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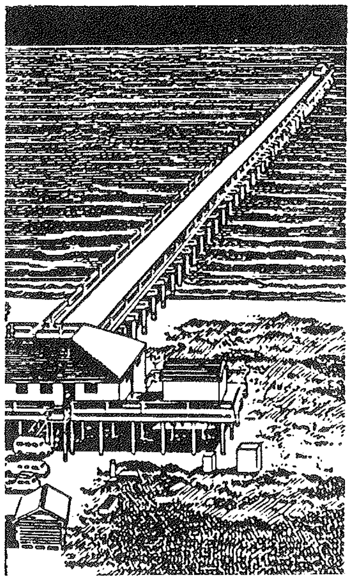

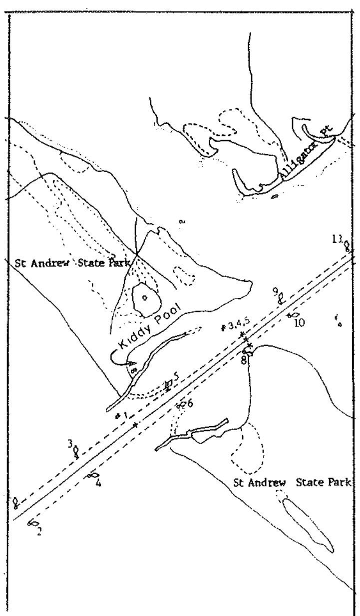

TECHNICAL REPORT CERC-89-7

A STUDY OF SAND WAVES IN THE PANAMA CITY, FLORIDA, ENTRANCE CHANNEL

by

W. Jeff Lillycrop, Julie Dean Rosati, David D. McGehee

Coastal Engineering Research Center

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39181-0631

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The entrance channel to St. Andrew Bay, near Panama City, Florida, is subject to the formation of large sand waves. A study was undertaken to determine the extent of the problem, as related to navigation, and to assess possible mitigative alternatives. The inlet was originally constructed in the early 1930's and now must be dredged every 12 to 24 months as a result of the large sand waves which form in the navigation channel.

The study considered structural changes to the inlet/jetty system using "INLET," a one-dimensional inlet flow model. Various alternatives were assessed to determine if structural modifications would help reduce sand wave sizes and/or decrease the necessary dredging frequency. Alternative dredging techniques were also investigated to identify more cost-effective methods of maintaining the sand wave prone navigation channel.

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PREFACE

The US Army Engineer District, Mobile (SAM), requested the US Army Engineer Waterways Experiment Station's (WES's) Coastal Engineering Research Center (CERC) to conduct a study of sand waves in the St. Andrew Bay entrance channel located near Panama City, Florida. Funding authorizations by SAM were granted in accordance with Intra-Army Order No. AD-86-3018.

The study was conducted at CERC under general direction of Dr. James R. Houston and Mr. Charles C. Calhoun, Jr., Chief and Assistant Chief, CERC, respectively; and under direct supervision of Mr. Thomas W. Richardson, Chief, Engineering Development Division (CD); and Ms. Joan Pope, Chief, Coastal Structures and Evaluation Branch (CD-S). The study was conducted by Mr. W. Jeff Lillycrop, Ms. Julie D. Rosati, and Mr. David D. McGehee, CD. Report figures were drafted by Messrs. Perry Reed and Leslie Wallace, CD. Report editing was performed by Ms. Shirley A. J. Hanshaw, Information Products Division, Information Technology Laboratory, WES.

Throughout the study, coordination was maintained with Mr. Pete Robinson of SAM. The Panama City Area Office assisted with field data collection and general site support through the following individuals: Messrs. Alton Colvin, Harry Peterson, Jack Branning, and "Gator" Brown.

Acting Commander and Director of WES during publication of this report was LTC Jack R. Stephens, EN. Technical Director was Dr. Robert W. Whalin.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic yards	0.7645549	cubic metres
feet	0.3048	metres
feet per second	0.5921	knots
inches	2.54	centimetres
knots (international)	0.5144444	metres per second
miles (US statute)	1.609347	kilometres
square miles	2.589998	square kilometres
tons (2,000 pounds, mass)	907.1847	kilograms

A STUDY OF SAND WAVES IN THE PANAMA CITY, FLORIDA, ENTRANCE CHANNEL

PART I: INTRODUCTION

Background

1. At the request of the US Army Engineer District, Mobile (SAM), a study of sand waves in the Panama City Entrance Channel was conducted by the Waterways Experiment Station's (WES's) Coastal Engineering Research Center (CERC). Sand waves in the entrance channel to St. Andrew Bay are a navigation hazard and a maintenance problem. Although ships rarely bump bottom, sand waves can grow large enough to reduce authorized channel depths. Within about 18 months after dredging, sand waves having heights as great as 15 ft* are present and must be removed. To maintain the inlet channel, frequent over-depth dredging is required.

2. Little is known about the formation and migration of sand waves. What is known comes mostly from laboratory flume test results of sand ripples to explain the much larger bed forms. From flume tests it is known that sand waves form only under certain flow conditions and require a sufficient sand source. To mitigate sand wave formation and increase the maintenance dredging interval, flow velocities must be modified and/or the sediment supply reduced.

3. In an effort to reduce dredging requirements, tests were conducted to study potential changes to the inlet to modify existing flow conditions and to determine methods for reducing the amount of sediment entering the channel. A complete background investigation of the study area was performed, including a review of all available literature. An evaluation of inlet hydraulics was conducted and a computer model used to simulate inlet hydraulics. Sediment sources were identified and various alternatives were considered to reduce the amount of sediment entering the channel from these sources.

