Geological Circular 84-6

Historical Shoreline Changes in Corpus Christi, Oso, and Nueces Bays, Texas Gulf Coast

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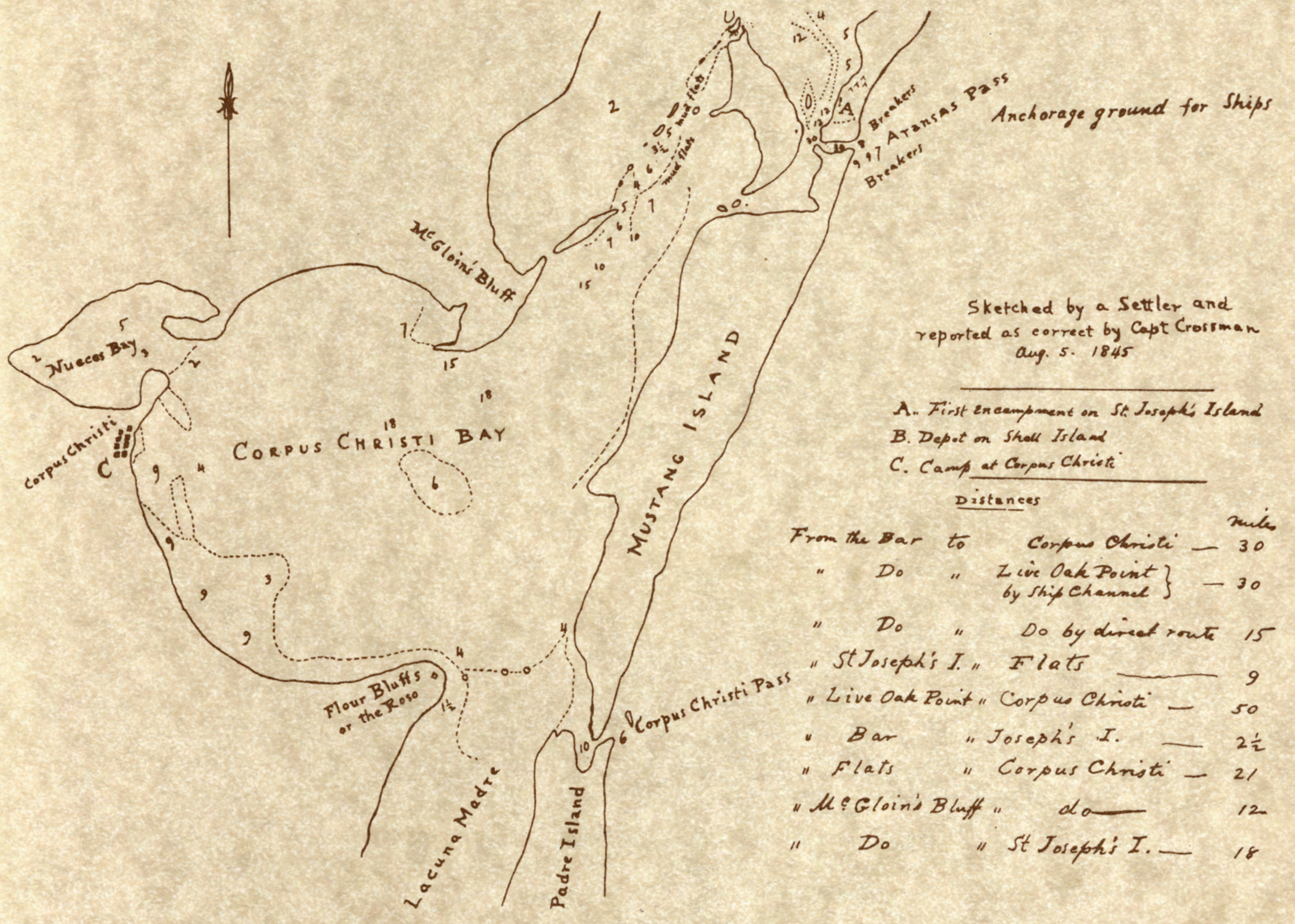

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HISTORICAL SHORELINE CHANGES IN CORPUS CHRISTI, OSO, AND NUECES BAYS, TEXAS GULF COAST

by

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Cover: Map of the Corpus Christi Bay area, sketched by an early settler. Reproduced from the original map, which is kept at the Texas State Archives, Austin.

