GEOLOGICAL CIRCULAR **75-4**

SHORELINE CHANGES IN THE VICINITY OF THE BRAZOS RIVER DELTA (SAN LUIS PASS TO BROWN CEDAR CUT)

AN ANALYSIS OF HISTORICAL CHANGES OF THE TEXAS GULF SHORELINE

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ABSTRACT

Historical monitoring in the vicinity of the Brazos River delta (San Luis Pass to Brown Cedar Cut) records the nature and magnitude of changes in position of the shoreline and vegetation line and provides insight into the factors affecting those changes.

Documentation of changes is accomplished by the compilation of shoreline and vegetation line position from topographic maps, aerial photographs, and coastal charts of various vintages. Comparison of shoreline position based on topographic charts (dated 1852-56) and aerial photographs (taken in 1930-37, 1956-57, 1965, and 1974) indicates short-term changes of accretion and erosion along the Gulf shoreline between San Luis Pass and Brown Cedar Cut. *Erosion* produces a net loss in land, whereas *accretion* produces a net gain in land. Comparison of the vegetation line based on the aforementioned aerial photographs indicates definite short-term cycles of erosion related to storms (primarily hurricanes) and recovery during intervening years of low storm incidence.

Long-term trend or direction of shoreline changes averaged over the 122-year time period of this study indicates a decrease in net erosion from 1,325 feet at San Luis Pass to 250 feet at a point approximately 3.5 miles east of the Freeport jetties. Net accretion recorded for the shoreline segment from 3.5 miles east of the jetties to just east of the San Bernard River varied from 325 feet on the old Brazos delta to 6,000 feet on the new Brazos delta. Net accretion was recorded in the vicinity of the old Brazos delta because the shoreline accreted after construction of the jetties in 1896. Subsequent shoreline erosion has not reached the pre-jetty (1852-53) shoreline position. A diversion channel constructed in 1929 rerouting the Brazos River 6.5 miles west of the Freeport jetties led to the destruction of the old Brazos delta and construction of the new Brazos delta. After 1929, the old delta entered into an erosional phase, and the new delta began prograding at the mouth of the diversion channel. Erosion predominated along the remaining segment of shoreline from the San Bernard River to Brown Cedar Cut. Maximum net erosion for this segment was 1,850 feet; minimum net erosion was 500 feet.

Both erosional and accretionary rates of shoreline change have been high for this segment of the Texas Coast. Average net erosion east of the old Brazos delta was 769 feet or 6.3 feet per year, whereas average net accretion along the deltaic shoreline was 2,317 feet or 19 feet per year. Average net erosion westward from the new Brazos delta to Brown Cedar Cut was 1,541 or 12.7 feet per year.

Because of limitations imposed by the technique used, rates of change are subordinate to trends or direction of change. Furthermore, values determined for long-term net changes should be used in context. The values for rates of net change are adequate for describing long-term trends; however, rates of short-term changes may be of greater magnitude than rates of long-term changes, particularly in areas where both accretion and erosion have occurred.

Major and minor factors affecting shoreline changes include: (1) climate, (2) storm frequency and intensity, (3) local and eustatic sea-level conditions, (4) sediment budget, and (5) human activities. The major factors affecting shoreline changes along the Texas Coast, including the shoreline between San Luis Pass and Brown Cedar Cut, are a deficit in sediment supply, relative sea-level rise, and compactional subsidence. Changes in position of the vegetation line are primarily related to storms.

Studies indicate that changes in shoreline and vegetation line between San Luis Pass and Brown

Cedar Cut are largely the result of natural processes. The only exceptions are accretion and erosion associated with the jetties at the old Brazos River and construction and destruction of the old and new Brazos deltas subsequent to diversion of the Brazos River in 1929. A basic comprehension of these physical processes and their effects is requisite to avoid or minimize physical and economic losses associated with development and use of the coast.

INTRODUCTION

The Texas Coastal Zone is experiencing geological, hydrological, biological, and land use changes as a result of natural processes and man's activities. What was once a relatively undeveloped expanse of beach along deltaic headlands, peninsulas, and barrier islands is presently undergoing considerable development. Competition for space exists among such activities as recreation, construction and occupation of seasonal and permanent residential housing, industrial and commercial development, and mineral and resource production.

Studies indicate that shoreline and vegetation line changes between San Luis Pass and Brown Cedar Cut and along other segments of the Texas Gulf Coast are largely the result of natural processes. A basic comprehension of these physical processes and their effects is requisite to avoid or minimize physical and economic losses associated with development and use of the coast.

The usefulness of historical monitoring is based on the documentation of past changes in position of shoreline and vegetation line and the prediction of future changes. Reliable prediction of future changes can only be made from determination of long-term historical trends. Therefore, the utility of the method dictates the type of data used. Topographic maps dating from 1852 provide a necessary extension to the time base, an advantage not available through the use of aerial photographs which were not generally available before 1930.

Purpose and Scope

In 1971, the Bureau of Economic Geology initiated a program in historical monitoring for the purpose of determining quantitative long-term shoreline changes. The recent acceleration in Gulf-front development provided additional incentive for adequate evaluation of shoreline characteristics and documentation, where change is occurring by erosion and by accretion, or where the shoreline is stable or in equilibrium.

The first effort in this program was an investigation of Matagorda Peninsula and the adjacent Matagorda Bay area, a cooperative study by the Bureau of Economic Geology and the Texas General Land Office. In this study, basic techniques of historical monitoring were developed; results of the Matagorda Bay project are now nearing publication (McGowen and Brewton, in press).

In 1973, the Texas Legislature appropriated funds for the Bureau of Economic Geology to conduct historical monitoring of the entire 367 miles of Texas Gulf shoreline during the 1973-1975 biennium. Work versions of base maps (scale 1:24,000) for this project are on open file at the Bureau of Economic Geology. Results of the project are being published in a series of reports; each report describes shoreline changes for a particular segment of the Texas Gulf Coast. This report covering the Gulf shoreline from San Luis Pass to Brown Cedar Cut (fig. 1) is the third in that series.

General Statement on Shoreline Changes

Shorelines are in a state of erosion, accretion, or are stabilized either naturally or artificially. Erosion produces a net loss in land, accretion produces a net gain in land, and equilibrium conditions produce no net change. Shoreline changes are the response of the beach to a hierarchy of natural cyclic phenomena including (from lower order to higher order) tides, storms, sediment supply, and relative sea-level changes. Time periods for these cycles range from daily to several thousand years. Most beach segments undergo both erosion and accretion for lower order events, no matter what their long-term trends may be. Furthermore, long-term trends can be unidirectional or cyclic; that is, shoreline changes may persist in one direction, either accretion or erosion, or the shoreline may undergo periods of both erosion and accretion. Thus, the tidal plane boundary defined by the intersection of beach and

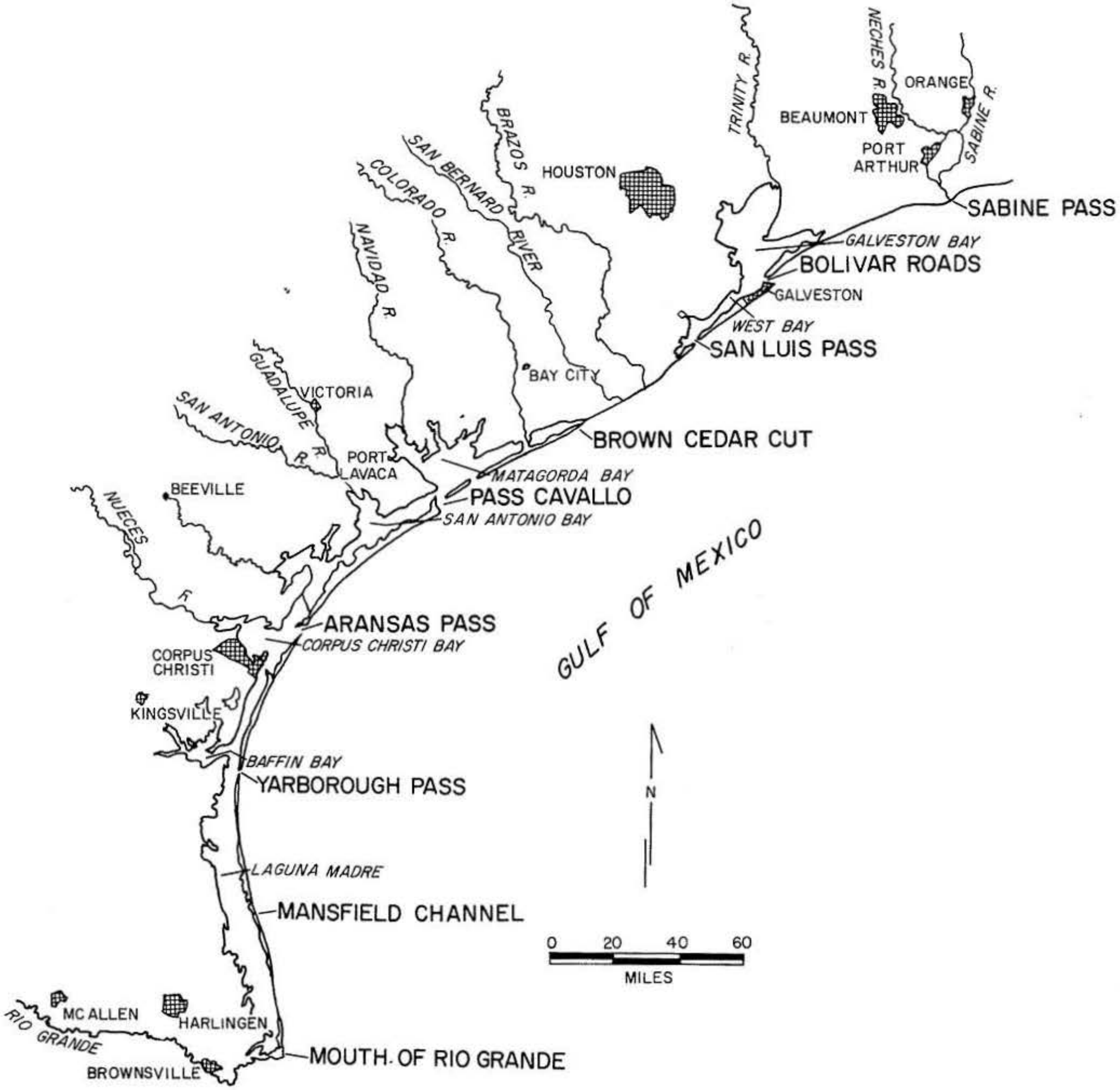

Figure 1. Index map of the Texas Gulf shoreline.

mean high water is not in a fixed position (Johnson, 1971). Shoreline erosion assumes importance along the Texas Coast because of active loss of land, as well as the potential damage or destruction of piers, dwellings, highways, and other structures.

Acknowledgments

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Cooperation of personnel with the U. S. Army Corps of Engineers, Galveston District aided in the acquisition of materials and information. The Texas General Land Office and Texas Highway Department provided access to some of the aerial photographs. Meteorological data was provided by the National Climatic Center and the National Hurricane Center.

HISTORICAL SHORELINE MONITORING

GENERAL METHODS AND PROCEDURES USED BY THE BUREAU OF ECONOMIC GEOLOGY

Definition

Historical Shoreline Monitoring is the documentation of direction and magnitude of shoreline change through specific time periods using accurate vintage charts, maps, and aerial photographs.

Sources of Data

Basic data used to determine changes in shoreline position are near-vertical aerial photographs and mosaics and topographic charts. Accurate topographic charts dating from 1850, available through the Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), were mapped by the U. S. Coast Survey using plane table procedures. Reproductions of originals are used to establish shoreline position (mean high water) prior to the early 1930's. Aerial photography supplemented and later replaced regional topographic surveys in the early 1930's; therefore, subsequent shoreline positions are mapped on individual stereographic photographs and aerial photographic mosaics representing a diversity of scales and vintages. These photographs show shoreline position based on the sediment-water interface at the time the photographs were taken.

Procedure

The key to comparison of various data needed to monitor shoreline variations is agreement in scale and adjustment of the data to the projection of the selected map base; U. S. Geological Survey 7.5-minute quadrangle topographic maps (1:24,000 or 1 inch = 2,000 feet) are used for this purpose. Topographic charts and aerial photographs are either enlarged or reduced to the precise scale of the topographic maps. Shorelines shown on topographic charts and sediment-water interface mapped directly on sequential aerial photographs are transferred from the topographic charts and aerial photographs onto the common base map mechanically with a reducing pantograph or optically with a Saltzman projector. Lines transferred to the common base map are compared directly and measurements are made to quantify any changes in position with time.

Factors Affecting Accuracy of Data

Documentation of long-term changes from available records, referred to in this report as *historical monitoring*, involves repetitive sequential mapping of shoreline position using coastal charts (topographic surveys) and aerial photographs. This is in contrast to short-term monitoring which employs beach profile measurements and/or the mapping of shoreline position on recent aerial photographs only. There are advantages and disadvantages inherent in both techniques.

Long-term historical monitoring reveals trends which provide the basis for projection of future changes, but the incorporation of coastal charts dating from the 1850's introduces some uncertainty as to the precision of the data. In contrast, short-term monitoring can be extremely precise. However, the inability to recognize and differentiate long-term trends from short-term changes is a decided disadvantage. Short-term monitoring also requires a network of stationary, permanent markers which are periodically reoccupied because they serve as a common point from which future beach profiles are made. Such a network of permanent markers and measurements has not been established along the Texas Coast and even if a network was established, it would take considerable time (20 to 30 years) before sufficient data were available for determination of long-term trends.

Because the purpose of shoreline monitoring is to document past changes in shoreline position and to provide basis for the projection of future changes, the method of long-term historical monitoring is preferred.

Original Data

Topographic surveys.—Some inherent error probably exists in the original topographic surveys conducted by the U. S. Coast Survey [U. S. Coast and Geodetic Survey, now called National Ocean Survey]. Shalowitz (1964, p. 81) states ". . . the degree of accuracy of the early surveys depends on many factors, among which are the purpose of the survey, the scale and date of the survey, the standards for survey work then in use, the relative importance of the area surveyed, and the ability and care which the individual surveyor brought to his task." Although it is neither possible nor practical to comment on all of these factors, much less attempt to quantify the error they represent, in general the accuracy of a particular survey is related to its date; recent surveys are more accurate than older surveys. Error can also be introduced by physical changes in material on which the original data appear. Distortions, such as scale changes from expansion and contraction of the base material, caused by reproduction and changes in atmospheric conditions, can be corrected by cartographic techniques. Location of mean high water is also subject to error. Shalowitz (1964, p. 175) states "... location of the high-water line on the early surveys is within a maximum error of 10 meters and may possibly be much more accurate than this."

Aerial photographs.—Error introduced by use of aerial photographs is related to variation in scale and resolution, and to optical aberrations.

Use of aerial photographs of various scales introduces variations in resolution with concomitant variations in mapping precision. The sediment-water interface can be mapped with greater precision on larger scale photographs, whereas the same boundary can be delineated with less precision on smaller scale photographs. Stated another way, the line delineating the sediment-water interface represents less horizontal distance on larger scale photographs than a line of equal width delineating the same boundary on smaller scale photographs. Aerial photographs of a scale less than that of the topographic base map used for compilation create an added problem of imprecision because the mapped line increases in width when a photograph is enlarged optically to match the scale of the base map. In contrast, the mapped line decreases in width when a photograph is reduced optically to match the scale of the base map. Furthermore, shorelines mechanically adjusted by pantograph methods to match the scale of the base map do not change in width. Fortunately, photographs with a scale equal to or larger than the topographic map base can generally be utilized.

Optical aberration causes the margins of photographs to be somewhat distorted and shorelines mapped on photographic margins may be a source of error in determining shoreline position. However, only the central portion of the photographs are used for mapping purposes, and distances between fixed points are adjusted to the 7.5-minute topographic base.

Meteorological conditions prior to and at the time of photography also have a bearing on the accuracy of the documented shoreline changes. For example, deviations from normal astronomical tides caused by barometric pressure, wind velocity and direction, and attendant wave activity may introduce errors, the significance of which depends on the magnitude of the measured change. Most photographic flights are executed during calm weather conditions, thus eliminating most of the effect of abnormal meteorological conditions.

Interpretation of Photographs

Another factor that may contribute to error in determining rates of shoreline change is the ability of the scientist to interpret correctly what he sees on the photographs. The most qualified aerial photograph mappers are those who have made the most observations on the ground. Some older aerial photographs may be of poor quality, especially along the shorelines. On a few photographs, both the beach and swash zone are bright white (albedo effect) and cannot be precisely differentiated; the shoreline is projected through these areas, and therefore, some error may be introduced. In general, these difficulties are resolved through an understanding of coastal processes and a thorough knowledge of factors that may affect the appearance of shorelines on photographs.

Use of mean high-water line on topographic charts and the sediment-water interface on aerial photographs to define the same boundary is inconsistent because normally the sediment-water interface falls somewhere between high and low tide. Horizontal displacement of the shoreline mapped using the sediment-water interface is almost always seaward of the mean high-water line. This displacement is dependent on the tide cycle, slope of the beach, and wind direction when the photograph was taken. The combination of factors on the Gulf shoreline which yield the greatest horizontal displacement of the sediment-water interface from mean high water are low tide conditions, low beach profile, and strong northerly winds. Field measurements indicate that along the Texas Gulf Coast, maximum horizontal displacement of a photographed shoreline from mean high-water level is approximately 125 feet under these same conditions. Because the displacement of the photographed shoreline is almost always seaward of mean high water, shoreline changes determined from comparison of mean high-water line and sediment-water interface will slightly *underestimate rates of erosion* or slightly overestimate rates of accretion.

Cartographic Procedure

Topographic charts.—The topographic charts are replete with a 1-minute-interval grid; transfer of the shoreline position from topographic charts to the base map is accomplished by construction of a 1-minute-interval grid on the 7.5-minute topographic base map and projection of the chart onto the base map. Routine adjustments are made across the map with the aid of the 1-minute-interval latitude and longitude cells. This is necessary because: (1) chart scale is larger than base map scale; (2) distortions (expansion and contraction) in the medium (paper or cloth) of the original survey and reproduced chart, previously discussed, require adjustment; and (3) paucity of culture along the shore provides limited horizontal control.

