

ENGINEERING GEOLOGY CRITERIA FOR DREDGED MATERIAL
DISPOSAL IN UPPER LAGUNA MADRE, TEXAS

A Thesis

by

JAMES EDMELLAIRE STINSON II

Submitted to the Graduate College of
Texas A&M University
in partial fulfillment of the requirement for the degree of
MASTER OF SCIENCE

December 1977

Major Subject: Geology

ABSTRACT

Engineering Geology Criteria for Dredged Material
Disposal in Upper Laguna Madre, Texas. (December 1977)
James E. Stinson II, B.S., George Washington University
Chairman of Advisory Committee: Dr. C. C. Mathewson

Channels in Murdock Basin, Upper Laguna Madre, fill with sediment dispersed from adjacent subaqueous dredged material disposal sites. Original dredging placed the material in a series of disposal mounds close to and parallel to the channel. Three disposal sites in different water depths, revealed varying conditions of sediment dispersion and island erosion. Water depth at the different sites varies from 0 to 1.5 feet in the wind tidal flats, 1 to 3 feet in the shoal area, and 4 to 6 feet in the middle of Murdock Basin.

Measurements using air photographs taken in 1953 and 1960, and from field surveys made in 1974, delineated the dimensions and changes in the morphology of the dredged material mounds. In the wind tidal flats, the dispersion area decreased 28 percent between 1953 and 1960 and then increased 130 percent of the original dispersion area between 1960 and 1974. The volume of dredged material, decreased a total of 46 percent between 1953 and 1974. Dispersion areas around shoal water islands increased about 160 percent in the first 7 years (1953-1960) and 230 to 350 percent in 20 years (1953-1974). The radius of the dispersion areas increased from 1.5 to 2.0 times the original radius. The volume of dredged material, however, decreased only 4 to 6 percent. Deep water islands showed minimal changes in dispersion area and island morphology.

The morphologic changes observed at these sites reflect different wave and wind tidal current characteristics.

Factors controlling the stability of the dredged material islands are the: 1) amount of disturbance of the sediments caused by dredging, 2) water depth at the disposal site, 3) frequency of wave attack on the island, 4) wind tidal currents, 5) sediment characteristics and 6) vegetation.

ACKNOWLEDGEMENTS

This study was made possible through funding supplied by Sea Grant. I wish to thank Dr. C. C. Mathewson for his support and valuable criticism; Dr. Wayne M. Ahr and Dr. Robert S. Schiller for serving on my committee and their suggestions; my fellow students for their assistance during the field study, including Jim and Karen Clary, Brent and Joy Sears, Larry Minter, Mic McHam, Don Piper, Fred Dingus, Bill Schneider, Les Levitan and Larry Dyke. I would especially like to thank Sun Company who, through their generosity, made possible extensive and repeated field studies.

TABLE OF CONTENTS

	Page
ABSTRACT	iii
ACKNOWLEDGEMENTS	v
LIST OF TABLES	viii
LIST OF FIGURES	ix
INTRODUCTION	1
PREVIOUS WORK	3
STUDY AREA	6
<u>Geologic Setting</u>	6
<u>Bathymetry</u>	12
<u>Climate</u>	12
<u>Fetch</u>	13
<u>Tides</u>	15
<u>Circulation</u>	16
INVESTIGATION	18
<u>Field and Volumetric Measurements</u>	18
<u>Calculation of 1953 Island Volumes</u>	22
<u>Volume Calculation for the 1974 Islands</u>	22
<u>Sediment Sampling and Analysis</u>	23
CHARACTERISTICS OF SEDIMENTS IN THE STUDY AREA	27
<u>Bed Description</u>	27
<u>Texture</u>	27
MECHANISMS OF SEDIMENT TRANSPORT	40
DREDGED MATERIAL ISLAND DISPERSION	44

<u>Shoal Water Islands</u>	44
Crane Island Volume	48
Crane Island Area	51
Seven Islands Volume	56
Seven Islands Area	56
DEEP WATER ISLAND	62
WIND TIDAL FLATS ISLANDS	65
ACTIVE PROCESSES AND DISCUSSION	71
<u>Erosion and Redeposition</u>	71
<u>Vegetation</u>	75
<u>Island and Channel Orientation</u>	78
CONCLUSIONS AND CRITERIA FOR SITE SELECTION	86
REFERENCES CITED	89
VITA	93

LIST OF TABLES

Table		page
1	Percent by weight of sediments at disposal sites and surrounding areas	29
2	Averaged values of mean grain size and sorting coefficient for sample locations	32
3	Summary of calculated wave data for the study area. Fetch = 3 mi.	43
4	Surface areas of islands in 1953, 1960, and 1974 (acres)	55

LIST OF FIGURES

Figure		page
1	Map of the geomorphic features of the south Texas coast .	7
2	Map of study area showing dredged material islands and channel locations	8
3	Frequency of wind by direction at Corpus Christi	14
4	Wind roses compiled from data recorded at the weather monitoring station during field investigation	19
5	Sketch of drogue used for current measurement in Murdock Basin	20
6	Location of samples collected from Murdock Basin	24
7	A triangle diagram of sand-shell-mud contents of samples in the Crane Island area	33
8	A triangle diagram of sand-shell-mud contents of samples in the Seven Islands area	35
9	A triangle diagram of sand-shell-mud contents of samples in the wind tidal flats	36
10	A triangle diagram of sand-silt-clay contents of samples in the Crane Island area	37
11	A triangle diagram of sand-silt-clay contents of samples in the Seven Islands area	38
12	A triangle diagram of sand-silt-clay contents of samples in the wind tidal flats	39
13	Erosion, transportation, and deposition velocities for different grain sizes	41
14	Simplified sketch of the design for the dredging permit submitted to the U. S. Army Corps of Engineers	45
15	A sketch of a typical cross-section from the design permit submitted to the U. S. Army Corps of Engineers . . .	46
16	Location map of specific dredged material island sites in Murdock Basin	47

Figure		page
17	Channel and dredged material islands at the Crane Island location in 1953 soon after dredging was completed . . .	49
18	Topographic map of Crane Island in 1974 compared with the 1953 island outline	50
19	Study island at the Crane Island location in 1953 soon after dredging was completed	52
20	Study island at the Crane Island location in 1960	53
21	Study island at the Crane Island location in 1974	54
22	Study island at the Seven Islands location in 1953 . . .	57
23	Study island at the Seven Islands location in 1974	58
24	Looking west at Seven Islands in 1974	59
25	Study island at the Seven Islands location in 1960 . . .	60
26	On the east side of a deep water island looking southwest at the south spit	63
27	Looking northeast at a deep water island in 1974	63
28	A comparison of the outline of the deep water island in 1953 and 1960	64
29	Study island at the wind tidal flats location in 1953 soon after dredging was completed	66
30	Study island at the wind tidal flats location in 1974 . .	67
31	Study island at the wind tidal flats location in 1960 . .	69
32	Looking west at the wind tidal flats and channel in 1974	70
33	Wave-cut escarpment on the north side of Crane Island . .	72
34	Simplified diagram of Murdock Basin showing directions of sediment transport	74
35	Graph of subaerial surface area erosion for the study islands	76
36	High water and waves leave an accumulation of grass on top of the island above the escarpment	77

Figure		page
37	Grasses are seen as dark patches rimming the perimeter of Crane Island	77
38	Simplified sketch of the design for the dredging permit submitted to the U. S. Army Corps of Engineers for the Crane Island location	79
39	Simplified sketch of the design for the dredging permit submitted to the U. S. Army Corps of Engineers for the Seven Islands location	80
40	Simplified sketch of the design for the dredging permit submitted to the U. S. Army Corps of Engineers for the wind tidal flats location	81
41	Suggested placement and orientation of dredged material disposal sites and channels in Murdock Basin with respect to the sediment transport directions . . .	83
42	Channel complex in the wind tidal flats in 1960	84

INTRODUCTION

With the continuing development of the coastal zone for industrial, commercial and residential use it has been necessary to modify the area to supply ample space for development. A great deal of modification has occurred in the coastal estuaries to provide ideal sites for industries needing waterways for bulk hauling and for developing residential and recreational areas. To make locations attractive, dredging has been used to modify the estuaries by creating channels for access and landfill for area expansion. Dredging operations have become so extensive in some areas, Smith (1975) has described it as the dominant geologic process.

The dredging procedure may simply be defined as a reworking of the sediments to reshape the estuary. Two methods of dredging are hydraulic and mechanical. Herbich (1975) has discussed these methods and others in depth. Disposal of the dredged material can be either confined or open water dumping. Confined disposal is the discharge of dredged sediments behind dikes or levees, where the sediment settles, the water is drained off, and the discharge site is eventually filled. Open water disposal is the discharge of dredged sediments in open water without any type of confinement, usually forming subaqueous mounds which as disposal continues may or may not become subaerial. About two-thirds of all dredged material in the United States is disposed in open water with the remainder being deposited in confined

The citations on the following pages follow the style of the Bulletin of the Association of Engineering Geologists.

areas or onshore (Boyd et al, 1972).

The disposal of dredged material is an environmental and monetary problem for the U. S. Army Corps of Engineers and private contractors. Of the two methods, confined and open water, the least expensive is the latter. The disposal of dredged material next to the channel minimizes handling costs and reduces dredging time. Open water disposal has been used extensively along the Gulf Coast for the dredging of the Gulf Intracoastal Waterway and private channels, resulting in a series of small dredged material islands paralleling the channels. Many of these islands are vegetated and have been utilized as locations for fish camps, navigational aids and as nesting grounds for various species of bird life.

The dispersion of the dredged sediment creates a problem in Upper Laguna Madre. The dredged channels in the upper lagoon fill during their operational life necessitating maintenance dredging. The dredged channels in this area are part of a major seaway, the Gulf Intracoastal Waterway, dredged in 1949, and a channel complex of the Sun Oil Company, dredged in the 1950's. Field observations of the channels and the adjacent dredged material islands indicate that a majority of the material filling the channels is possibly contributed by the dispersion from the adjacent dredged material islands. With channel costs increasing due to the increasing costs of dredging, it is necessary to establish a disposal criteria to modify the present dredged material placement methods and to make predictions of the dispersion directions and rates.

PREVIOUS WORK

In previous work on dredged material, investigators have closely examined the physical, biological, and chemical effects of dredging operations. The research dealing specifically with the physical parameters has examined the dispersion of dredged material over short periods of time.

It has been the responsibility of the U. S. Army Corps of Engineers since 1824 to develop and maintain waterways. The basic construction and maintenance criteria of the Corps of Engineers for dredged channels has been empirical. Previously, Corps decisions concerning open water disposal of dredged material have been primarily based on economic considerations. Disposal costs have been minimized by depositing the dredged material in selected disposal areas near the dredging sites, but in locations that would have a minimum direct effect on other important activities in the area including beach areas, water intakes and commercial fishing areas (Meccia, et al., 1975).

The U. S. Army Corps of Engineers (1942) conducted a field and model study of Galveston Bay, Texas, to determine the origin of material causing shoaling in the ship channels. The field study included an investigation of the meteorologic and hydrologic factors influencing Galveston Bay. The Corps concluded that the stormy weather, waves and currents eroded the dredged material islands recirculating the material.

Wilson (1950) studied the effects of shell dredging on oysters and concluded that the principle factors of dredged material distribution were grain size, salt water action (flocculation), wind action, and

bottom topography. He observed that the sediment moved with the current and a considerable amount entered the channel in Copano Bay, Texas.

Hellier and Kornicker (1962) studied sedimentation from a hydraulic dredge in a bay. Their primary interests were the amount and rate of sedimentation surrounding a hydraulic dredged discharge. They suggested placement location of dredged material but failed to define the environmental conditions affecting the dredged material.

Crickmore (1968) proposed a method to predict infilling rates in newly dredged channels with the use of radioactive sand tracers. He suggested that oscillatory wave motions were effective stirrers of bottom sediment and that tidal currents carried the sediment which determined their general orientation.

Bassi (1974) tried to determine the ultimate destination of material from one unconfined dredged material area in Galveston Bay, Texas. He found that the dredged sediment covered an area three times as large as the original proposed site. He made the suggestion that extensive environmental data should be collected in future studies.

It can be concluded from the previous work that it is necessary to examine the physical, biological and chemical factors in depth to determine the physical parameters significant in dredged material dispersion and transport. In addition, it is necessary to define the principal factors controlling the rate and direction of dredged material movement.

Price (1947) defined the principal factors operating in the estuaries and lagoons along the Texas Coast as tidal currents, waves, wind driven currents, gravitational settling of sediments, chemical precip-

itation, growth of bottom dwelling organisms with the accumulation of hard parts of other organisms, and the effects of rainfall and wind on the basin margins. He also observed that the construction of ship channels and the formation of a broken line of dredged material mounds effectively segmented the lagoons and bays, breaking up wave formations and retarding the surface water movement driven by the winds. In 1952, Price realized the importance of historical data to determine inlet stability and orientation in a delta. He recommended relocation or reorientation of inlets with respect to the dominant tidal currents and wind driven currents to reduce maintenance. His recommendations were made from close observation of the inlets as they are affected by the varying tidal and wind driven currents of the area. His observations of the physical factors affecting inlets introduced the question of whether or not there would be a similar morphologic response in an enclosed lagoon unaffected by tidal change.

After the examination of historical aerial photographs of Upper Laguna Madre, it was noted that dredged material island morphologies changed over time, and that the channels varied in extent of infilling. Price's conclusion of reorientation of the channels with the direction of greatest flow may very well hold for an enclosed lagoon. Because of the recommendations made by Price, this study was conducted to further understand the erosional processes in the enclosed lagoon west of Padre Island.

STUDY AREA

The area of Padre Island and Laguna Madre at Yarbrough Pass was chosen for study to investigate the physical processes of sediment transport on the island and in the lagoon. It is an excellent area for such a study because it is close to active aeolian dune fields and the channel network in the lagoon. This area is subject to future development for public recreation and private industry and the environmental impact of this future development on the island and lagoon must be kept to a minimum. Thus, this study is very timely in light of future construction and dredging in the area.

The study area is situated in southeast Texas in an area commonly referred to as the coastal bend (fig. 1) and is bounded on the east and west by $97^{\circ} 26'$ and $97^{\circ} 22'$ west longitude and on the north and south by $27^{\circ} 16'$ and $27^{\circ} 09'$ north latitude (fig. 2). The geomorphic areas at these boundaries are Baffin Bay to the north, Padre Island to the east, Middle Ground to the south and the Texas mainland to the west. This area is in Upper Laguna Madre at Yarbrough Pass, specifically, Murdock Basin. Dredged material islands and channels examined in the study are in or surrounding Murdock Basin.

The aerial extent of the study area is approximately 7.5 miles north to south and 3 miles east to west, comprising some 22.5 square miles.

Geologic Setting

Laguna Madre is a long, narrow lagoon on the coastal plain which is part of a broad homocline downflexed on the edge of the Gulf of

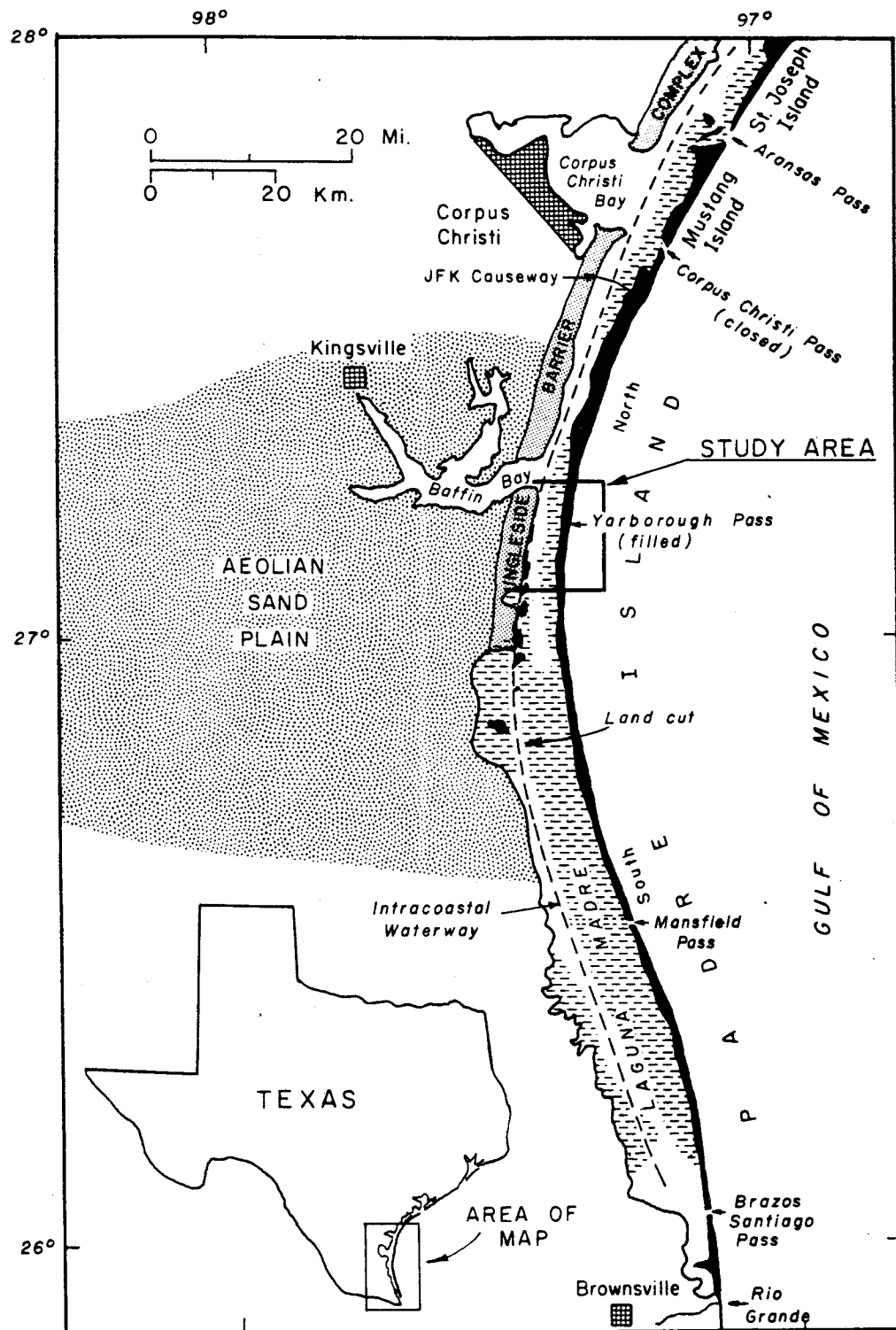


FIGURE 1. Map of the geomorphic features of the south Texas coast. The study area is in the vicinity of Yarbrough Pass

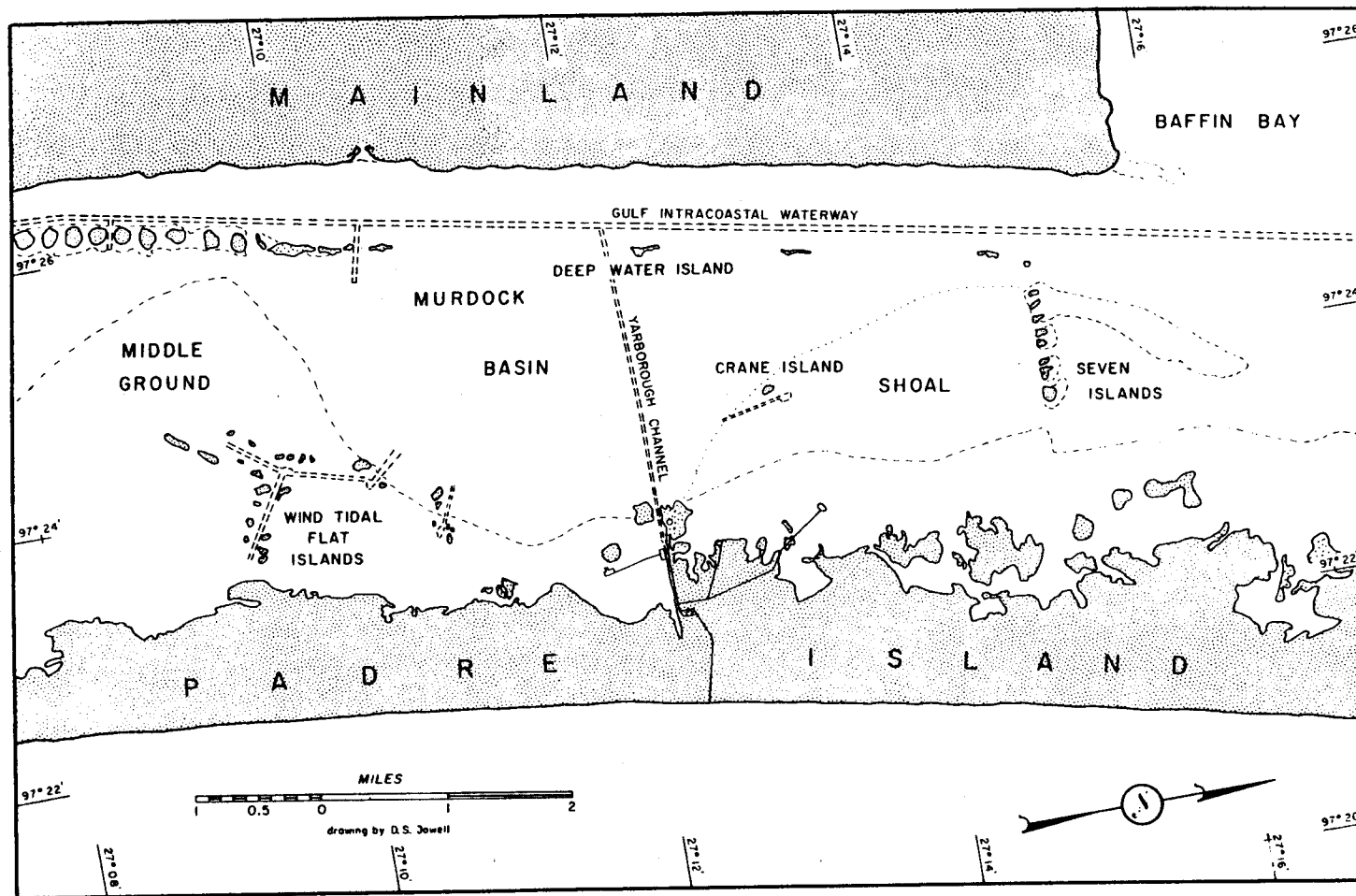


FIGURE 2. Map of study area showing dredged material islands and channel locations

Mexico geosynclinal basin. Numerous bays are developed on the coastal plain including drowned river valleys, deltaic interdistributary bays and lagoons. The bays are separated from the Gulf of Mexico by a long chain of barrier islands broken by narrow inlets.

Laguna Madre is the result of a barrier island build up with the post-glacial rise in sea level. To the west and north of the study area is Baffin Bay, a drowned stream valley formed before the build up of the barrier island (Price, 1947), and to the south is a broad aeolian plain. The surface deposits along this region are late Quaternary clayey sands spread fairly uniformly throughout the area. Outcrops of Beaumont clay can be found in Baffin Bay with late Pleistocene coquina outcropping on the shoreline at the mouth of Baffin Bay (Rusnak, 1960).

Evidence of an earlier high stand of sea level can be seen north of Baffin Bay at Flour Bluff, a ridge believed to have formed during the Sangamon stage of the late Pleistocene (Price, 1933). The earlier barrier island extended south to the Rio Grande. The sands of the southern part of this island did not stabilize and were blown inland forming a broad aeolian plain (Price, 1933).

To the east of Laguna Madre is Padre Island. Padre Island probably originated as a line of islands formed over high points on the Pleistocene surface because these points withstood wave attack and thereby served as accumulation centers for sand. The true offshore bar did not develop until the islands were tied together by littoral drift. As sea level rose, the islands shifted inland and built into the continuous feature which exists today (Fisk, 1949). Once sea level stabilized, Padre Island entered its regressive state (Fisk, 1959). Padre Island

can be described as a complex of geomorphic zones paralleling the coast; the beach, foredunes, active dune fields, marsh, deflation flats and the wind tidal flats.

The formation of barrier islands has been under debate for many years, but geologists have shown that the barrier islands of the present Texas coast formed some 5,000 years ago as the sea level stabilized after the Wisconsin glacial stage. Several theories have been proposed for the formation of barrier islands. Gilbert (1885) proposed the formation of islands through spit accretion, sand deposited by littoral currents causing spit growth at offsets along the coastline. Continuous deposition forms a peninsula which is eventually severed from the mainland by storm waves and becomes an island. Hoyt (1967) proposed that barrier islands formed as a result of submergence of the beach and dune ridge with the rise in sea level. The flats behind the dune ridge were inundated, separating the dune ridge and the beach from the mainland creating islands.

Otvos (1970) proposed that barriers were developed from offshore bars. Wave action caused an upward aggradation of submerged shoal areas and builds an offshore bar above sea level. Eventually, the bar stabilizes with vegetative cover and becomes a barrier island.

