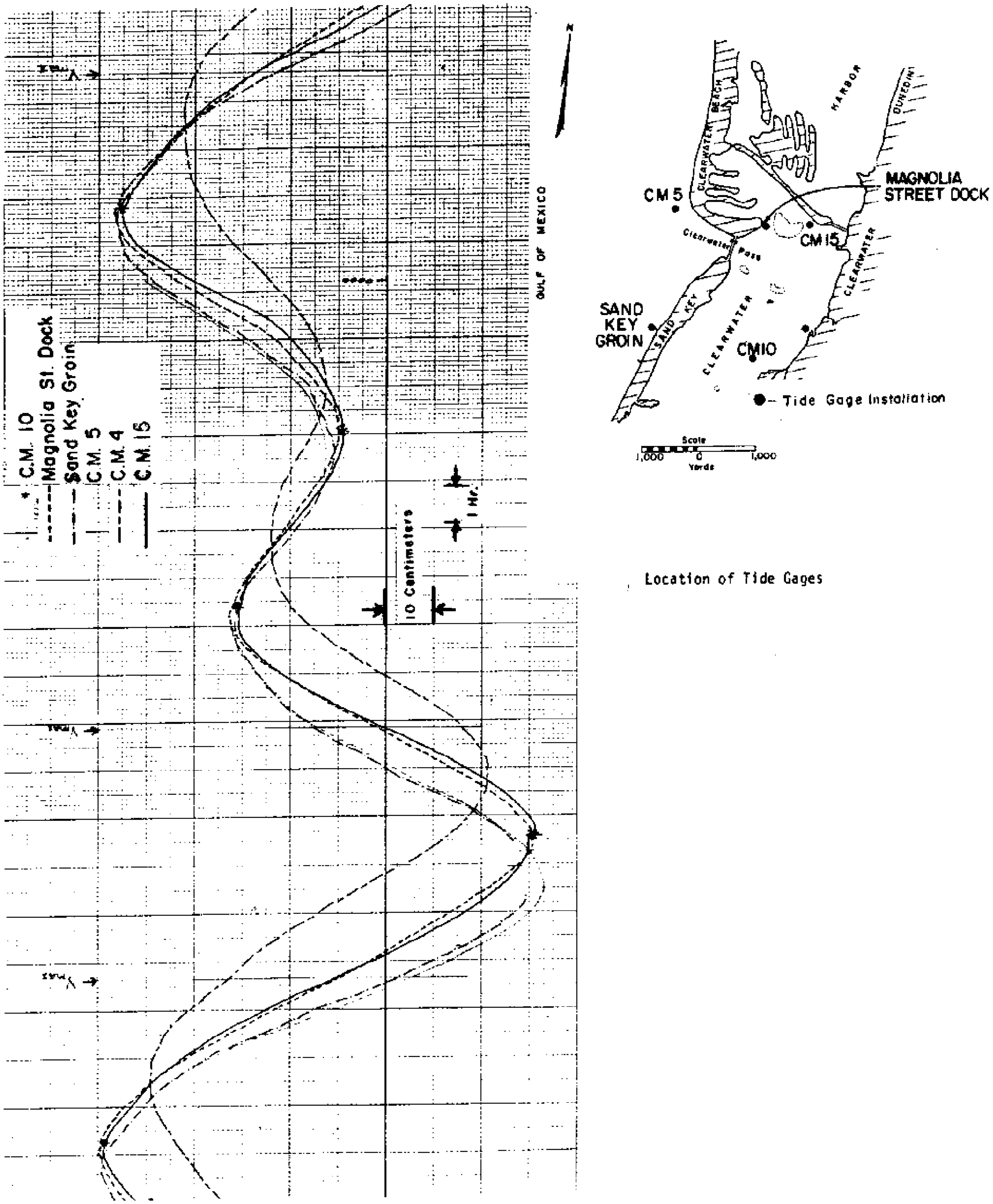
[1] Information obtained during telephone conversation with NOS personnel at Rockville, MD, July 1982.



Location of Tide Gages

FIGURE 6.1. Tides and Corresponding Times of Maximum Inlet Velocity (COEL, 1973).

6.2 Currents

The long shore current inside the breaker zone is usually caused by incident waves breaking obliquely to the shore and may be very strong during periods of intense wave action. Saloman (1974), while measuring surface and bottom currents on calm days during the middle of flood and ebb tides along 1,000 meter transects seaward and normal to Sand Key, recorded velocities generally in the 9 to 15 centimeters per second range, and stronger in the vicinity of the pass. These measurements were taken with a hand held current meter. The stronger currents are caused by the variable head difference between Gulf and bay water surface elevations. During flood tide the flow converges towards and into the inlet while the ebb jet draws water from both coasts towards the inlet. On a low wave energy coast such as the Gulf Coast of Florida the influence of these currents plays a dominant role in sediment transport in the vicinity of inlets (Dean, 1975). The zone of influence over which these currents are significant will vary with variations in the tidal range, winds, waves, and seasonal climatic changes.

Ebb current flow in the bay has its null point midway between Belleair Shores and Indian Rocks Beach, while the flood current flow had its null point near Belleair. In a more recent monitoring study conducted by the Coastal and Oceanographic Engineering Laboratory (1977), it was noted that the bay shoals divide the flow into two major and one minor stream. The two major flows come from the Intracoastal Waterway and the northern branch of the Federal inlet navigation project.

One reason tidal flows favor the north side of the inlet is because of the alinement of the bay channel coming from the Gulf Intracoastal Waterway. The 1973 Coastal and Oceanographic Engineering Laboratory report suggested that a more southerly realinement of this channel and dredging of the bay shoals and inlet would minimize scour around bridge piles at the northern end of the Clearwater Pass bridge.

6.3 Hydraulic Parameters

a. Maximum Current. Measurements at three stations along the throat cross section taken by the University of Florida's Coastal and Oceanographic Engineering Laboratory personnel on the 26th and 27th of September 1972, in conjunction with the Clearwater Pass model study (COEL, 1973) indicated a spring maximum surface velocity of 1.28 m/sec during ebb tide, with a corresponding 1.25 m/sec surface velocity for flood tide. The throat cross section was approximately 45 meters west of the Clearwater Pass Bridge and 30 meters west from the northern most tip of Sand Key. The station recording the maximum velocities had a water depth of about 2 meters. The maximum cross sectional average velocity was 0.91 m/sec for ebb tide and 0.82 m/sec for flood tide. The measured cross sectional area to MSL during the observation period was 1,107 m^2. Although the maximum spring tide was observed to be 0.90 meters, the range had considerable diurnal inequality and the average range over the observation period was closer to 0.79 meters.

b. Tidal Prism. The tidal prism is the volume of water that is drawn into the bay, from the ocean and through the inlet during flood tide. Using a sinusoidal ocean tide and a quadratic head loss due to friction, Keulegan (1967) derived the following approximate expression for the tidal prism:

$$P = \frac{V_{max} \, T \, A_c}{C_k \, \pi} \qquad (6.2)$$

Where:

A_c = the throat cross sectional area
V_{max} = the cross sectionally averaged spring maximum velocity
T = Ocean tidal period
C_k = Coefficient intended to account for the actual flow rates non-linear departures from an assumed sinusoidal function. C_k varies with the repletion coefficient, K, and ranges from 0.81 to 1.