Aerial photographs.—Accuracy of aerial photograph mosaics is similar to topographic charts in that quality is related to vintage; more recent mosaics are more accurate. Photograph negative quality, optical resolution, and techniques of compiling controlled mosaics have improved with time; thus, more adjustments are necessary when working with older photographs.

Cartographic procedures may introduce minor errors associated with the transfer of shoreline position from aerial photographs and topographic charts to the base map. Cartographic procedures do not increase the accuracy of mapping; however, they tend to correct the photogrammetric errors inherent in the original materials such as distortions and optical aberrations.

Measurements and Calculated Rates

Actual measurements of linear distances on maps can be made to one-hundredth of an inch which corresponds to 20 feet on maps with a scale of 1 inch = 2,000 feet (1:24,000). This is more precise than the significance of the data warrants. However, problems do arise when rates of change are calculated because: (1) time intervals between photographic coverage are not equal; (2) erosion or accretion is assumed constant over the entire time period; and (3) multiple rates ($\frac{n^2-n}{2}$, where n represents the number of mapped shorelines) can be obtained at any given point using various combinations of lines.

The beach area is dynamic and changes of varying magnitude occur continuously. Each photograph represents a sample in the continuum of shoreline changes and it follows that measurements of shoreline changes taken over short time intervals would more closely approximate the continuum of changes because the procedure would approach continuous monitoring. Thus, the problems listed above are interrelated, and solutions require the averaging of rates of change for discrete intervals. Numerical ranges and graphic displays are used to present the calculated rates of shoreline change.

Where possible, dates when individual photographs actually were taken are used to determine the time interval needed to calculate rates, rather than the general date printed on the mosaic. Particular attention is also paid to the month, as well as year of photography; this eliminates an apparent age difference of one year between photographs taken in December and January of the following year.

Justification of Method and Limitations

The methods used in long-term historical monitoring carry a degree of imprecision, and trends and rates of shoreline changes determined from these techniques have limitations. Rates of change are to some degree subordinate in accuracy to trends or direction of change; however, there is no doubt about the significance of the trends of shoreline change documented over more than 100 years. An important factor in evaluating shoreline changes is the total length of time represented by observational data. Observations over a short period of time may produce erroneous conclusions about the long-term change in coastal morphology. For example, it is well established that landward retreat of the shoreline during a storm is accompanied by sediment removal; the sediment is eroded, transported, and temporarily stored offshore. Shortly after storm passage, the normal beach processes again become operative and some of the sediment is returned to the beach. If the shoreline is monitored during this recovery period, data would indicate beach accretion; however, if the beach does not accrete to its prestorm position, then net effect of the storm is beach erosion. Therefore, long-term trends are superior to short-term observations. Establishment of long-term trends based on changes in shoreline position necessitates the use of older and less precise topographic surveys. The applicability of topographic surveys for these purposes is discussed by Shalowitz (1964, p. 79) who stated:

> "There is probably little doubt but that the earliest records of changes in our coastline that are on a large enough scale and in sufficient detail to justify their use for quantitative study are those made by the Coast Survey. These surveys were executed by competent and careful engineers and were practically all based on a geodetic network which minimized the possibility of large errors being introduced. They therefore represent the best evidence available of the condition of our coastline a hundred or more years ago, and the courts have repeatedly recognized their competency in this respect . . . ."

Because of the importance of documenting changes over a long time interval, topographic charts and aerial photographs have been used to study beach erosion in other areas. For example, Morgan and Larimore (1957), Harris and Jones (1964), El-Ashry and Wanless (1968), Bryant and McCann (1973), and Stapor (1973) have successfully used techniques similar to those employed herein. Previous articles describing determinations of beach changes from aerial photographs were reviewed by Stafford (1971) and Stafford and others (1973).

Simply stated, the method of using topographic charts and aerial photographs, though not absolutely precise, represents the best method available for investigating long-term trends in shoreline changes.

Limitations of the method require that emphasis be placed first on *trend* of shoreline changes with rates of change being secondary. Although rates of change from map measurements can be calculated to a precision well beyond the limits of accuracy of the procedure, they are most important as *relative* values; that is, do the data indicate that erosion is occurring at a few feet per year or at significantly higher rates. Because sequential shoreline positions are seldom exactly parallel, in some instances it is best to provide a range of values such as 10 to 15 feet per year. As long as users realize and understand the limitations of the method of historical monitoring, results of sequential shoreline mapping are significant and useful in coastal zone planning and development.

Sources and Nature of Supplemental Information

Sources of aerial photographs, topographic charts, and topographic base maps used for this report are identified in appendix C. Additional information was derived from miscellaneous reports published by the U. S. Army Corps of Engineers and on-the-ground measurements and observations including beach profiles, prepared as a part of this investigation.

Relative wave intensity, estimated from photographs, and the general appearance of the beach dictate whether or not tide and weather bureau records should be checked for abnormal conditions at the time of photography. Most flights are executed during calm weather conditions, thus eliminating most of this effect. On the other hand, large-scale changes are recorded immediately after the passage of a tropical storm or hurricane. For this reason, photography dates have been compared with weather bureau records to determine the nature and extent of tropical cyclones prior to the overflight. If recent storm effects were obvious on the photographs, an attempt was made to relate those effects to a particular event.

Considerable data were compiled from weather bureau records and the U. S. Department of Commerce (1929-1973) for many of the dates of aerial photography. These data, which include wind velocity and direction and times of predicted tidal stage, were used to estimate qualitatively the effect of meteorological conditions on position of the sediment-water interface (fig. 2).

Monitoring of Vegetation Line

Changes in position of the vegetation line are determined from aerial photographs in the same manner as changes in shoreline position with the exception that the line of continuous vegetation is mapped rather than the sediment-water interface. Problems associated with interpretation of vegetation line on aerial photographs are similar to those encountered with shoreline interpretation because they involve scale and resolution of photography as well as coastal processes. In places, the vegetation "line" is actually a zone or transition, the precise position of which is subject to interpretation; in other places the boundary is sharp and distinct, requiring little interpretation. The problems of mapping vegetation line are not just restricted to a geographic area but also involve changes with time. Observations indicate that the vegetation line along a particular section of beach may be indistinct for a given date, but subsequent photography may show a well-defined boundary for the same area, or vice versa. In general, these difficulties are resolved through an understanding of coastal processes and a thorough knowledge of factors that affect appearance of the vegetation line on photographs. For example, the vegetation line tends to be ill defined following storms because sand may be deposited over the vegetation or the vegetation may be completely removed by wave action. The problem of photographic scale and optical resolution in determination of the position of the vegetation line is opposite that associated with determination of the shoreline. Mapping the vegetation line is more difficult on larger scale photographs than on smaller scale photographs, particularly in areas where the vegetation line is indistinct, because larger scale photographs provide greater resolution and much more detail. Fortunately, vegetation line is not affected by processes such as tide cycle at the time the photography was taken.

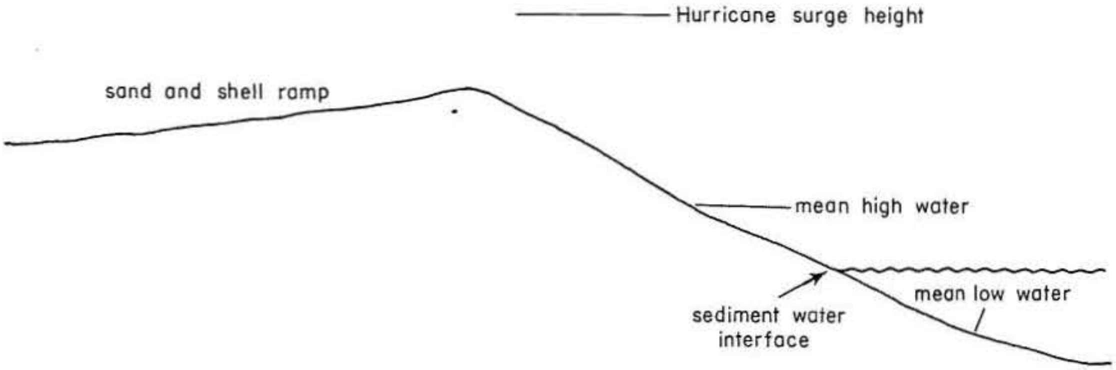

Figure 2. Generalized diagram of beach profile.

PREVIOUS WORK

The new Brazos delta has been the subject of numerous investigations because of its recent development and rapid progradation. Furthermore, the availability and frequency of aerial photography in the area of the old and new Brazos deltas have promoted the detailed study of the shoreline changes in that area. Brief descriptive accounts of changes at the mouths of the old and new Brazos Rivers were provided by Bates (1953), El-Ashry (1966), and Shepard and Wanless (1971).

Beach profiles have been surveyed by the Galveston District, U. S. Army Corps of Engineers (1968-1974) at inlets and midpoints between the inlets along the Texas Coast. These profiles show both erosional and accretionary short-term changes in proximity to the Freeport jetties. Midpoint surveys on Sargent Beach document erosion of about 25 feet between 1970 and 1974.

Herbich and Hales (1970) investigated changes in the vicinity of San Luis Pass based on comparison of a series of hydrographic charts dated from 1859 to 1969. However, the actual changes were only briefly discussed and quantitative data were not presented. Accretion and erosion at the east end of Follets Island were attributed to seasonal changes, i.e., erosion during the winter and accretion during the summer.

A regional inventory of Texas shores was conducted by the U. S. Army Corps of Engineers (1971b). No quantitative data were given; however, the study delineated areas of critical and noncritical erosion. The shoreline from San Luis Pass westward for a distance of approximately 12 miles was classified as an area of critical erosion. From this point to the east jetty, two small areas of noncritical erosion were identified. Sargent Beach was also classified as an area of critical erosion with two adjacent areas of noncritical erosion.

Mason and Sorensen (1971) conducted a study of changes at Brown Cedar Cut including a detailed account of the inlet's history. The effects of shoreline processes, tropical storms, and winter storms on the stability of the inlet were also considered in their study. Stages of development and subsequent changes in the tidal delta associated with Brown Cedar Cut were investigated by Piety (1972), who calculated that long-term shoreline erosion on Matagorda Peninsula averaged 23 feet per year. Shoreline retreat along Sargent Beach was recognized by Aves (1958) who described a clay outcrop exposed by erosion.

In another recent study, Seelig and Sorensen (1973a) presented tabular data regarding mean low-water shoreline changes along the Texas Coast; values calculated for the rates of shoreline change between San Luis Pass and Brown Cedar Cut were included in their report. Their technique involved the use of only two dates (early and recent); the change at any point was averaged over the time period between the two dates. Cycles of accretion and erosion were not recognized and few intermediate values were reported; thus, in certain instances, the data are misleading because of technique. Furthermore, data retrieval is difficult because points are identified by the Texas coordinate system. Rates of erosion ranging from 5 to 19 feet per year were reported for Follets Island. Accretionary rates ranging from 2 to 55 feet per year were documented for the old and new Brazos River delta; however, the remaining segment of shoreline between the new delta and Brown Cedar Cut was erosional at rates ranging from 9 to 15 feet per year.

Seelig and Sorensen (1973b) also conducted a study of shoreline changes between the Brazos River and Brown Cedar Cut. Shoreline changes were presented in a generalized manner; recent shoreline erosion reported for Sargent Beach averaged 30 feet per year. Estimated volume losses resulting from shoreline erosion were also presented.

Historical shoreline monitoring of Matagorda Peninsula and Matagorda Bay was conducted by McGowen and Brewton (in press). The maps accompanying their report depict Gulf shoreline changes between Caney Creek and Brown Cedar Cut from 1856 to 1956 that are equivalent to those changes in shoreline position discussed herein.

Changes in the Gulf shoreline have also been mapped by the Bureau of Economic Geology as part of the Environmental Geologic Atlas of the Texas Coastal Zone. The active processes maps of that publication series delineate four shoreline states: (1) erosional, (2) depositional, (3) equilibrium, and (4) artificially stabilized. Although the Gulf shoreline conditions presented in the Coastal Atlas and in the publications of the historical monitoring project are in general agreement, there are certain areas where the acquisition of more recent data indicates conditions that are different from those presented in the Coastal Atlas. The shoreline conditions published in the present report are both current and quantitative rather than qualitative; therefore where there is disagreement, the conditions published herein supersede the conditions presented on the active processes maps of the Coastal Atlas.

PRESENT BEACH CHARACTERISTICS

Texture and Composition

The beach between San Luis Pass and Brown Cedar Cut varies in texture and composition from mud or thin sand veneer over mud with high concentrations of shell material, rock fragments, and caliche nodules to dominantly sand with minor shell material. Shell material is comprised of whole and broken surf zone, shelf, and bay species, with bay species (*Crassostrea virginica*, *Rangia cuneata*, and *Mercenaria)* being most abundant in certain areas.

The sand fraction is comprised of well-sorted, fine to very fine sand composed primarily of quartz, some feldspar, and heavy minerals (Bullard, 1942; Rogers and Strong, 1959; Hsu, 1960; Nienaber, 1963; Garner, 1967; Bernard and others, 1970; Seelig and Sorensen, 1973b). Shell content on Sargent Beach ranges from 20 to 70 percent, whereas the shell content varies from 2 to 10 percent along the remaining beach from San Luis Pass to Brown Cedar Cut (Seelig and Sorensen, 1973b). Analysis of heavy minerals (Bullard, 1942; Nienaber, 1963) indicates that minerals characteristic of the Brazos River include garnet, tourmaline, rutile, zircon, and staurolite, with minor amounts of hornblende and pyroxene.

Along the beach west of the San Bernard River, outcrops of clay are exposed at low tide and in the swash zone during periods of increased wave activity (Aves, 1958; Nienaber, 1963; Seelig and Sorensen, 1973b).

Beach Profiles

Beach width for this segment of the Texas Coast generally varies from 50 to 75 feet between San Luis Pass and Brown Cedar Cut. Beach width increases to about 100 feet on Follets Island (fig. 3). In general, beach width and beach slope are related. Narrow beaches are relatively steep (3 to 4 degrees), whereas wider beaches have a more gentle seaward slope. Daily changes in beach appearance reflect changing conditions such as wind direction and velocity, wave height, tidal stage, and the like. Accordingly, beach profiles are subject to change depending on beach and surf conditions that existed when measurements were recorded. In general, the most seaward extent of a beach profile is subjected to the greatest changes because in this area breakpoint bars are created, destroyed, and driven ashore. Under natural conditions, the landward portion of a beach profile is affected only by spring and storm tides of more intense events such as tropical cyclones. With increased use of the beach, however, minor alterations in beach profiles occasionally may be attributed to vehicular traffic and beach maintenance such as raking and scraping.

Beach profiles presented in figure 3 were constructed using the method described by Emery (1961). The profiles, considered typical of certain segments of the coast between San Luis Pass and Brown Cedar Cut, represent beach conditions on January 13-15, 1975. High tide mark was identified by sand wetness and position of debris line. Beach profiles have also been surveyed by the Galveston District, U. S. Army Corps of Engineers (1968-1974). Comparison of beach profiles and beach scour patterns by Herbich (1970) suggests that beach condition (breaker bar spacing and size) may be similar over a relatively long period of time except during and immediately after storm conditions. Therefore, unless beach profiles are referenced to a permanent, stationary control point on the ground, comparison of profiles at different times may be very similar, but the absolute position of the beach can be quite different. Thus, a beach profile may appear similar (except after storms) for a long period of time but the entire profile may shift seaward (accretion) or landward (erosion) during the same period.

Dunes are not common along this segment of the Texas Coast. Extant dunes are low, generally less than 5 feet in height, and discontinuous. Many areas have virtually no dunes. Low discontinuous dunes occur intermittently from the new Brazos delta to approximately four miles north of the Freeport jetties and in the vicinity of San Luis Pass.

Beach profile is controlled primarily by wave action. Other factors determining beach characteristics are type and amount of beach sediment available and the geomorphology of the adjacent land (Wiegal, 1964). In general, beach slope is inversely related to grain size of beach material (Bascom, 1951). Thus, beaches composed of fine sand are generally flat. Beach width along the Texas Coast is primarily dependent on quantity of sand available. Beaches undergoing erosion due to a deficit in sediment supply are narrower than beaches where there is an adequate supply or surplus of beach sand. For example, the beach on Follets Island is wider than Sargent Beach where erosion is greater.

