INVESTIGATION OF SHORELINE CHANGES AT SARGENT BEACH, TEXAS

By

William Newton Seelig and R. M. Sorensen
Division of Coastal and Ocean Engineering
Department of Civil Engineering
Texas A&M University
Now with
Coastal Engineering Research Center
Fort Belvoir, Virginia

September 1973

TAMU-SG-73-212

Partially supported through Institutional Grant 04-3-158-18 to Texas A&M University, by the National Oceanic and Atmospheric Administration's Office of Sea Grants, Department of Commerce.

Coastal and Ocean Engineering Division
Report No. 169 C.O.E.

$3.00

Order from:

Department of Marine Resources Information
Center for Marine Resources
Texas A&M University
College Station, TX 77843

ABSTRACT

An environmental study was conducted at Sargent Beach, Texas, an erosive beach bordering the Gulf of Mexico. The objectives of this study were to determine the characteristics of the beach, the magnitudes of changes which have occurred at Sargent Beach, and to analyze possible factors which may be controlling the observed beach changes. Results show the beach has eroded at an increasing rate since at least 1930 with recent shoreline retreat rates averaging 30 feet per year. Storms are the primary agents that remove material from the beach, while lost sediments are not replaced because Brazos River sands normally expected to move alongshore are trapped in the Brazos delta. Hurricanes may free stored deltaic sands carrying major quantities offshore from beach areas. Beach erosion is further aggravated by decreased sand input to the coast from the Brazos River due to alterations to the river and its drainage basin in the 1940's.

ACKNOWLEDGEMENTS

Research described in this thesis was conducted as part of the continuing research program in Coastal and Ocean Engineering at Texas A&M University.

A review of this report by Dr. Robert E. Schiller, Jr., Dr. Wayne Ahr, and Dr. Ernest Kistler is very much appreciated. In addition, the many hours of discussion with Dr. Clarence Welborn, U.S. Geological Survey, and Mr. Howard Wolfe, National Ocean Survey and support by Mr. Edward Stokely, Dow Chemical Company, led to significant progress in obtaining both materials and ideas used in this paper. Special thanks also go to Kenneth DeFehr, James Sealy, and John R. Long for their suggestions, assistance in fieldwork, and aid in preparation.

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CHAPTER I

INTRODUCTION

Residents of Sargent Beach, Texas, a coastal community seventy-one miles southwest of Houston, have been concerned about shoreline retreat and the resulting loss of property, including beach houses, in the area (Figure 1). A preliminary study by the authors of Corps of Engineers' aerial photographs of the beach revealed that six houses were lost between 1968 and 1969 (Figure 2) and seven additional houses were destroyed by natural forces by 1973.

A second study was made of the entire Texas coast using topographic maps for 1850 through 1966 to reveal that six major areas including Sargent Beach have a net mean high water line retreat of greater than 10 feet per year for time intervals on the order of a century: an area west of Sabine Pass, the west end of Galveston Island, the coast from the San Bernard River through Brown Cedar Cut (including Sargent Beach), Pass Cavallo, an area southwest of Corpus Christi, and southern Padre Island (Figure 3, Seelig and Sorensen, 42).

Of these six shoreline retreat zones, the three eastern areas including Sargent Beach, are each accompanied by an area of shoreline

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The citations on the following pages follow the style of the Journal of the Waterways, Harbors and Coastal Engineering Division, Proceedings of the American Society of Civil Engineering.

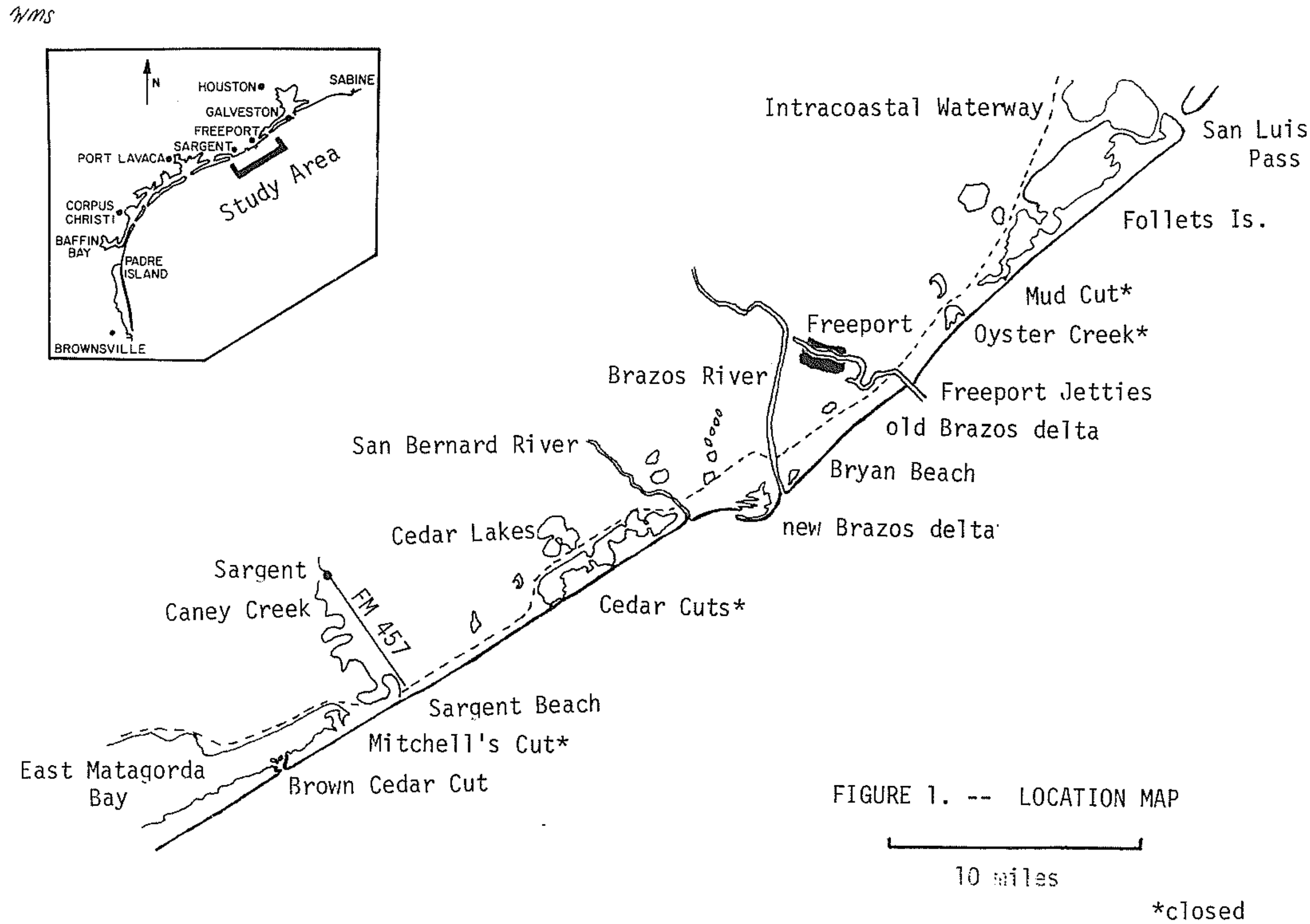

FIGURE 1. -- LOCATION MAP

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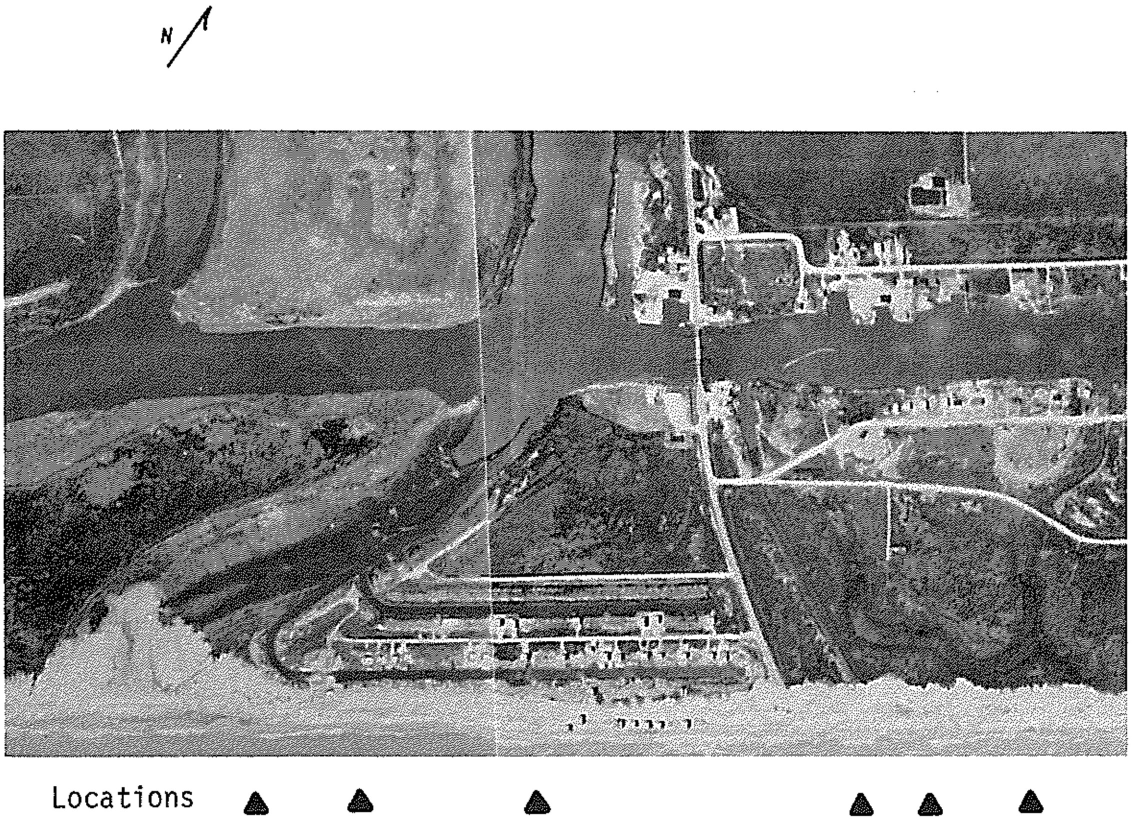


FIGURE 2.

LOCATIONS OF HOUSES LOST AT SARGENT 1968 -69

(photo by Corps of Engineers, Galveston District)

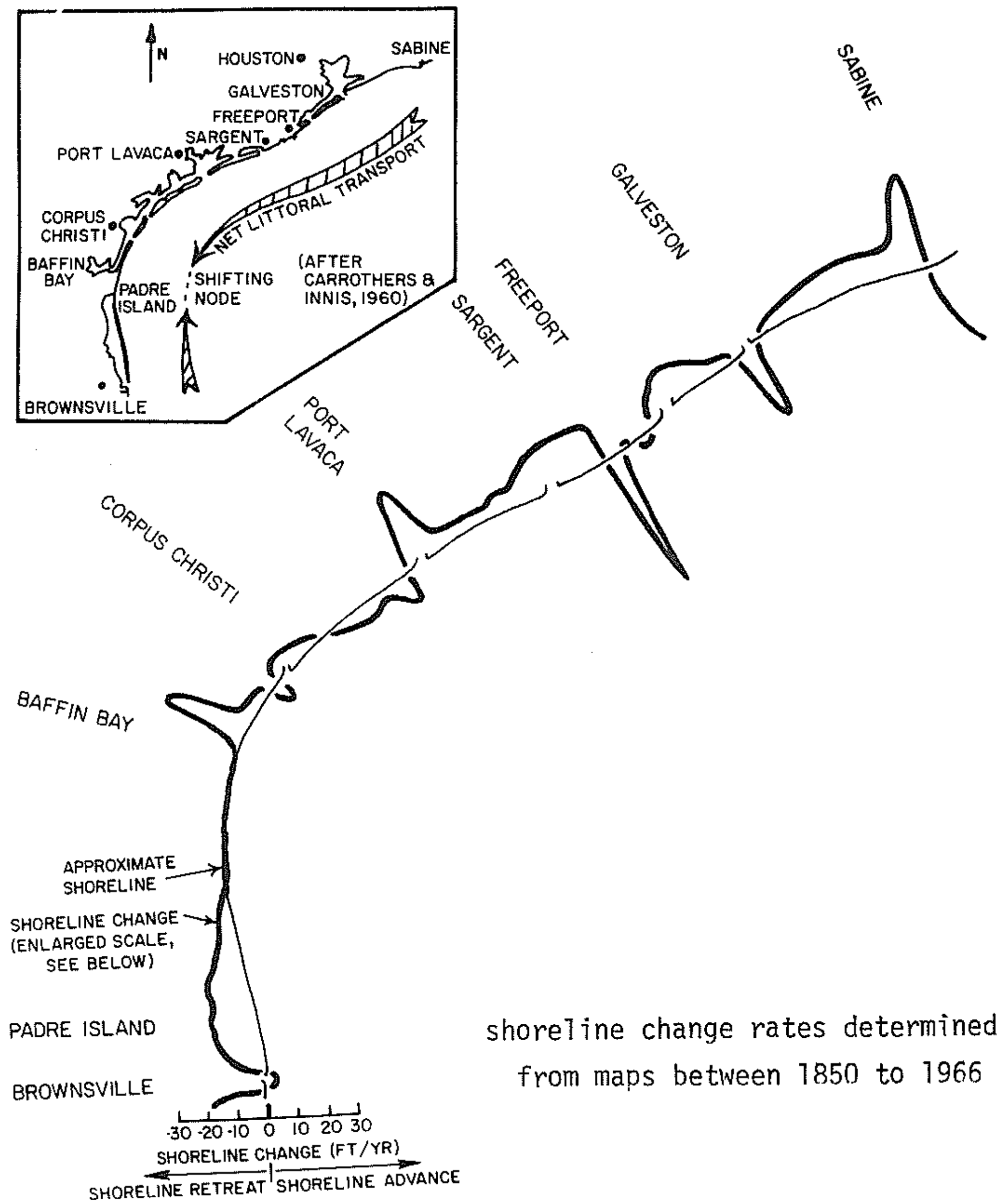


FIGURE 3. -- HISTORIC TEXAS SHORELINE CHANGES (after Seelig and Sorensen, 42)

advance immediately to the east (Figure 3). In fact, the zone east of Sargent Beach, the Brazos delta area, has the highest rate of shoreline advance found on the Texas coast. Since Carothers and Innis (9) and Mason and Sorensen (31) suggest that the net littoral transport at Sargent Beach is from east to west, the study area is defined to include the forty-seven miles of coast between San Luis Pass thirty-five miles updrift from Sargent Beach to west of Brown Cedar Cut.

The objectives of this study are to determine characteristics of Sargent Beach, measure the beach changes, and to analyze possible factors which may be causing the observed beach changes. To fulfill this objective, a section on coastal changes is first developed which summarizes the history of the study area and presents the observed long-term and short-term coastal changes at Sargent Beach. Second, the sediment characteristics of the study area are discussed. Third, the oceanographic factors: wave climate, littoral transport, and storm conditions are analyzed to determine the possible influence of these parameters on the observed beach changes at Sargent Beach. Fourth, geologic processes such as subsidence, river sediment input, and sediment losses to inlets are estimated to determine their influence on Sargent Beach. Finally, conclusions are presented by balancing the sand budget for the study area and summarizing observations from previous sections.

CHAPTER II

COASTAL CHANGES

Historical Development

Before presenting detailed analyses of coastal changes at Sargent beach, a description of the study area and a summary of major events are developed using previous literature, records, photographs, topographic and hydrographic maps, weather information, and tide records.

The study area as it exists today is atypical for the Texas coast because it does not include the barrier island system found in other areas (Figure 1). Only the most westward and eastward tips of the study area have extensive varrier islands with Brown Cedar Cut to the west connecting the Gulf of Mexico to East Matagorda Bay. To the east of Brown Cedar Cut another inlet, Mitchell's Cut, also connected the bay and Gulf for a short period, but has been closed in recent years. Caney Creek at Sargent has been closed throughout the well documented period of study, 1930 to 1973, but may have been open in 1852. Bouma and Bryant (6) believe that Caney Creek was actually a distributary of the Colorado River several centuries ago (Figure 4). Two small inlets, both called

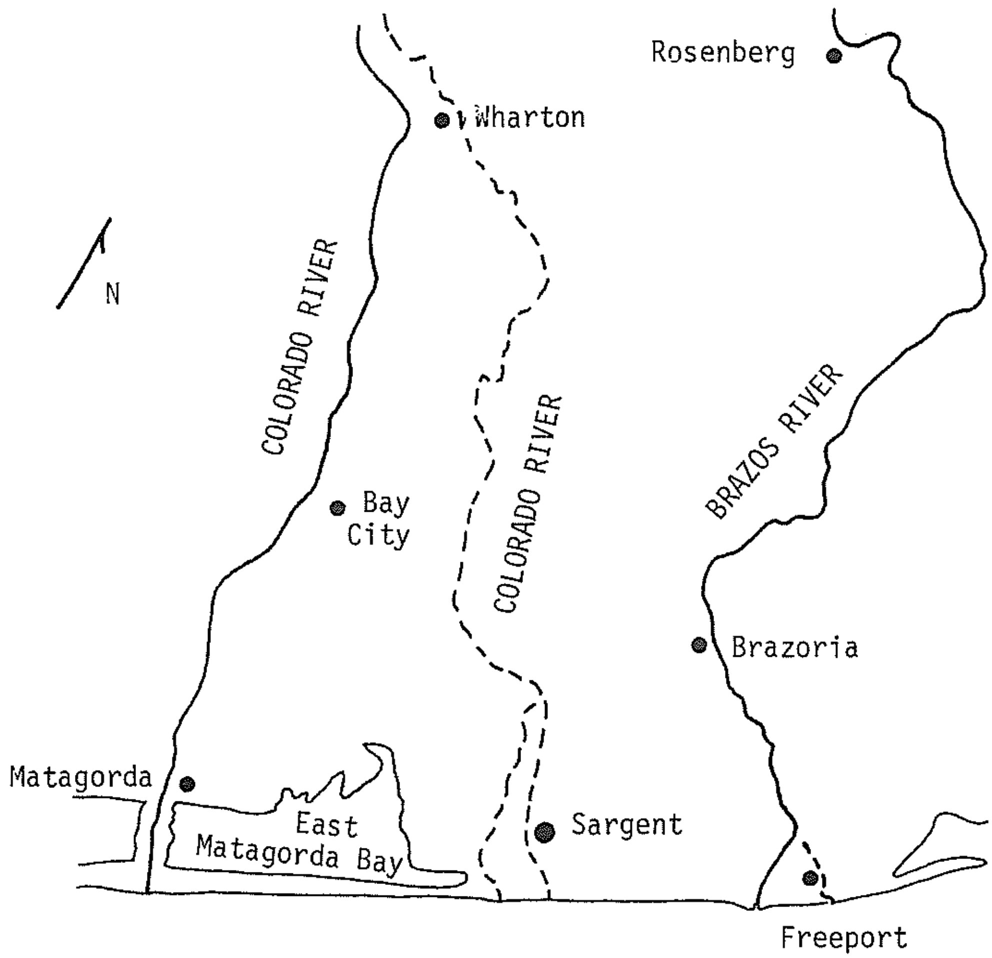


FIGURE 4. -- PRESENT AND FORMER MAJOR RIVER LOCATIONS
(after Bouma and Bryant, 6)

A FEW CENTURIES AGO - - - - -

PRESENT ———

Cedar Cut, have periodically connected Cedar Lakes with the Gulf and were closed during 1972-73. A river to the east of Cedar Lakes, the San Bernard River, is assumed to be insignificant to the study area because the sediment load and water discharge of the San Bernard are less than one percent of the Brazos River values (Adey and Cook, 1). The Brazos River, however, supplies a major portion of the recent sediments to this section of the coast, so detailed analyses of this river and the old and new Brazos deltas of the river are presented.

East of the present course of the Brazos is the former outlet to the coast, the Freeport Harbor, which is now an artifically enclosed bay protected by jetties. East of this area two temporary cuts, Oyster Creek and Mud Cut, have opened from time to time and are assumed insignificant because their small size restricts possible effects of the inlets to only localized areas. Finally, Follets Island which terminates at San Luis Pass, rounds out the area of study.

Major events and changes in the study area are listed in chronological order below.

1852:

The first detailed topographic surveys of San Luis Pass through Matagorda Bay became available in an original 1/20,000 scale (National Ocean Survey, 34). These sheets indicate that the Sargent Beach shoreline in plan was essentially straight with sand beaches (Figure 5). Caney Creek adjacent to Sargent Beach was connected to the Gulf of Mexico. The Brazos River, emptying into the Gulf 23 miles east of Sargent Beach, had only a small subaerial delta with a major offshore bar to the west of the river mouth (Figure 6 and Figure 7, OVERSIZE SHEET, in pocket).

1866, 1867, 1871:

The study area may have been affected by major hurricanes which struck the Texas coast (Price,

1875:

Mitchell's Cut, an inlet 2.8 miles to the west of Sargent Beach opened as the result of a storm of unknown dimensions (Mason and Sorensen, 31).

1881 to 1886:

Initial attempts were made by private interests to establish a permanent harbor at the mouth of the Brazos River by initiating construction of jetties on both sides of the river mouth (Wisner, 56). The project was terminated due to a lack of funds, but maps suggest that a delta began forming immediately (Figure 6).

1888, 1895:

Price reports hurricanes were observed on the Texas coast during these two years.

1899:

The federal government took over bankrupt private harbor firms and completed the Freeport Jetties. Corps of Engineers records

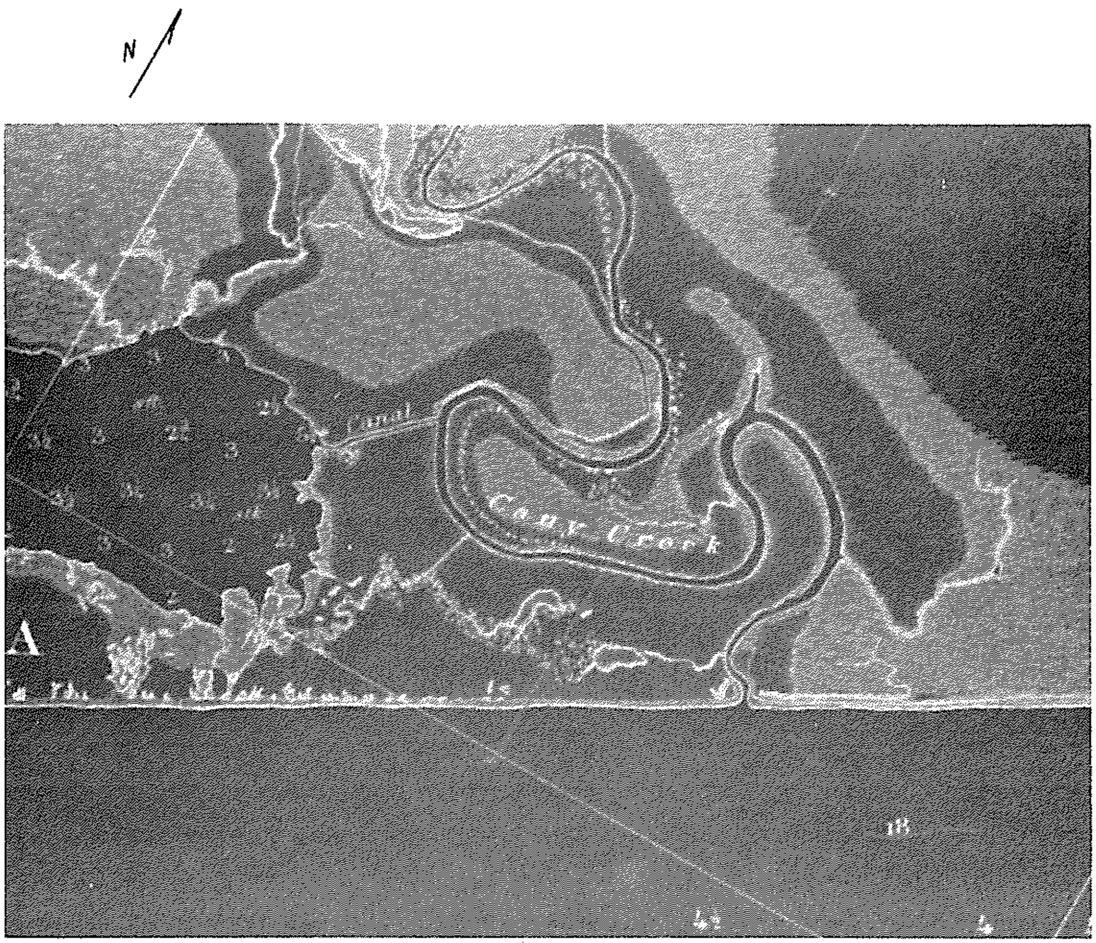


FIGURE 5.

SARGENT AND VICINITY FOR 1852
(from Chart 206 dated 1858)

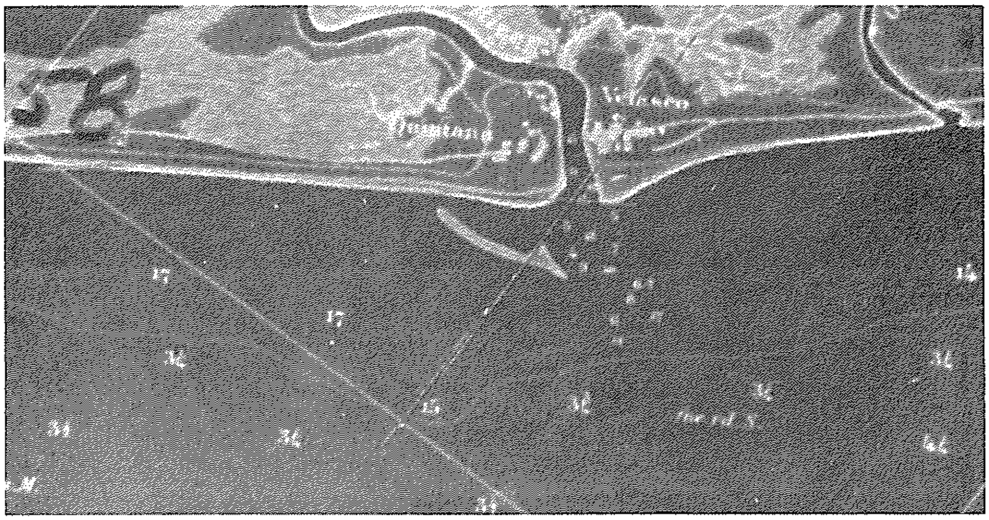
Chart 206 dated April 1858

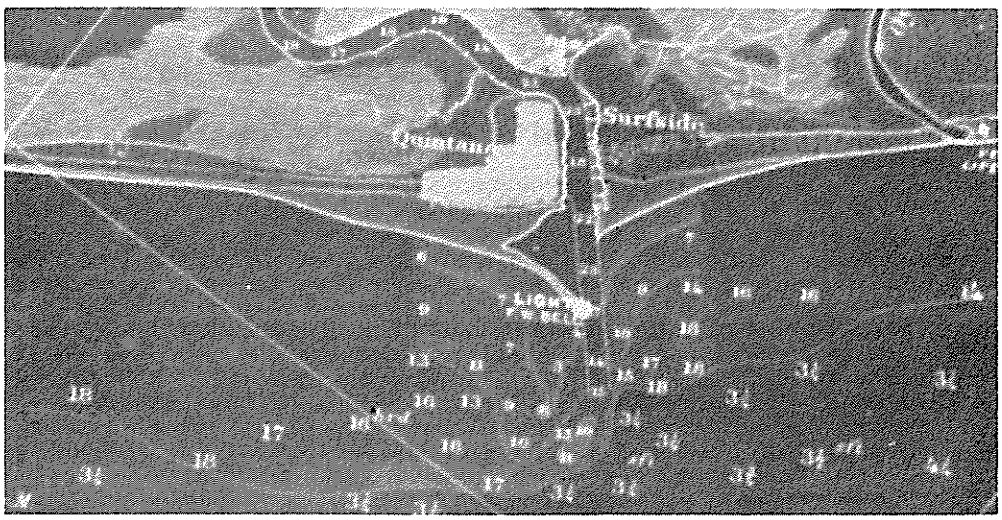
(survey date 1852)

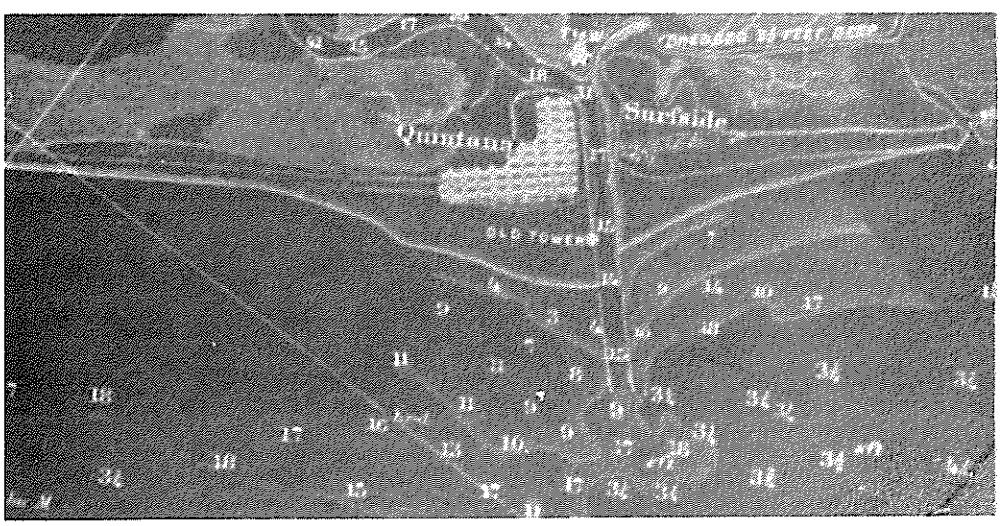
Chart 206 dated January 1881

Chart 206 dated March 1909

FIGURE 6. -- THE OLD BRAZOS DELTA PRIOR TO 1930


Velasco
Quintana


Surfside
Quintana


Surfside
Quintana

show that only minor repairs have been made to the jetties from 1899 to 1973, so they provide an excellent reference mark for photographs and maps since 1899.

1900:

A hurricane with high winds, heavy rains, and an estimated storm tide of 11 feet destroyed a major section of the port of Galveston (Price, 37).

1904:

Mitchell's Cut was closed, probably due to the action of littoral transport in vicinity of the inlet (Mason and Sorensen, 31).

1905:

An artifical cut known as Browns Cut was dredged at the eastern end of Matagorda Bay. Mason and Sorensen (31) conclude that this cut probably closed quickly due to inadequate design.

1909:

Photographs show that a hurricane with storm tides of 9 feet destroyed the town of Velasco, adjacent to Freeport Harbor, leaving only several buildings standing (photographs available at the Freeport Chamber of Commerce).

1915:

Reports were made of 13 foot hurricane tides for the open coast near Galveston (Price, 37).

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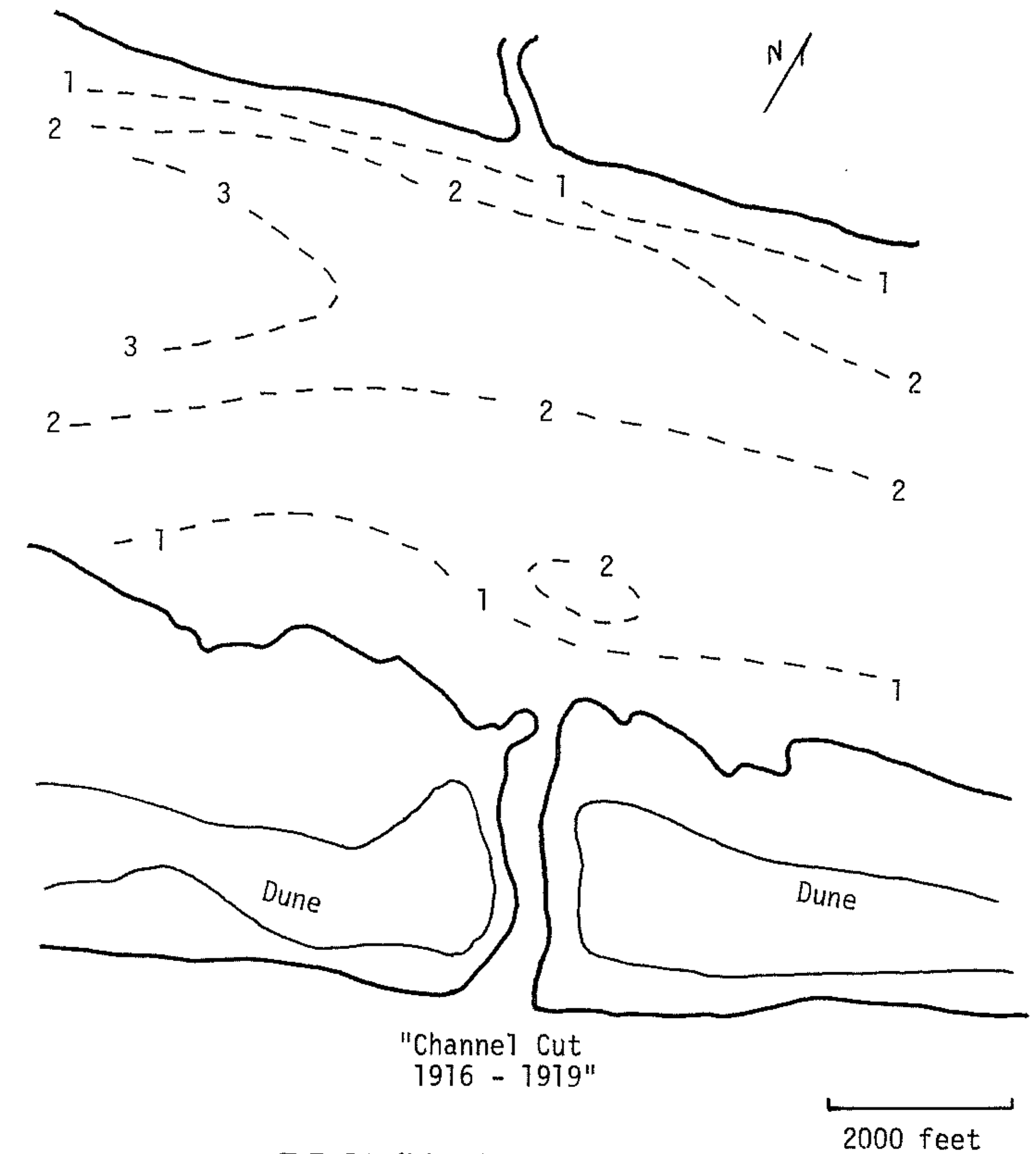
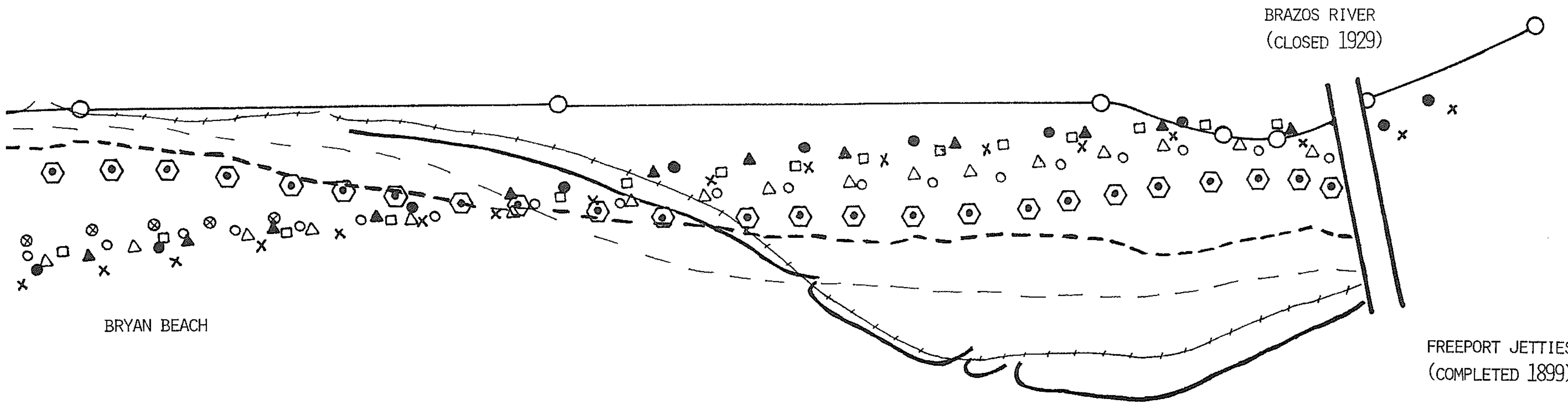


FIGURE 8. -- **BROWN CEDAR CUT 1920 - 1921**

topography August-October 1921
hydrography August 1920 - July 1921
by U. S. Engineers

shoreline

depth, in feet



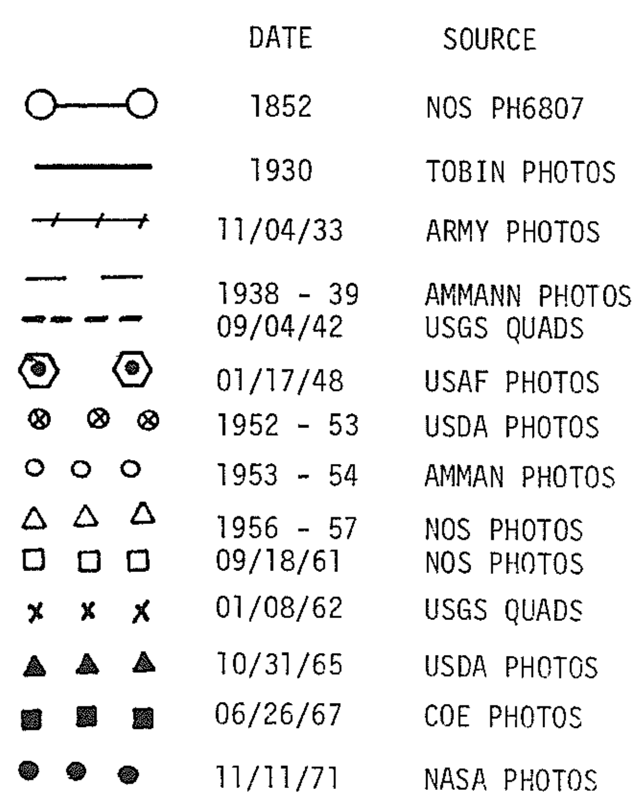


FIGURE 7.