Using an average value for C_k of 0.86 (Keulegan and Hall, 1950) and an A_c of 1,107 square meters, the hydraulically computed tidal prisms is 1.89 x 10^7 m^3.

c. Lag of Slack Water. From the 26 to 27 September spring tidal record for the Sand Key groin and Magnolia Street gauges (COEL, 1973), the approximate phase lag of slack high water between the Gulf and inlet was 26 minutes. (See figure 6.1 for the location of tide gauges). The corresponding phase lag for low waters was 60 minutes. Using Keulegan's (1976) phase lag versus repletion coefficient, K, relationship, an average phase lag of 43 minutes for Clearwater Pass corresponds to a K value of 1.30 (a detailed definition of Keulegan's repletion coefficient is given in Section 6.5c).

d. Tidal Period. The Gulf tidal period near the pass varies from near 12.4 to 24.8 hours depending upon the dominance of the semi-diurnal or diurnal components. On 26 September 1972 the time between high high water (HHW) and low high water (LHW) for ebb flow was 14.0 hours.

e. Bay Range. The bay range was computed by averaging the ranges obtained from 4 bay tide gauges (COEL, 1973). The average bay range during the period of observation was 0.85 meters. Using Keulegan's (1967) relationship between the ratio of bay amplitude to ocean amplitude, a_b/a_o, and the repletion coefficient, a K value of 1.3 corresponds to an a_b/a_o ratio of 0.95. This is in agreement with the measured a_b/a_o of 0.95.

f. Bay Area. Assuming that as the bay rises and falls it maintains a horizontal surface, and that the sides of the embayment are vertical, a measure of the effective bay area may be obtained by dividing the spring tidal prism by the bay tide range. The resulting bay area is 1.82 x $10^7 m^2$. Clearwater Harbor has an approximate area of 1.2 x 10^7 m^2 which indicates that a portion of St. Joseph's Sound north of the Clearwater Causeway is associated with the Clearwater Pass flow regime. This can be checked by comparing the effective bay areas for Hurricane and Dunedin Passes with the bay area between the Clearwater and Honeymoon Island Causeways measured to be approximately of 2.14 x 10^7 m^2. A Corps of Engineers report (1981) lists the effective bay areas for Hurricane and Dunedin Passes as 1.39 x 10^7 m^2 and 0.4 x 10^7 m^2, respectively. The difference in actual and effective bay areas for these two passes is comparable to the area needed to complete the effective bay area for Clearwater Pass.

g. Hydraulic Parameters Summarized. The following is a summary of the hydraulic parameters for Clearwater Pass obtained from field measurements made on 26 and 27 September 1972 (no adjustments made to obtain long-term parameters):

Spring Gulf tide range: 0.90 m
Spring bay tide range = 0.85 m
Spring max. cross sectional avg. velocity (flood) = 0.82 m/sec
Spring max. cross sectional avg. velocity (ebb) = 0.91 m/sec
Spring max. cross sectional avg. velocity (average flood & ebb) = 0.87 m/sec
Spring tidal prism = 1.89 x 10^7 m^3
Effective bay area = 1.82 x 10^7 m^2
Tidal period 14.0 hrs (during observation period)
Inlet throat cross sectional area (below MSL) = 1,107 m^2
Inlet throat surface width = 402 m
Inlet throat hydraulic radius mean depth = 2.75 m
Lag of slack water after HW in gulf = 26 min
Lag of slack water after LW in gulf = 60 min

6.4 Inlet Stability

a. Historic Stability. As discussed in section 5.2, during the period from 1926 to 1980 the inlet underwent a considerable amount of narrowing and reduction in cross sectional area. During this period the construction of the Clearwater causeway, the Honeymoon Causeway, and the Clearwater Pass Bridge (see figure 5.6) restricted the available bay area and associated tidal prism that could move through Clearwater, Dunedin, and Hurricane Passes. Construction within the bay itself, which created emergent finger islands for real estate development, further reduced the effective bay area. By altering one of the hydraulic parameters, man had disturbed the sedimentary equilibrium, and in adjusting to the decreasing tidal prism, Clearwater Pass steadily narrowed. By 1968, although the inlet continued to decrease in width, further decreases were accompanied by corresponding increases in depth. Thus more recently, the throat cross sectional area appears to be oscillating about an equilibrium value. Table 6.1 shows the historic variation of the throat cross section area. Since the limits of the pass are now well-defined (construction of the north and south jetties) and the city of Clearwater plans to maintain an adequate cross section in the inlet to reduce velocities around the bridge piers, we should expect only minor variations in all the hydraulic parameters, unless man again makes significant modifications to the flow regime.

TABLE 6.1

Inlet Throat Cross Sections at Clearwater Pass, Florida

Date	Area of Inlet Below MSL (m^2)
1926[1]	2,960
1950[1]	2,340
September 1962[2]	1,540
August 1968[2]	1,390
August 1969[2]	1,480
November 1969[2]	1,730
October 1972[3]	1,110
February 1977[4]	1,230

[1] Dean and Walton (1975)
[2] COEL (1970)
[3] COEL (1973) unpublished data
[4] COEL (1977)

b. Empirical Relationship. For stable inlets that are in non-silting, non-scouring sedimentary equilibrium, O'Brien (1969) developed an empirical relationship between the spring tidal prism, P, and the throat cross sectional area, Ac, which may be expressed as:

$$A_c = a_1 P^{m1} \tag{6.3}$$

where a_1 and m_1 are empirical coefficients. Jarrett (1976) using data from numerous North American inlets obtained values of a_1 and m_1 of 3.4×10^{-4} and 0.86, respectively, for Gulf Coast inlets with no jetty or one jetty. Using an A_c of 1.107 m^2, the calculated tidal prism for Clearwater Pass is $1.61 \times 10^7 m^3$. This is only 15 percent less than the measured tidal prism of $1.89 \times 10^7 m^3$, which falls well within the limits of Jarrett's observed data points. This indicates that the inlet should be in or very near sedimentary equilibrium.

c. Stability Diagram. The stability of an inlet can be evaluated in terms of the relationship between Keulegan's repletion coefficient, K, and a dimensionless velocity, ν (Escoffier, 1977). K and ν are defined as follows:

$$K = \frac{Tg^{1/2}}{(2a_o)^{1/2}} \quad \frac{Ac}{\pi \quad Ab} \quad \frac{1}{\left(K_{en} + K_{ex} + \frac{fL_cW_c}{4A_c}\right)^{1/2}} \qquad (6.4)$$

$$\nu = \frac{V_{max}}{(2a_og)^{1/2}} \qquad (6.5)$$

where
T = tidal period
$2a_o$ = ocean tide range
Ac = inlet throat cross sectional area
Ab = bay surface area
f = Darcy-Weisbach friction factor
W_c = surface width at the throat
L_c = Length of an equivalent inlet with a constant cross section equal to the throat section of the real inlet and a head loss due to friction as measured for the real inlet (O'Brien and Clark, 1973, 1974).
K_{en} & K_{ex} = entrance and exit loss coefficients for the inlet
Vmax = maximum cross section averaged velocity through the inlet
g = acceleration due to gravity

This method for obtaining the stability curve for a given inlet is described by Escoffier (1977). The method used herein requires the use of the following additional relationships:

$$W_c = (0.8591 \ Ac)^{0.84} \qquad (6.6)$$

where Wc and Ac are in meters and square meters, respectively. This applies for inlets without jetties with a Wc > 150 meters (after Graham and Mehta, 1980).

$$Vmax = \frac{2a_o \ (\pi) \ Ab}{T \quad Ac} V'max$$

(6.7)

The procedure for obtaining the stability curve is outlined below:

a) Determine K, the repletion coefficient for the inlet from the measured phase lag, ϵ, using Keulegan's plotted K versus ϵ curve (Keulegan, 1967);

b) Using equation 6.4 and the hydraulic parameters developed in the previous section, 6.4b, calculate an equivalent L_c;

c) Calculate values of K for a wide range of A_c values, using equation 6.6 to determine a W_c for each A_c, and equation 6.4 to obtain K;

d) Obtain V'_{max} from Keulegan's (1967) V'_{max} versus K relationship;

e) using equations 6.7 and 6.5 calculate the corresponding value of for each A_c; and

f) Plot ν versus K.