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ABSTRACT

Changes in the position and stability of shorelines around Corpus Christi, Oso, and Nueces Bays, Texas Gulf Coast, were documented using historical-monitoring techniques. This was accomplished by comparing shorelines depicted on topographic surveys (dated 1867 to 1882) and aerial photographs (taken in 1930 to 1937 and in 1982), measuring the magnitude (distance) of shoreline movement at specific sites, calculating the rates of change for particular time periods (late 1800's to 1930's, 1930's to 1982, and late 1800's to 1982), and summarizing the magnitudes and rates of change in tables and on maps. Geological interpretations of the maps and photographs were used in conjunction with meteorological data and historical records to explain the important shoreline stability trends revealed by the maps and tabulated data.

Unprotected sediments forming the margins of Corpus Christi, Oso, and Nueces Bays are modified by natural coastal processes and by human activities that together cause shoreline movement. The unstabilized shorelines include high, nearly vertical clay bluffs, moderate slopes composed mainly of sand, salt-water marshes, sand and shell beaches, and newly formed areas filled by dredged material. Composition of the shoreline material and orientation of the shoreline with respect to prevailing wind directions and wave fetch largely determine the response and consequent movement of the shoreline. In some areas, property owners have attempted to stabilize the shoreline and prevent further erosion by building seawalls and bulkheads and by using riprap to dissipate wave energy.

Contributing to shoreline changes are (1) regional and worldwide climate, (2) local changes in relative sea-level position, (3) local alterations in sediment supply, (4) frequent and intense storms, and (5) human activities. Historical data compiled for these factors indicate that warming temperatures, rising sea level, decreasing sediment supply, recurring severe storms, and ongoing human activities all promote continued erosion of most unprotected bay shorelines. Frequent periods of high waves as well as reduction and disruption of longshore sediment transport are the primary causes of the continued retreat of unprotected shorelines of Corpus Christi and adjacent bays.

Keywords: shoreline changes, coastal processes, geologic hazards, Texas Gulf Coast

INTRODUCTION

Texas bays (fig. 1) are fronted by both stable and unstable shorelines that stretch for more than 3,300 mi. Field observations and regional mapping suggest that many of the shorelines are unstable and are retreating landward at rates ranging from a few feet to a few tens of feet per year. In some bays, biologically productive wetlands and other areas of State-owned natural resources are diminishing. The substantial cumulative land areas removed through either long- or short-term erosion translate directly to significant economic losses, both to the State and to private landowners. Furthermore, legal questions regarding property ownership may arise because of shoreline movement; public and private investments may be jeopardized and property damaged or destroyed as shoreline positions change. Taken together, the individual and corporate losses are of sufficient magnitude to warrant an investigation of shoreline movement.

Bay shoreline changes are attributable to natural processes and human activities. Regardless of the cause, vast land areas are being lost in some places and gained in others; accurate estimates of land losses and gains or of their equivalent economic values are unavailable because bay shoreline changes have not been systematically investigated. This study (1) quantifies the significant shoreline changes that occurred near Corpus Christi during the past century, (2) describes the physical processes that cause shoreline movement, and (3) discusses the anticipated future changes on the basis of long-term historical records and present-day coastal conditions.

Shoreline Changes

Shorelines are in a state of erosion or accretion, or they 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. Shorelines move in response to a hierarchy of natural cyclic phenomena including (from lower to higher order) tides, storms, sediment supply, and relative sea-level changes. Time periods for these cycles range from less than a day to several thousand years. Many shoreline segments undergo both erosion and accretion as a result of lower order events, no matter what their long-term trends may be. Furthermore, long-term trends can be unidirectional or cyclic; that is, shorelines may persistently either accrete or erode, or they may undergo periods of both erosion and accretion.

Related Studies

In 1971, the Bureau of Economic Geology initiated a research program to determine the long-term magnitude and rates of shoreline changes along the Texas coast. The main objectives