Of the proposed theories, Hoyt's (1967) is most applicable to Padre Island. The lack of open marine sediments in the lagoon suggests that the island did not form from an offshore bar. Formation by spit accretion, however, cannot be refuted because evidence of spit growth caused by longshore drift can be seen today.

Shepard (1960) in reviewing barrier island formation best summa-

rizes with "the recent Gulf Coast studies have not solved the question of local versus longshore drift origin of the barriers, but there is little necessity for deciding between the two, because both are probably important."

As described by Rusnak (1967), Murdock Basin in Upper Laguna Madre (see fig. 1) is an "inverse-filled basin whose source of sediment supply is from the sea by eroding locally available deposits and carrying them into the basin . . .". An inverse-filled basin is one of several types of estuarine sedimentation. Rusnak also defines temperate estuaries with moderate run-off as positive-filled basins which are filled by lateral distribution of suspended river and biological materials. He defines non-filling estuaries as neutral-filled basins in which the basin sediment is redistributed without a change in volume. An example of a neutral-filled basin might be the smooth oval lakes and inlets on the east side of the Mississippi Deltas where local erosion occurs due to tidal currents (Shepard, 1960).

The concept of an inverse-filled basin is emphasized by the work of Mathewson, et al. (1975). A hurricane breach of the foredune wall moves beach and dune sand toward the lagoon. Aeolian processes create a dune field which migrates across the island continuously being replenished by the aeolian transported beach sands. Historical aerial photographs show that some dune fields move more than 100 feet per year toward the lagoon (Piper, 1975). The wind tidal flats are the result of the sand migration, and this large expanse of flats has divided Laguna Madre into the upper and lower sections.

Bathymetry

Upper Laguna Madre has a centrally sloping floor on the east side with a few elongated basins on the west side (Rusnak, 1960). The west side of Murdock Basin is from six to eight feet deep shallowing eastward to the flats. Water depths average 15 feet in the Gulf Intracoastal Waterway. The west and northwest edges of the basin are rimmed by shallow platforms of carbonate cemented coquina reefs covered by extensive layers of sepulid worm tubes and barnacles (Rusnak, 1960). Parts of these platforms have been destroyed by the dredging of the Gulf Intracoastal Waterway. Subaerial islands resulting from dredging in this area have a composition of a highly erosion resistant mixture of reef boulders and coarse shell. Other sediments consist of Holocene sands and muds which are slowly covering Pleistocene sediments at an estimated rate of 0.4 feet per 100 years (Rusnak, 1960).

Climate

The climatic conditions of Upper Laguna Madre are classified as semi-arid (Thorntwaite, 1948) with evaporation exceeding precipitation and run-off (Pritchard, 1952). The 50 year record of the mean annual rainfall is 21 inches per year (Rusnak, 1960). As a result this estuary is hypersaline. The Upper Laguna Madre salinities may vary from 22 to 45 parts per thousand chlorinity. Extremes have been recorded within the lagoon up to 113.9 parts per thousand salinity (Hedgpeth, 1953). Variations of salinity due to cloud bursts and excessive run-off last only a short time.

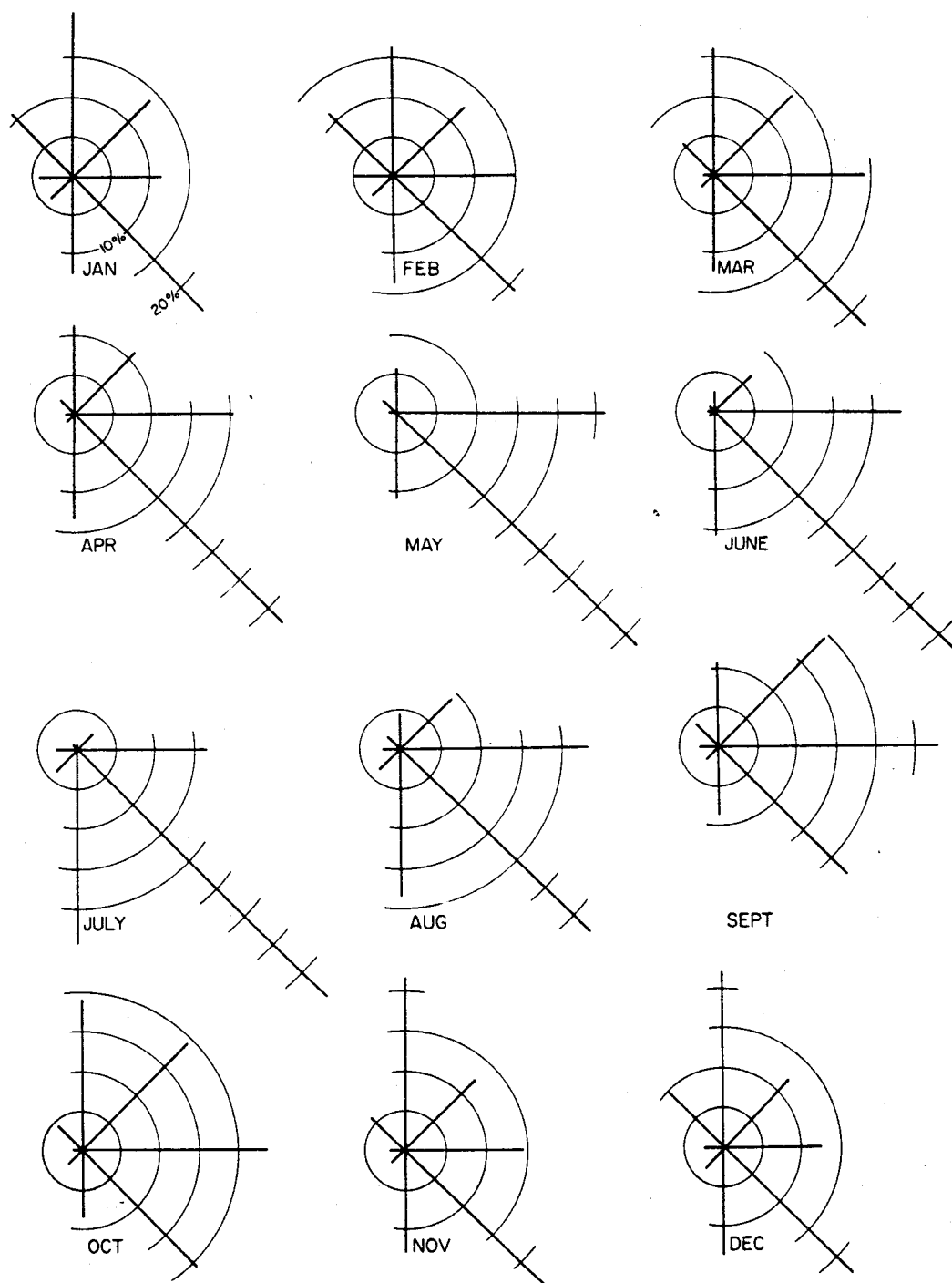
Channel dredging has increased circulation between basins, decreasing salinities slightly and reducing the occurrence of salt deposits, but the hypersalinity is still high enough to reduce the size of various fauna in the area, for example, Mulinia lateralis, Pholas Campechiensis, and Tagelus (Hunter, et al., 1972).

As noted by Price (1952) and Stinson and Clary (1974), wind in South Texas is subequally divided in velocity, direction and duration between the strong offshore, longshore, "northers" of winter and the equally strong and prevailing onshore southeasterly winds of summer. Wind roses of wind frequencies recorded at Corpus Christi (fig. 3) illustrate the higher frequency of occurrence of "northers" in the winter months.

Wind intensities varied from the gentle southeasterly breezes of 6-10 mph to "northers" gusting over 50 mph. Southeasterly winds maintain a constant velocity in fair weather picking up in the afternoon with the development of thermal convections over the land. "Northers" almost always associated with storms produce winds of usually higher intensity, though frequency of occurrence is a great deal less annually as seen in the wind roses (fig. 3).

Fetch

Fetch lengths of the wind for the island locations change as the basin configuration changes. Changes in the basin referred to are basin infilling and segmentation. Infilling creates shoals limiting the water depth and wave action. As shoaling increases parts of the lagoon become segmented which shortens the fetch for potential wave



% FREQUENCY OF WIND BY DIRECTION AT CORPUS CHRISTI
(1887-1968)

FIGURE 3. Frequency of wind by direction at Corpus Christi. Note that the southeast wind has a higher frequency during the year (U. S.N.W.S.C., 1970)

propagation. The basin shape changes as it is segmented to maintain an equilibrium with the current forces. Basin infilling and segmentation lowers the current forces allowing for more material to settle out (Price, 1947). With the formation of lines of dredged material islands the basin is segmented and fetch lengths are further reduced, decreasing wave size and propagation.

Tides

Water level changes in Laguna Madre are not tidal effects but wind effects. Lunar tidal differences in the area on the outer coast of Padre Island may vary from -3.0 feet at lowest water to +1.0 feet at high water. In Corpus Christi Bay, the water exchange from bay to Gulf is restricted to Aransas Pass and Corpus Christi fish pass, keeping tidal fluctuations restricted to 0.5 to 1.5 feet. Laguna Madre is further separated from Gulf tidal circulation by a solid fill causeway, the John F. Kennedy Causeway from Flour Bluff to Padre Island. The causeway effectively reduces tidal flow into Laguna Madre to make it insignificant as a factor affecting water circulation and water level change in the lagoon. No effect is felt in the study area some 30 miles south of the causeway. To the south of the study area, the next Gulf inlet is Mansfield Pass some 35 miles away. Tidal influence has been seen up to the land cut separating Lower and Upper Laguna Madre, at which point tidal influence ceases (Rusnak, 1960).

Circulation

The circulation of water in Upper Laguna Madre is controlled by wind. Wind tides can vary depths in Upper Laguna Madre from 1 to 4 feet. (Rusnak, 1960) depending upon wind directions. The restrictions created by dredged material islands in the lagoon and the narrow passages to the Gulf waters creates a lag time for water level equilibration from tidal surges in the Gulf. Prevailing winds from the southeast create a northern circulation in Laguna Madre, which continues as the wind maintains the steady south to north direction. Water will move into southern Laguna Madre through Mansfield cut and slowly move north through the land cut into Upper Laguna Madre. Similarly, north winds will blow water to the south through the land cut into southern Laguna Madre.

The water removed from Murdock Basin by the south winds moves north raising the water levels in the north lagoon near the causeway. As noted by Brandes et al., (1970), equilibration of the water level at the causeway due to wind set up takes some 8 hours. With a change of wind direction to the north, the water is blown back to the south into the basins raising the water level and inundating the wind tidal flats.

Extreme weather conditions will create excessive water flow. With high intensity storms high winds create wind tidal surges into Murdock Basin increasing the water level which allows for larger waves and increases the wave erosion of the dredged material islands.

Hurricanes will blow enough water into the basin to raise the water level above the dredged material islands. Island erosion is low at this time. As noted by Miller (1975), the energy release of waves is manifested for the most part in the bore of the wave which shapes the foreshore. With the extreme high water covering the islands neither breakers nor bore have a chance to form, reducing erosion.

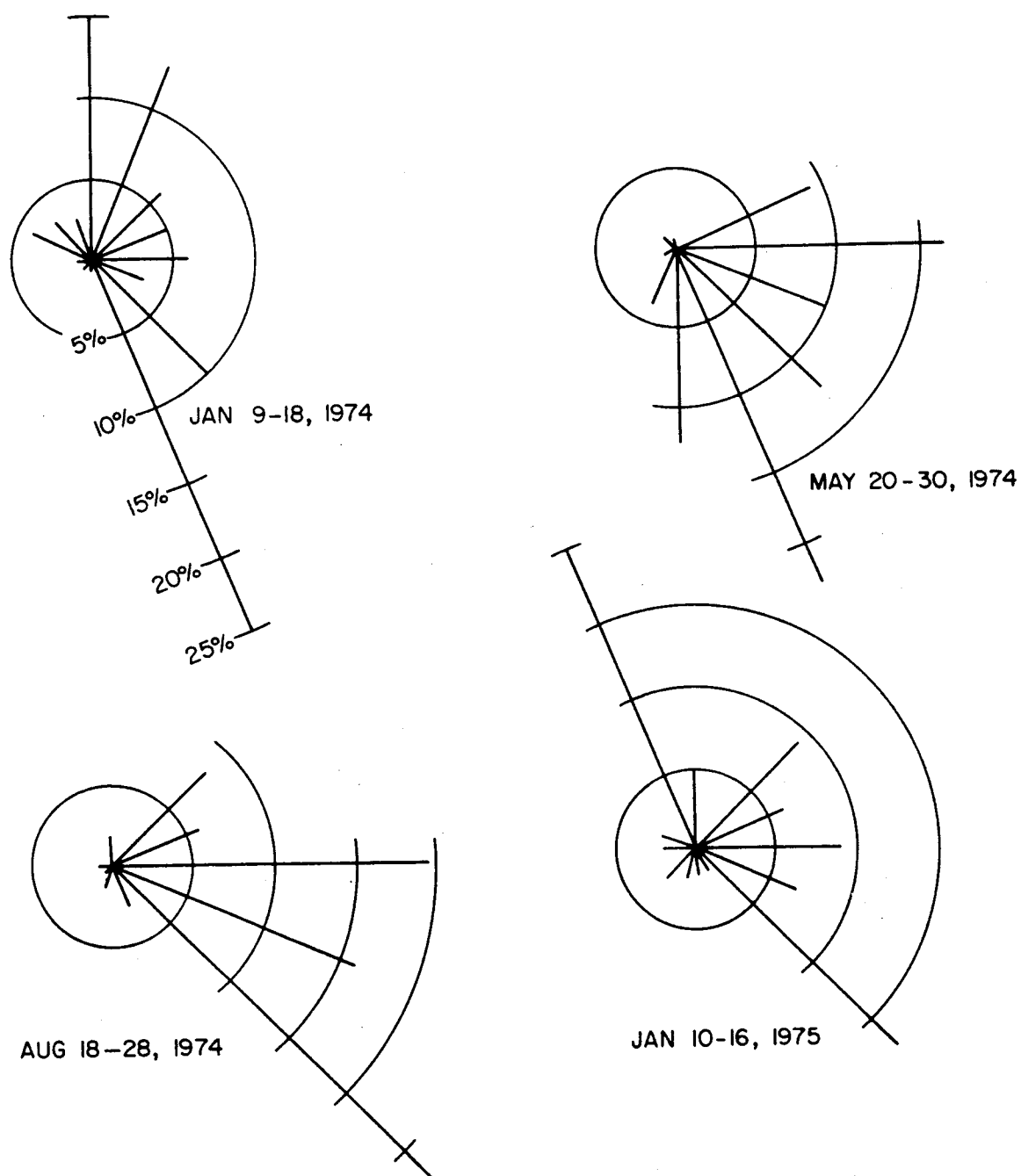
INVESTIGATION

This project was funded by Sea Grant and Sun Oil Company to study sand transport across Padre Island and into Laguna Madre. Field work for the study was spaced over a two year period to take advantage of the changing weather and water conditions controlling sediment transport. Field surveys were conducted in the months of January 1974, May 1974, August 1974, and January 1975.

Field and Volumetric Measurements

During the field surveys the weather was monitored hourly from a temporary weather station. Weather observations were made with the use of an electrical anemometer with a remote display unit giving wind velocity and direction. (Fig. 4 shows wind roses of study area.) This instrument was mounted 30 feet above the ground, 39 feet above sea level. Wet and dry bulb temperatures were measured with a sling psychrometer and barometric pressure measured with an aneroid barometer. Wind direction changes could be easily correlated with variations in pressure and temperature to delineate the passing of frontal systems in the area and to anticipate conditions of high sediment entrainment within the lagoon.

Current measurements for water circulations, to confirm the observation of Rusnak (1960) were made at the south end of the study area in the Gulf Intracoastal Waterway. The measurements were made by timing current drogues over a measured distance. The current drogues consisted of surface floats with metal fins set at depths from 3 to 9 feet below the surface (fig. 5). Measurements were made just after



% FREQUENCY OF WIND BY DIRECTION AT YARBOROUGH PASS

FIGURE 4. Wind roses compiled from data recorded at the weather monitoring station during field investigation

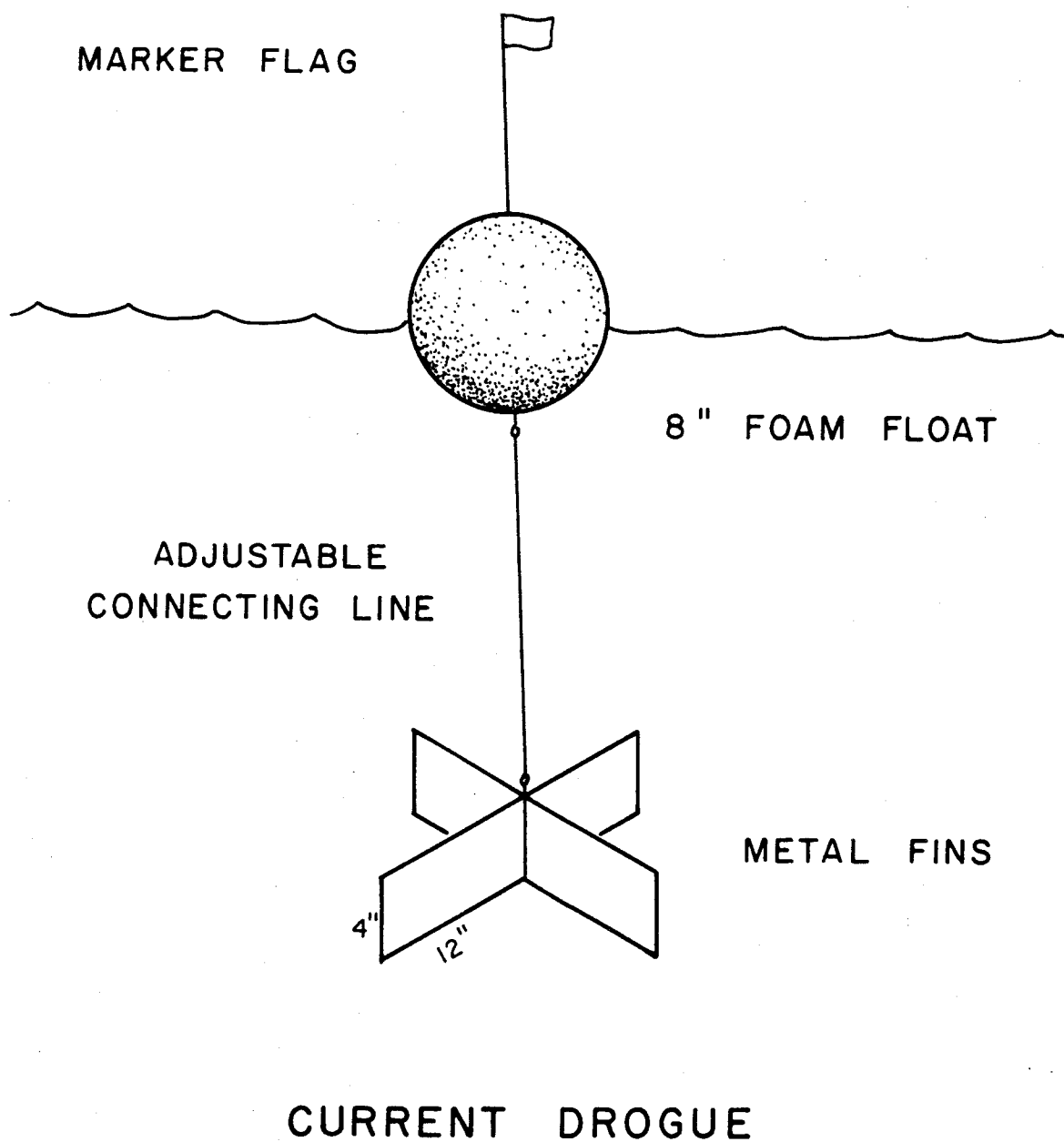


FIGURE 5. Sketch of drogue used for current measurement in Murdock Basin

a wind shift from northwest to southeast and after the wind had blown for 24 hours from the southeast.

Four locations for the dredged material investigation were selected with the aid of aerial photographs and nautical charts. These locations included the wind tidal flats, the Seven Islands complex, Crane Island and a deep water island next to the Gulf Intracoastal Waterway (fig. 2). Each island was surveyed to establish the present island morphology. Surveys were conducted with a transit and stadia rod to map the subaerial areas, vegetation and prominent features. An arbitrary baseline was established at the water line on the day of the survey. For a bathymetric survey around the island two methods were employed. Range poles were set on the island to control eight ranges 45 degrees apart extending offshore. In shallow water a rodman aligned himself with a set of range poles and walked offshore keeping himself aligned with the range and choosing points to be surveyed. At each point the transit man recorded a bearing on the stadia rod and the water depth. In deep water it was necessary to use the R. B. Spoilbank, a 16 foot flat bottom aluminum boat. The operator piloted the craft along each range line at a fixed speed. At the beginning and end of each run, the survey team recorded a bearing on the boat to locate its position on the range line. As the boat moved along the range, the crew recorded the indicated water depths from the depth sounder every 15 seconds. These offshore surveys were then used to define the extent of the dredged material dispersion.

To study the dredged material dispersion and volume change, historical air photographs of the site were measured and compared. The 1953 photographs show the island configurations before alteration by

erosion. Comparing the 1953 and 1960 photographs and the 1974 field surveys an estimate of area and volume change over the 20 year period was made.

Calculation of 1953 Island Volumes

The volumes of the dredged material islands were calculated by the use of a K & E planimeter. To establish the area, 1953 aerial photographs of the island locations were enlarged in scale for close measurement, and a circle of the same area was assumed for the calculation of the radius. It was assumed that the initial configuration of the islands was a half prolate spheroid, the volume of which is:

$$V = \frac{1}{2} (4/3\pi a^2 b)$$

a = the radius of the island

b = the height of the island

The height of the island is assumed not to vary significantly over time due to the tight scrub vegetation protecting the top of the island from washover or aeolian processes. To check the island volume, the volume of sediment removed from the channel is estimated by measuring the length and width of the channel and assuming a depth of six feet as specified to the Corps of Engineers. Island volume calculations are within 5 per cent of the initial sediment volume removed from the channels.

Volume Calculation for the 1974 Islands

Volumes of the 1974 islands were calculated by using contour maps plotted from field survey data. The area contained within each contour

was measured with a K & E planimeter. To calculate the volume the method of slices was used. Each contour defines a slice, and the volume of each slice is equal to the measured area times the contour interval, 0.5 feet. This method assumes a stepped surface on the island which is not valid. To account for the volume between the contour area edges, the area within the inner contour is subtracted from the area within the outer contour to give the area of the annulus. The area of the annulus is multiplied by the contour interval, 0.5 feet, and then by $\frac{1}{2}$ to give the volume of the annulus with a slope from the inner contour to the outer contour. The assumption of a straight slope from contour to contour is validated by field observation.

Sediment Sampling and Analysis

Sediment sampling was conducted on and around the dredge material islands using two methods. Plastic core tube was used to sample sediments on the islands and in shallow water. A metal capped core tube of approximately four feet in length was driven into the sediment with the use of a sledge hammer to a depth of 3.5 feet. Once the tube had been driven into the sediment, it was pulled or dug out depending on the ease of withdrawal. With the removal of the tube, the ends were sealed to prevent loss of moisture and sediment. A clam shell sampler was used to sample sediments in the channels and areas too deep for the manual coring method. Grab samples were packed into Whirl-pac bags to be analyzed for texture. Additional samples were taken with a 2.5 foot hand coring device and bagged for later analysis. Sample locations are plotted on a map of the study area (fig. 6).