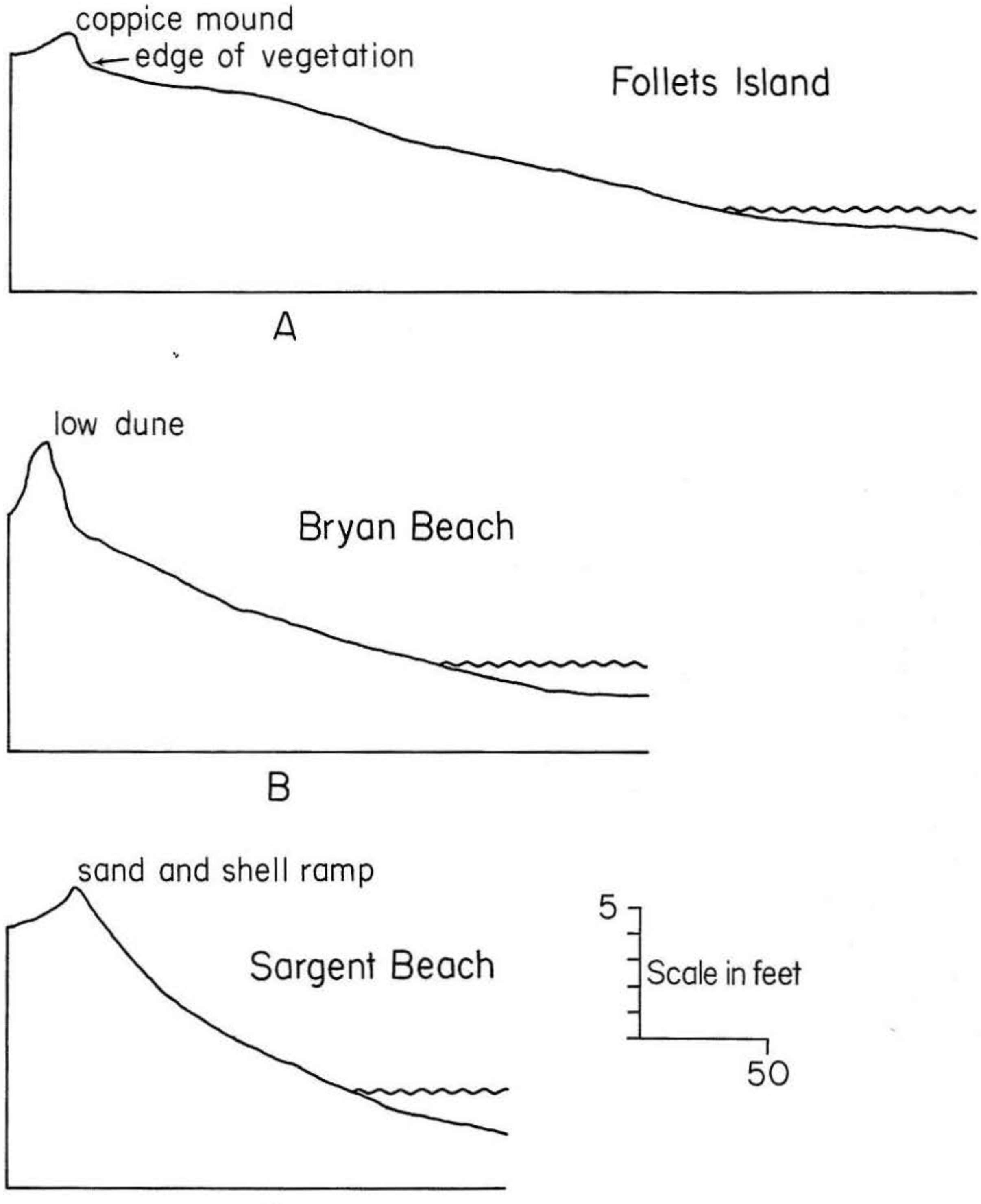

Figure 3. Beach profiles, San Luis Pass to Brown Cedar Cut, recorded January 13-15, 1975. Locations plotted on figure 7.

HUMAN ALTERATIONS OF NATURAL CONDITIONS

Brazos River

Brazos River (Freeport Harbor)

The first modification of the Brazos River was a canal dredged from near the mouth of the Brazos River through Oyster Bay to the mouth of Galveston Bay (U. S. Army Corps Engineers, 1896-97b). Construction of this canal, a federally funded project, was initiated in 1850 and completed in 1851. In 1866, the Brazos Internal Improvement and Navigation Company was chartered by the Texas Legislature to deepen the channel over the river-mouth bar. At this time, water over the bar was 3 to 9 feet deep and the channel position varied. The project was abandoned in 1874 due to a lack of funds.

The U. S. Army Corps of Engineers proposed a project to remove the river-mouth bar and construct two converging jetties of closely driven palmetto piling. Congress appropriated funds for the project in 1881; however, work on the project was not initiated (U. S. Army Corps Engineers, 1896-97a). An amended proposal, presented in 1880, recommended construction of two parallel jetties consisting of brush mattresses weighted by stones and concrete blocks. Jetty construction commenced in 1881 and continued until 1886 when the operation was suspended due to a lack of funds. The east jetty was completed to a length of 2,433 feet, but only 700 feet of foundation was laid for the west jetty before work ceased.

An inspection of the jetties in September 1887 showed that the combined effects of subsidence, wave action, and the teredo caused destruction of a considerable part of the east jetty. At that time, the channel was not restricted by the jetties but crossed the east jetty 600 feet from the outer end. The Corps of Engineers favored abandoning the jetty project and suggested deepening the Galveston Bay-Brazos River Canal as an alternative shipping route. This decision was based in part on the lack of tidal scour within the jettied Brazos River channel (U. S. Army Corps Engineers, 1896-97a).

The Texas Legislature passed a statute April 1887, authorizing creation of a private corporation for the purpose of constructing and owning a deepwater channel between the mouth of the Brazos River and the Gulf. The resulting company, Brazos River Channel and Dock Company, proposed the construction of two parallel jetties 4,000 feet long of brush mattresses weighted by stones and crowned along the outer half with stones or concrete blocks. Work commenced in March 1889 and was completed by April 1896. Upon completion, the jetties were 560 feet apart; the east and west jetties extended into the Gulf 4,700 and 5,018 feet, respectively. Paired spur dikes were built every 400 feet to maintain the channel between the jetties. These improvements provided a channel depth of 14 feet at mean low tide (U. S. Army Corps Engineers, 1896-97a). Although the Corps of Engineers indicates little or no change in the shoreline adjacent to the jetties during this period (U. S. Army Corps Engineers, 1896-97a), topographic maps of the same vintage show approximately 500 feet of accretion adjacent to the west jetty.

Storm damage associated with the 1900 hurricane resulted in lowering of the crests of the east and west jetties by 4 and 2 feet, respectively. Consequently, recommendations were made to extend the jetties and construct a cap of granite blocks (U. S. Army Corps Engineers, 1900b, c). The River and Harbor Act of 1899 appropriated funds for repair and extension of the jetties provided that the Brazos River Channel and Dock Company transfer ownership of the existing jetties and channel to the U. S. Government. This transfer was accomplished in April 1899 (U. S. Army Corps Engineers, 1915). Extension of the jetties was completed in 1908 with spur dikes and bank protection (U. S. Army Corps Engineers, 1922).

Repairs to the jetties were made in 1914. At the same time, a channel 18 feet deep and 150 feet wide was dredged from the Gulf to the rail yard (U. S. Army Corps Engineers, 1915). Channel siltation was a continuous problem with maintenance dredging required three times in one year.

In 1917, plans for harbor improvements were modified to provide for a channel 22 feet deep and 150 feet wide from the jetties to docking facilities. The channel was dredged to attain those dimensions, and spur dikes and bank protection were constructed in 1919 (U. S. Army Corps Engineers, 1919a). Although delayed by flooding, dredging operations continued through 1923 when the project was about 85 percent completed. Channel depths at that time were 20 feet in the Gulf and 22 feet in the area from the jetties through the turning basin (U. S. Army Corps Engineers, 1923). During the next few years, attempts were made to maintain the channel dimensions, but periodic flooding substantially increased the dredging load because increased siltation caused shoaling of the channel (U. S. Army Corps Engineers, 1924, 1927).

Even though the diversion channel was constructed in 1928 and 1929, dredging continued in the harbor area. By 1931, the Gulf channel had been dredged to 25 feet (U. S. Army Corps Engineers, 1931).

A new project, proposed in 1932, called for a channel 32 feet deep and 300 feet wide from the Gulf to the jetties and 30 feet deep and 200 feet wide from the jetties to the Brazosport turning basin (U. S. Army Corps Engineers, 1932). Work on this project continued for several years. The project was maintained during the 1940's and 1950's although recommendations were made to increase channel depths to 38 feet (U. S. Army Corps Engineers, 1950). In 1961, preliminary plans were made to increase channel depths between the jetties and across the outer bar. By 1964, deepening of the channel entrance to 38 feet was completed (U. S. Army Corps Engineers, 1964).

In 1970, the Corps of Engineers proposed relocation of the Brazos River jetties in order to widen the harbor entrance. This project is still pending (U. S. Army Corps Engineers, 1970).

Brazos River Diversion Channel

In 1923, the Federal government considered abandoning the Freeport Harbor because of recurring high maintenance costs due to siltation from frequent floods (Fox, 1931); construction of the diversion channel was proposed to alleviate this problem. The Rivers and Harbors Act of March 1925 appropriated funds for the construction of a diversion dam and the dredging of a diversion channel to convert the old Brazos River channel into a tidally controlled harbor (U. S. Army Corps Engineers, 1929). Excavation to relocate the mouth of the river 6.5 miles to the west commenced in August 1928, and the diversion channel was completed by September 1929 (U. S. Army Corps Engineers, 1930). Alterations of the natural processes attendant with this channel construction caused obvious shoreline changes related to human activities.

River Basin Development

Discharge records for the Brazos River at the Richmond gaging station were studied to determine the effects of dam construction on the sediment load at or near the mouth of the river (figs. 4 and 5). The dams on the Brazos River or its tributaries are located in the interior of the State; Possum Kindgom Lake, completed March 1941, was the first reservoir to be completed on the river (Texas Water Development Board, 1967b). The Glen Rose gaging station, downstream from the Possum Kingdom Dam, recorded a sharp decline in suspended sediment upon completion of the dam (Nienaber, 1963). The Richmond gaging station showed a low in both total discharge and total suspended sediment in 1942; however, data for 1943 and 1944 are equal to pre-dam conditions (figs. 4 and 5). The largest reservoir on the Brazos River, Lake Whitney, was completed in April 1951. The effects of this reservoir upon the river discharge were complicated by drought conditions also affecting discharge from the late 1940's to the middle 1950's. Reservoirs completed on major tributaries of the Brazos River during the 1960's include Proctor Reservoir (September 1963), Waco Reservoir (February 1965), Sommerville Reservoir (January 1967), and Stillhouse Reservoir (1968) (Texas Water Development Board, 1967b). The effect of reservoirs upon transported total bed load by the Brazos River is difficult to evaluate. Seelig and Sorensen (1973b) estimated that the rate of sand transported to the Gulf after the 1940's was reduced by two-thirds based on predicted bed load equations.

Oyster Creek

The dredging in 1850 of the Brazos River-Galveston Bay canal directly affected Oyster Creek channel (U. S. Army Corps Engineers, 1899a). A portion of the channel approximately 3,000 feet inland from the mouth was incorporated into the dredged canal. Upon completion of the canal, Oyster Creek was intentionally closed by a barge sunk across the channel just seaward of the intersection of Oyster Creek and the canal (U. S. Army Corps Engineers, 1899a). An 1852 map indicated that the mouth of Oyster Creek was still open, but shortly thereafter, natural littoral pro-

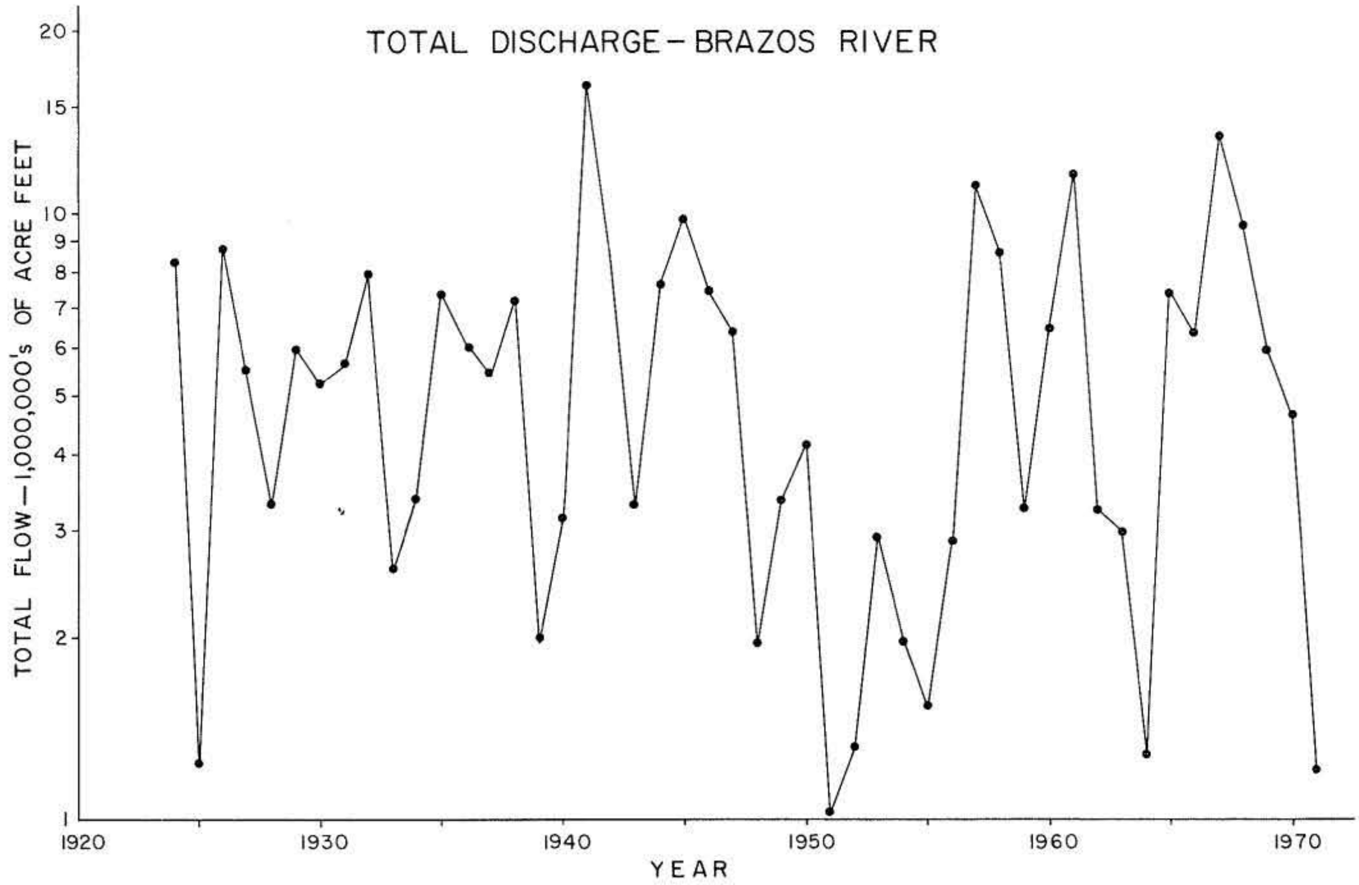

Figure 4. Total discharge of Brazos River recorded at Rosenberg-Richmond Station (1924-1973) (Texas Board of Water Engineers, 1961; Texas Water Commission, 1964; Texas Water Development Board, 1967a, 1970, and 1974).

cesses closed the mouth of the creek (U. S. Army Corps Engineers, 1899a).

Caney Creek

Around 1855, the "Big Canal" was dredged to connect Caney Creek and east Matagorda Bay (U. S. Army Corps Engineers, 1899b). The 1856 topographic survey shows the mouth of the creek still open; however, shoaling and closure at the mouth of Caney Creek occurred sometime prior to 1930.

Apparently there is some confusion about the origin of Mitchell's Cut. Moore (1905) stated that the cut was opened during the storm of 1875, whereas the U. S. Army Corps of Engineers (1899b) stated that Mitchell's Cut was dredged through Matagorda Peninsula connecting east Matagorda Bay and the Gulf southeast of the "Big Canal." Of course it is possible that a natural storm washover channel was later reopened by dredging.

San Bernard River

Several proposals to improve the San Bernard River channel since 1900 have been made. In 1900, the U. S. Army Corps of Engineers proposed a dredged channel to connect the San Bernard River and the Brazos River-Galveston Bay canal (U. S. Army Corps Engineers, 1900a). This proposal was withdrawn by 1919 (U. S. Army Corps Engineers, 1919b). Oil and sulfur production in the vicinity of the San Bernard River revitalized interest in an improved channel. Consequently, a proposal was made (U. S. Army Corps Engineers, 1938) to deepen the existing channel to 9 feet with a channel width of 199 feet from the Intracoastal Waterway to State Highway 35. In addition, an improved deepwater channel with jetty protection at the river mouth was proposed. The latter half of this proposal was never realized. The river channel was dredged from the Intracoastal Waterway to a point 28 miles upstream in 1938 (U. S. Army Corps Engineers, 1938). The proposal for jetty construction was abandoned.

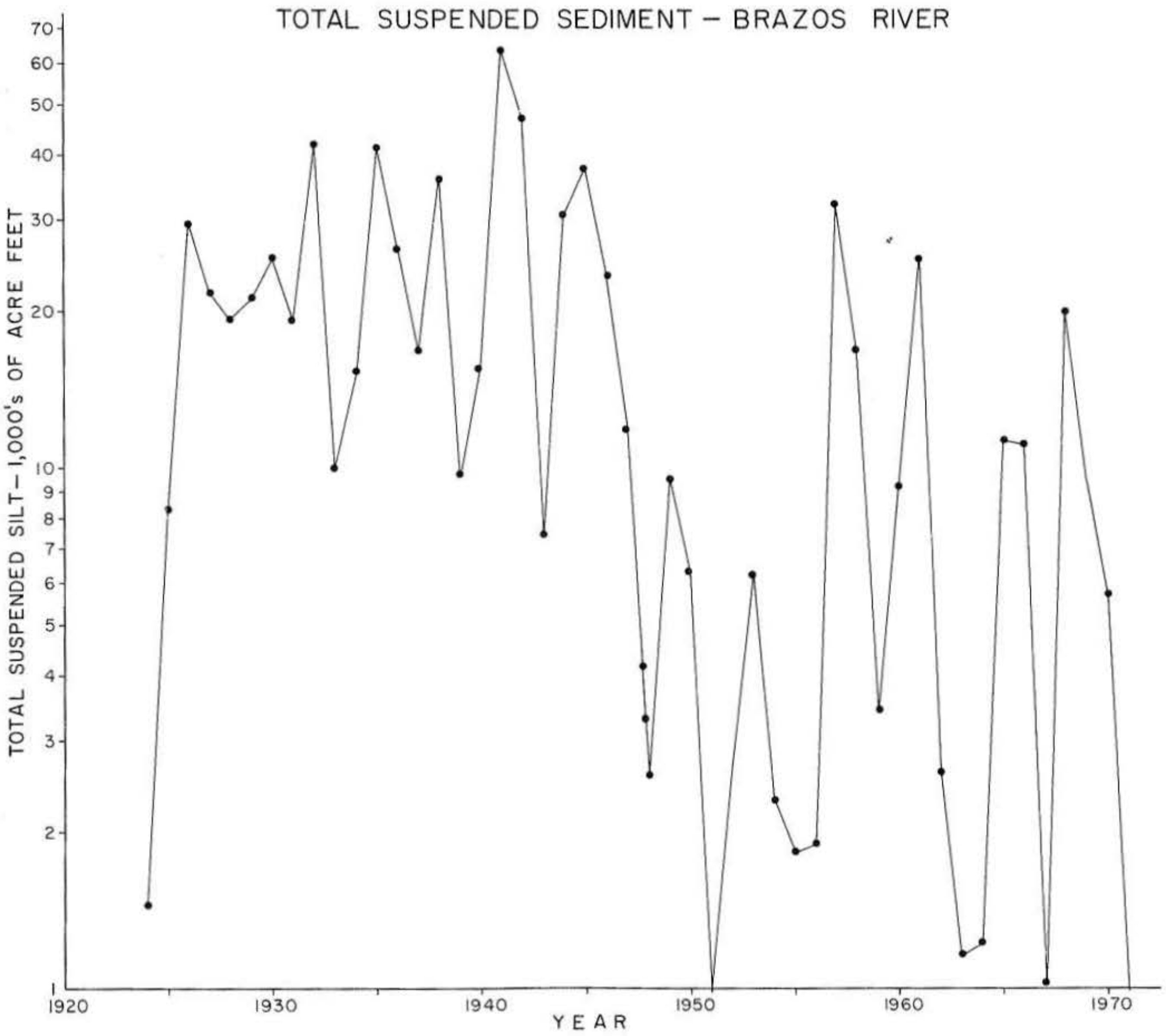

Figure 5. Total suspended sediment of Brazos River recorded at Rosenberg-Richmond Station (1924-1973) (Texas Board of Water Engineers, 1961; Texas Water Commission, 1964; Texas Water Development Board, 1967a, 1970, and 1974).