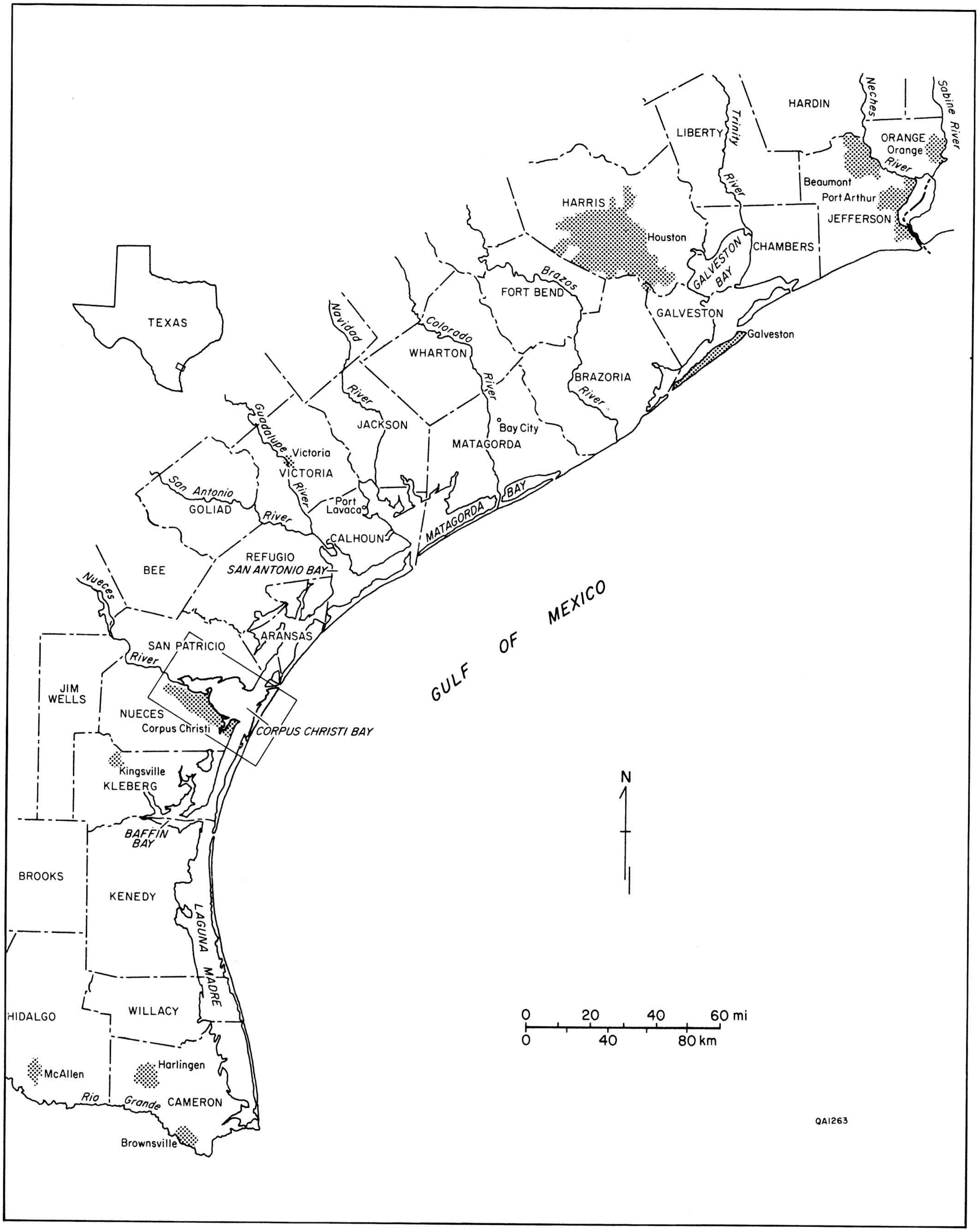

Figure 1. Map of the Texas Coastal Zone. Outlined area includes Corpus Christi, Oso, and Nueces Bays.

of this historical-monitoring program are documenting and quantifying past changes in shoreline position and predicting future changes.

Qualitative descriptions of shoreline stability throughout Corpus Christi, Nueces, and Oso Bays were presented on regional maps of the Texas Coastal Zone (Brown and others, 1974, 1976); however, the bay shoreline along Mustang Island (White and others, 1978) is the only segment of Corpus Christi Bay that has previously been studied using historical-monitoring techniques. Because data on shoreline conditions reported in this circular are more recent and quantitative, they supersede data presented in the previous publications.

METHODS AND PROCEDURES

Historical shoreline monitoring involves documenting the direction and magnitude of shoreline changes between specific times using accurate vintage charts, maps, and aerial photographs.

Sources of Data

Near-vertical aerial photographs, photomosaics, and topographic charts were used to determine changes in shoreline position (app. C). Accurate topographic charts dating from 1867, available through the U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), were mapped by the U.S. Coast Survey using plane-table procedures. Reproductions of original charts were used to establish the pre-1930 shoreline position (mean high water). Aerial photographs supplemented and later replaced regional topographic surveys in the early 1930's; therefore, subsequent shoreline positions were mapped on individual stereographic photographs and aerial photomosaics taken between 1930 and 1982. These photographs show shoreline position, which is determined by the position of sediment-water interface at the time the photographs were taken.