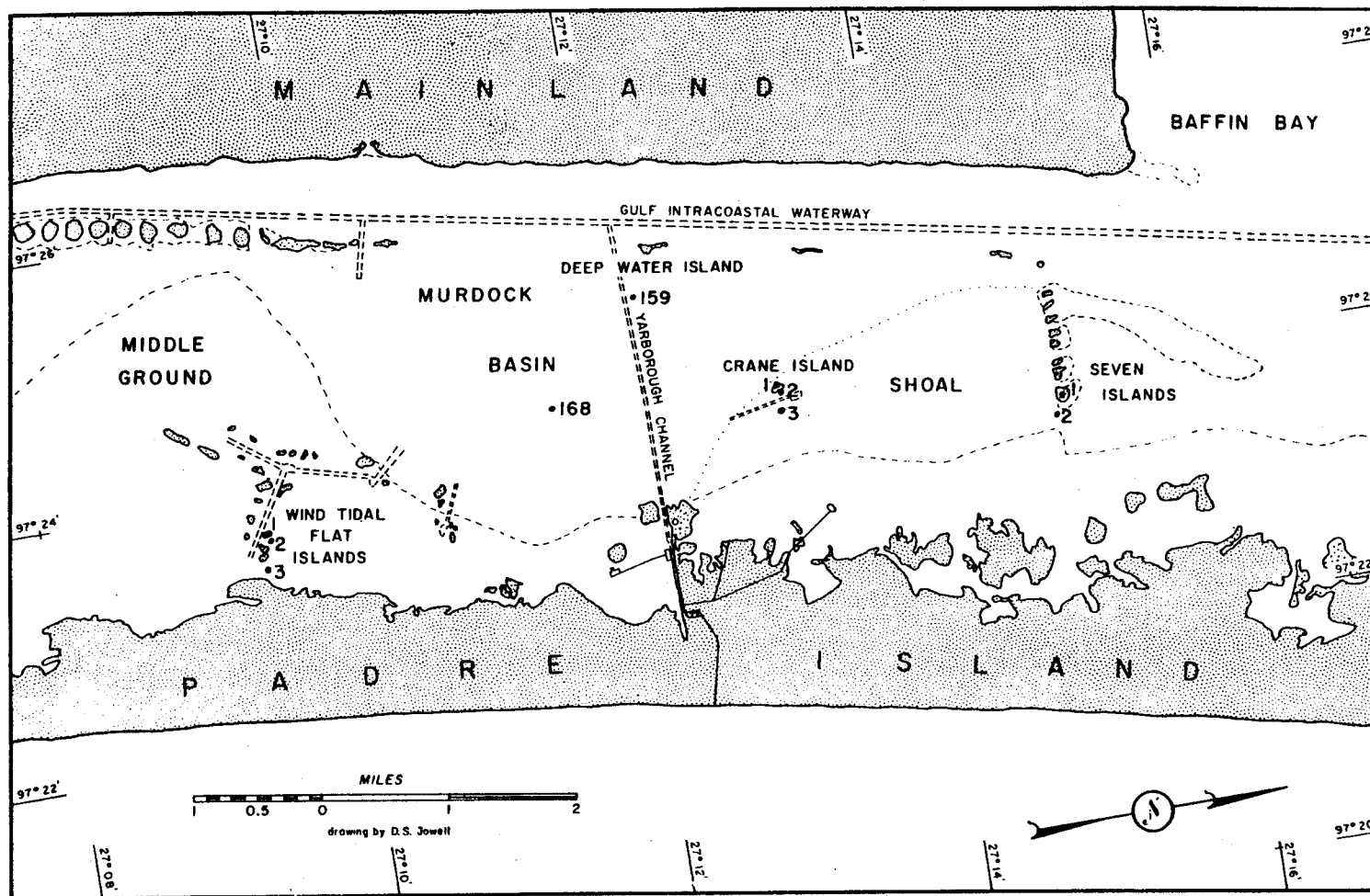


FIGURE 6. Location of samples collected from Murdock Basin

To retrieve the core sediments the core tube was cut with a power saw. The core was carefully cut in half with a spatula, one half to be used for textural analysis, the other to be impregnated. The core was impregnated using the method described by Burger et al., (1969). The ratio of epoxy to hardener used was 5 parts of #6005 epoxy, 5 parts of #6010 epoxy to 3 parts of #850 hardener and 1 part of #830 hardener. For a core approximately 3 feet in length one part equalled 30 ml.

After experimenting with Burger's method it was found that a better relief-peel could be made if the core was allowed to dry for several hours before impregnation. Masking tape was used around the edge of the core tube to make a trough $\frac{1}{2}$ inch deep. The epoxy was slowly poured into the trough with care to avoid disturbing the sediment. The epoxy set up in several hours and cured in 24 hours. Because of the brittleness of the epoxy, pieces of string were used as reinforcing material to increase the strength of the epoxy and core. The impregnated core was removed from the tube by pulling a screw-driver tip the length of the core between the epoxy and the core tube. Unimpregnated sediments were removed by blowing forced air over the core leaving an undisturbed section representing the near surface stratigraphy.

The remaining core half was sampled for textural analysis. Sediment samples to be analyzed for particle size and distribution (using the method described by Folk, 1968) were first wet sieved through a 63 micron sieve to separate the muds from the shell and sands. The muds if of sufficient quantity were then transferred to 1000 ml cylinders for pipette analysis. The remaining sand and shell was dried and sieved through a 500 micron sieve to separate the sand

and shell. The sand fraction was analyzed for particle size with a visual accumulation tube as described by Colby and Christensen (1956).

CHARACTERISTICS OF SEDIMENTS IN THE STUDY AREA

Bed Description

The undisturbed lagoon floor is a relatively smooth surface of dark gray to black organic muds held by an algal mat. Where the mat has been removed dark gray, very fine sands and broken shell are exposed. Small scale bed forms i.e., ripples and scour marks could be seen in areas having sufficient current. Dredged channels cutting the lagoon interrupt the smooth flat lagoon floor and are lined with black organic muds which are unconsolidated and have little cohesion.

The dredged material deposits show a distinct smooth and barren surface characterized by a gray, very fine sand and broken shell. Small scale ripples can be seen when there is a sufficient water movement i.e., wind tidal currents or wave oscillations. The dredged material deposits are quite distinct and can be easily delineated from the lagoonal sediments by their color difference and lack of organic material.

Texture

Laguna Madre appears to have three dominant sediment types which are found in various mixtures. The most dominant type is the Padre Island sand, a fine to very fine grained aeolian sand. The sands are found throughout the lagoon intermixed with varying proportions of muds and shell. The shell concentrations are dominant in washover zones on the eastern shore of the lagoon and the western shore at locations of ancient bioherms. Dredged material islands near this western shore are

principally shell, the finer material having been removed by current winnowing. Areas of less vigorous current activity are characterized by fine sands and silt and clay layers agglutinated by algal mats.

Dredged material island sediments show similar distribution trends. The deep water islands near the western shore are dominantly broken shell with eroded concretions from the dredging of the reef complex in the area. The shoal water islands are composed of the fine sand with limited shell and various amounts of silt and clay trapped in the surrounding algal mats. The islands in the wind tidal flats are dominated by the barrier island sand and have low amounts of suspended material as a result of the seasonal drying conditions and absence of the algal mat. Silt and clay content is generally lower in the dredged sediments because of the winnowing process taking place during sediment discharge from the dredge. Silts and clay will easily go into suspension and are transported away from the disposal sites.

Size analysis of the sediments showed a phi range of ϕ 1.0 (0.5 mm) to ϕ 4.0 (0.0625 mm) with mean values from ϕ 2.45 (0.183 mm) to ϕ 3.02 (0.123 mm) for areas outside the disposal areas and ϕ 2.13 (0.228 mm) to ϕ 3.01 (0.124 mm) in the disposal areas (see Table 1). Calculating a mean grain size for each core revealed an increasing phi value for cores outside the disposal area. This is attributed to the dredging and the separation of the coarse and fine fractions when the slurry is discharged. The very fine grained sands, silts and clays are remaining in suspension and are removed from the discharge area by currents.

Sorting characteristics vary throughout the core samples but

Table 1. continued

	<u>Shell</u>	<u>Sand</u>	<u>Silt</u>	<u>Clay</u>	<u>φ₅₀</u>	<u>σ</u>	<u>d_{50mm}</u>	
Seven Islands core #2 ESE of disposal area	7.8	36.3	23.5	32.4	2.71	.49	0.153	
	2.4	58.2	17.0	22.4	2.67	.46	0.157	
	1.7	96.1		2.2	2.57	.43	0.168	
	7.1	42.1	14.1	36.7	2.45	.46	0.183	
	3.2	92.3		4.5	2.75	.49	0.149	
	5.4	52.0	11.8	30.8	2.51	.39	0.176	
Wind Tidal Flat Island core #1	3.7	93.9		2.4	2.45	.28	0.183	
	2.4	55.4	14.6	27.6	2.85	.41	0.139	
	4.1	95.2		0.7	2.47	.39	0.180	
Wind Tidal Flat Island core #2	54.1	44.9		1.1	2.44	.48	0.184	
	3.4	96.6			2.69	.35	0.155	
	14.2	72.2	11.0	2.6	2.78	.48	0.146	
	4.3	90.6	4.0	1.1	2.50	.39	0.177	
Wind Tidal Flat Island core #3	2.5	94.4		3.2	3.02	.70	0.123	
	1.3	80.0	2.1	16.6	2.84	.75	0.140	
		86.3	5.6	8.1	2.69	.40	0.155	
	6.9	80.6	4.3	8.2	2.83	.53	0.141	
	3.8	76.2	1.9	18.1	3.21	1.23	0.108	
	1.9	82.5	5.6	10.0	2.96	.88	0.129	
	3.8	85.0	1.9	9.3	2.67	.30	0.157	
Samples in center of	158	15.3	34.6	29.5	20.6	2.97	.47	0.128
Murdock Basin	169	20.9	46.3	21.0	11.7	3.04	.48	0.122

Note: Values found in the column between Silt and Clay are the combined percentages of the Silt and Clay fractions.

$$\sigma_{\phi} = \frac{1}{2}(\phi_{16} - \phi_{84})$$

when averaged (Table 2.) show differences in sorting from one location to the next. Sediments in the Crane Island area show an increased value for the sorting coefficient of dredged material, a value of σ_p , .44 and .42 as compared to .34 of sediments undisturbed by dredging.

This difference is not apparent at the seven islands location with values of σ_p .46 for dredged material and .45 for lagoonal sediments.

The wind tidal flat sediments show a decrease in the sorting coefficient in contrast to the other areas. This location is unique to the shoal water areas and deepwater in that it has periods of drying. Sediments introduced by aeolian processes appear to affect the sorting. Dredged sediments do not show this effect because of winnowing during times of inundation removing the fine sediments.

The most distinguishable characteristic of the dredged sediments is the silt and clay content. Lagoonal sediments have a larger percentage of fines. Averaged values for core samples of Crane Island show 6% mud in the dredged sediments, 31% in lagoonal sediments, Seven Islands dredged material 16%, lagoon 33%, wind tidal flats show 9% island, 14% flats. In contrast, grab samples from the middle of Murdock Basin have 32% to 50% silt and clay. The lower percentage in the dredged material is attributed to the dredging process resuspending the material, and the wind tidal currents dispersing it from the disposal site.

The sand-shell-mud contents of the samples at Crane Island are plotted on a triangle diagram (fig. 7). A comparison of the dredged material to lagoon samples near Crane Island and samples from the

Table 2. Averaged values of mean grain size and sorting coefficient for sample locations

	ϕ_{50}	σ_{ϕ}	d_{50mm}
Crane Island core #1	2.72	.44	0.152
Crane Island core #2	2.76	.42	0.148
Crane Island core #3	2.89	.34	0.135
Seven Islands core #1	2.54	.46	0.172
Seven Islands core #2	2.61	.45	0.164
Wind Tidal Flats core #1	2.59	.36	0.166
Wind Tidal Flats core #2	2.60	.43	0.165
Wind Tidal Flats core #3	2.89	.68	0.135

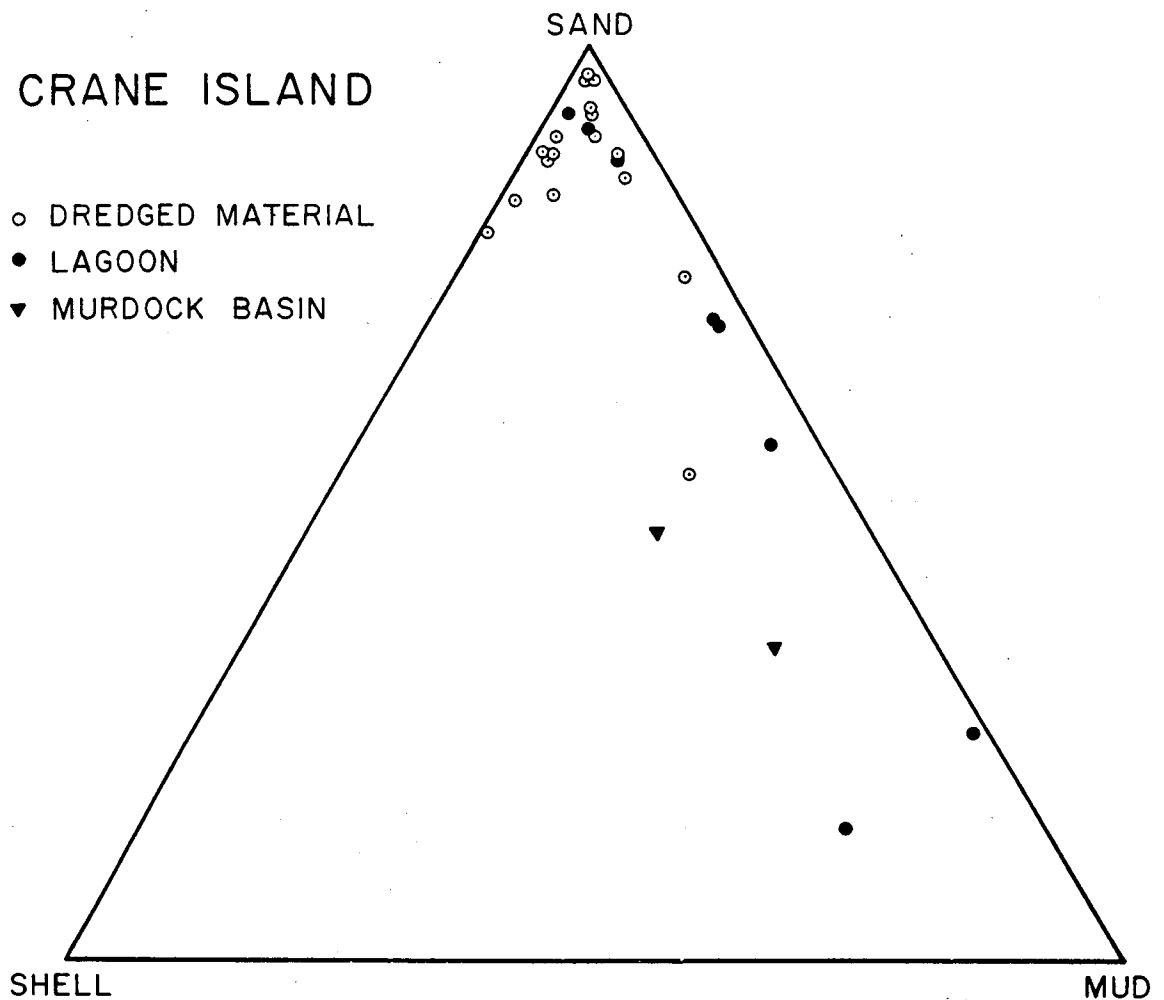


FIGURE 7. A triangle diagram of sand-shell-mud contents of samples in the Crane Island area. Dredged material represents samples taken on the island and in the dispersion area. Lagoon represents samples taken outside of the dispersion area. Murdock Basin represents samples from the center of the basin away from major disposal areas

middle of Murdock Basin show that the dredged material is low in mud with a high percentage of sand. This is attributed to the dredging process and current action at the time of disposal. A similar trend of the sand-shell-mud is seen at the Seven Islands location (fig. 8). At the wind tidal flats the mud content is comparatively lower than the other sites (fig. 9). The high velocity, shallow water flow across the flats during high winds carries the mud in suspension off the flats into the lagoon. With the flats blown dry the winds then winnow much of the silts and clays out of the sediment and carry it away. In each triangle diagram two samples from the center of Murdock Basin have been plotted to act as a reference for comparison with the other samples and to further illustrate the difference of the sand-shell-mud content between dredged material and the lagoonal sediments.

The sand-silt-clay triangle diagrams show the high sand content in the dredged sediments. The surrounding lagoonal sediments at Crane Island (fig. 10) and Seven Islands (fig. 11) have a higher silt-clay content. The wind tidal flats (fig. 12) again show a very low percentage of silt and clay for the surrounding area. Samples from the center of Murdock Basin have been plotted on each diagram and show a similarity to the samples of Crane Island and Seven Islands but are again quite different from the wind tidal flats. It might be mentioned here that the dredged material is dominantly sand and once deposited on the lagoon floor little or no compaction will occur. Island heights will stay the same except for change due to erosion.

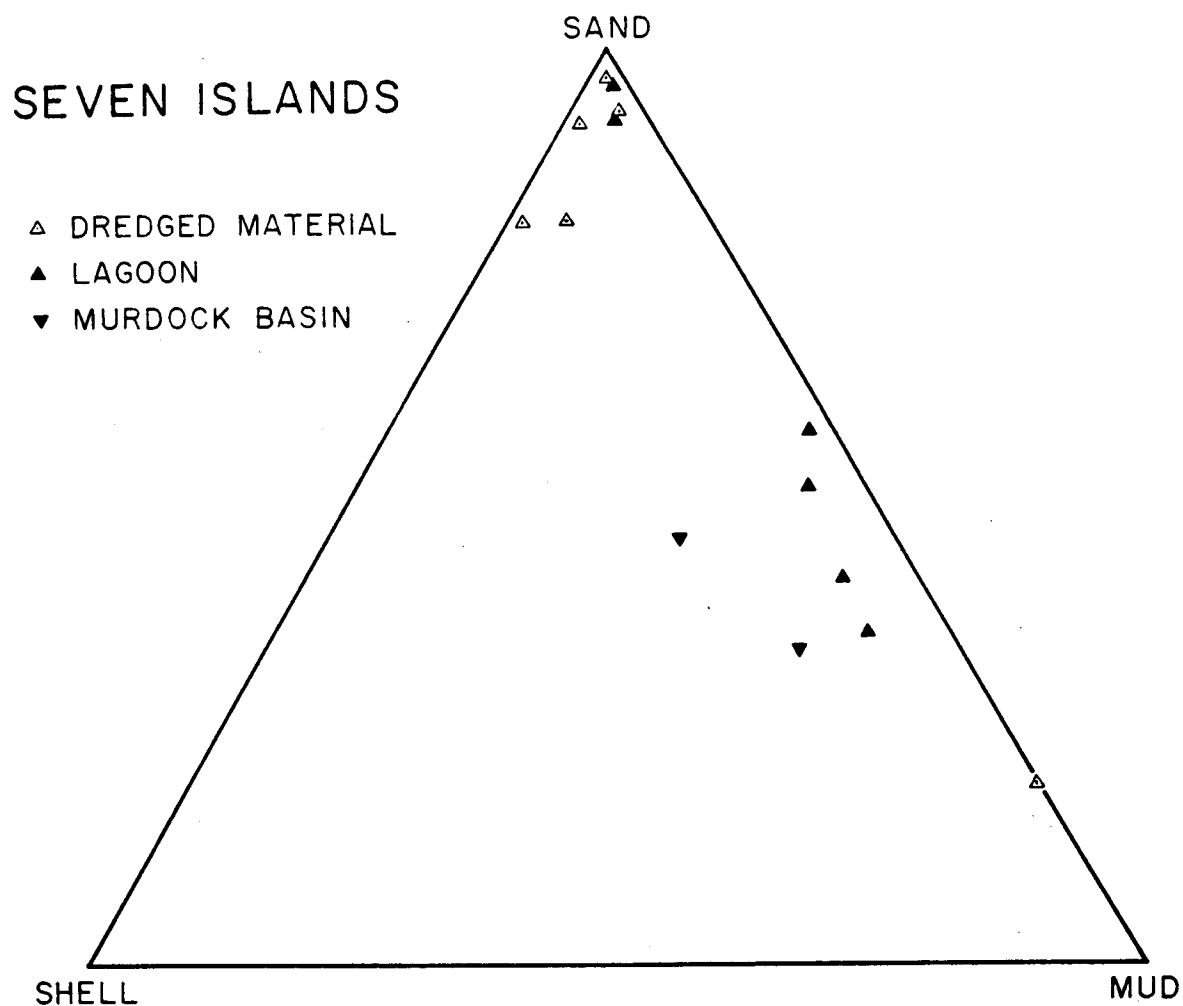


FIGURE 8. A triangle diagram of sand-shell-mud contents of samples in the Seven Islands area. Dredged material represents samples taken on the island. Lagoon represents samples taken outside of the dispersion area. Murdock Basin represents samples from the center of the basin away from major disposal areas

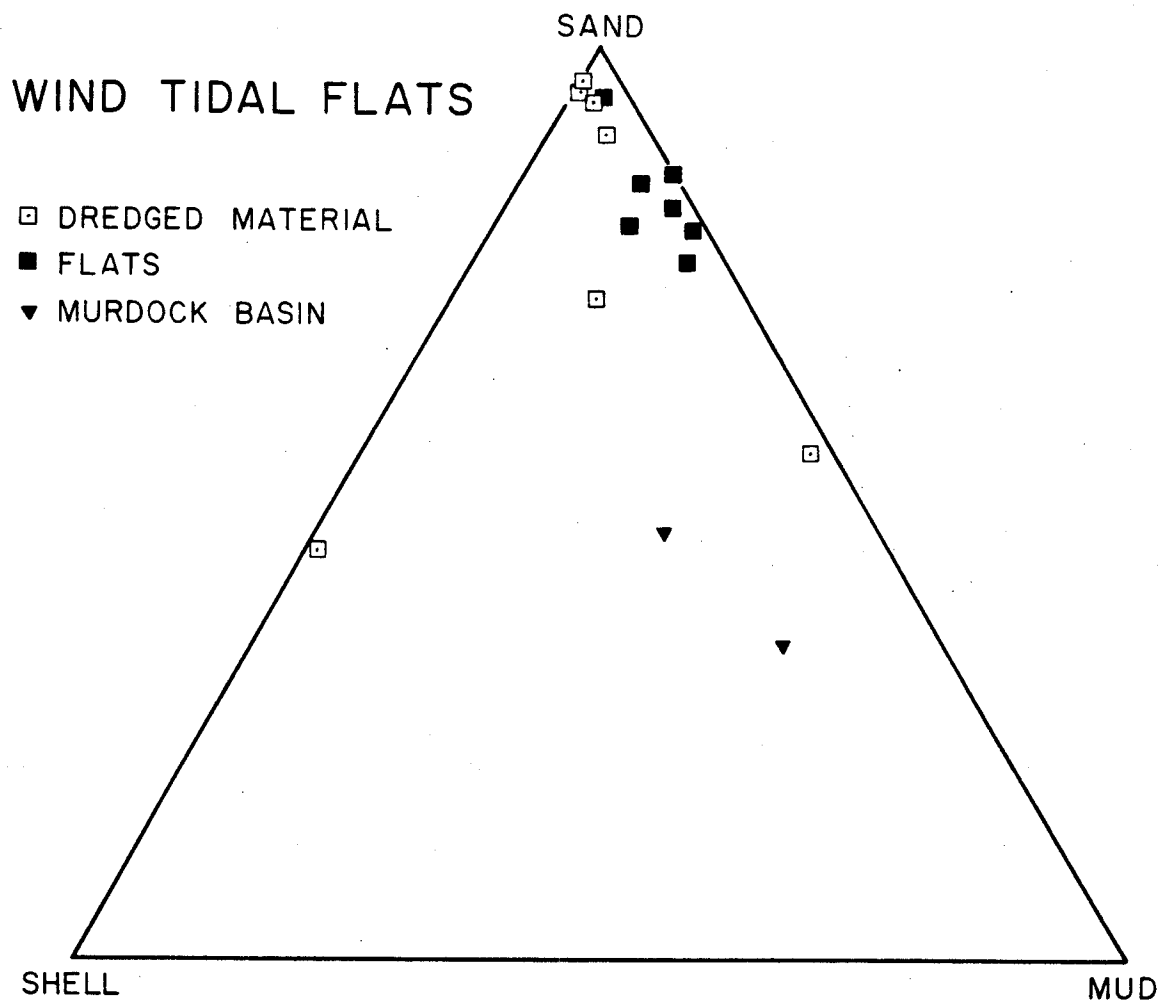


FIGURE 9. A triangle diagram of sand-shell-mud contents of samples in the wind tidal flats. Dredged material represents samples taken on the island and in the dispersion area. Flats represents samples taken on the flats outside of the dispersion area. Murdock Basin represents samples from the center of the basin away from major disposal areas