Study Location and General Conditions

4. The study site is located at the entrance channel to St. Andrew Bay, Panama City, Florida (Figure 1). Comprising an area approximately 100 miles

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

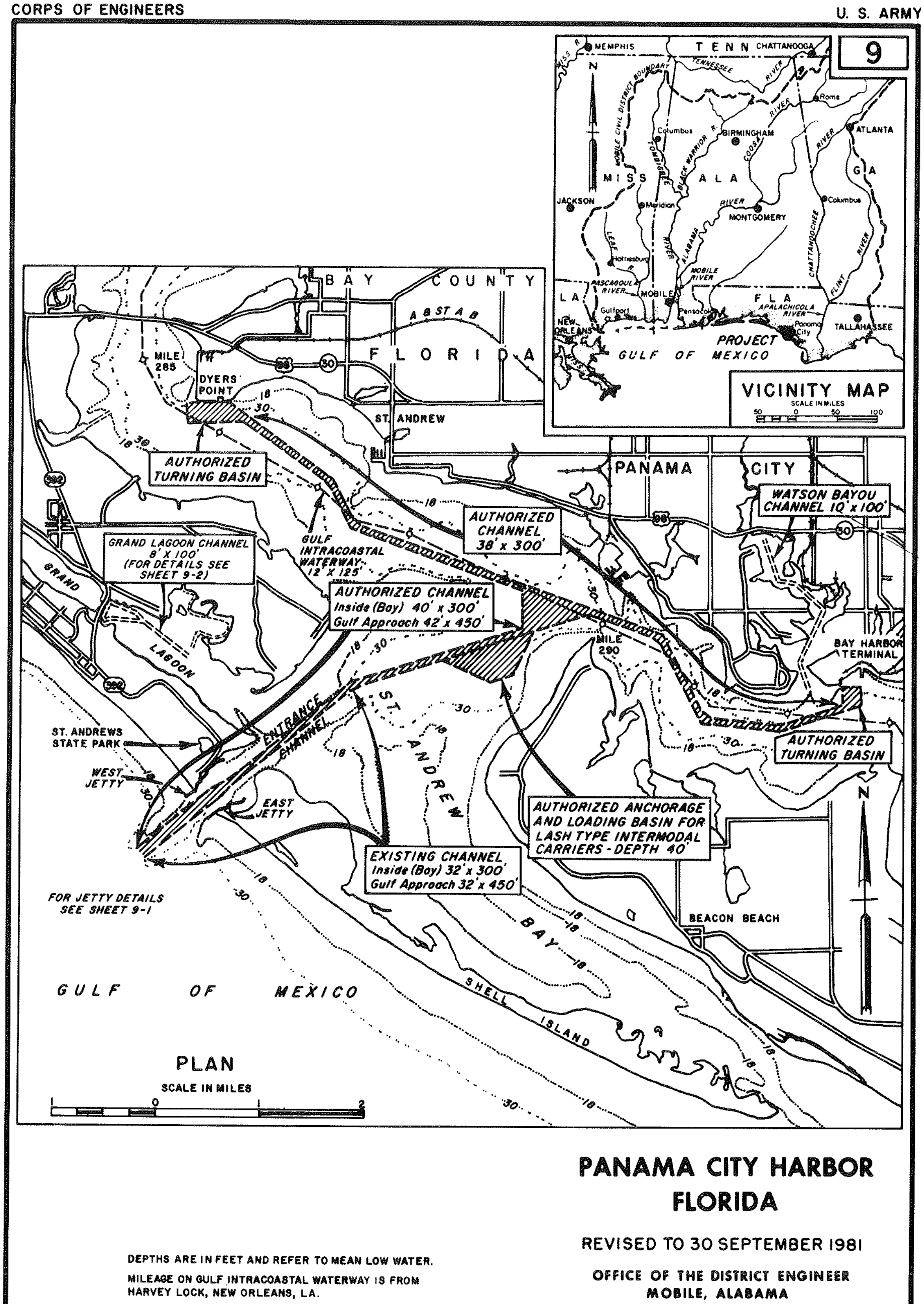

Figure 1. Study location

from Pensacola, Florida, and about 100 miles from the Florida state capital at Tallahassee, the St. Andrew Bay system consists of four adjacent bays: St. Andrew Bay, West Bay, East Bay, and North Bay (Table 1). For purposes of this report, St. Andrew Bay will be used to refer to the complete system, including all four bays, unless otherwise specified. The area of the bay system is approximately 108 square miles.

Table 1

Bay System Size

Bay	Surface Area square miles	Mean Depth mlw*
West	27.5	7.7
North	10.4	8.3
St. Andrew	40.9	15.5
East	29.2	12.4

* Mlw = mean low water.

5. The entrance channel and jetties, completed in 1934, separate Lands End Peninsula from what is now Shell Island. The channel is a federally maintained navigation channel consisting of a 450-ft wide, 32-ft-deep (mlw) approach channel from the gulf. The channel narrows to 300 ft wide about half-way through the inlet throat but remains 32 ft deep into the bay. The inlet is stabilized by two stone jetties spaced 1,500 ft apart.

6. The complete Panama City Harbor Navigation Project consists of the entrance channel, a small channel in Grand Lagoon, and the bay channel which crosses St. Andrew Bay and connects to the Panama City port facilities. The complete project, including authorized channel dimensions, is shown in Figure 1. Land adjacent to the inlet is owned by the State of Florida, and the west side of the inlet has been developed for recreational use.

7. The inlet cross section is generally shallower on the east side, with depths averaging about 6 to 12 ft. Actual navigation channel depth varies with location and condition of the sand waves but generally is about 30 to 35 ft. Along the west side of the inlet the natural inlet thalweg has created a scour problem along the jetty, generating depths as great as 45 to 50 ft.

8. Sediment within the study area consists of fine- to medium-grained

Table 2

Sediment Analysis of Entrance Channel

Sample Number	Coarse Sand %	Medium Sand %	Fine Sand %	Silt Sand %
1	4	74	15	7
2	3	52	38	7
3	-	15	76	9
4	1	39	52	8
5	1	49	40	10

sand. Table 2 presents an analysis of sediment samples taken from the navigation channel center line (Figure 2) within the inlet throat for a draft environmental statement (US Army Corps of Engineers (USACE) 1975). Bottom