Procedures

The key to detecting shoreline movement is agreement of scale and projection between the original data and the selected map base. For this, U.S. Geological Survey 7.5-minute quadrangle topographic maps (1:24,000, or 1 inch = 2,000 ft) were used. Topographic charts and aerial photographs were either enlarged or reduced to the scale of the topographic maps. Shorelines shown on topographic charts and sediment-water interfaces mapped directly on sequential aerial photographs were optically transferred, using a Saltzman projector, from the topographic charts and aerial photographs onto a common base map. Lines transferred to the base map allowed direct comparison and quantification of changes in shoreline position with time.

Factors Affecting Accuracy of Data

Original Data

Topographic Surveys

Some inherent error probably exists in the original topographic maps prepared by the U.S. Coast Survey (now called National Ocean Service). Shalowitz (1964) described possible sources of error and the degree of accuracy of these maps; in general, recent surveys are more accurate than older surveys. Error can also be introduced by physical changes in material on which the original data appear. Such distortions, however, are usually minor and can be corrected by cartographic techniques.

Aerial Photographs

Use of aerial photographs of various scales introduces differences in resolution with concomitant differences in mapping precision. The sediment-water interface can be mapped with greater precision on large-scale photographs than on small-scale photographs. Fortunately, photographs at a scale equal to or larger than that of the topographic base map were available for this study.

Optical aberration slightly distorts the margins of photographs. To avoid this distortion, only the central part of each photograph was used for mapping, and distances between fixed points within the central part of the photograph were adjusted to the 7.5-minute topographic base.

Meteorological conditions before and during photography also affect the accuracy of documented shoreline changes. For example, deviations from normal astronomical tides caused by unusual barometric pressure, wind velocity and direction, and attendant wave activity might introduce anomalies in apparent shoreline positions. Most photographic missions, however, are flown during calm weather, thus minimizing the effects of abnormal meteorological conditions.

Interpretation of Photographs

On a few photographs, both the beach and wave zone are bright white (high albedo) and cannot be precisely differentiated. The shoreline is projected through these areas; therefore, some error may have been introduced. In general, these difficulties were resolved through an understanding of coastal processes and the ability to accurately interpret aerial photographs.

Using the mean high-water line on topographic charts and the sediment-water interface on aerial photographs to define the same boundary is inconsistent because the sediment-water interface normally 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 depends on the tidal cycle, slope of the beach, and wind direction when the photograph was taken. The low tide range (0.5 ft) and the narrow beaches (< 15 ft) along most of the Texas bay shorelines substantially reduce the potential difference between the mean high-water line and the sediment-water interface, thus making this source of error negligible in most areas.

The advantage of consecutive mapping of the sediment-water interface is the internal consistency from one shoreline type to another; a definite disadvantage is the underestimated bluff retreat in areas where a rapidly receding cliff is separated from the sediment-water interface by a horizontal distance of several hundred feet. Magnitudes of bluff retreat were measured in selected areas where this separation occurs.

Cartographic Procedures

Topographic Charts

The topographic charts include a 1-minute grid, along with a depiction of permanent geographic features, that makes it easy to transfer the shoreline position from chart to base map. Where the chart material is distorted, lakes, stream valleys, meander loops, and the 1-minute latitude and longitude cells control alignment and scale adjustment across the chart. In general, areas with many distinctive geographic features provide the most geographic control and are associated with the highest confidence level.

Aerial Photographs

As with topographic charts, newer aerial photographs are more accurate than older ones. Quality of photographic negatives, optical resolution, and techniques of compiling controlled mosaics have improved with time; thus fewer adjustments are necessary when working with newer photographs.

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

Measurements and Calculated Rates

Measurements of linear distances on maps can be made to 0.01 inch, which corresponds to 20 ft on maps at a scale of 1 inch = 2,000 ft (1:24,000). This is more precise than the data warrant. Problems do arise, however, when rates of change are calculated because (1) time intervals between mapped shorelines are not equal; (2) erosion or accretion is assumed to be constant over the entire time period between mapped shorelines; and (3) different rates can be obtained at any given point using various combinations of lines. The problems are interrelated, and solutions require the averaging of rates of change for discrete time intervals.

Tables, numerical ranges, and graphic displays can be used to illustrate shoreline changes, but the calculated rates should be used with caution and in context for several reasons. First, the inequality of time periods between the mapped shoreline positions may have introduced a sampling bias because the optimum time interval cannot be determined. Such an interval would include not only periods when the true changes in shoreline position followed the same trend but also those periods when shorelines changed at similar rates. Second, the sampling technique commonly fails to show precisely when the reversals in trend occurred. If the trend remains unchanged, it is possible to detect variability in the rates of change (acceleration and deceleration). If, however, the trend reverses between two sequential periods, then the mid-date, or date common to both periods, is assumed to be the time of trend reversal; this causes underestimated rates of change for one of the periods.