Here it should be mentioned that an entirely satisfactory technique for determining inlet stability is not yet available. Keulegan's (1957) derivations require a sinusoidal ocean tide and bay depths significantly greater than the bay tidal range. At Clearwater Pass, with its mixed tide and shallow bay area, these assumptions do not hold. However, although not strictly applicable, the stability diagram technique is a simple and available tool which can be used to provide useful engineering insight, especially when supported by results obtained from alternate empirical methods. To obtain the closest approximation to Kuelegan's sinusoidal forcing function, the tidal prism was calculated from measurements made during the ebb cycle from high high water (HHW) to low low water (LLW), see figure 6.1, and the period was measured from high high water (HHW) to low high water (LHW).

The stability curve thus obtained for Clearwater Pass using values of A_c between 90 and 1500 square meters is displayed in figure 6.2.

Escoffier (1940) and O'Brien and Dean (1972) have shown that when the actual K value for an inlet $K_{act} > K_{\nu max}$, the inlet is hydraulically stable. Here $K_{\nu max} = 0.45$ is the value of K associated with the peak value of ν. For $K_{act} < K_{\nu max}$ the inlet is unstable. We have already determined that the repletion coefficient for Clearwater Pass is approximately 1.30. This value is clearly much larger than $K_{\nu max}$, thus indicating that the pass is stable.

From 1968 to 1977 the throat cross section appears to have been oscillating about some equilibrium value (see Table 6.1), while the width decreased from 700 to 420 meters (see Table 5.2). During this period, the bay area and effective inlet length, L_c, remained nearly constant. Assuming the relationship between A_c and W_c expressed in equation (6.6) holds, and using equation (6.4) to evaluate the repletion coefficient, the wider inlet of 1968 would have had a K value of less than 1.3. Thus, it appears that the recent narrowing trend has been associated with an increase in inlet stability.

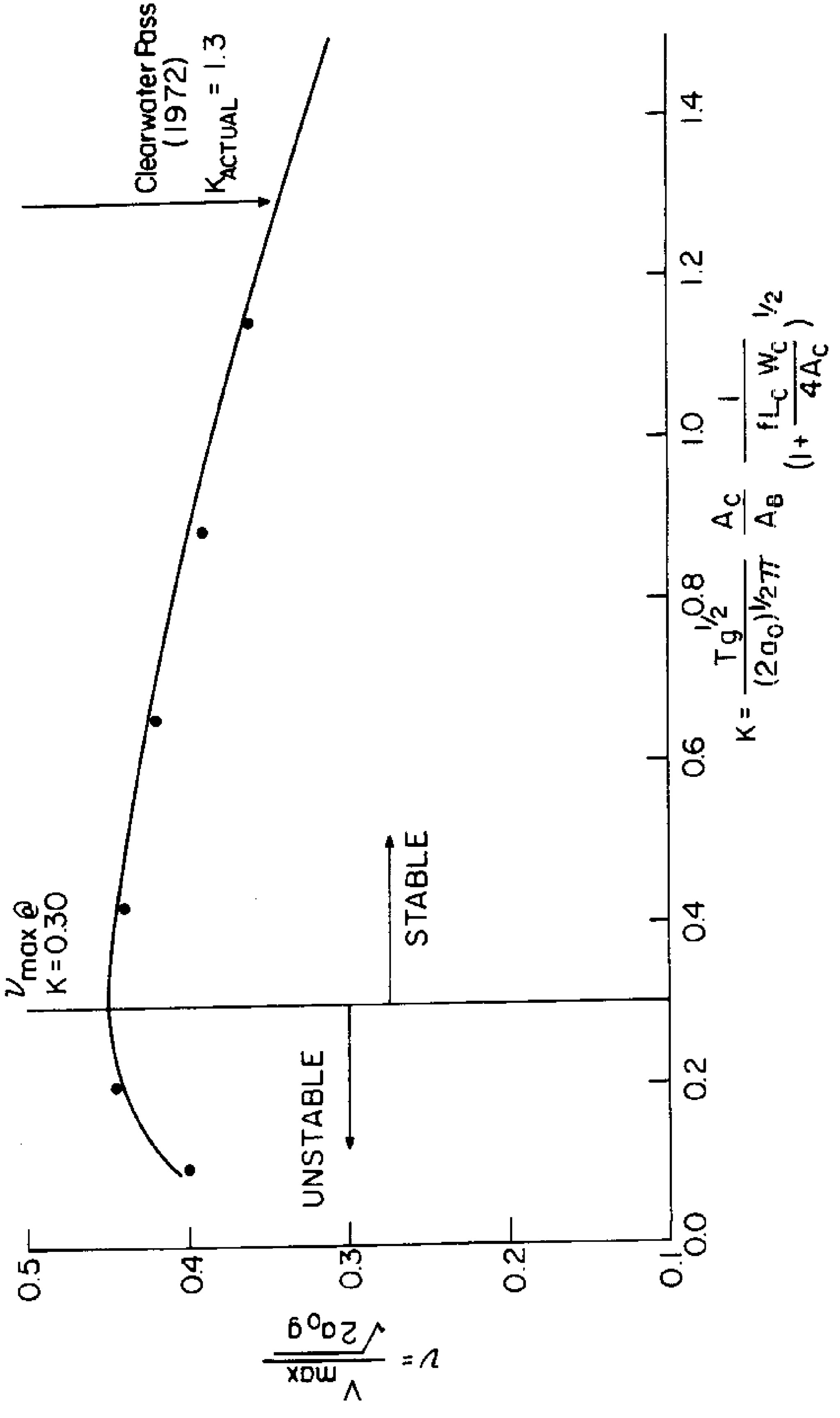


FIGURE 6.2. Stability Curve for Clearwater Pass.

VII. SEDIMENTARY PROCESSES

7.1 Historic.

During interglacial stages of the Pleistocene epoch (associated with higher sea level elevations), the present southern mainland area of Pinellas County existed as an island in the mouth of a very large embayment in the coast, which has been reshaped in geologically recent times into what is now Tampa Bay. It is believed that the small Pinellas Island was gradually joined to the mainland to the north by longshore sedimentary processes. The present offshore barrier islands are believed to have been formed with the rock headland at Indian Rock as their nucleus during the Pleistocene-recent interval (Riggs, 1974).

7.2 Sea Level Rise.

The results of changes in sea level are important in the long run and should not be overlooked in any investigation of coastal process. This is especially true in Florida because of its low topographic relief, where small changes in sea level result in large increases in submergent or emergent land area. Bruun (1962) conducted investigations into sea level rise and made the following conclusions: (1) the earth is presently in an interglacial stage (a warming trend causing general rise in sea level), but heading toward another glacial stage, perhaps 10,000 to 15,000 years hence; (2) though marked by minor alternating colder and warmer cycles, the present short-term general trend of increasing warmth should continue for at least two to three hundred years; (3) sea level has been relatively stable during the past 5,000 years, but minor fluctuations of up to 3 to 7 meters have occurred; and (4) since the period from 1,500 to 4,000 years ago, sea level has risen approximately 2 meters or an average of 1.2 mm per year. Hicks (1981) indicates an average annual rise along the Gulf Coast of Florida of approximately 1.5 mm since 1940. Using the "equilibrium beach concept" (Bruun 1962) and assuming that the offshore bottom, for any rise in sea level, will undergo a gradual adjustment process tending to keep the equilibrium form, Bruun estimates that a rise of 0.3 m may cause shoreline recessions of more than 35 meters.

7.3 Distribution

The marine bottom off the coast of Sand Key and Clearwater Beach Island has two active areas, one along the beach, the other over the offshore bars. These areas are separated by a broad, nearly flat, surface of stable muddy sediments (Winston, et.al, 1968). Normal waves produce an abrupt transition from the muddy sands to a clean, winnowed sand, and shell at the toe of the beach. They produce ripples in the beach sands and develop a distinct breaker bar off the gently sloping beaches. Other current-wave agitation apparently occurs on the offshore bars at the westward edge of the muddy sand bottom. Sand surfaces on the higher of these bars are commonly ripple-marked and debris oscillates from ripple crest to crest even on relatively calm days (Winston, et. al, 1968.) The offshore bars and interspersed rock surfaces probably owe their origins to storm waves. The bars are alined parallel to one another and oblique to the barrier shore, and may reflect the action of storm waves from the west and southwest. Some of the lower bars are coated with algae and obviously not actively building under normal processes (Winston, et. al, 1968).