Late Quaternary Time

The late Quaternary history of the Texas Coast between San Luis Pass and Brown Cedar Cut is dominated by the postglacial evolution and development of the Holocene Brazos-Colorado fluvial-deltaic system (fig. 6). According to LeBlanc and Hodgson (1959), sediment supply from the combined drainage basins of the Colorado and Brazos Rivers was sufficient to fill their estuaries and form a broad deltaic plain. This deltaic plain extended gulfward for a considerable distance as indicated by the truncated meanderbelts of abandoned fluvial channels (Caney and Oyster Creeks). Undoubtedly, ancestral equivalents of Follets Island and Matagorda Peninsula existed seaward of their present position when the Colorado-Brazos delta had attained its maximum gulfward position. This is substantiated by the exposure of lagoonal sediments in the Sargent Beach area.

During the past several hundred years, conditions that promoted seaward accretion have been altered both naturally and more recently to some extent by man. Consequently, sediment supply to the Texas Coast has diminished and erosion is prevalent. The effects of these changes, as well as the factors related to the changes, are discussed in following sections.

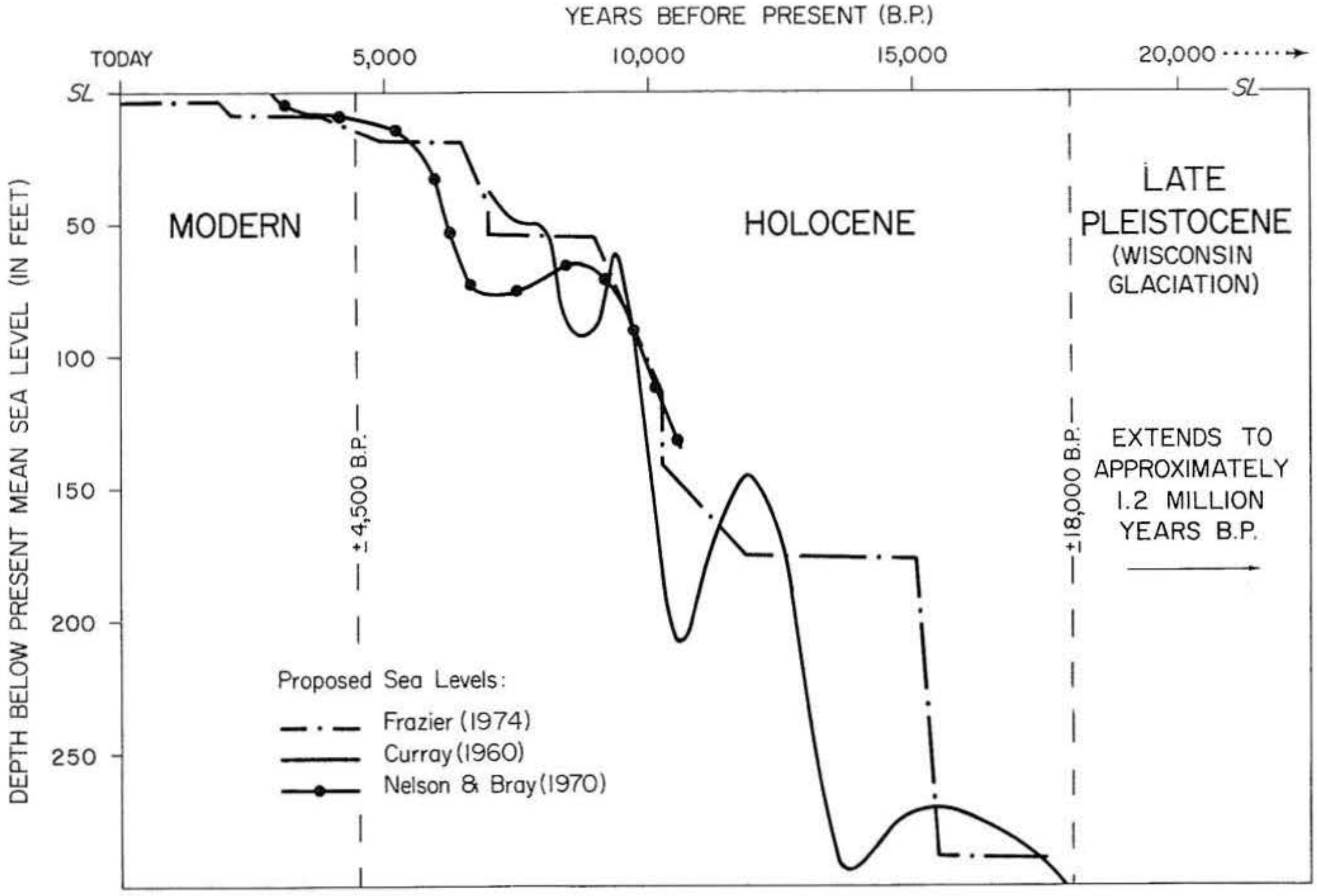

Figure 6. Proposed sea-level changes during the last 20,000 years; sketch defines use of Modern and Holocene. After Fisher and others, 1973.

Historic Time

Shoreline changes and tabulated rates of change between 1852-56 and 1974 at 44 arbitrary points spaced 5,000 feet apart along the base map (fig. 7) are presented in appendix A. In general, the tabular data indicate that this segment of the Texas Coast, with the exception of the shoreline comprising the Brazos River delta, was in a state of erosion for the 122-year period of study. The shoreline along the old and new Brazos deltas underwent short-term periods of accretion and erosion; however, net accretion was recorded for this segment (points 13-25).

The following classification of rates of change is introduced for the convenience of describing changes that fall within a particular range:

Rate (ft/yr)	Designation
0-5	minor
5-15	moderate
15-25	major
>25	extreme

1852-56 to 1930-37.—Between 1852-56 and 1930-37, the shoreline eroded at 36 of the 44 points (appendix A). The remaining 8 points which experienced accretion were located in the vicinity of the old Brazos River delta.

The shoreline between San Luis Pass and Swan Lake (points 1-12) experienced minor erosion except near San Luis Pass (point 1) where erosion was moderate. Erosion varied from a maximum of 1,250 feet or 15.9 feet per year at point 1 to a minimum of 25 feet or less than 1 foot per year at point 3. Average erosion was 290 feet or 3.7 feet per year.

In 1852 and 1867, San Luis Island was separated from Follets Island by Cold Pass which was open to the Gulf. By 1930, the Gulf side of Cold Pass was closed by littoral processes, but the pass remained open to Christmas Bay.

The 1852 shoreline between points 13 and 21 was nearly straight; however, by 1881 the river had formed an arcuate delta 2,000 feet into the Gulf (Shepard and Wanless, 1971) as a result of jetty construction. The delta continued to prograde seaward until 1929 when the diversion channel was constructed. The 1930 shoreline represents the most seaward position of the old Brazos delta. The highest rates of delta accretion were recorded at points located west of the river mouth in the direction of longshore currents. Accretion ranged from 6,100 feet or 77.7 feet per year at point 17 to 75 feet or less than 1 foot per year at point 20 near the western margin of the delta. Average accretion for the old Brazos delta was 2,125 feet or 27.2 feet per year.

The remaining segment of shoreline, points 21-44, removed from the direct influence of active delta building, experienced moderate erosion that varied from 100 feet or 1.3 feet per year at point 21 on the delta margin to 1,075 feet or 13.3 feet per year at point 44 near Brown Cedar Cut. Average erosion for these 24 points was approximately 635 feet or 8 feet per year.

A total of 10 storms (appendix B) may have affected this segment of the Texas Coast between 1852 and 1930 (1854, 1871, 1877, 1880, 1886, 1891, 1895, 1900, 1909, and 1915); five of these were major hurricanes (1854, 1886, 1900, 1909, and 1915) (U. S. Army Corps Engineers, 1962a; Price, 1956). Surge heights for the 1854 and 1886 storms (table 1) were not recorded in the Freeport area.

Shoreline changes resulting from the 1900 storm were included in a report of damage to the Brazos River jetties (U. S. Army Corps Engineers, 1901). The shoreline at the east jetty eroded 500 feet; however, farther east the shoreline accreted 200 to 300 feet. The shoreline eroded 1,500 feet along the beach segment extending 2,000 feet west of the west jetty. For the next 3,800 feet farther west, the shoreline eroded from 200 to 300 feet. The reported erosion adjacent to the west jetty was somewhat misleading because of the configuration of the prestorm shoreline. An offshore bar at the mouth of the river (fig. 8) was intersected on the eastern end by jetty construction and later the western end was joined to the shoreline by accretion. This resulted in the formation of an embayment between the bar and pre-jetty shoreline. Thus, destruction of the bar by the 1900 storm would have indicated excessive erosion.

1930-37 to 1956-57.—The most dominant shoreline change during this period resulted from construction of the diversion channel and rerouting of the Brazos River west of the original mouth.

Table 1. Maximum hurricane surge height recorded at Freeport and Galveston, 1852-1974.

Date	Surge Height (feet)	Location	Reference
1900	7.5-8.0	Freeport	U. S. Army Corps Engineers, 1900b
1909	9.0	Freeport	U. S. Army Corps Engineers, 1962a
1915	12.7	Galveston	U. S. Army Corps Engineers, 1962a
1932	High wind, low surge	Freeport	U. S. Army Corps Engineers, 1962a
1934	10.2	Freeport	U. S. Army Corps Engineers, 1962a
1941	9.5	Freeport	U. S. Army Corps Engineers, 1962a
1942	10.1	Freeport	U. S. Army Corps Engineers, 1962a
1943	5.7	Galveston	U. S. Army Corps Engineers, 1962a
1945	4.1	Freeport	U. S. Army Corps Engineers, 1962a
1949	9.6	Freeport	U. S. Army Corps Engineers, 1962a
1957	5.0	Freeport	Moore and others, 1957
1961	12.0	Freeport	U. S. Army Corps Engineers, 1962b
1967	5.0	Freeport	U. S. Army Corps Engineers, 1968
1971	6.0	Freeport	Simpson and Hope, 1972
1973	4.5	Freeport	Frank and Hebert, 1974

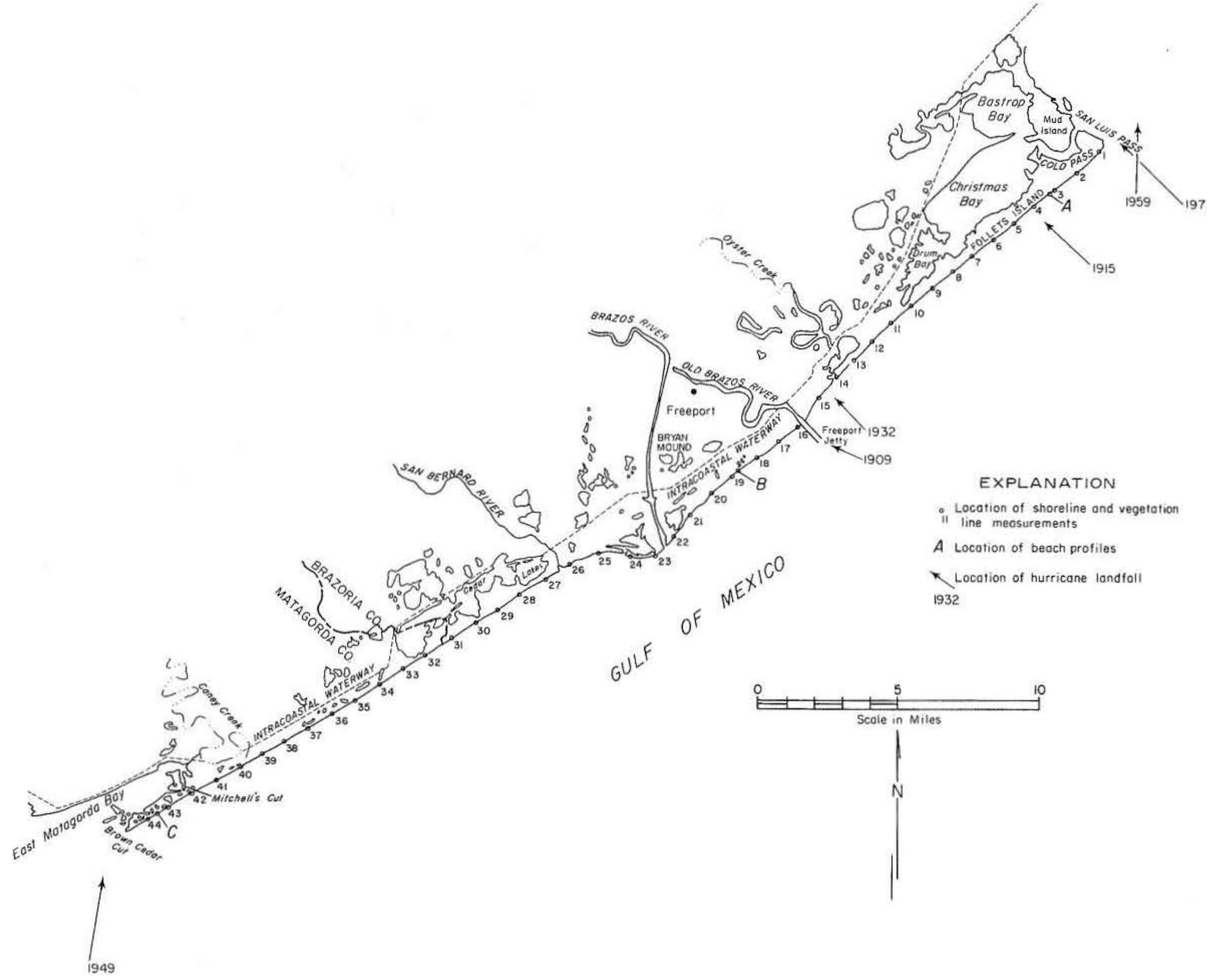

Figure 7. Location map of points of measurement, beach profiles, and hurricane landfall.

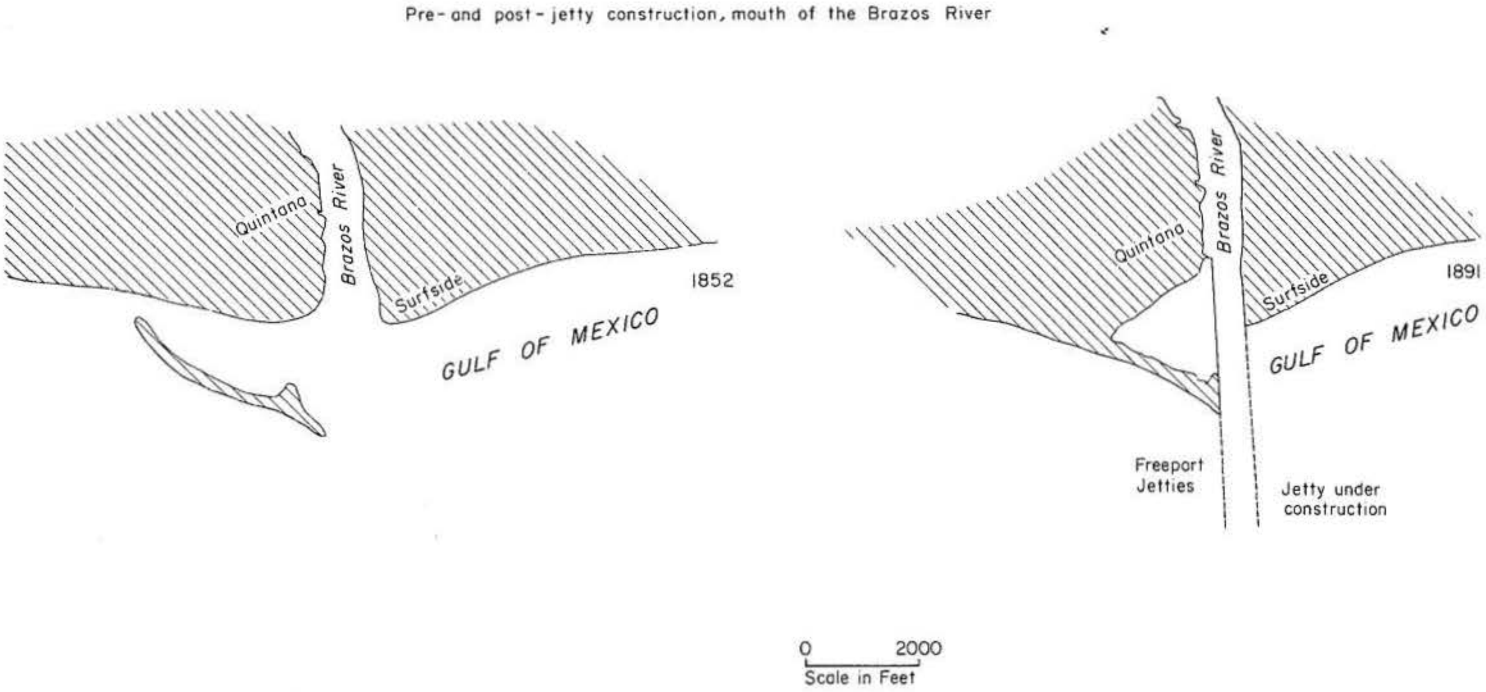

Figure 8. Shoreline configuration at the mouth of the Brazos River before and after jetty construction. From topographic maps 412 and 2047, National Oceanic and Atmospheric Administration.