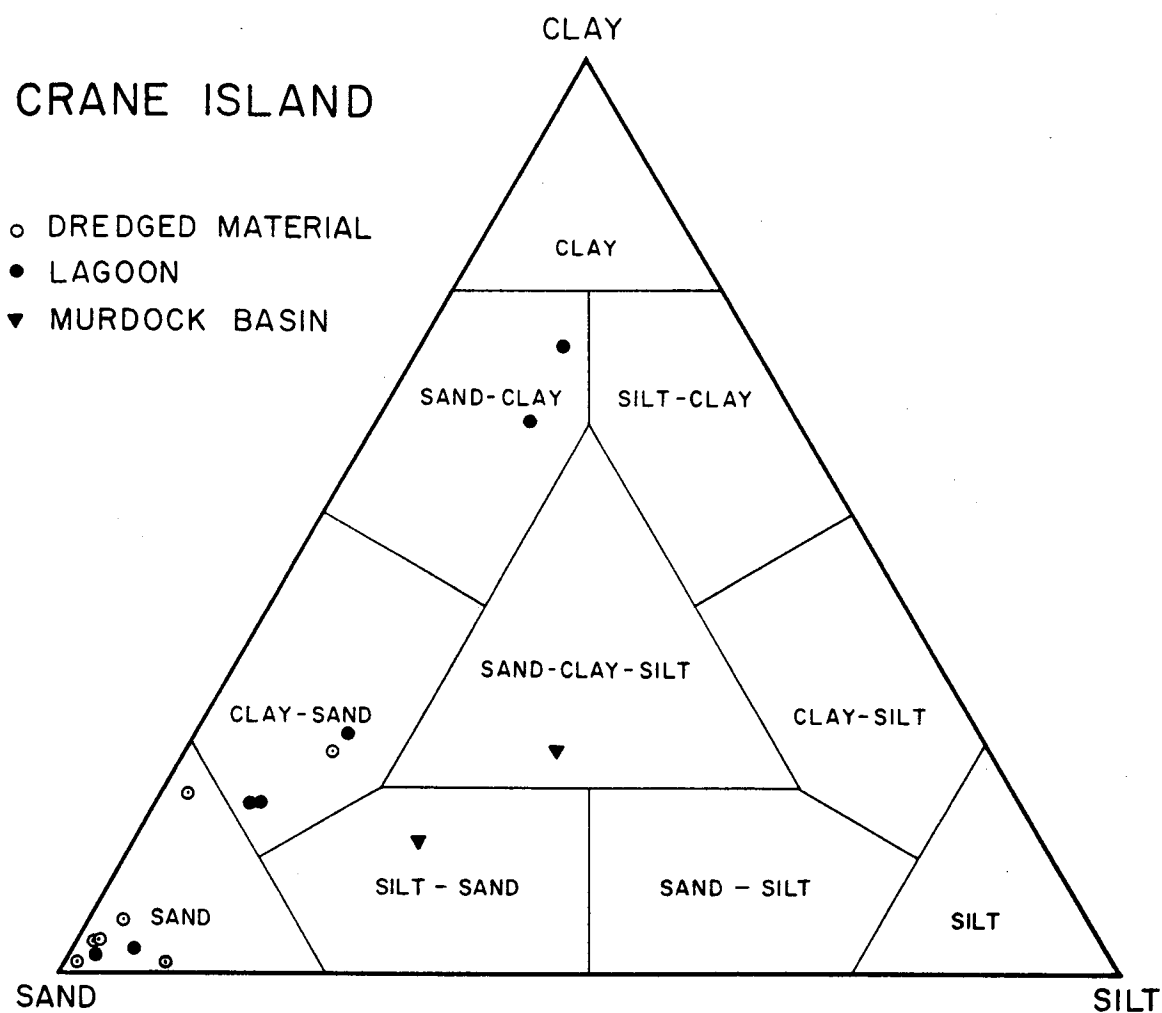


FIGURE 10. A triangle diagram of sand-silt-clay contents of samples in the Crane Island area. Dredged material represents samples taken on the island and in the dispersion area. Lagoon represents samples taken outside of the dispersion area. Murdock Basin represents samples from the center of the basin away from major disposal areas

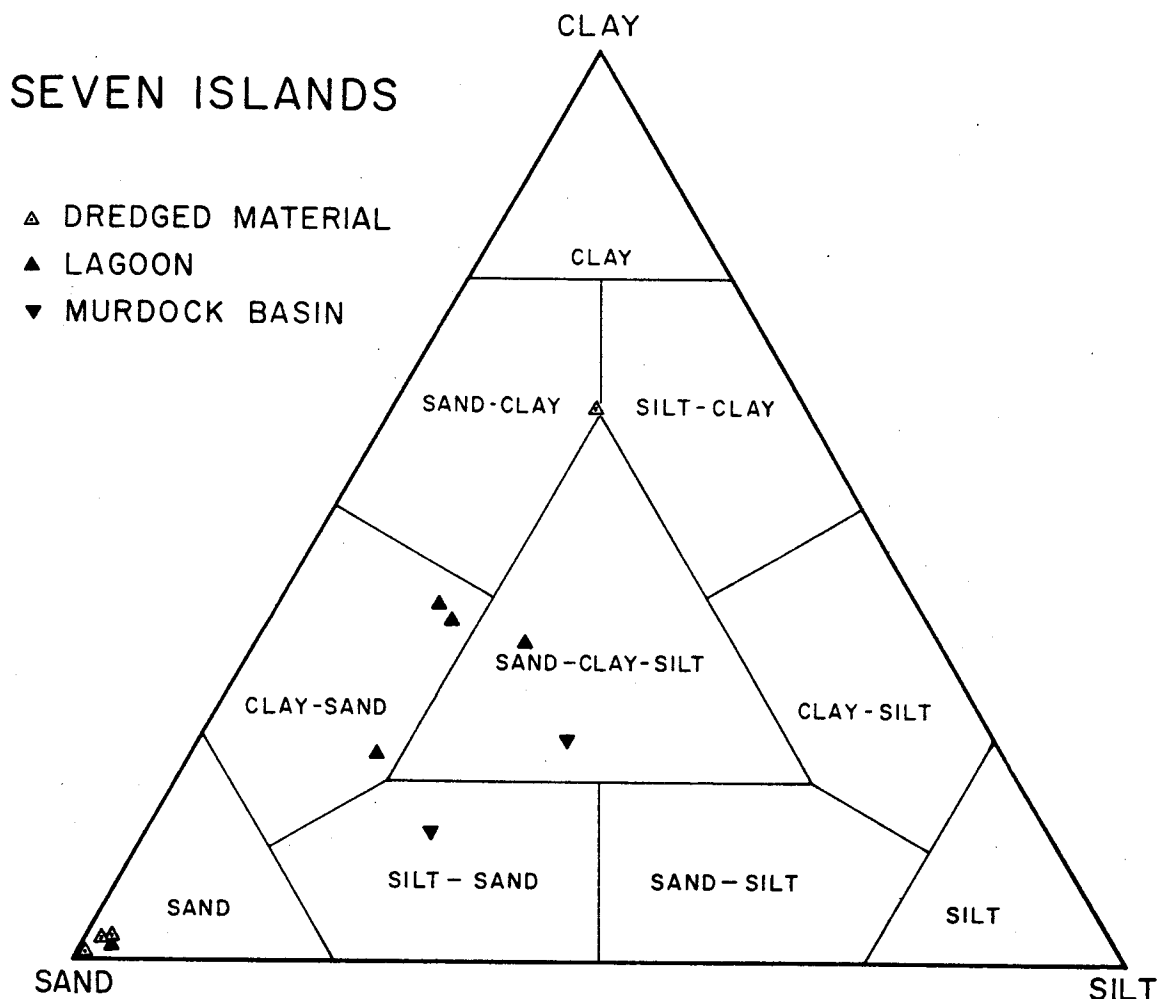


FIGURE 11. A triangle diagram of sand-silt-clay contents of samples in the Seven Island area. Dredged material represents samples taken on the island. Lagoon represents samples taken outside of the dispersion area. Murdock Basin represents samples from the center of the basin away from major disposal areas

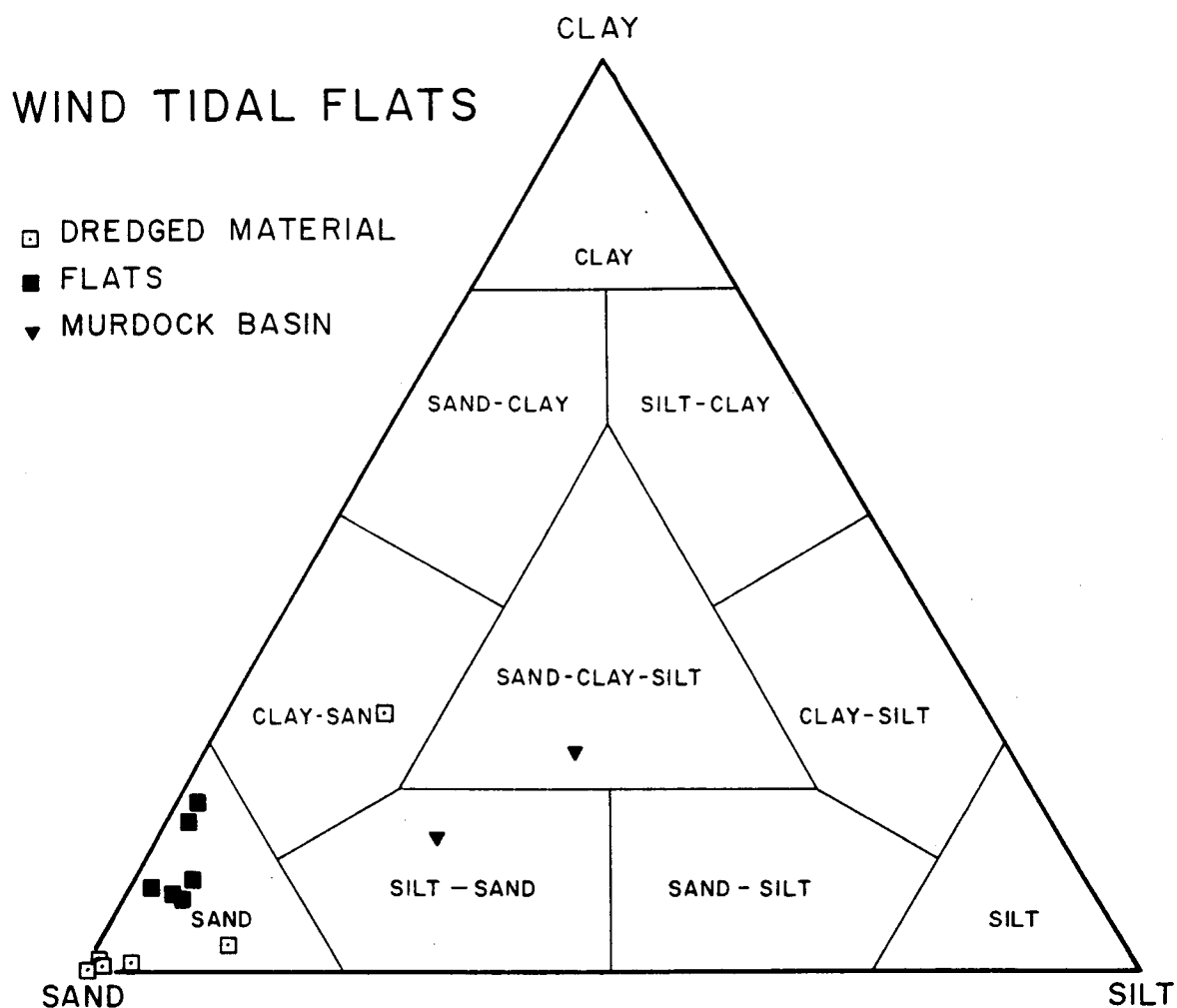


FIGURE 12. A triangle diagram of sand-silt-clay contents of samples in the wind tidal flats. Dredged material represents samples taken on the island and in the dispersion area. Flats represents samples taken on the flats outside of the dispersion area. Murdock Basin represents samples from the center of the basin away from major disposal areas

MECHANISMS OF SEDIMENT TRANSPORT

The purpose of this discussion is to provide a general correlation between the physical forces and the resultant effects. The waters of Upper Laguna Madre are relatively unaffected by astronomical tides; currents in the lagoon are the result of wind.

The current velocity necessary to dislodge a sand grain from the bottom is called its critical velocity, and the rate at which the grain settles back to the bottom is termed the settling velocity. The interaction of the sediment settling characteristics and the flow characteristics of the water mass determines whether sediments remain at rest or are transported (Inman, 1949).

The critical velocity of grains is a function of the grain diameter, density of sediment, density of water, acceleration of gravity, packing coefficient of sediment and the angle of repose of grains on bottom. Most of these variables are relatively constant at any given time. The size of a grain and the slope angle of the bottom seem to be the most important factors controlling the critical velocity.

Sundborg (1956) conducted experiments to determine the critical velocity by determining a velocity gradient above the sediment water interface and then relating these velocities at a given point, one meter above the bed, to the initial movement of the sand grains. The relationship of flow velocity to grain size has been plotted by Postma (1967) using data from Sundborg (1956) and his own observations (fig. 13).

As can be seen from figure 13, the critical erosion velocity

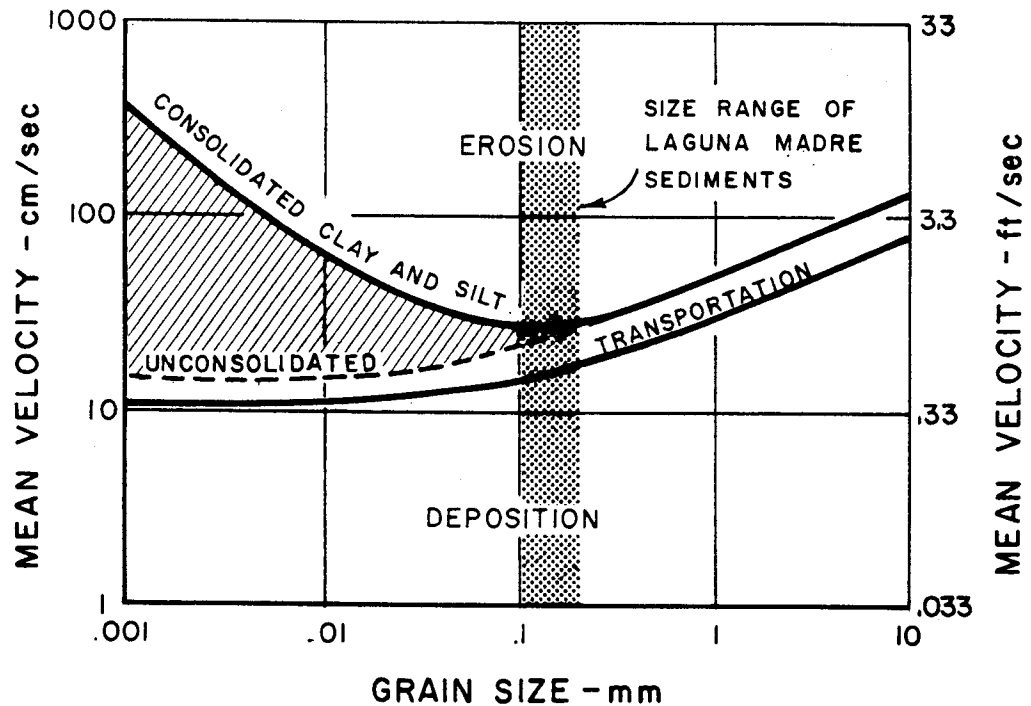


FIGURE 13. Erosion, transportation, and deposition velocities for different grain sizes. Velocities shown are at 15 cm above bottom (after Postma, 1967)

increases directly with grain size for grains above 0.2 mm. Below this size, in the silt and clay range, degree of consolidation becomes a controlling factor in that the highly consolidated clays require a greater velocity to initiate erosion. The erosion curve requires a 30% greater velocity than deposition, and it increases as the sediments become finer and more consolidated. The physical significance of this is that a fluid mass is able to carry as suspended load material that it would not be able to scour at the same velocity. Once a particle has

been put into suspension, it may not settle until the velocity drops sufficiently to allow deposition, an important factor in shoaling in estuaries.

The shallowness of the estuary is such that water movement due to wave action is felt at the bottom. Movement at the bed will scour the sediments and introduce them into the suspended load subject to transport by currents. Figure 13 shows the velocities necessary for scour and erosion for the particular grain sizes.

Table 3 presents a brief summary of the wave properties associated with wind velocity and water depth in the study area. The horizontal velocity at the bottom for the wave components has been calculated for average wind velocities and two extreme conditions. During average wind condition, erosional velocities are only recorded in the shallow water, 2 to 4 feet deep, and 25 mph wind velocity. Extreme conditions listed show high horizontal velocities at the bed. It should also be noted that except during calm periods the bottom velocities are sufficient to transport material originally suspended during dredge discharge spreading the material over a wide area. The purpose of this paper is not to examine the dispersion or resuspension immediately following the dredging but after many years. The following discussion examines dredged material island alteration over a 20 year period.

Table 3. Summary of calculated wave data for the study area,
Fetch = 3 mi,

Wind Velocity (mph)	Wave Height (feet)	Wave Period (sec.)	Water Depth (feet)	Horizontal Velocity @ Bottom (ft/sec)
12	0.44	1.09	2	0.31
	0.59	1.31	4	0.16
	0.65	1.41	6	0.07
	0.68	1.49	8	0.03
25	0.69	1.34	2	0.75
	1.07	1.68	4	0.66
	1.27	1.89	6	0.51
	1.40	1.99	8	0.36
30	0.27	0.89	0.5	0.81
50	2.11	2.36	6	1.36

Note: Equations 3-25 and 3-26 of Shore Protection Manual, 1973 were used for calculations.

$$\frac{gH}{U^2} = 0.289 \tanh \left[0.578 \left(\frac{gd}{U^2} \right)^{0.75} \right] \tanh \left\{ \frac{0.0125 \left(\frac{gF}{U^2} \right)^{0.42}}{\tanh \left[0.578 \left(\frac{gd}{U^2} \right)^{0.75} \right]} \right\}, \quad (3-25)$$

and

$$\frac{gT}{2\pi U} = 1.20 \tanh \left[0.520 \left(\frac{gd}{U^2} \right)^{0.375} \right] \tanh \left\{ \frac{0.077 \left(\frac{gF}{U^2} \right)^{0.25}}{\tanh \left[0.520 \left(\frac{gd}{U^2} \right)^{0.375} \right]} \right\}, \quad (3-26)$$

H = wave height (ft)

g = 32 ft/sec²

U = wind velocity (mph)

d = depth (ft)

F = fetch (ft)

T = period (sec)

DREDGED MATERIAL ISLAND DISPERSION

The problem of sediment dispersion is ubiquitous when open water disposal methods are used. In the study area open water disposal was used to minimize channel dredging costs, but this has not proved to be the case. Due to the physical conditions present in Laguna Madre many of the channels have filled because of sediment movement from the disposal sites. Sediment movement is anticipated but the quantity and direction is unknown. The dredging permit design has not taken into account the extensive sediment dispersion characteristic of the area. A simplified design sketch is seen in figure 14, and figure 15 is a typical design cross-section of the disposal site after the proposed dredging. The designer has placed the dredged material 200 feet from the channel believing this to be a sufficient distance to keep sediment from moving back into the channel. Unfortunately, his assumption was not correct.

This study has examined several locations in Laguna Madre; shoal water disposal islands, wind tidal flats disposal islands, and a deep water disposal island in an attempt to define the factors which control the dredged sediment movement and the extent of dispersion.

Shoal Water Islands

The shoal water islands studied are Crane Island and Seven Islands located in the northern section of Murdock Basin (see fig. 16). These islands have been designated as shoal islands because they are on a shoal and are surrounded by water that does not exceed 3 feet in depth except during extreme conditions. These islands are composed of

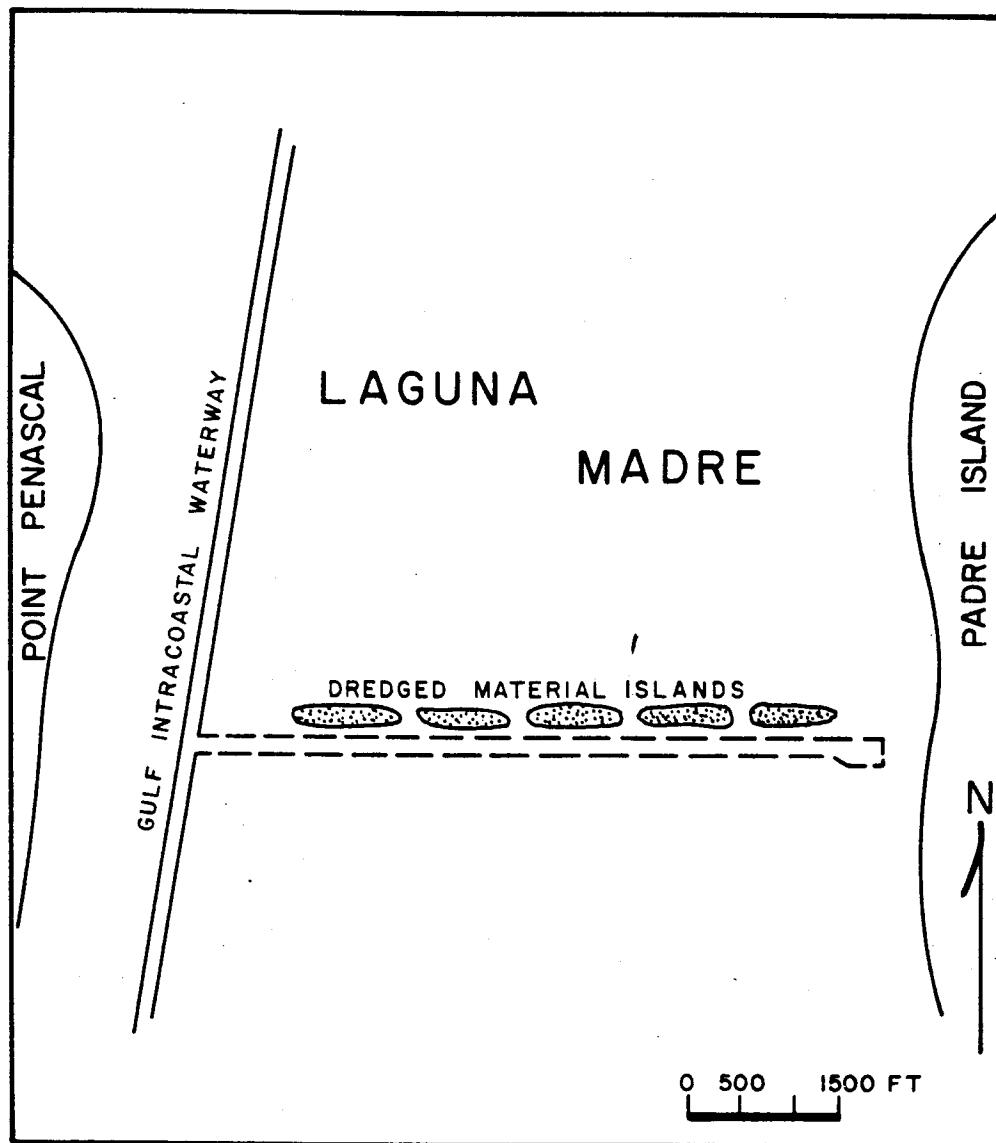


FIGURE 14. Simplified sketch of the design for the dredging permit submitted to the U. S. Army Corps of Engineers

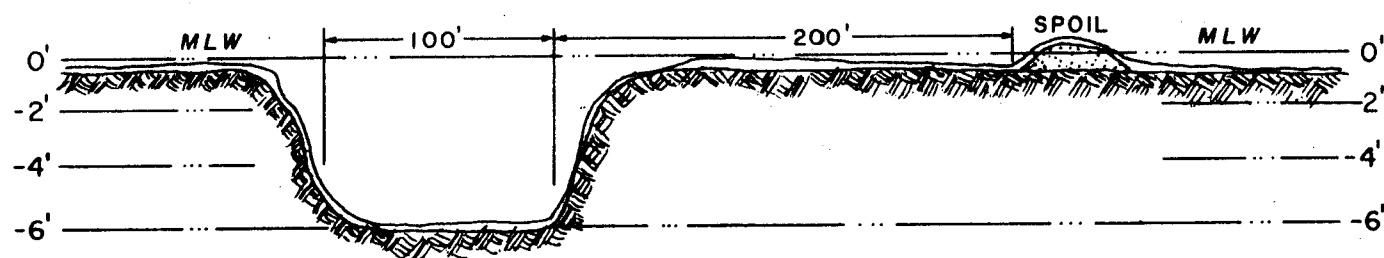


FIGURE 15. A sketch of a typical cross-section from the design permit submitted to the U. S. Army Corps of Engineers

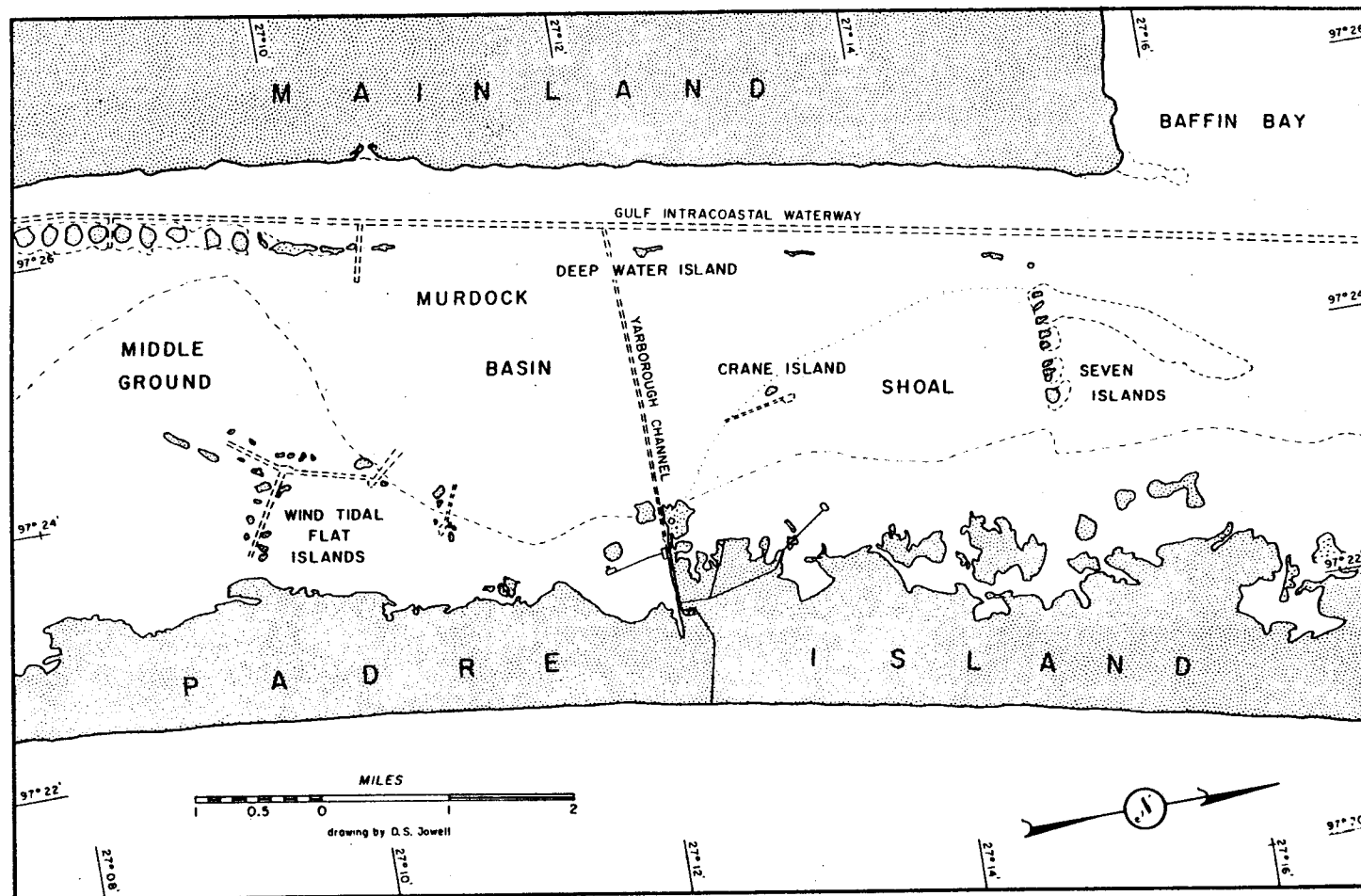


FIGURE 16. Location map of specific dredged material island sites in Murdock Basin

sand, shell and mud and are subaerial with a covering of dense scrub vegetation. Surrounding the islands is a fine sand covered by an algal mat holding silts and clays.