7.4 Sediment Characteristics

The dark to medium grey, muddy sand grades into light grey, clearer sand in a shoreward direction, and then into clean, well-sorted quartz sand and sandy shell characteristic of the inlet and adjacent beaches (Winston et. al, 1968). Beach sand is typically fine-grained quartz with less than 10 percent shell. Sediment samples were collected by the Coastal and Oceanographic Engineering Laboratory of the University of Florida in 1969. It was found that the sand on the beaches, and up to a depth of 3 meters (MSL), had a grain size ranging from 0.1 mm to 0.7 mm, with a median grain size, D_{50}, of about 0.22 mm. The D_{50} grain size for some representative locations are displayed in figure 7.1.

Winston et. al (1968) in preparing their geologic evaluation of the area noted that the highest concentration of nonsoluable heavy minerals in the Clearwater Beach Island area occured in the offshore bar sands, which averaged 0.6 percent, and decreased to an average of 0.4 percent and 0.3 percent in the beach and pass sands and sediment veneers, respectively. The muddy sands contained 0.4 percent nonsoluable heavy minerals. In contrast, north Sand Key was found to have a high percentage, 1.4, of total heavy minerals; however, an average of 73 percent of this was phosphorite. Consequently, the average of nonsoluable heavy minerals was again 0.4 percent. The high phosphorite was due to the frequent occurrence of exposed surfaces of phosphatic Miocene limestone over the sea floor in this area.

7.5 Volumetric Changes

a. Outer Coastline. The U.S. Army Corps of Engineers computed volumetric changes from 1950 to 1964-65 are shown in table 7.1 (U.S. Army Corps of Engineers, 1966). The average annual net change, generally from the nearshore zone at Clearwater Beach Island (profiles taken out to wading depth), was 20,000 cubic meters of accretion. The average annual net change from the nearshore zone along the northern half of Sand Key was 27,500 cubic meters of erosion. Although erosion was indicated at the northern tip of Sand Key, a study of aerial photography shows that this area was steadily accreting but the alignment of this portion of the island was also shifting eastward. Eliminating profiles 21 through 23 associated with this island realignment yields an annual erosion rate of 8,400 cubic meters.

These quantities are affected by artificial fill introduced into the littoral system and by numerous beach protection structures built into the nearshore zone. Artificial fill placed by local interests between the survey dates included 115,000 cubic meters at Clearwater Beach in 1950, and a continuous undeterminable amount of rubble fill. Converting 115,000 m^3 to

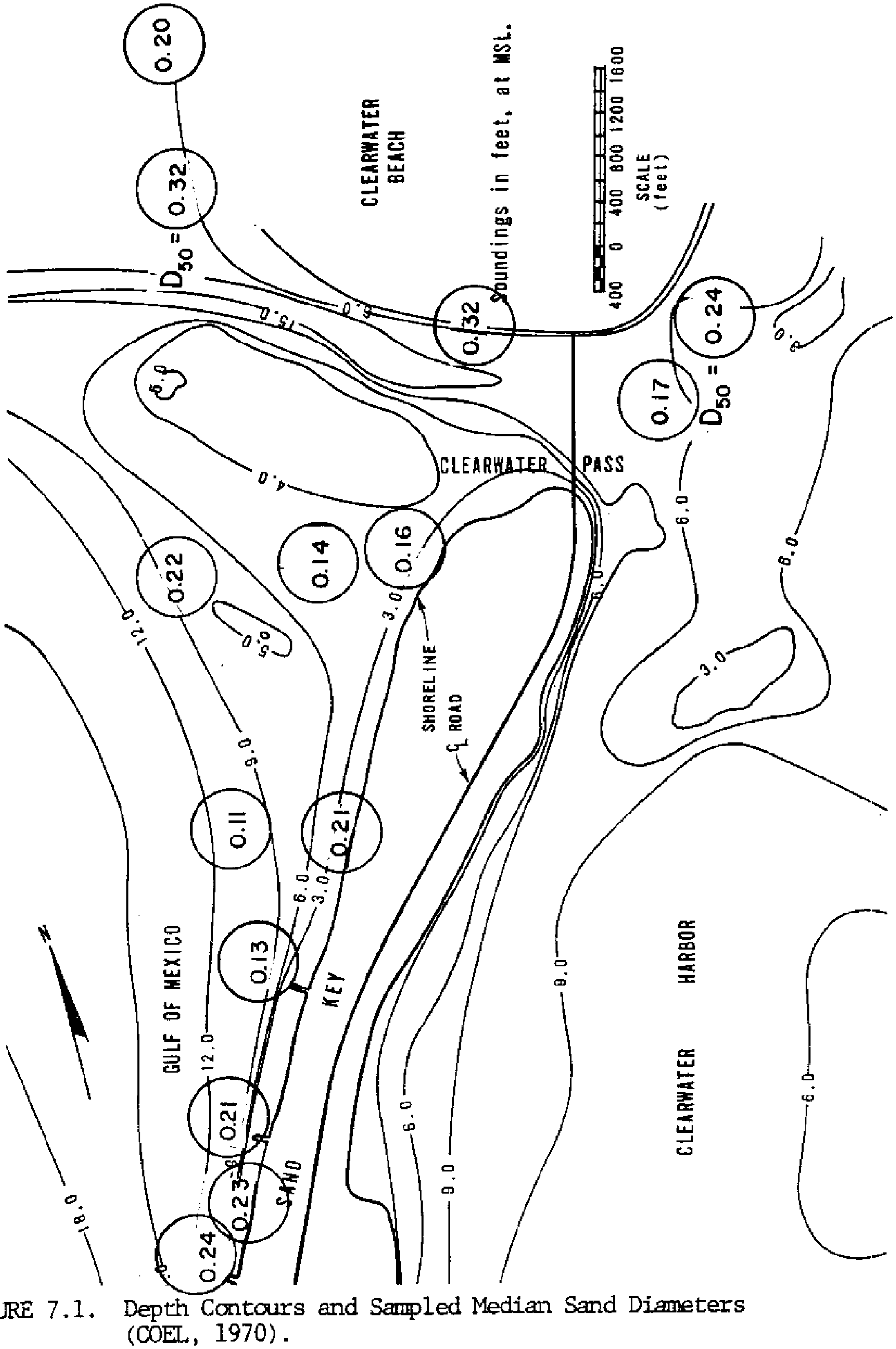


FIGURE 7.1. Depth Contours and Sampled Median Sand Diameters (COEL, 1970).

an average annual artificial nourishment (accretion) rate over the 15-year period of record yields 8,000 cubic meters per year. When this is subtracted from the average computed accretion rate for Clearwater Beach Island, an accretion rate of 12,000 cubic meters per year is obtained.