The old delta entered an erosional cycle, and new delta construction was initiated at the mouth of the new channel.

The shoreline between points 1 and 10 continued to erode; however, the rates of erosion increased (appendix A). Erosion ranged from 125 feet or 4.9 feet per year at point 10 to 1,200 feet or 47.1 feet per year at San Luis Pass. Average shoreline erosion for this segment was 442 feet or 17.3 feet per year.

Minor accretion occurred between points 11 and 15 due to the entrapment of sediment by the east jetty. The shoreline remained relatively unchanged at point 11, but accretion increased to 125 feet near the east jetty at point 14. Rates of accretion for this segment of the shoreline were greater between 1856 and 1930.

Diversion of the Brazos River prevented fluvial transport of sediment through the old channel, thus the shoreline from the west jetty to point 19 underwent erosion that varied from 4,700 feet at point 17 to 1,350 feet at point 18. By 1956, the offshore bars outlining the seaward limits of the old delta had been destroyed.

The new Brazos delta extends from point 19 to point 25. Extreme accretion along this segment of the shoreline ranged from 725 feet or 27.4 feet per year at point 25 to 6,800 feet or 256.6 feet per year at point 23. The seaward limits of the new delta were also defined by offshore bars. Seelig and Sorensen (1973b) state that the new delta attained its most seaward position by 1948. They also reported that the new delta suddenly prograded 8,000 feet between 1946 and 1948. Discharge data for the Brazos River at Richmond showed a marked increase in total water discharged and total suspended sediment recorded between 1941 and 1947. The highest peak, attained in 1945 (figs. 4 and 5), was associated with a major hurricane which made landfall near Port Aransas and drifted northwestward parallel to the coast where it passed west of Matagorda, Texas. Excessive precipitation related to passage of that hurricane was recorded along the coast (Sumner, 1946).

Between 1930 and 1957, the shoreline segment from point 26 to Brown Cedar Cut eroded a minimum of 150 feet or 7.7 feet per year at point 42. Maximum erosion was 725 feet or 27.4 feet per year at point 35; average erosion was about 470 feet. The average rate of shoreline erosion from the San Bernard River to Brown Cedar Cut greatly increased in comparison to the erosional rate between 1857 and 1930-37. The increased rate of erosion is attributed to the entrapment of sand at the Brazos River delta and the subsequent alterations in the wave refraction pattern resulting from the progradation of the new delta. Mason and Sorensen (1971) documented the migration of Brown Cedar Cut and stated that by 1948 the shoreline west of Brown Cedar Cut was offset approximately 300 feet seaward from the east shoreline. By 1953, the offset was approximately 400 feet (Mason and Sorensen, 1971). Between 1937 and 1953, a spit formed toward the southwest attendant with westward pass migration of approximately 1,400 feet.

Six major storms crossed the Texas Coast within 50 miles of Freeport between 1930 and 1957. Surges of these storms (table 1) were recorded in the Freeport area by the U. S. Army Corps of Engineers (1962a).

A September 1942 uncontrolled photo index of the area from point 1 through point 11 showed damage resulting from the 1941 and 1942 storms. The pass between San Luis Island and Follets Island appeared to have been inundated and several washovers occurred between points 6 and 10.

1956-57 to 1965.—During this interval of time, shoreline changes near San Luis Pass reversed from erosion to accretion. Accretion at point 1 was 550 feet. The shoreline east of the Freeport jetties was erosional at all points except points 1, 9, and 12, where accretion was exhibited and at points 6 and 11 where the shoreline remained relatively stationary. Erosion between points 2 and 5 ranged from 425 feet to 100 feet; erosion at other points along this segment was either 50 or 25 feet. With the exception of minor accretion at point 20, erosion west of the jetties ranged from 100 feet at point 19 to 825 feet at point 23.

The location of delta building shifted to the west and was limited to points 24 through 26. Extreme accretion at these three points ranged from 200 feet at point 26 to 1,800 feet at point 24. With the exception of point 34 which remained relatively unchanged and point 35 which exhibited minor accretion (25 feet), the shoreline west of the Brazos delta (points 27-44) eroded from 75 to 350 feet. Average erosion for this segment was 180 feet. Although Brown Cedar Cut was closed in 1965, the inlet had migrated west approximately 525 feet and by 1960 the channel width had narrowed to about 100 feet (Mason and Sorensen, 1971). Hurricane Carla (1961) opened a wide, shallow channel at Brown Cedar Cut, but scouring effect was minimal and complete filling of the channel was accomplished late in 1964 (Lockwood and Carothers, 1967). Shortly thereafter, a channel was dredged through the cut, but this channel remained open only one week (Mason and Sorensen, 1971).

Only two storms affected the shoreline from San Luis Pass to Brown Cedar Cut between 1956 and 1965. Audrey (1957) which made landfall in Louisiana produced a 4-foot tide in the vicinity of Brown Cedar Cut (Mason and Sorensen, 1971). Hurricane Carla, which made landfall approximately 45 miles west of Brown Cedar Cut, produced a maximum open coast storm tide of 12 feet near Freeport (U. S. Army Corps Engineers, 1962b). Shepard and Wanless (1971) reported that approximately one-third of the subaerial part of the new delta was destroyed by Carla. Seelig and Sorensen (1973b) reported that due to Carla the sediments were reoriented, forming a barrier bar on the new delta strongly skewing the overall subaerial shape to the west. After Carla, the old delta was eroded a distance of one-half mile (Shepard and Wanless, 1971), and the shoreline was again nearly straight.

1965 to 1974.—Between 1965 and 1974, the eastern tip of San Luis Island continued to accrete (575 feet), and the accretion extended westward to include point 2 (200 feet). From point 2 to point 22, the shoreline was erosional with rates varying from moderate to extreme. The area of extreme erosion was on the old delta west of the jetties (points 16-20). Erosion along this segment ranged from 75 feet to 600 feet and averaged about 207 feet or 23.1 feet per year. Rates of erosion increased along this segment of the coast between 1965 and 1974.

The new Brazos delta continued to build seaward and westward (points 23-26). By 1974, the new delta had accreted a maximum distance of 6,000 feet at point 24. The remaining shoreline segment (points 27-44) continued to erode, but the rate of erosion again increased between 1965 and 1974. Average shoreline erosion from the San Bernard River to Brown Cedar Cut was 235 feet.

Between 1965 and 1974, two minor hurricanes made landfall between Galveston and Freeport. A 6-foot surge was recorded at Freeport during Hurricane Fern, 1971 (Simpson and Hope, 1972) and a 4.5-foot surge was recorded at Freeport during Hurricane Delia in 1973 (Frank and Hebert, 1974). However, this segment of the coast was also affected by surges and wave action associated with two major storms which crossed the coast to the south of the study area. Beulah, 1967, which made landfall near Brownsville, produced a 5-foot surge at Freeport (U. S. Army Corps Engineers, 1968) and Celia in 1970, which crossed the coast near Corpus Christi, produced a 2-foot surge and high waves at Brown Cedar Cut (Mason and Sorensen, 1971).

Net Historic Change (1852-56 to 1974)

Calculations from previously determined changes provide information on the net effect of shoreline retreat and advance between San Luis Pass and Brown Cedar Cut (appendix A and figure 9). Using the earliest shoreline as a base line, the comparison is equal to the difference between the earliest and latest shorelines.

Net erosion predominated from point 1 to point 12 (fig. 9); however, accretion occurred at point 1 from 1956 through 1974 and at point 2 from 1965 to 1974. The average net erosion between points 1 and 12 was about 770 feet. Net accretion was recorded at points 13-15 east of the Freeport jetties. Erosion occurred at these three points between 1956 and 1974, but average net accretion of 658 feet occurred. Net accretion was also recorded for points 16 through 25 on the old Brazos River delta. Although the shoreline between points 16 and 18 eroded after construction of the diversion channel in 1929, net accretion in the vicinity of the old delta averaged 875 feet. Net shoreline accretion from point 18 to point 25 ranged from 1,175 feet to 6,000 feet. Because of the westward migration of the delta, various portions of the new delta have been subjected to erosion. The average net accretion for the new delta was 2,225 feet. The shoreline at point 26 experienced net erosion of 500 feet; however, the point is located on the westernmost margin of the new delta and has undergone accretion since 1957. The remaining segment of the shoreline (points 27-44) has experienced continuous erosion since 1853-56. Average net erosion for this segment was 1,540 feet.

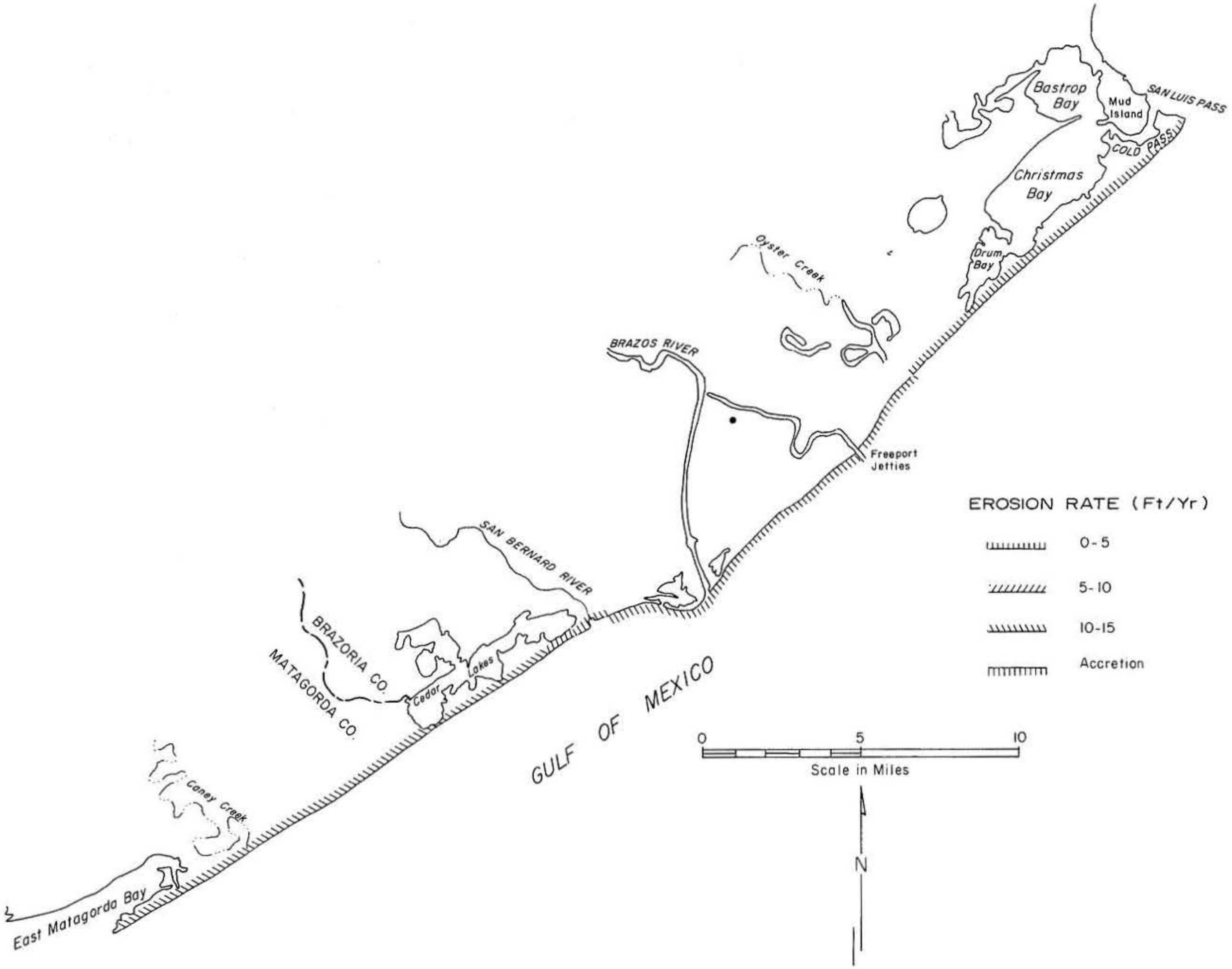

Figure 9. Net shoreline changes between San Luis Pass and Brown Cedar Cut, based on variable time periods from 1852-1856 to 1974.

Rates of change were also calculated for net change between 1852-56 and 1974; the results are included in appendix A. These figures estimate long-term net effect, but the values should be used in context. The values for rates of net change are adequate for describing long-term trends; however, rates of short-term changes may be of greater magnitude than rates of long-term changes, particularly in areas where both accretion and erosion have occurred.

Net rates of erosion and accretion are relatively high along this segment of the Texas Coast. Net rates of erosion on Follets Island decrease from 10.9 feet per year at San Luis Pass to 2.0 feet per year at point 12 where shoreline changes were influenced by the Freeport jetties. The average net rate of erosion was 6.3 feet per year. Net rates of accretion recorded from points 13 to 25 ranged from 2.7 feet per year immediately east of the jetties at point 13 to 49.6 feet per year on the new Brazos delta at point 23. The average net rate of accretion was 10 feet per year. Point 26 experienced long-term erosion of 4.1 feet per year; however, the westward migration of the new delta began affecting this area in 1957, and the shoreline experienced accretion of 23.5 feet per year between 1957 and 1965 and 61.1 feet per year since 1965. The shoreline west of the influence of the delta experienced moderate net erosion ranging from 10.5 feet per year at point 27 to 15.3 feet per year at point 31. Average net rate of erosion was 12.7 feet per year. This same shoreline segment (points 27 to 44) has experienced increased average rates of erosion for the entire 122-year period of study. Average rates of erosion between 1852 and 1937 were 9.3 feet per year. They increased from 18.1 feet to 23.3 feet per year for the succeeding time periods. The average rate of erosion from 1965 to 1974 again increased to 25.8 feet per year.

Although average erosional rates from points 3 to 10 generally have been less than those previously mentioned, they too have increased throughout the study period. Average rates of erosion increased sequentially from 2.2 to 11.0 feet per year and from 11.0 to 17.6 feet per year. The most recent average rates of erosion are 18.75 feet per year.

CHANGES IN POSITION OF VEGETATION LINE

Changes in the vegetation line (appendix A) are considered independently from shoreline changes because, in many instances, the nature of change and rate of shoreline and vegetation line recovery are quite dissimilar. Thus, the shoreline and vegetation line should not be viewed as a couplet with fixed horizontal distance; this is illustrated in figure 10. Although response of the shoreline and vegetation line to long-term changes is similar, a certain amount of independence is exhibited by the vegetation line because it reacts to a different set of processes than does the shoreline.

Accurate information on position of vegetation line is neither available for the middle 1800's nor for the early 1900's. Therefore, accounts of changes in vegetation line are restricted to the time period covered by aerial photographs (1930-1974).

1930-37 to 1956-57.—In general, changes in the position of the vegetation line between 1930 and 1956-57 are similar to shoreline changes for this same period (fig. 10). Between San Luis Pass and point 10, the vegetation line retreated from 50 feet (point 5) to 475 feet (point 2). From point 11 to point 14, the vegetation line advanced from 25 feet to 150 feet (fig. 10). Immediately east of the east jetty (point 15), the vegetation line retreated 50 feet.

A continuous vegetation line west of the Freeport jetties was not mapped on the 1930 photomosaics because of the complexity of the old Brazos delta. Nevertheless, the vegetation line retreated with the destruction of the old delta. Between point 19 and point 25, the position of the vegetation line was influenced by building of the new delta. Advancement of the vegetation line in this area ranged from 325 feet at point 25 to 6,750 feet at point 23.