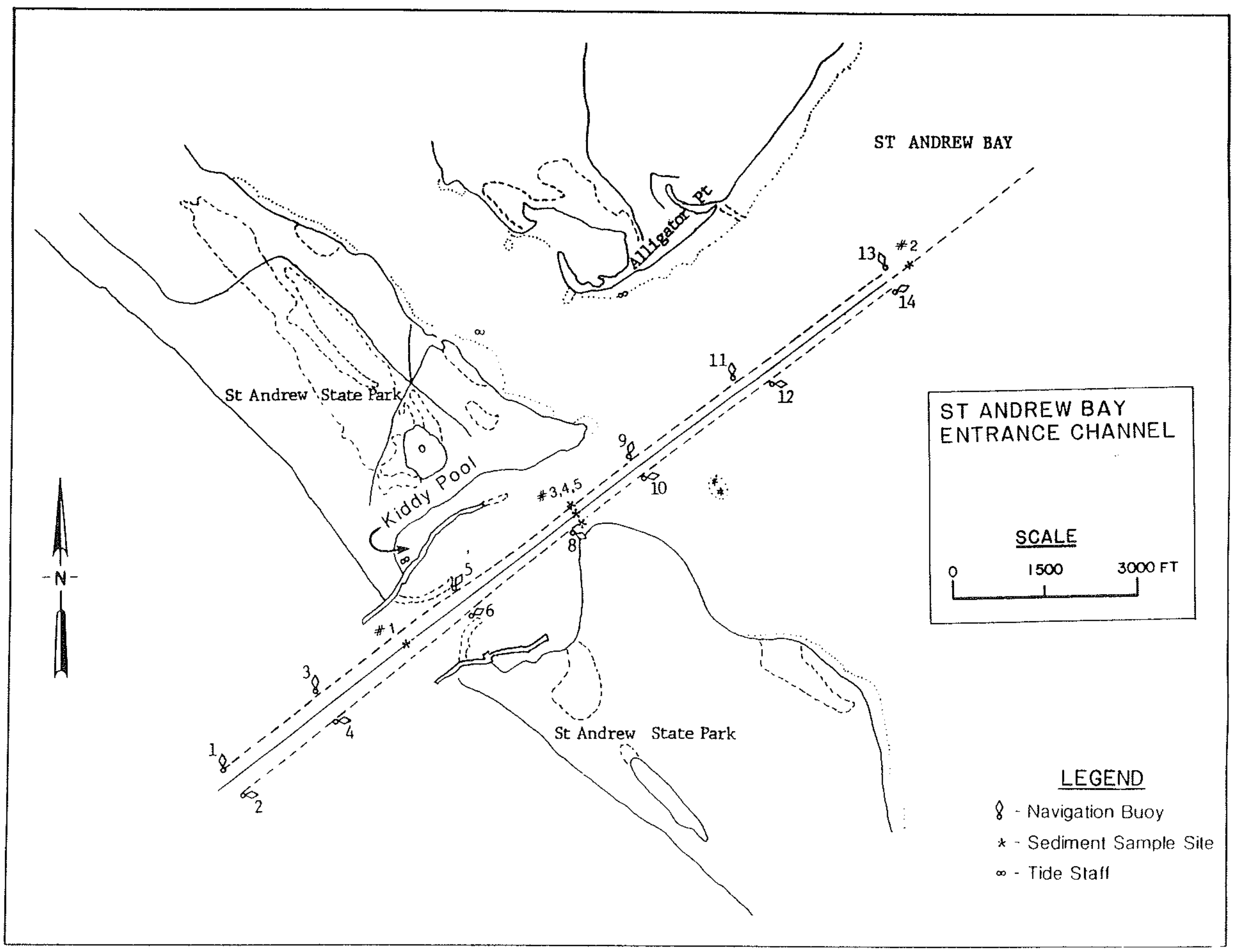

Figure 2. Location map

sediment in the Panama City Entrance Channel is characterized by quartz sand with grain size varying between 0.2 mm to approximately 0.35 mm.

9. Erosion problems resulted in construction of rubble-mound jetty wings which extend back from the jetties toward the bay to help stabilize the shoreline. Erosion from behind the jetty wings has created protected areas on either side of the inlet. The area on the west side of the inlet is used by the park as a swimming area and is referred to as the "Kiddy Pool."

10. Average wind speeds and directions for each month are presented in Table 3 (see Appendix C of Beach Erosion Control and Hurricane Protection, Interim Feasibility Report for Panama City Beach (SAM 1976.)) The data used to prepare the table were collected between 1884 and 1968, the majority being between 1954 and 1968.

11. Offshore wave heights for the area average 2 to 4 ft based on long-term averages by the National Climatic Data Center using Shipboard Synoptic Meteorological Observations (SSMO) (SAM 1976). However, during storms heights of up to 15 ft have been recorded. Hurricanes impact the area with a frequency of occurrence being one storm every 3.8 years.

Table 3

Average Wind Speed and Direction

Month	Wind Speed*	Prevailing Direction
January	15.3	East
February	15.8	Northeast
March	13.9	Southeast
April	12.8	Southeast
May	10.1	East
June	9.6	East
July	9.2	Southeast
August	9.7	East
September	13.9	East
October	14.6	Northeast
November	14.8	East
December	15.4	East
Mean Annual	12.9	East

* In miles per hour.

Statement of the Problem

12. Since the inlet was completed in 1934, shoaling has been a continuous problem. The Panama City Harbor Federal Navigation Project has been dredged 26 times in the past 54 years, totaling over 10.6 million cu yd (approximately 200,000 cu yd annually). In addition to the shoaling problems, jetties built to stabilize the inlet have undergone continuous degradation. The west jetty has required rehabilitation many times because of deep scour holes along the inner jetty and near the seaward end.

13. Primary shoal formation consists of sand waves which are typically perpendicular to the channel through the entire inlet throat and into the bay. Heights of these sand waves vary from as large as 15 ft near the tips of the jetties to only a few feet within the bay. A more complete description of these bed forms is presented in Part III. Because of the size and relatively quick reformation rate of the sand waves, the inlet must be dredged approximately every 18 months.

14. The federally authorized navigation project provides for a channel depth of -32 ft mlw, but to cope with the sand waves problem, the inlet is typically dredged to -40 ft mlw. The inlet was last dredged in June 1986; however, a fathometer survey of the inlet 4 months later (the following October) showed sand waves had reformed with heights ranging between 6 to 8 ft. Another fathometer survey in July 1987 showed sand wave heights ranged between 8 to 12 ft, the largest being near the tips of the jetties. The inlet is again scheduled for maintenance dredging near the beginning of the 1988 calendar year.

15. Effective maintenance of the navigation channel requires reducing the size and/or the formation rates of the sand waves. Reducing the amount of sediment reaching the sand waves will slow their formation rates after dredging, thus increasing maintenance dredging intervals. Reducing sediment transport into the inlet requires identification of the primary sediment sources followed by modifications to reduce the amount of sediment entering the entrance channel. Part IV addresses the sedimentation problem and discusses potential solutions to reduce sediment transport into the navigation channel.