TABLE 7.1

Volumetric Accretion and Erosion
1950 to 1964-65 (1,000 cubic meters)
(From USACE Pinellas County Report, 1966)

Profile		Total Net Change		Average Annual Change		Net Annual Change
		Accretion	Erosion	Accretion	Erosion	
			Clearwater Beach Island			
(3)	2		27		2	-2
(3)	3		229		16	-16
	4	271		19		+19
	5	77		5		+5
(3)	6		32		2	-2
	8	85		6		+6
	10	89		6		+6
	13	67		5		+5
(3)	15		31		2	-2
	16	26		2		+2
	TOTAL	615	319	43	22	+21
			North End of Sand Key			
(3)	21	23		2		+2
	22		89		6	-6
	23		97		7	-7
	24		32		2	-2
	25		34		2	-2
	26		15		1	-1
	27		84		6	-6
	28		21		2	-2
	29	5			0	0
	30		11		1	-1
	31		5		0	0
	32		28		2	-2
	33	27			0	+2
(3)	34		4		1	0
	35		8		2	+1
	36		24	2		-1
	TOTAL	55	452	4	32	-25

---

(1) Represents nearshore losses, unless otherwise marked.
(2) Minus sign indicates erosion; plus sign indicates accretion.
(3) Long profiles; those not noted as (3) were taken to wading depth only.
(4) Profile numbers correspond to profile lines indicated in figure 5.8.

b. Inlet. In addition to the erosion and accretion on adjacent beaches, shoaling in the navigation channel makes a significant contribution to the littoral budget. From the Army Corps of Engineers' dredging records, the navigation channels accreted an average of 21,000 cubic meters of sand annually between 1960 and 1977. Up until 1969 this material, most of which had fallen into the bar channel, was placed in submerged disposal sites south and adjacent to the bar channel and flanking the bay channel (see Figure 4.1). Since then all maintenance material has been placed at the northern end of Sand Key. Much of the sand deposited adjacent to the bar channel is probably returned to the channel through the bar bypassing mechanism. In 1977, the University of Florida's Coastal and Oceanographic Engineering Laboratory in a monitoring study, indicated that sand was bypassing the Clearwater Inlet through shoals in the inlet mouth. A rapid rate of travel was measured and indicated that this shoal region was very active. Since the construction of the south jetty, part of the northerly drift, presumably between Indian Rocks Beach and the northern tip of Sand Key, is retained behind this jetty to form new beach area.

There is an interesting area of controversy over the type of bypassing that dominates the Clearwater Pass system. According to the model study report (COEL, 1973), the bypassing mechanism of the inlet was tidal-flow dominant. However, a sand tracer study performed in conjunction with a more recent monitoring study (COEL, 1977) provided strong evidence that bar bypassing dominated, at least during the period of observation. Because winter months are typically associated with a higher energy wave climate, summer months being calmer, it is most probable that tidal bypassing is more significant during summer months. In the winter the tidal prism is probably less effective in maintaining a strong bar channel, and bar bypassing may dominate.

c. Bar Volume. Dean and Walton (1975) have presented a technique for estimating the volume of sand contained in the inlet by comparing idealized contour lines (that would run approximately parallel to the shoreline, if no inlet were present) with actual surveyed contours. A seaward migration of depth contours with time would thus correspond to an increase in bar volume. Applying this technique to the near shore bathymetric contours obtained from the 1972 model study data yields a bar volume of 1.5×10^6 cubic meters. This value, as well as the bar volumes calculated by Dean and Walton (1975) for 1926 and 1950 surveys data are given in table 7.2.

TABLE 7.2

Computed Bar Volumes 1926 to 1972

Survey Data Year	Bar Volume (m^3)	A_c (Throat cross sectional area in m^2)
1926	2.38×10^6	2,960
1950[1]	3.71×10^6	2,340
1950[2]	2.29×10^6	2,070
1972	1.5×10^6	1,110

---

[1] Dean and Walton (1975)

[2] Walton and Adams (1976)

Since the inlet's cross sectional area has gradually diminished from 1926 to 1972, it could be assumed that the tidal fores acting to increase bar volumes should also diminish. Thus from 1926, wave energy associated with storms would effect a net migration of material from the original bar towards shore and into the longshore littoral system. However, the 1926 and 1950(Walton and Adams, 1976)bar volume estimates are nearly equal and errors associated with the extent of coastline over which volumes were computed may explain the deviations in Dean and Walton's (1975) 1950 and the 1972 bar volume estimates. In which case, all four values could have been computed for the same "actual" bar volume (i.e., a bar that has experienced no change with time). Without a more detailed investigation into the data used and calculations performed to obtain these estimates, a long range trend in bar volume development cannot be identified.

d. Inner Shoals. For a non-migrating inlet, inner shoals could develop to a stage where they would be in equilibrium. As the inner shoals grow, an upward bottom slope develops from the inlet toward the bay and in the equilibrium stage, the downward seaward gradient produces a force which opposes those acting to cause additional material to be deposited within the bay (Dean and Walton, 1975). Historic dredging records (section 4.3), indicate that until 1970 material from initial construction and subsequent maintenance of the Clearwater Pass navigation project was placed in disposal areas within the bay and inlet. In addition, a decreasing inlet cross section has reduced the volume required for equilibrium inner shoals. Although available bathymetric data of the bay are not of sufficient detail to permit evaluation of historic trends in inner shoal volume, a near equilibrium condition has probably been reached. Additional modification of the inlet or bay would reactivate this area as either a source or sink in the sedimentary budget.

7.6 Littoral Material Balance

In analyzing the sedimentary budget for Clearwater Pass, a control volume is selected as indicated in figure 7.2. The north and south boundaries extend normal to the shoreline and are chosen so that inlet transporting effects can be neglected. The southern boundary is 8 kilometers from the inlet, while the northern boundary is selected midway between Dunedin and Clearwater Passes, a distance of 2.7 kilometers. The location of the offshore boundary is discussed in the next subsection. Using Q to represent a rate of sediment transport, the material balance for the drift rates indicated in figure 7.2 may be expressed as follows:

$$\frac{\Delta \forall}{\Delta t} = Q_1 + Q_3 + Q_5 + Q_7 - (Q_2 + Q_4 + Q_6 + Q_8) \qquad (7.1)$$

Where $\Delta \forall$ is the change of sediment volume within the control volume over a period Δt . It is assumed that over a significantly long period (20 to 30 years) the total volume of sediment within the control volume does not change appreciably, i.e. $\Delta \forall = 0$. To obtain the sediment budget Q_1 through Q_8 must be evaluated.

a. Onshore-Offshore Transport Rates, Q_5 and Q_6. Although onshore-offshore transport rates will decrease with distance from shore, it is difficult to obtain quantitative estimates. For this reason the seaward boundary of the control volume is located far enough from shore, so that these transport rates are negligable, i.e., $Q_5 = 0$ and $Q_6 = 0$. From the Shore Protection Manual (U.S. Army Corps of Engineers, 1977) this depth approximately corresponds to the deepest shore-parallel contour, generally between 4.5 and 18 meters. In the vicinity of Clearwater Pass, the deepest shore-parallel contour occurs in about 5.5 to 6 meters of water about 2 kilometers offshore. Geologically speaking, over millions of years wave action will result in a gradually receding coastline, the eroded sediments moving further and further seaward along the shoreface terrace.

b. Longshore Transport Rates, Q_1, Q_2, Q_3, and Q_4. The stretch of beach to the south of the pass is relatively straight and a line drawn perpendicular to the coastline has a bearing, θ_n , of 284 degrees relative to north (see figure 7.2). The boundary normal to the shoreline north of the pass has a bearing of 276 degrees. Using Walton's (1976) littoral drift roses, Q_1 through Q_4 were calculated. The results are summarized in Table 7.3.