As mentioned earlier the winds vary the water depth from 1 to 4 feet covering or exposing large parts of the island shore lines. This variation in water depth appears to be a major factor in the island erosion. To know if the original island volume has changed a comparison of aerial photographs and volumes was made.

Crane Island Volume

For the volume calculation for the 1953 and 1974 island, a height of 4.5 feet was assumed. This assumption is valid because of evidence of an impact crater from the original dumping process.

Crane Island as defined in 1974 is the remains of a series of islands formed in 1953 (fig. 17). A comparison of the island outlines (fig. 18) shows that there has been a considerable amount of sediment movement. Using the method for volume calculation as described previously a volume of 29,808 cubic yards was calculated for the 1953 Crane Island. In 1974, Crane Island had a volume of 28,702 cubic yards, a decrease of 4 percent of the original 1953 volume. Over a twenty year period this is a loss of about 55 cubic yards a year if it is assumed that the island erodes at a constant rate. This author believes this assumption to be invalid until the island reaches an equilibrium shape. Once at equilibrium, erosion would then be a function of the varying water depths and wave intensities from the time of initial island formation, a more accurate estimate of the erosion rate is impossible.

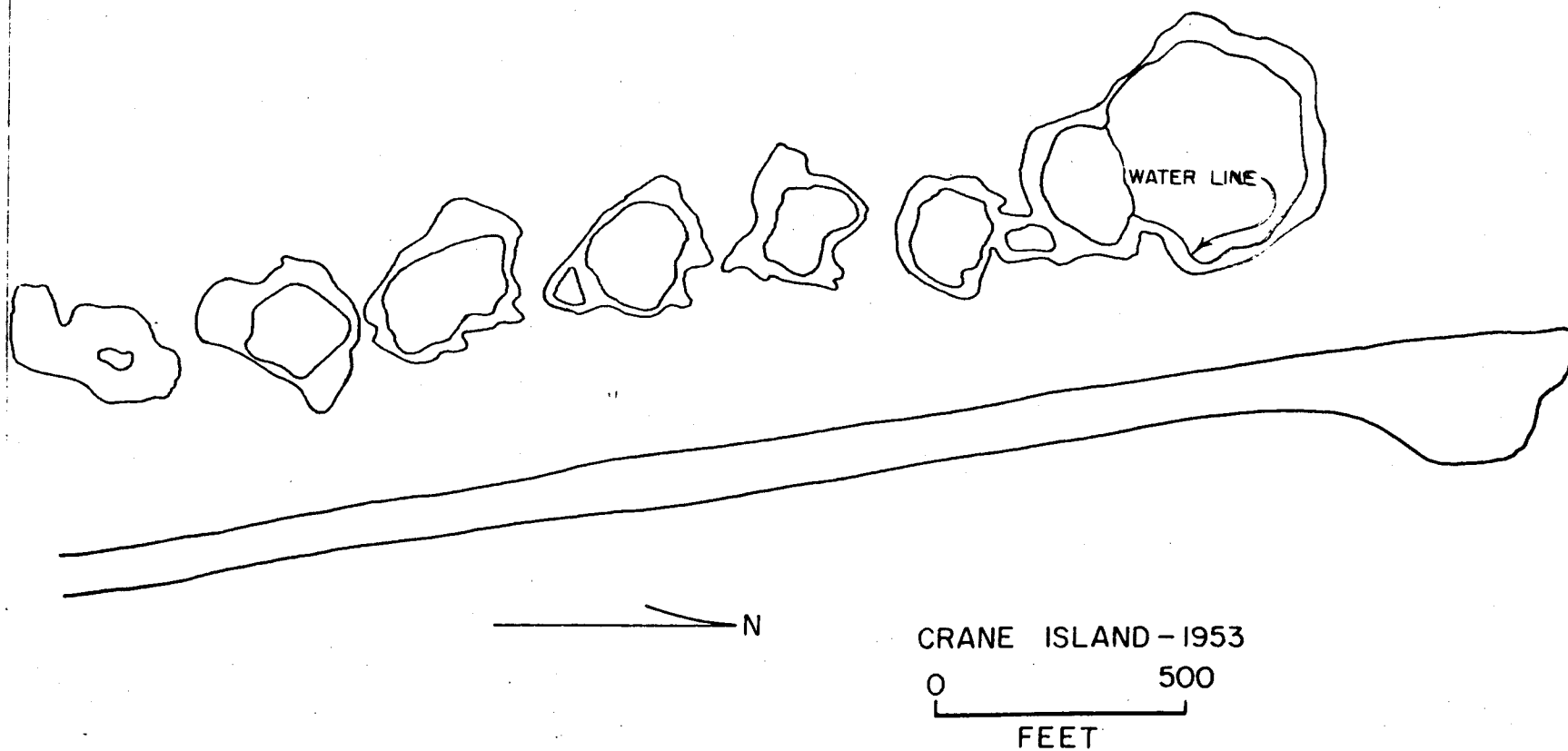


FIGURE 17. Channel and dredged material islands at the Crane Island location in 1953 soon after dredging was completed

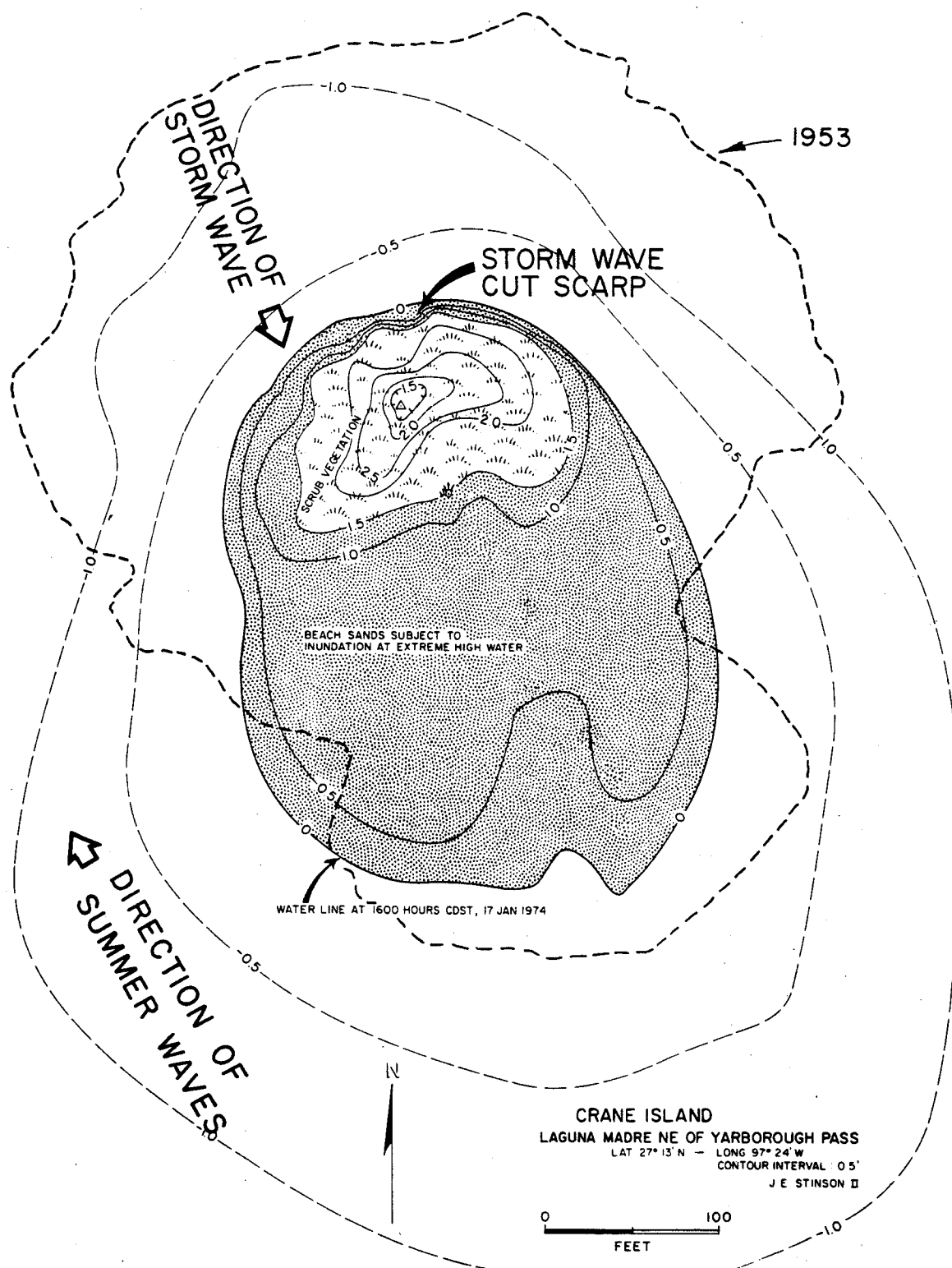


FIGURE 18. Topographic map of Crane Island in 1974 compared with the 1953 island outline. A majority of the island sediment has moved to the south

As can be seen in figure 18, much of the sediment has moved to the south, yet there is only a loss of 4 percent of the original volume. This suggests that there has not been a loss of material into the adjacent channel but a shift of location along the channel. The channel has not acted as a trap for the sediment because of its alignment with the dominant wind directions. The prevailing southeast winds blow water to the north carrying sediment parallel to the channel and north winds move water and sediment to the south parallel to the channel.

Crane Island Area

A comparison of the Crane Island areas of 1953 (fig. 19), 1960 (fig. 20), and 1974 (fig. 21) was made to estimate the extent of dispersion of the dredged sediments. The area of dispersion is delineated by the contrast of the unvegetated dredged material next to the vegetated lagoon bottom. The subaerial areas were differentiated by the light colored dry sand, the darker sand on the circumference of the island was assumed to be underwater. Areas are listed in table 4.

The total area of Crane Island in 1953 was measured at 6.16 acres, by 1960 this area had increased 164 percent and in 1974 the total dispersion area was 354 percent of the original configuration.

The 1953 subaerial area was 4.31 acres, and it had decreased by 61 percent by 1960. From 1960 to 1974 the area decreased only three percent more. The erosion rate is not linear. At some point in the history of the island an equilibrium configuration was attained and the erosion rate became very low. The decrease of erosion over time is attributed to the development of the equilibrium profile of the island

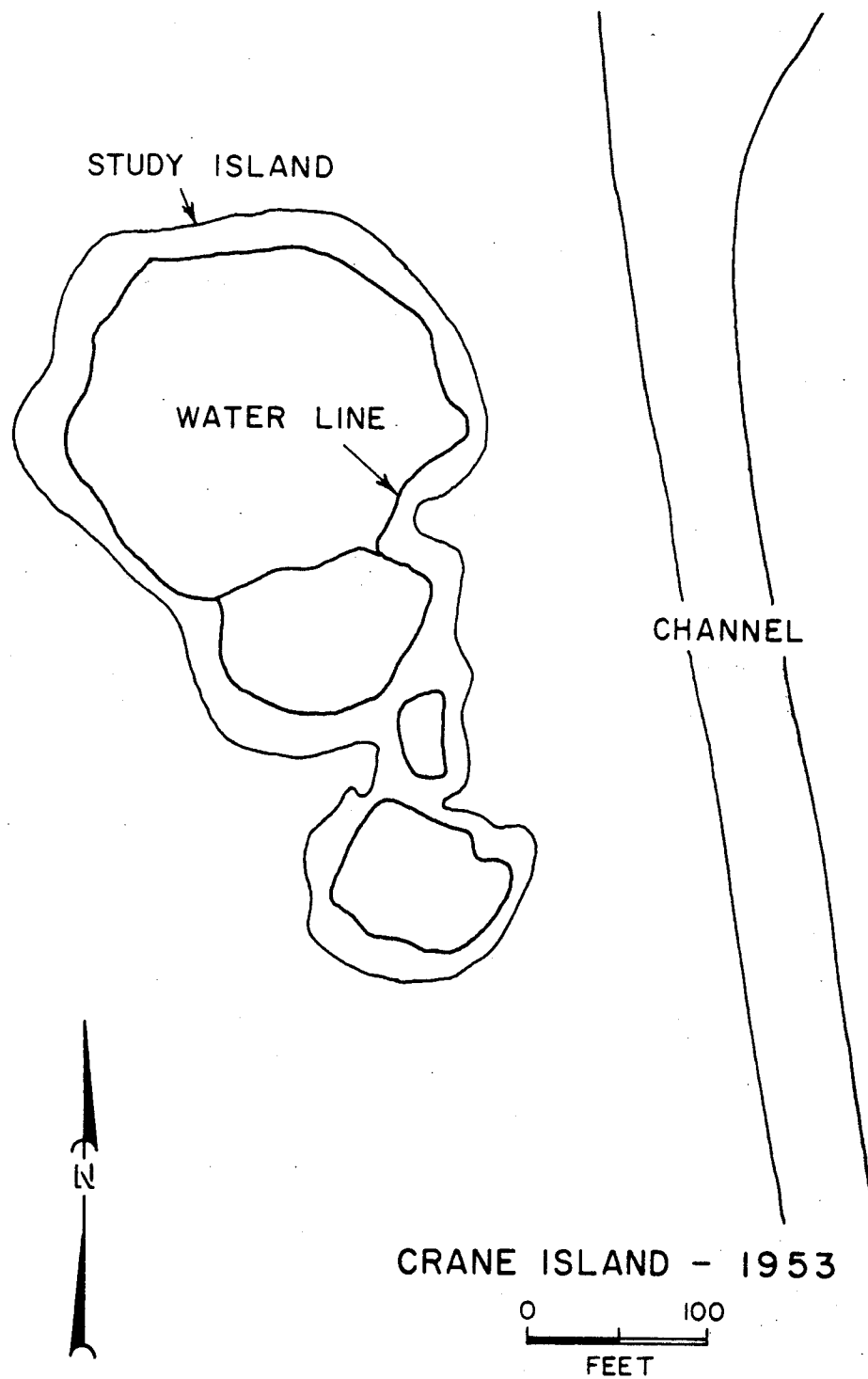


FIGURE 19. Study island at the Crane Island location in 1953 soon after dredging was completed

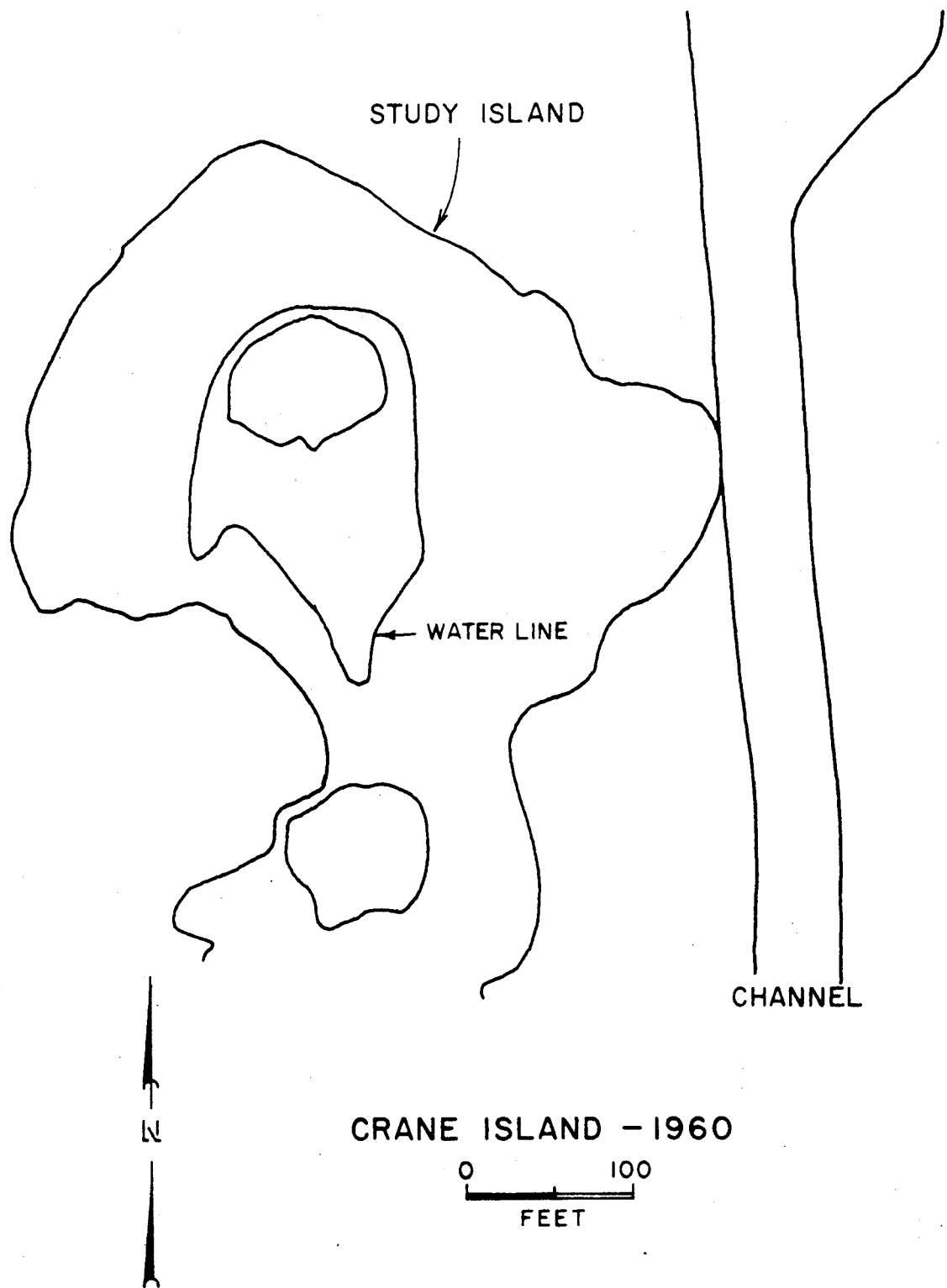


FIGURE 20. Study island at the Crane Island location in 1960. Note that the dispersion of dredged sediment is encroaching on the channel

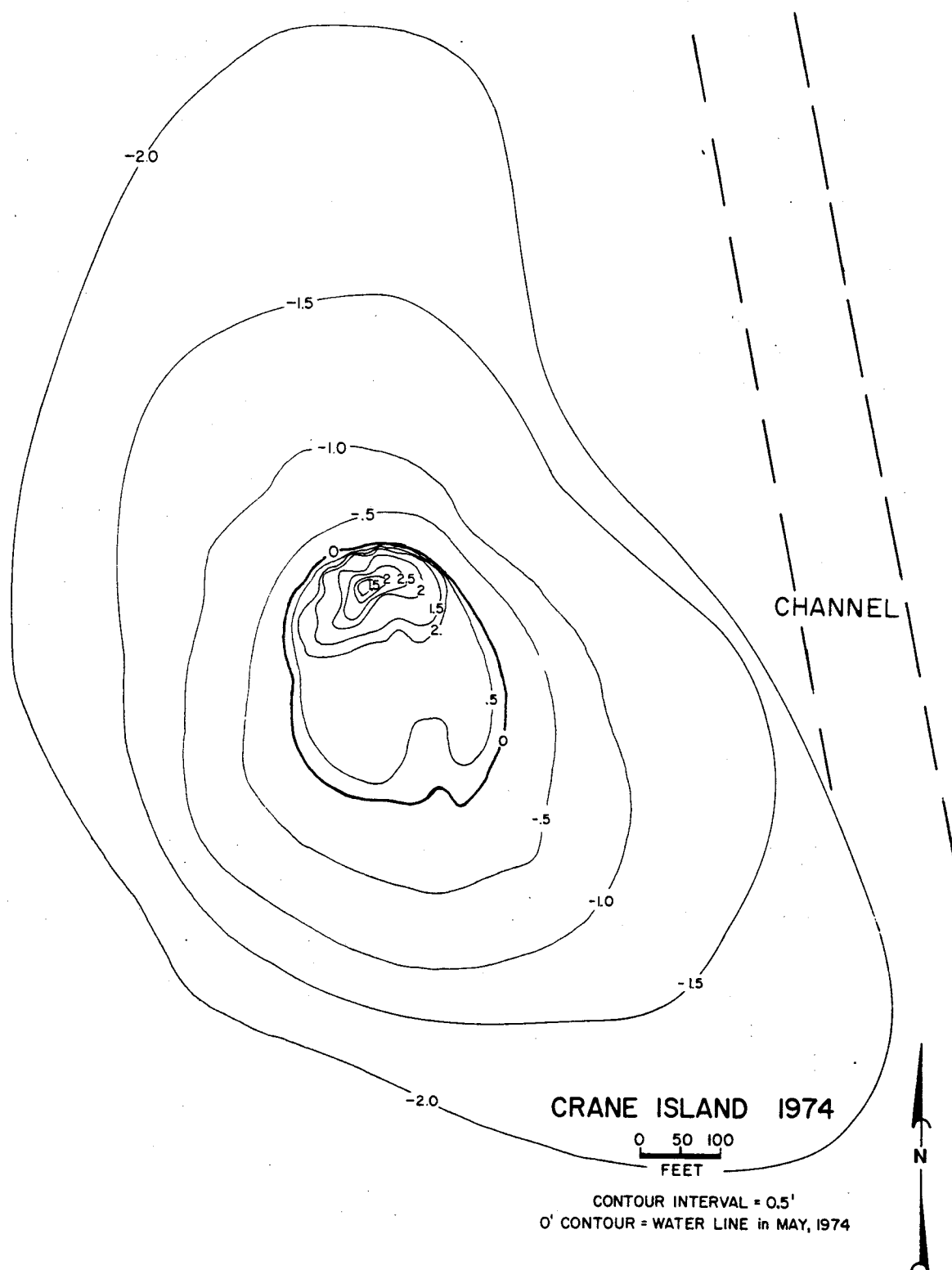


FIGURE 21. Study island at the Crane Island location in 1974. Note that the dredged sediment has moved partially into the channel but maintenance dredging has not been necessary

Table 4. Surface areas of islands in 1953, 1960, and 1974 (acres)

	<u>1953</u>	<u>1960</u>	<u>1974</u>
Crane Island (total)	6.16	10.11	21.78
(subaerial)	4.31	1.70	1.54
Seven Islands (total)	8.22	13.61	18.50
(subaerial)	7.14	2.75	2.36*
Wind Tidal Flat Islands			
3 island set (total)	7.97	6.67	4.74
(subaerial)	7.97	1.72	0.27**
East Island of set			
(total)	3.65	2.63	4.74
(subaerial)	3.65	0.59	0.27**
Mid and West Islands			
of set (total)	4.32		
(subaerial)	4.32		trace
Mid Island (total)		2.14	
(subaerial)		0.61	trace
West Island (total)		1.90	
(subaerial)		0.53	trace

* -0.5' contour used for area measurement

** 1.0' contour used for area measurement

and the growth of vegetation on the dredged material.