16. Because bed form size is strongly related to current velocity, reducing the height of the sand waves will require modifications which change bottom current velocity. Figure 3 shows a generalized relationship between

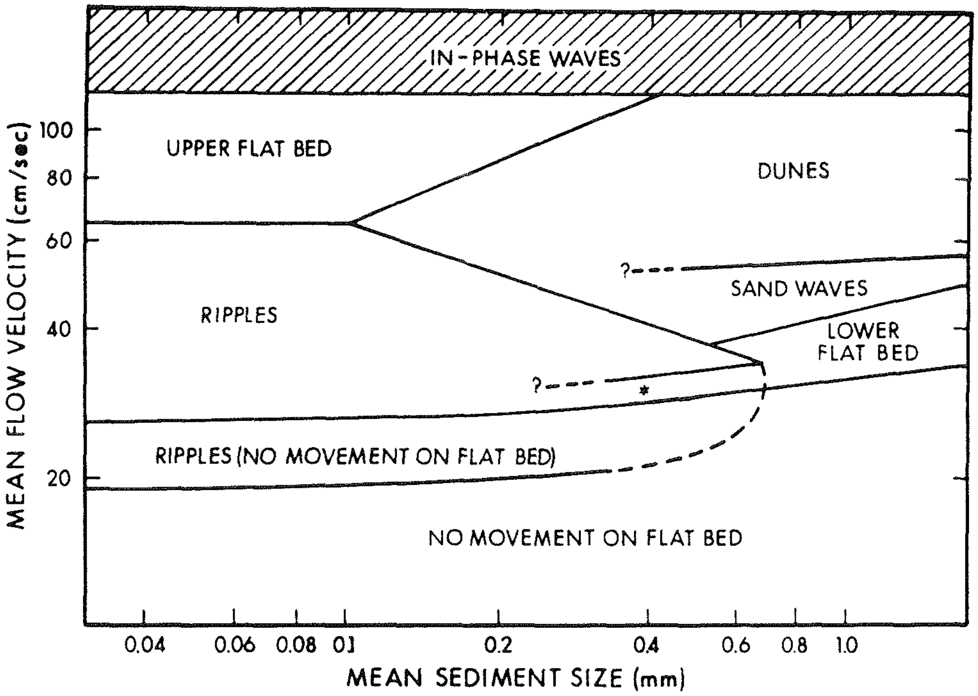

Figure 3. Flow versus sediment relationship (SEPM 1975)

mean sediment size, mean flow velocity, and characteristic bed forms based on two-dimensional laboratory studies (Society of Economic Paleontologists and Mineralogists (SEPM) 1975). Threshold velocity for sediment movement is approximately 20 cm/sec, and formation of each bed form depends on sediment size and velocity. Boundaries in this figure are approximate based on laboratory flume experiments and are not a completely accurate representation of the larger scale processes found in nature.

17. The jetties and jetty wings have required continuous maintenance since they were completed in 1934. Since 1950 the jetties have required over 65,000 tons of stone for maintenance (Figure 4). Because of their potential role in mitigating sand wave problems in the inlet, they have been considered in this study.

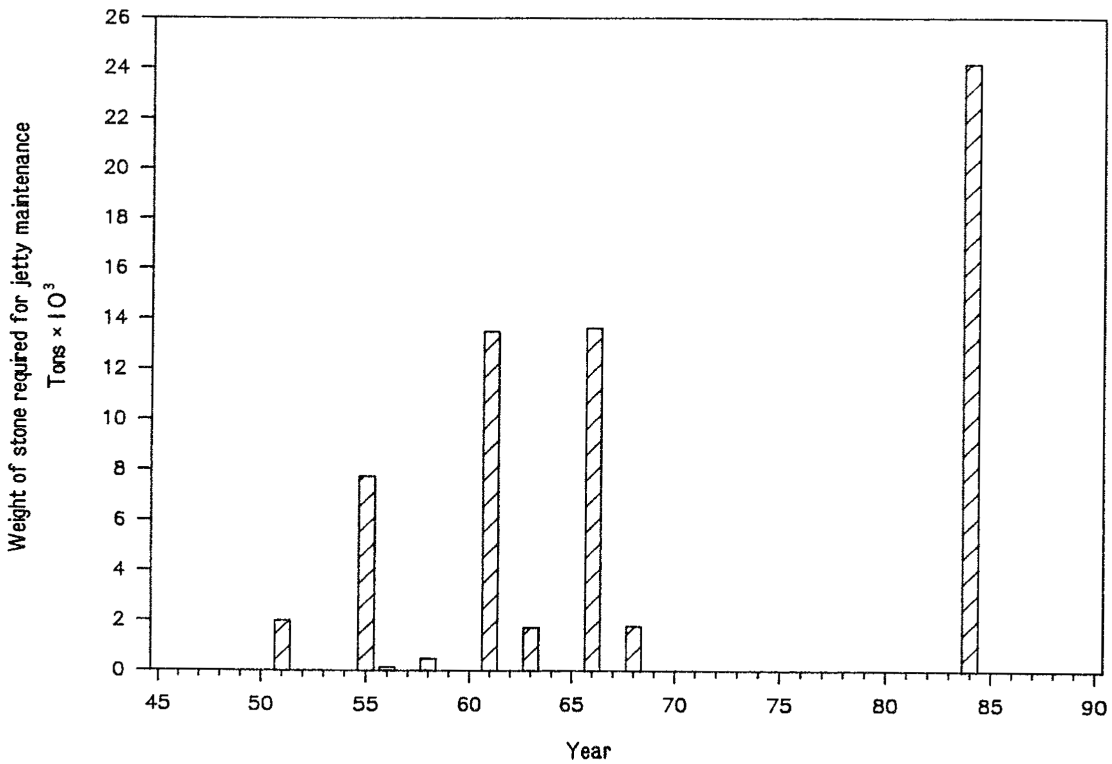

Figure 4. Jetty maintenance at Panama City, FL

PART II: SAND WAVE CHARACTERISTICS

18. Little is known about the formation and migration of sand waves in a natural setting. Basic prototype theory comes from limited field observations and extension of laboratory flume tests of sand ripples to explain the much larger bed form. From flume tests it is known that sand waves will not form without sufficient sand supply and that certain flow conditions must exist before ripples begin to form and migrate. Also, once threshold of movement (critical) velocities are achieved, further increases in velocity produce higher migration rates. Because laboratory studies are generally conducted at much smaller scales than exist in nature, extrapolation of theory from lab to nature is inexact. A very useful product of these studies lies in the identification of the primary factors involved in the formation of sand waves. As stated previously, for sand waves to form there must be (a) a nearly continuous supply of sand and (b) currents of sufficient strength and duration to cause sediment motion. Without both of these elements sand waves will not form. Since sand waves do form in the Panama City Entrance Channel, both of these must be present.