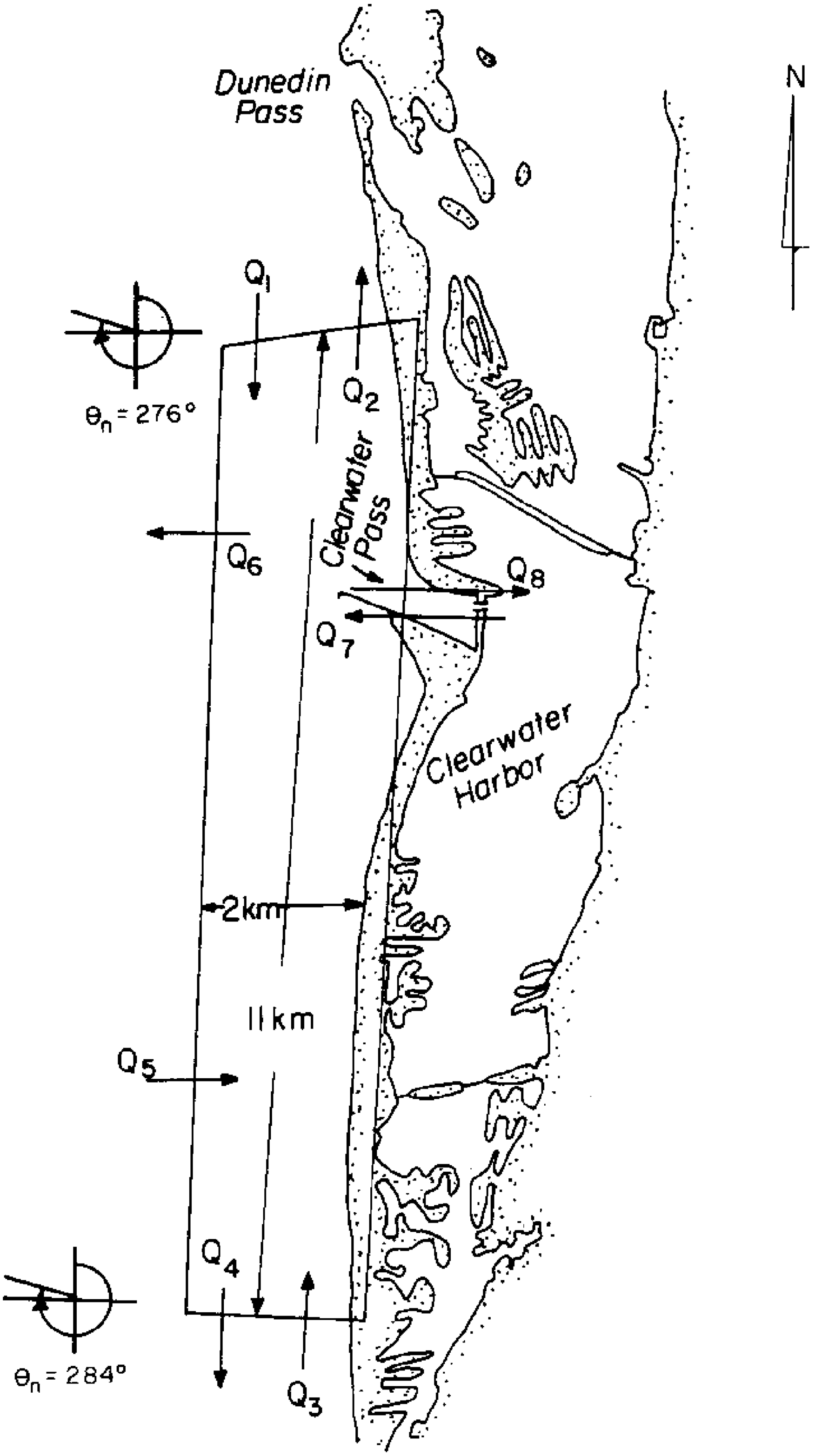


FIGURE 7.2. Control Volume for Evaluation of Sediment Balance.

Table 7.3

Estimates of Longshore Transport Rates Using Littoral Drift Roses

	Item	Annual Transport Rate (m^3/yr)
	North Boundary, θn = 276°	
Q_1 =	Southward into control volume	112,000
Q_2 =	Northward out of control volume	39,000
	South Boundary, θn = 284°	
Q_1 =	Northward into control volume	39,000
Q_2 =	Southward out of control volume	117,000
	Average Northward Drift Rate	39,000
	Average Southward Drift Rate	115,000
	Net Drift Rate North to South	76,000
	Gross Drift Rate	154,000

These results are not consistent with the physiographic pattern in the area, since gradual accretion at the north end of Sand Key is indicative of a net northward drift rate. Bruun (1957) estimated the net littoral drift rate in the vicinity of Clearwater Pass to be between 38,000 and 76,000 m3/yr from south to north. Alternate calculations contained in the Clearwater Pass model study report (COEL, 1973) that were based on deepwater wave data off Tampa Bay also indicate a net northward drift rate resulting from the dominance of swell from the southwest.

Walton's littoral drift roses are derived using wave data contained in a Summary of Synoptic Meteorological Observations (SSMO) U.S. Naval Weather Service Command, 1969). Harris (1973) has demonstrated that visual recording techniques, used to obtain the data for the 1969 edition of SSMO, bias the reporting of wave direction, and that there is no correlation between measured and observed wave period. This, combined with the presence of oblique offshore bars in the Clearwater area, which are not included in Walton's refraction calculations, may be responsible for the apparent discrepancy in the direction of net littoral drift.

Because Clearwater Pass is in a normally low wave energy area, a significant portion of the volume of sediment transported in any given year is moved by larger waves that accompany storm events, in which case the offshore bar configuration may be a critical factor in establishing the net longshore littoral transport rate. Due to their peculiar oblique alinement (running NW-SE) these shoals would tend to refract large waves approaching from the northwest counter-clockwise, thus ultimately approaching the coast from a more southerly direction. Waves from the southwest are already alined normal to these shoals and would experience less refraction. Thus, in addition to dissipating wave energy through breaking and bottom friction (the latter may be far less important), the offshore bar system may be responsible for the apparent northward net longshore transport rate, when the offshore wave climate may indicate otherwise.

c. Inlet and Inner Shoals, Q_7 and Q_8. Clearwater Pass is a Federal navigation project and it is assumed that the sediment deposited in the outer bar and inner bay channels will be regularly dredged and deposited on adjacent beaches. From the discussion in section 7.4d, near sedimentary equilibrium is assumed. Q_7 and Q_8 are, therefore, effectively zero.

At this point it is apparent that, although the basic procedures for evaluating sedimentary balance is fairly straight forward, available data are not adequate to quantitatively evaluate the budget in the vicinity of Clearwater Pass. However, it is apparent that if the bay shoals and bar system are in equilibrium and the net transport into the control volume equals the net transport out, any erosion along one reach should be compensated for somewhere within the control volume by an equal amount of accretion. Referring to table 7.1, the total volume of sediment accreted north of the pass between 1950 and 1965 was nearly equal to the volume eroded south of the pass, thus supporting this hypothesis.

VIII. WATER QUALITY

8.1 General

Hydrographic, physical, chemical, and biological data from the nearshore environment were collected by Saloman (1974) for the National Marine Fisheries Service prior to the initiation of a Corps of Engineers' beach restoration project for Sand Key. These data are contained in a two volume set entitled "Hydrographic Observations in the Gulf of Mexico off Pinellas County, Florida (Nov. 1970 to Jan. 1972)" by C. H. Saloman. Monthly samples were collected at a total of 33 stations located 15, 305, and 610 meters from shore along ten shore normal transects. During the observation period, water quality values in the nearshore environment were fairly stable and exhibited relatively minor changes between surface and bottom, distances from shore, distances along shore, and seasons. The influence of Clearwater Pass is evident as a nutrient source to the adjacent coastal areas. Information for the subsequent paragraphs pertains to the data obtained by Saloman between November, 1970 and January, 1972.

8.2 Water Temperatures

The average surface temperature ranged from a low of 13.6° C in February to a high of 29.9° C in July. Temperatures from December through April were generally below 20° C. The overall average temperature at the surface was the same as at the bottom. The mean values for any month never differed by more than a tenth of a degree, thus indicating a uniform, homogeneous water column.

8.3 Salinity

The average salinity for the period of record was 33.7 parts per thousand, with a range from 30.3 to 36.4. Periods of lower salinity occurred from February through April and August through November. As expected of a well-mixed water column, there were only minor salinity variations between the bottom and surface (Saloman, 1974).

8.4 Total Phosphorus

The average value of total phosphorus off Sand Key was measured to be 4.12 micrograms/liter. However, the range of individual values was from 0.75 to 16.75 micrograms/liter. The greatest fluctuation from the mean occurred during the summer months and the least during March and April. Bottom waters tended to have slightly higher values than surface, but the difference was never over 1 microgram/liter. Total phosphorus values were generally higher close to shore and decreased gradually at sampling locations farther offshore. Values in Clearwater Pass and adjacent stations were higher, supporting the belief that nutrient-rich waters enter the gulf from the harbor.