Justification and Limitations of Methods

As discussed, the methods used in long-term historical monitoring may be slightly imprecise; hence calculations for trends and rates of shoreline changes determined from these techniques have limitations. Rates of change are somewhat less accurate than are trends or direction of change; however, the significance of the trends of shoreline change documented for more than 100 years is beyond question.

Method limitations require emphasizing the trend of shoreline changes; rates of change are secondary. Although rates of change derived from map measurements can be precisely calculated well beyond the limits of accuracy of the procedure, they are most important as indicators or as relative values; that is, the data can indicate whether changes are occurring at a few feet per year or at significantly higher rates.

Sources 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 prepared by the U.S. Army Corps of Engineers, from visits with various officials of the City of Corpus Christi and personnel at the Corpus Christi Naval Air Station, and from on-the-ground measurements and observations, including beach profiles, prepared as a part of this investigation.

ORIGIN OF TEXAS BAYS

Texas bays were formed principally by large-scale sea-level fluctuations (on the order of a few hundred feet) that occurred during the Quaternary Period in conjunction with repeated advance and retreat of great continental ice sheets (fig. 2). As the glaciers grew, much water

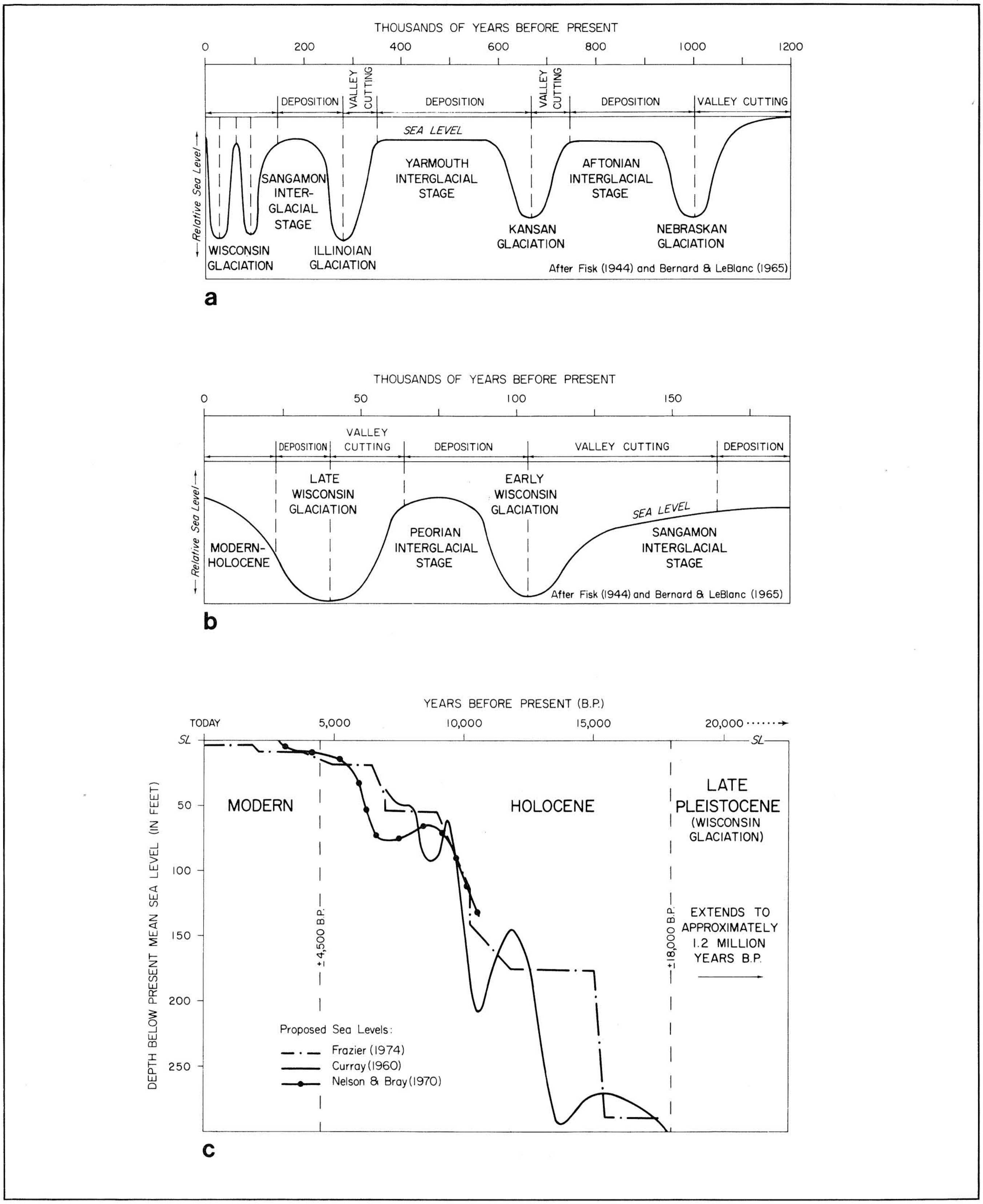

Figure 2. Sea-level changes associated with expansion and contraction of continental glaciers. (a) Generalized Pleistocene sea-level variations and attendant erosional and depositional episodes. (b) Generalized sea-level changes during Wisconsin glacial and interglacial stages. (c) Interpreted sea-level changes during the last 20,000 years. From Brown and others (1976).

was stored as ice, causing a fall in sea level. Subsequent melting of the ice sheets released this water and caused sea level to rise.