19. As flow velocity over a flat erodible bed increases, sediment begins to move and small ripples form. These ripples are generally long crested and two-dimensional, and they face and move in a downstream direction. Figure 5 shows a generalized bed configuration for these conditions. As flow velocities further increase, crests divide and the bed becomes three-dimensional. Ripples are small, having heights of only a few centimeters and crest-to-crest lengths on the order of 10 to 20 cm.

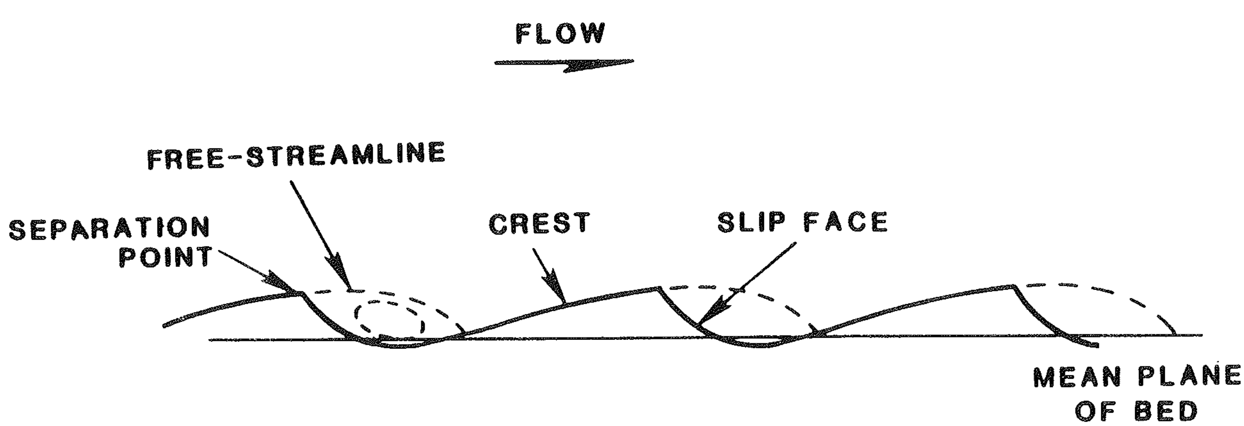

Figure 5. Bed-form characteristics

20. With further increases in flow velocity, larger bed forms appear. These are often called megaripples and are larger than ripples but smaller than sand waves such as those in the entrance channel at Panama City. Megaripples are also long crested and two-dimensional, and they face and move in the downstream direction. Megaripples have heights ranging from 30 cm to several meters and wave lengths up to a few tens of meters. Ripples are often found on the upstream faces of the larger megaripples.

21. Sand waves form as flow velocities increase further. They are larger than the other bed forms previously described and are not as closely spaced. Their heights have been reported to be as great as 12 m with wavelengths of hundreds of meters. However, sand waves found in the Panama City channel range between 2 to 5 m in height with wavelengths between 30 and 60 m. The sand waves considered in this study are subjected to an oscillatory tidal flow with change of direction occurring about every 12 hr. However, the path of the sand waves tends to be unidirectional with shape and advance rate determined by the strongest current speed and/or duration. The influence of current duration is not as well quantified as the other parameters considered in describing formation of sand waves.

PART III: LITERATURE REVIEW

22. A literature search was conducted to review studies concerning coastal processes in the vicinity of St. Andrew's Bay. Of particular interest was literature discussing aspects of sand waves at the site. This section briefly summarizes background information available and focuses on a study by Salsman, Tolbert, and Villars (1965) titled "Sand Ridge Migration in St. Andrew Bay, Florida."

23. Stapor (1973) discusses the recent (since 1779) evolution of Shell and Crooked Islands (Figure 6); and by comparing bathymetries of 1877, 1930 and 1946, he estimates the rate of longshore transport in the region. The rate is estimated to be almost evenly balanced, with approximately 153,000 cu yd/yr to the west and 141,000 cu yd/yr to the east, for a net transport rate of 12,000 cu yd/yr to the west during the period of the study.

24. A study by Wang et al. (1978) estimated rates of longshore sediment transport at Panama City Beach located just west of St. Andrew Bay (Figure 1). Transport rates were estimated using two methods: by measuring the quantity of material trapped at a littoral barrier (groin) intermittently from August 1975 to October 1977 and by a sand tracer experiment conducted from 18 to 24 October 1977. Because the groin was neither long nor high enough to intercept all longshore-moving material, the authors believe that the estimated net quantity (6,000 cu yd/yr) was too low. The sand tracer experiment suggested rates of 510,000 cu yd/yr to the west and 300,000 cu yd/yr to the east, for a net sediment transport rate of 210,000 cu yd/yr to the west for the mid-October 1977 time period.

25. Other studies which have included estimates of the rate of longshore sediment transport in the vicinity of the St. Andrew Bay entrance channel include Walton (1979) and SAM (1976). Walton estimated sediment transport potential, based on SSMO data, to be 219,000 cu yd/yr to the west and 192,000 cu yd/yr to the east, for a net westerly transport of 27,000 cu yd/yr. SAM, using the littoral drift rose method (Walton 1973), estimated a total gross sediment transport potential of 413,000 cu yd/yr for a net westerly transport of 6,800 cu yd/yr.