From west of the delta to point 42, the vegetation line suffered maximum retreat. Erosion ranged from 175 feet at point 41 to 700 feet at point 31. Average retreat of the vegetation line for this segment was approximately 425 feet. An area of overlap between the 1930 and 1937 photomosaics (between points 41 and 42) depicts the combined effects of the 1932 and 1934 hurricanes. Comparison of pre-hurricane and post-hurricane conditions in the area of photograph overlap indicates that the vegetation line was eroded

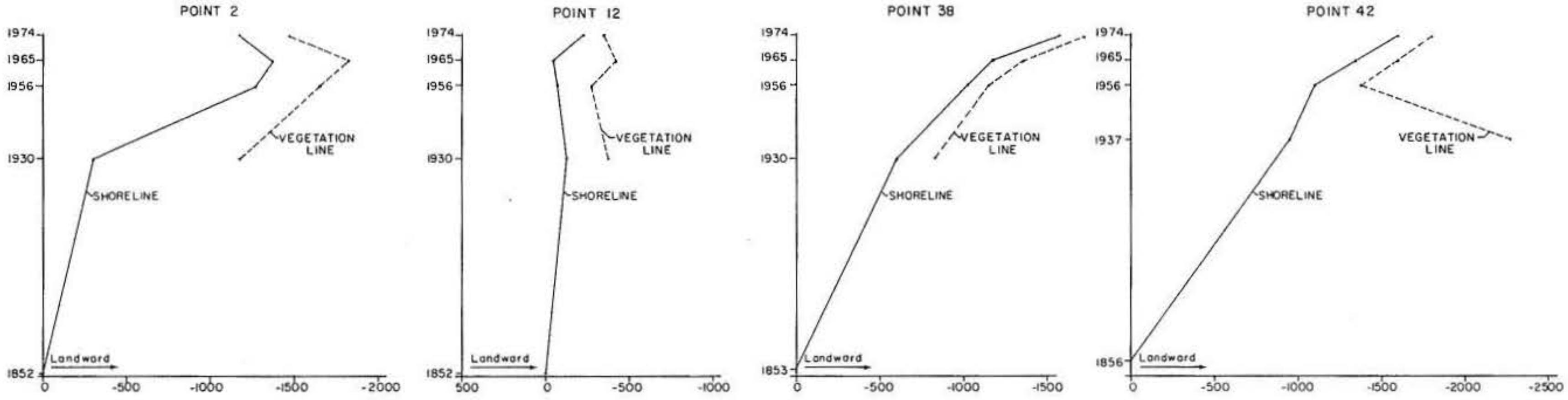

Figure 10. Relative changes in position of shoreline and vegetation line at selected locations, San Luis Pass to Brown Cedar Cut.

approximately 1,000 feet. The rest of the peninsula was virtually denuded of vegetation; only a few isolated vegetated areas were present on the back island. By 1956, the vegetation line had recovered a distance of 900 feet at point 42 (fig. 10). In the area of photograph overlap (between points 41 and 42), the vegetation line had recovered a distance of 600 feet. In no area did the vegetation line return to its 1930 position because the shoreline continued to erode.

The 1939 photo index also showed the damage to the vegetation resulting from the 1932 and 1934 storms. The 1934 storm produced a surge of 10.2 feet in the Freeport area (U. S. Army Corps Engineers, 1962a). Little damage to vegetation occurred on Follets Island; however, westward from point 6, the vegetation was covered by sand and completely removed in areas of washover channels. Much of the vegetation in the area of Cedar Lakes was also covered by sand.

Little change in the position of the vegetation line was observed between 1939 and 1944. The storms of 1941 and 1942 prevented recovery of the vegetation. The vegetation on Matagorda Peninsula between Mitchell's Cut and Brown Cedar Cut was removed by the storms in 1941 and 1942. The major storm in 1942 made landfall near the Matagorda area causing considerable erosion of the vegetation line. This is indicated by aerial photographs taken shortly after the storm. Only minor recovery in the vegetation occurred between 1942 and 1944.

By 1953, the vegetation between San Luis Pass and Cedar Lakes had recovered slightly from storm damage. However, the area between Brown Cedar Cut and Mitchell's Cut was still essentially barren. Considerable recovery in vegetation occurred along this segment of the coast by 1956.

1956-57 to 1965.—During this period, the vegetation line retreated at all points except 1, 25, and 26 where it advanced seaward. The vegetation line at San Luis Pass (point 1) advanced 700 feet. This advance corresponds to shoreline accretion initiated some time between 1956 and 1965. Accretion of the vegetation line from 200 to 400 feet also occurred on the Brazos delta, but retreat of the vegetation line was recorded at the remaining 41 points. Erosion ranged from less than 10 feet to a maximum of 1,100 feet. As in the period between 1930-37 to 1956-57, erosional rates increased west of the Brazos delta.

Retreat of the vegetation line during this period may be partially attributed to the erosional effects of Hurricane Carla (1961). A storm surge of 12 feet, recorded near Freeport, was responsible for considerable damage (U. S. Army Corps Engineers, 1962b). The effect of the storm is reflected in the overall ragged appearance of the 1965 vegetation line and the presence of washover sand which partially buried vegetation in some areas. Post-storm recovery by 1965 was indicated by the construction of coppice mounds in front of the continuous vegetation line and in previously active washover channels.

1965 to 1974.—Perhaps the most significant difference in changes in position of the vegetation line between 1965 and 1974 and earlier periods was the distance the vegetation line retreated. Except in the area between points 32 and 39, the amount of retreat was considerably less between 1965 and 1974. This trend probably reflects continued recovery from Carla and the low incidence of storms. No major storm affected the area between 1965 and 1974, and only two minor storms made landfall between Galveston and Freeport. A 6-foot surge at Freeport was associated with Hurricane Fern in 1971. In 1973, tropical storm Delia crossed the Texas Coast twice and caused a 4.5-foot surge at Freeport and Sargent Beach (Frank and Hebert, 1974). Trends of advance and retreat of the vegetation line between 1965 and 1974 are not as obvious as in the two earlier time periods. Points 1 and 2 (fig. 10) at San Luis Pass show accretion of 400 and 350 feet, respectively, whereas erosion increased from 25 feet at point 3 to 175 feet at point 6. From point 6 to the new Brazos delta (point 21), four points (8, 10, 12, and 15) show an advance of 75 to 100 feet, three points (16, 17, and 19) recorded retreat of 100 to 200 feet, and the remaining points recorded advances and retreats of less than 10 feet (9, 11, 13, 14, 18, and 20). The vegetation line on the delta (points 21 to 25) continued to advance but at a slower rate; accretion ranged from 250 feet at point 25 to 625 feet at point 21.

Accretion was recorded at points 27 and 30, whereas the vegetation line at other points west of the new delta retreated from 50 feet to 400 feet. Extreme erosion occurred between points 36 and 39.

Net changes in vegetation line were calculated as they were for shoreline changes. However, it should be emphasized that shifts in vegetation line are related primarily to storms. Net accretion of the vegetation line occurred at San Luis Pass (point 1). The remaining points between San Luis Pass and the new delta exhibit a net erosion of the vegetation line with the exception of points 11 and 12 where a minor net gain of 25 feet was recorded. Net accretion of the vegetation line occurred on the new delta (points 21 to 25), but major net erosion occurred from the new delta to point 41. The vegetation line at points 42 through 44 experienced net accretion which reflects recovery of the vegetation line following the 1932 and 1934 storms that virtually denuded the peninsula between Brown Cedar Cut and Mitchell's Cut.

In general, the long-term change in position of the vegetation line is similar to that of the shoreline. However, short-term changes in position of the vegetation line reflect climatic conditions and take place independent of shoreline changes. This is demonstrated in figure 10 which illustrates that the horizontal separation between shoreline and vegetation line displays short-term variations.

FACTORS AFFECTING SHORELINE AND VEGETATION LINE CHANGES

Geologic processes and, more specifically, coastal processes are complex dynamic components of large-scale systems. Coastal processes are dependent on the intricate interaction of a large number of variables such as wind velocity, rainfall, storm frequency and intensity, tidal range and characteristics, littoral currents, and the like. Therefore, it is difficult, if not impossible, to isolate and quantify all the specific factors causing shoreline changes. Changes in vegetation line are more easily understood. However, in order to evaluate the various factors and their interrelationship, it is necessary to discuss not only major factors but also minor factors. The basis for future prediction comes from this evaluation.

Climate

Climatic changes during the 18,000 years since the Pleistocene have been documented by various methods. In general, temperature was lower (Flint, 1957) and precipitation was greater (Schumm, 1965) at the end of the Pleistocene than at the present; the warmer and drier conditions, which now prevail, control other factors such as vegetal cover, runoff, sediment concentration, and sediment yield. Schumm (1965) stated that "... an increase in temperature and a decrease in precipitation will cause a decrease in annual runoff and an increase in the sediment concentration. Sediment yield can either increase or decrease depending on the temperature and precipitation before the change."

Changes in stream and bay conditions, as well as migration of certain plant and animal species in South Texas since the late 1800's, were attributed to a combination of overgrazing and more arid climatic conditions (Price and Gunter, 1943). A more complete discussion of the general warming trend is presented in Dunn and Miller (1964). Manley (1955) reported that postglacial air temperature has increased 13°F in the Gulf region. Furthermore, Dury (1965) estimated that many rivers carried between 5 and 10 times greater discharge than present-day rivers. His remarks included reference to the Brazos and Mission Rivers of Texas. Observations based on geologic maps prepared by the Bureau of Economic Geology (Fisher and others, 1972) confirm that many rivers along the Texas Coastal Plain were larger and probably transported greater volumes of sediment during the early Holocene. This, in turn, affected sediment budget by supplying additional sediment to the littoral drift system. Droughts are a potential though indirect factor related to minor shoreline changes via their adverse effect on vegetation. Because dunes and beach sand are stabilized by vegetation, sparse vegetation resulting from droughts offers less resistance to wave attack. Severe droughts have occurred periodically in Texas; the chronological order of severe droughts affecting the Texas Coast between San Luis Pass and Brown Cedar Cut is as follows: 1891-1893, 1896-1899, 1916-1918, 1937-1939, 1954-1956 (Lowry, 1959).

Unfortunately, past changes in the position of vegetation line resulting from storms and droughts generally cannot be independently distinguished by sequential aerial photography. By monitoring hurricanes and droughts in relation to time of available photography, however, one can correlate the short-term effects of these factors, providing the time lapse between photos is not too great.

Storm Frequency and Intensity

The frequency of tropical cyclones is dependent on cyclic fluctuations in temperature; increased frequency of hurricanes occurs during warm cycles (Dunn and Miller, 1964). Because of their high frequency of occurrence and associated devastating forces and catastrophic nature, tropical cyclones have received considerable attention in recent years. Accurate records of hurricanes affecting the Texas Gulf Coast are incomplete prior to 1887, when official data collection was initiated simultaneously with the establishment of the Corpus Christi weather station (Carr, 1967).

According to summaries based on records of the U. S. Weather Bureau (Price, 1956; Tannehill, 1956; Dunn and Miller, 1964; Cry, 1965), some 62 tropical cyclones have either struck or affected the Texas Coast during this century (1900-1973). The average of 0.8-hurricane per year obtained from these data is similar to the 0.67 per year average reported by Hayes (1967) who concluded that most of the Texas coastline experienced the passage of at least one hurricane eye during this century. He further concluded that every point on the Texas Coast was greatly affected by approximately half of the storms classified as hurricanes.

Comparisons of the different types of some of the more recent hurricanes are available; the effects of Hurricanes Carla (1961) and Cindy (1963) on South Texas beaches were compared by Hayes (1967). Hurricanes Carla, Beulah (1967), and Celia (1970) were compared by McGowen and others (1970); individual studies of Hurricanes Carla, Beulah, Celia, and Fern were conducted by the U. S. Army Corps of Engineers (1962b, 1968, 1971c, 1972).

Destructive forces and storm damage.—Carla was one of the most violent storms on record because of her extreme size and high storm surge; the entire coast from San Luis Pass to Brown Cedar Cut was inundated. Maximum surge elevation on the open coast (12 feet) was recorded near Freeport (U. S. Army Corps Engineers, 1962b). Flooding also occurred in low-lying areas as a result of Hurricanes Beulah and Fern (U. S. Army Corps Engineers, 1968, 1972). Prior to Carla (1961), nine severe storms affected the segment of coast within a 50-mile radius of Freeport. The most destructive storms occurred in 1900, 1915, 1934, and 1942 (U. S. Army Corps Engineers, 1962a). During the 1900 storm, the town of Velasco was nearly destroyed. Levee construction in the immediate vicinity of Freeport has helped mitigate damage due to the surge associated with more recent storms.

High velocity winds with attendant waves and currents of destructive force scour and transport large quantities of sand during hurricane approach and landfall. The amount of damage suffered by the beach and adjoining areas depends on a number of factors including angle of storm approach, configuration of the shoreline, shape and slope of Gulf bottom, wind velocity, forward speed of the storm, distance from the eye, stage of astronomical tide, decrease in atmospheric pressure, and longevity of the storm. Hayes (1967) reported erosion of 60 to 150 feet along the fore-island dunes on Padre Island after the passage of Hurricane Carla. Most tropical cyclones have potential for causing some damage, but as suggested by McGowen and others (1970), certain types of hurricanes exhibit high wind velocities, others have high storm surge, and still others are noted for their intense rainfall and aftermath flooding.

Hurricane surge is the most destructive element on the Texas Coast (Bodine, 1969). This is particularly true for the coast from Sabine Pass to Matagorda Peninsula because of low elevations and lack of high foredunes that can dissipate most of the energy transmitted by wave attack. Because of the role hurricane surge plays in flooding and destruction, the frequency of occurrence of high surge on the open coast has been estimated by Bodine (1969). Included in his report are calculations for Freeport, which suggest that surge height of 10 feet can be expected approximately 2.5 times every 100 years. Maximum hurricane surge predicted was 13 feet. These estimates were based on the most complete records of hurricane surge elevations available for the Texas Coast. Surge for specific storms was compiled by Harris (1963). Wilson (1957) estimated deepwater hurricane wave height of between 40 and 45 feet once every 20 years for Gilchrist (about 70 miles northeast of Freeport on Bolivar Peninsula). Maximum deepwater hurricane wave height predicted for the same location was 55 feet with a recurrence frequency of once every 100 years. Consequently, dissipated energy from breaking storm waves can be tremendous under certain conditions.

Changes in beach profile during and after storms.—Beach profiles adjust themselves to changing conditions in an attempt to maintain a profile of equilibrium; they experience their greatest short-term changes during and after storms. Storm surge and wave action commonly plane off preexisting topographic features and produce a featureless, uniformly seaward-sloping beach. Eroded dunes and wave-cut steps (see fig. 3) are common products of the surge. The sand removed by erosion is either (1) transported and stored temporarily in an offshore bar, (2) transported in the direction of littoral currents, and/or (3) washed across the barrier island and peninsula through hurricane channels. Sediment transported offshore and stored in the nearshore zone is eventually returned to the beach by bar migration under the influence of normal wave action. The processes involved in beach recovery are discussed by Hayes (1967) and McGowen and others (1970).

Foredunes are the last line of defense against wave attack, and thus, afford considerable protection against hurricane surge and washover. Dunes also serve as a reserve of sediment from which the beach can recover after a storm. Sand removed from the dunes and beach, transported offshore and returned to the beach as previously described, provides the material from which coppice mounds and eventually the foredunes rebuild. Thus, dune removal eliminates sediment reserve, as well as the natural defense mechanism established for beach protection.

Whether or not the beach returns to its prestorm position depends primarily on the amount of sand available. The beach readjusts to normal prestorm conditions much more rapidly than does the vegetation line. Generally speaking, the sequence of events is as follows: (1) return of sand to beach and profile adjustment (accretion); (2) development of low sand mounds (coppice mounds) seaward of the foredunes or vegetation line; (3) merging of coppice mounds with foredunes; and (4) migration of vegetation line to prestorm position. The first step is initiated within days after passage of the storm and adjustment is usually attained within several weeks or a few months. The remaining steps require months or possibly years and, in some instances, complete recovery is never attained. This sequence is idealized for obviously if there is a post-storm net deficit of sand, the beach will not recover to its prestorm position; the same holds true for the vegetation line. Occasionally the vegetation line will recover completely, whereas the shoreline will not; these conditions essentially result in reduction in beach width.

Apparently three basic types of shift in vegetation line are related to storms, and consequently, the speed and degree of recovery is dependent on the type of damage incurred. The first and simplest change is attributed to deposition of sand and ultimate burial of the vegetation. Although this causes an apparent landward shift in the vegetation line, recovery is quick (usually within a year) as the vegetation grows through the sand and is reestablished.

The second type of change is characterized by stripping and complete removal of the vegetation by erosion. This produces the featureless beach previously described; oftentimes the wave-cut steps and eroded dunes mark the seaward extent of the vegetation line. Considerable time is required for the vegetation line to recover because of the slow processes involved and the removal of any nucleus around which stabilization and development of dunes can occur.

Selective and incomplete removal of vegetation gives rise to the third type of change. Frequently, long, discontinuous, linear dune ridges survive wave attack but are isolated from the post-storm vegetation line by bare sand. Recovery under these circumstances is complicated and also of long duration. The preserved dune ridge does provide a nucleus for dune development; at times, the bare sand is revegetated and the vegetation line is returned to its prestorm position. This type of erosion was not observed between San Luis Pass and Brown Cedar Cut; however, it has been documented on other segments of the Texas Coast.

Local and Eustatic Sea-Level Conditions

Two factors of major importance relevant to land-sea relationships along the coast between San Luis Pass and Brown Cedar Cut are (1) sea-level changes, and (2) compactional subsidence. Shepard (1960b) discussed Holocene rise in sea level along the Texas Coast based on C^{14} data. Relative sea-level changes during historical time are deduced by monitoring mean sea level as determined from tide observations and developing trends based on long-term measurements (Gutenberg, 1933, 1941; Marmer, 1949, 1951, 1954; Hicks and Shofnos, 1965; Hicks, 1968, 1972). However, this method does not distinguish between sea-level rise and land-surface subsidence. More realistically, differentiation of these processes or understanding their individual contributions, if both are operative, is an academic question; the problem is just as real no matter what the cause. A minor vertical rise in sea level relative to adjacent land in low-lying coastal areas causes a considerable horizontal displacement of the shoreline in a landward direction (Bruun, 1962).

Swanson and Thurlow (1973) attributed the relative rise in sea level at Freeport (fig. 11) to compactional subsidence. Their conclusion was based on tide records between 1955 and 1971. Tide data are also available for Galveston from 1904 (Gutenberg, 1933; Marmer, 1951), and the trend has indicated rising sea level since that time. Interpreted rates of sea-level rise depend a great deal on the specific time interval studied; thus, short-term records can be used to demonstrate most any trends. On the other hand, long-term records provide a better indication of the overall trend and are useful for future prediction. Rates of relative sea-level rise determined by previous workers range from 0.013 to 0.020 feet per year or 1.3 to 2.0 feet per century. It is readily apparent that rises in sea level of this order of magnitude may cause substantial changes in shoreline position.