The Quaternary Period, which has been divided into the Pleistocene and Holocene Epochs, began 2 to 3 million years ago with the onset of a major continental glaciation (sea-level fall). The Pleistocene lasted until approximately 18,000 years ago and was characterized by several major glacial advances and retreats. The succeeding Holocene, defined as the time since the peak of the last major glaciation, has therefore been a time of sea-level rise. The term "Modern" is commonly used to refer to the last 5,000 years, when the Holocene sea-level rise slowed considerably (fig. 2).

Late Pleistocene Sea-Level Highstand

Pleistocene fluvial and deltaic sediments (Beaumont Formation) cover much of the western part of the Corpus Christi area (fig. 3). These sediments were deposited in both marine and nonmarine environments (Brown and others, 1976), which indicates that sea level was near its present-day level at some time during the Pleistocene. Wilkinson and others (1975) and Winker (1979) consider Beaumont deposits to be contemporaneous with the last Pleistocene highstand.

The Pleistocene fluvial and deltaic deposits form the bluffs common in Corpus Christi, Oso, and Nueces Bays. These deposits are found at elevations greater than 10 to 15 ft above current sea level and are composed mostly of interdistributary mud and lesser amounts of distributary and fluvial sand and silt (Brown and others, 1976).

Another laterally extensive Pleistocene unit is the Ingleside barrier-strandplain system (fig. 3), composed almost entirely of sand. This unit has been interpreted as a barrier-island/lagoon system (Price, 1958) or alternatively as a strandplain system not having a continuous lagoon landward of the major sand body (Wilkinson and others, 1975). Winker (1979) considered the Ingleside to be contemporaneous with Beaumont fluvial and deltaic deposits.

Late Pleistocene Sea-Level Lowstand

After deposition of the Ingleside sand, sea level fell at the onset of the last major Pleistocene glaciation (late Wisconsin). Estimates of the magnitude of sea-level fall cluster near 400 ft below present sea level (LeBlanc and Hodgson, 1959; Curray, 1960; Frazier, 1974). Rivers and streams entrenched in response to the lowered base level. Wright (1980) used cores and seismic reflection profiles to determine that valleys of the ancestral Nueces River and its tributaries were incised about 125 ft below present sea level (fig. 4).