BRAZOS DELTAS 1852 - 1971

(SEE TEXT AND APPENDICIES FOR NOTES ON SOURCES AND DETAILS)

1 MILE

1 KM

JMS 6/01/73

1916-1919:

A survey of the Intracoastal Waterway by the U. S. Engineers August 1920 to October 1921 shows "Channel Cut 1916-1919" for Brown Cedar Cut (Figure 8)*. Note that no washover fan is present in Matagorda Bay or dredging spoils indicated on the banks. This evidence suggests that either Brown Cedar Cut was artifically re-opened by fishing interests as in 1905, or that storm tides associated with 1916 and 1919 hurricanes cut the inlet from the bay through to the Gulf.

1929:

The Brazos River entering the Gulf of Mexico at the Freeport Jetties was artifically rerouted almost six miles to the west in an effort to reduce flooding and shoaling at Freeport (Figure 9). Corps of Engineers partial surveys at the mouth of this new outlet show that a delta began building immediately (Appendix D). At the same time a delta also began forming in Matagorda Bay after a log jam on the Colorado River was freed, breaking loose large volumes of sediments (Bouma and Bryant, 6).

1930:

Aerial photographs for the study area became available (Tobin

*Mason and Sorensen (31) conclude that the cut opened in 1929 based on USCGS Charts 1283, but review of the chart records shows that there was a 10 year lag between the survey and chart dates. This type of serious problem was found throughout the charts, so Charts 1283 should not be used for detailed engineering purposes without first consulting National Ocean Survey records (located in Rockville, Maryland).

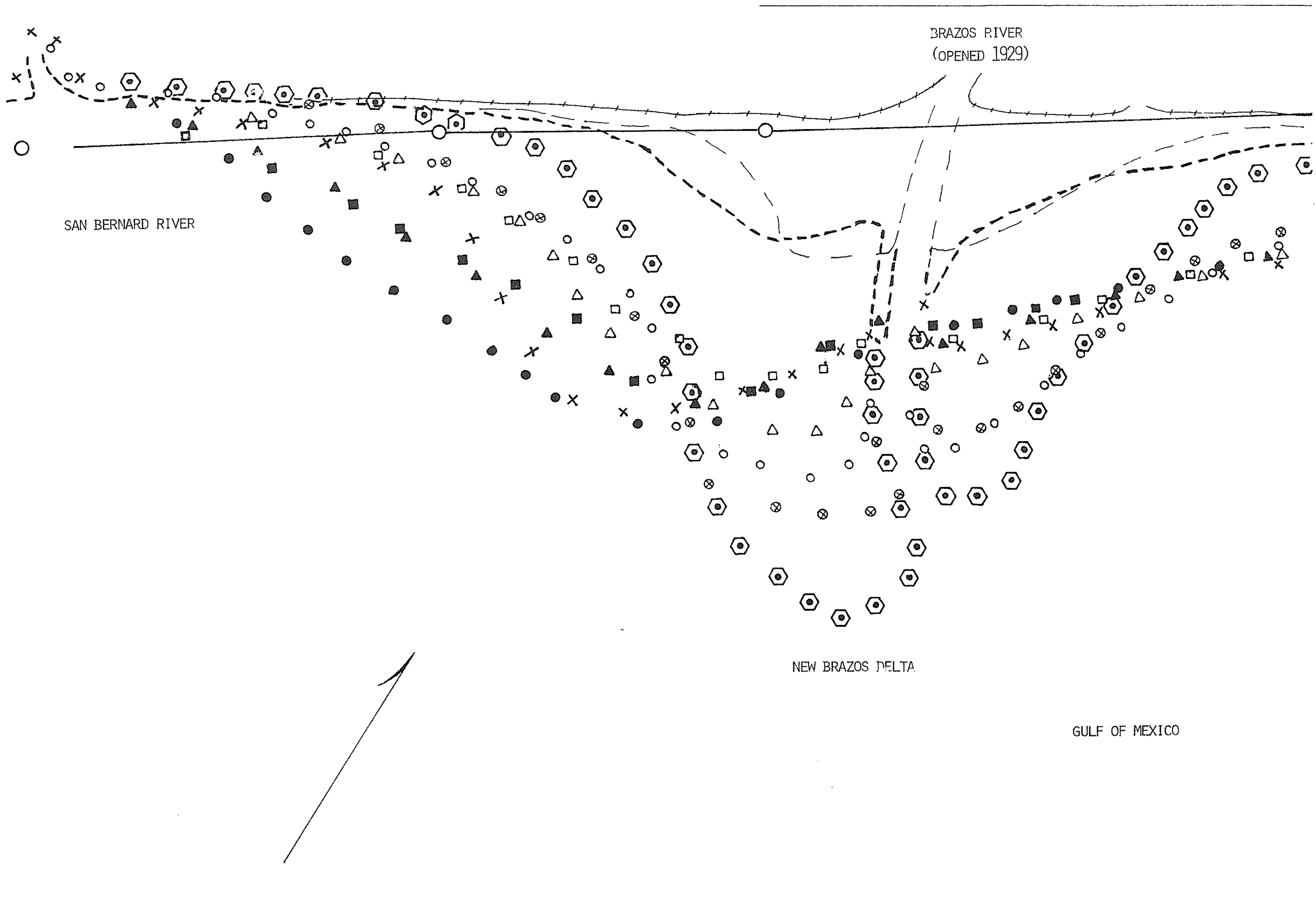

BRAZOS RIVER
(OPENED 1929)
SAN BERNARD RIVER
NEW BRAZOS DELTA
GULF OF MEXICO

FIGURE 9. -- BRAZOS RIVER DELTAS

(photos 12/18/38 to 1/20/39, uncontrolled mosaic, available at Galveston District, COE)

1 Mile

Surveys, San Antonio) showing that a delta grew one mile into the Gulf to the west of the Freeport Jetties between 1852 and 1930 (Figure 7, Appendix D). For the same time interval the Sargent Beach shoreline retreated landward over 800 feet with a mean recession rate of 11 feet per year.

1932:

Freeport experienced a hurricane tide reaching a maximum of six feet (Bodine, 3).

1933:

Hurricanes in both August and September hit the study area with storm tides of several feet. Aerial photographs by the Army Air Corps taken in November (Figure 10) were used as a base by the National Ocean Survey to make a topographic map of the Sargent Beach area showing that the coastline receded 29 feet per year 1930 to 1933, while the old Brazos delta also began to decrease in size. In addition, a new Brazos delta formed at the rerouted river mouth (Figure 7, Appendix D).

1934:

The continued growth of the Colorado River delta completely divided Matagorda Bay leaving Brown Cedar Cut as the sole outlet of the newly formed East Matagorda Bay to the Gulf of Mexico. During the same year a July hurricane inundated the study area with tides of 10.2 feet (Bodine, 3).

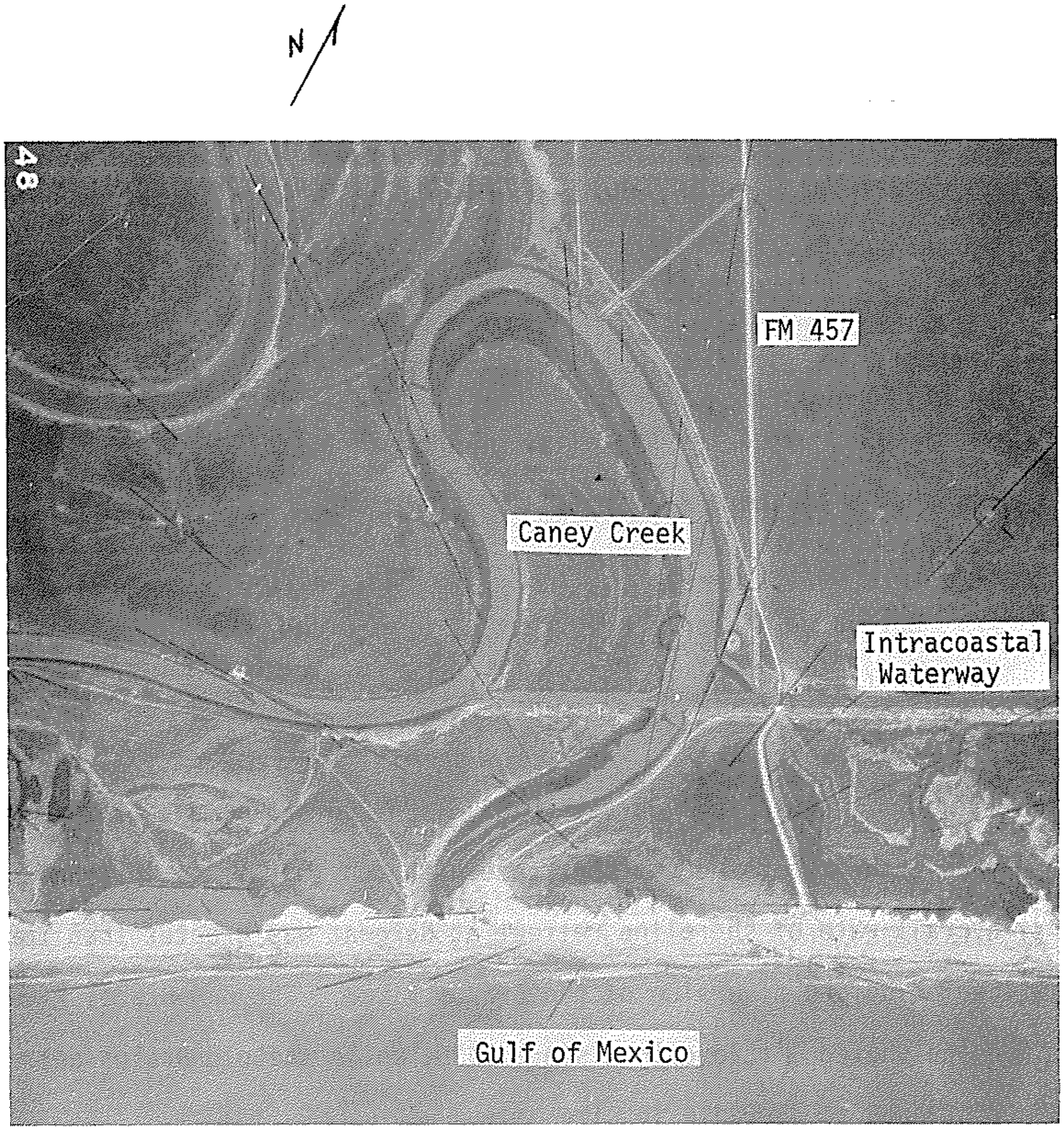


FIGURE 10. -- SARGENT 4 NOVEMBER 1933

(photo by Army Air Corps, photo number 48, available from National Ocean Survey)

1937:

The first complete hydrographic survey for the area between Brown Cedar Cut to the new Brazos delta was conducted by the Coast and Geodetic Survey showed the submerged new delta to have a triangular shape with both height and base dimensions in plan to be approximately 12,00 feet (Figure 11).

1938,1939:

the subaerial portion of the old Brazos delta retreated 1000 feet since 1937, while the shoreline of the new Brazos delta grew a comparable distance (Figures 7, 9 and Appendix D).

1941:

Hurricane tides of nine feet were recorded at the Freeport Jetties (Bodine, 3).

1942:

U. S. Geological Survey (USGS) 1/24,000 scale maps of the coast made after the 30 August hurricane with ten foot tides indicate the overall rate of shoreline retreat at Sargent was greater than for the period before diversion of the Brazos River. The new Brazos River delta showed little change since 1938, while the old Brazos delta continued to decrease in size.

1943:

Freeport was hit by a hurricane with a storm tide of unknown dimensions. A drawdown of 5.5 feet occurred at Galveston. Although this unusual tide is not expected to have a direct impact on beach areas, it may have allowed damaging waves to reach lower on the

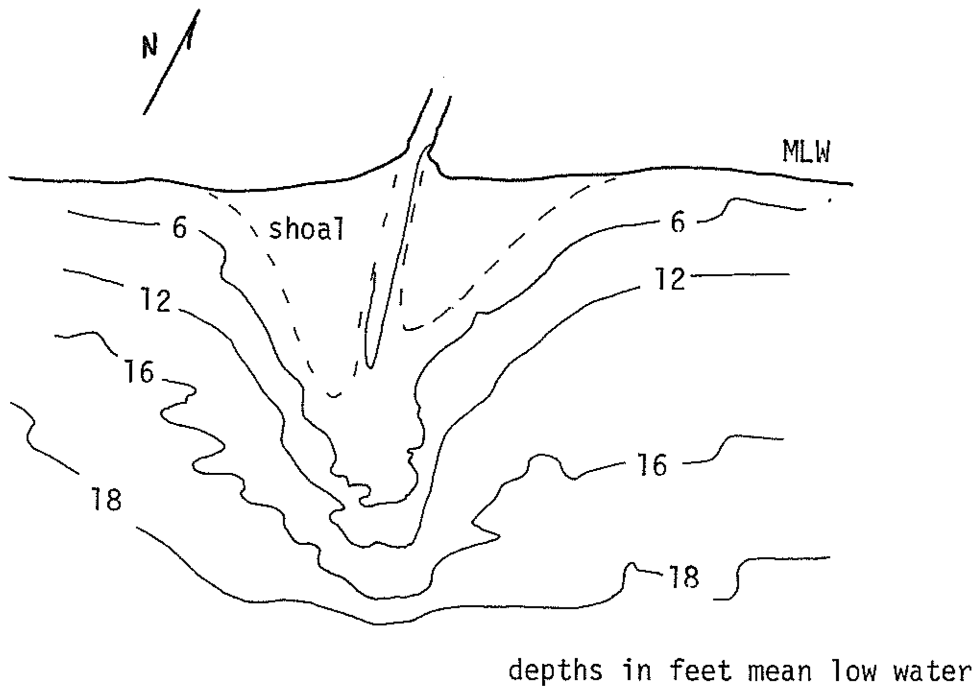


FIGURE 11. -- NEW BRAZOS DELTA 1937

(after National Ocean Survey)

beach profile than normal and caused high ebbing velocities at Brown Cedar Cut.

1946:

Photographs by the U. S. Department of Agriculture of the new Brazos delta show the shoreline changed only an insignificant amount between 1942 and 1946.

1948:

U. S. Air Force aerial photographs taken during January document the most seaward intrusion on record of the shoreline of the new Brazos delta (Figure 7, Appendix D). While the subaerial delta changed little from 1933 to 1946, it suddenly grew 8000 feet into the Gulf in less than two years. At the same time, the old Brazos delta continued to decline at the same rate since 1930. Note that the mouth of the Brazos River at this time was directed forty-five degrees eastward.

1949:

Hurricane tides of approximately eight feet were reported at Freeport (Bodine, 3).

1952, 1953:

The Sargent Beach shoreline as well as the waterlines of the two Brazos deltas retreated while the old Brazos delta, adjacent to the Freeport Jetties, has approximated the 1852 shoreline. Also note that the waterline in the area of the old Brazos delta and Bryan Beach has reached the approximate position it retained 1952 through 1973. On this shoreline a node, an area of relatively little change from 1930 to 1973, exists 12,000 feet west of the Freeport Jetties. This nodal point lies immediately between two deltas with some of the highest shoreline change of the Texas coast (Figure 7).

1953, 1954:

Although Sargent Beach experienced coastal erosion, the Freeport and new Brazos delta areas showed little change (Figure 7, Appendix D).

1956, 1957:

Minor modifications occured to the barrier bars of the new Brazos delta late in 1956 through January 1957. Later in June of 1957 a hurricane with 4.5 foot tides at Freeport hit the study area (Bodine, 3).

1961:

On 11 September 1961 hurricane "Carla" with 10.8 foot tides struck Freeport and vicinity. Except for the barrier sand bars on the new Brazos delta which were swept away, the delta as of 18 September kept approximately the same configuration as in 1956-57 (Figure 7, Appendix D).

1962:

Sediments reoriented by hurricane "Carla" formed a barrier bar on the New Brazos Delta, strongly skewing the overall subaerial shape to the west (Figure 7, Appendix D).

1965:

The shoreline retreat at Sargent increased, as measured from photographs, while the new Brazos delta continued to migrate westward.

1967:

Increased interest in the Texas coast led to the initiation by the Corps of Engineers of periodic surveys of selected areas in Texas, including four profiles spaced at 1000 foot intervals at Sargent beach adjacent to FM Road 457. The 1967 surveys show that erosion had temporarily reached a level that caused a shoreline change rate of -70 feet per year. The new Brazos delta showed little change since 1965. The study area experienced tides of over four feet associated with hurricane "Beulah".

1969:

Photographs by the National Aeronautics and Space Administration before and after hurricane "Camille" showed the hurricane had no apparent influence on the configuration of the Brazos delta (not illustrated).

1971:

Aerial photography for November revealed that since hurricane "Fern", 7-13 September with 5.3 foot storm tides, the Brazos delta migrated westward.

1972:

On 23 November after a winter storm, Sargent Beach was exposed at low tide, showing its composition to be largely clay outcroppings with a layer of sand and shell covering only the beach area above mean sea level. A stump imbedded in the clay protrudes from the beach at approximately two feet above the mean water level, suggesting that this area was once an inland zone capable of supporting large trees (Figure 12).

1972, 1973:

Overflights by the authors on 26 September 1972 and 26 January 1973 revealed that no major subaerial changes occurred to the study area between flights. A hydrographic survey of the Brazos deltas and an offshore profile of Sargent Beach February through June, however, disclosed that since 1937 the hydrography has altered significantly.

Examination and analysis of specific factors believed to be related to the beach changes at Sargent Beach are examined from an engineering standpoint in the following chapters.

Observed Beach Changes at Sargent Beach

Several parameters such as shoreline position, slope of the beach at mean sea level, and the volume of the beach are used to describe a beach. Measurement of these parameters with time are then used to determine rates of change, for example, the shoreline change rate.

Long term. Long term changes are defined as those measurements made at one year intervals or longer. For example, the shoreline, or the local waterline, was measured for ten dates 1852 to 1972 from maps and photographs to show the shoreline at Sargent

FIGURE 12.

SARGENT BEACH 23 NOVEMBER 1972

(photo taken east of FM 457, looking east,
author's photo)

Beach has retreated approximately 2000 feet during this time interval (Figure 13). Further examination of the shoreline position reveals that the shoreline retreated at a mean rate of 11 feet per year 1852 to 1930 with the waterline retreat rate increasing to 31 feet per year for 1967 to 1972.

To examine long term profile change at Sargent Beach, offshore profiles opposite FM Road 457 for 1937 and 1973 are compared (Figure 14) showing largest have occured within the 10 foot contour mean low water.

Short term. Short term changes are defined as changes determined from measurements made at less than one year intervals. The most detailed short term information on Sargent Beach consists of 15 survey dates of four profiles surveyed by the U. S. Army Corps of Engineers, Galveston District, for 1967 through 1972. The four profiles were spaced at 1000 foot intervals and generally surveyed to include the +5 and -5 foot contours mean sea level (Figure 15).

Three paramters used in this study to describe Sargent Beach are the mean sea level (MSL) intercept change, the volume change, and the beach slope at mean sea level. These parameters are defined as:

mean sea level intercept change - the distance between the position of the most landward point where the 0 foot contour (MSL) intercepts the beach profile for two sucessive dates. For profiles illustrated in Figure 15 the change is negative indicating shoreline retreat. (Note, if profiles were surveyed

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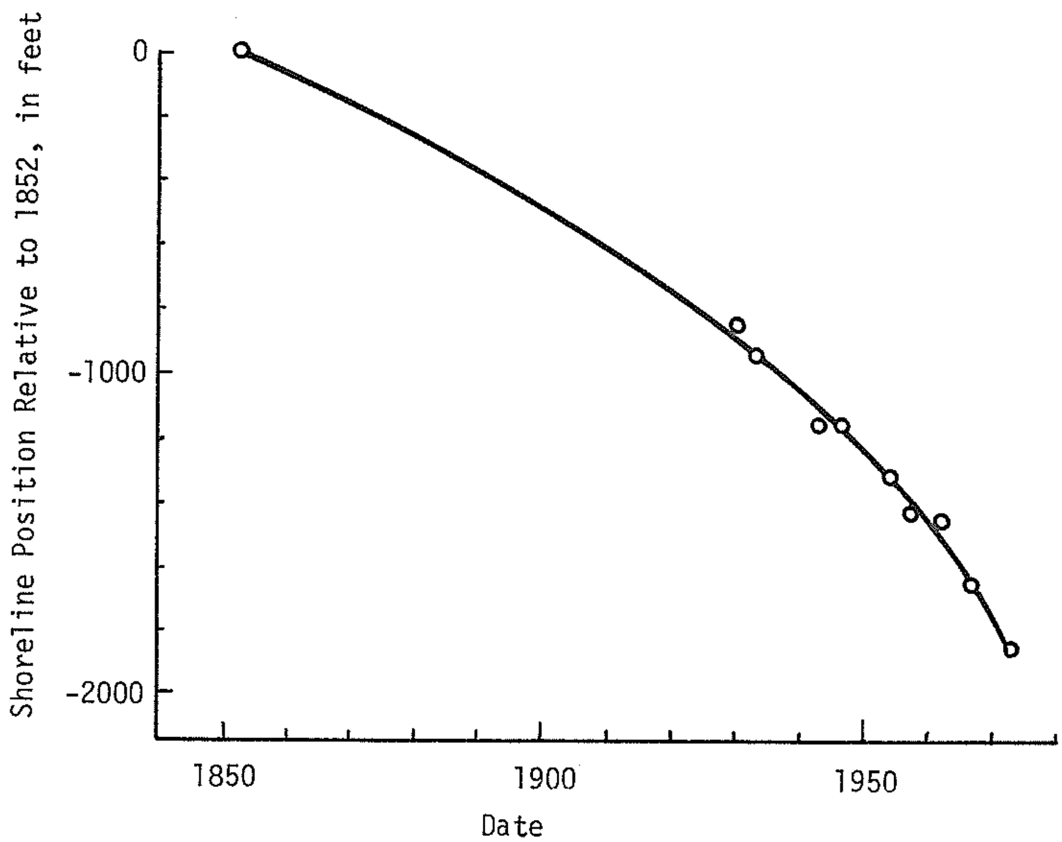

FIGURE 13.

HISTORICAL SHORELINE POSITION FOR SARGENT, TEXAS

(reduced from photographs and maps)

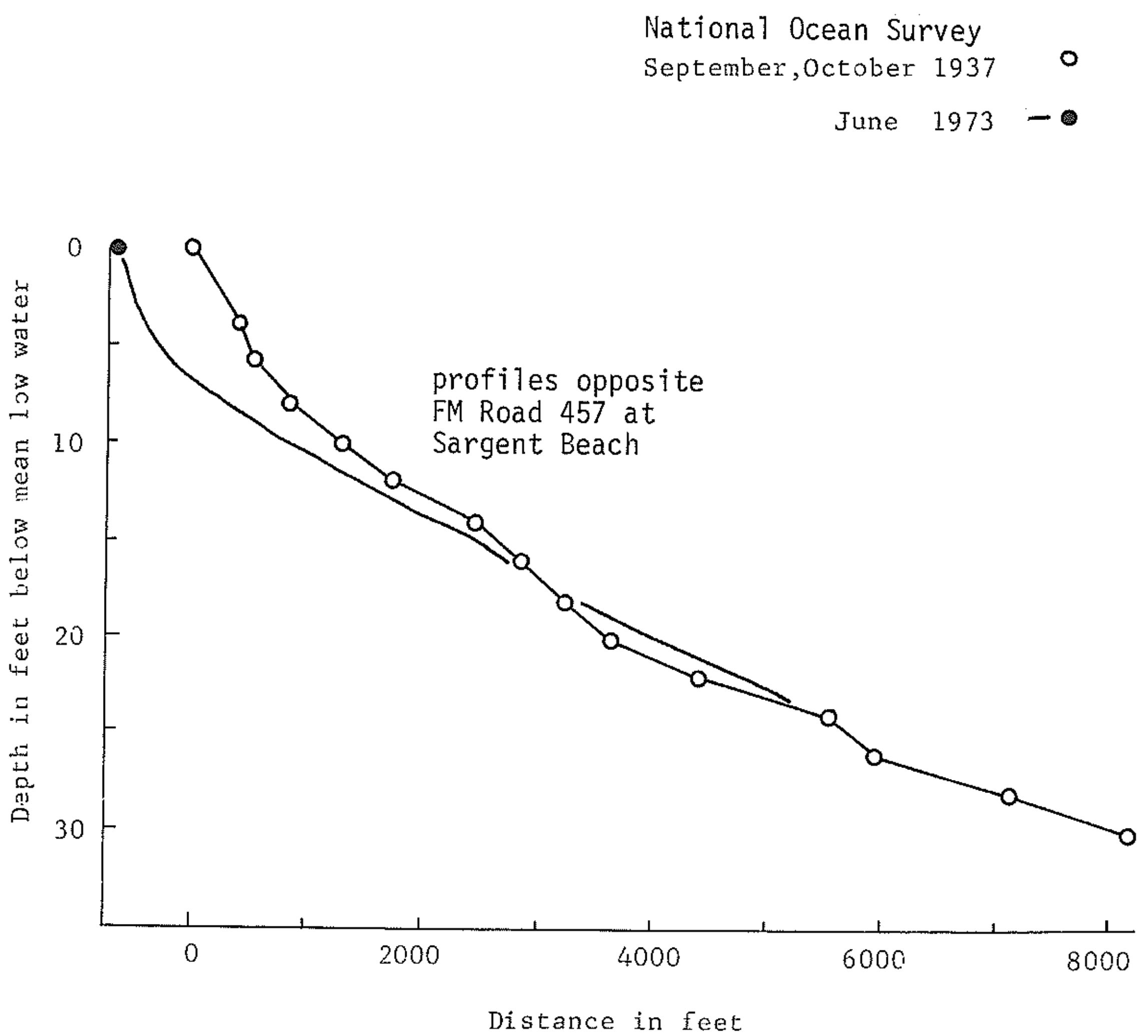

FIGURE 14. -- SARGENT OFFSHORE PROFILES 1937 and 1973

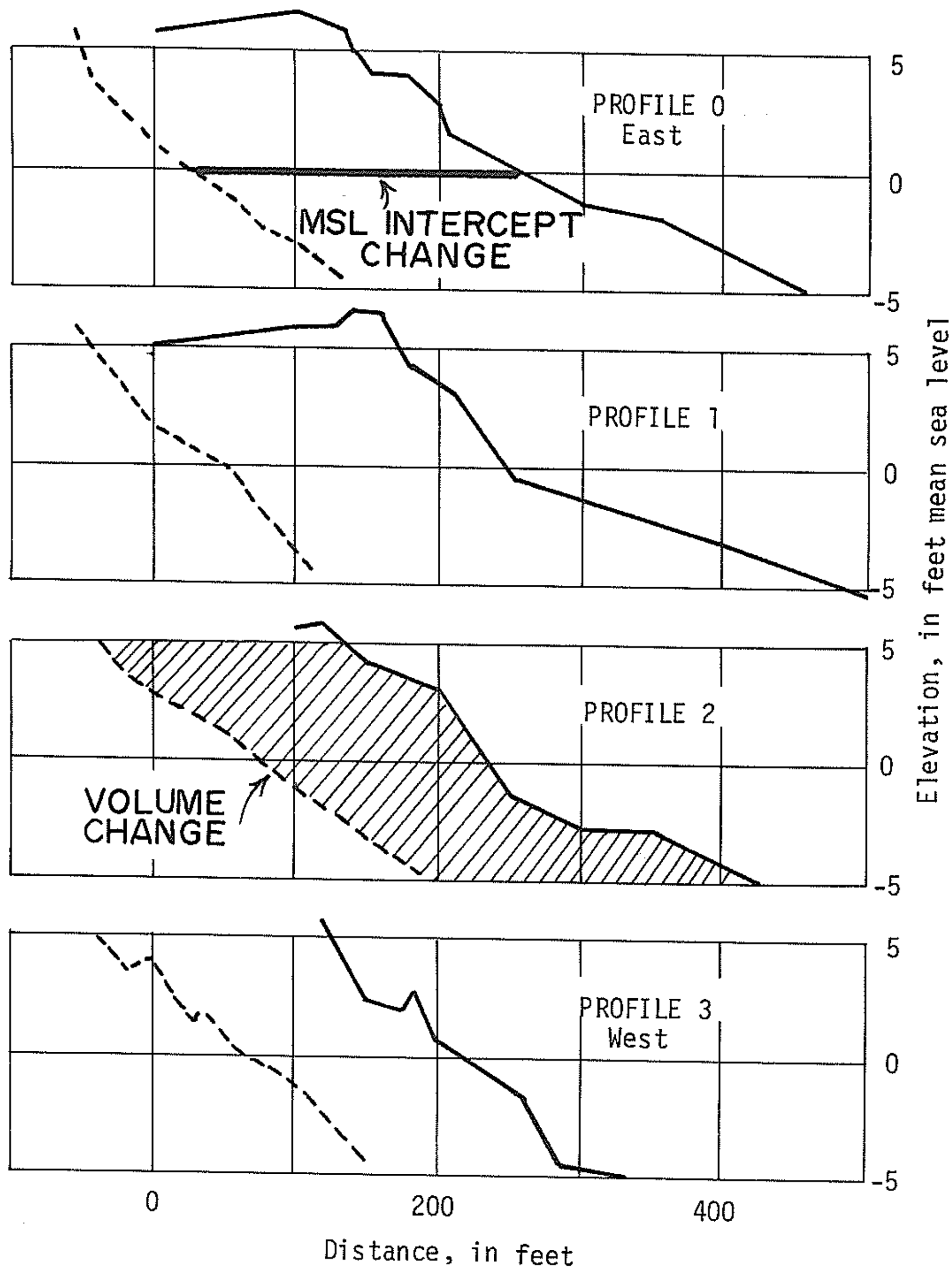

FIGURE 15. -- SELECTED SARGENT BEACH PROFILES

(after U. S. Army Corps of Engineers, 48) ——— 5/23/67 - - - 9/ 6/72 further offshore it is possible that an offshore bar could reach above the 0 foot contour resulting in multiple definition of MSL intercept change, but surveys studied here were made only to the first -5 foot contour, so this problem is not encountered, C. J. Galvin, personal communication).

volume change - the net volume per foot of beach (used here with units cubic feet per foot of beach) change for two dates between the most landward intercepts of the +5 and -5 foot MSL contours, where a negative value as for profiles in Figure 15, indicate a net loss of material from this section of beach. As Figure 14 illustrates the beach volume changes beyond the -5 foot contour are significant of the long term, so the total volume change in the coastal zone may be larger than profiles between the +5 and -5 foot contours indicate.

slope at mean sea level - the slope of the beach survey line which intersects the mean sea level contour. A positive slope is defined to represent a beach sloping toward the Gulf.

The cumulative beach changes of both mean sea level intercept and volume for the mean of the four Sargent Beach profiles show the beach on the average lost 390 cubic feet per year per foot of beach of sediments and the shoreline retreated 31 feet per year from 1967 to 1972. The increasing rate of shoreline retreat illustrated in Figure 13 for long term changes was not detected by the short term surveys 1967 to 1972 (Figure 16), so no acceleration

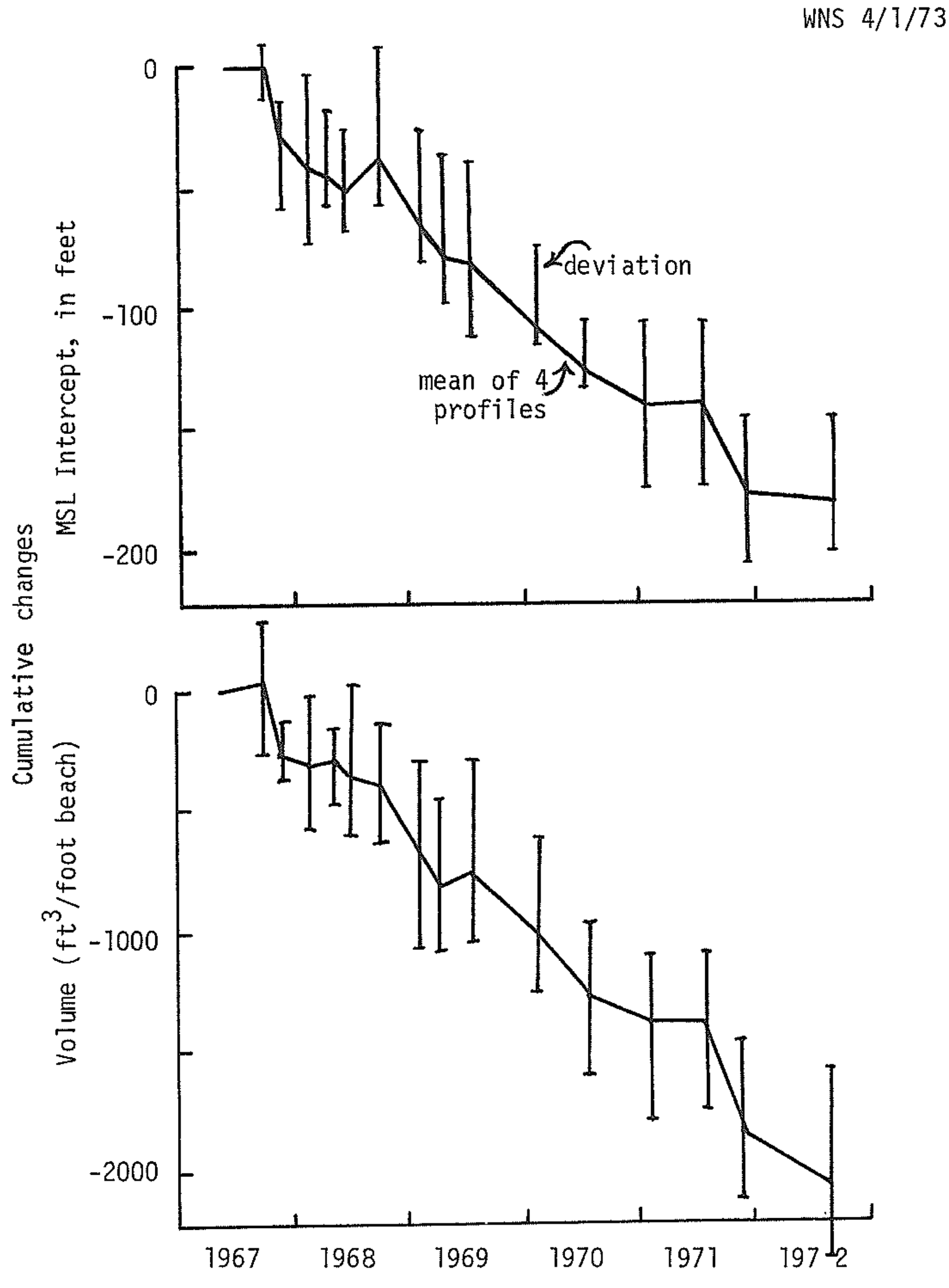

FIGURE 16.-- CUMULATIVE BEACH CHANGES AT SARGENT
(May 1967 datum)

(after U. S. Army Corps of Engineers profiles, 48) of the value of the beach parameters is assumed for 1967 to 1972.

A plot of the probability of mean Sargent Beach changes for five categories of change shows that for 1967 to 1972 the shoreline advanced and the beach accreted approximately twenty-five percent of the time while for seventy-five percent of the time the waterline retreated and the beach eroded (Figure 17).

The concave shape of the Sargent Beach profiles (Figure 15) also suggests that the beach is predominantly erosive (Everts, 16) and Wiegel, 54).

In addition to the mean changes of all four profiles, the profile changes between two dates for the profiles spaced 1000 feet along Sargent Beach are examined to show that changes vary with distance. For example, one end of the beach may erode while the other accretes (May to September 1967) or one profile shows different characteristics than the other three (January to July 1971). Even over the five year interval 1967 to 1972, the east end of Sargent Beach, as measured by profiles 0 and 1, was eroding forty to sixty percent faster than the western profiles 2 and 3 with the highest erosion taking place on the flatter profiles (Figure 18) (Everts, 16).

On the average Sargent Beach profiles maintain the same shape (Figure 15), so shoreline change, ΔI (in feet) and beach volume change, ΔV (in cubic feet per foot of beach) are related by:

$$\Delta V = k \, \Delta I \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where k equals 13 square feet per foot of beach for Sargent Beach.