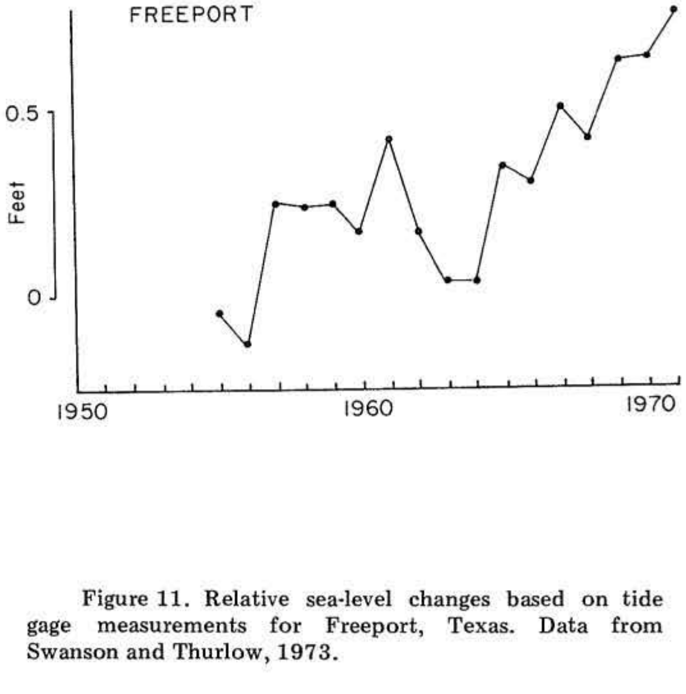

Figure 11. Relative sea-level changes based on tide gage measurements for Freeport, Texas. Data from Swanson and Thurlow, 1973.

There is increasing concern regarding land-surface subsidence in the Houston-Galveston area associated with production of oil (Pratt and Johnson, 1926) and withdrawal of ground water (Winslow and Doyel, 1954; Gabrysch, 1969). Total land-surface subsidence recorded in the Freeport area has been between 1 and 2 feet (Brown and others, 1974). Although the shoreline segment between San Luis Pass and Brown Cedar Cut does not appear to be affected significantly at the present, continued withdrawal and concomitant decline in fluid pressure could eventually affect this coastal segment as the cone of depression spreads outward from the area of principal withdrawal. Such would augment the effects of compactional subsidence and lead to future loss of land at the land-water interface.

Sediment Budget

Sediment budget refers to the amount of sediment in the coastal system and the balance among quantity of material introduced, temporarily stored, or removed from the system. Because beaches are nourished and maintained by sand-size sediment, the following discussion is limited to natural sources of sand for the coast from San Luis Pass to Brown Cedar Cut.

Johnson (1959) discussed the major sources of sand supply and causes for sand loss along coasts. His list, modified for specific conditions along the Texas Coast, includes two sources of sand: major streams and onshore movement of shelf sand by wave action. Sand losses are attributed to (1) transportation offshore into deep water, (2) accretion against natural littoral barriers and man-made structures, (3) excavation of sand for construction purposes, and (4) eolian processes.

The sources of sediment and processes referred to by Johnson have direct application to the area of interest. Sources of sand responsible for the incipient stages of development and growth of Follets Island, Matagorda Peninsula, and the Brazos delta probably include both sand derived from shelf sediment and the Brazos and Colorado Rivers. Van Andel and Poole (1960) and Shepard (1960a) suggested that sediments of the Texas Coast are largely of local origin. Shelf sand derived from the previously deposited sediment was apparently reworked and transported shoreward by wave action during the Holocene sea-level rise (fig. 6). McGowen and others (1972) also concluded that the primary source of sediment for Modern sand-rich barrier islands such as Galveston Island was local Pleistocene and early Holocene sediment on the inner shelf, based on the spatial relationship of the different age deposits. Unfortunately much of the shelf between San Luis Pass and Brown Cedar Cut is underlain by clay, thus precluding the reworking and landward transport of substantial amounts of sand.

Progradation of the new Brazos delta appears to be an enigma in view of the fact that the old Brazos River was unable to construct a substantial delta (U. S. Army Corps Engineers, 1853-54) prior to river mouth improvements and construction of an impermeable barrier (jetties). Closer examination of the problem, however, suggests that building of the new Brazos delta is the result of an oversupply of sediment derived primarily from: (1) normal fluvial sediment transport; (2) channel erosion during adjustment of the diversion channel; and (3) erosion of the old Brazos delta. When dredged, the cross section along most of the diversion channel was about one-third that of the Brazos River channel (Fox, 1931). The volume of sediment contributed during adjustment of the diversion channel is unknown but it probably was subordinate to the sediment supplied by destruction of the old Brazos delta.

Another important factor in building of the new Brazos delta was the change in wave refraction pattern attendant with deposition of sediment at the mouth of the diversion channel. This process in conjunction with littoral currents probably continues to be significant in the westward migration of the new delta.

Initially progradation was rapid because of increased sediment supply and shallow water depths. The new Brazos delta could be decreased substantially in size or almost entirely eliminated as the sediment supply from the river and from reworking of the old Brazos delta is reduced.

Sediment supplied by major streams is transported alongshore by littoral currents. Because of the orientation of the shoreline, south and southwest winds promote drift to the northeast. Under the influence of dominant east and southeast winds, littoral drift is from east to southwest along the upper Texas Coast (fig. 12). Although there are indications that sediment discharge was greater during the early Holocene, Texas streams were in the process of filling their estuaries and were not contributing significant quantities of sand to the littoral currents. As previously mentioned, the Brazos and Colorado Rivers were able to fill their estuaries and debouch directly into the Gulf, therefore, contributing substantially to the sediment budget.

Bernard and others (1959) presented data, which indicated that Galveston Island was in an accretionary state between 6,000 and 1,600 years B.P. (before present). Radiocarbon data from Gould and McFarlan (1959) suggested that shoreline accretion in the Sabine Pass area was initiated approximately 2,800 years ago. This was also the time period when the Mississippi River was debouching sediment into the Gulf of Mexico under shoal water conditions (Morgan and Larimore, 1957; Frazier, 1967). In this situation, wave action and longshore currents would be better able to transport fine sand. For the past 300 to 400 years (Morgan and Larimore, 1957), the Mississippi River has deposited its load in the deep water off the present birdfoot delta lobe, and consequently, the sand, which subsides in the water-saturated prodelta clays, is stored therein and does not become part of the littoral drift system.

Shoreline erosion at rates from 7.5 and 62.0 feet per year has been documented along the Louisiana Coast between 1812 and 1954 (Morgan and Larimore, 1957). Some of the eroded material is added to the littoral system, but this does not represent a significant contribution to the upper Texas Coast owing to the low percentage of sand in the sediment and the fact that most of this material is trapped by the jetties at Sabine Pass (Morgan and Larimore, 1957). The same holds true for the eroded sediment west of Sabine Pass, which is trapped by the jetties at the entrance to Galveston Harbor.

Sand losses listed by Johnson (1959) do not include sediment removed by deposition from tidal deltas and hurricane washovers; these are two important factors on the Texas Coast (fig. 12). Minor amounts of sand may be moved offshore in deeper water during storms and some sand is blown off the beach by eolian processes, but the high rainfall and dense vegetation preclude removal of large quantities of sand by wind. Sand removed by

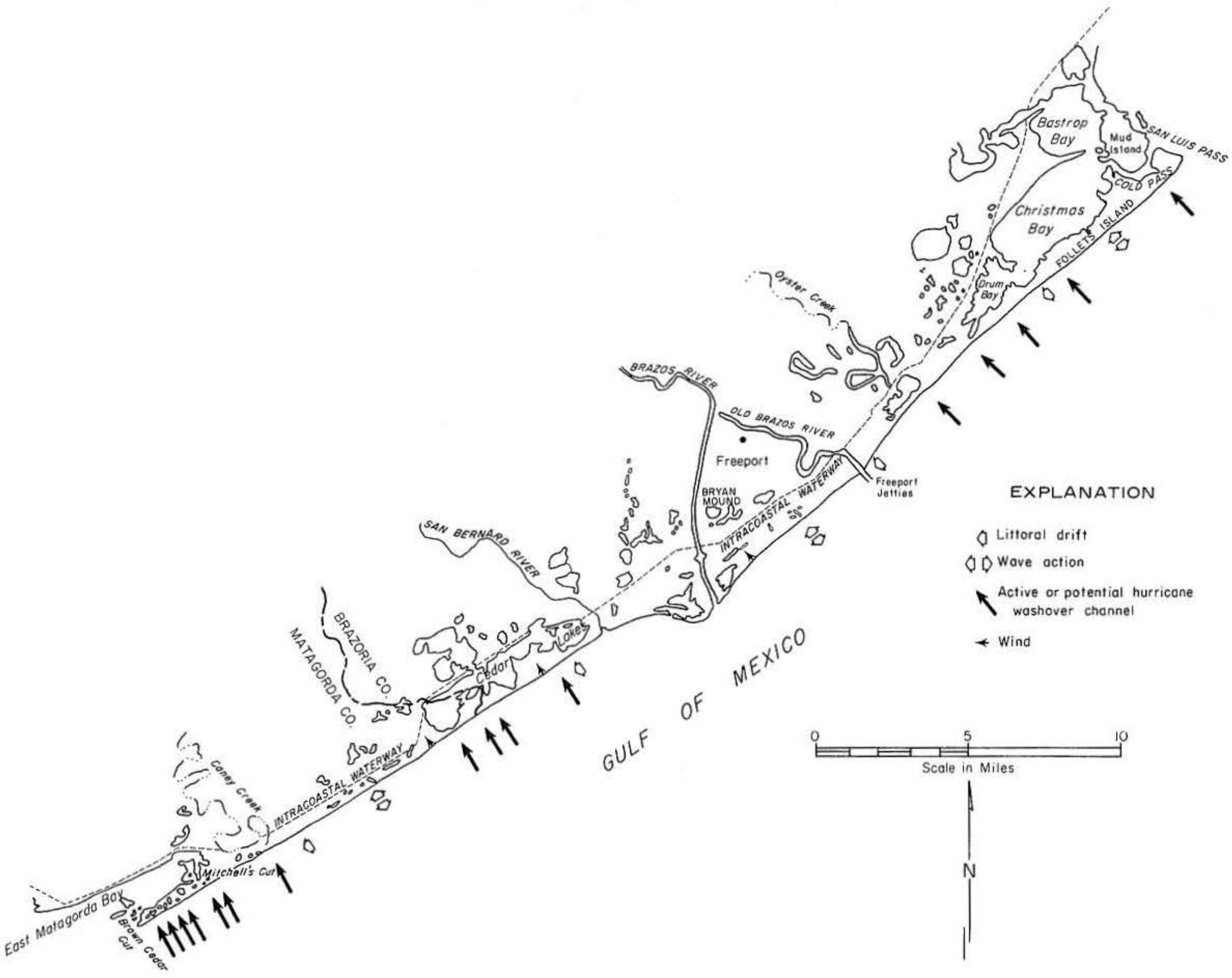

Figure 12. Generalized diagram of sediment transport directions along the upper Texas Coast between San Luis Pass and Brown Cedar Cut.

man-made structures and for construction purposes is discussed in the following section on human activities.

Human Activities

Shoreline changes induced by man are difficult to quantify because human activities promote alterations and imbalances in sediment budget. For example, construction of dams, erection of seawalls, groins, and jetties, training of the Mississippi River, and removal of sediment for building purposes all contribute to changes in quantity and type of beach material delivered to the Texas Coast. Even such minor activities as vehicular traffic and beach scraping can contribute to the overall changes, although they are in no way controlling factors. Erection of impermeable structures and removal of sediment have an immediate, as well as a long-term effect, whereas a lag of several to many years may be required to evaluate fully the effect of other changes such as river control and dam construction.

Construction of the jetties was initiated in 1881 and completed in 1908. The Brazos River was diverted to its present location in 1929. Furthermore, dredging of Freeport Harbor has been conducted periodically to maintain and deepen the channel. All these projects serve to alter natural processes such as inlet siltation, beach erosion, and hurricane surge. Their effect on shoreline changes is subject to debate, but it is an elementary fact that impermeable structures interrupt littoral drift and impoundment of sand occurs at the expense of the beach downdrift of the structure. Thus, it appears reasonable to expect that any sand trapped by the jetties and new Brazos delta is compensated for by removal of sand downdrift, thus increasing local erosion problems. Local interests have constructed groins to reduce erosion in the Sargent Beach area; however, those structures that have not been destroyed are ineffective.

The deltaic plain of the Mississippi River is characterized by both minor and major distributaries, most of which have been blocked off from the main river and thus prevented from transporting major quantities of sediment to the Gulf. Levee construction in 1868 eliminated flow through Bayou Plaquemine; discharge through Bayou Lafourche was controlled in 1904 (Gunter, 1952). But the main controls placed on the river system occurred when locks were constructed to prevent increased discharge into the Atchafalaya River, which would have eventually caused diversion of the Mississippi River because of the shorter Gulf route. The impact of these controls in modifying sediment budget is not documented, but any increase in sediment supply to the littoral system would be helpful under natural conditions. However, the presence of jetties and the proposed extension of some into deeper water would virtually guarantee the exclusion of most sand transported by littoral currents for beach nourishment.

EVALUATION OF FACTORS

Shore erosion is not only a problem along United States coasts (El-Ashry, 1971) but also a worldwide problem. Even though some local conditions may aggravate the situation, major factors affecting shoreline changes are eustatic conditions (compactional subsidence on the Texas Coast) and a deficit in sediment supply. The deficit in sand supply is related to climatic changes, human activities, and the exhaustion of the shelf supply through superjacent deposition of finer material over the shelf sand at a depth below wave scour.

Tropical cyclones are significant geologic agents and during these events, fine sand, which characterizes most of the Texas beaches, is easily set into motion. Silvester (1959) suggested that swell is a more important agent than storm waves in areas where longshore drift is interrupted and sand is not replenished offshore. For the purposes of this discussion, the individual effects of storms and swell is a moot question. Suffice it to say that water in motion is the primary agent delivering sand to or removing sand from the beach and offshore area. There is little doubt, however, that storms are the primary factor related to changes in vegetation line.

PREDICTIONS OF FUTURE CHANGES

The logical conclusion drawn from factual information is that the position of shoreline and vegetation line will continue to retreat landward as part of a long-term, erosional trend. The combined influence of interrupted and decreased sediment supply, relative sea-level rise, and tropical cyclones is insurmountable except in very local areas such as river mouths. There is no evidence that suggests a long-term reversal in any trends of the major causal factors. Weather modification research includes seeding of hurricanes (Braham and Neil, 1958; Simpson and others, 1963), but human control of intense storms is still in incipient stages of development. Furthermore, elimination of tropical storms entirely could cause a significant decrease in rainfall for the southeastern United States (Simpson, 1966).

Borings by Bernard and others (1970), the Bureau of Economic Geology, and W. Leeper (personal communication) indicate that the Holocene Brazos-Colorado fluvial-deltaic sequence is about 25 to 35 feet thick; the areas of greater thickness are associated with abandoned channel and point-bar deposits. These post-Pleistocene deposits are comprised primarily of clay and silt except for the point-bar deposits which are mostly sand. The underlying Pleistocene sediments are dominantly clay. Consequently, large portions of the shelf in this area are underlain by clay. Thickness of transgressive beach deposits ranges from 0 to 6 feet under Follets Island and Matagorda Peninsula (Bernard and others, 1970; W. Leeper, personal communication). Therefore, this thin veneer of sand is neither sufficient to prevent nor to minimize shoreline erosion.

The shoreline could be stabilized at enormous expense by a solid structure such as a seawall; however, any beach seaward of the structure would eventually be removed unless maintained artificially by sand nourishment (a costly and sometimes ineffective practice). The U. S. Army Corps of Engineers (1971a, p. 33) stated that "While seawalls may protect the upland, they do not hold or protect the beach which is the greatest asset of shorefront property." Moreover, construction of a single structure can trigger a chain reaction that requires additional structures and maintenance (Inman and Brush, 1973).

Maintenance of some beaches along the Outer Banks of North Carolina has been the responsibility of the National Park Service (Dolan and others, 1973). Recently the decision was made to cease maintenance because of mounting costs and the futility of the task (New York Times, 1973).

It seems evident that eventually nature will have its way. This should be given utmost consideration when development plans are formulated. While beach-front property may demand the highest prices, it may also carry with it the greatest risks.