Seven Islands Volume

A comparison of the island volume changes in the Seven Islands area showed that for the 1953 island (fig. 22), the volume was 35,363 cubic yards. The volume of this island correlates with the amount of material removed from an adjacent section of the channel dredged to six feet.

The 1974 volume was 33,140 cubic yards (fig. 23). (Due to the vast spread of a thin veneer of sediment around the island, the volume at -1.5 foot contour interval was used because the -2.0 contour does not close. This volume was not divided in half as described by the method to account for any sediment dispersed outside the survey area.) This is 94 percent of the 1953 volume. The sediments have dispersed over a wider area and have filled the adjacent channel (fig. 24).

Island volume calculations show that there has not been an appreciable loss of volume, but rather an increase in the dispersion area of the sediments. This increase of the dispersion area and the direction of dispersion acts as a threat to the adjacent channels demanding maintenance to keep the channels open.

Seven Islands Area

Examining the surface area of the Seven Islands complex in 1953, the island complex (see fig. 22) had an original dispersion area measured at 8.22 acres. In 1960, the area (fig. 25) had increased 160 percent similar to Crane Island and in 1974, the dispersion area had

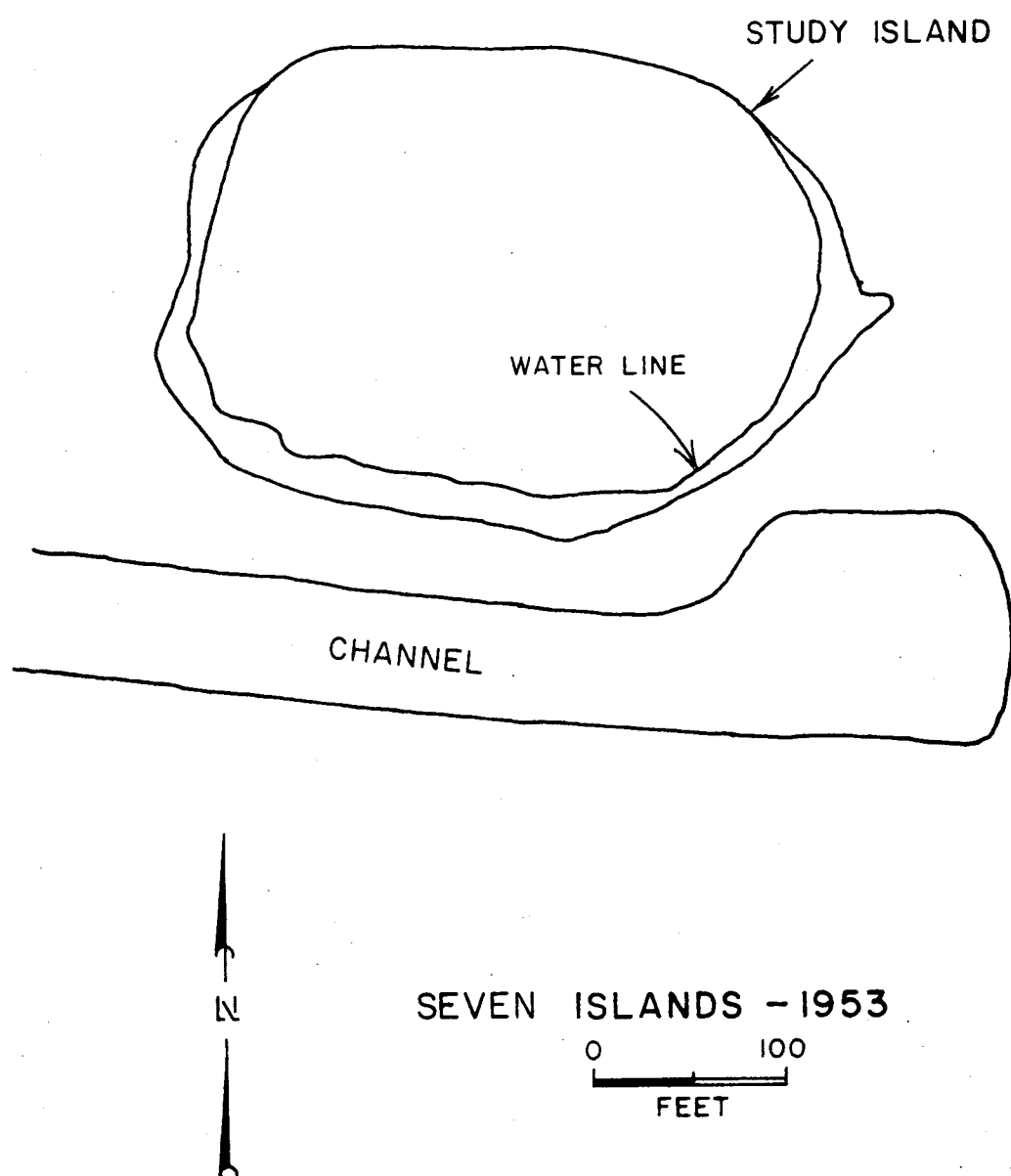


FIGURE 22. Study island at the Seven Islands location in 1953 soon after dredging was completed

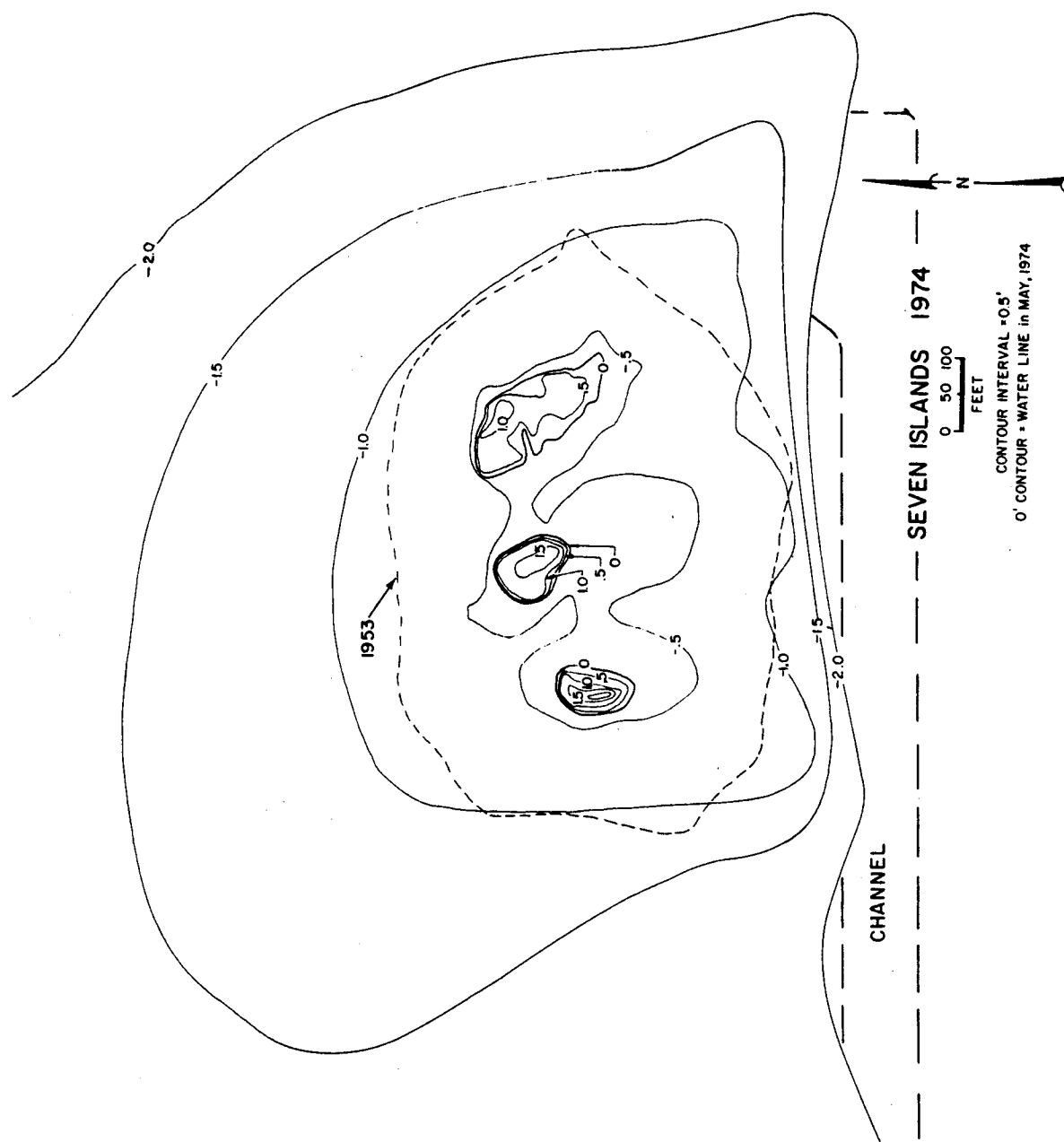


FIGURE 23. Study Island at the Seven Islands location in 1974. Note that the dispersion area has increased since 1953 and sediment has moved into the channel

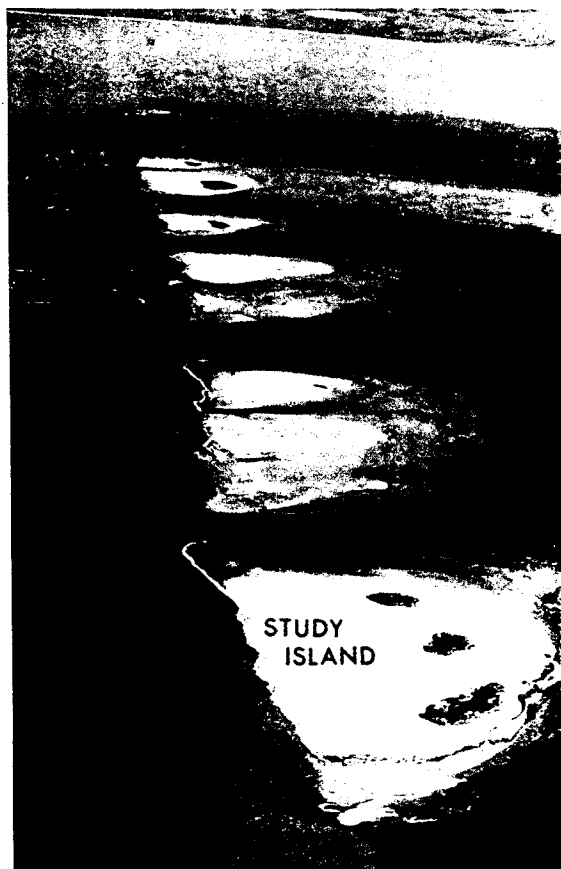


FIGURE 24. Looking west at Seven Islands in 1974. Lobes of sediment from the island fill the channel with light gray sands. The channel fill is partially vegetated with the dark algal mat

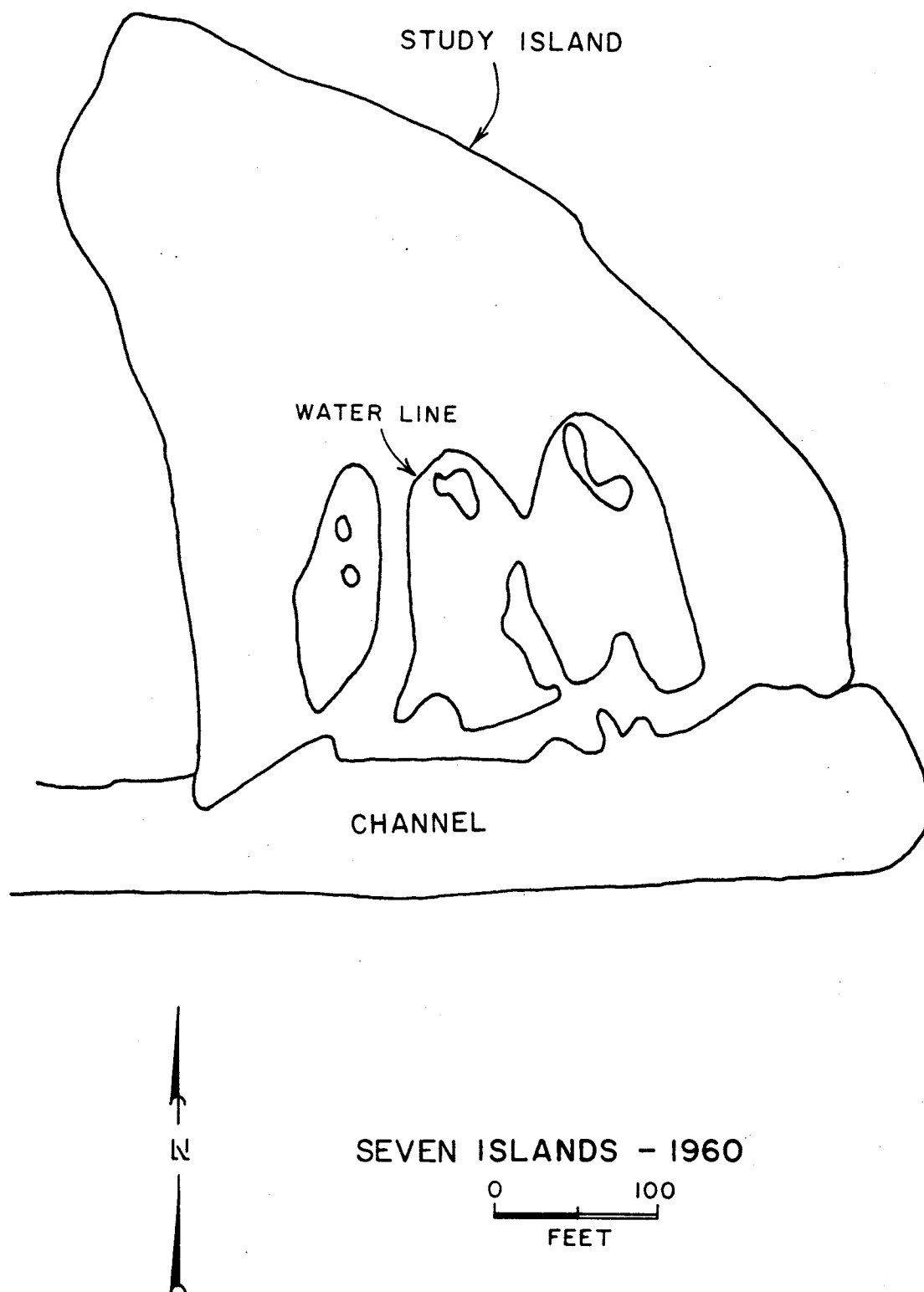


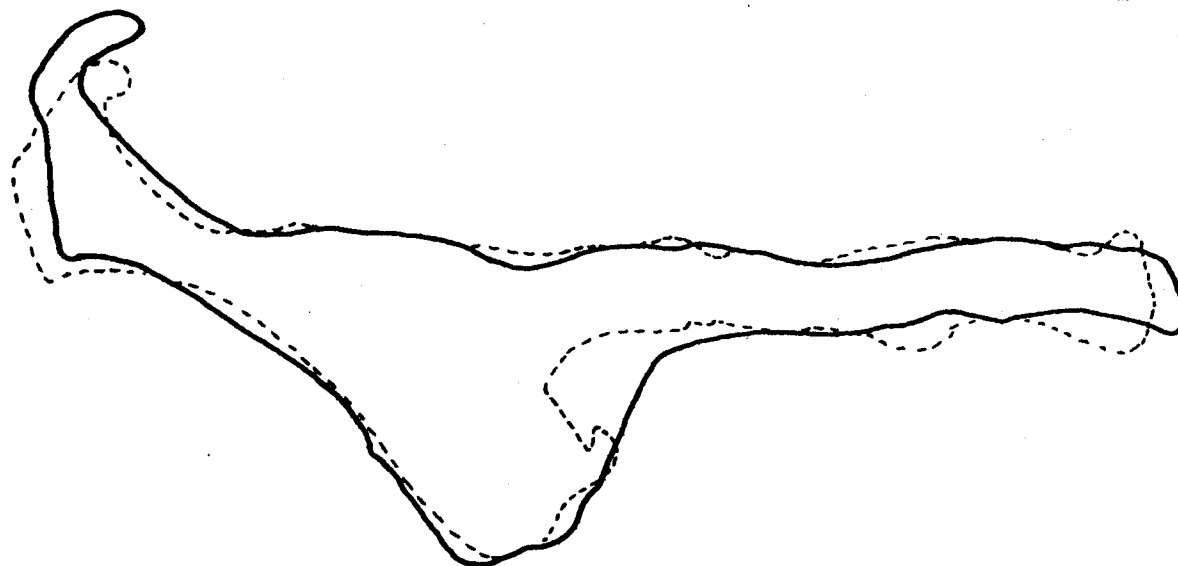
FIGURE 25. Study island at the Seven Islands location in 1960. Note that the enlarged dispersion area has encroached up the channel

increased 225 percent from the original configuration.

The subaerial area decreased from 7.14 acres in 1953 to 38 percent in 1960 and to 33 percent in 1974. There was a 62 percent change from 1953 to 1960 and only a 5 percent change from 1960 to 1974. This is a similar trend to that seen at Crane Island emphasizing the idea that an equilibrium form is reached soon after the formation of the island.

The extent of dispersion from the original dumping site can be seen in figure 23. Sediment movement has been to both the north and south, and the present morphology of the island as observed in the field shows that the majority of the sediment has moved to the south into the channel and is removed from the system. The material in the channel is predominantly sand with silt and clay partially covered by an algal mat.