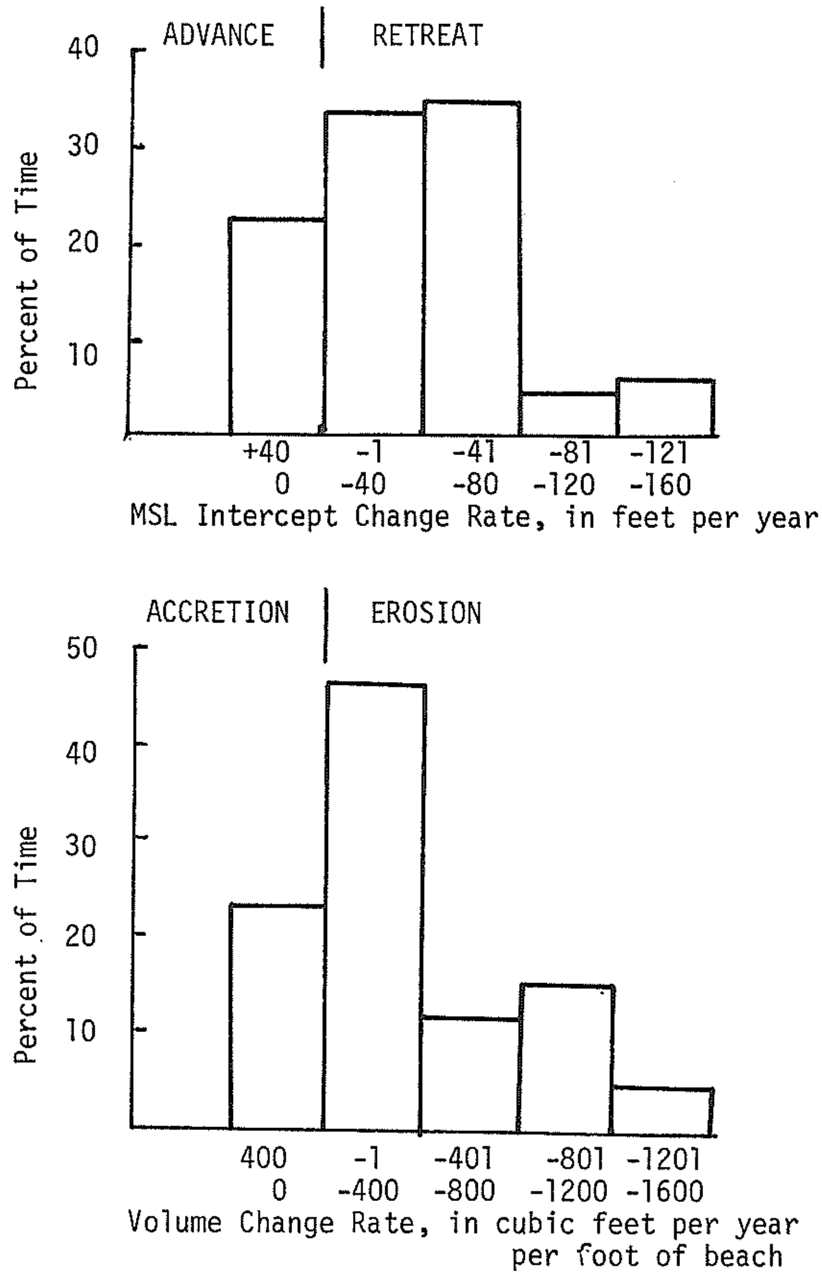

FIGURE 17. -- PROBABILITY OF BEACH CHANGES 1967-72

(profiles by U. S. Army Corps of Engineers, 48)

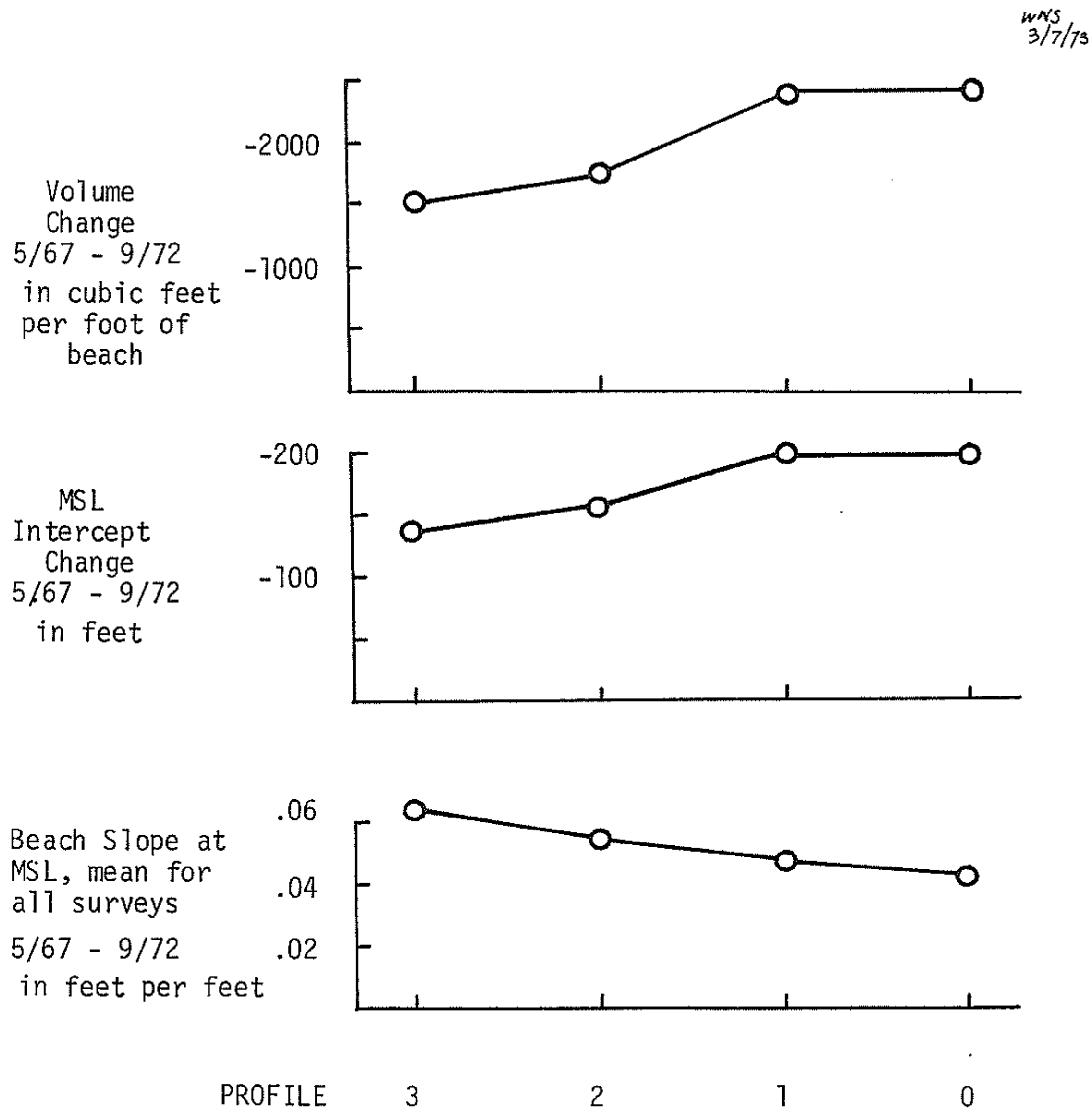

FIGURE 18. -- SUMMARY OF BEACH CHARACTERISTICS FOR SARGENT BEACH

(after U. S. Army Corps of Engineers profiles, 48)

With equation (1) shoreline changes, for example measurements from aerial photographs, can be used to approximate volume changes of Sargent Beach for the +5 to -5 foot contours.

CHAPTER III

SEDIMENTS

Sediment size is an important property to the dynamics of a sediment system (Graf, 31) and to the sediment budget of an area. For the study area sediment size was analyzed for two regions, the beach zone and offshore areas.

Beach Sediments

Nienaber (35) observes that the sand layer at Sargent Beach is actually "a thin veneer from high tide to some feet below tide, but during periods of increased activity a hard slippery clay bottom is exposed", as Figure 12 illustrates.

To determine the general distribution of beach sands in this sand layer samples were collected on 23-24 November 1972 at the local waterline on 0.5 to 1.0 mile intervals for the entire length of the study area from Brown Cedar Cut to San Luis Pass (Figure 1). In this procedure, a three inch diameter jar was used to collect a three hundred gram sample by scraping the upper 0.5 cm of sediment in the zone of wave run-up. These samples were then analyzed by: 1) removing shell (twenty to seventy percent of the total sample by weight for Sargent Beach and less than ten percent for other areas), 2) sieving out sand particles greater than 0.85 mm, and 3) analyzing the remaining sediment using a visual accumulation tube (Colby and Christensen, 1956).

The effective median fall diameter, D_{50}, of these samples is approximately a constant 0.15 mm for sediments for San Luis Pass through the San Bernard River and rises to a maximum of 0.3 mm at Sargent Beach, falling off to 0.2 mm of the east tip of Brown Cedar Cut (Figure 19). Sargent Beach has as high as seventy percent shell for some samples and is the only location with sand particles with diameters greater than 0.85 mm in significant quanities at the water-line. Also, the entire beach area from west of the San Bernard River to Sargent (Figure 19) has scattered clay outcroppings exposed at low tide (Figure 12). These clays are associated with mudballs on the beaches which Nienaber (35) attributes to "a process of vertical caving in chunks".

Offshore Sediments

During the summer of 1952 Odem (36) took a series of thirty-nine cores, approximately four feet in length, throughout regions of the new Brazos delta. Sixteen of the thirty-nine cores are described by Odem to have on the order of seventy percent sand.

A second set of six cores taken during the winter 1972-73 is available for the area from four to thirty-five miles offshore of the new Brazos delta in an eleven mile wide strip. Initial examination of these cores shows a sand layer two inches thick covers a large

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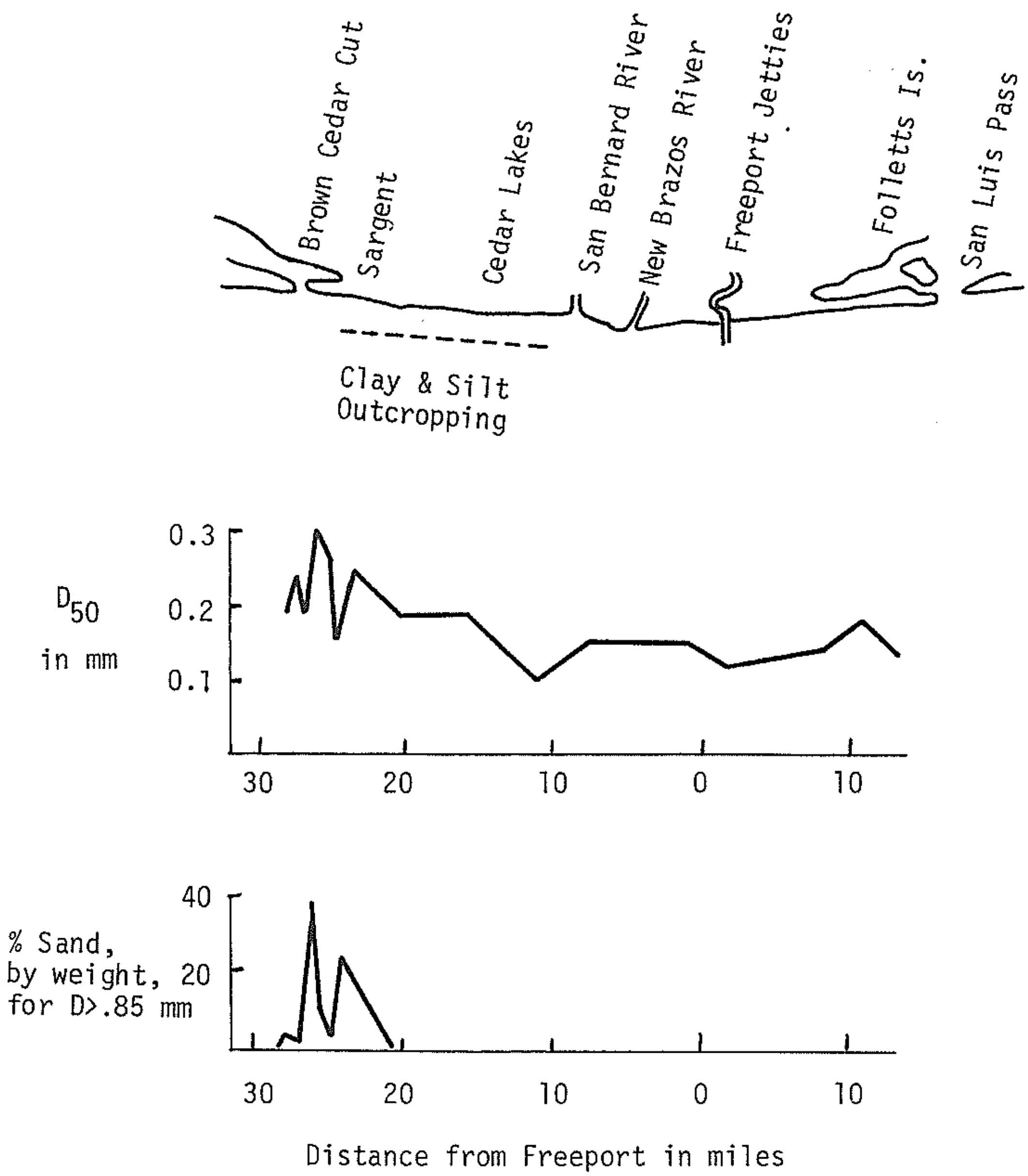

FIGURE 19. -- SEDIMENT CHARACTERISTICS
FOR THE STUDY AREA

portion of the offshore area adjacent to the Brazos delta. The remaining several feet of sediment of these cores is fine silt and clay size material (personal communication, Dr. J. F. Slowey, Civil Engineering Department, Texas A&M University).

Surface sediments for a seven-hundred and fifty square mile area offshore of both the new and old Brazos deltas were analyzed by Nienaber (35) for depths out to the 120 foot contour. Of these samples the mean sediment size within the 60 foot contour is inversely related to water depth with most samples described as fine sand.

Conclusions

The unusually coarse and and high shell fraction found at Sargent Beach may be reminants of the former Colorado River bed and bays (personal communication, Dr. McGowan, University of Texas, Bureau of Economic Geology, September, 1972). The underlying clay may have been associated with lagoonal areas capable of supporting large trees (for example the stump imbedded in Sargent Beach, Figure 12). Since clay is more difficult to erode than sand (Graf, 20), this Sargent Beach clay layer serves to protect the beach (Nienaber, 35), which otherwise might erode at higher rates than described in the section on observed beach changes at Sargent Beach.

The sediment parameters median fall diameter, D_{50}, and coefficient of uniformity, Cu (defined as D_{60} / D_{10}), both are inversely related to beach volume change rates and proportional to beach slope at mean sea level.

For the offshore samples, the two inch sand layer reported as far as thirty-five miles offshore of the new Brazos delta strongly resembles a 1.9 inch sand layer which Hayes (21,22) observed to be deposited in southwest Texas by hurricane "Carla" in 1961. By making a series of cores as far as twenty miles offshore both before and after the hurricane, Hayes found little sand before the hurricane with up to almost two inches present in the same area after "Carla". The sand must have been either: 1) washed offshore by hurricane waves, or 2) carried offshore by hurricane generated turbidity currents. Since Nienaber (35) does not detect high percentages of sand in the offshore areas in 1955 while the 1972-73 cores do indicate sand, the sand layer may be partly due to hurricanes.

For sediments coarser than a median diameter of .004 mm adjacent to the Brazos delta, contours of median sediment size (Nienaber, 35) quantitatively suggest a net longshore current to the west interacted with the Brazos River to give the skewed pattern illustrated in Figure 20 (Bates, 2 , and Bonham-Carter and Suterland, 5).

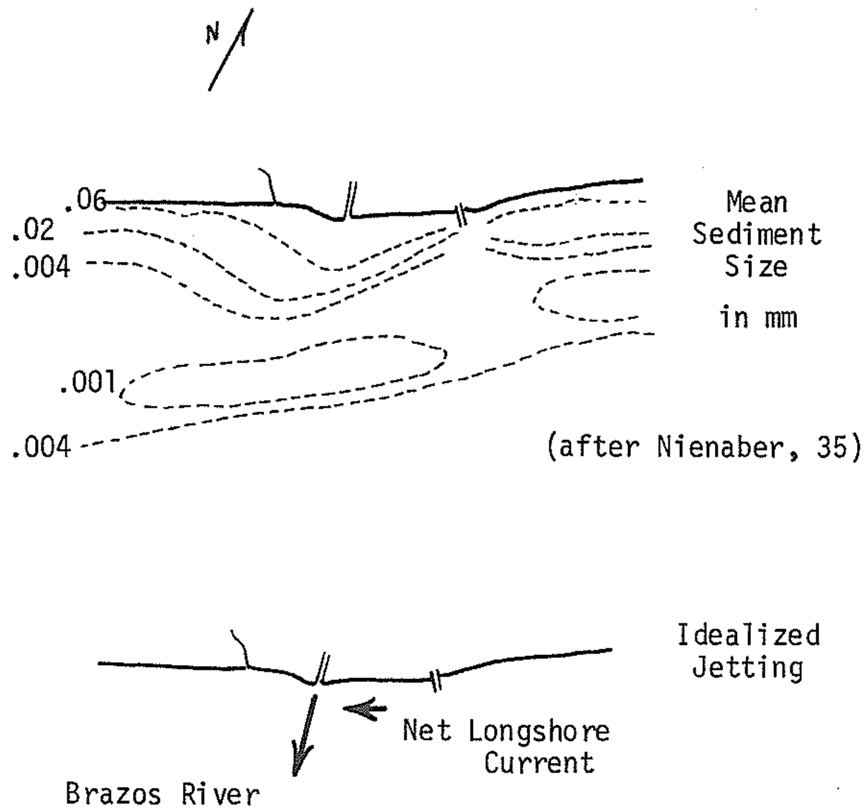

FIGURE 20. -- OFFSHORE SEDIMENTS 1955

CHAPTER IV

OCEANOGRAPHIC FACTORS

Wave Climate

The wave climate offshore of the study area for non-hurricane conditions must be known to predict nearshore wave energy levels. Hurricanes, because of their unusually large capacity to transport sediment (Hayes, 22), are treated in the next section.

Two sources are currently available to provide non-hurricane wave information. First, a step resistance gage operated by the Coastal Engineering Research Center collected wave data from March 1965 to July 1967 at the Galveston Pleasure Pier at Galveston, Texas. These data have been analyzed for significant wave height and period (Thompson and Harris, 46).

Second, wave climate has been hindcast from synoptic weather data at four hour intervals for 1950, 1952, and 1954 offshore of Caplan, Texas, just east of Galveston (Bretschnieder, 7).

To compare the wave energy for the two sets of information, the offshore hindcast waves were refracted to the gage location using the linear theory approximation (U. S. Army Corps of Engineers, 47). Waves with an offshore component of direction are assumed to have insignificant energy onshore. Waves with onshore components were refracted graphically on USCGS Chart 1283 toward the Galveston

Pleasure Pier to the gage water depth of seventeen feet.

The resulting energy spectrum for hindcast waves was approximately the same as the spectrum determined from the CERC gage statistics with the hindcast prediction reporting twenty-five percent more total energy than the wave gage (Figure 21, Appendix E). This difference could be due to the different years sampled (Wiegel, 54), so hindcast waves for Caplan are assumed to adequately represent the magnitude of the wave energy climate.

In addition to this total wave energy, a second wave parameter, direction, must be known to compute the magnitude of longshore energy as waves approach the beach. Two independent sources of information are available to check hindcast wave direction in the vicinity of the Galveston Pleasure Pier: 1) aerial photographs, and 2) volunteer Littoral Environment Observations (LEO, sponsored by the Engineering Evaluation Branch, Coastal Engineering Research Center). Results of these sources are given in Table 1.

All three sources differ in the distribution of flow, but they all indicate that flow is more frequent to the west than to the east, so hindcast wave direction is also assumed to be adequate.

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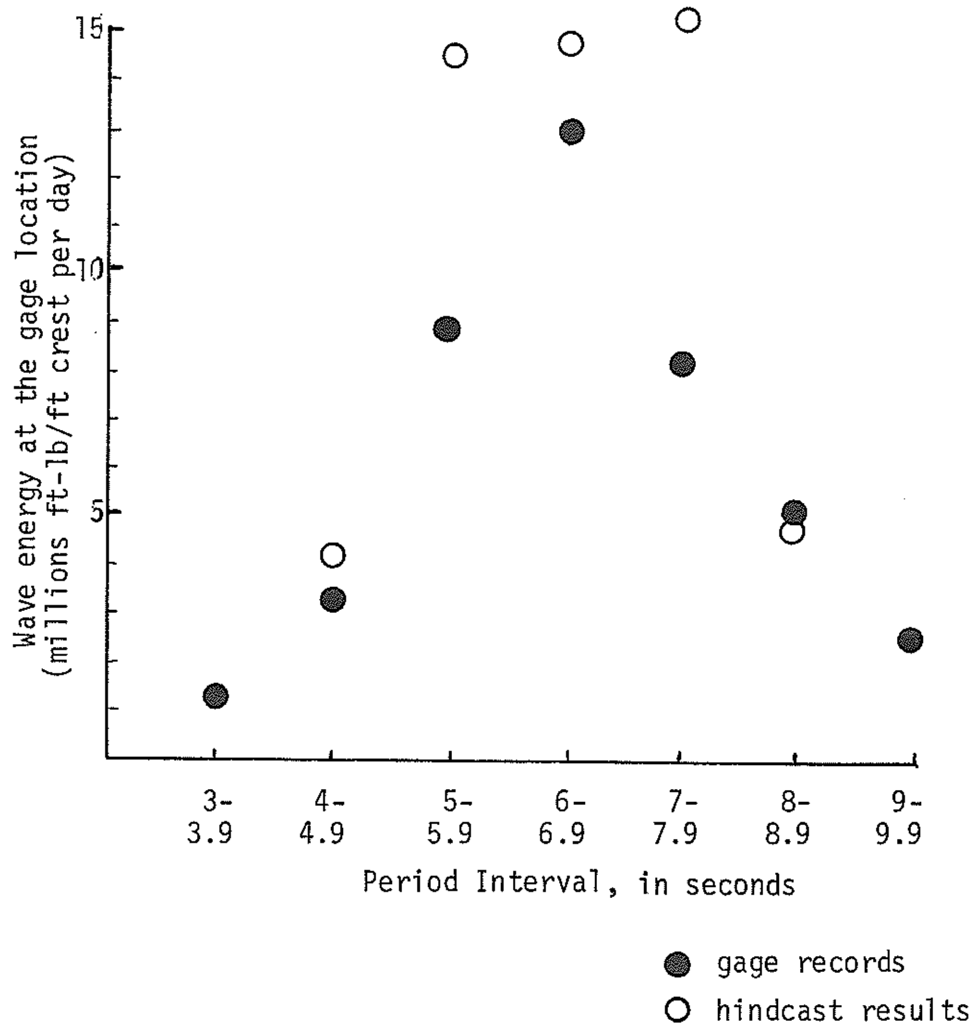

FIGURE 21. -- WAVE ENERGY SPECTRA FOR RECORDED AND REFRACTED HINDCAST WAVES AT THE GALVESTON PLEASURE PIER LOCATION

(wave data by Bretschneider, 7, and Thompson, 46)

TABLE 1.

DISTRIBUTION OF LONGSHORE CURRENT DIRECTION

Source	Percent Occurance			Comments
Direction--	To West(+)	No Flow	To East(-)	
Caplan waves linearly refracted to the gage location	25	55*	20	1950,52,54 for 4 hour intervals
Aerial photos	60	10	30	25 dates, biased in favor of clear weather
LEO observations	40	25	35	April to August 1972

*includes "calm" defined as wave heights of less than one foot (Bretschnieder, 7)

Littoral Transport

Littoral transport is the component of sediment movement parallel to the shoreline. Waves and associated longshore currents are generally the driving force (Savage, 39) with actual drift rates also related to local hydrography and sediment availability. Due to the continually changing wave conditions, transport may change direction periodically; therefore engineers employ two parameters known as the net and gross littoral drift, Q_n and Q_g. Net drift is defined as the vector sum of littoral transport with gross drift defined as the sum of the magnitudes of drift rates as illustrated in Figure 22.

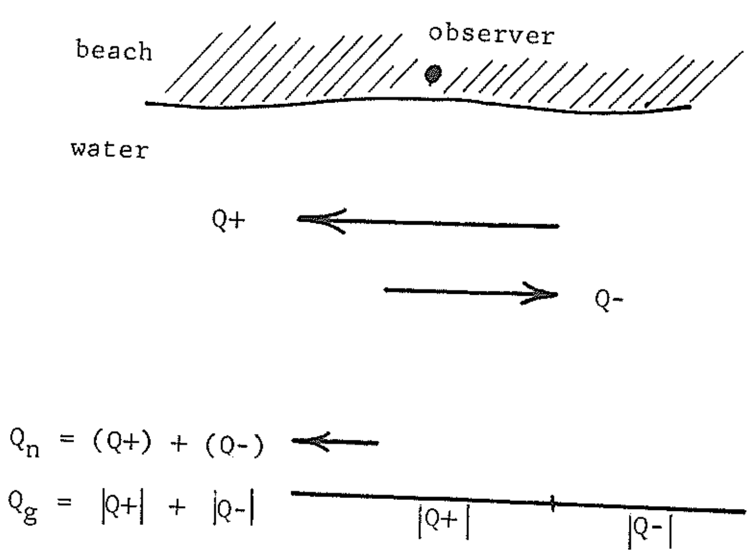

FIGURE 22 . — LITTORAL DRIFT DEFINITIONS

Where littoral drift is predominantly in one direction, the magnitudes of net and gross rates are approximately the same, or $Q_n/Q_g = \pm 1$. If littoral drift is approximately balanced in opposing directions the net drift becomes small and $Q_n/Q_g = 0$.

Actual littoral drift rates change with time and are difficult to measure (Johnson, 28). Three techniques are therefore used to estimate both net and gross littoral transport for the Sargent Beach area. First, the hindcast deepwater wave statistics (Bretschnieder, 7), assumed to represent deepwater non-hurricane wave conditions, were refracted to Sargent Beach using linear theory models (U. S. Army Corps of Engineers, 47) to determine the components of longshore wave energy. Littoral drift rates were assumed to be a function of the longshore energy (Savage, 39, Mason, 32) and to give estimated net and gross littoral transport (Table 2).

Second, Mason and Sorensen (31) observed the spit growth of Brown Cedar Cut by making successive surveys with time. This growth was assumed to be a fraction of littoral transport (Brunn and Gerritsen, 8) to approximate longshore transport (Table 2).

Third, the longshore component of sand movement was assumed to be trapped by the Freeport navigation channel (Carothers and Innis, 9), so that the volume of sand dredged from the channel represents a fraction of the gross local littoral transport. The Freeport Navigation Channel is dredged several times a year, so the rate of dredging was assumed to equal gross longshore transport

TABLE 2. -ESTIMATED LITTORAL DRIFT RATES FOR NON-HURRICANE CONDITIONS

Source & Assumptions	Net Transport Q_n*	Gross Transport Q_g*	Q_n/Q_g
	Sargent and Brown Cedar Cut		
Seelig Caplan wave data (7) CERC refraction (47) 1938 3 ft. contours d_b/H_b = .78 (19) Savage formula (39)	.8	18.	.05
Seelig (same as above) Inman formula (26,32)	.3	7.	.05
Seelig Caplan wave data (7) Weggel trial & error wave breaking (51)	.4	16.	.02
Mason (31) Caplan wave data (7) assume parallel contours Savage formula (39)	.5	8.	.06
Mason (31) growth of Brown Cedar Cut	.5 to 2.4	8. to 27.	
	Freeport		
Seelig maintenance dredging (1967-1972) (50)		32.	
Carothers (9) maintenance dredging		19.	

*in millions of cubic feet per year
to convert to millions of cubic yards per year multiply by .037
to convert to millions of cubic meters per year multiply by .028

(Table 2).

Examination of results for all sources (Table 2) suggests major aspects of littoral transport for the study area are: all net drift estimates are positive indicating net drift is from the east to the west, and net rates are considerably smaller in magnitude than gross rates.

An additional method of qualifying the littoral transport was applied by classifying inlets based upon the work by Galvin (19), which gives the following relation between inlet type and longshore transport:

Inlet Type	Observed Conditions
overlapping	adequate sediment, $Q_g = Q_n$
updrift offset	adequate sediment, $Q_g \geq Q_n$
downdrift offset	insufficient sediment, $Q_g \gg Q_n$
negligible offset	insufficient sediment, $Q_n = 0$

When these criteria are applied to inlets adjacent to the study area (Table 3) the conclusions suggest net littoral drift was in a positive direction, or to the west; the magnitude of gross sediment transport is significantly larger than the magnitude of net transport; and the sediment supply is limited.

TABLE 3. INLET CLASSIFICATION*

Inlet (date)	Type	Conclusion
Pass Cavallo (1800's-)	downdrift offset	$Q_g \geqq Q_n$ **
Brown Cedar Cut (1933)	negligible offset	$Q_n = 0$ **
(1973)	overlapping	Q_n is to the west
San Luis Pass (1800's-)	slight downdrift offset	$Q_g \gg Q_n$ **
Galveston (1800's -)	downdrift offset	$Q_g \gg Q_n$ **

* based on Galvin, 19
** insufficent sediment

Finally, development of the shoreline adjacent to Freeport provides insight into the effect of littoral drift and jetty interaction on the adjacent shoreline. A small net longshore transport rate causes only minor shoreline deviation from a straight coast (Johnson, 28) with updrift accretion, such as for Freeport in 1971 (Figure 23). The addition of sediment between the jetties, such as by the Brazos River in 1930, however, leads to major accretion on the downdrift side of the jetties (Figure 23).

Hurricanes and Storm Conditions

Calculation of wave energy at Sargent using hindcast wave statistics (Wilson, 55) for the 4,5 September 1933 hurricane indicates that in just over two days the same order of magnitude

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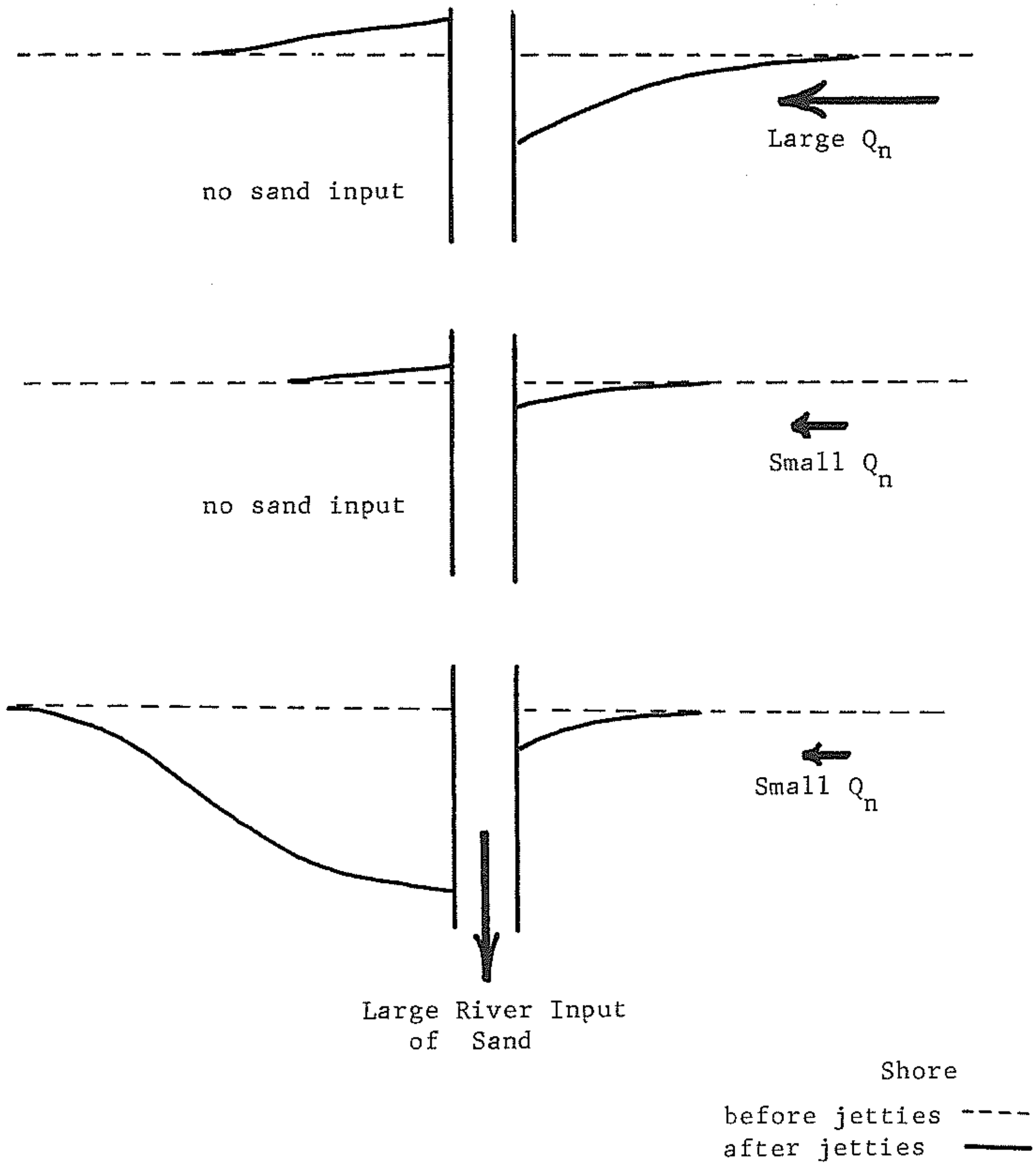


FIGURE 23. -- JETTY EFFECTS ON SHORELINE CONFIGURATION

of sediment may have been moved alongshore as during a non-hurricane year (Appendix B, Table B-3).

Unfortunately, the extreme forces associated with hurricanes have discouraged the implementation of expensive techniques to measure storm parameters in the Gulf. In addition, each hurricane has its own particular character making hindcast difficult (Bodine, 4). The few wave hindcasts, however, available for selected hurricanes (Wilson, 55) give the same general direction picture as the non-hurricane wave system: hurricane waves may move sediment in the positive or negative direction, but on the average maximum waves are higher and more frequent from the southeast resulting in net drift to the west (Table 4).

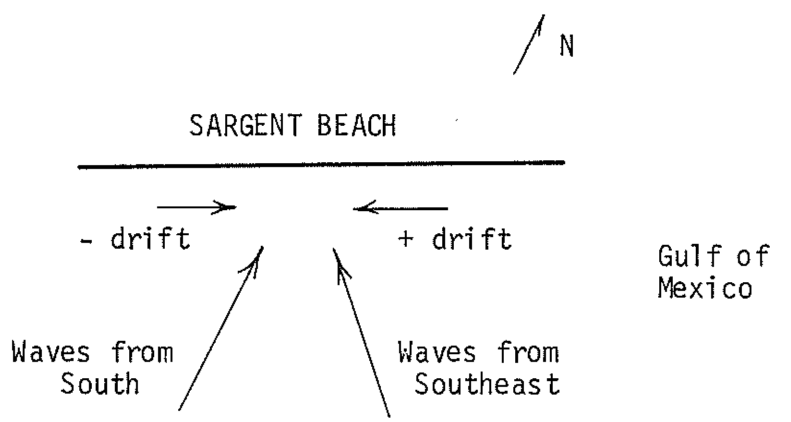
A second hydraulic parameter used to quantify major storms was the storm tide, or the "observed tide at a time when this is significantly affected by meterological factors" (Harris, 23). Naturally, these same storm factors may also cause damaging waves, so storm tide was assumed to be a representative parameter of potential damage to the beach.

To investigate the role of storm tides, the maximum tide at Freeport (U. S. Army Corps of Engineers, Galveston District, 49), assumed to be representative of conditions at Sargent Beach, was determined between successive survey dates for Sargent Beach 1967 through 1972 and shown to be a fair indicator of volume changes to the beach (Figure 24, Appendix B). Winds, as represented by the

TABLE 4. -- HINDCAST MAXIMUM WAVE HEIGHTS
FOR HURRICANES OFF GILCREST (after Wilson, 55)

Date		Wave Height, in Feet From South	From Southeast
September 1900		---	14
August 1915		4	28
September 1915		(7)	(10)
September 1919		(21)	(14)
January 1921		(33)	17
August 1932		(5)	31
September 1933		(3)	28
October 1949		21	17
	MEAN	12	20

( ) Predicted Using Generalized Model



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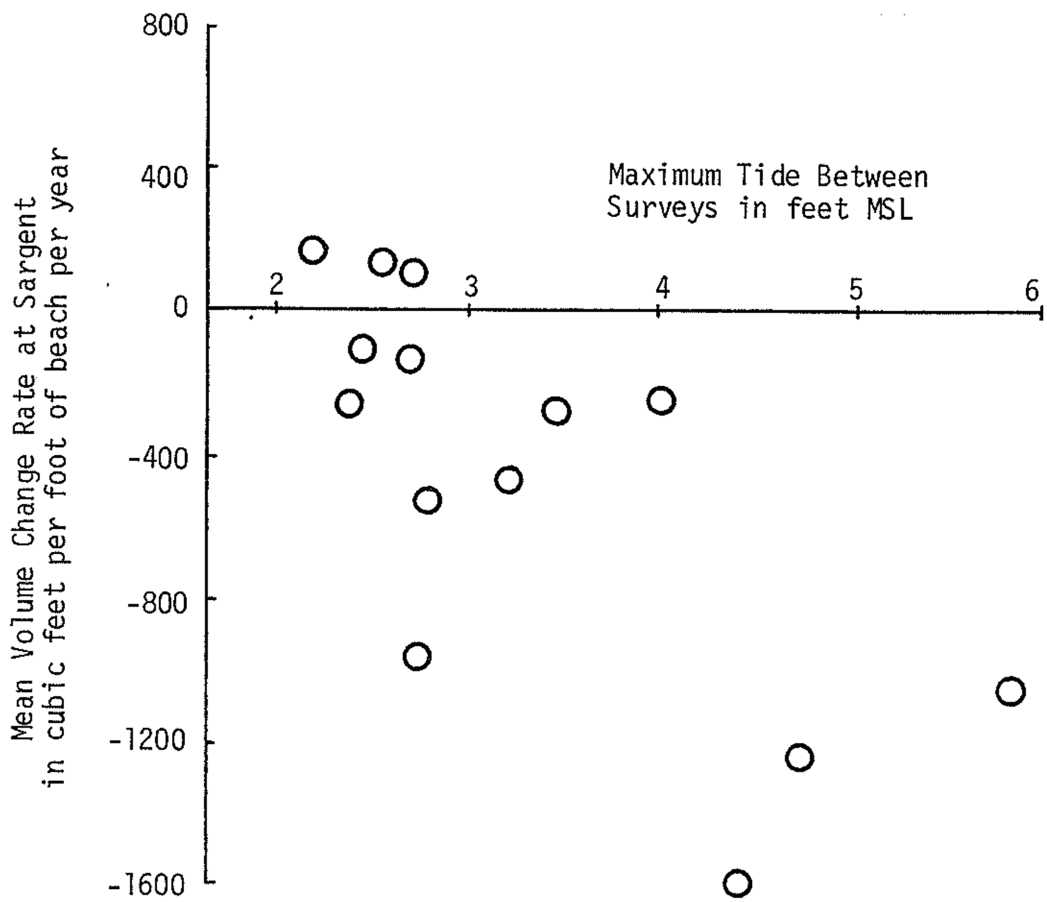

FIGURE 24.

MAXIMUM TIDES VS.
VOLUME CHANGE RATES AT SARGENT
1967 — 1972

(data by U. S. Corps of Engineers, 48, 49)

Fastest Mile (National Oceanic and Atmospheric Administration) also empirically indicate beach volume changes (Appendix B, Figure B-2).