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APPENDIX A

+ accretion
- erosion

Shoreline Changes

beach segment San Luis Pass to Brown Cedar Cut

Point	Time	Dist. ft	Rate ft per yr	Time	Dist. ft	Rate ft per yr	Time	Dist. ft	Rate ft per yr	Time	Dist. ft	Rate ft per yr	Net Time	Net Dist.	Net Rate
1	1852 1930	-1250	-15.9	1930 1956	-1200	- 47.1	1956 1965	+ 550	+ 61.1	1965 1974	+ 575	+ 63.9	1852 1974	-1325	- 10.9
2	"	- 300	- 3.8	"	- 975	- 38.2	"	- 100	- 11.1	"	+ 200	+ 22.2	"	-1175	- 9.6
3	"	- 25	- 0.3	"	- 600	- 23.5	"	- 425	- 47.2	"	- 75	- 8.3	"	-1125	- 9.2
4	"	- 50	- 0.6	"	- 300	- 11.8	"	- 300	- 33.3	"	- 225	- 25.0	"	- 875	- 7.2
5	"	- 50	- 0.6	"	- 250	- 9.8	"	- 125	- 13.9	"	- 300	- 33.3	"	- 725	- 5.9
6	"	- 200	- 2.5	"	- 350	- 13.7	"	0	0	"	- 200	- 22.2	"	- 750	- 6.1
7	"	- 275	- 3.5	"	- 275	- 10.8	"	- 25	- 2.8	"	- 125	- 13.9	"	- 700	- 5.7
8	"	- 300	- 3.8	"	- 150	- 5.9	"	- 50	- 5.6	"	- 150	- 16.7	"	- 650	- 5.3
9	"	- 325	- 4.1	"	- 200	- 7.8	"	+ 50	+ 5.6	"	- 150	- 16.7	"	- 625	- 5.1
10	"	- 275	- 2.5	"	- 125	- 4.9	"	- 25	- 2.8	"	- 125	- 13.9	"	- 550	- 4.5
11	"	- 300	- 3.8	"	0	0	"	0	0	"	- 150	- 16.7	"	- 450	- 3.7
12	"	- 125	- 1.6	"	+ 50	+ 2.0	"	+ 25	+ 2.8	"	- 175	- 19.4	"	- 250	- 2.0
13	"	+ 325	+ 4.1	"	+ 125	+ 4.9	"	- 50	- 5.6	"	- 75	- 8.3	"	+ 325	+ 2.7
14	"	+ 775	+ 9.9	"	+ 125	+ 4.9	"	- 50	- 5.6	"	- 125	- 13.9	"	+ 725	+ 5.9
15	"	+1200	+15.3	"	+ 75	+ 2.9	"	- 50	- 5.6	"	- 225	- 25.0	"	+1000	+ 8.1
16	"	+4550	+56.7	"	-3250	-127.4	"	- 350	- 38.9	"	- 225	- 25.0	"	+ 725	+ 5.9
17	"	+6100	+77.7	"	-4700	-184.3	"	- 400	- 44.4	"	- 275	- 30.6	"	+ 725	+ 5.9
18	"	+3300	+42.0	"	-1350	- 52.9	"	- 475	- 52.8	"	- 300	- 33.3	"	+1175	+ 9.6
19	"	+ 675	+ 8.6	1930 1957	+1600	+ 62.7	1957 1965	- 100	- 12.5	"	- 250	- 27.8	"	+1925	+ 15.8
20	1853 1930	+ 75	+< 1.0	"	+2600	+ 98.1	"	+ 50	+ 6.3	"	- 200	- 22.2	1853 1974	+2525	+ 20.9

+ accretion
- erosion

Shoreline Changes

beach segment San Luis Pass to Brown Cedar Cut

Point	Time	Dist. ft	Rate ft per yr	Time	Dist. ft	Rate ft per yr	Time	Dist. ft	Rate ft per yr	Time	Dist. ft	Rate ft per yr	Net Time	Net Dist.	Net Rate
21	1853 1930	- 100	- 1.3	1930 1957	+3650	+137.7	1957 1965	- 200	- 25.0	1965 1974	- 200	- 22.2	1853 1974	+3150	+ 26.0
22	"	- 250	- 3.2	"	+5450	+205.7	"	- 750	- 93.8	"	- 600	- 66.7	"	+3850	+ 31.8
23	"	- 225	- 2.9	"	+6800	+256.6	"	- 825	- 97.1	"	+ 250	+ 27.8	"	+6000	+ 49.6
24	"	- 425	- 5.5	"	+3350	+126.4	"	+1800	+211.8	"	+ 850	+ 94.4	"	+5575	+ 46.1
25	"	- 625	- 8.1	"	+ 725	+ 27.4	"	+1150	+135.3	"	+1200	+133.3	"	+2450	+ 20.2
26	"	- 675	- 8.7	"	- 575	- 21.7	"	+ 200	+ 23.5	"	+ 550	+ 61.1	"	- 500	- 4.1
27	"	- 775	-10.0	"	- 350	- 13.2	"	- 100	- 11.8	"	- 50	- 5.6	"	-1275	- 10.5
28	"	- 700	- 9.0	"	- 400	- 15.1	"	- 250	- 29.4	"	- 150	- 16.7	"	-1500	- 12.3
29	"	- 750	- 9.7	"	- 350	- 13.2	"	- 275	- 32.4	"	- 150	- 16.7	"	-1525	- 12.6
30	"	- 675	- 8.7	"	- 500	- 18.9	"	- 350	- 41.2	"	- 100	- 11.1	"	-1625	- 13.4
31	"	- 825	-10.6	"	- 550	- 20.8	"	- 200	- 23.5	"	- 275	- 30.6	"	-1850	- 15.3
32	"	- 625	- 8.1	"	- 650	- 24.5	"	- 150	- 17.6	"	- 300	- 33.3	"	-1725	- 14.3
33	"	- 575	- 7.4	"	- 575	- 21.7	"	- 225	- 26.6	"	- 225	- 25.0	"	-1600	- 13.2
34	"	- 700	- 9.0	"	- 625	- 23.6	"	0	0	"	- 300	- 33.3	"	-1625	- 13.4
35	"	- 725	- 9.4	"	- 725	- 27.4	"	+ 25	+ 2.9	"	- 300	- 33.3	"	-1725	- 14.3
36	"	- 650	- 8.4	"	- 500	- 18.9	"	- 150	- 17.6	"	- 350	- 38.9	"	-1650	- 13.6
37	"	- 500	- 6.5	"	- 375	- 14.2	"	- 200	- 23.5	"	- 375	- 41.67	"	-1450	- 12.0
38	"	- 600	- 7.7	1930 1956	- 425	- 16.3	1956 1965	- 150	- 16.7	"	- 400	- 44.4	"	-1575	- 13.0
39	"	- 650	- 8.4	"	- 525	- 19.8	"	- 100	- 11.1	"	- 275	- 30.6	"	-1550	- 12.7
40	"	- 650	- 8.4	"	- 600	- 22.6	"	- 150	- 16.7	"	- 275	- 30.6	"	-1675	- 13.8

+ accretion
- erosion

Shoreline Changes

beach segment San Luis Pass to Brown Cedar Cut

Point	Time	Dist. ft	Rate ft per yr	Time	Dist. ft	Rate ft per yr	Time	Dist. ft	Rate ft per yr	Time	Dist. ft	Rate ft per yr	Net Time	Net Dist.	Net Rate
41	1853 1930	- 550	- 7.1	1930 1956	- 425	- 16.3	1956 1965	- 300	- 33.3	1965 1974	- 200	- 22.2	1853 1974	-1475	- 12.2
42	1856 1937	- 950	-12.6	1937 1956	- 150	- 7.7	"	- 250	- 36.1	"	- 250	- 22.8	1856 1974	-1600	- 13.2
43	"	-1000	-12.3	"	- 250	- 12.8	"	- 250	- 27.8	"	- 150	- 16.7	"	-1650	- 14.0
44	"	-1075	-13.3	"	- 350	- 17.9	"	- 75	- 8.3	"	- 150	- 16.7	"	-1650	- 14.0

+ accretion
- erosion

Vegetation Line Changes

beach segment San Luis Pass to Brown Cedar Cut

Point	Time	Dist. ft	Rate ft per yr	Time	Dist. ft	Rate ft per yr	Time	Dist. ft	Rate ft per yr	Time	Dist. ft	Rate ft per yr	Net Time	Net Dist.	Net Rate
1				1930 1956	- 75	- 2.9	1956 1965	+ 700	+77.7	1965 1974	+ 400	+44.4	1930 1974	+1025	+ 23.3
2				"	- 475	-18.6	"	- 175	-19.4	"	+ 350	+38.9	"	- 300	- 6.8
3				"	- 225	- 8.8	"	- 400	-44.4	"	- 25	- 2.8	"	- 650	- 14.7
4				"	- 150	- 5.9	"	- 300	-33.3	"	+ 50	+ 5.6	"	- 400	- 9.1
5				"	- 50	- 2.0	"	- 275	-30.6	"	- 50	- 5.6	"	- 375	- 8.5
6				"	- 150	- 5.9	"	- 100	-11.1	"	- 175	-19.4	"	- 425	- 9.7
7				"			"			"			"		
8				"	- 100	- 3.9	"	- 150	-16.7	"	+ 75	+ 8.3	"	- 175	- 4.0
9				"	- 175	- 6.9	"	- 75	- 8.3	"	0	0	"	- 250	- 5.7
10				"	- 100	- 3.9	"	- 100	-11.1	"	+ 100	+11.1	"	- 100	- 2.3
11				"	+ 150	+ 5.9	"	- 125	-13.9	"	+< 10	+< 1.0	"	+ 25	+< 1.0
12				"	+ 100	+ 3.9	"	- 150	-16.7	"	+ 75	+ 8.3	"	+ 25	+< 1.0
13				"	+ 25	+< 1.0	"	- 75	- 8.3	"	-< 10	-< 1.0	"	- 50	- 1.1
14				"	+ 25	+< 1.0	"	- 75	- 8.3	"	+< 10	+< 1.0	"	- 50	- 1.1
15				"	- 50	- 2.0	"	- 125	-13.9	"	+ 75	+ 8.3	"	- 100	- 2.3
16				"			"	- 325	-36.1	"	- 125	-13.9	"	- 450	- 10.2
17				"			"	- 375	-41.7	"	- 150	-16.7	"	- 525	- 12.1
18				1930 1957			1957 1965	- 500	-62.5	"	-< 10	-< 1.0	"	- 500	- 11.4
19				"	+2200	+83.0	"	- 175	-21.9	"	- 100	-11.1	"	- 275	- 6.2
20				"	+2700	+101.9	"	- 225	-28.1	"	-< 10	-< 1.0	"	- 225	- 5.1

+ accretion
- erosion

Vegetation Line Changes

beach segment San Luis Pass to Brown Cedar Cut

Point	Time	Dist. ft	Rate ft per yr	Time	Dist. ft	Rate ft per yr	Time	Dist. ft	Rate ft per yr	Time	Dist. ft	Rate ft per yr	Net Time	Net Dist.	Net Rate
21				1930 1957	+3675	+138.7	1957 1965	-1000	-125.0	1965 1974	+ 625	+69.4	1930 1974	+3300	+ 75.0
22				"			"			"			"		
23				"	+6750	+254.7	"	-1100	-129.4	"	+ 600	+66.7	"	+6250	+142.0
24				"			"			"			"		
25				"	+ 325	+ 12.3	"	+ 400	+ 47.1	"	+ 250	+27.8	"	+ 975	+ 22.2
26				"	- 450	- 16.9	"	+ 200	+ 23.5	"	- 200	-22.2	"	- 450	- 10.2
27				"	- 400	- 15.1	"	- 200	- 23.5	"	+ 25	+ 2.8	"	- 575	- 13.1
28				"	- 400	- 15.1	"	- 225	- 26.5	"	- 50	- 5.6	"	- 675	- 15.3
29				"	- 325	- 12.3	"	- 300	- 35.3	"	- 50	- 5.6	"	- 675	- 15.3
30				"	- 500	- 18.9	"	- 500	- 58.8	"	+ 125	+13.9	"	- 875	- 19.9
31				"	- 700	- 26.4	"			"			"		
32				"	- 650	- 24.5	"	- 75	- 8.8	"	- 200	-22.2	"	- 925	- 21.0
33				"	- 600	- 22.6	"	- 200	- 23.5	"	- 225	-25.0	"	-1025	- 23.3
34				"	- 525	- 19.8	"	0	0	"	- 225	-25.0	"	- 750	- 17.0
35				"	- 400	- 15.1	"	- 75	- 8.8	"	- 175	-19.4	"	- 650	- 14.7
36				"	- 425	- 16.0	"	- 300	- 35.3	"	- 300	-33.3	"	-1025	- 23.3
37				"	- 225	- 8.5	"	- 200	- 23.5	"	- 400	-44.4	"	- 825	- 18.7
38				"	- 325	- 12.5	"	- 200	- 22.2	"	- 375	-41.7	"	- 900	- 20.4
39				"	- 425	- 16.3	"	- 200	- 22.2	"	- 250	-27.8	"	- 875	- 19.9
40				"	- 250	- 9.4	1956 1965	- 325	- 36.1	"	- 75	- 8.3	"	- 650	- 10.2

+ accretion
- erosion

Vegetation Line Changes

beach segment San Luis Pass to Brown Cedar Cut

Point	Time	Dist. ft	Rate ft per yr	Time	Dist. ft	Rate ft per yr	Time	Dist. ft	Rate ft per yr	Time	Dist. ft	Rate ft per yr	Net Time	Net Dist.	Net Rate
41				1930 1957	- 175	- 6.6	1956 1965	- 350	- 38.9	1965 1974	- 100	-11.1	1930 1974	- 625	- 14.2
42				1937 1957	+ 900	+ 46.1	"	- 225	- 25.0	"	- 200	-22.2	1937 1974	+ 475	+ 12.8
43				"	+ 800	+ 41.0	"	- 450	- 50.0	"	- 25	- 2.8	"	+ 325	+ 8.8
44				"	+1200	+ 61.5	"	- 225	- 25.0	"	- 75	- 8.3	"	+ 900	+ 24.3

APPENDIX B

Tropical Cyclones Affecting the Texas Coast 1854-1973
(compiled from Tannehill, 1956; Dunn and Miller, 1964; and Cry, 1965).

Intensity Classification from Dunn and Miller

	Maximum Winds	Minimum Central Pressures
Minor	Less than 74	above 29.40 in.
Minimal	74 to 100	29.03 to 29.40 in.
Major	101 to 135	28.01 to 29.00 in.
Extreme	136 and higher	28.00 in. or less

Year	Area	Intensity	Year	Area	Intensity	Year	Area	Intensity
1854	Galveston southward	major	1900	Upper coast	extreme	1940	Upper coast	minimal
1857	Port Isabel	?	1901	Upper coast	minor	1940	Upper coast	minor
1866	Galveston	minimal	1902	Corpus Christi	minimal	1941	Matagorda	minimal
1867	Galveston southward	major	1908	Brownsville	?	1941	Upper coast	minimal
1868	Corpus Christi	minimal	1909	Lower coast	minor	1942	Upper coast	minimal
1871	Galveston	minor	1909	Velasco	major	1942	Matagorda Bay	major
1871	Galveston	minimal	1909	Lower coast	minimal	1943	Galveston	minimal
1872	Port Isabel	minimal	1910	Lower coast	minor	1943	Upper coast	minor
1874	Indianola	minimal	1910	Lower coast	minimal	1945	Central Padre Island	minor
1874	Lower coast	minor	1912	Lower coast	minimal	1945	Middle coast	extreme
1875	Indianola	extreme	1913	Lower coast	minor	1946	Port Arthur	minor
1876	Padre Island	?	1915	Upper coast	extreme	1947	Lower coast	minor
1877	Entire coast	minimal	1916	Lower coast	extreme	1947	Galveston	minimal
1879	Upper coast	minor	1918	Sabine Pass	minimal	1949	Freeport	major
1880	Lower coast	major	1919	Corpus Christi	extreme	1954	South of Brownsville	minor
1880	Sargent	?	1921	Entire coast	minimal	1955	Corpus Christi	minimal
1880	Brownsville	major	1921	Lower coast	minor	1957	Beaumont	minor
1881	Lower coast	minimal	1922	South Padre Island	minor	1957	Sabine Pass	minimal
1885	Entire coast	minimal	1925	Lower coast	minor	1958	Extreme southern coast	minimal
1886	Upper coast	minor	1929	Port O'Connor	minimal	1958	Corpus Christi	minimal
1886	Entire coast	extreme	1931	Lower coast	minor	1959	Galveston	minimal
1886	Lower coast	minimal	1932	Freeport	major	1960	South Padre Island	minor
1886	Upper coast	minimal	1933	Lower coast	minor	1961	Palacios	extreme
1887	Brownsville	minimal	1933	Matagorda Bay	minor	1963	High Island	minimal
1888	Upper coast	minimal	1933	Brownsville	major	1964	Sargent	minor
1888	Upper coast	minor	1933	Brownsville	minimal	1967	Mouth Rio Grande	major
1891	Entire coast	minimal	1934	Rockport	minimal	1968	Aransas Pass	minor
1895	Lower coast	minor	1934	Entire coast	minor	1970	Corpus Christi	major
1895	Lower coast	minor	1936	Port Aransas	minimal	1970	High Island	minor
1897	Upper coast	minimal	1936	Lower coast	minor	1971	Aransas Pass	minimal
1898	Upper coast	minor	1938	Upper coast	minor	1973	High Island	minor

APPENDIX C

List of Materials and Sources

List of aerial photographs used in determination of changes in vegetation line and shoreline. *Indicates vegetation line and/or shoreline was used in map preparation.

Date		Source of Photographs
Nov. 1930	*	Tobin Research Inc.
March 1937	*	Tobin Research Inc.
Feb. 1939		U. S. Department of Agriculture
Sept. 1942		U. S. Army Corps Engineers
Nov. 1943		U. S. Department of Agriculture
July 1944		U. S. Department of Agriculture
Dec. 1953		U. S. Department of Agriculture
Aug., Sept. 1956	*	Tobin Research Inc.
Feb., July 1957	*	Tobin Research Inc.
Sept. 1961		Natl. Oceanic and Atmospheric Admin.
Oct. 1965	*	Natl. Oceanic and Atmospheric Admin.
June 1967		U. S. Army Corps Engineers
June 1974	*	Texas Highway Department

List of Maps Used in Determination of Shoreline Changes

Date		Description	Source of Maps
Feb., March, April	1852	topographic map 412	Natl. Oceanic and Atmospheric Admin.
May, June	1853	topographic map 375	Natl. Oceanic and Atmospheric Admin.
	1855	hydrographic survey 474 (3)	Natl. Oceanic and Atmospheric Admin.
	1856	topographic map 557	Natl. Oceanic and Atmospheric Admin.
	1856	hydrographic survey 539 (1)	Natl. Oceanic and Atmospheric Admin.
June	1858	hydrographic survey 656	Natl. Oceanic and Atmospheric Admin.
May	1867	hydrographic survey 931	Natl. Oceanic and Atmospheric Admin.
May	1882	hydrographic survey	U. S. Army Corps Engineers
Dec.	1891	topographic map 2047	Natl. Oceanic and Atmospheric Admin.
Jan.	1897	topographic map 2250	Natl. Oceanic and Atmospheric Admin.

List of 7.5-minute quadrangle topographic maps used in construction of base map. Source of these maps is the U. S. Geological Survey.

San Luis Pass, Texas
Christmas Point, Texas
Freeport, Texas
Jones Creek, Texas
Cedar Lakes East, Texas
Cedar Lakes West, Texas
Sargent, Texas
Brown Cedar Cut, Texas