GULF INTRACOASTAL WATERWAY



DEEP WATER ISLAND

----- 1953

~~~~~ 1960

FIGURE 28. A comparison of the outline of the deep water island in 1953 and 1960. Compared to the other islands the change from 1953 to 1960 is small

## WIND TIDAL FLATS ISLANDS

The islands in the wind tidal flats are subjected to a set of different processes as compared to deep water and shoal water islands. The wind tidal flats are south of Murdock Basin (see fig. 16) and are subject to periodic drying and inundation. These islands are vegetated with sparse scrub vegetation and are composed of sand, shell and mud and show little topographic relief due to erosion before stabilization. The surrounding sediments are sands and mud with patches of algal mat. Because of the severe drying in the summer, the mat dies and is quickly ripped up when the area is inundated by water. Island sediments are not eroded appreciably when dry because of a high capillary water table and stabilization by vegetation.

For realistic comparison of the areas in 1953 and 1974, it was necessary to separate the eastern mound of the 1953 island complex (fig. 29). The area was measured and assuming a height of 4 feet the volume was calculated as 15,684 cubic yards.

A volume calculation for the 1974 island shape was made from the contour map. The base of the island was assumed to be just below the -0.5 contour interval because of the aerial extent of the contour and the lack of change seen in the areas beyond the contour (fig. 30). The volume of the 1974 configuration is 8499 cubic yards, some 54 percent of the original volume. This is a larger difference than those seen at the other locations and is due to processes unique to this location.

Surface area changes do not follow the same patterns as the other islands investigated. The dispersion area decreases from 3.65

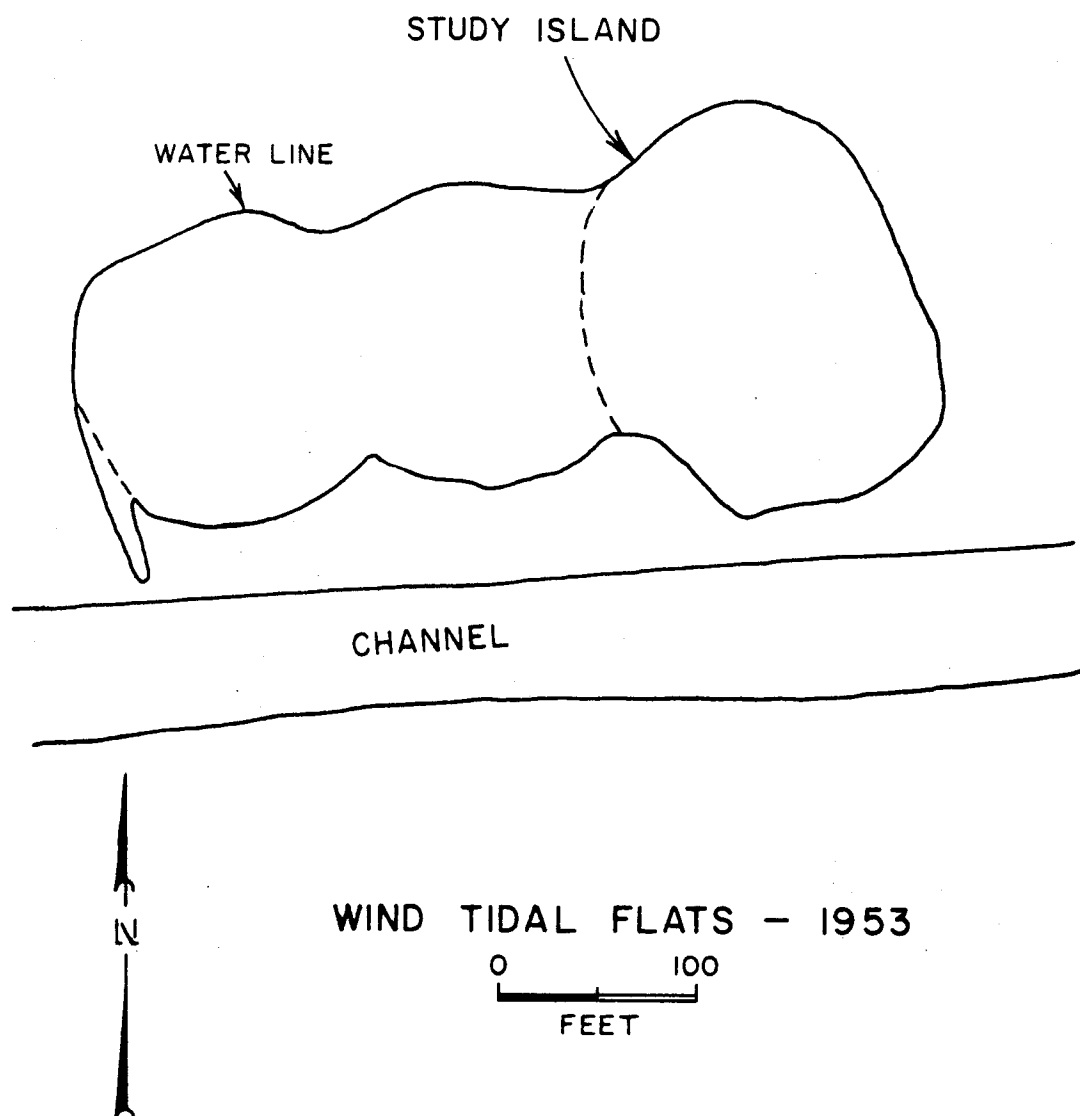


FIGURE 29. Study island at the wind tidal flats location in 1953 soon after dredging was completed. The study island is only part of the island complex

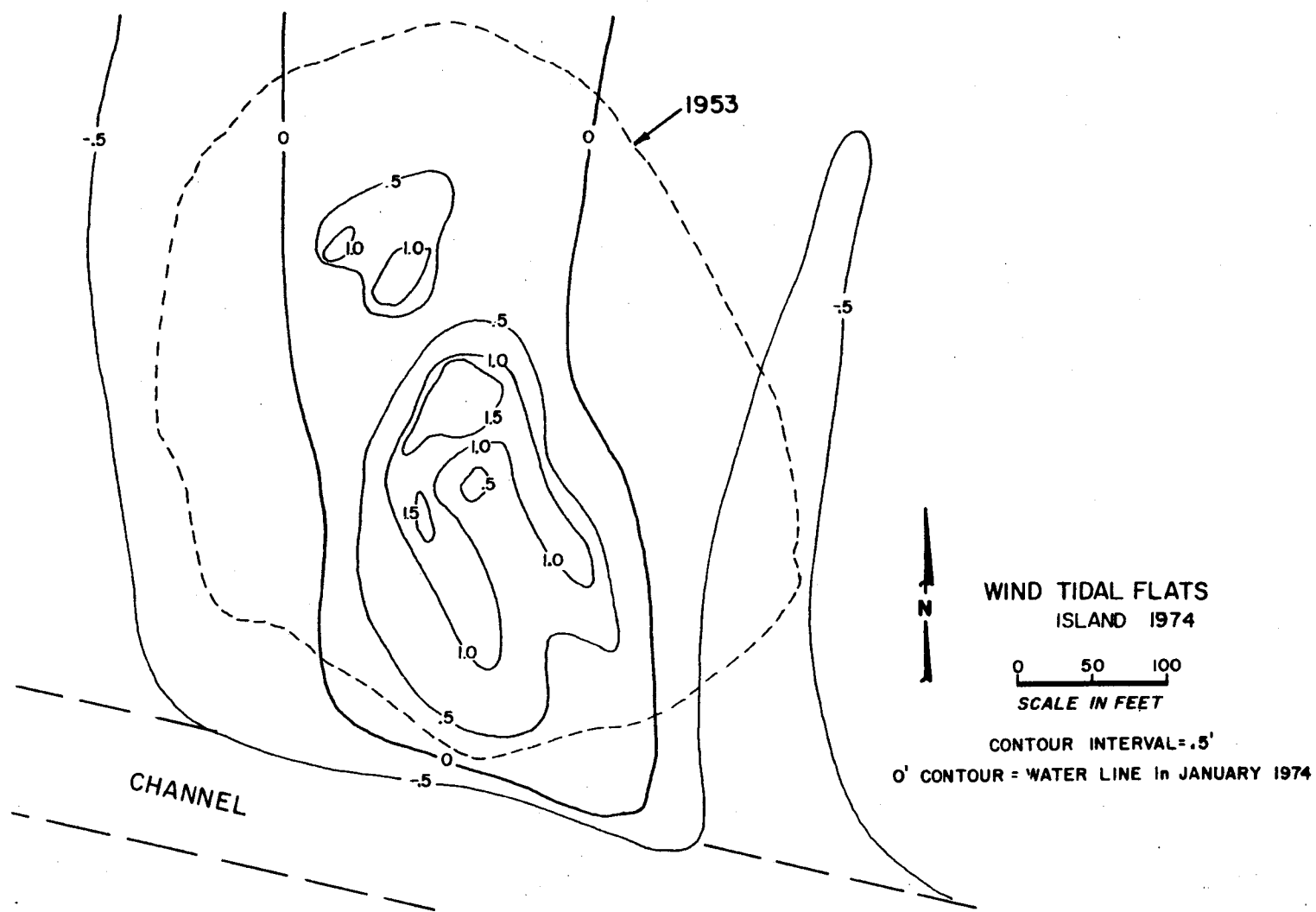


FIGURE 30. Study island at the wind tidal flats location in 1974. The dispersion area has moved into the channel and the subaerial area is greatly reduced

acres in 1953 to 2.63 acres in 1960, a decrease of 28 percent and increases in 1974 to 4.74 acres or 130 percent of the original dispersion area.

The subaerial areas seem to follow a similar trend to that of the other islands. From 1953 to 1960 the subaerial area is reduced by 84 percent, and in 1974 the area is reduced to 8 percent. This change is quite drastic but expected and evidenced both in the field and in the aerial photographs. Several of the dredged material islands west of the surveyed island have been eroded and that material has moved into the channel (figs. 31 & 32). This author believes that these islands had a lower profile and were inundated and eroded by the north wind-wave attack and currents.

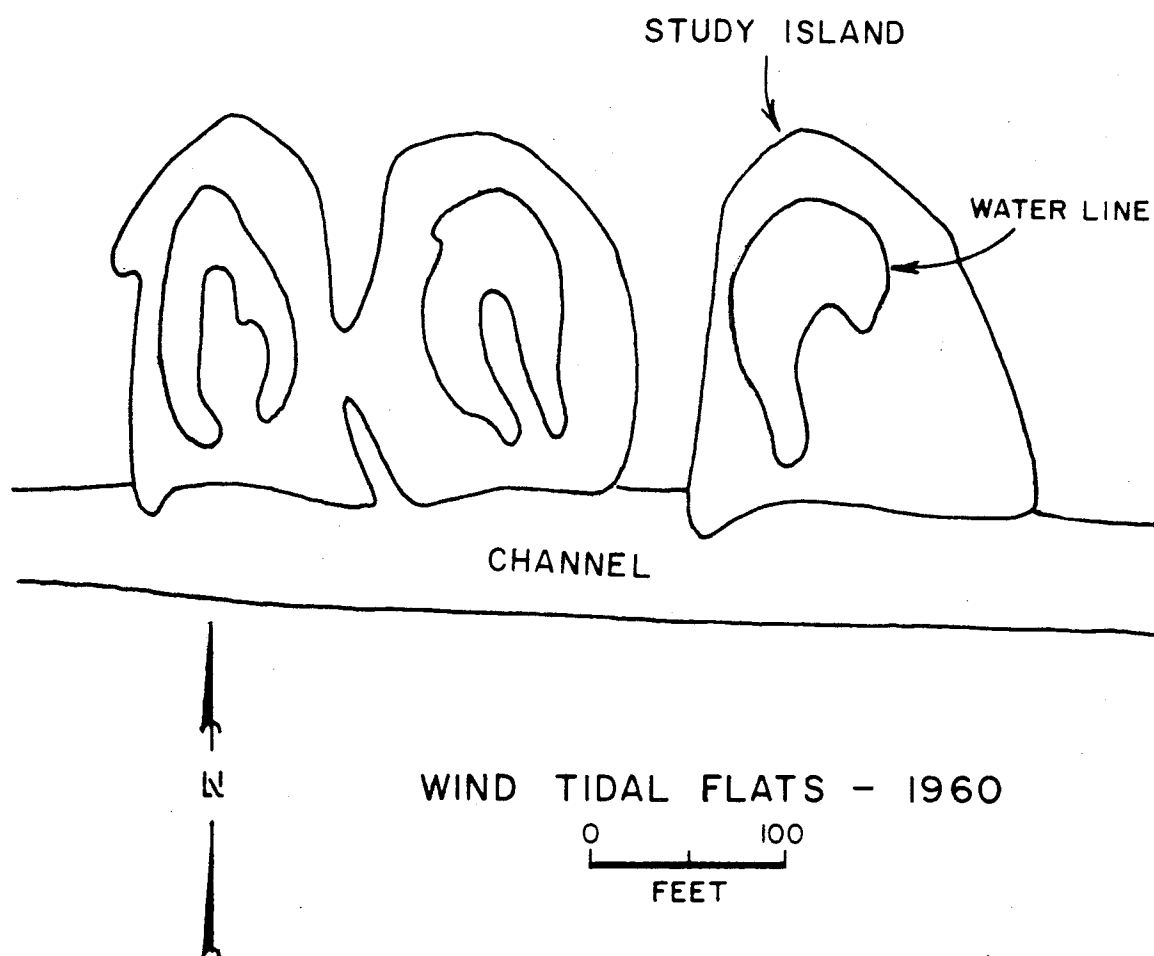


FIGURE 31. Study island at the wind tidal flats location in 1960. The enlarged dispersion area has moved into the channel and currents have separated the study island from the original island complex

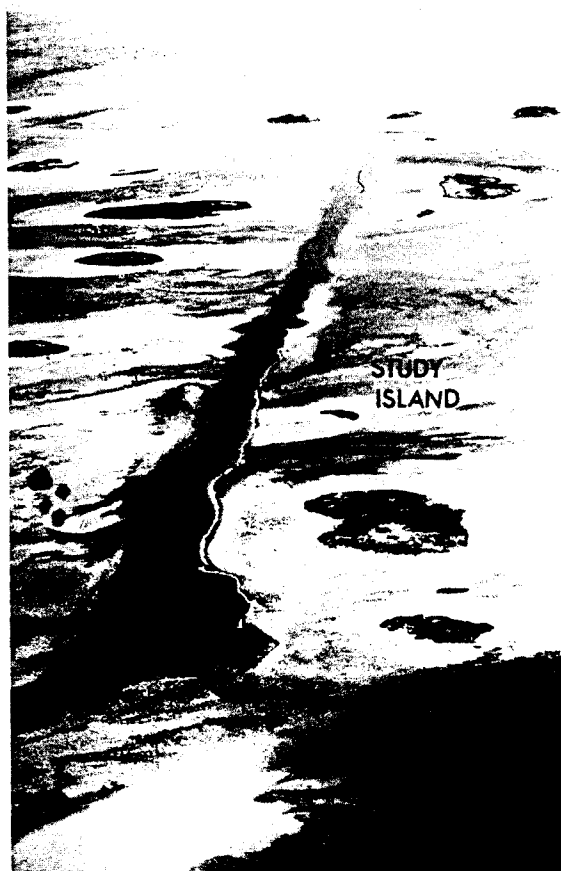


FIGURE 32. Looking west at the wind tidal flats and channel in 1974. Lobes of sediment have moved from the islands on the north side of the channel into the channel. Islands on the south side of the channel indicate that there has been a need for extensive maintenance to keep this channel open

## ACTIVE PROCESSES AND DISCUSSION

### Erosion and Redeposition

The wind is the dominant factor affecting the erosion of dredged material islands in Laguna Madre. Field observations have shown that the wind-generated processes manifest themselves in characteristic morphologies either on the islands or on the surrounding shorelines.

As noted earlier, with a change in wind direction there is also a change in the water depth. The north winds move water south in the lagoon, and the resulting rise in water level inundates the wind tidal flats and the back island areas. The north winds of high intensity propagate waves which attack the north shore of the islands developing a wave-cut escarpment on the north side of the island with shoaling to the south (fig. 33). The height of the escarpment is dependent on the depth of the water, wave intensity and the extent of vegetation on the island.

The root system of the vegetation stabilizes the island sediments and holds a vertical face of unconsolidated shell, sands, and mud. The material removed by erosion is carried around the island and deposited as shoals to the south of the island.

The north winds are most often associated with a high pressure front. With the passage of the front the wind direction returns to the southeast. During the change in wind direction the water level remains high and is influenced by the south winds. The short period of wave attack from the south at this time is sufficient to carry



FIGURE 33. Wave-cut escarpment on the north side of Crane Island. The photograph was taken during a period of low water. Note the accumulation of grass at the base of the escarpment and the knife for scale

sediment to the north enlarging the dispersion area. The water level soon drops, and wave erosion is reduced as the wave base decreases. The drop in water level dries the wind tidal flats. The influence of the aeolian processes is low because the capillary water level is at the surface keeping the sediments wet. It was noted that the sands above the water level are held by vegetation keeping sediment movement to the north at a minimum. Shoals due to the aeolian processes can be seen in the area, but they are of insignificant volume.

In the western section of Murdock Basin water depths are approximately six feet deep. Dredged material islands in this area having achieved an equilibrium shape and stabilized are little affected by water level fluctuations. The deep water islands, always surrounded by more than three feet of water, are adjacent to the Gulf Intracoastal Waterway. These islands are higher than the shoal water and wind tidal flat islands and historically appear to be more stable. The shoreline is armored with reef boulders overlying coarse shell which protects the shore during water level fluctuations keeping sediment transport low. Southern waves have cut a linear beach on the southeast shore and reworked the spit on the south end of the island. North waves with the aid of boat wakes have worked the west shore into a straight beach and reworked sediments on the spit (see fig. 27).

The dominant sediment transport directions as examined in the field are summarized in figure 34. The northern winds setting up water in the lagoon increase wave attack on the islands transporting sediment to the south. Southern winds have little affect with the

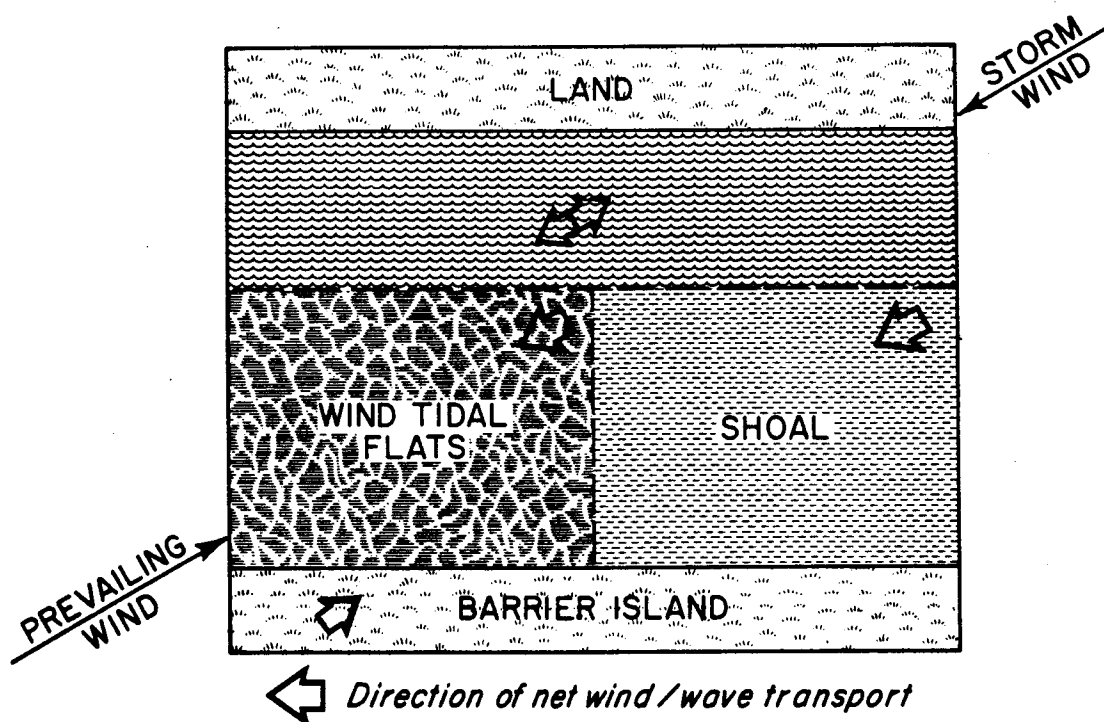


FIGURE 34. Simplified diagram of Murdock Basin showing directions of sediment transport. In the wind tidal flats and shoal areas the storm winds control the transport direction

associated low water levels except near the center of Murdock Basin where water level fluctuations have comparatively little effect, and sediment is transported to the north.

Comparing the rates of erosion of the shoal water islands and the wind tidal flats islands a similarity is evident between Crane Island and Seven Islands. Plotting the percent change of the sub-aerial surface area shows a rapid change in the first seven years with minimal variation over the next thirteen years (fig. 35). It appears that at some point during the first seven years the islands establish an equilibrium profile and erosion is reduced.

#### Vegetation

Vegetation plays a major role in island stabilization. The sediments are predominately sand and shell when first placed at the disposal site. With the introduction of the scrub grasses and brush a humus develops which promotes a more dense growth of the existing plants. This vegetative growth covers an area delineated by the seasonal high water line. During extreme high water and high wave conditions the islands have been over topped by waves leaving an accumulation of seagrasses which further aid in the stabilization of the surface sediments and add to the developing top soil. Many of the islands now support rookeries which aid in the fertilization of the soil and introduce additional types of vegetation.

The sea grasses do not grow adjacent to the islands but are found on or near the mainland shore. The grasses are torn loose by storms and accumulate on the islands as mats (figs. 36, 37). The mats

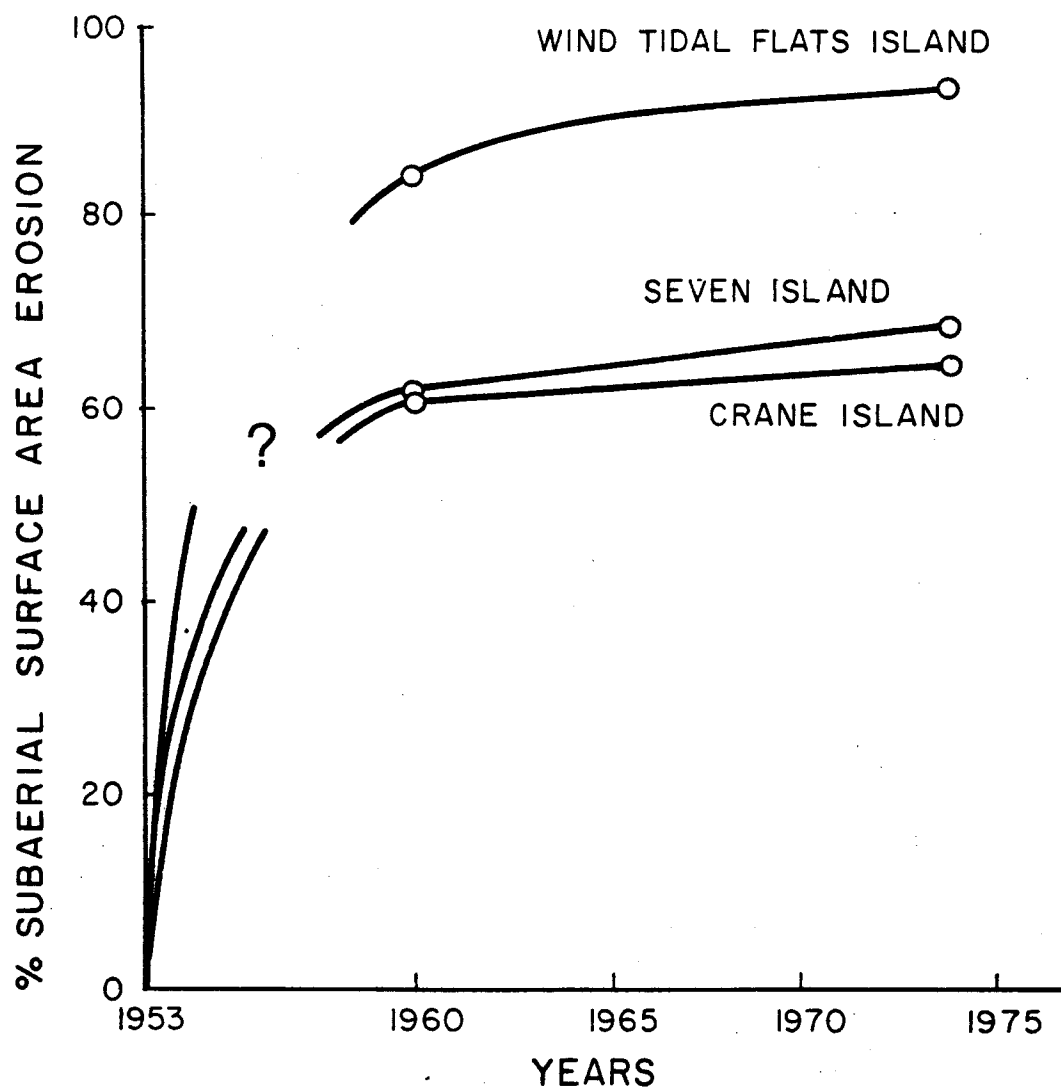


FIGURE 35. Graph of subaerial surface area erosion for the study islands. Crane Island and Seven Islands are subject to similar physical conditions in contrast to the Wind Tidal Flats Island



FIGURE 36. High water and waves leave an accumulation of grass on top of the island above the escarpment. Compare with figure 33, page 72. Note cigarette lighter for scale



FIGURE 37. Grasses appear as dark patches rimming the perimeter of Crane Island. Note the line of breakers

act as a breakwater dissipating the wave energy keeping erosion low. Changes in water level can be depicted by the ring of grasses left on the Crane Island.

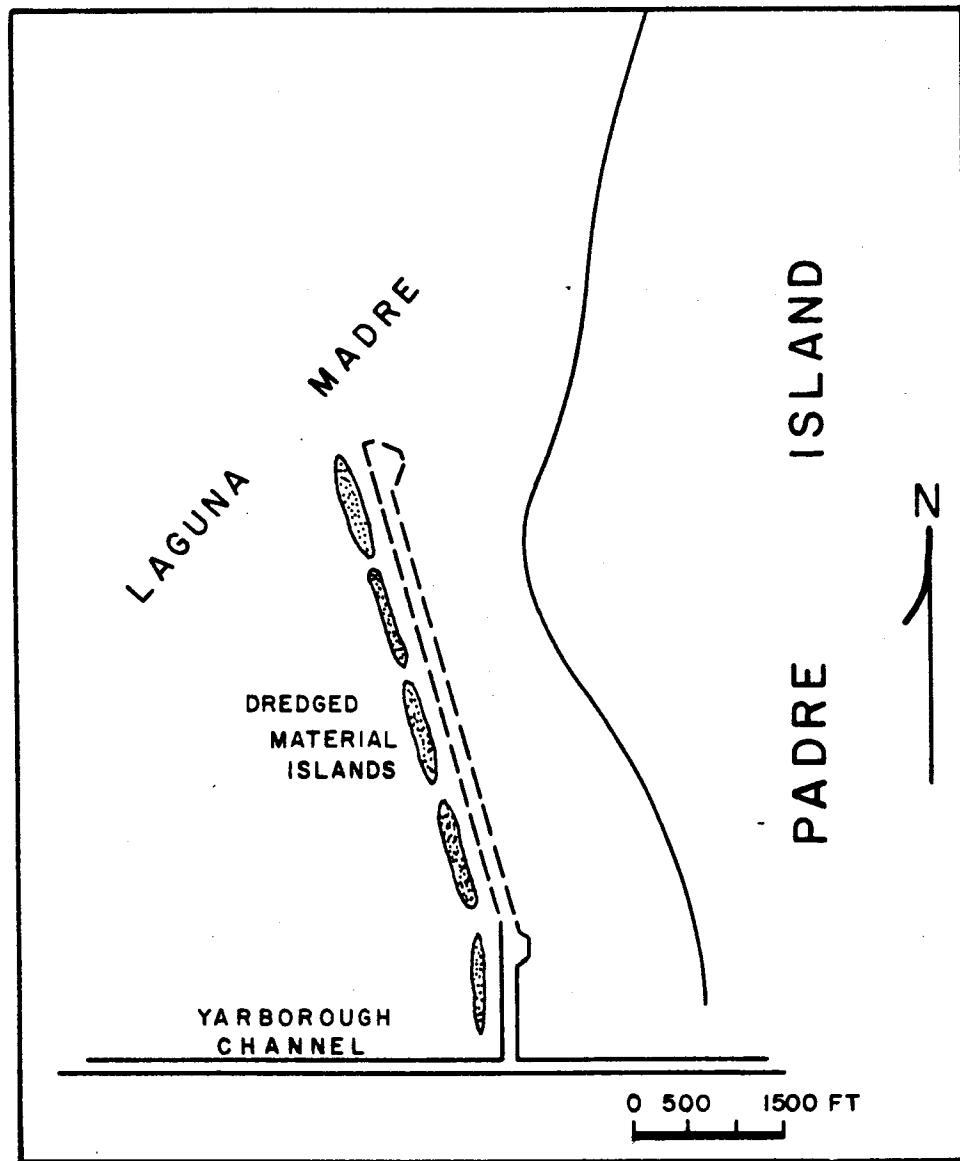
Just outside the dispersion area the lagoon floor is covered with an algal mat holding the silts and clays. Remnants of the mat have been found on the islands as algal filaments intermixed with the sand, silts, and clays forming an erosion resistant layer near the surface on the island shoals. Formation of this layer is the result of high water and low wave action allowing for algal growth to take hold.

Research conducted by Texas A&I University has shown that with the introduction of various types of vegetation to a virgin disposal mound a stable island can be established in three years (Davis, 1975). This is important to State and Federal fish and wildlife agencies who are trying to increase the number of rookeries and the fish population in restricted marsh and lagoonal areas.

#### Island and Channel Orientation

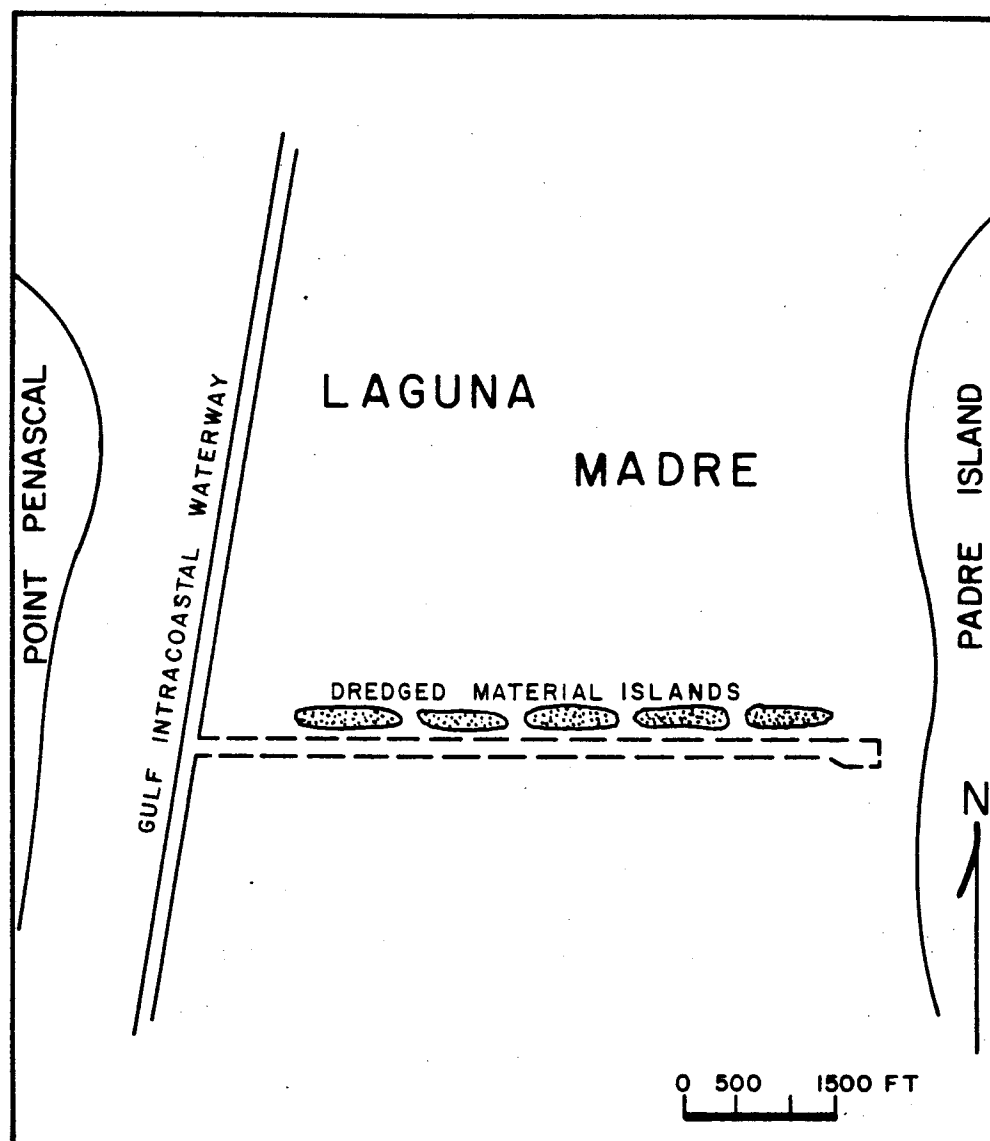
The Corps of Engineers is responsible for the issuance of dredging permits in the Murdock Basin area. The permits issued in 1953 show the basic channel design and the desired location for the disposal sites. Figures 38, 39, and 40 are simplifications from those original permits.

Examining the island and channel orientations it appears that the applicant believed that the dominant sediment transport direction would be to the north, a function of the prevailing southeast winds. From a cursory examination of the area and the processes, it would be



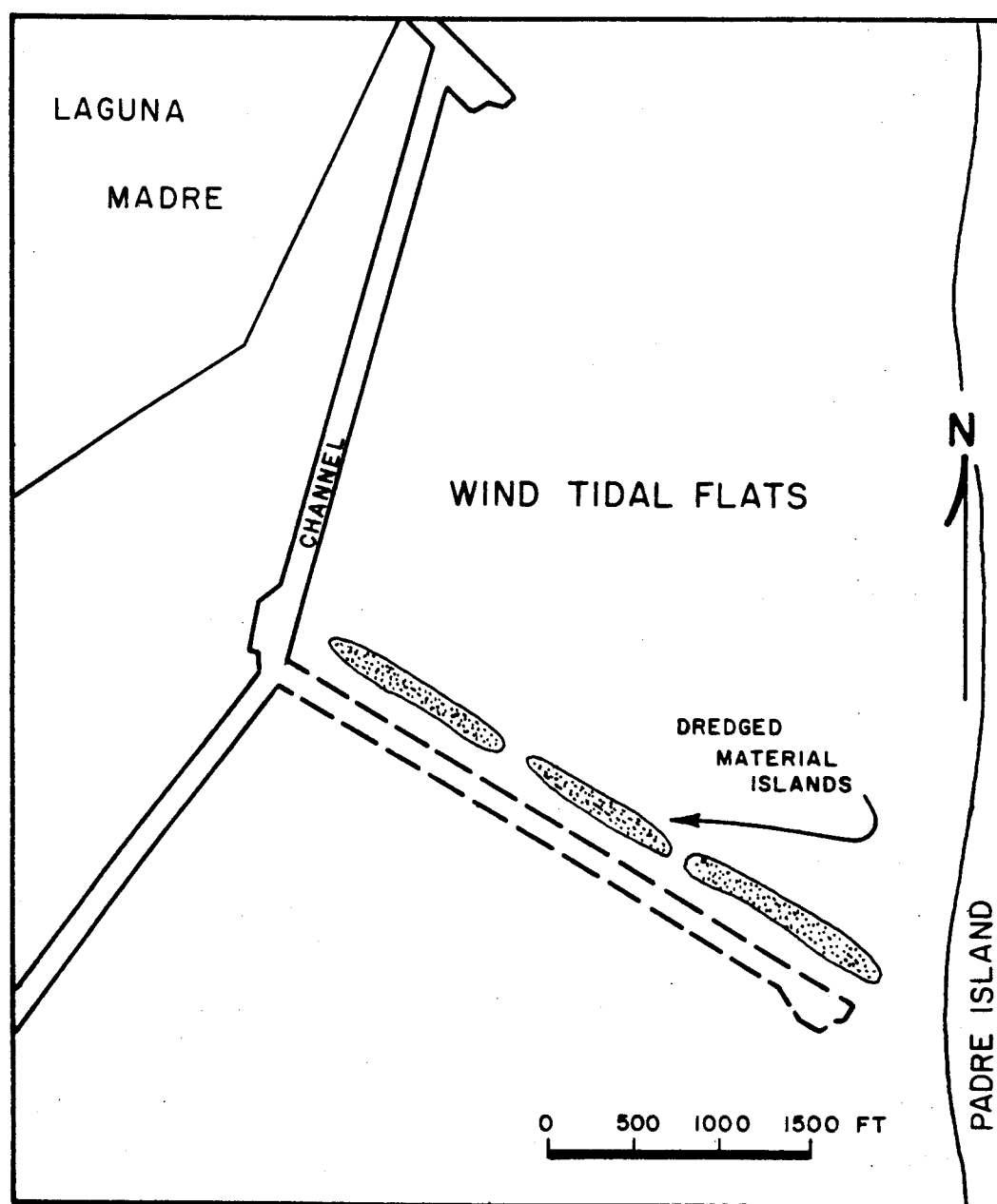
## CRANE ISLANDS

FIGURE 38. Simplified sketch of the design for the dredging permit submitted to the U. S. Army Corps of Engineers for the Crane Island location



## SEVEN ISLANDS

FIGURE 39. Simplified sketch of the design for the dredging permit submitted to the U. S. Army Corps of Engineers for the Seven Islands location



## WIND TIDAL FLAT ISLANDS

FIGURE 40. Simplified sketch of the design for the dredging permit submitted to the U. S. Army Corps of Engineers for the wind tidal flats location

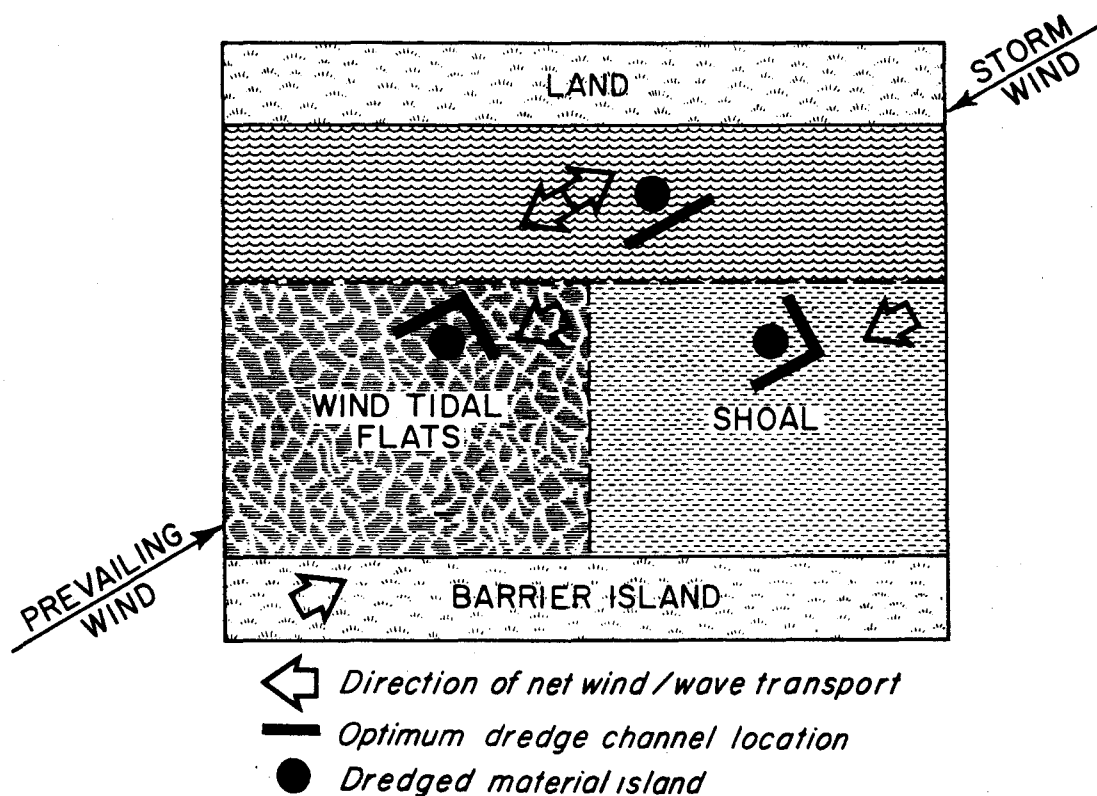


FIGURE 41. Suggested placement and orientation of dredged material disposal sites and channels in Murdock Basin with respect to the sediment transport directions.

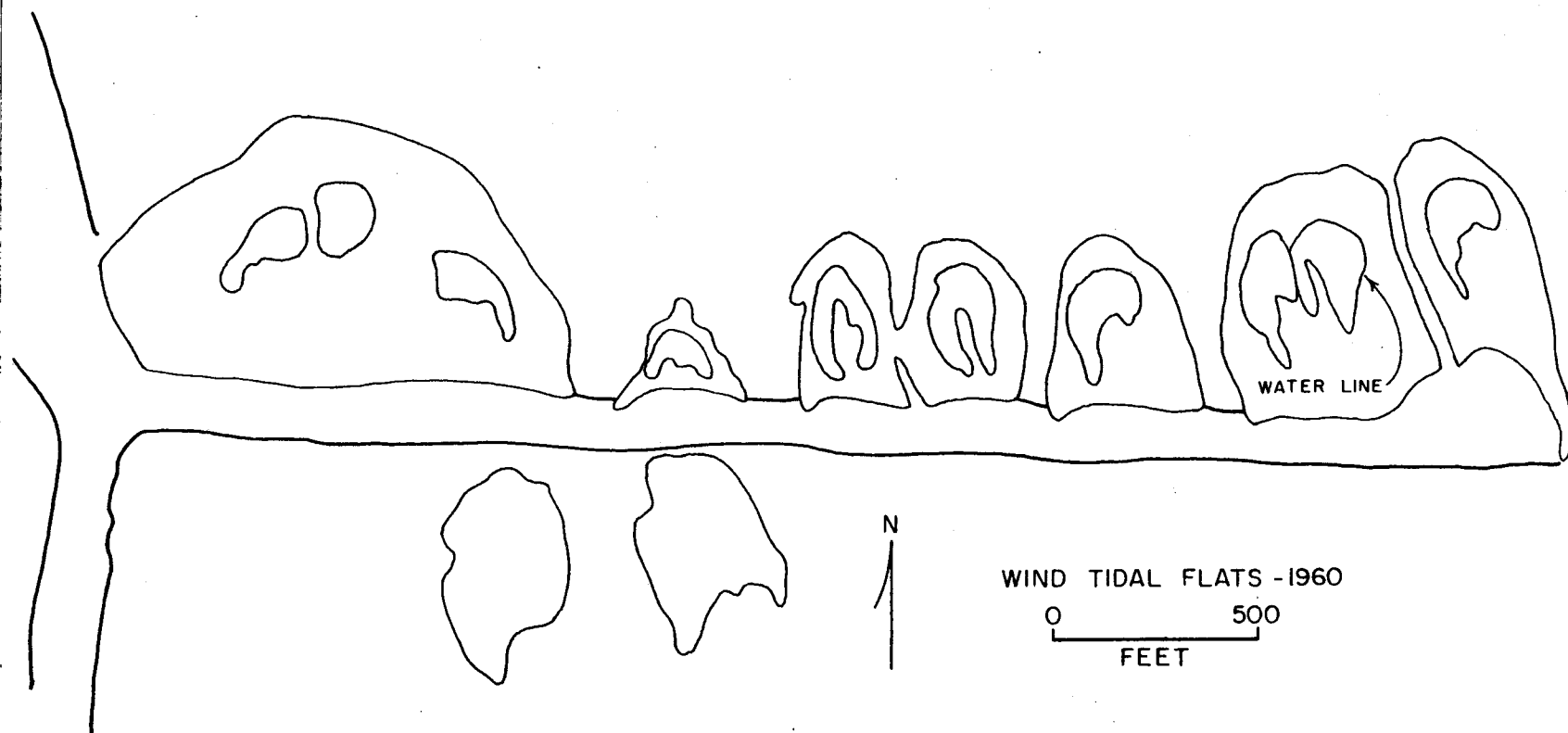


FIGURE 42. Channel complex in the wind tidal flats. in 1960. Note erosion of islands on the north side of the channel. Islands on the south side of the channel are the result of maintenance dredging prior to 1960

channel, and infilling due to the return of dredged material to the channel has remained at a minimum. This channel has remained open without maintenance since its original dredging.