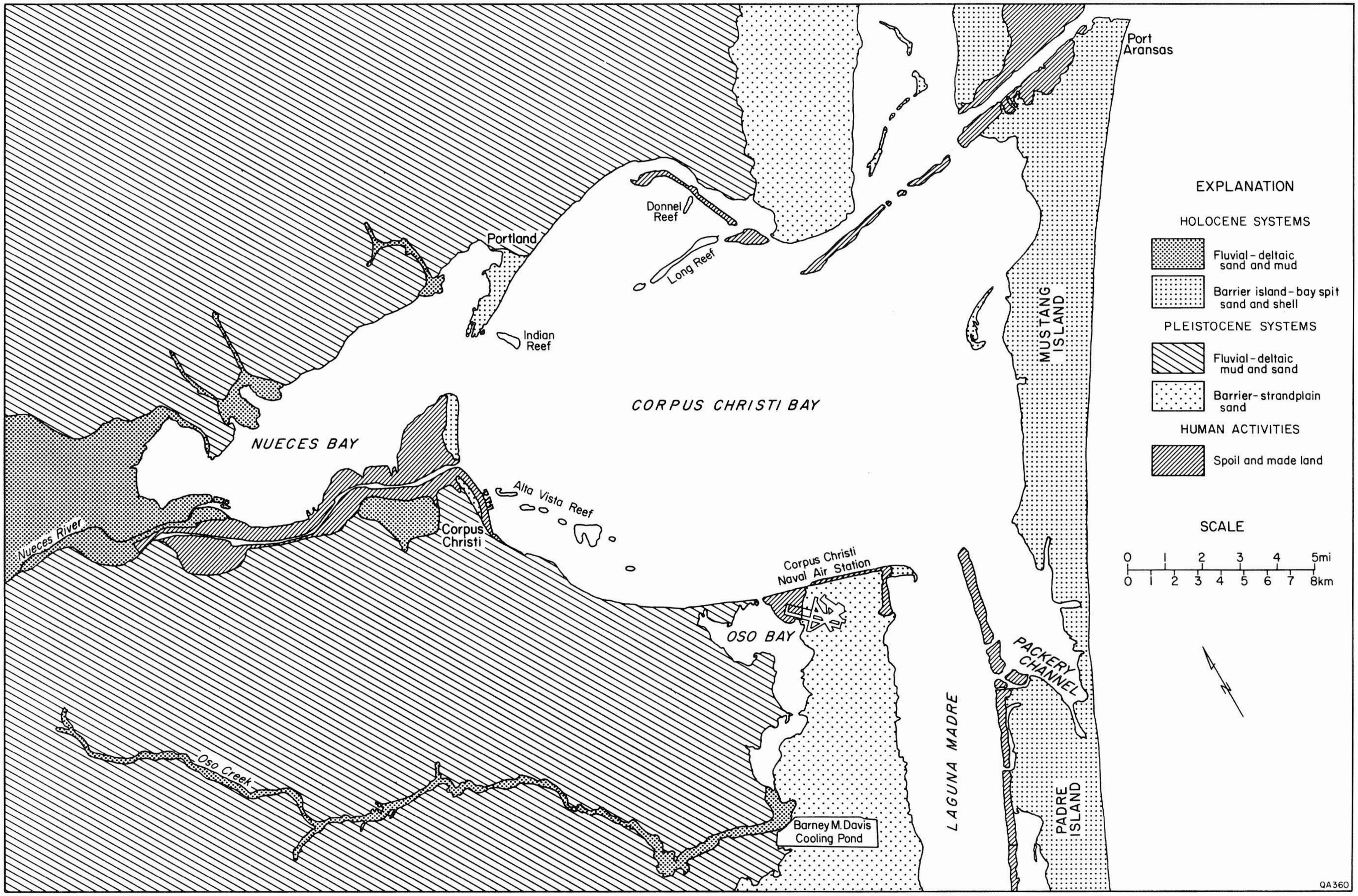

Figure 3. Generalized geologic map of the Corpus Christi area. Modified from Brown and others (1976).