To test the longer term effects of hurricanes on Sargent Beach, the available storm tide records at Galveston and Freeport (Bodine, 3) were first compared to show that storm tides at Freeport were on the average thirty percent higher than at Galveston (Figure 25) or:

$$T^{F}_{max} = \begin{cases} 1.3 \; T^{G}_{max} \\ \leq \text{ maximum tide on the coast} \\ \geq \text{ normal high tide} \end{cases} \quad \ldots\ldots (2)$$

where T_{max} equals the maximum tide level in feet, the superscript F refers to Freeport and G indicates Galveston. This relation was then used to predict maximum hurricane storm tides not observed at Freeport (Table 5).

Figure 26 illustrates the resulting relation between shoreline change rate for successive dates for available data since 1930 and the maximum hurricane tide between dates (Appendix B). Surprisingly, higher tides are associated with smaller waterline position changes at Sargent Beach. Several possible mechanisms causing this phenomena are suggested:

1) Major hurricanes with associated storm tides may move a large volume of back-beach and dune material seaward towards the

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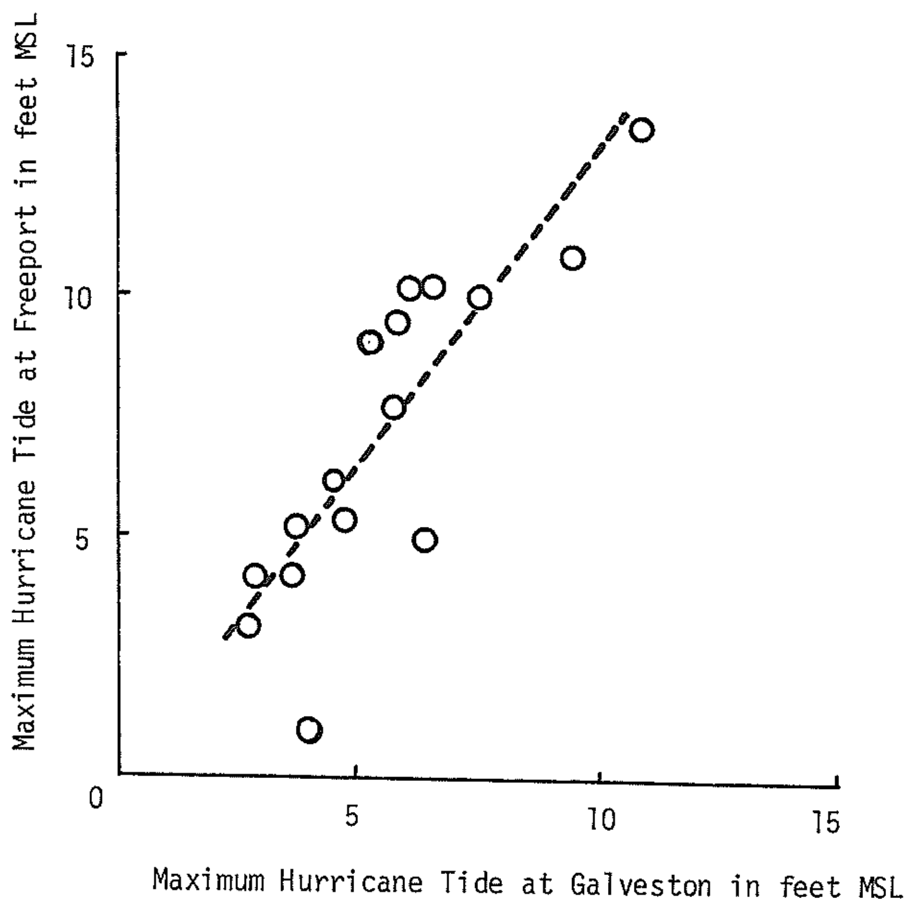

FIGURE 25.
RELATION BETWEEN FREEPORT AND
GALVESTON MAXIMUM HURRICANE TIDES

(data by Bodine, 3 and
U. S. Corps of Engineers, 49)

TABLE 5.

STORM TIDE RECORDS FOR FREEPORT AND GALVESTON 1900 to 1972 (1)

Landfall Location	Date of Landfall	Max Storm Tide on Open Coast (ft MSL)	Max Storm Tide at Galveston (ft MSL)	Dist from Freeport to Landfall (R-right, L-left) (miles)	Max Storm Tide at Freeport (ft MSL)
Galveston	8 Sept 1900	11.0	11.0	50 L	14[2]
Freeport	21 July 1909	9.0	5.2	0	9.0
Galveston	16 Aug 1915	12.7	12.7	50 L	13.5
Mustang Is.	18 Aug 1916	9.2	2.5	151 R	3
Port Aransas	14 Sept 1919	11.1	7.6	149 R	10.0
Port O'Connor	22 Jan 1921	7.1	1.0[3]	80 R	1
Port O'Connor	28 Jan 1929	3.0	1.0	80 R	1
Freeport	13 Aug 1932	6.1	4.5	0	6.1
Port Isabel	4 Aug 1933	4.5	4.4	265 R	4.5
Port Isabel	5 Sept 1933	11.0	4.6	265 R	6
Rockport	25 July 1934	10.2	6.0	140 R	10.2
Galveston	7 Aug 1940	2.1	2.1	50 L	1
Freeport	23 Sept 1941	9.5	5.7	0	9.5
Port O'Connor	30 Aug 1942	10.0	6.3	80 R	10.0
Port Bolivar	27 July 1943	3.0	-5.5	55 L	?
Port Aransas	27 Aug 1945	9.0	2.8	149 R	4.1
Freeport	4 Oct 1949	7.8	5.7	0	7.8
Louisiana	Jan 1957		6.1		4.5
Galveston	25 Jan 1959	2.8	2.8	50 L	1
Port O'Connor	11 Sept 1961	12.3	9.4	80 R	10.8
High Island	17 Sept 1963	4.2	4.0	101 L	1.0
Brownsville	20 Sept 1967		3.7	265 R	4.3
Louisiana	Aug 1969		3.0		3.0
Corpus Christi	3 Aug 1970		3.9	149 R	4.1
Port O'Connor	7-13 Sept 1971	5.6	4.7	80 R	5.3

(1) Based upon Corps of Engineers, Galveston District records and Bodine (1969)

(2) Estimated from relation between storm tides at Freeport and Galveston. (see text)

(3) No storm surge, so storm tide equals high tide.

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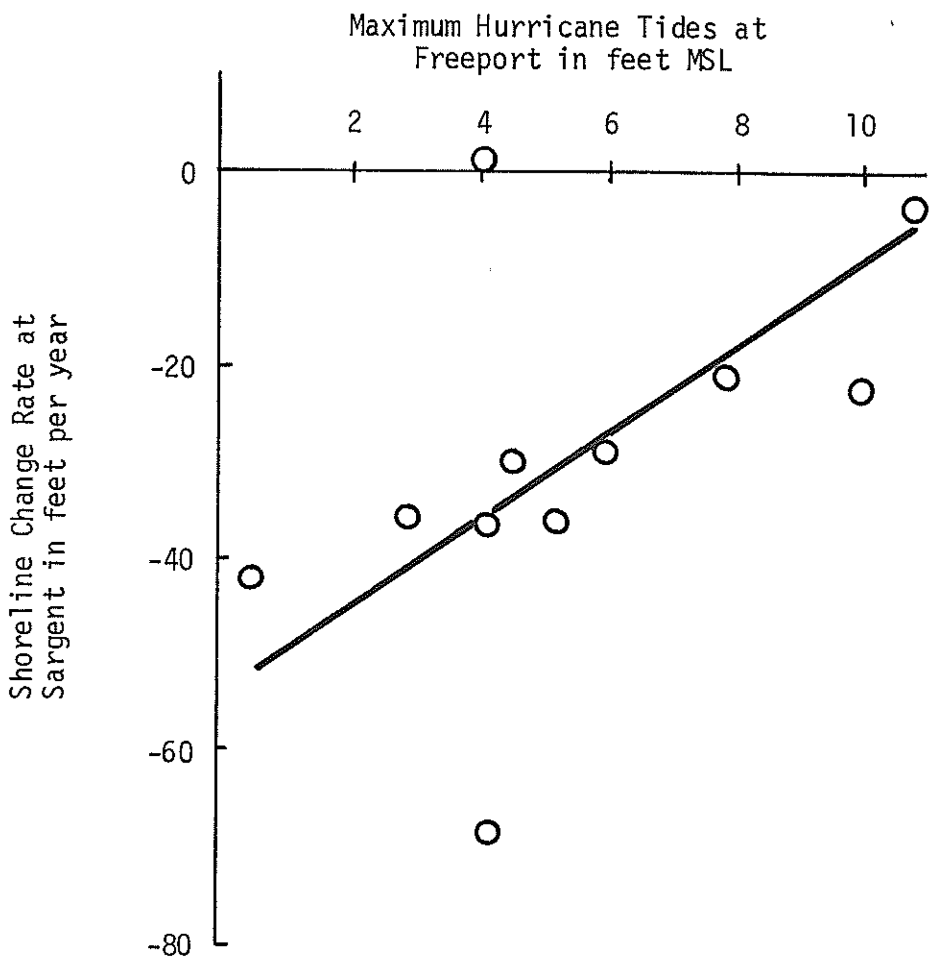

FIGURE 26.

MAXIMUM HURRICANE TIDES VS. SARGENT SHORELINE CHANGE RATES 1930 - 1972

(shoreline change rates from photos,
tides after Bodine, 3)

waterline (Hayes, 22 , and Davis, 14).

2) A high tide may protect the section of the beach adjacent to the normal waterline with a blanket of water.

3) A portion of the sand moved seaward may form bars which will move landward and rejoin with the beach (Price, 38).

4) While a hurricane may cause a large initial damage to Sargent Beach, it may also break loose vast amounts of sand from the Brazos delta complex, some of which is available to move alongshore to partially replenish depleted Sargent Beach sands (Figure 27). Other sands are carried offshore (Hayes, 21).

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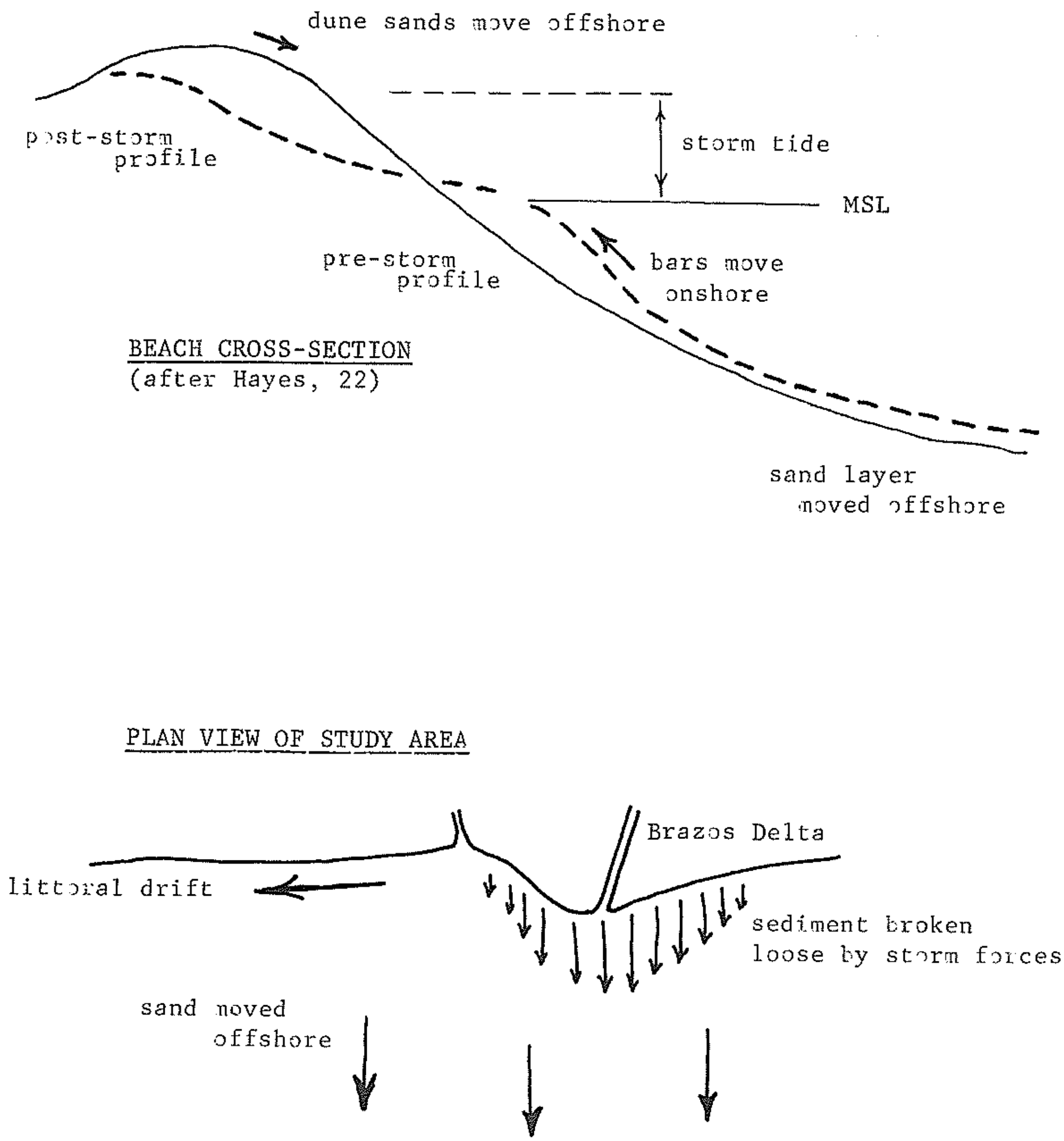

FIGURE 27.— HURRICANE BEACH PROCESSES AT SARGENT

CHAPTER V

GEOLOGIC FACTORS

Subsidence

As the elevation of a coastal area subsides relative to the sea level the waterline advances landward and upper beach sediments are exposed to potentially destructive waves (Figure 28). Since numerous recently installed tide gages on the Texas coast reveal subsidence for the past ten to twelve years (Swanson and Thurlow, 45) and longer for Galveston (Hicks, 25), subsidence can be estimated for Sargent using the following table.

TABLE 6. ESTIMATED SUBSIDENCE AT SARGENT, TEXAS

Location	Factors	Subsidence in feet		
		1959-71	1930-72	1852-1972*
Galveston Pier 21	ground water withdrawl	.258	.79	
Pleasure Pier	"	.366		
Freeport	recent delta	.480	1.5 **	3
Sargent	recent delta oil withdrawl		2	5

*estimated using Pier 21, 1909-71
** predicted values underlined, extrapolated using Pier 21 and 1909-1971

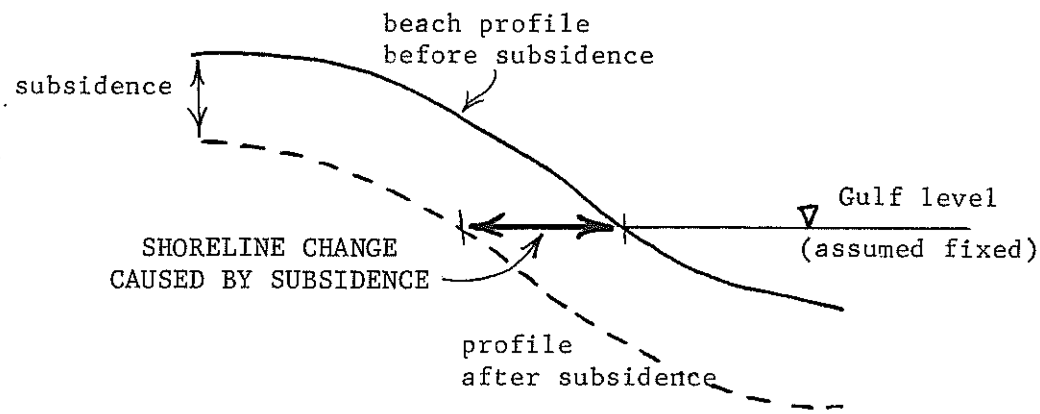

Figure 28 .— GENERALIZED BEACH SUBSIDENCE

Sargent is assumed to have a subsidence rate similar to the Freeport area because of the similar deltaic environments, although either the recent oil withdrawl at Sargent or the former mining of Bryan Mound may have affected subsidence rates in the two areas. The two Galveston gages located only several miles apart show significantly different subsidence rates, possibly due to pumping of the ground-water table, so without further study the predicted Freeport subsidence provides only a clue to the value of maximum vertical land and sea level long term changes at Sargent Beach.

Using the predicted subsidence at Sargent Beach of 2 feet 1930 to 1972 and 5 feet 1852 to 1972, in conjunction with an approximate beach slope of 0.04, the calculated shoreline changes due to subsidence amount to 50 and 130 feet of shoreline retreat, respectively. However, these predicted waterline changes amount to less than ten percent of the actual changes of 990 and 1830 feet, so subsidence is estimated to be a relatively insignificant factor in the observed shoreline retreat at Sargent.

Note that Sargent Beach profile changes 1967 to 1972, presented in the section titled Observed Beach Changes at Sargent Beach, were determined from profiles referenced to a local bench mark. If the entire area, including the bench mark, subsided then changes relative to sea level were even greater than indicated.

River Sediment Input

Analysis of a coastal region by Johnson (29) revealed that rivers supply a significant volume of beach size material to nourish adjacent beaches. Silt records of Texas streams (Stout, Bentz, and Ingram, 44 , Adey and Cook, 1 , Cook, 12 , and Cook, 13) indicate that the Brazos River is by far the most important river for this study, so discussion below is directed to the Brazos. In addition, both the new Brazos delta up to five miles offshore (Nienaber, 35) and the adjacent beaches are composed largely of sand, so the fraction of the Brazos River sediment load in the sand sizes, material greater than 0.062 mm in diameter, is examined in detail.

To determine the rate of sand transport of the Brazos River two steps are required: first, calculation of the total sediment discharge, and second, determination of the fraction of sand in the sediment load. The sediment discharge is divided into two sections: (a) the suspended load, which is measured using an integrating sampler run from its lowest measuring point to the surface, and (b) the bed or unmeasured load moving in the zone missed by the sampler (Figure 29).

Suspended load. The suspended load of the Brazos River at the Richmond Bridge near Richmond, Texas is measured daily by the U. S. Geological Survey, so records available for water years 1922 to

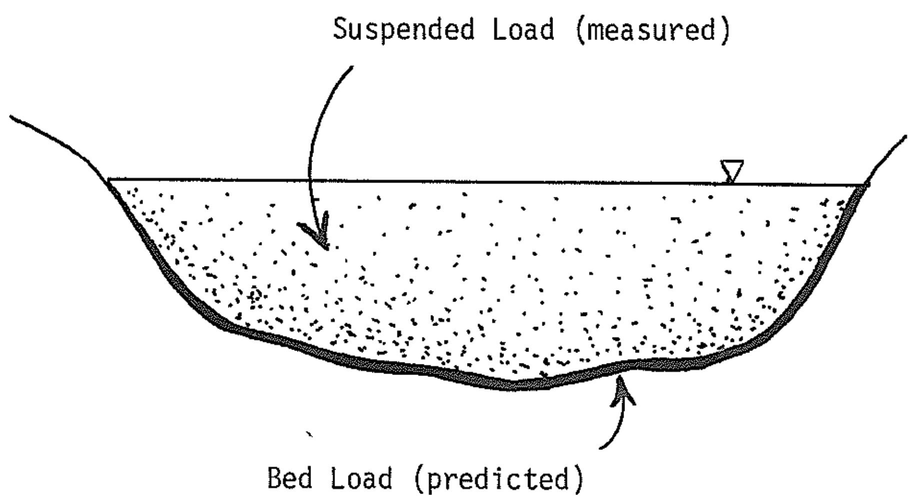

FIGURE 29. -- RIVER CROSS-SECTION

1965 are used to approximate the suspended load (Welborn, 52).

The annual suspended loads for water years 1922 to 1965 can be classified into three periods when plotted on a parts per million (ppm) vs. a yearly basis (Figure 30): (A) 1922 through 1940 with the silt load of the Brazos River averaging approximately 5000 ppm, (B) 1941 to 1950 with the silt load dropping steadily from 5000 to 2000 ppm, and (C) 1951 to 1965 with the load declining slightly, but remaining in the 1000 to 3000 ppm range.

Predicted bed load. The second zone of sand movement, the bed load, is not measured by the sampling procedure, so Welborn (52) predicted the bed load for the Brazos River at Richmond for river conditions in the 1960's using a Colby (11) technique. Welborn's curve of bed load vs. river discharge can be fitted by the relation:

$$Q_u^C = -.4775 \times 10^3 + .3519\, Q - .3334 \times 10^{-4}\, Q^2 + .1459 \times 10^{-8}\, Q^3 - .2148 \times 10^{-13}\, Q^4 + .1048 \times 10^{-18}\, Q^5 \quad (3)$$

for river discharges of 3,000 to 77,500 cubic feet per second, where Q_u^C is the predicted bed sediment load in tons per day for time period (C), 1951 to 1973, and Q is the mean daily river discharge in cubic feet per second (Figure 31). For lowest river flows the above relation is inadequate so:

$$Q_u^C = 0.1\, Q \quad (4)$$

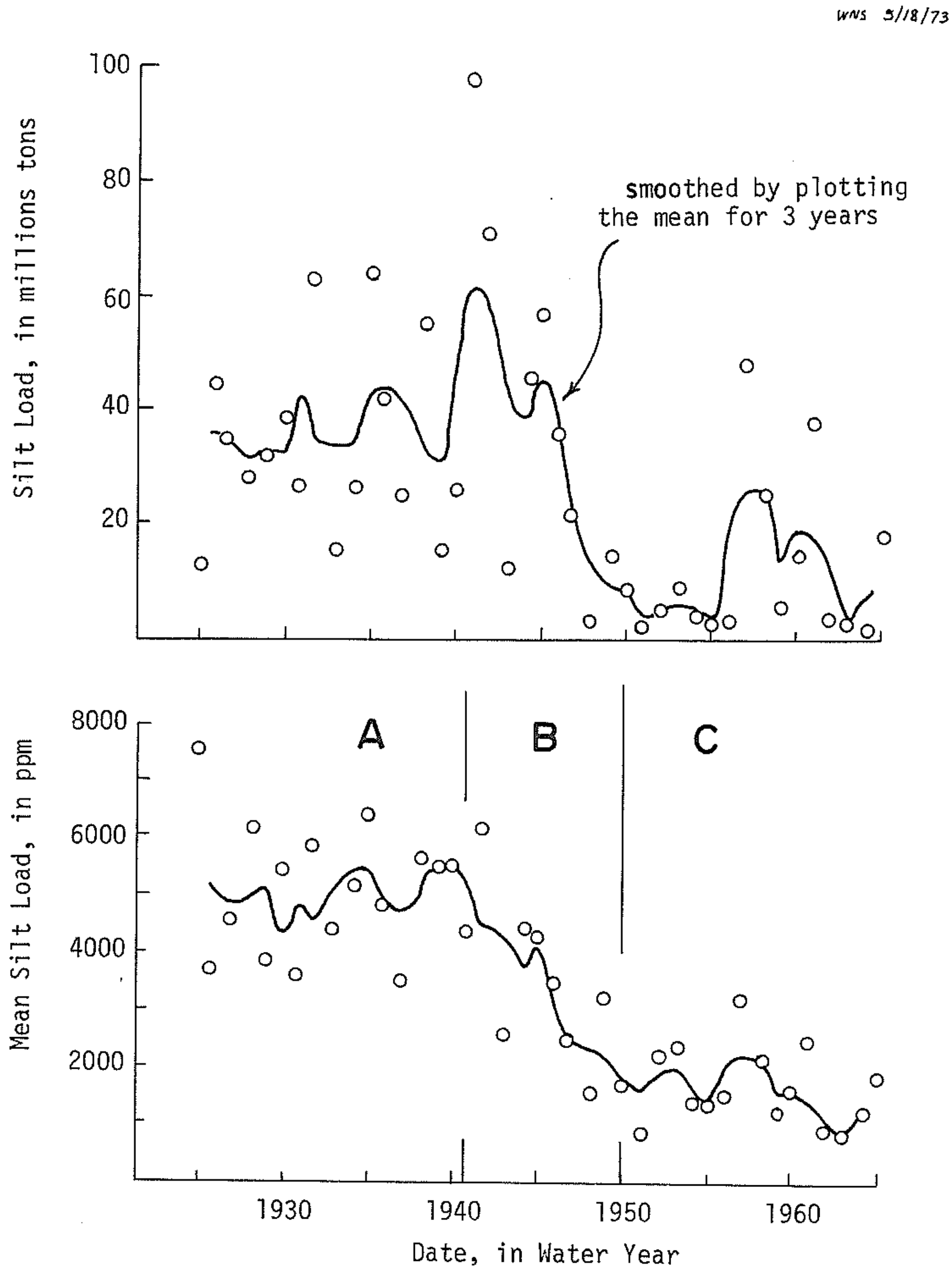

FIGURE 30. -- SILT LOAD OF THE BRAZOS RIVER

(after Stout, 44, Adey, 1, Cook, 12 and 13)

4/12/73 nms

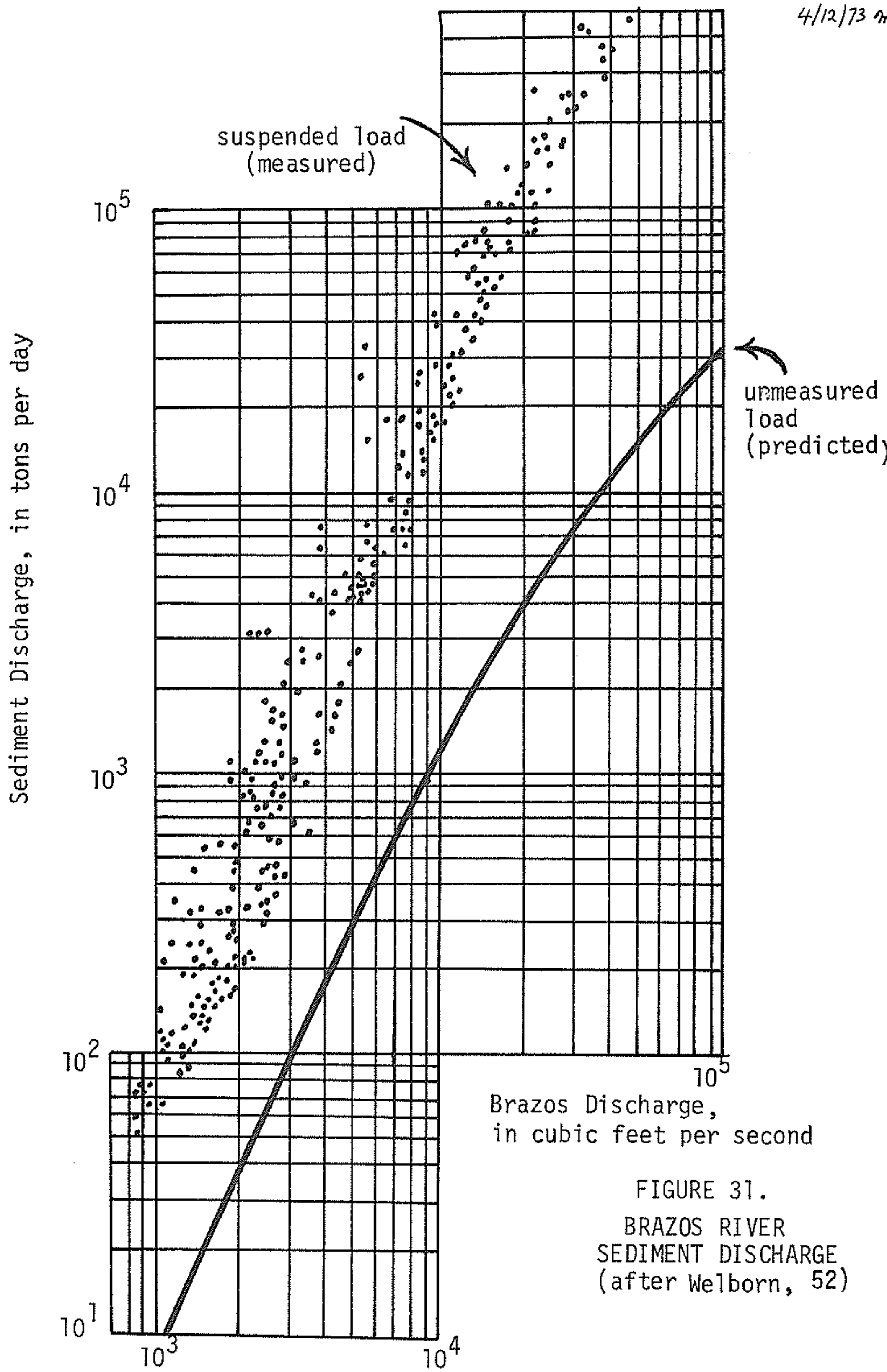

FIGURE 31.

BRAZOS RIVER
SEDIMENT DISCHARGE
(after Welborn, 52)

is assumed.

Note that equations (3) and (4) were derived using river conditions for period (C) with low suspended load conditions, and may not be valid for river conditions prior to 1951 due to an overall change in the suspended load concentration (Figure 30). To account for the long term suspended sediment load's influence on the bed load Colby's "availability ratio", a constant used to correct bed load predictions, is applied to equations (3) and (4) to obtain:

$$Q_u^A = 1.5 \; Q_u^C \quad \ldots\ldots\ldots\ldots \quad (5)$$

and

$$Q_u^B = 1.2 \; Q_u^C \quad \ldots\ldots\ldots\ldots \quad (6)$$

where superscripts refer to the category of river flow where A = water years 1923 to 1940, B = 1941 to 1950, and C = 1951 to 1973.

To further simplify calculations, fourteen months of record in the 1960's covering a wide range of discharge conditions were tested by computing monthly unmeasured sediment first on a daily basis, and second, on a monthly basis. Results agreed to within five percent, so mean monthly calculation were employed in this thesis.

To determine the proportion of sand in these river loads, samples were analyzed (Welborn, 53) to show that the bed load is consistently at least 98 percent sand size, 0.062 mm, or larger. The suspended load, however, has sand ranging from 1 to 36 percent of the load (Welborn, 53) with no relation to river discharge, so a mean of 10 percent sand is arbitrarily used for these calculations (Figure 32).

All of the sand transported by the Brazos River at Richmond. one-hundred miles from the coast, is assumed to reach the Gulf of Mexico at the rate of the sand load at Richmond, so equations (3), (4), (5), and (6) were used to predict the sediment load. Ten percent and ninety-eight percent, respectively, of the suspended and bed loads are assumed to be sand. Assuming the specific weight of sand is ninety-three pounds per cubic foot, the yearly sand volume reaching the coast was estimated (Appendix F). A plot of the cumulative sand load of the Brazos River (Figure 33) shows that the rate of sand input to the Gulf after the 1940's is one-third the rate of sand input before the 1940's.

Computation of the percentage of total sand transported to the coast by the Brazos River vs. the portion of highest river flows show a large fraction of the sand input to the coast was transported in a relatively short time. For example, ninety percent of the sand was transported during the twenty-five percent highest river flows.

Conclusions. The decline of predicted sand load of the Brazos River in the 1940's was apparently due to completion of a series of

6/20/73 WNS

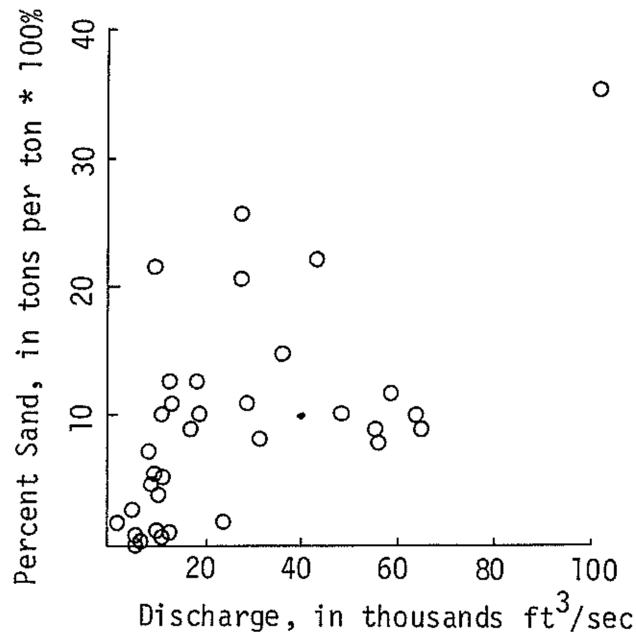

FIGURE 32. -- PERCENTAGE OF SAND FOR SUSPENDED LOADS OF THE BRAZOS RIVER

(after Welborn, 53 , Richmond Bridge suspended samples)

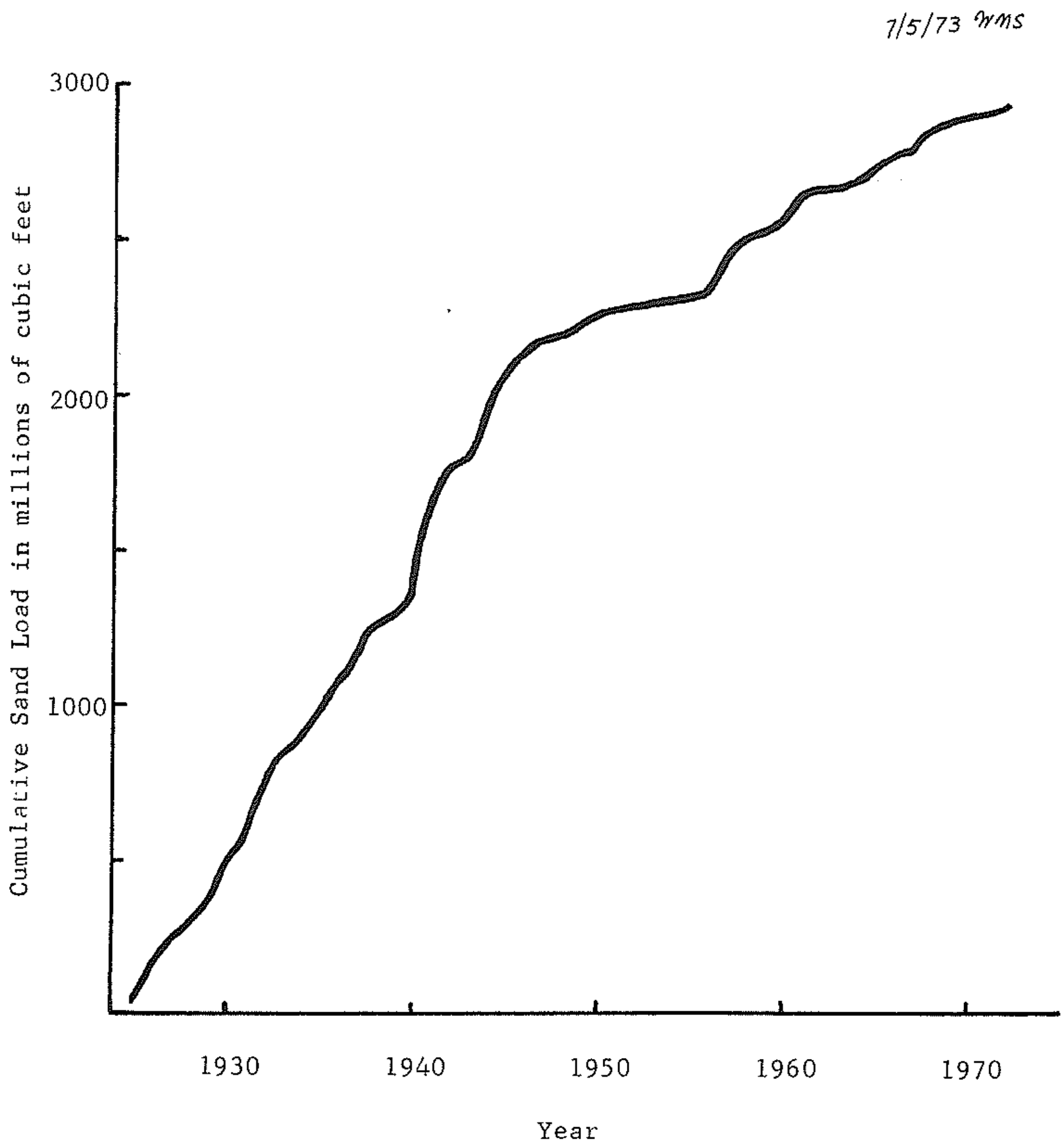

FIGURE 33.—— CUMULATIVE SAND LOAD OF THE BRAZOS RIVER AT RICHMOND

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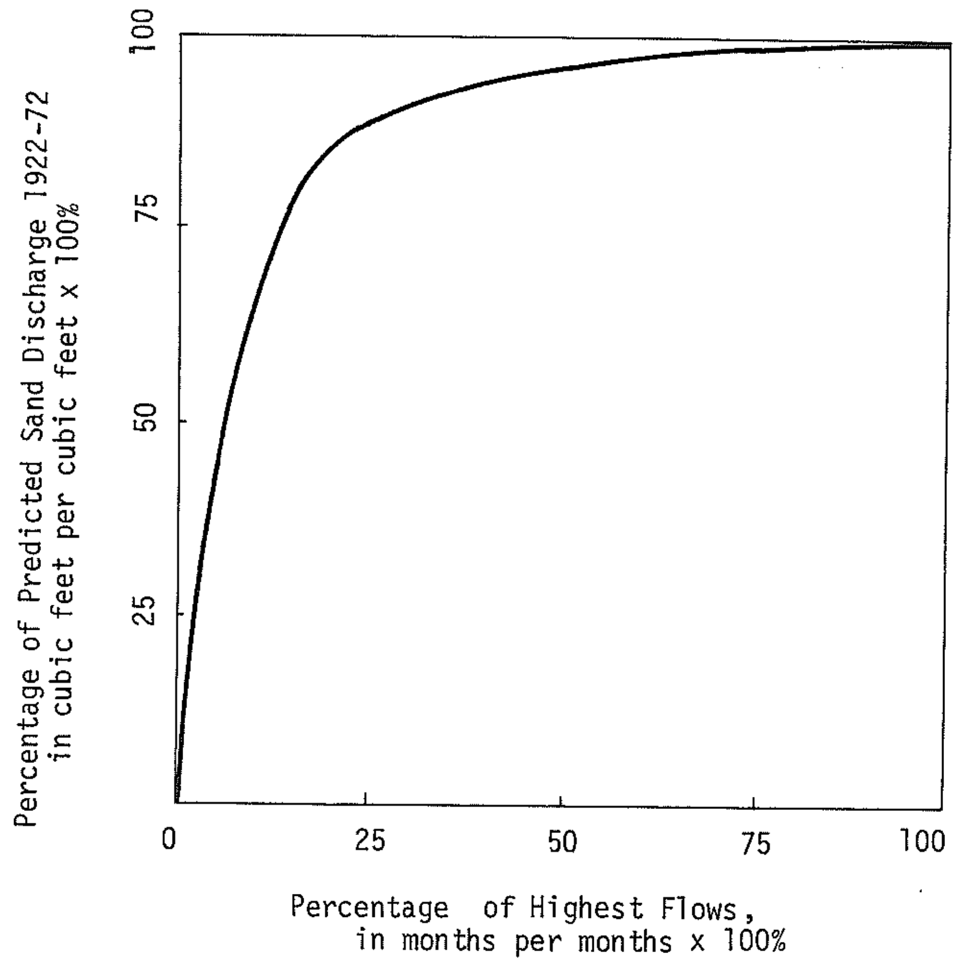

FIGURE 34. -- PERCENTAGE OF PREDICTED SAND DISCHARGE FOR THE BRAZOS RIVER FOR THE PERCENTAGE OF HIGHEST RIVER FLOWS

dams beginning with Possum Kingdom (Sealy, 41), improved soil conservation, and the widespread transition from cotton production to grains and grazing in the Brazos Valley during World War II (personal communication, U. S. Department of Agriculture, College Station, Texas).