26. Ichiye and Jones (1961) measured temperature, salinity, and currents over several 24-hr periods for five seasons between 1957 and 1959 in the St. Andrew Bay system. The velocity data in the channel were measured as

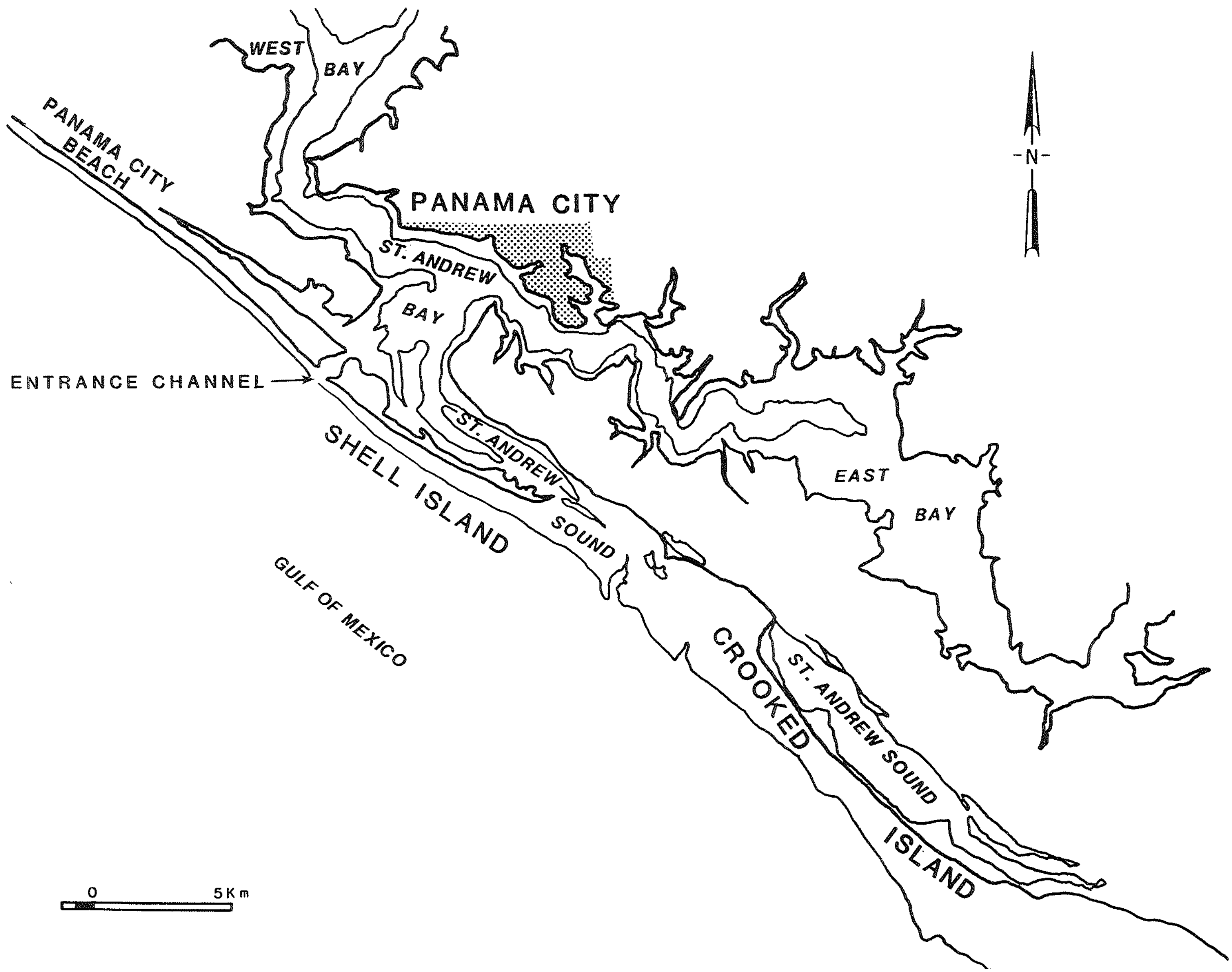

Figure 6. St. Andrew Bay and vicinity

1.7 and 2.0 ft/sec, for the flood and ebb currents, respectively. Current velocities as low as 0.023 ft/sec (0.7 cm/sec) could move fine sand and silts.

27. Several studies discuss erosion of Panama City Beach located west of the St. Andrew Bay entrance channel (e.g., Saloman et al. 1982, Culter and Mahadevan 1982). According to results of these studies, the erosion of this area is most likely due to partial blockage of westward-moving littoral material at the St. Andrew Bay entrance channel.

28. Salsman, Tolbert, and Villars (1966) document an investigation of the sand ridges in St. Andrew Bay. The fine grained (0.135-mm) sandy bottom undulations were discovered in the fall of 1982 and were located in 11 m of water in an area marked "mud" on nautical charts. Prior to the St. Andrew Bay cut in 1934, Shell Island protected the bay from high currents, and only finer sediments could be transported and deposited in the bay. However, the new entrance resulted in higher currents and wave energy in the bay, and it could now transport sand-sized material. Two distinct sediment regimes were found in the bay during an earlier study (Waller 1961): sandy areas near the entrances and in all areas shallower than 6 m and silty clay areas in deeper water. The sand ridges were monitored for over 2 years. The ridges were perpendicular to the channel axis, being from 30 to 60 cm in height, with wave lengths of 13 to 20 m. The ridges were asymmetric in shape, with steep slopes facing down current. The ridges moved during the predominant flood current, and the rate of migration was estimated to be 1.35 cm/day. The authors estimate that each ridge left behind a layer of sand averaging 12 cm in thickness as it passed a particular point.

29. Reviewed studies indicate that the rate of net longshore sediment transport in the vicinity of St. Andrew Bay entrance channel is relatively low, with a slight east-to-west dominance. The man-made cut in Shell Island, creating the St. Andrew Bay entrance channel, allows higher currents and waves to transport sand into the channel and the bay. Sand is deposited in the channel and bay during flood currents, removing littoral material from the system and thereby creating erosion problems for adjacent beaches.

PART IV: PROJECT SITE EVALUATION

Inlet History

30. Literature from the Panama City Area Office and SAM provide extensive information about the construction and maintenance history of the inlet and jetties. This section summarizes the extensive work which has been performed during the past 54 years. Prior to construction of the existing navigation channel through Lands End Peninsula, the harbor entrance was through East Pass (Figure 1), approximately 7 miles east of the existing channel. This channel was described as "torturous" in a letter report* from the SAM District Engineer to the Gulf of Mexico Division Engineer in New Orleans and, in fact, was not used at night or during storms by deeper draft vessels. East Pass was maintained with a channel depth of 22 ft and width of 200 ft. From the gulf entrance of East Pass to the Panama City harbor facilities was a distance of about 5 miles. It was because of this long and dangerous channel that "New Pass" was constructed and completed in 1934.