The deep water island next to the Gulf Intracoastal Waterway has changed very little since its formation in 1949. Field observations have shown some shoaling into the Gulf Intracoastal Waterway. Some sediment movement to the south was noted, but due to the short fetch of the north winds this transport is minimal. Changes in water depth which are significant to the shallow water islands have little effect on the deep water islands. Transport of sediment from the deep water islands is a function of fetch length and intensity of the wind generated waves.

## CONCLUSIONS AND CRITERIA FOR SITE SELECTION

Open water dredged material disposal is one alternative for the relocation of channel sediments. When it is necessary to utilize this alternative the physical processes must be considered to keep island erosion and channel maintenance to a minimum.

1. The processes to be considered in Upper Laguna Madre are the winds, waves and wind tidal currents. Upper Laguna Madre is a shallow water environment subject to water depth changes of one to two feet during the year. These variations of water depth allow for varying wave intensities and erosion rates. The shoal water islands lost from four to six percent of their original volume compared to 46 percent lost in the wind tidal flats.
2. Dispersion area changes follow similar trends between locations; the total dispersion area increases 130 to 350 percent and the subaerial areas decrease 60 to 90 percent. The percent change of the subaerial surface areas shows a rapid change in the first seven years with little variation over the next thirteen years. To predict the long-term fate of the dredged material it is essential that the disposal sites be monitored for several years after the dredging.
3. Dredged sediments do not contrast a great deal with the original lagoonal sediments. The dredged sediments have a slightly larger mean grain size and little difference in the sorting coefficient.
4. The dredged material islands which are several feet above the high water line stabilize quicker and hold more of the sediment at the site as compared to islands with lower profiles.

estimated dredged material volumes in disposal sites with similar conditions. It is necessary to place dredged material a distance of at least 2 times the radius of the proposed disposal island from the channel. This allows a large area for dispersion as the island develops an equilibrium profile.

Before the dredging an assessment of the dredged sediments is necessary to evaluate pollution problems and vegetation potential. If no restrictions are put on the material a stabilization program for fertilization and planting can be initiated soon after dredging.

To further reduce dispersion of the sediments during the dredging operations a turbidity curtain should be used.

To predict the erosion and sediment transport direction from the island the circulation patterns should be evaluated to define the hydrologic regime around the island and the variation of the circulation due to tidal flow, water depth and extreme conditions created by storms and hurricanes which over a short period of time change the water depth, current flow and create highly erosive waves. Defining the circulation patterns for normal and extreme conditions allows for a prediction of the sediment transport direction.

The site chosen for a disposal area must be a sufficient distance away from the channel to allow adequate room for sediment dispersion as the dredged material achieves an equilibrium shape.

The cost of such a site investigation to evaluate the sediments and the processes is minimal compared to the high cost of continued channel maintenance.

## REFERENCES CITED

- Bassi, D. E., and Basco, D. R., 1974, Field study of an unconfined spoil disposal area of the Gulf Intracoastal Waterway in Galveston Bay, Texas: Texas A&M University, Sea Grant Publication N. 74-208, Coastal and Ocean Engineering Division Report N. 174, 74 p.
- Basco, David R., Bouma, Arnold H., and Dunlap, Wayne A., 1974, Assessment of the factors controlling the long-term fate of dredged material deposited in unconfined subaqueous disposal areas: U. S. Army Engineer Waterways Experiment Station, Final Report, December 1974, 238 p.
- Boyd, M. B., Saucier, R. T., Keeley, J. W., Montgomery, R. L., Brown, R. D., Mathis, D. B., and Guice, C. J., 1972, Disposal of Dredge Spoil Problem Identification and Assessment and Research Program Development. U. S. Army Waterways Experiment Station, Tech. Rep. H-72-8, 121 p.
- Brandes, R. S., White, W. A., Hill, F. R., Masch, F. D., 1970, Analysis of hurricane tides at Padre Island, Texas: Proceedings of the 12th Coastal Engineering Conference, American Society of Civil Engineers.
- Burger, John A., Klein, George deVries, and Sanders, John E., 1969, A field technique for making epoxy relief-peels in sandy sediments saturated with salt water: Journal of Sedimentary Petrology, V. 39, N. 1. pp. 338-341.
- Clary, J., Stinson, J., and Tanenbaum, R. J., 1974, Coastal aeolian fans-mechanism of landward sand transport: ABSTRACT, Geological Society of America annual meeting, Miami Beach, Florida, November.
- Colby, B. C., and Christensen, R. P., 1956, Visual accumulation tube for size analysis of sands: Journal of the Hydraulics Division, American Society of Civil Engineers, V. 82, N. HY3, Proceedings Paper 1004, June, pp. 1004-1017.
- Crickmore, M. J., 1968, The use of tracers to determine infill rates in projected dredged channels: Proceeding of the Symposium on Dredging, Institute of Civil Engineers, pp. 55-66.
- Cronin, L. E., Briggs, R. B., Flemer, D. A., Pfitzenmeyer, H. T., Goodwyn, F., Dovel, W. L., and Ritche, D. E., 1970, Gross physical and biological effects of overboard spoil disposal in upper Chesapeake Bay: Natural Resources Institute, University of Maryland, Special Report.
- Davis, Richard., 1975, Personal Communication, Texas A&I University.
- ✓ Fisk, H. N., 1949, Geological investigation of the Laguna Madre flats; unpublished report, Humble Oil & Refining Company, Houston, Texas.

Fisk, H. N., 1959, Padre Island and the Laguna Madre flats, coastal South Texas: Second Coastal Geography Conference, Coastal Studies Institute, Louisiana State University, April.

Folk, R. L., 1968, Petrology of sedimentary rocks: The University of Texas, Austin, Texas, 170 p.

Gilbert, G. K., 1885, The topographic features of lake shores: U. S. Geological Survey 5th Annual Report, pp. 69-123.

Hedgpeth, J. W., 1973, An introduction to the zoogeography of the Northwestern Gulf of Mexico with reference to the invertebrate fauna: Contributions to Marine Science, University of Texas Publication, V. 3, N. 1, pp. 111-224.

Hellier, T. R., Jr. and Kornicker, L. S., 1962, Sedimentation from a Hydraulic Dredge in a Bay: Univ. Texas, Pub. Inst. Mar. Sci., V. 8, p. 212-215.

Herbich, J. R., 1975, Coastal and deep water dredging: Gulf Publishing Company, Houston, Texas, 622 p.

Hoyt, J. H., 1967, Barrier island formation: Geological Society of America Bulletin, V. 78, pp. 1125-1136.

Hunter, R. E., Watson, R. L., Hill, G. W., Dickinson, D. A., 1972, Modern depositional environments and processes, Northern and Central Padre Island, Texas: Gulf Coast Association of Geological Society, October 14.

Inman, D. L., 1949, Sorting of sediments in light of fluid mechanics: Journal of Sedimentary Petrology V. 29, N. 1.

Mathewson, C. C., Clary, J. H., Stinson II, James E., 1975, Dynamic physical processes on a South Texas barrier island - impact on maintenance: OCEAN IEEE 1975 Conference on Engineering in the Ocean Environment and 11th Annual Meeting of the Marine Technology Society, San Diego, California, September IEEE Publication, 75 CHO 995-1 OEC.

May, E. B., 1973, Environmental effects of hydraulic dredging in estuaries: Alabama Marine Resources Bulletin, N. 9, 88 p.

Meccia, R. M., Allanach, W. C., and Griffis, F. H., 1975, Engineering challenges of dredged material disposal: Journal of the Waterways, Harbors and Coastal Engineering Division, American Society of Civil Engineers, V. 101, N. WW1, Proceeding Paper 11096, February, pp. 1-13.

Miller, R. L., 1975, The mechanics of surf and sediment interaction: ABSTRACT, American Association of Petroleum Geologists, Society of Economic Paleontologists and Mineralogists Annual Meeting, Dallas, Texas.

Nautical Chart 895-SC, 1974, Intracoastal Waterway, Laguna Madre, Middleground to Rincon de San Jose, Texas: U. S. Department of Commerce, National Oceanic and Atmospheric Administration, National Oceanic and Atmospheric Administration, National Ocean Survey, May 18.

Nautical Chart 11308 (893-SC), 1974, Intracoastal Waterway, Redfish Bay to Middleground including Baffin Bay, Texas: U. S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Survey, August 10.

Otvos, E. G., 1970, Development and migration of barrier islands, Northern Gulf of Mexico: Geological Society of America Bulletin, V. 81, pp. 241-246.

Piper, D. P., 1975, A geo-economic evaluation of barrier island developments: M. S. Thesis, Texas A&M University.

Postma, H., 1967, Sediment transport and sedimentation in the estuarine environment: in Lauff, G. H., (ed.), Estuaries Publication N. 83, American Association for the Advancement of Science, Washington, D. C.

Price, W. A., 1933, Role of diastrophism in topography of the Corpus Christi Area, South Texas: American Association of Petroleum Geologists, V. 17, N. 8, pp. 907-962.

Price, W. A., 1947, Equilibrium of form and forces in tidal basins of the coast of Texas and Louisiana: American Association of Petroleum Geologists, V. 31, N. 9, Tulsa, Oklahoma.

Price, W. A., 1952, Reduction of maintenance by proper orientation of ship channels through tidal inlets: in Johnson, J. W., (ed.), Coastal Engineering, Proceedings of Second Conference, Houston, Texas, November 1951: Berkley, California, Council on Wave Research, Engineering Foundation, pp. 243-255.

Pritchard, D. W., 1952, Estuarine hydrography: Advances in Geophysics, V. 1, pp. 243-280.

✓ Rusnak, G. A., 1960, Sediments of Laguna Madre, Texas: in F. P. Shepard, F. B. Phleger, and T. H. Van Ande., (eds.), Recent sediments, Northwest Gulf of Mexico, American Association of Petroleum Geologists, Tulsa, Oklahoma.

Rusnak, G. A., 1967, Rates of accumulation in modern estuaries: in Lauff, G. H., (ed.), Estuaries Publication 83, American Association for the Advancement of Science, Washington, D. C.

Saville, T., Jr., 1954, The effect of fetch width on wave generation: TM-70, U. S. Army Corps of Engineers, Beach Erosion Board, Washington, D. C., December.

Shepard, F. P., 1960, Gulf Coast barriers: in Shepard, F. P., (ed.), Recent Sediments, Northwest Gulf of Mexico, American Association of Petroleum Geologists, Tulsa, Oklahoma.

Slotta, L. S., Sollitt, C. K., Bella, D. A., Hancock, D. R., McCauley, J. E., and Parr, R., 1973, Effects of hopper dredging in channel spoiling in Coos Bay, Oregon: in Interdisciplinary Studies of the School of Engineering, School of Oceanography, Oregon State University, 133 p.

Smith, D. D., 1975, Dredging and spoil disposal - major geologic processes in San Diego Bay, California: preprint, Third International Estuarine Research Federation Conference, Galveston, Texas.

Stinson, James, and Clary, James, 1974, Wind wave alteration of spoil islands - Laguna Madre, Texas: ABSTRACT, 1974 Annual Meeting, Geological Society of America, Miami, Florida.

Sundborg, Ake, 1956, The River Klaralven - a study of fluvial processes: Geografiska Annaler, V. 38, pp. 127-316.

Thorntwaite, C. W., 1948, An approach toward a rational classification of climate: Geography Review, V. 38, pp. 127-316.

U. S. Army Corps of Engineers, 1942, Report on Galveston Bay, Texas, for the reduction of maintenance dredging: V. 1, 151 p.

U. S. Army Corps of Engineers, 1973, Shore protection manual: U. S. Army Coastal Engineering Research Center, V. III, A-B, three volumes.

U. S. Army Coastal Engineering Research Center, 1973, Forecasts for lakes, bays, and estuaries: Shore Protection Manual, U. S. Army Corps of Engineers, V. 1, pp. 3-33.

U. S. Naval Weather Service Command, 1970, Summary of synoptic meteorologic observations, North American coastal marine areas: Naval Weather Service, V. 6, May.

Wilson, W. B., 1950, The effects of sedimentation due to dredging operations on oysters in Copano Bay, Texas: M. S. Thesis, Texas A&M University, 128 p.

Zupan, A. W., 1971, Surficial sediments and sedimentary structures, Middleground, Padre Island, Texas: M. S. Thesis, Texas A&M University.