8.5 Total Kjeldahl Nitrogen

The average value of total kjeldahl nitrogen off Sand Key was 25.6 micrograms/liter, with a range from 4.2 to 165.9 micrograms/liter. Highest monthly averages occurred during the winter months. There was only a 1.7 micrograms/liter difference between the surface and bottom values, and again concentration in the pass and adjacent transects was higher.

8.6 Dissolved Oxygen

The average value of dissolved oxygen (DO) was measured to be 4.33 ml/liter, with a range from 0.57 to 6.12. As expected DO levels at the surface were higher than at the bottom and higher in the summer than during the colder winter months. Critically low values of oxygen (below 2.00 ml/liter) occurred in only 0.7 percent of the observations.

8.7 pH

The average pH in the offshore area was 8.06, with a range from 6.81 to 8.36. Monthly averages varied only slightly, and only during 3 months did average pH levels drop below 7.0. Values in the pass were approximately the same as those for adjacent offshore areas.

8.8 Turbidity

The average turbidity in the area was measured to be 7.5 JTU with a range from 1.0 to 55.0 JTU. Monthly averages ranged from 4.3 to 17.9, with highest turbidities during winter months when heavier seas resuspend fine bottom sediments. Surface turbidities were generally 1.6 JTU lower than at the bottom, and both values gradually decreased with distance from the shore.

IX. SUMMARY

The purpose of this report has been to assemble available information of coastal engineering significance that pertains to Clearwater Pass and adjacent areas. It should be noted that the inlet system is dynamic and the sedimentary and hydraulic characteristics described herein are continuously adjusting to both short-term and long-term natural and man-induced changes. Some of the more important or interesting findings are summarized below:

1. Clearwater Pass, 40 kilometers north of the entrance to Tampa Harbor, is a natural inlet separating two of the barrier islands which extend 72 kilometers along the Gulf coast of Pinellas County. Other local inlets in the barrier chain are Dunedin and Hurricane Passes 5.6 and 12.1 kilometers north of Clearwater Pass, repectively.

2. Historically it is believed to be one of the oldest inlets in the area, having been in existence as early as the days of the original Spanish exploration of the region.

3. The bedrock underlying the study area is the Tampa limestone formation of Early Miocene Age (35 million years old). This rock is overlain by deposits of prerecent (older than 10,000 years) muddy sands and recent offshore bar sands whose thicknesses are variable and range from nearly no cover 2 kilometers offshore to 5.5 meters at the shoreline.

4. The Clearwater Pass area experiences mild winters, with average highs of 16.7°C, and long relatively humid summers, with average highs of 22.2°C. The mean annual rainfall is approximately 122 centimeters, the majority of which occurs during the summer months.

5. Prevailing winds are from the north and northeast during the winter months, while easterly and southerly winds predominate during the remainder of the year. Waves affecting the area's coastline are rarely in excess of 2 meters and generally average less than 1 meter. The largest percent of onshore swell is from the southwest.

6. Using storm data recorded from 1900 to the present, the probability of at least one hurricane passing within an 80 kilometer radius of Clearwater in any given year is 12 percent. The probability of at least one hurricane passing within the same radius in 5 years is 63 percent. Hurricane Gladys, in 1968, was the last hurricane to cause extensive damage and major coastal changes in the area.

7. The barrier islands on either side of the pass lie within the Federal Insurance Administration's designated 100-year coastal flood plain. During the 100-year flood, these islands would be inundated and subjected to wave action.

8. Clearwater Beach Island was originally purchased from the Federal government in 1893 for $200.00. Accelerated real estate development began in 1924, when the island was christened "Mandalay -- the isle of a thousand palms."

9. The Garden Memorial Causeway was completed in 1927 and marked the first of man's major alterations to the bay and coastal hydraulic regime. The pass thus began its long history of constriction, with Sand Key migrating northward in response to the reduction in bay area and corresponding decrease in tidal prism.

10. In 1975 and 1981, the City of Clearwater constructed a 1,200 meter-long south jetty and a 244 meter-long north jetty, respectively, to improve navigational safety and help decrease scour around several of the Clearwater Pass bridge piles.

11. In 1981 the city also purchased a 30 cm hydraulic dredge and began excavating material from the inlet shoals to reduce tidal velocities. The dredged material has been used to nourish the eroded coastline south of the pass, to fill scour holes, and to build additional width on the city's public beaches north and south of the pass.

12. In addition to the northward extension of Sand Key, there has been a general trend of erosion south of the inlet. Erosion and accretion have occurred north of the pass during the periods from 1873 to 1950 and 1950 to 1965, respectively. Both north and south of the pass the 4 and 5 meter contours have experienced a significant net movement towards the coast.

13. Measurements indicate that the inlet's throat section has decreased from 2,900 m^2 in 1926 to 1,210 m^2 in 1977, while the throat width decreased from 1,390 meters to 420 meters.

14. Inlet parameters derived from hydraulic measurements taken in September, 1972, are as follows:

Spring ocean tide range = 0.90 m
Spring bay tide range = 0.85 m
Average spring maximum cross sectional velocity
= 0.87 m/sec
Average spring tidal prism = 1.89×10^7 m^3
Calculated effective bay area = 1.82×10^7 m^2
Average lag of slack water = 42 min

15. Stability calculations support evidence that the pass is stable. There is also evidence that the narrowing trend from 1968 to 1977 was associated with an increase in inlet stability.

16. The outer bar volume is estimated to be approximately 2 million cubic meters. Historic data are not adequate to determine whether this volume has been increasing, decreasing, or has remained nearly constant.

17. Estimates of the net littoral drift rate for the area are inconsistent and range from 76,000 m^3/yr southward to between 38,000 and 76,000 m^3/yr northward. Historic wave data are insufficient to verify any of the estimates. However, observed physiographic changes support a net northward littoral transport rate.

18. Sampling and testing procedures conducted in January, 1972, indicate that water quality values in the nearshore environment were fairly stable and exhibited relatively minor changes between surface and bottom, distance from shore, distance along shore, and from one season to the next. The pass acts as the exchange agent whereby nutrient rich bay waters and adjacent coastal waters are mixed.

X. REFERENCES

Barwis, J. H., "Catalog of Inlet Aerial Photography," *Coastal Engineering Research Center GITI Report 75-2*, U.S. Army Corps *of Engineers, Waterways Experiment Station, Vicksburg*, Mississippi, June, 1975, pp. 52-54.

Bureau of Economic and Business Research, *1980 Florida Statistical Abstract*, College of Business Administration, *University of Florida*, Gainesville, Florida, March, 1980.

Bruun, P., "Sea Level Rise as a Cause of Shore Erosion," *Engineering Progress at the University of Florida*, Vol. XVI, No. 5, Coast*al and Oceanographic Engineering Laboratory, Un*iversity of Florida, Gainesville, Florida, May, 1962.

Bruun, P., Gerritsen, F., and Morgan, W. H., "Florida Coastal Problems," *UFL/COEL-58/020*, Coastal and Oceanographic Engineering Laboratory, *University of F*lorida, Gainesville, Florida, 1958.

"Coastal Engineering Hydraulic Model Study of Clearwater Pass," *UFL/COEL-73/008*, Coastal and Oceanographic Engineering Laboratory, *University of F*lorida, Gainesville, Florida, March, 1973.

"Coastal Engineering Study of Clearwater Pass and Sand Key," *UFL/COEL-70/011*, Coastal and Oceanographic Engineering Laboratory, *University of F*lorida, Gainesville, Florida, June, 1970.

Cooke, C. W., "Geology of Florida," *Florida Geological Survey Bulletin No. 29*, Florida Geological Survey, *Tallahassee, Florida, 1945*.