31. The new channel project was 10,500 ft long with approximately 3,000 ft through Lands End Peninsula and dry land. The cut divided the Lands End Peninsula and created Shell Island. Two riprap jetties were built to stabilize the new cut. They extended gulfward to the 12-ft contour and were built on 2-ft-thick rock mattresses with steel sheet-pile cores along the jetty axis. The east jetty, from the low water line extended 500 ft offshore and the west jetty, from the low water line, extended 550 ft offshore. Both jetties had crest elevations of +6 ft mlw and crest widths of 8 ft and were spaced 1,500 ft apart. Original construction of New Pass included rubble-mound jetty wings with steel sheet-pile cores extending landward 300 ft.

32. Soon after project completion the channel banks, especially at the landward end of the jetties, began to experience substantial erosion caused by gulf waves. In 1935 steel sheet-pile bulkheads consisting of a single row of 15-ft piles were built into the channel and reinforced with steel sheet-pile groins and buttresses, all having a crest elevation of +2.5 ft mlw. The bulkheads were 800 ft and 1,050 ft long for the east and west jetties,

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* Letter report titled "St. Andrew Bay Entrance Channel," April 1938, from COL R. Park, District Engineer, to Division Engineer, Gulf of Mexico Division, New Orleans, LA.

respectively. Work on the bulkheads was completed in May 1935. Within 6 months the west bulkhead was destroyed, and the east bulkhead was significantly damaged by unspecified causes. Repairs to the east section were made by placing large stone in front of the structure. Not long after this too failed, and in 1936 the large stones were removed.

33. In July 1936 a hurricane caused catastrophic damage to the jetties. Wing crest elevations went from +6 ft mlw to approximately +1 ft mlw. Extensive repairs were made in 1937 and early 1938. Reinforced asphaltic concrete mats, 2 in. thick and extending out 24 ft from the toe of the existing rock jetties and wings, were placed and anchored with large precast asphaltic three-sided forms, or prisms. Hot asphaltic concrete was formed and smoothed over the existing jetties. The crest elevations were restored to +6 ft mlw, and the crest width was 8 ft. A complete pictorial record of this restoration at the Panama City Area Office provides a fascinating look at the jetty reconstruction project nearly 50 years ago.

34. Flanking by waves of the west jetty was causing erosion problems; consequently, in 1939 the jetty wings were extended. The next year the wings were repaired, and 2 years later in 1942 the wings were lengthened by 680 and 800 ft for the east and west jetties, respectively. An inspection of the jetties in 1945 revealed that they were in relatively good shape except for some settling at the head of the west jetty.

35. Between 1934 and 1946 the channel banks suffered significant erosion and receded over 900 and 1,200 ft on the east and west banks, respectively. As a result of the shoaling that occurred, the channel was dredged nine times between 1935 and 1945. Table 4 summarizes information obtained from the area office and gives the year and volume of material removed during this 11-year period. As can be seen from the table, shoreline change during this period was dramatic. Figure 7 shows a shoreline change map with a precut shoreline (1855), including a small lake that was drained during initial construction, the postconstruction shoreline immediately following project completion (1934), and the 1945 shoreline. The location of the jetty wings in relation to the 1934 shoreline is also depicted.

36. In May 1946 a report* was prepared by the Shore Protection Board

* Letter report titled "Report on the Effect of Proposed Channel Improvements at St. Andrew Bay, Florida," May 1946, War Department, Shore Protection Board, Washington, DC.

Table 4

Dredging Events Between 1934 and 1945

Year	Volume of Material cu yd
1935	1,295,894
1936	0
1937	956,342
1938	457,501
1939	338,159
1940	262,522
1941	386,229
1942	491,762
1943	0
1944	0
1945	279,171
Total	4,467,580