Dams may reduce the sand load of the Brazos River by two mechanisms. First, as a dam smooths out the Brazos River hydrograph, for example to reduce peak flood flows, the sediment load is greatly reduced because both suspended and bed loads are non-linearly related to river discharge (Figure 31). As a hypothetical example, assume the total river water discharge is a constant 10^4 cubic feet per second with control by a dam. Figure 31 is used to predict a bed load of 1.2×10^3 tons per day or 4×10^5 tons per year. If the dam did not restrict flow so that during periods of low flow the Brazos operated at 5×10^3 cubic feet of water per second, with high flows of 2.5×10^4 cubic feet per second, then the total bed load would amount to 6×10^6 tons per year. Note that for this example, the dam smooth out the hydrograph and at the same time reduces the sand reaching the coast by a factor of ten although the total yearly discharge of water is the same. No sand is physically caught by the dam, yet it drastically reduces sand available to the beach.

Second, a dam may physically trap sand because the low flows in a reservoir cause sand to be deposited.

When comparing the Brazos River sediment load to the Sargent Beach changes, the most obvious relation is the overall decrease in river sand input to the coast accompanied with an increase in shoreline and beach sediment losses 1930 to 1972.

Sediment Losses to Inlets

Examination of the Study area (Figure 1) suggests that Brown Cedar Cut is the major inlet which may affect the recent sediment budget at Sargent (Schmeltz and Sorensen, 40).

A hydrographic survey by the U. S. Engineers of Brown Cedar Cut August 1920 to July 1921 (Figure 8) is the only survey available for East Matagorda Bay, so aerial photographs 1933, 1954, and 1973 are used to provide clues to the maximum amount of sediment deposited in the bay (Figures 35, 36, 37). Each of these photos shows major underwater features enabling areas of shoaling to be determined. If as a first approximation, the maximum volume of sediment trapped is arbitrarily assumed to equal a fraction of the volume of a prism formed by the 1921 hydrography, the area of shoaling, and sea level, the rates of shoaling given in Table 7 can be determined.

FIGURE 35.

BROWN CEDAR CUT 7 DECEMBER 1933

(photo by Army Air Corps, available at NOS)

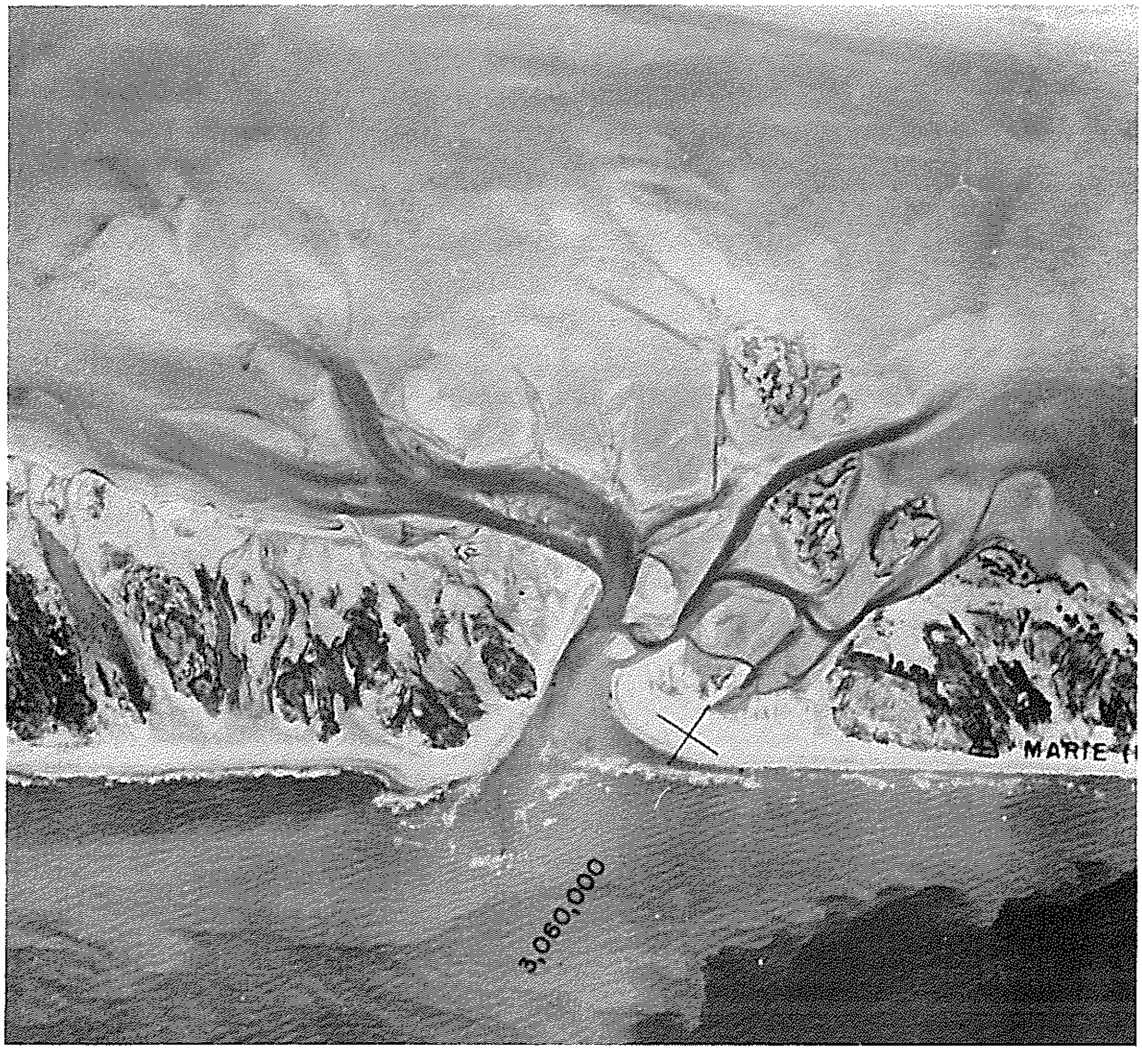

FIGURE 36.

BROWN CEDAR CUT JANUARY to MARCH 1954

(photo by Ammann Int., San Antonio, Texas)

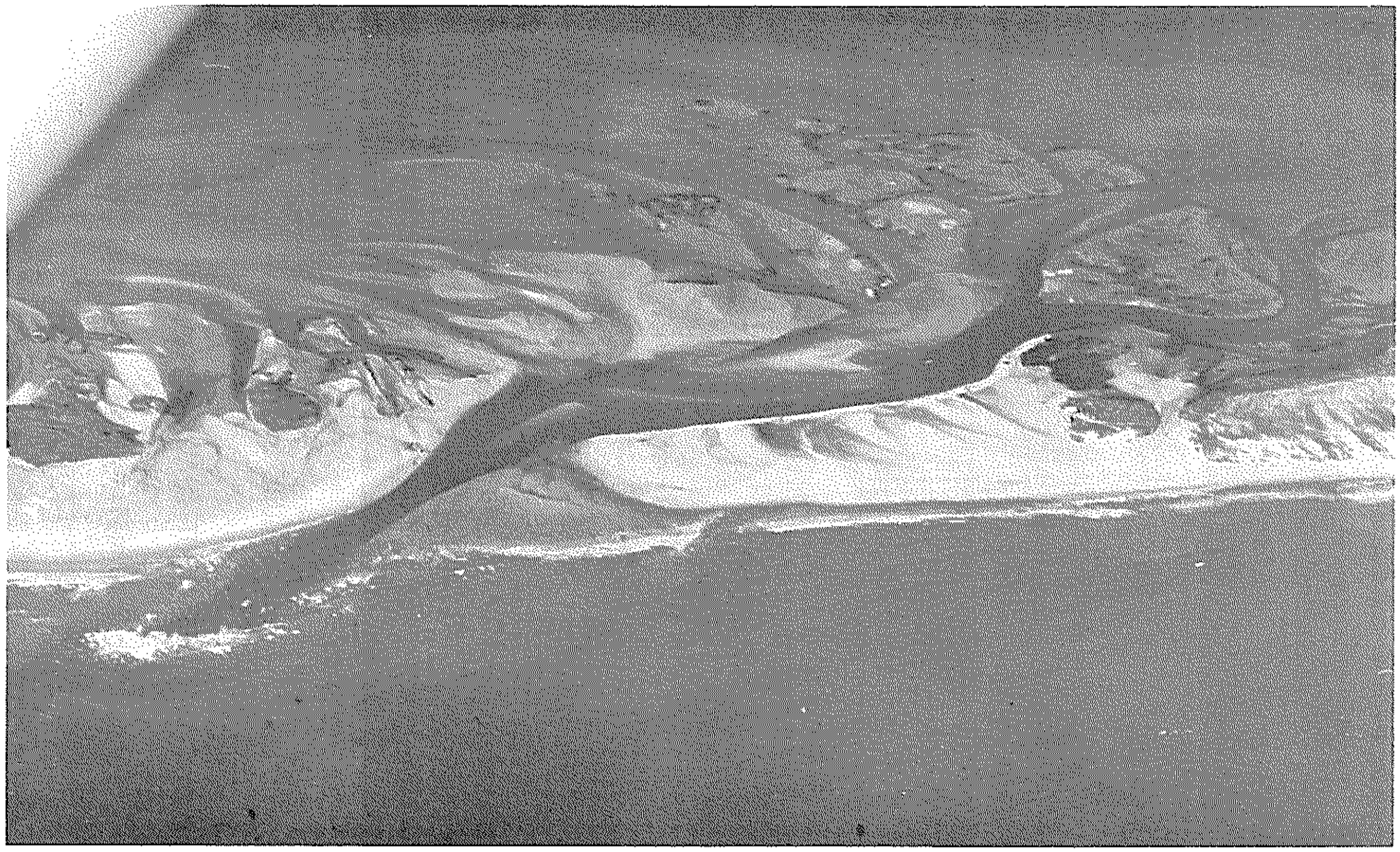

FIGURE 37.

BROWN CEDAR CUT 26 JANUARY 1973
(author's photo, taken at low tide)

TABLE 7. SEDIMENT LOSSES TO BROWN CEDAR CUT

Dates	Fraction of Prism Shoaled	Max Volume of Sediment*	Max Rate of Shoaling**
1921 - 1933	.5 of 1933 prism	11	.8
1933 - 1954	.5 of 1954 prism	25	1.
1921 - 1973	1. of 1954 prism	50	1.

* in millions of cubic feet
** in millions of cubic feet per year

Sediment Storage in the Brazos Deltas

As outlined in the section on Historical Development, the shoreline indicated that only a small delta existed at the mouth of the Brazos River in 1852. Construction of the Freeport Jetties in the late 1800's, however, apparently trapped river sands to form a major delta on the down drift side of the jetties. When the Brazos River was diverted to the west in 1929, the replenishing river sand supply was cut off in the jetty area and this old Brazos delta then began to migrate westward under the influence of longshore transport. Simultaneously a new Brazos delta began to form from remnants of the old delta and continued river sediment input.

Graf (20) summarizes that sand requires higher velocities to scour than to transport. This implies that the Brazos deltas, once formed, locked in sand that would otherwise have been carried if still in a suspended form. In addition, the numerous logs on the delta trap windblown sand (Sealy, 41), and the plentiful nutrients carried by the Brazos River encourage rapid vegetation growth, requiring higher velocities to dislodge sand to satisfy longshore transport (Appendix D).

To quantitatively determine the volume of sediment trapped in the deltas, hydrographic surveys for 1937 and 1973 (Appendix D) were superimposed to construct an isopach map, or map of change (Figure 38) with original work conducted on a 1/24,000 scale. For this thirty-six year period, the net effect within the 30 foot contour of processes is to remove 1600 million cubic feet of sediment out of the vicinity of the old Brazos delta west of the Freeport Jetties, while 2300 million cubic feet of sediments are deposited at the new Brazos delta westward to Cedar Lakes. Since sea level is used as a reference, subsidence effects are included in the calculations.

To test the mechanisms controlling changes to the Brazos deltas, the shoreline changes 1933 to 1939 and 1939 to 1942 (Figure 7) are compared to predicted energy along the beach. The 1937 hydrography out to the 100 foot depth contour was assumed representative for both time intervals and used as the base for linearly refracting offshore waves (Bretschnieder, 1956) to determine the longshore wave energy for 3000 foot sections of beach for the area Surfside to the San Bernard River. Littoral

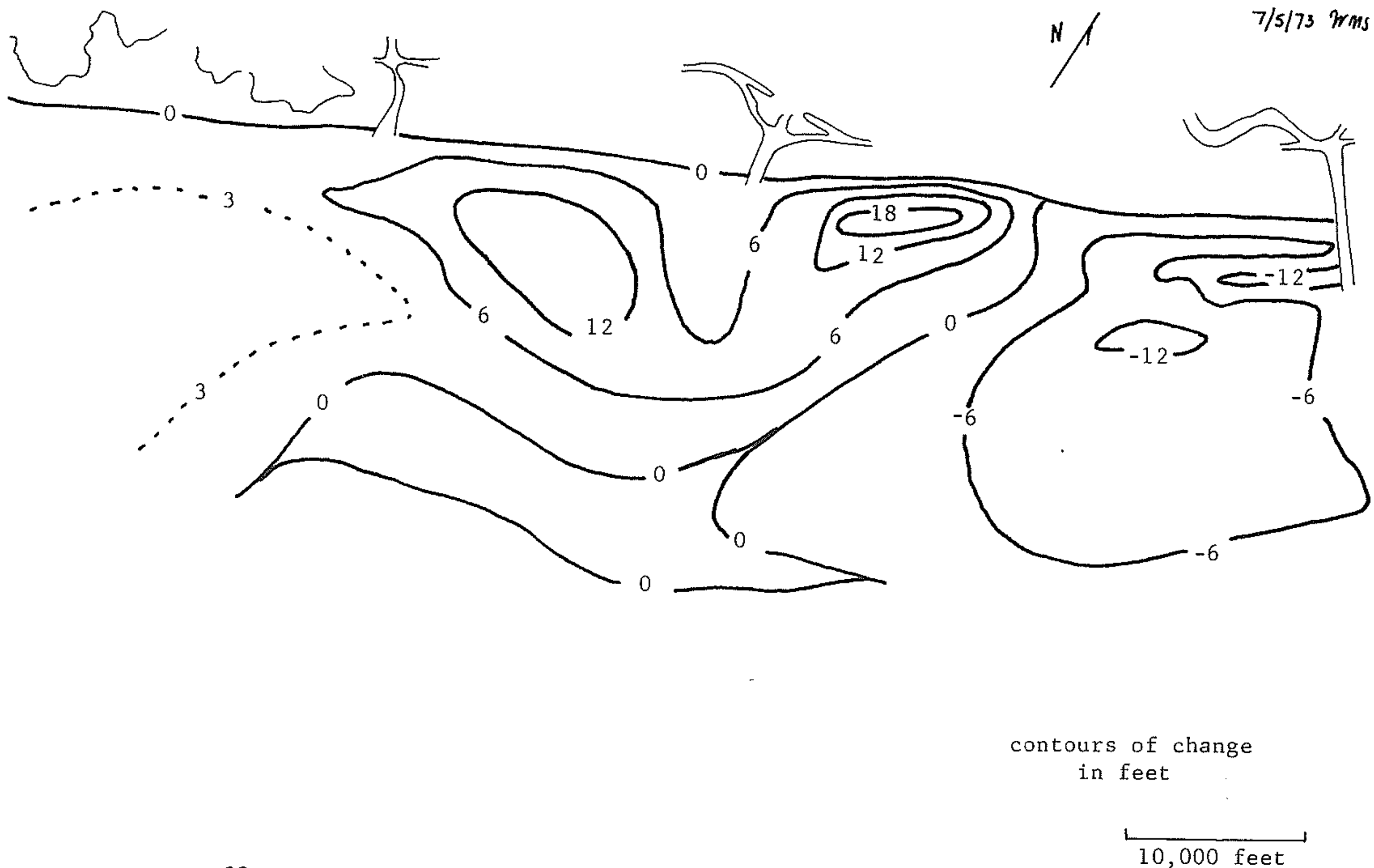

FIGURE 38. — ISOPACH MAP OF THE BRAZOS DELTAS 1937 TO 1973

transport was then assumed to be a linear function of longshore energy (Savage, 39) so that the volume of material transported out of each section by longshore transport and its direction could be approximated. The total sediment volume for each 3000 foot section of beach equaled the sum of sand entering from adjacent sections, minus the volume of sediment lost from the given section. Shoreline changes are assumed to be proportional to beach volume changes, as shown at Sargent Beach, so that shoreline changes for a given section of beach are expected to be related to the incoming longshore energy for adjacent sections of beach with the longshore energy toward the given section minus the longshore energy of the section in question.

The resulting plot of shoreline change vs. longshore energy difference shows that for most sections shoreline changes 1933 through 1942 are largely controlled by longshore transport (Figure 39). The new Brazos delta sections, however, do not follow the trends of other beach areas because the delta is probably strongly influenced by sediment input of the Brazos River.

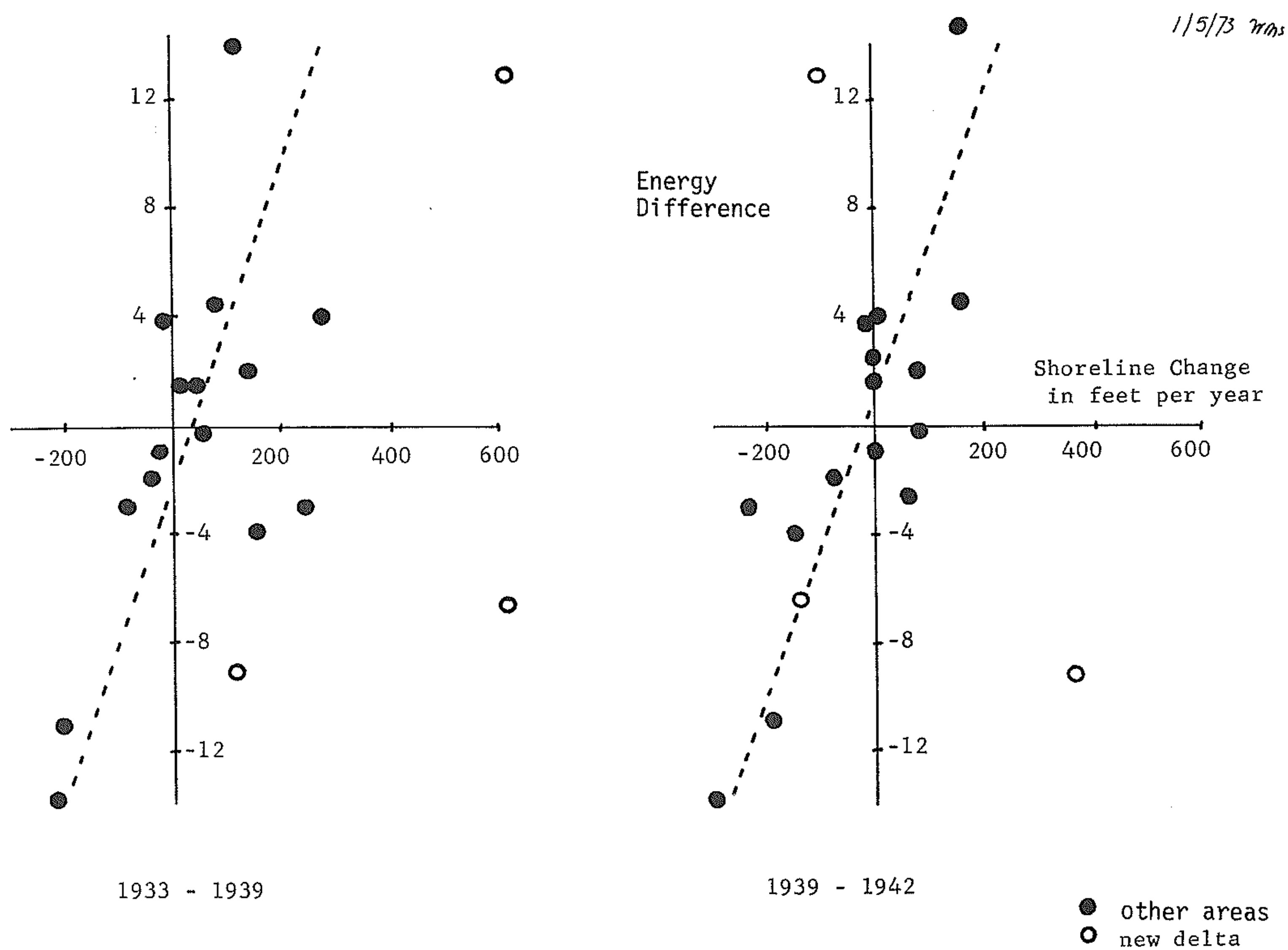

FIGURE 39. - BRAZOS DELTA SHORELINE CHANGES VS. ENERGY CHANGES

CHAPTER VI

SUMMARY AND CONCLUSIONS

The Sediment Budget

To determine the sediment budget for the study area estimates from previous chapters can be combined for 1937 to 1973. Major assumptions and areas of study which the author believes need additional study are marked with an asterisk, *.

(1) Beach Losses

The Sargent Beach shoreline has retreated 730 feet with the entire 100,000 feet of coast from the San Bernard River to Brown Cedar Cut retreating at a similar rate (from maps and photographs). If five percent is due to subsidence, then the remaining 690 feet must be the result of a change in sediment distribution. Since 12 cubic feet of sediments per foot of beach is lost within the +5 to -5 contours for each foot change in the shoreline, then minimum sand losses, assuming 70 percent sand are:

$$.7 \times 12\ ft^3/ft^2 \times 690\ ft \times 100{,}000\ ft \quad = \quad \underline{580 \times 10^6\ ft^3}$$

with unknown additional amounts lost below the -5 foot contour*.

(2) Old Brazos Delta

A measured 1600 million cubic feet of sediment are lost from the old Brazos delta. If 20 percent is arbitrarily assumed lost east of the Freeport Jetties due to shifting littoral transport and the old Brazos delta is composed of 70 percent sand, then net sand moved offshore or westward is:

$\underline{900 \times 10^6 \ ft^3}$

(3) New Brazos Delta

2300 million cubic feet of sediment is deposited in the new Brazos delta and westward toward Cedar Lakes. Assuming 70 percent sand*, the sand gained is:

$\underline{1600 \times 10^6 \ ft^3}$

(4) Brazos River Sand Input

Sand carried by the Brazos River at Richmond assumed to reach the coast is estimated to be:

$\underline{1800 \times 10^6 \ ft^3}$

(5) Losses to Brown Cedar Cut

Maximum sand volumes lost through Brown Cedar Cut to East Matagorda Bay is estimated to be:

$\underline{35 \times 10^6 \ ft^3}$

(6) Littoral Transport at Sargent Beach

For non-hurricane conditions is predicted to be:

$\underline{40 \times 10^6 \ ft^3}$

(7) Hurricane Littoral Transport

Hurricane littoral transport is unknown*

(8) Sand Moved Offshore

The sand layer believed moved offshore by hurricanes is unknown*, however, it may be extremely important to the sediment budget of the study area. Studies such as by Hayes (21 and 22) are suggested.

The final sand budget leaves approximately 1200×10^6 cubic feet of sand unaccounted for, but may partially have been moved by hurricane littoral drift and movement offshore (Figure 40).

Conclusions

Sargent Beach can be classified as an erosive coastal zone with erosion rates increasing steadily 1930 to 1972. This erosion is apparently due to the higher rate of sediment transport out of the beach area than to Sargent Beach.

The first factor in time observed to prevent large quantities of sand from reaching Sargent Beach was construction of the Freeport Jetties in the late nineteenth century which trapped a delta of sand. Littoral drift may have otherwise carried this Brazos River sand westward, but the jetties served to interrupt flow patterns allowing sands to be deposited.

Rerouting the Brazos River in 1929 did not, however, add significant amounts of sand to Sargent Beach. Although the jetties' delta immediately began to be transported westward, the jetting

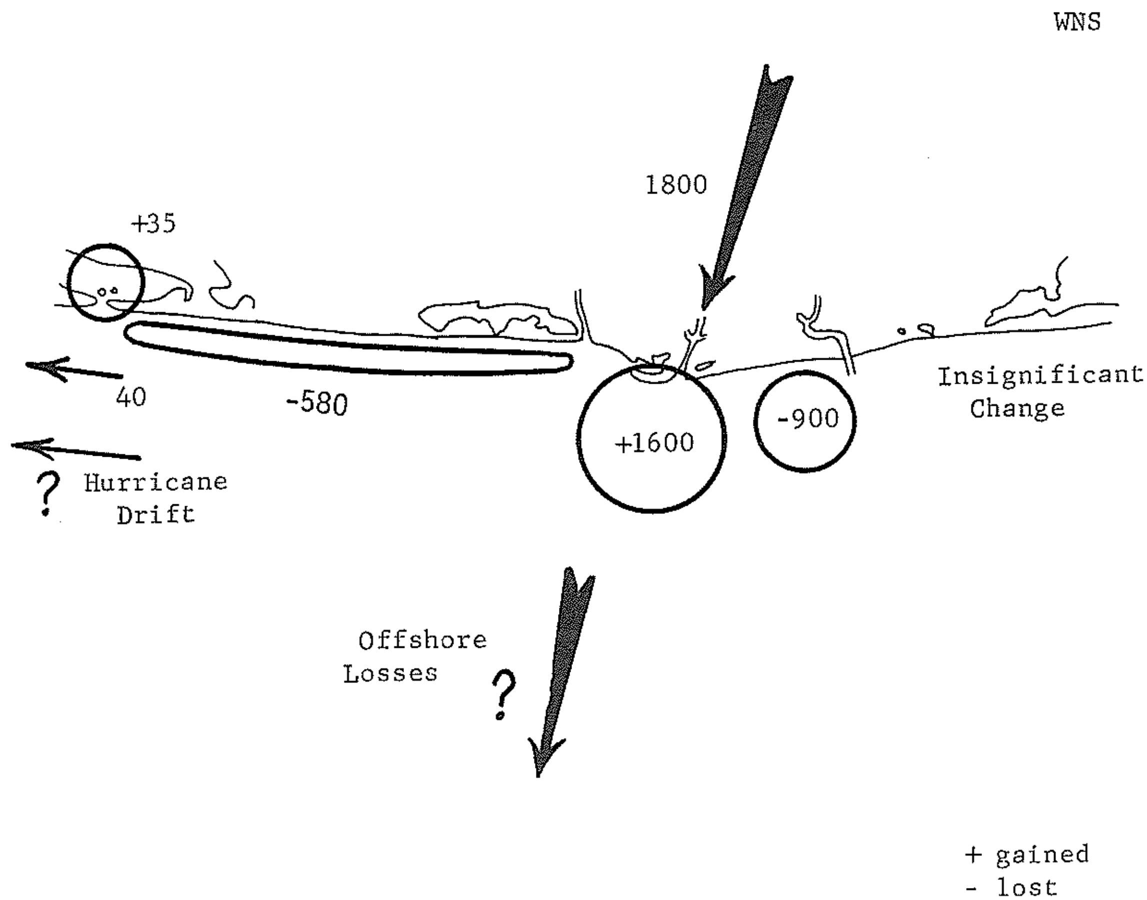

FIGURE 40.— THE SEDIMENT BUDGET
(in millions of cubic feet
of sand 1937 to 1973)

action of the river and other unknown factors apparently blocked longshore transport to form a new delta at the mouth of the relocated river.

The relation of non-hurricane and hurricane forces with the beach and delta system is an additional factor involved with the Sargent erosion. Forces associated with storms expected to occur several times each year remove major volumes of sediment from Sargent Beach, however, the same storms apparently do not replace lost sediments by moving deltaic materials westward. Hurricanes are able to break loose sediments from the densely vegetated Brazos deltas, and may add some sands to Sargent Beach, but most sediments are probably lost offshore reducing the sand potentially available to the beach.

The sediment load of the Brazos River, which is the major source of sand for this section of coast, is also posing a threat to the sand budget due to changes affecting the river during the past one-third century. Construction of dams in conjunction with changes to the drainage basin, both in the 1940's, has reduced the sand input to the coast after the 1940's to one third of the rate before the 1940's.

The above conclusions lead to the prediction that for the next quarter of a century Sargent Beach will continue to erode with a minimum shoreline retreat of 30 feet per year, if the present factors remain in effect. The Intracoastal Waterway adjacent to

Sargent Beach will be threatened by storm conditions, at first by connection with private canals adjacent to the beach (Figure 2). The reduced sand load of the Brazos River in addition to hurricanes will lead to major erosion of Bryan Beach and decline in the size of the present Brazos delta, while Freeport and Surfside coasts will show little change.

The U. S. Army Corps of Engineers, Galveston District, recommends that an eight mile section of coast including Sargent Beach should be controlled by a groin system supplemented with beach sand nourishment updrift of the groins to reduce erosion. The estimated cost of this project is $8,550,000 (personal communication, Mr. C. Pawlik, 1973).

APPENDIX A. -- REFERENCES

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APPENDIX B. -- SARGENT CHANGES, PROFILE RESULTS, AND ENVIRONMENTAL CONDITIONS

The parameters of shoreline position, profile changes at Sargent, associated maximum tides, winds, and the predicted sand input from the Brazos River are summarized.

Note that maximum wind speeds between surveys correlate with maximum storm tides between surveys probably because periods of high winds and tides are both associated with storm conditions. Since tides and profile changes correlate, winds therfore are a fair empirical indicator of profile changes. However, the direction of most of these winds is offshore so that they would tend to cut down wave energy and storm tide levels

Table B-1

SARGENT
SHORELINE POSITION

Date	Time Interval In Years	Position* In Feet	Rate of Shoreline Change In Feet/Year	Source**
1852		0		a
	77		-11	
1930		-839		b
	3.3		-29	
4 November 1933		-935		a,b
	10.0		-23	
17 October 1943		-1164		b
	3.2		+1	
1946-1947		-1168		b
	7.1		-21	
January-March 1954		-1310		b
	2.9		-30	
1956-1957		-1430		b
	6.1		-3	
6 February 1963		-1450		b
	4.8		-42	
26 June 1967		-1650		b

* Relative to 1852, - indicates shoreline retreat
** a = T sheet, b = aerial photographs

Table B-2.

SARGENT PROFILE CHANGES AND ENVIROMENTAL CONDITIONS
1967 to 1972

Survey Date	Time Interval, In Years	Change* in MSL Intercept Position, In feet	Rate of* MSL Intercept Change, in feet per year	Volume* Change, in Cubic feet per foot of beach	Volume Change* Rate, in cubic feet per foot of beach per year	Winds, fastest mile at Galveston, in miles per hour (direction)	Tides, maximum tide at Freeport between survey dates, in feet MSL	Predicted Rate of Sand Input to the Coast from the Brazos River, in millions of cubic feet per year
23 May 1967	.30	0	0	30.8	140	36 (NE)	2.6	2
11 Sept 1967	.19	-13.7	-143	-302	-1600	47 (NW)	4.3	4
20 Nov 1967	.17	-12.5	- 72	-81.8	- 480	32 (NE)	3.1	40
23 Jan 1968	.12	-4.7	-42	19.2	160	32 (NW)	2.2	27
8 Mar 1968	.22	-5.2	-23	-38.6	- 180	42 (NW)	2.7	140
29 May 1968	.37	15.0	40	-46.5	-130	40 (W)	2.5	60
11 Oct 1968	.27	-25.5	-95	-275	-1000	37 (NE)	2.6	8
17 Jan 1969	.12	-15.7	-128	-139	-1200	54 (SE)	4.7	15
3 Mar 1969	.29	-3.0	-11	33	110	33 (SE)	2.9	85
16 Jun 1969	.63	-26.8	-43	-213.5	- 340	45 (E)	3.5	4
19 Jan 1970	.44	-20.2	-46	-244.3	-550	40 (NE)	2.8	39
30 Jun 1970	.54	-15.0	-28	-140	-260	44 (NE)	4.1	4
19 Jan 1971	.51	0	0	5.7	10	37 (NW)	3.4	1
16 Jul 1971	.43	-31.3	-72	-441.	-1000	43 (E)	5.7	11
21 Dec 1971	.72	-2.5	- 4	-231	- 320	38 (NW)	2.5	2
6 Sept 1972								

*Mean of 4 profiles

5/29/73 wms

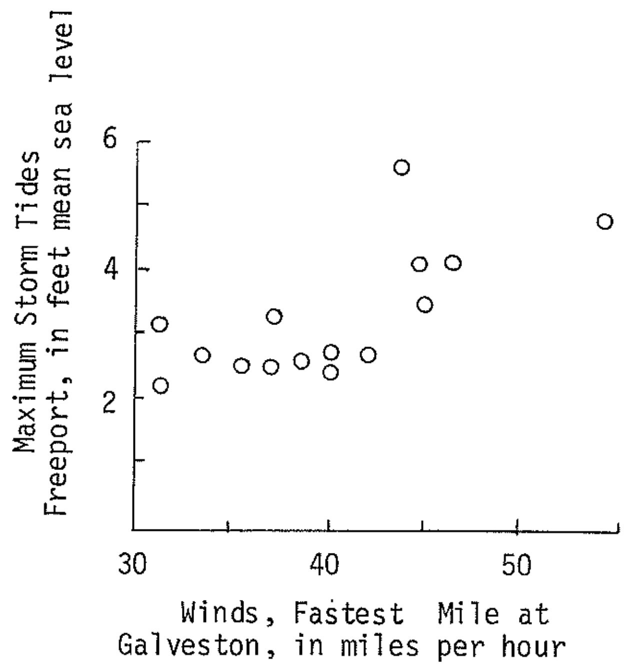


FIGURE B-1.

MAXIMUM WINDS AND TIDES BETWEEN
SURVEYS AT SARGENT 5/67 through 9/72

(information supplied by U. S. Army Corps of Engineers, Galveston District and National Oceanographic and Atmospheric Administration)

4/6/73 mms

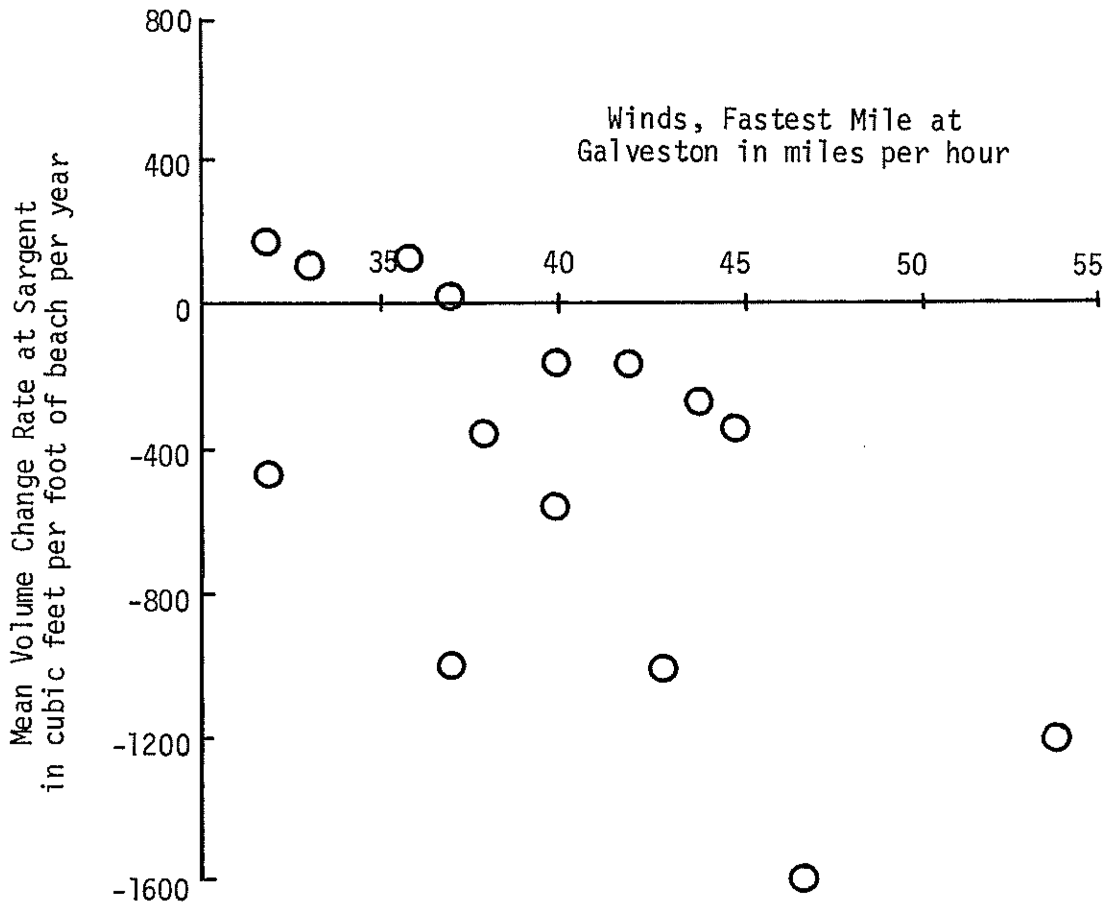


FIGURE B-2.