Dean, R. G. and Walton, T. L., Jr., "Sediment Transport Processes in the Vicinity of Inlets with Special Reference to Sand Trapping," *Estuarine Research*, Vol. 2, Geology and Engineering, Academic Press, Inc., *New N.Y., 19*75, pp. 129-149.

Escoffier, F. F., "Stability of Tidal Inlets," *Shore and Beach*, Am. Shore and Beach Preservation Assoc., Vol. 8, No. *4, October, 19*40, pp. 114-115.

Escoffier, F. F., "Hydraulics and Stability of Tidal Inlets," *GITI Report No. 13*, U.S. Army Corps of Engineers, Coastal Engineering *Research Center*, Fort Belvoir, Virginia, August, 1977.

Graham, D. S. and Mehta, A. J., "Burial Design Criteria for Tidal Flow Crossings," *Transportation Engineering Journal*, ASCE, Vol. 107, No. TE2, Proc. Pa*per 16146, March, 1981, pp. 227-2*42.

Harris, D. L., "Characteristics of Wave Records in the Coastal Zone," *R2-73*, U.S. Army Corps of Engineers Coastal Engineering Research *Center*, Fort Belvoir, Va., 1973.

Harris, D.L., "Tide and Tidal Datums in the United States," Special Report No. 7, U.S. Army Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, Virginia, 1981.

Heath, R. C., and Smith, P. C., "Groundwater Resources of Pinellas County, Florida," Report of Investigations No.12, Prepared by the United States and Florida Geological Surveys, Tallahassee, Florida, 1954.

Hicks, S. D., "Long-Period Sea Level Variations for the United States Through 1978,": Shore and Beach, Am. Shore and Beach Preservation Assoc., Vol. 49, No.2, April, 1981, pp. 26-29.

Jarrett, J. T., "Tidal Prism-Inlet Area Relationships," GITI Report No. 3, U.S. Army Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, Virginia, February, 1976.

Keulegan, G. H., and Hall, J. U., "A Formula for the Calculation of the Tidal Discharge Through an Inlet," U.S. Army Corps of Engineers Beach Erosion Board Bulletin, Vol. 4, January, 1950, pp. 15-29.

Keulegan, G. H., "Tidal Flow in Entrances, Water-level Fluctuations of Basins in Communication with Seas," Technical Bulletin No. 14, Committee on Tidal Hydraulics, U.S. Army Corps of Engineers, Vicksberg, Mississippi, June, 1967.

Lynch-Blosse, M. A., "Inlet Sedimentation at Dunedin and Hurricane Passes, Pinellas County, Florida," Masters' Thesis-University of South Florida, Tampa, Florida, December, 1977.

Marmer, H. A., "Tidal Datum Planes," Special Report No. 135, Revised (1951) Edition, U.S. Coast and Geodetic Survey, 1951.

Mehta, A. J., "Hydraulics of Tidal Inlets: Simple Analytical Models for the Engineer, Parts I & II," UFL/COEL-75/019, Coastal and Oceanographic Engineering Laboratory, University of Florida, Gainesville, Florida, 1975.

Miller, I., and Freund, J. E., "The Poisson Distribution," Probability and Statistics for Engineers, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1965, pp. 48-50.

"Monitoring Study of Clearwater Pass, Clearwater, Florida," UFL/COEL-77/003, Coastal and Oceanographic Laboratory, University of Florida, Gainesville, Florida, September, 1977.

National Marine Fisheries Service, "Florida Landings, Annual Summary 1969," 1969.

National Marine Fisheries Service, "Florida Landings, Annual Summary, 1978," 1978.

National Oceanic and Atmospheric Administration, "Tide Tables 1982, High and Low Water Predictions, East Coast of North and South America," National Ocean Survey, Rockville, Maryland, 1982.

O'Brien, M. P., and Clark, R. R., "Hydraulic Constants of Tidal Entrances I; Data from NOS Tide Tables, Current Tables, and Navigation Charts," UFL/COEL Technical Report No. 21, Coastal and Oceanographic Engineering Laboratory, University of Florida, Gainesville, Florida, 1973.

O'Brien, M. P., and Clark, R. R., "Hydraulic Constants of Tidal Estuaries," Proceedings of the 14th Coastal Engineering Conference, Copenhagen, Denmark, 1974, pp. 1546-1565.

O'Brien, M. P., and Dean, R. G., "Hydraulic and Sedimentary Stability of Coastal Inlets, "Proceedings of the 13th Coastal Engineering Conference, ASCE Vol II, Vancouver, Canada, July, 1972, pp. 761-780.

Riggs, S. R. and O'Connor, M. P., "Barrier Island Nearshore System of the Central Florida Gulf Coast," Sea Grant Publication UNC-SG-74-04, University of North Carolina Sea Grant Program, January, 1974.

Rosen, D. S., "Beach and Nearshore Sedimentation on Caladesi Island State Park, Pinellas County, Florida," Masters' Thesis-University of South Florida, Tampa, Florida, December, 1976.

Saloman, Carl H., "Hydrographic Observations in the Gulf of Mexico off Pinellas County, Florida (November 1970-January 1972)," Data Report 78, National Marine Fisheries Service, Panama City, Florida, June, 1974.

"Satelite Applications to a Coastal Inlet Study, Clearwater Beach, Florida," UFL/COEL-77/026, Coastal and Oceanographic Engineering Laboratory, University of Florida, Gainesville, Florida, December, 1977a.

Tedrick, P. A., "Direction of Longshore Drift, Littoral Current Velocities, and Sand Migration Along the Pinellas County Florida Coastline from 1925 to 1970, With Prediction of Future Trends," Masters' Thesis University of South Florida, Tampa, Florida, August, 1972.

U.S. Army Corps of Engineers, "Wave Statistics for the Gulf of Mexico off Tampa Bay, Florida," Technical Memorandum No. 89, Beach Erosion Board, Office of the Chief of Engineers, Washington, D.C., July, 1945.

U.S. Army Corps of Engineers, "Preliminary Examination Report on Big and Little Passes, Clearwater Bay, Florida," Jacksonville District, Jacksonville, Florida, February, 1949.

U.S. Army Corps of Engineers, "Beach Erosion Control Study on Pinellas County, Florida," Jacksonville District, Jacksonville, Florida, January, 1966.

U.S. Army Corps of Engineers, "Shore Protection Manual," Coastal Engineering Research Center, Fort Belvoir, Va., 1977.

U.S. Army Corps of Engineers, "Dunedin and Hurricane Passes, Pinellas County, Florida, Improvements for Small Boat Navigation, Detailed Project Report," Jacksonville District, Jacksonville, Florida, 1981.

U.S. Naval Weather Service Command, "Summary of Synoptic Meteorological Observations, Vol. 3 & 4, May, 1975.

Walton, T.L., Jr. "Littoral Drift Computations Along the Coast of Florida by Means of Ship Wave Observations," Technical Report No. 15, Coastal and Oceanographic Engineering Laboratory, University of Florida, Gainesville, Florida, 1973.

Walton, T. L., Jr., "Littoral Drift Estimates Along the Coast of Florida," Florida Sea Grant College Report No. 13, Coastal and Oceanographic Engineering Laboratory, University of Florida, Gainesville, Florida, August, 1976.

Walton, T. L., Jr., "A Relationship Between Inlet Cross Section and Outer Bar Storage," UFL/COEL-77/005, Coastal and Oceanographic Engineering Laboratory, University of Florida, Gainesville, Florida, April, 1977b.

Walton, T. L., Jr., and Adams, W. D., "Capacity of Inlet Outer Bars to Store Sand," Proceedings of the 17th Coastal Engineering Conference, ASCE Vol. II, 1976, pp. 1919-1937.

Winston, D., Riggs, S.W. O'Connor, M.P., Breuninger, R.H., "Geologic Evaluation of Coastal Petroleum Company's Offshore Lease from Honeymoon Island Area South to Blind Pass, Pinellas County, Florida," The Logo Group, February, 1968.