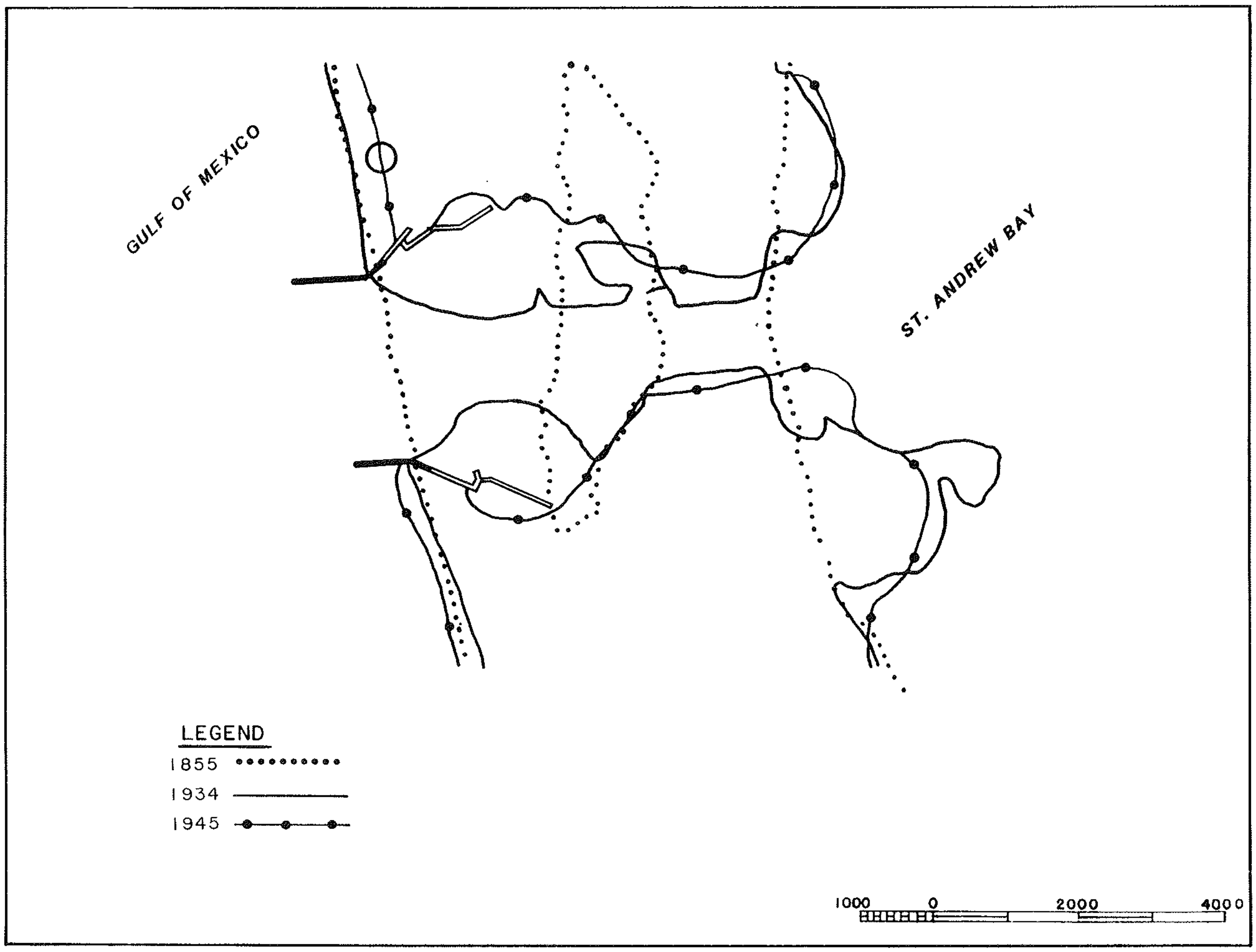

Figure 7. New channel entrance shoreline changes (1855 to 1945)

of the War Department which addressed the channel bank erosion problem. The report pointed out that even after the jetty wings had been lengthened, erosion and channel shoaling was still a serious problem. The cause of the erosion was reported to be incident waves from the gulf. Two possible solutions to this problem were presented: extend the jetties seaward to reduce incident wave heights reaching the channel banks or revet the channel banks through New Pass.

37. The problem with these short jetties was first discussed in a 1938 report* which stated that "the insufficiency of the length of the jetties and the divergence of the wings permit gulf storm waves to enter and cross the waterway and impinge upon the jetties and unprotected shoreline causing progressive widening of the cut." The report recommended the jetties be extended at least 1,500 ft.

38. A later report** considered the erosion along the west bank of the inlet and, more specifically, improvements to the west jetty wing to reduce this erosion. The Florida Park Service sponsored the study because they were interested in maintaining a recreational beach along the west shore of the inlet. The study included limited physical model tests to evaluate various jetty heights, permeability, and vertical structures behind the jetty. The report concluded that "it will involve not insignificant construction work to improve the existing jetty" and recommended periodic nourishment of the shoreline for maintaining a recreational beach.

39. Since construction of the inlet in 1934 the harbor project has been dredged 26 times, removing over 10.6 million cu yd of material (Figure 8). Unfortunately it is not possible to determine how much of that volume is directly from sand wave excavation because records only stated that dredging occurred for the Panama City Harbor navigation project and did not relate volumes to location.

Field Data Collection

40. The field data collection effort had the following objectives:

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* See note on p. 17.

** Unpublished report titled "Model Study for the Improvement of the Jetties of the St. Andrew Bay Entrance Channel," December 1958, Coastal Engineering Laboratory, University of Florida, Gainesville, FL.

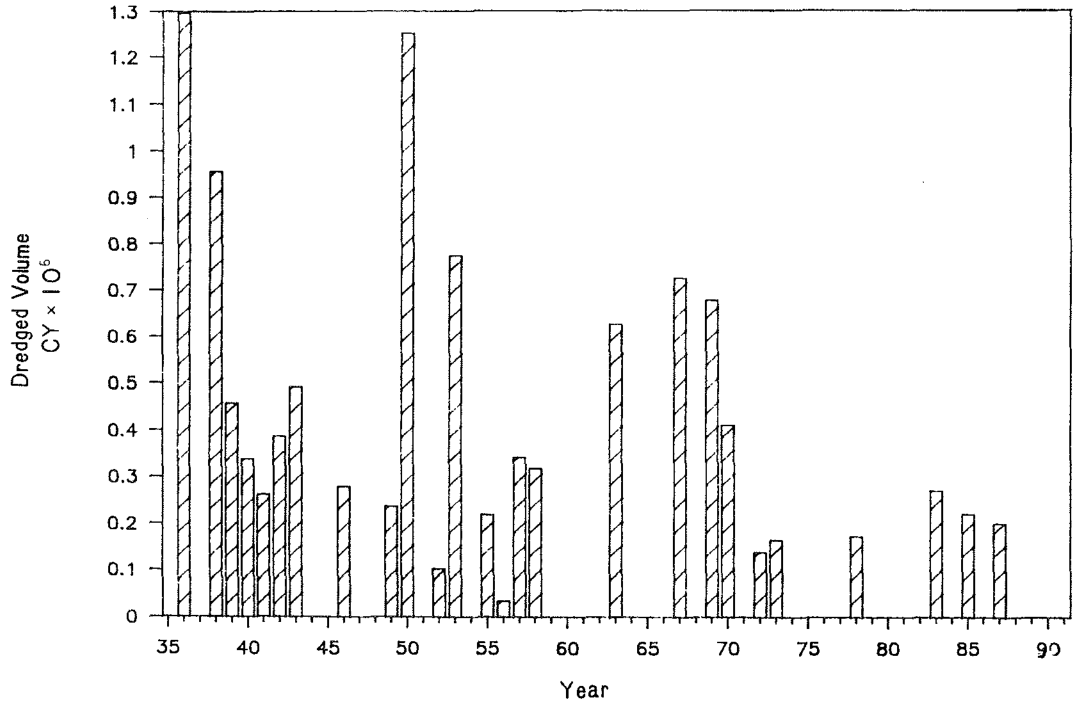

Figure 8. Panama City Harbor dredging events

a. Qualitatively monitor sand wave formation through time.

b. Determine hydraulic characteristics of the inlet necessary for the computer model.

c. Measure the velocity distribution associated with a fully developed bed form at the prototype site.

41. These objectives were met with the following monitoring elements:

a. Fathometer and side-scan sonar surveys.

b. Deployment of in situ and profiling current meters over several tidal cycles.

Bathymetric surveys

42. Bathymetric surveys using acoustic sounders (Raytheon fathometers) provided sufficient information from the routine channel condition surveys. These were used to identify individual features and their approximate distribution within the inlet. Five parallel survey lines spaced approximately 100 ft apart were used to monitor the sand waves. These were the east channel edge, the center line, the west channel edge, and two lines between the centerline and the two channel edges. Surveys were made on 16 October and 6 November 1986 and on 10 July 1987.

43. All surveys were conducted using the Panama City Area Office