MAXIMUM WINDS VS.
VOLUME CHANGE RATES AT SARGENT
1967 - 1972

TABLE B-3. -- LITTORAL TRANSPORT APPROXIMATION AT SARGENT BEACH FOR THE 4-5 SEPTEMBER 1933 HURRICANE

H_o = 15 feet for .96 day, H_o = 20 feet for .3 day, T_o = 10 sec, waves from southwest (a)

H_o	d_b	d/L_o	D_d	a_b	K_d	H_b	E_t	E_a	Q_a
ft	ft			degrees		ft	millions ft-lb/ft crest day		millions of cubic feet per day
(a)	(c)	(b)	(b)	(a)	(b)	(b)	(b)	(b)	(d)
15	12	.023	1.19	5	1.0	18	5830	510	1.8
20	16	.031	1.11	7	1.0	22	8710	1050	3.7

where $E_t = 1.8 \times 10^6 \; H^2 \; T$; in ft-lbs/ft crest-day (b)

$E_a = E_t \sin a_b \cos a_b$ (b)

$Q_a = 3510 \; E_a$; in cubic feet per day (d)

$d_b = .78 \; H_b$ (c) or approx. $.8 \; H_o$

Total Longshore Transport = .3 day x 1.8 million cubic feet/day + .96 day x 3.7 million cubic feet/day = <u>4 million cubic feet sand</u>

(a) Wilson, (55)
(b) Wiegel, (54), Chapters 2, 9
(c) Galvin, (18)
(d) Savage, (39)

APPENDIX C . -- NOTES ON SOURCES OF TOPOGRAPHIC AND HYDROGRAPHIC DATA FOR THE STUDY AREA

The following notes are provided to summarize all sources of photography, maps, and hydrographic surveys for the study area in hopes of reducing many tedious hours for future research.

Several cautions are also in order. First, Charts 206 and 1283 for the study area may be misleading for engineering purposes because the chart date may not correspond to the time original data was collected. For example, Chart 206, dated 1858, was made from topographic surveys of 1852. During these six years a single hurricane could have caused significant changes, leading to possible misinterpretation. A second more recent example is the 1966 edition of Chart 1283 which contains hydrographic surveys from the 1930's to describe a major portion of the new Brazos Delta. Clearly this delta has changed significantly in size, shape, and character, so that the chart may give the unsuspecting researcher a totally misleading picture.

Second, quoted scales on photographs are inaccurate in some cases so for detailed work the scale should be determined using known landmarks.

Table C-1. SOURCES OF SHORELINE INFORMATION FOR THE STUDY AREA

Dates		Coverage	Source*	Status E-examined only C-copied P-purchased	Comments
1852	1858	Matagorda Bay - Old Brazos Delta	NOS Chart 206(Archives)	P	Available from NOS Project PH6807
	1881	Matagorda Bay - Old Brazos Delta	NOS Chart 206(Archives)	P	Only Old Brazos Delta updated from 1858
	1909	Matagorda Bay - Old Brazos Delta	NOS Chart 206(Archives)	P	Only Old Brazos Delta updated from 1858
	1915	Matagorda Bay - Old Brazos Delta	NOS Chart 206(Archives)	P	Only Old Brazos Delta updated from 1858
	1917	Matagorda Bay - Old Brazos Delta	NOS Chart 206(Archives)	P	Only Old Brazos Delta updated from 1858
	1915	East Matagorda Bay - Old Brazos Delta	COE Survey	C	
Aug-Oct	1921	East Matagorda Bay - Old Brazos Delta	COE Survey	C	
	1924	Old Brazos Delta	NOS Chart 525	P	
	1929	Old & New Brazos Deltas	COE Survey	P,C	
	1930	East Matagorda Bay - Old Brazos Delta	Tobin Surveys Photos	P	Earliest photo coverage examined, quoted scale unreliable
4 Nov	1933	Sargent - San Luis Pass	NOS (by Army Air Corps)	P	Flight ACC-479 } also available
7 Dec	1933	Matagorda - Brown Cedar Cut	NOS (by Army Air Corps)	P	Flight ACC-488 } on NOS Topo sheets
	1937	Chart 1283		P	Most complete hydro & shoreline
18 Dec to 20 Jan	1938 1939	Old & New Brazos Delta	Ammann International & Kargl Aerial Surveys, LTD	C	Both sources have identical photos
18 Feb	1939	San Luis Pass		C	
	1942	Brown Cedar Cut - San Luis Pass	USGS Maps	P	
	1942	Brown Cedar Cut - San Luis Pass	USGS Photo Mosaics	C	Used to make USGS maps
4 Sept	1942	Old & New Brazos Deltas	TVA	C	Available to Galveston District
17 Oct	1943	Sargent	USDA	P	

11 Sept 1944	Brazos Area	Ammann International	E	
4 Sept 1945	New Brazos Delta	COE Photos	C	Oblique
Jan 1946	New Brazos Delta	USGS Photo Mosaic	C	
17 Jan 1948	Old & New Brazos Deltas	Air Force photos and mosaic	C	Available at Galveston District
31 Oct 1949	Old & New Brazos Deltas	Ammann International	P	
28 Apr 1952	New Brazos Delta	USDA Photos	C	
2 Apr 1952	Old Brazos Delta	USDA Photos	C	
13 May 1952	Old Brazos Delta	USDA Photos	C	
9 Jan 1953	Old Brazos Delta	USDA Photos	C	
Jan-Mar 1954	Sargent - Old Brazos Delta	Ammann International	P	
1956-57	Brown Cedar Cut - Old Brazos Delta	NOS B&W, IR Photos	E	Roll 13-10
16 Sept 1960	Study Area	NOS	E	Roll 20-23
17 Sept 1961	Old & New Brazos Deltas	NOS Photos	C	Roll 22-18
18 Sept 1961	Old & New Brazos Deltas	COE,NOS	C	Roll 22-20
8 Jan 1962	Cedar Lakes to San Luis Pass	USGS Maps	P	
	Cedar Lakes to San Luis Pass	Ammann International	E	Used to make USGS Maps
1 June 1962	Brown Cedar, Deltas	NOS Photos	E	Roll 24-26
5 May 1962	New Brazos Delta	COE Photos	C	
1 Oct 1962	Old & New Brazos Deltas	COE Photos	C	
1 Aug 1962	Cedar Lakes - San Luis	USGS Maps	P	
6 Feb 1963	Sargent	COE Photos	C	
27 Mar 1963	Old & New Brazos Deltas	COE Photos	C	
22 Oct 1965	Deltas, Sargent, Brown Cedar	NOS Photos	E	Roll 31-37
31 Oct 1965	Old & New Brazos Deltas	USDA Photos	C	
26 Dec 1965	Bryan Beach	USDA Photos	C	
1 June 1966	Old Delta - Jetties	Dow Chemical Co. Mosaic	C	
1 Oct 1966	East of Old Delta	USDA	C	
26 June 1967	Sargent to Freeport	COE	C,E	
10 Aug 1968	Sargent	COE Photos	C	
11 Sept 1969	Sargent	COE	C	

	1969	Jetties	COE Photos	E	
18 Apr	1969	Brazos Delta	United Aerial Mapping Mosaic	C	Available at Dow Chemical Co. and Chamber of Commerce
19 Aug	1969	Coast	NASA Mission 110	C	
9 Oct	1970	Sargent	COE	C	
	1970	Freeport Jetties	COE	E	
6 Nov	1970	Brown Cedar - San Bernard	NASA	C	
8 Mar	1971	Coast	NASA Mission 159	C	
18 May	1971	Coast	NASA Mission 165	C	
	1971	Sargent, Jetties	COE	E	
11 Nov	1971	Coast	NASA Mission 191	C	
	1972	Sargent, Jetties	COE	E	
26 Sept	1972	Freeport to Corpus Christi	Seelig Flight	C	Obliques
26 Jan	1973	Jetties to Brown Cedar	Seelig Flight	C	Obliques

NOTE: Sargent Beach (see text), Freeport Jetties and San Luis Pass surveys available from COE beginning in 1967. Brown Cedar Cut surveys available in Mason and Sorensen (31).
1852 surveys on contemporary coordinate systems from National Ocean Survey, NOAA, project PH6807.

*NOTES ON SOURCES

NOS - National Ocean Survey, Photo Information, Rockville, Maryland

COE - U. S. Army Corps of Engineers, Galveston District, Coastal Studies, Galveston, Texas.

Tobin Surveys - San Antonio, Texas.

Ammann International - San Antonio, Texas.

USGS - U. S. Geological Survey, Map Information Office, Washington, D. C.

TVA - Tennessee Valley Authority, photographs available at Galveston District, Galveston, Texas.

USDA - U. S. Department of Agriculture, Angleton, Texas.

NASA - National Aeronautics and Space Administration, aerial photography section, Clear Lake City, Texas.

TABLE C-2.

SOURCES OF HYDROGRAPHY

INFORMATION FOR THE STUDY AREA

Source(1)	Location	Dates of Surveys (2)
1	old Brazos delta	July 1921
2	old Brazos delta	January 1924
3	old Brazos delta	August to September 1925
5	old & partial new Brazos	21 to 28 July 1930
6	old & partial new Brazos	6 to 21 July 1931
7	old & partial new Brazos	6 to 21 June 1932
8	old & partial new Brazos	September to October 1934
H 6316	old & new Brazos deltas	11 July to 28 August 1937
H 6315	Sargent	28 September to 13 October 1937
12 BP 41035-6	old Brazos delta	23 to 26 August 1946
COE	old Brazos delta	1966
this study	old & New Brazos deltas	24 February to 28 June 1973

(1) National Ocean Survey standard numbers, Chart 1283, location and extent of surveys shown in figures.
(2) Standard date may be different from survey dates.

APPENDIX D . -- SELECTED PHOTOGRAPHS AND MAPS OF THE BRAZOS DELTAS

Attached are photographs of the Brazos deltas and maps of the new Brazos delta. The new delta shoreline maps are constructed from sources listed in Appendix III using the following proceedure:

1. The vegetation, water, and sand areas are identified , when possible, on the original sources and outlined in ink. Material is then copied on fine grained 35 mm black and white film using a 55 mm Nikor copy lens and copy stand. In the case of photographs, each is individually copied. Photo uncontrolled mosaics are not employed.

2. U. S. Geological Survey 1/24,000 scale quadrangles dated 1942 and 1962 are used as the base for construction of maps presented here because of the high quality of the USGS maps.

3. Negatives in 1. are projected with a conventional enlarger and continuously adjustedin scale in multiple directions to match the USGS map closest to the data of the photograph.

4. The scaled projection is photographically printed on a clear base material to give a translucent positive image.

5. Photos are attached to the USGS map. A map for the photography date is then constructed showing the shoreline, sand areas, regions of vegetation, and exposed water. In

addition, the 1852 shoreline, including turning points, as determined by the National Ocean Survey (34), is added to all maps for reference. See Seelig and Sorensen (42) for additional details on the 1852 shoreline information.

Hydrographic charts presented are adapted from National Ocean Survey standards for Chart 1283. Successive surveys are given including only the common plan areas for both surveys. Dates refer to actual survey dates and may not be representative of either the chart or standard dates.

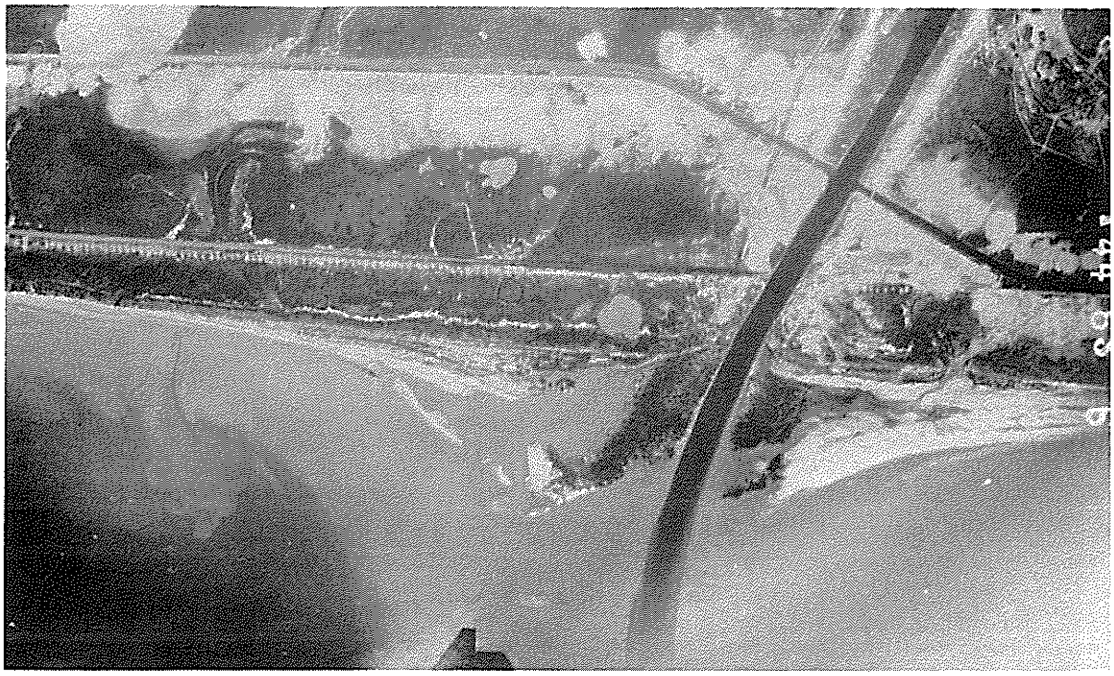
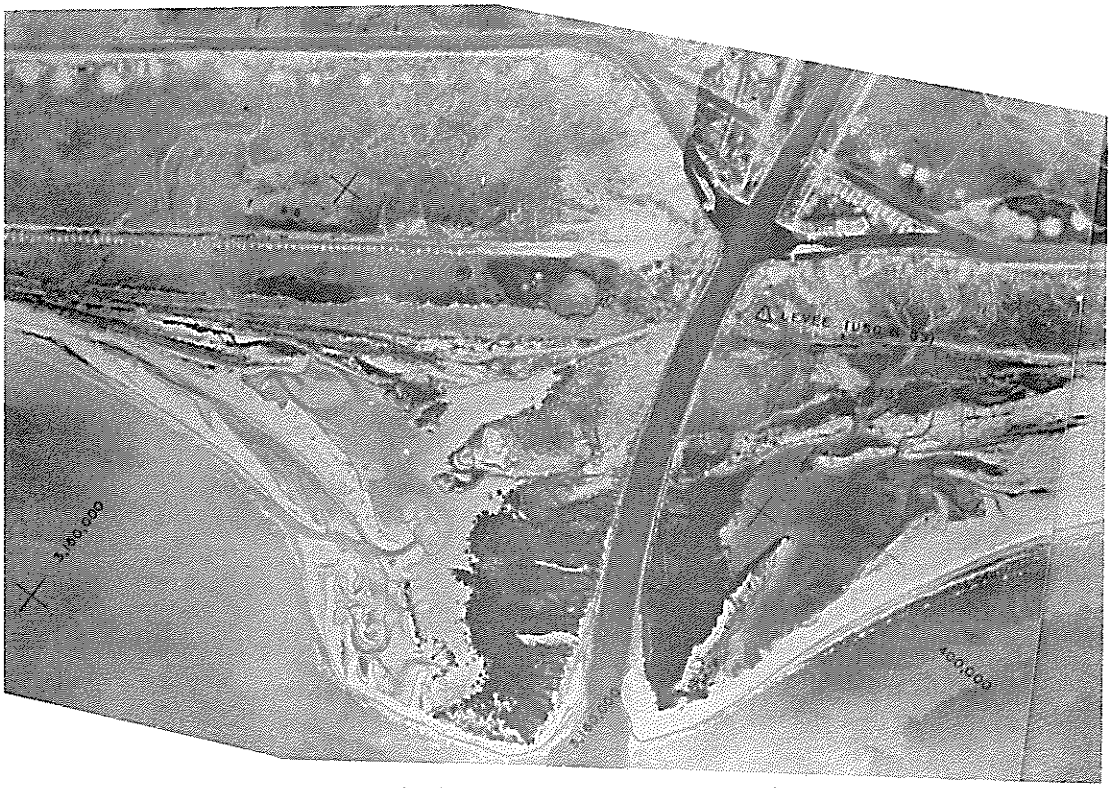


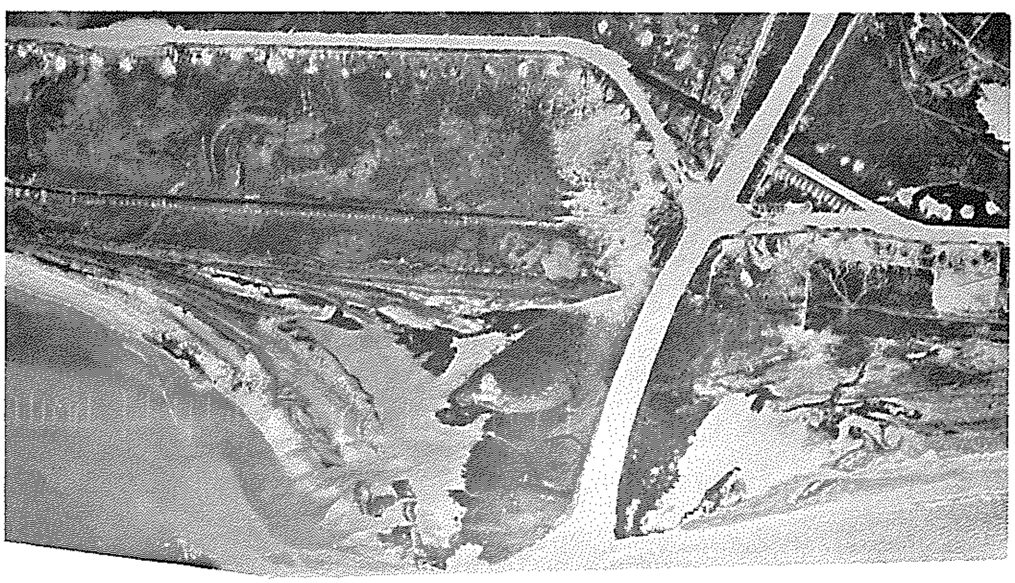
FIGURE D-1. NEW BRAZOS DELTA 9/4/42
(photo by Tennessee Valley Authority)

FIGURE D-2.

NEW BRAZOS DELTA 1/17/48
(photo by U.S. Air Force)

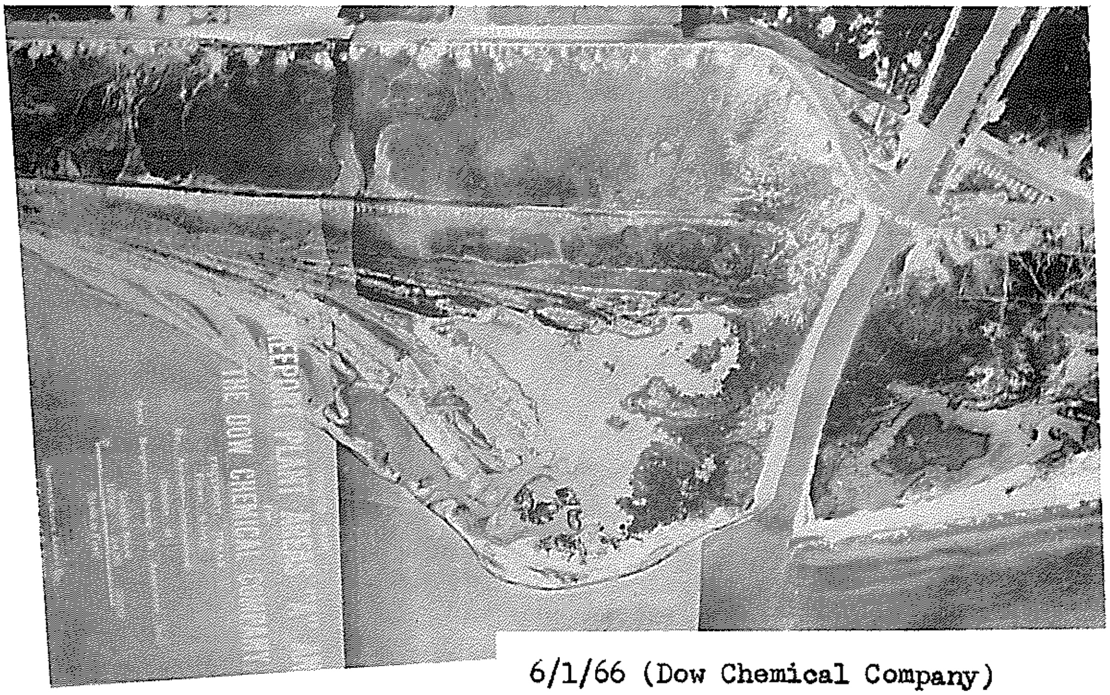


January - March 1954 (Ammann International)

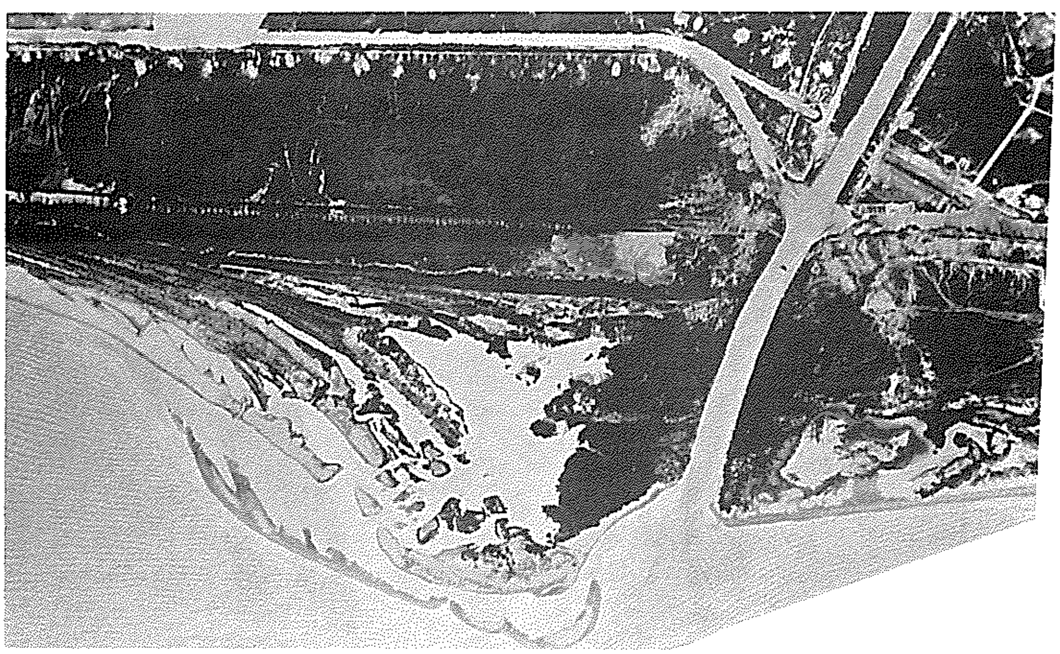


9/18/61 (National Ocean Survey)

FIGURE D-3. NEW BRAZOS DELTA



6/1/66 (Dow Chemical Company)



8/19/69 (National Aeronautics and Space Administration)

FIGURE D-4. NEW BRAZOS DELTA

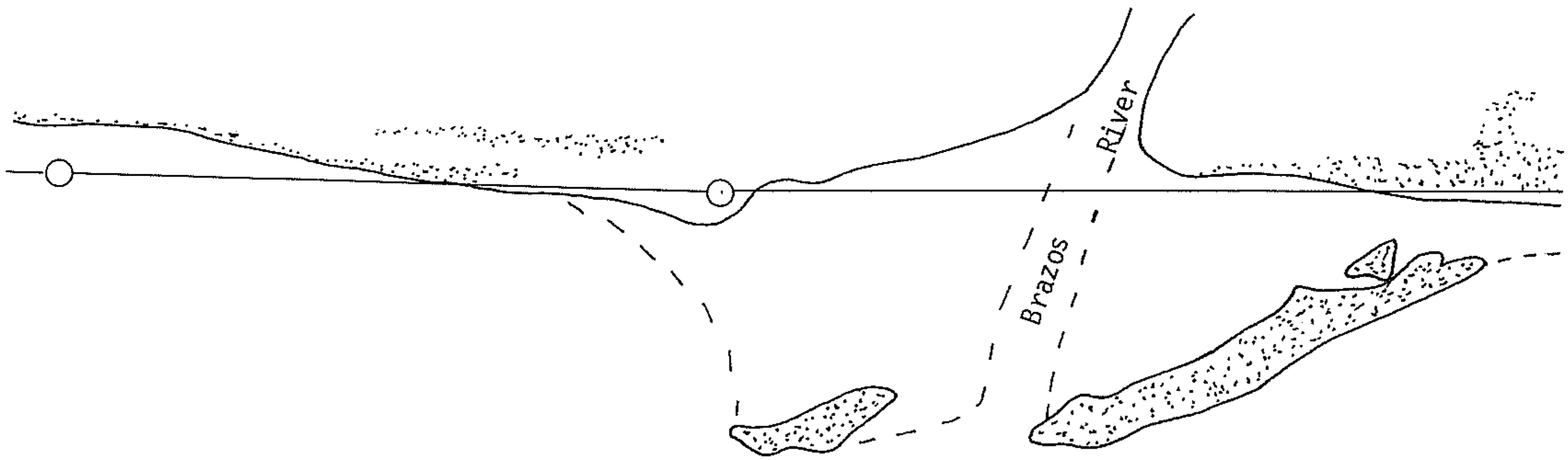


FIGURE D-5.

NEW BRAZOS DELTA

12/31/38 - 01/20/39

1 mile

6/5/73 mms

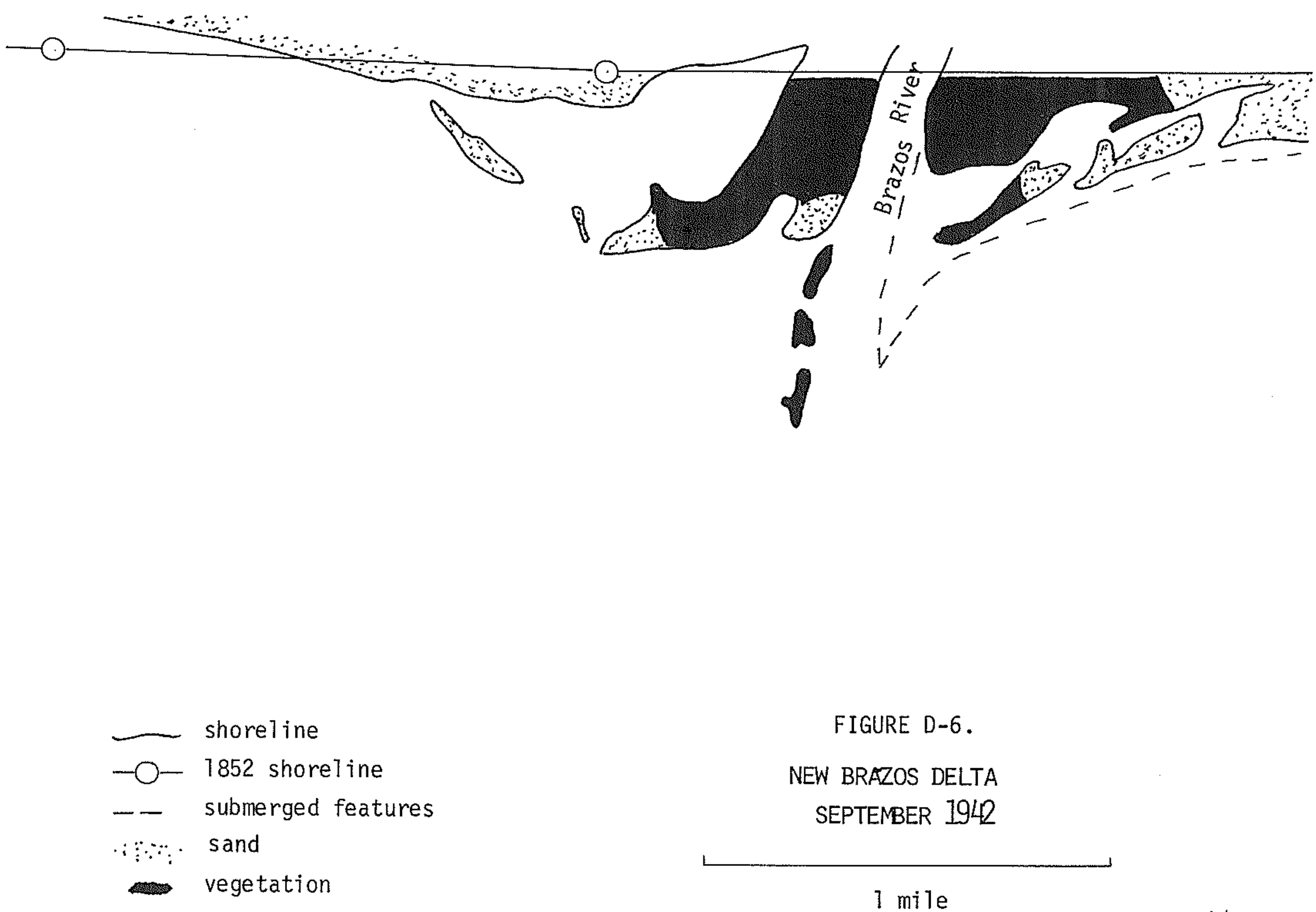


FIGURE D-6.

NEW BRAZOS DELTA
SEPTEMBER 1942

6/5/73 mms

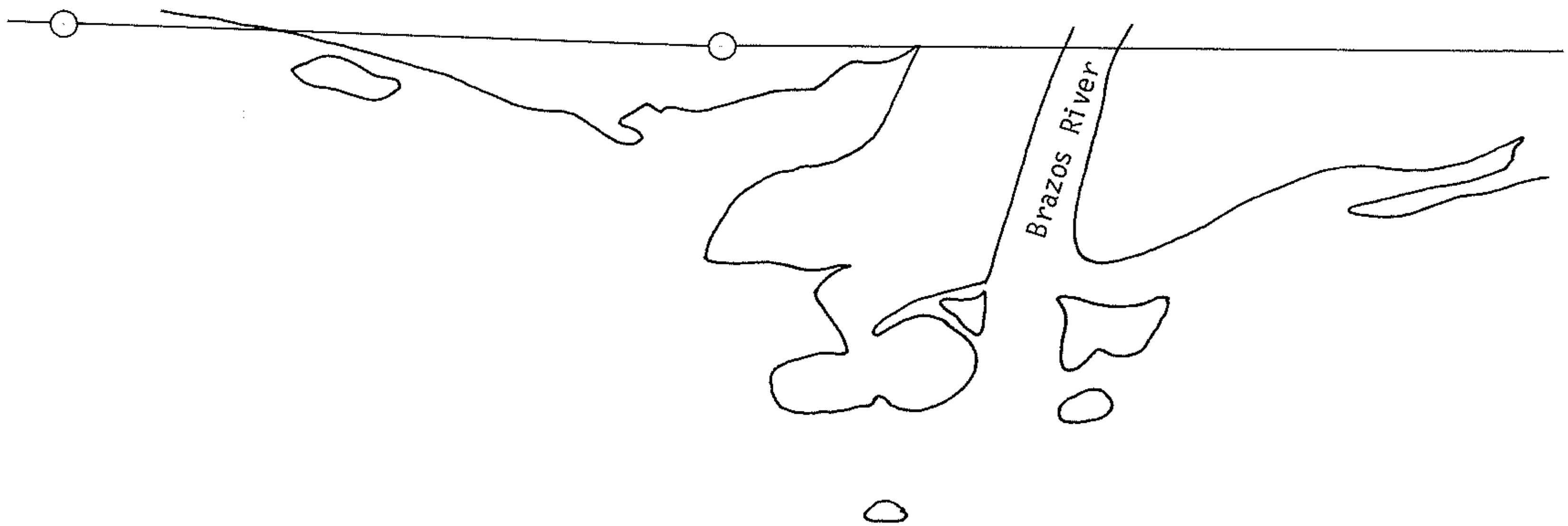


FIGURE D-7.

NEW BRAZOS DELTA
JANUARY 1946

1 mile

shoreline
1852 shoreline

6/5/73 mms

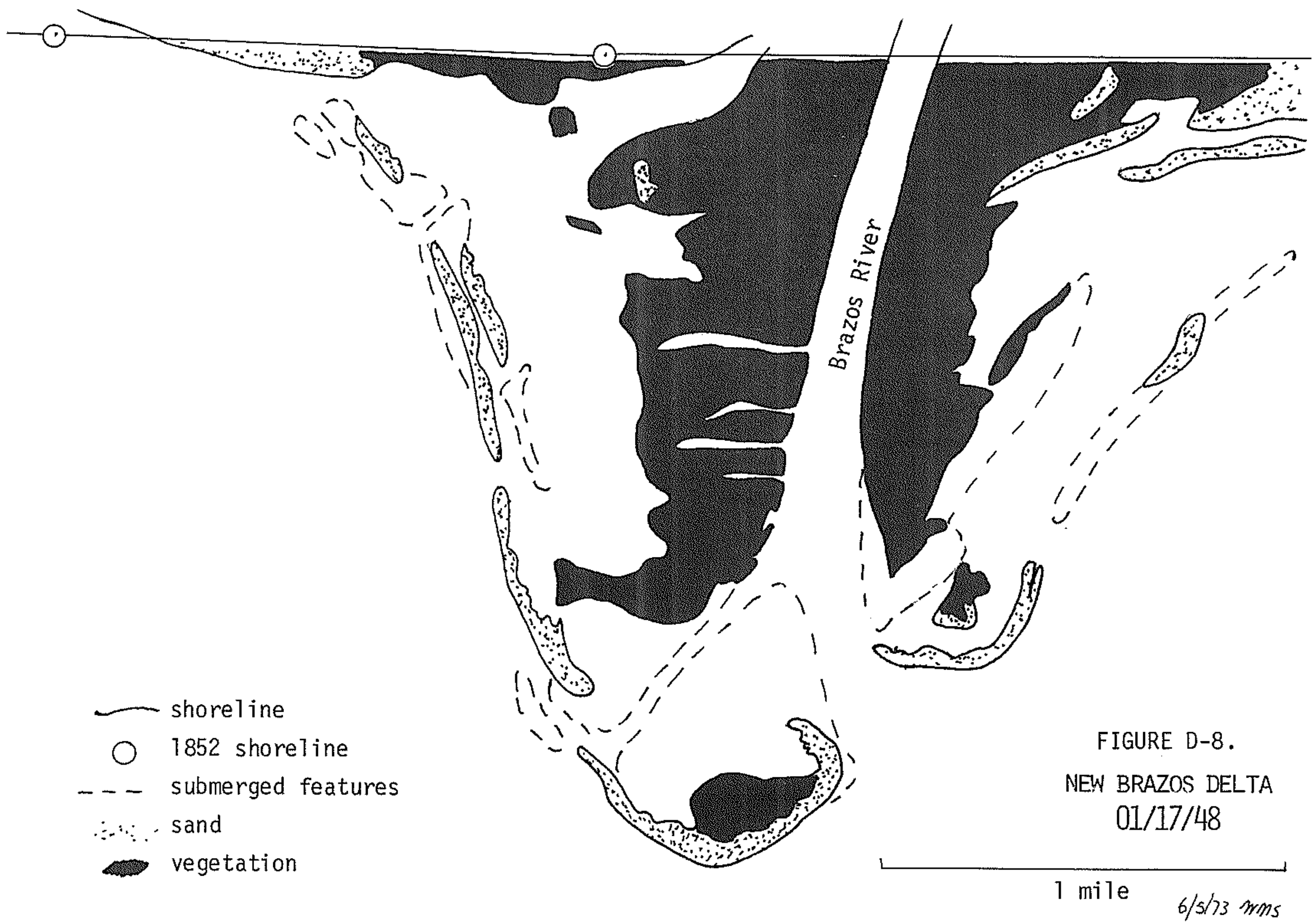


FIGURE D-8.
NEW BRAZOS DELTA
01/17/48

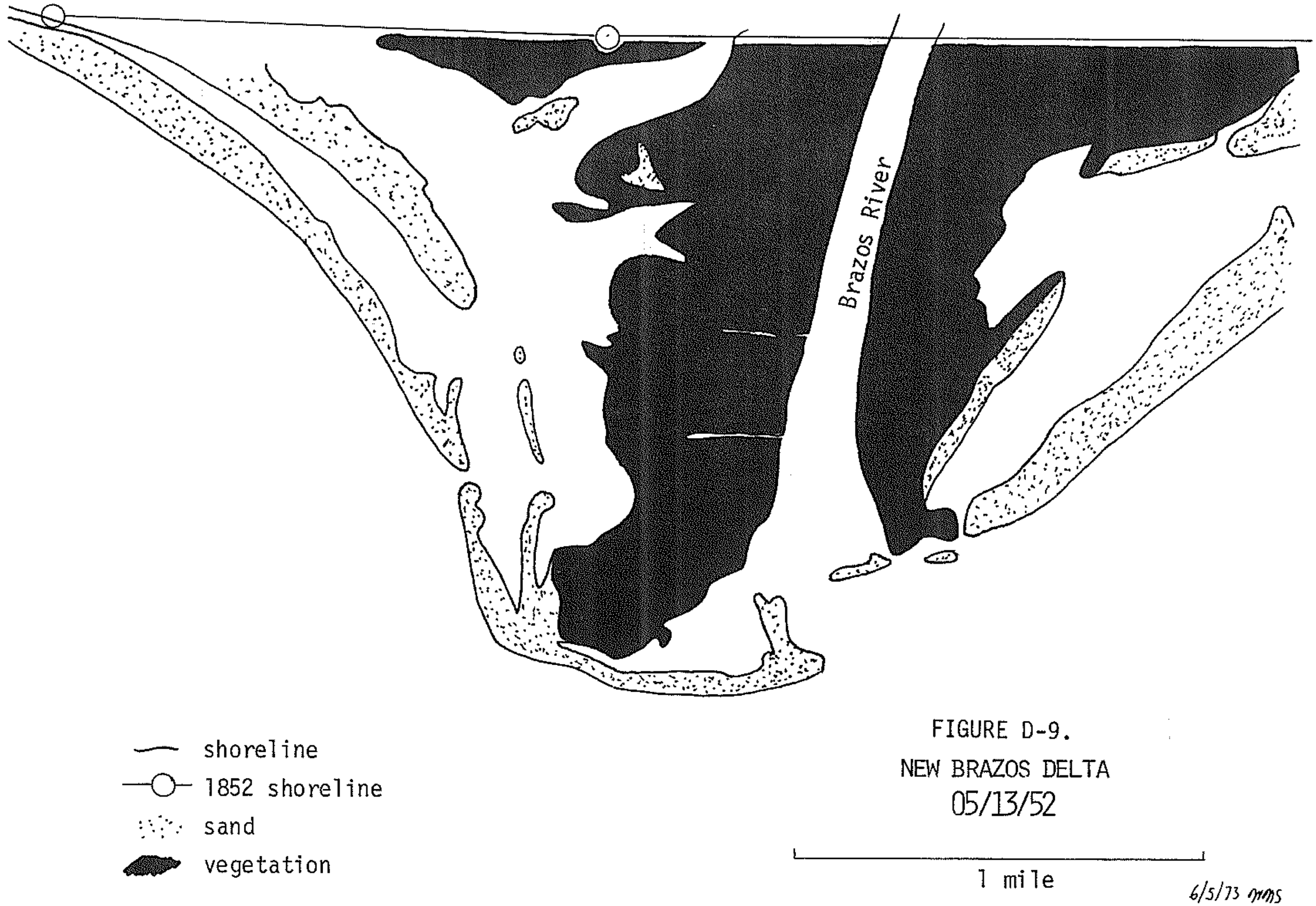


FIGURE D-9.
NEW BRAZOS DELTA
05/13/52

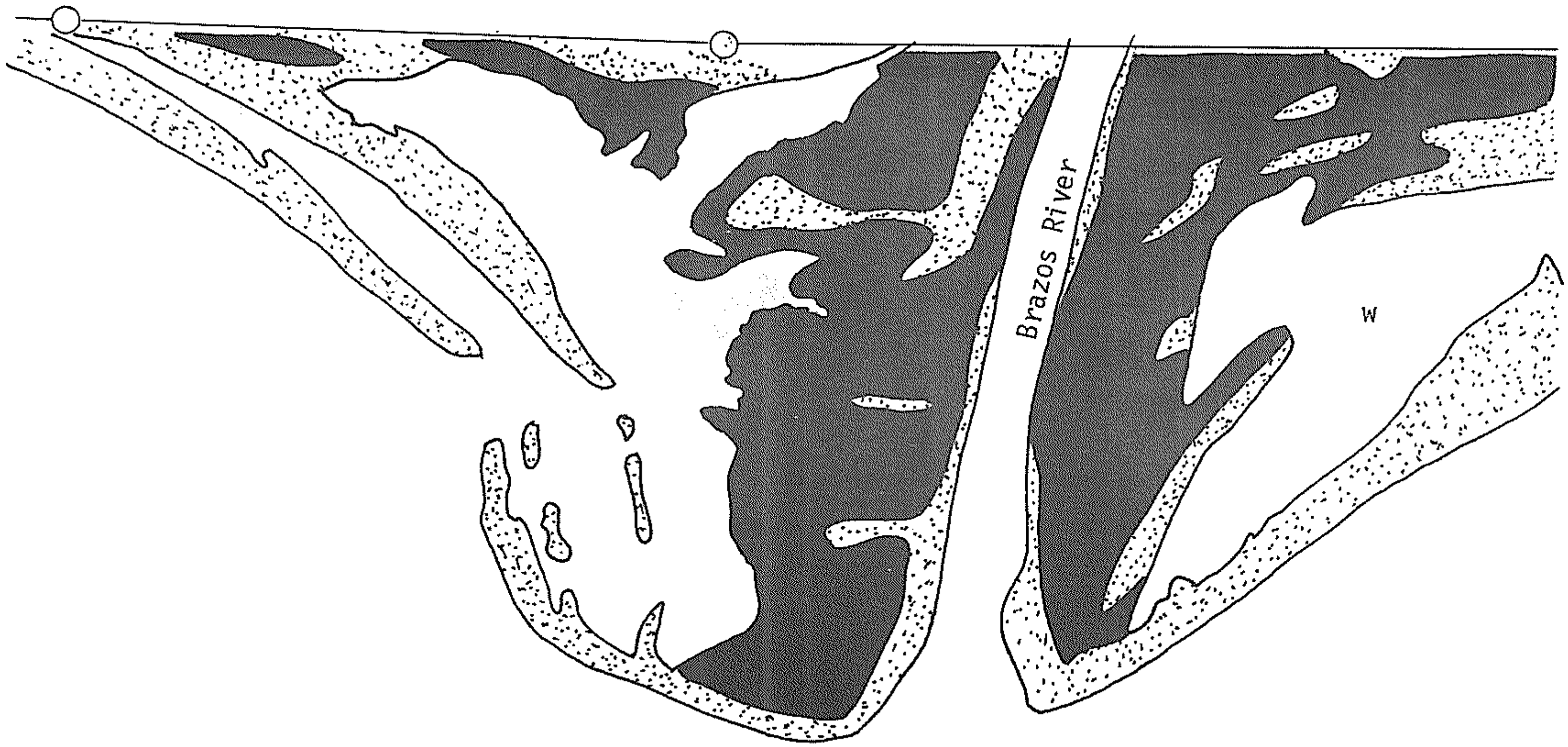
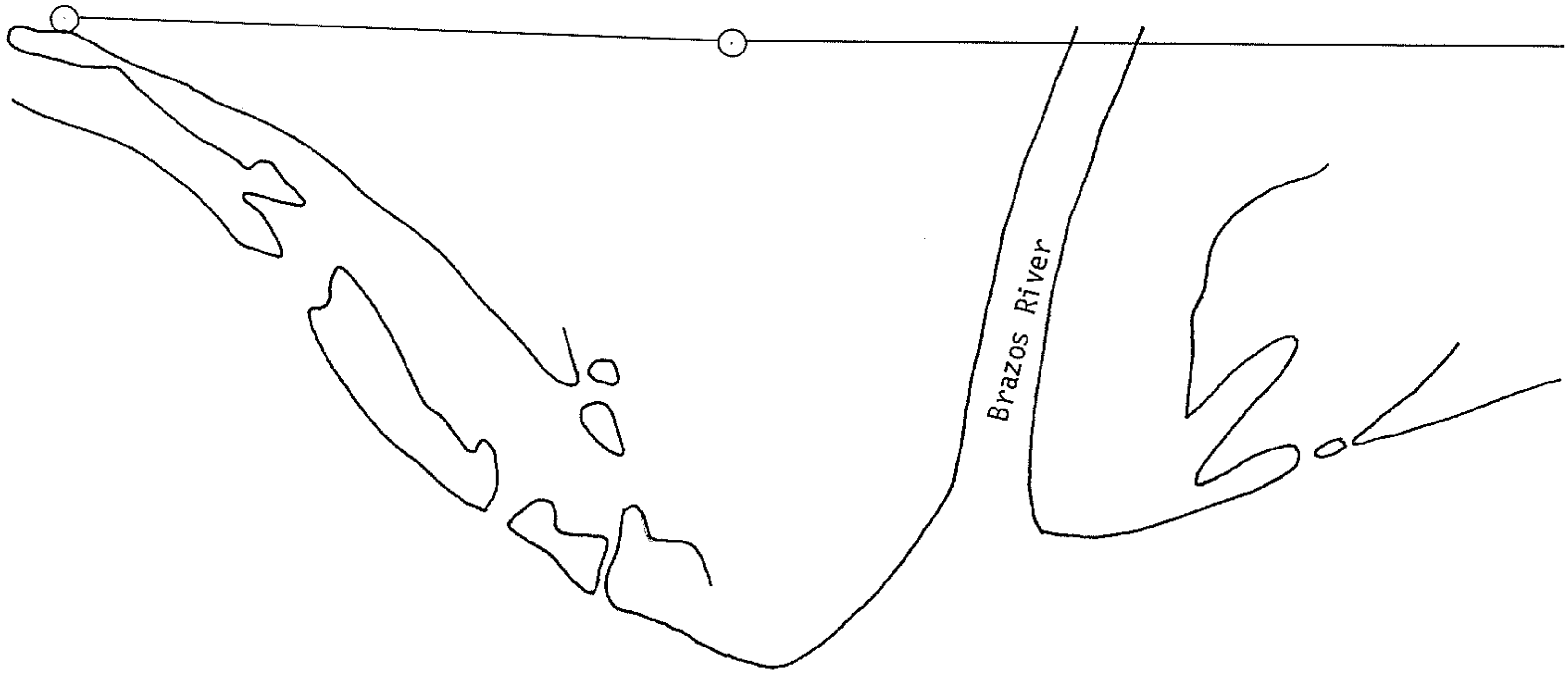


FIGURE D-10.

NEW BRAZOS DELTA
12/31/53 - 03/17/54



shoreline
1852 shoreline

FIGURE D-11.
NEW BRAZOS DELTA
1956 - 1957

1 mile

6/5/73 MMS

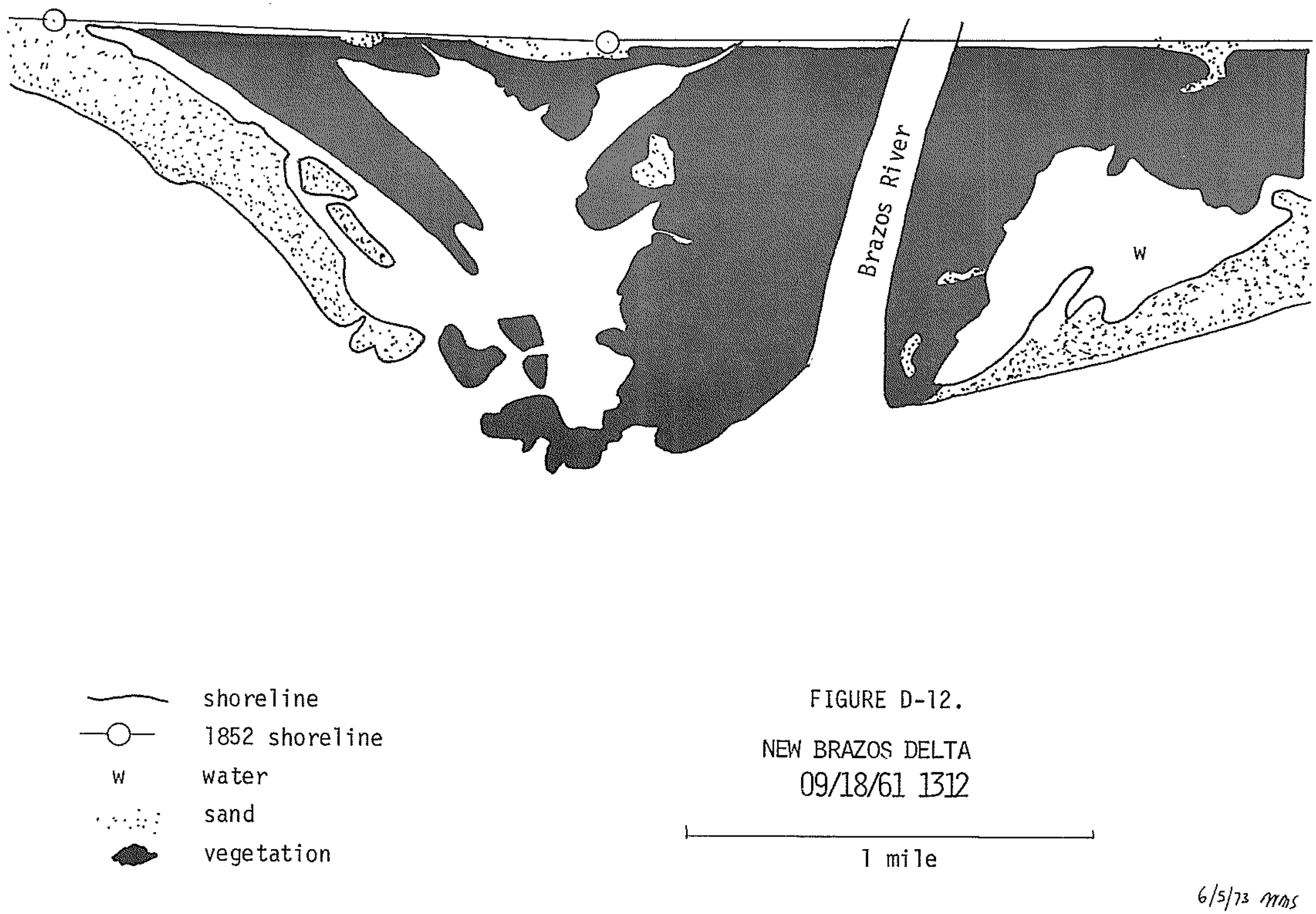
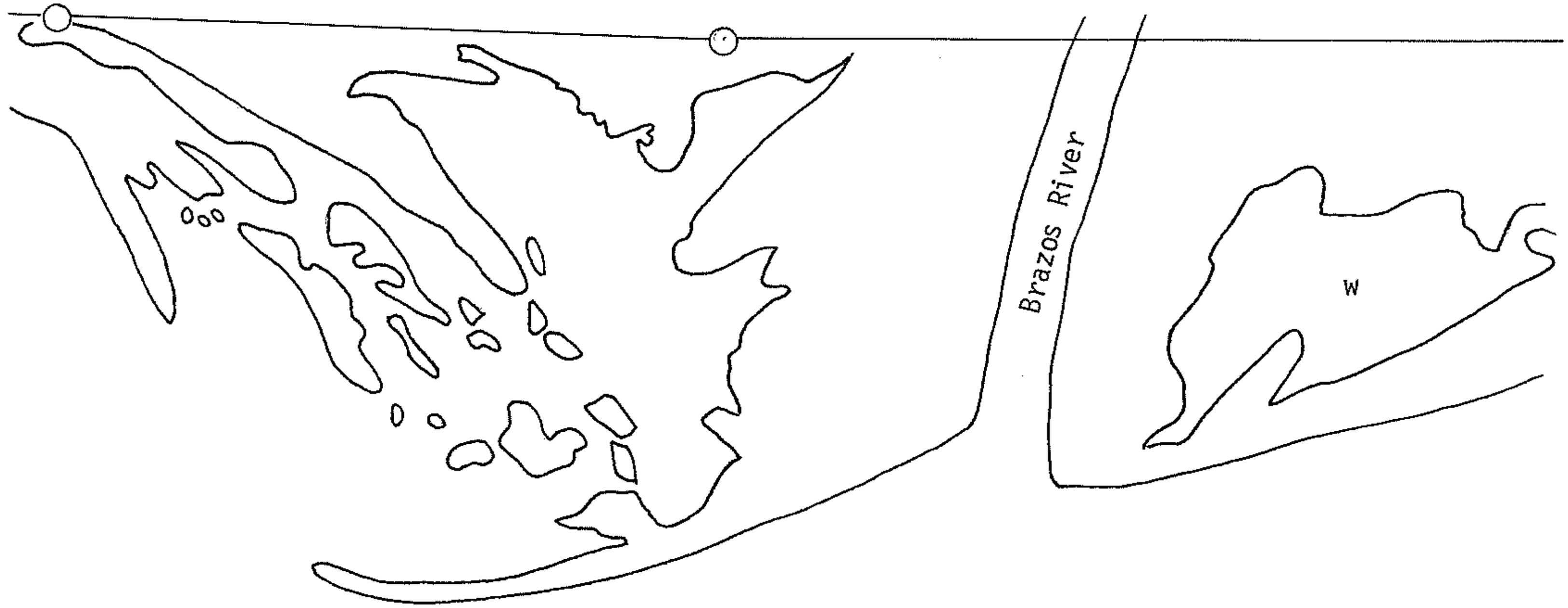


FIGURE D-12.

NEW BRAZOS DELTA
09/18/61 1312

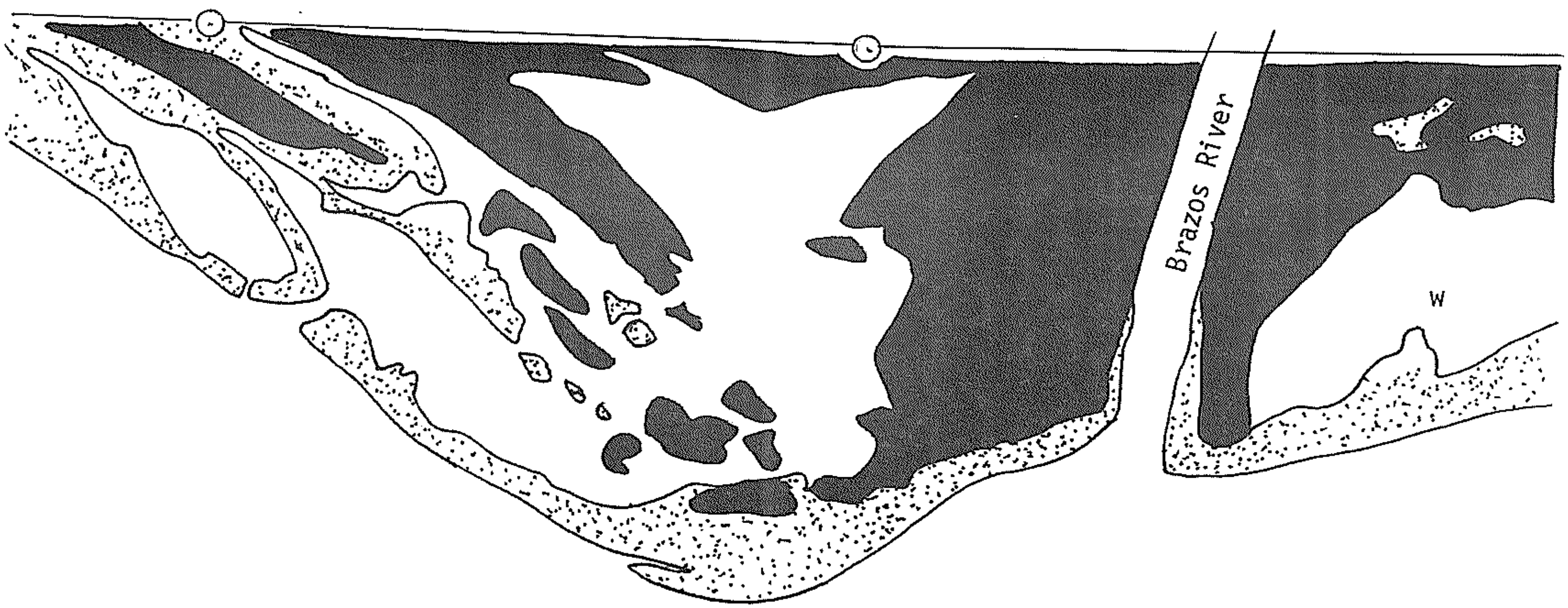


shoreline
1852 shoreline
w water

FIGURE D-13.
NEW BRAZOS DELTA
01/08/62

1 mile

6/5/73 WMS



shoreline
1852 shoreline
W water
sand
vegetation

FIGURE D-14.
NEW BRAZOS DELTA
10/31/65

1 mile

6/5/73 WWS

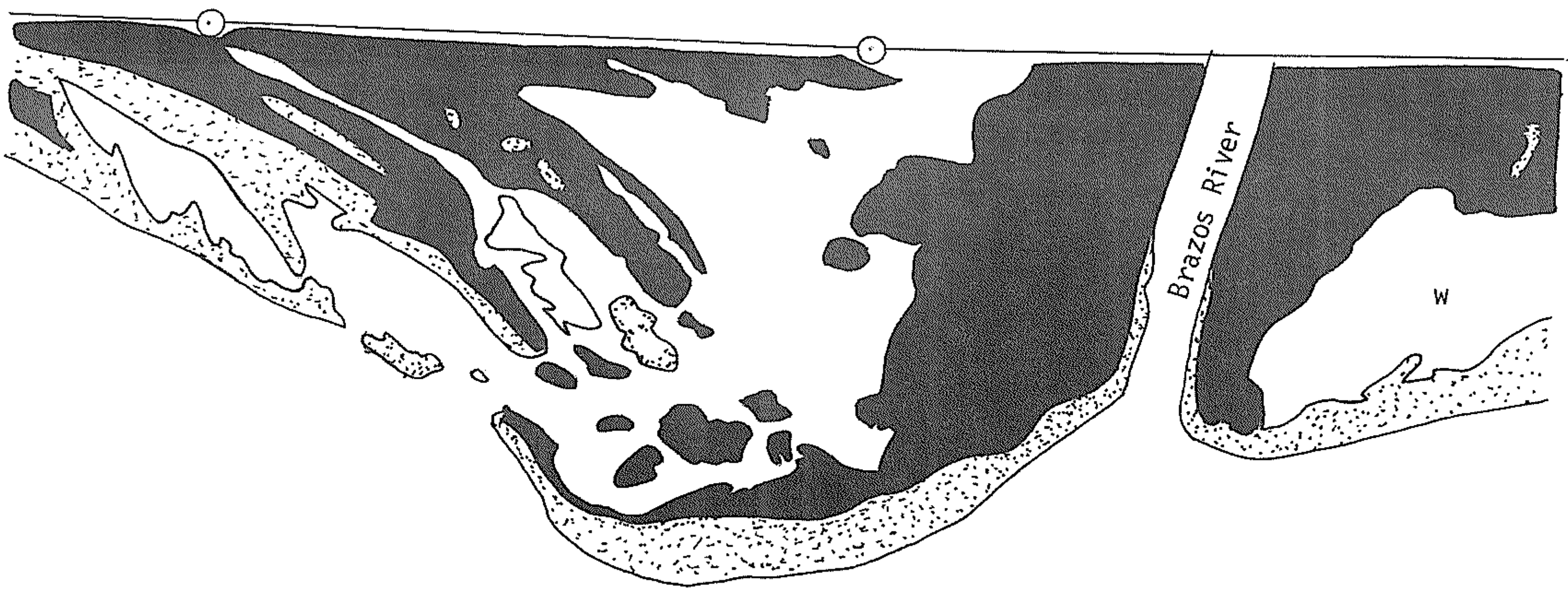


FIGURE D-15.

NEW BRAZOS DELTA
06/26/67

shoreline
1852 shoreline
w water
sand
vegetation

1 mile

6/5/73 mms

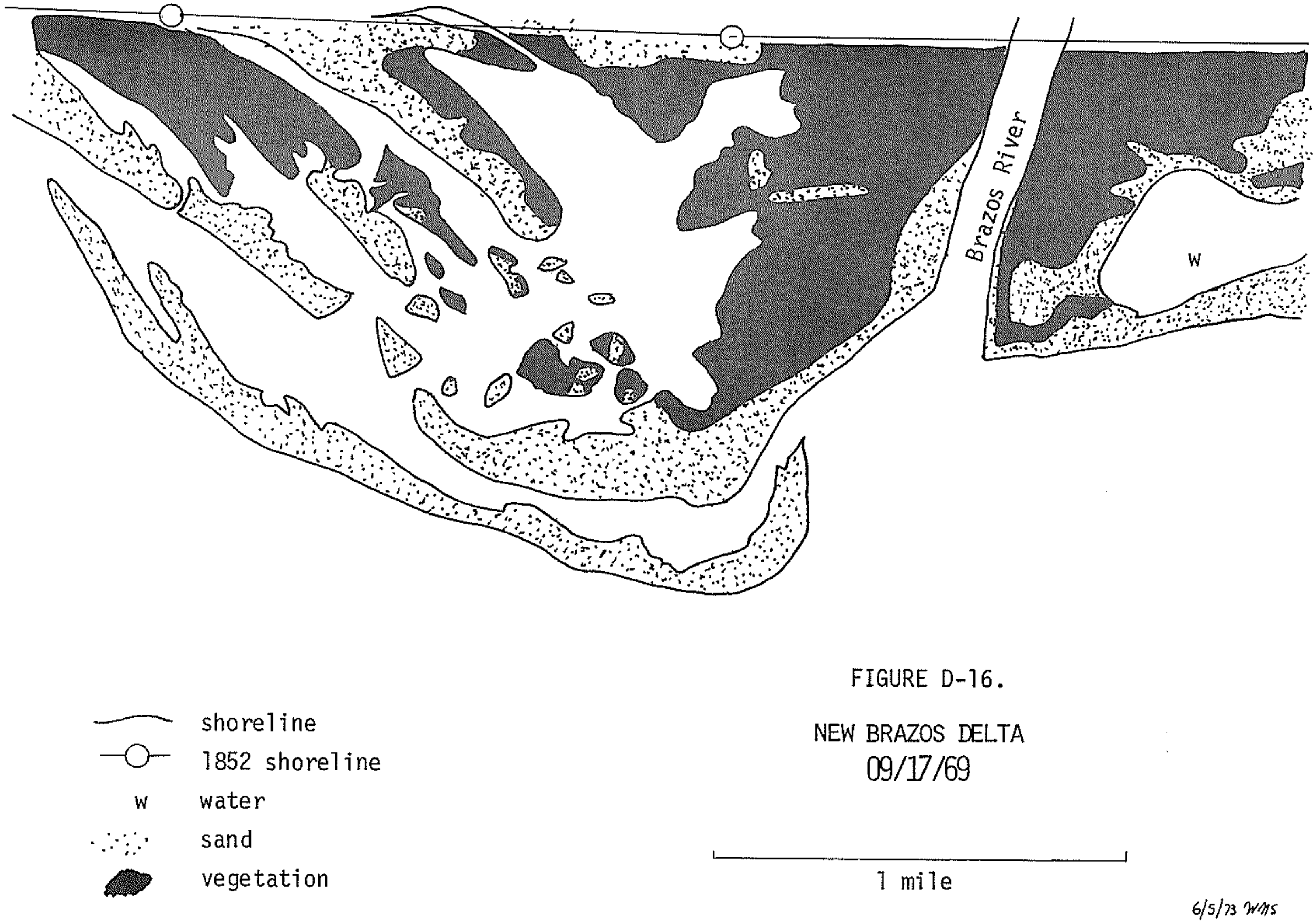


FIGURE D-16.

NEW BRAZOS DELTA
09/17/69

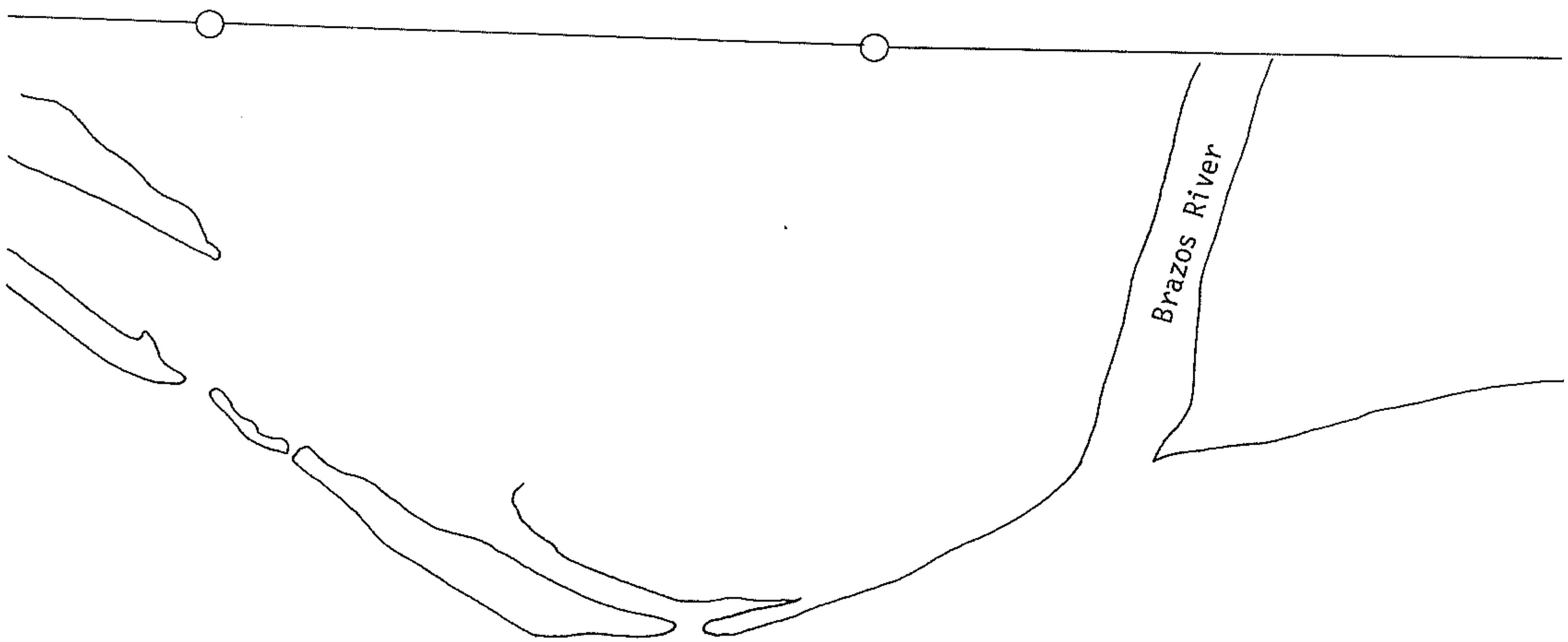


FIGURE D-17.

NEW BRAZOS DELTA

11/11/71

shoreline

1852 shoreline

1 mile

6/5/73 nms

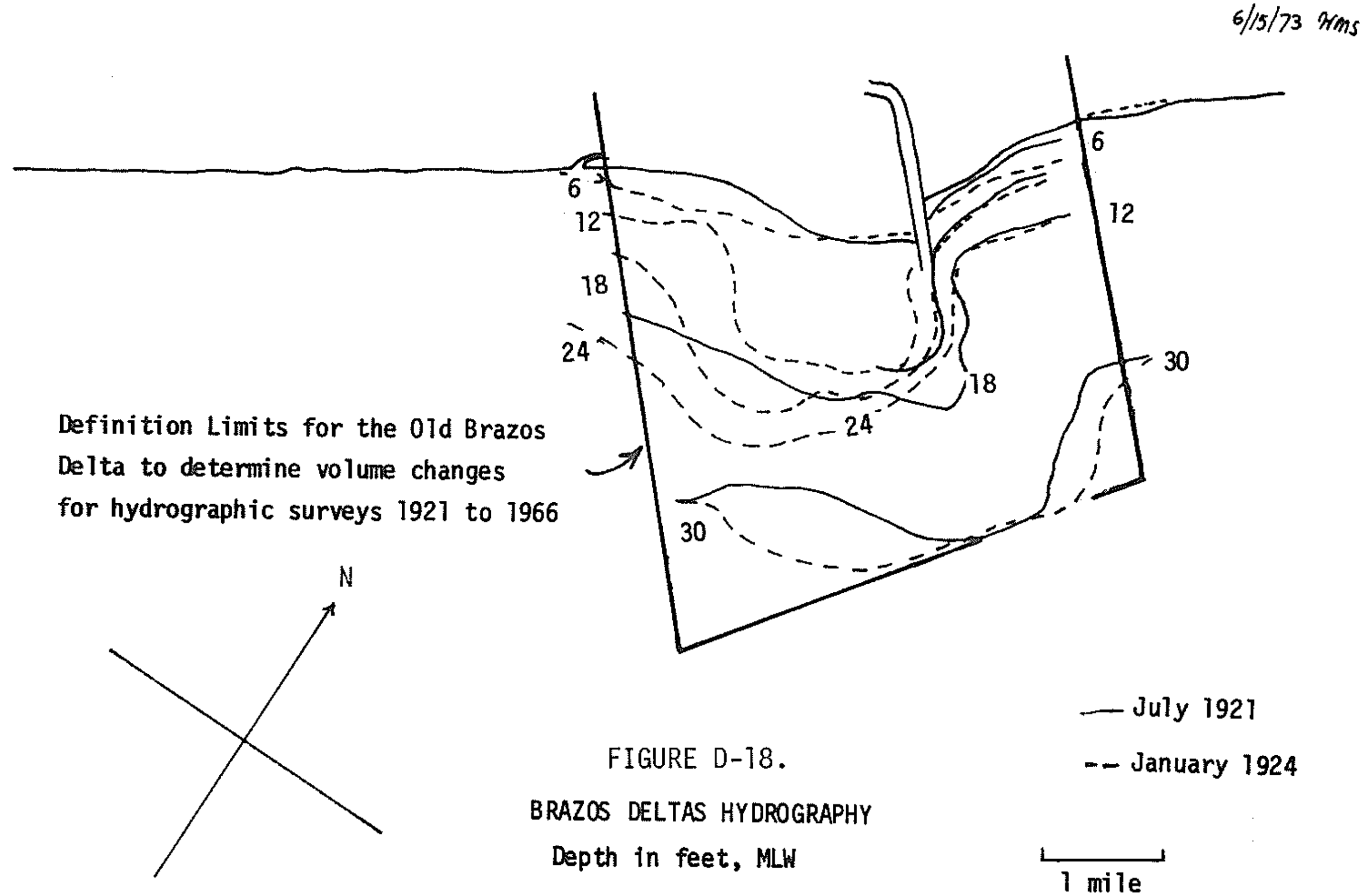


FIGURE D-18.

BRAZOS DELTAS HYDROGRAPHY

Depth in feet, MLW

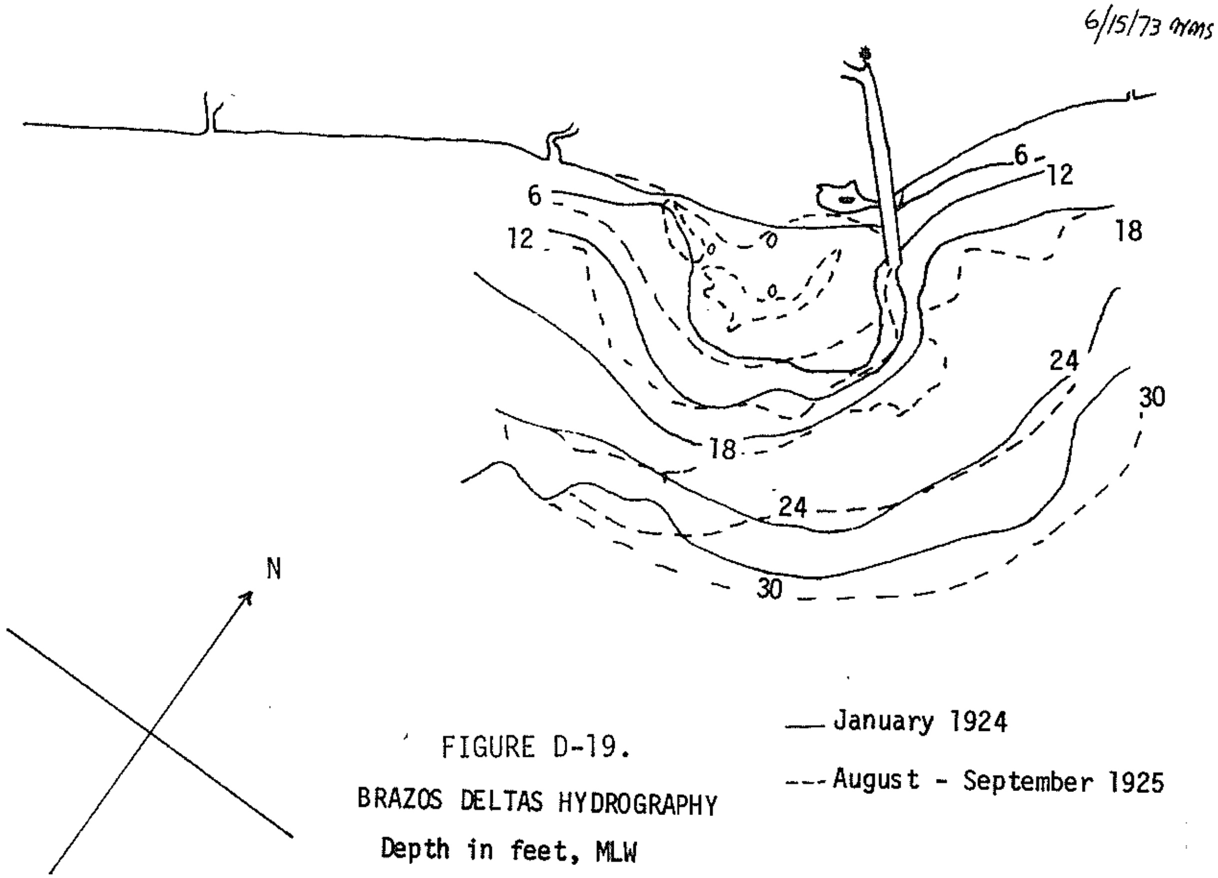
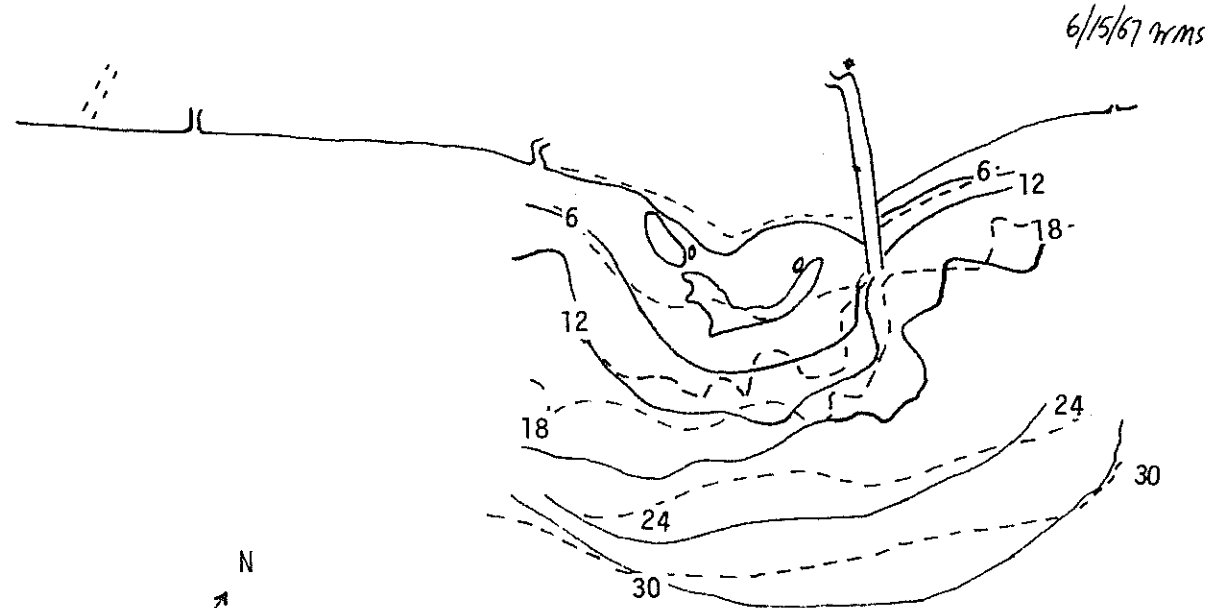


FIGURE D-19.
BRAZOS DELTAS HYDROGRAPHY
Depth in feet, MLW



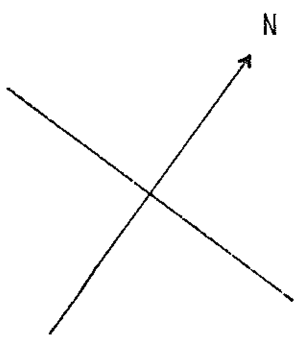


FIGURE D-20.

BRAZOS DELTAS HYDROGRAPHY

Depth in feet, MLW

—— August - September 1925

- - - 21 to 28 July 1930

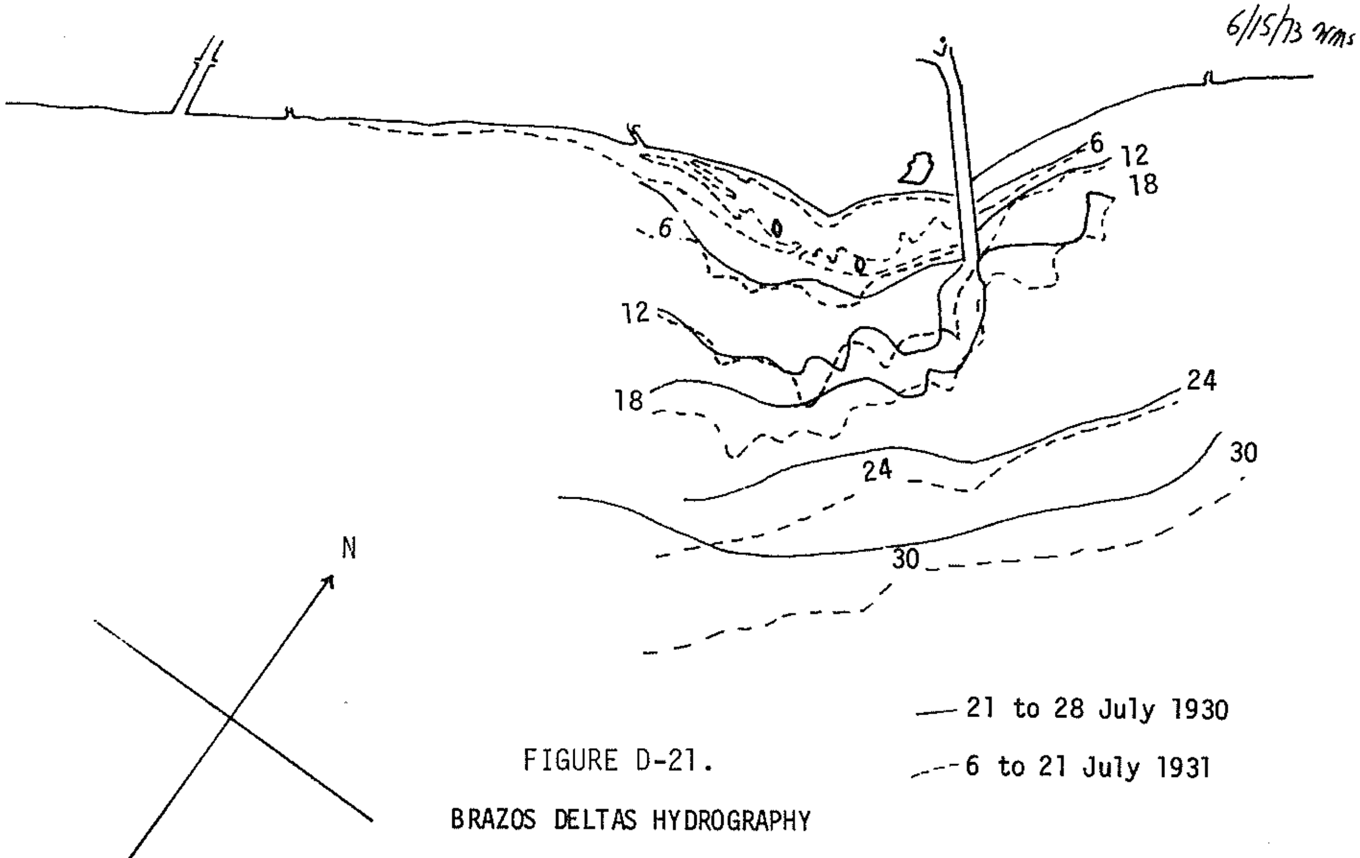


FIGURE D-21.

BRAZOS DELTAS HYDROGRAPHY

Depth in feet, MLW

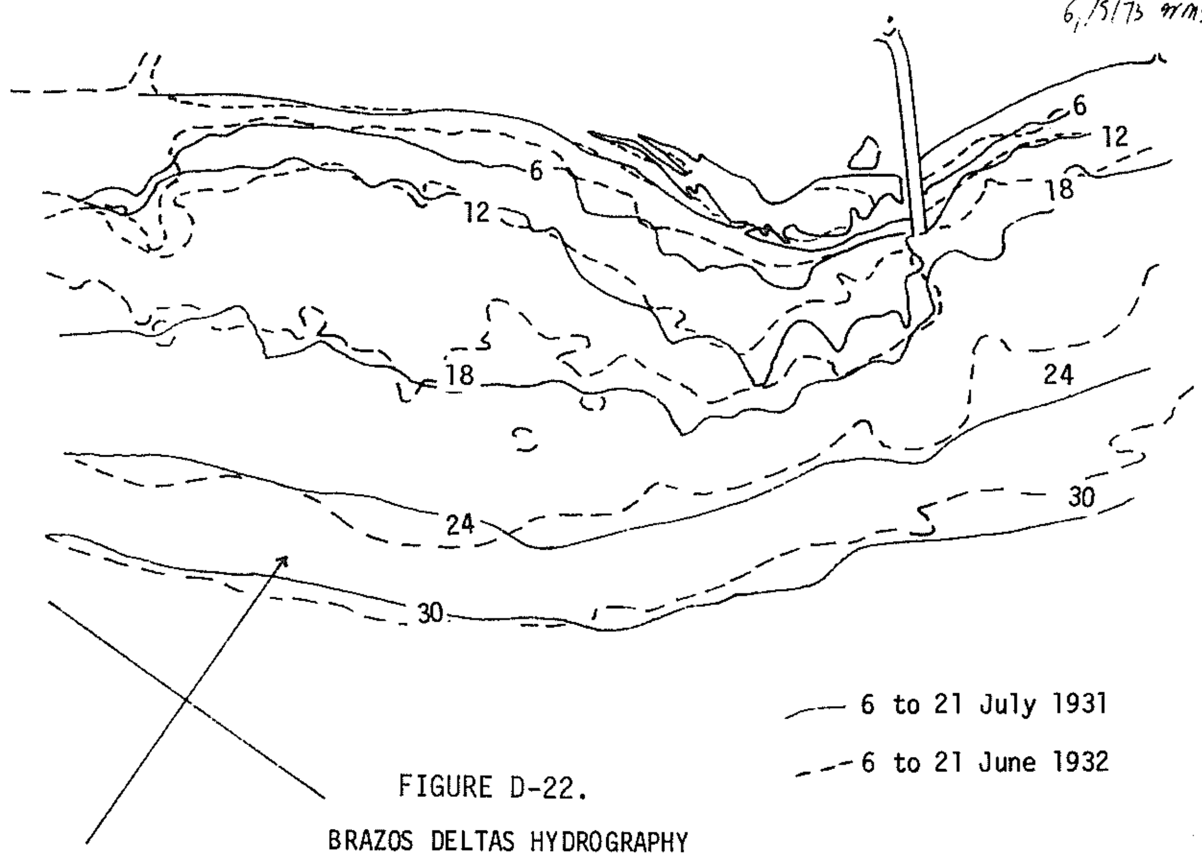


FIGURE D-22.
BRAZOS DELTAS HYDROGRAPHY
Depth in feet, MLW

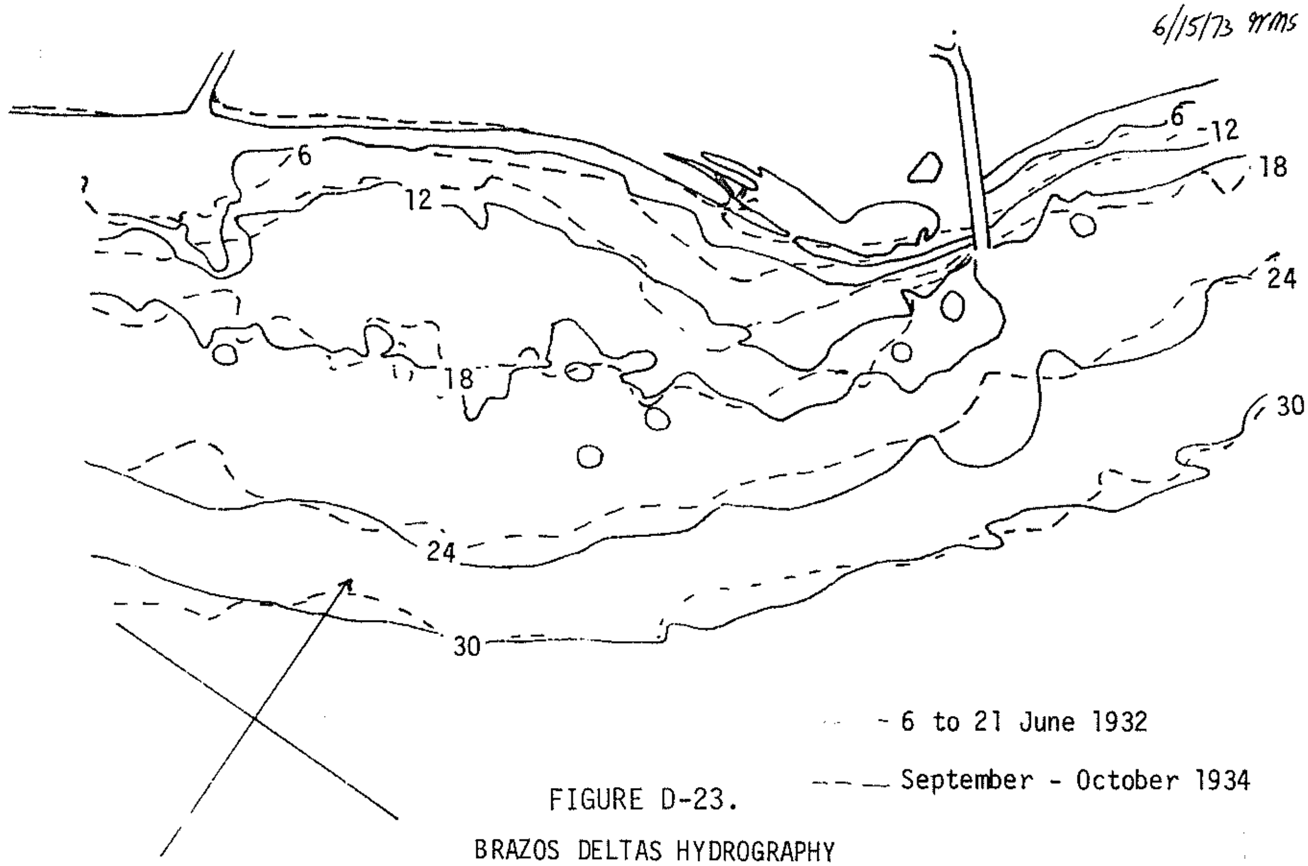


FIGURE D-23.
BRAZOS DELTAS HYDROGRAPHY
Depth in feet, MLW

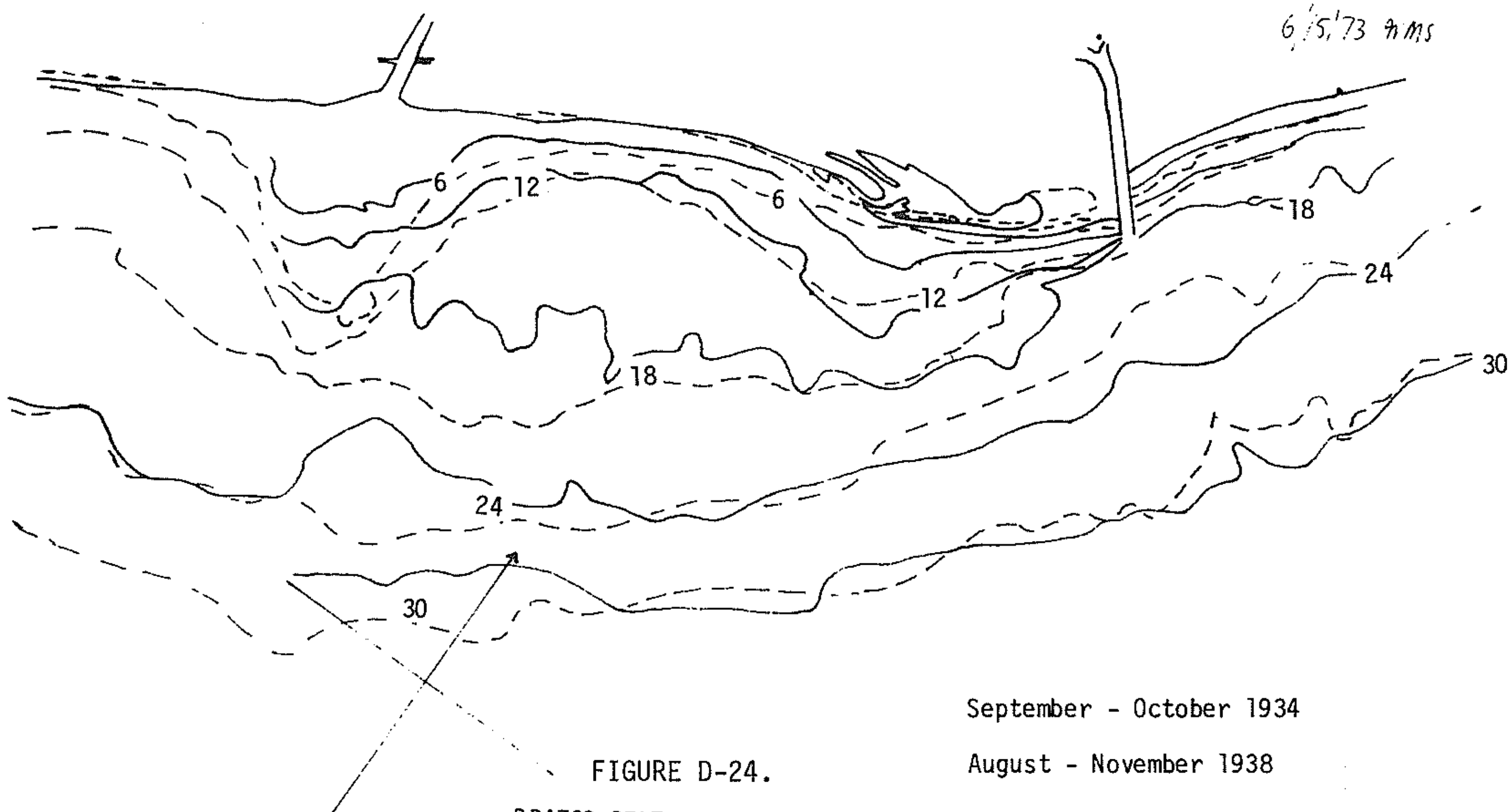


FIGURE D-24.
BRAZOS DELTAS HYDROGRAPHY
Depth in feet, MLW

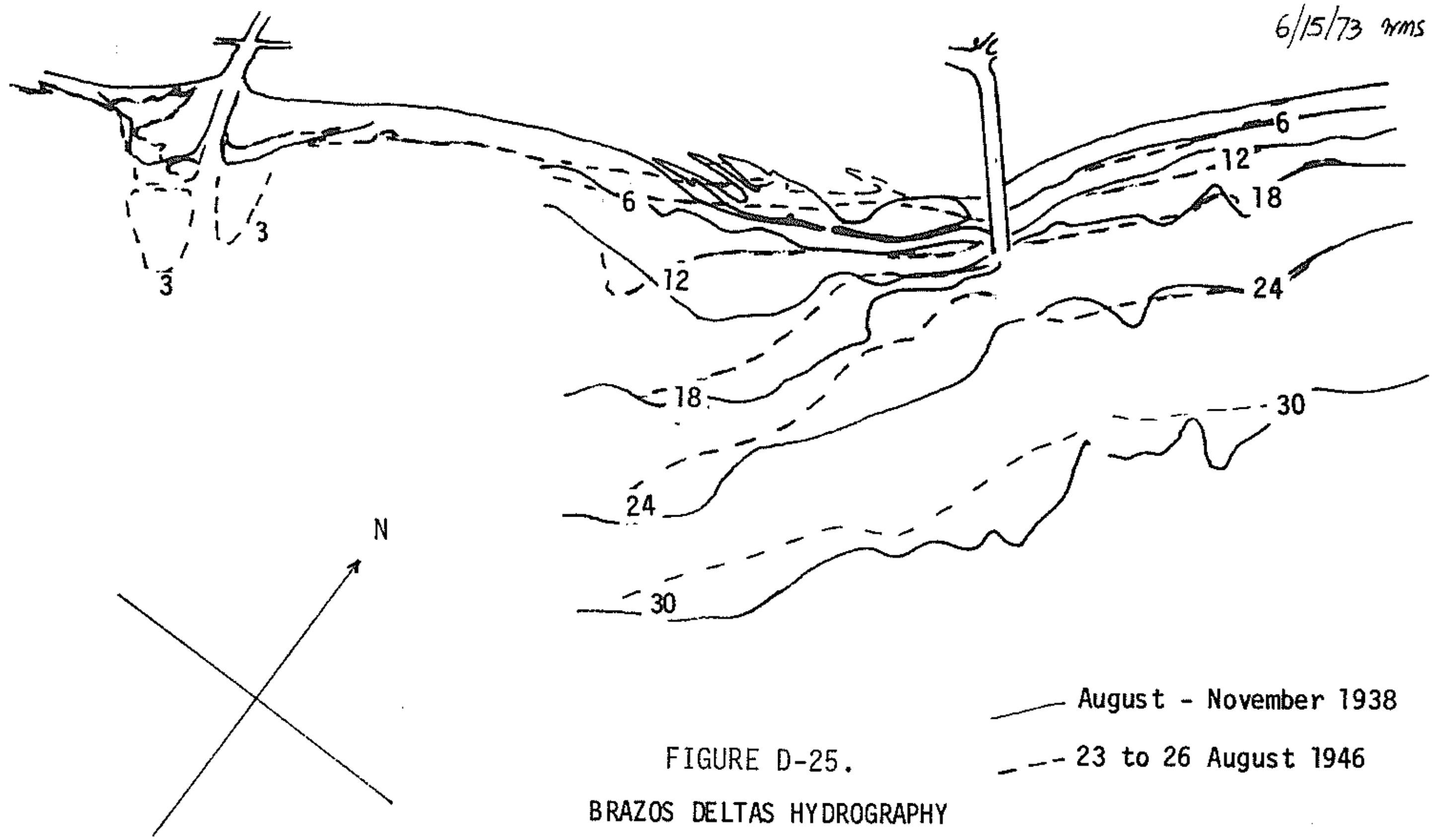
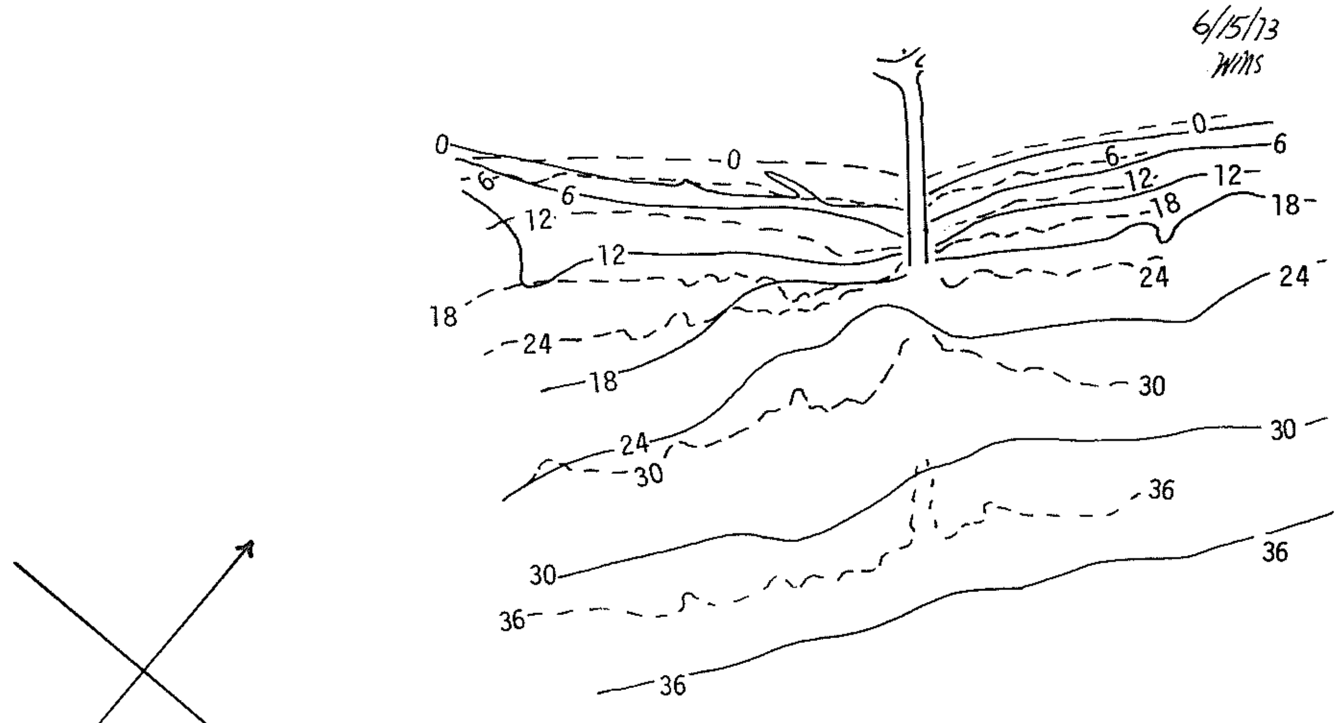


FIGURE D-25.
BRAZOS DELTAS HYDROGRAPHY
Depth in feet, MLW



—— 23 to 26 August 1946

- - - 1966

FIGURE D-26.

BRAZOS DELTAS HYDROGRAPHY
Depth in feet, MLW

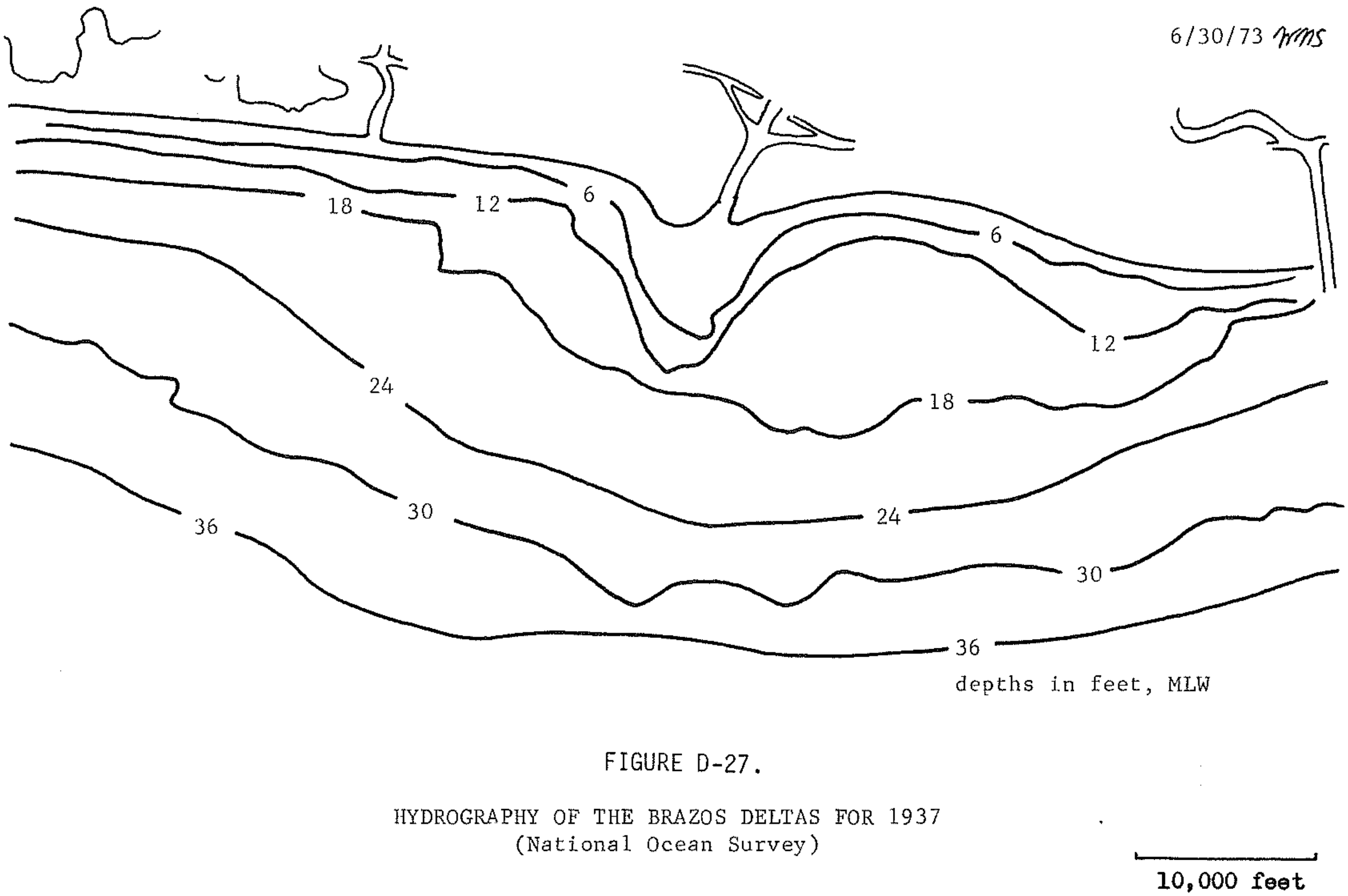


FIGURE D-27.

HYDROGRAPHY OF THE BRAZOS DELTAS FOR 1937
(National Ocean Survey)

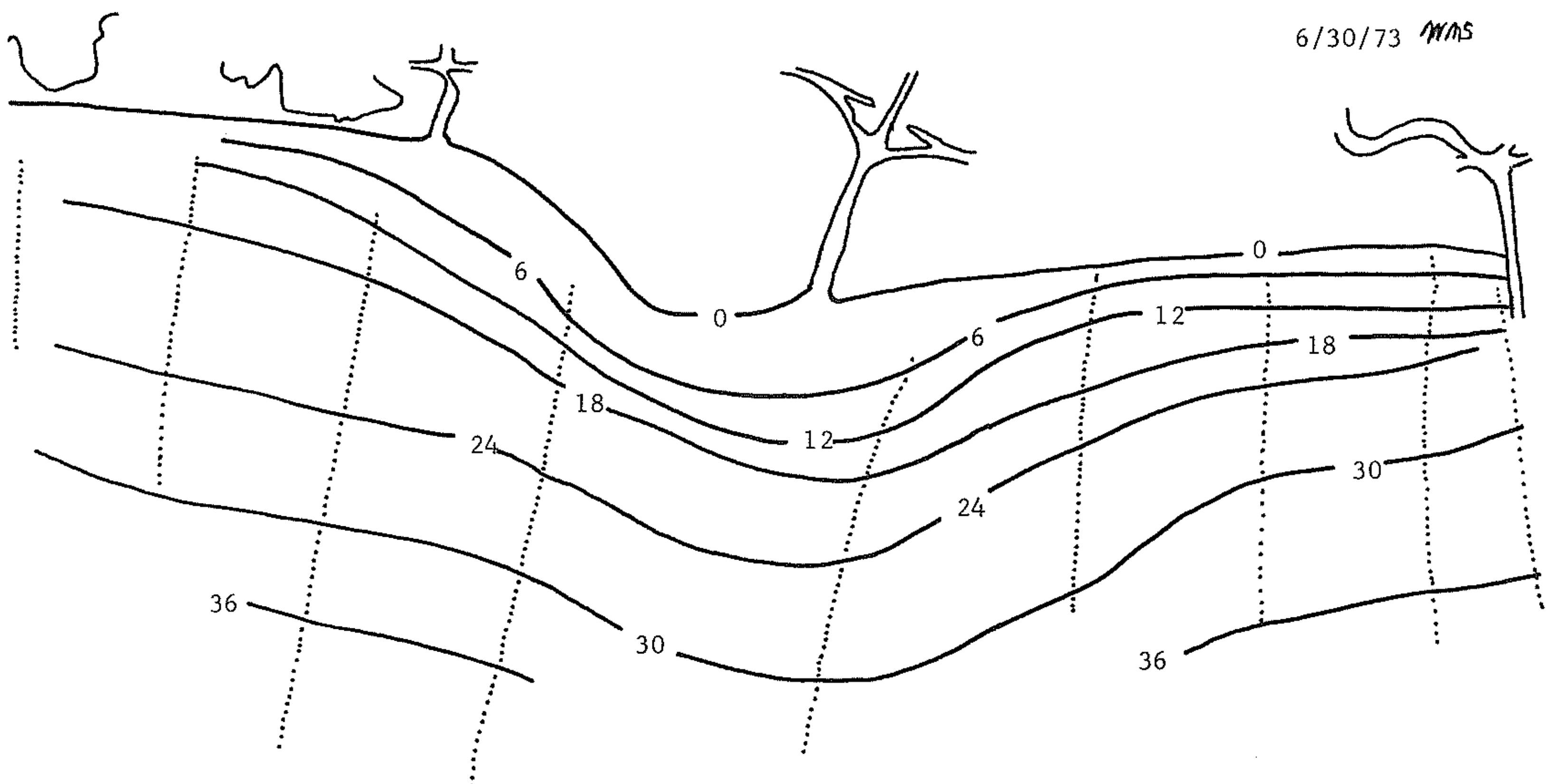


FIGURE D-28.

HYDROGRAPHY OF THE BRAZOS DELTAS FOR 1973
(this study)

10,000 feet

depth in feet MLW

profiles

APPENDIX E. -- WAVE CALIBRATION

Energy approximations using linear theory are presented using statistics determined from measurements made by the Coastal Engineering Research Center Galveston gage (46) and hindcast waves predicted for Caplan, Texas (7) refracted manually to the gage location.

WNS 6 Oct 72

TABLE E-1.
GALVESTON ENERGY APPROXIMATION
CERC GAGE 370 MARCH 1965 to JULY 1967

Period Interval (sec)	Occurance in hours per year (1) Height Interval in feet							Total hrs/yr	Proportion of time in hrs/hrs	Mean of Heights Squared in ft^2	Total Energy (2)
	0-1	1-2	2-3	3-4	4-5	5-6	6-7				
0-1.9	131							131			
2.-2.9	9							9			
3.-3.9	476	338	17					832	.095	2.28	1.32
4.-4.9	464	575	147	15				1200	.136	3.08	3.29
5.-5.9	678	1020	352	54	18	9		2135	.244	3.79	8.90
6.-6.9	470	952	438	53	21	11	11	1960	.224	4.06	13.20
7.-7.9	346	705	284	62	12			1410	.161	3.92	8.30
8.-8.9	240	296	85	42	14			678	.077	4.42	5.06
9.-9.9	47	155	47	16	15			280	.032	4.26	2.46
10-10.9		17	17	17				51			
11-11.9			18	17				35			
12-12.9						18		18			
13-13.9						17		17			

(1) weighted by period from a height vs. period distribution from waves/1000 waves (46)
(2) in millions of foot pounds per foot of crest per day

WNS 7 Nov 72

TABLE E-2.
ENERGY AT THE CERC GALVESTON GAGE LOCATION
FOR REFRACTED HINDCAST WAVES AFTER (7)

Period interval in seconds	Alongshore Energy (1) Wave Direction SW	S	SE	E	Net	Gross	Total Energy (1)
4.-4.9		-.31	.14	.06	-.11	.51	4.12
5.-5.9	-.07	-.77	.62	.46	.24	1.92	14.05
6.-6.9	-.11	-.91	.62	.21	-.19	1.85	14.45
7.-7.9		-.63	.71	.63	.11	1.37	15.50
8.-8.9			.39		.39	.39	4.85

(1) in millions of foot pounds per foot of beach per day

APPENDIX F. -- PREDICTED SAND LOAD OF THE BRAZOS RIVER

Information described in the section on River Sediment Input are used to predict the sand load of the Brazos River for both the suspended and unmeasured (or bed) loads.

ⓒ 8/73 wms

SAND LOAD OF THE
BRAZOS RIVER AT RICHMOND

in millions of cubic feet

Water Year	Suspended (After Texas Water Development Board)	Unmeasured*	Cumulative Suspended and Unmeasured
1925	27	2	29
1926	97	17	143
1927	74	9	226
1928	61	5	292
1929	69	15	376
1930	83	15	474
1931	60	8	542
1932	137	14	693
1933	33	5	731
1934	50	5	786
1935	137	23	946
1936	87	9	1042
1937	55	9	1106
1938	120	11	1237
1939	32	3	1272
1940	57	5	1328
1941	209	36	1573
1942	154	15	1742
1943	25	5	1772
1944	100	15	1887
1945	123	17	2027
1946	76	10	2113
1947	45	8	2166
1948	9	3	2178
1949	31	4	2213
1950	20	6	2239

SAND LOAD OF THE
BRAZOS RIVER AT RICHMOND
(continued)

in millions of cubic feet

Water Year	Suspended (After Texas Water Development Board)	Unmeasured*	Cumulative Suspended and Unmeasured
1951	2	1	2242
1952	9	2	2253
1953	20	4	2277
1954	8	2	2287
1955	6	2	2295
1956	6	2	2303
1957	104	30	2437
1958	55	10	2502
1959	11	4	2517
1960	30	7	2554
1961	83	17	2654
1962	9	4	2667
1963	5	2	2674
1964	4	1	2679
1965	40	13	2732
1966	40 *	10	2782
1967	3 *	2	2787
1968	60 *	13	2860
1969	20 *	6	2886
1970	10 *	5	2901
1971	2 *	2	2905
1972	8 *	4	2917

* Predicted

APPENDIX G.

Engineering Conversion Factors;
List of Symbols

TABLE G-1. ENGINEERING CONVERSION FACTORS

Multiply	by	To Obtain
feet	.3048	meters
miles	$.1609 \times 10^{1}$	kilometers
years	$.316 \times 10^{8}$	seconds
months	$.212 \times 10^{7}$	seconds
days	$.865 \times 10^{5}$	seconds
tons	$.907 \times 10^{3}$	kilograms
pounds	.454	kilograms
cubic feet	$.283 \times 10^{-3}$	cubic meters
cubic yards	.765	cubic meters
feet per year	$.965 \times 10^{-8}$	meters per second
cubic feet per second	$.283 \times 10^{-3}$	cubic meters per second
pounds per cubic feet	$.160 \times 10^{2}$	kilograms per cubic meter
tons per year	$.286 \times 10^{-4}$	kilograms per second
miles per hour	.446	meters per second
cubic yards per year	$.242 \times 10^{-7}$	cubic meters per second
cubic feet per foot of beach	$.929 \times 10^{-1}$	cubic meters per meter of beach
cubic feet per year per foot of beach	$.294 \times 10^{-7}$	cubic meters per second per meter of beach
pounds per foot of beach per day	$.525 \times 10^{-5}$	meter kilogram per meter of beach per second
foot pounds per foot of crest per day	$.525 \times 10^{-5}$	meter kilograms per meter of crest per second

TABLE G-2. LIST OF SYMBOLS

Symbols	Description
D_{50}	median fall diameter of a sediment sample; the diameter with 50% of the sample by weight finer than the given diameter
C_u	coefficient of uniformity = D_{60}/D_{10} where:
	D_{60} = fall diameter with 60% by weight finer than
	D_{10} = fall diameter with 10% by weight finer than
ΔI	change in mean sea level intercept
k	factor relating ΔI to ΔV; $\Delta I = k\ \Delta V$
Q	river water discharge
Q_n	net littoral transport
Q_g	gross littoral transport
Q_u	river bed or unmeasured load
T_m	maximum hurricane tide, where superscripts of F = Freeport, G = Galveston
ΔV	change in beach volume

VITA

William Newton Seelig was born in Washington, D. C. on December 1, 1948 to Mr. and Mrs. Walter R. Seelig, now residing at 8909 Victory Lane, Rockville, Maryland, 20854. He received a high school diploma in 1967 and went on to enter Virginia Polytechnic Institute and State University, Blacksburg, Virginia. There Mr. Seelig received a B. S. in Civil Engineering, 1972, in addition to a Co-operative Education diploma for his experience with the U. S. Army Corps of Engineers, Coastal Engineering Research Center, now at Fort Belvoir, Virginia. Upon graduation Mr. Seelig was employed in a temporary position at Coastal Engineering Research Center studying coastal processes.

This thesis was typed by W. N. Seelig.