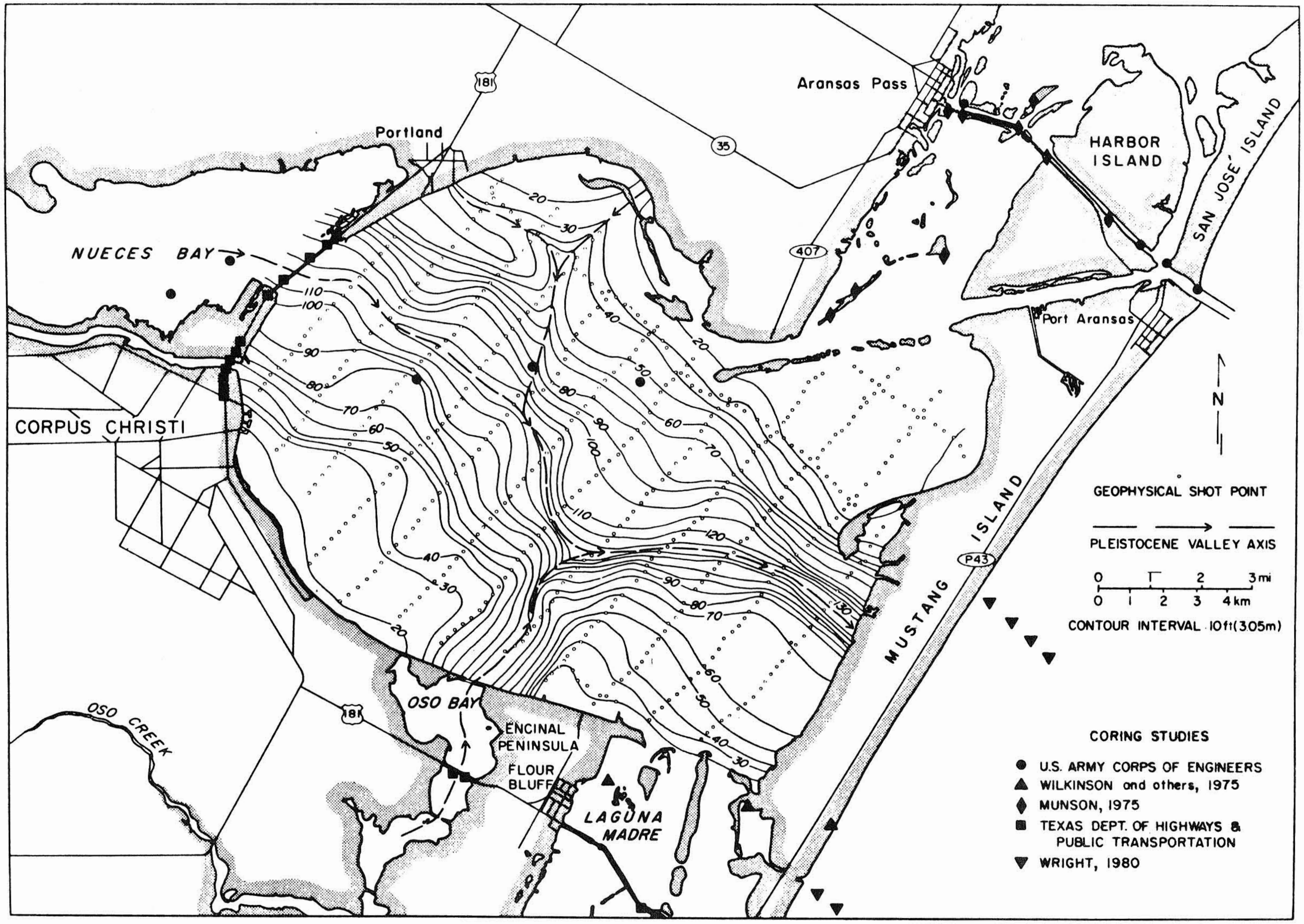

Figure 4. Contour map of the late Pleistocene erosional surface beneath Corpus Christi Bay. From Wright (1980).

Holocene Sea-Level Rise and Highstand

Sea-Level Changes

The last major glaciation began to wane about 18,000 years ago, causing sea level to rise at an average of about 2 to 3 ft per century, probably punctuated by several minor stillstands and reverses (fig. 2). About 5,000 years ago, the rate of sea-level rise decreased (fig. 2). Estimates of rates of rise during the last 3,000 years range from 1 to 5 inches per century (Flint, 1971); higher rates of change have been proposed on the basis of fragmentary evidence of reversals in the global sea-level trend for this period (Froomer, 1980; DePratter and Howard, 1981).

Sedimentation

During the Holocene sea-level rise, deposition of fluvial, deltaic, estuarine, and marine sediments partly filled the stream valleys incised during the late Pleistocene sea-level lowstand (Brown and others, 1976; Wright, 1980). The rate of sedimentation was lower than the rate of sea-level rise; thus the transgressive sequence preserved in the valley fill records the increasing marine influence during the early Holocene. Wright (1980) used the Holocene sea-level curves and the depth of Pleistocene valleys to estimate that marine waters entered the area of present-day Corpus Christi Bay 9,000 to 11,000 years ago. As marine waters flooded the valleys, waves broadened the newly formed estuaries by eroding valley walls.

By 4,500 years ago, sea level was probably within 15 ft of its present-day level. Filling of the estuaries by erosion of valley walls, deltaic deposition, influx of Gulf sediments through tidal inlets, and reef growth continued as the rate of sea-level rise diminished (Brown and others, 1976). About 3,000 to 2,500 years ago, the nuclei of north Padre, Mustang, and San José Islands formed from material derived from the erosion of deltaic headlands and the adjacent continental shelf. Longshore transport and spit accretion caused the barrier-island nuclei to grow and coalesce, resulting in the restriction and minor lateral migration of tidal inlets (Brown and others, 1976). Open-marine conditions in present-day northern Laguna Madre, Corpus Christi Bay, and Redfish and Aransas Bays ended as the barrier islands continued to accrete and tidal inlets closed. In addition, slow sea-level rise allowed the progradation of bayhead deltas such as the Nueces delta (fig. 3); this process continues in some areas (McGowen and Brewton, 1975).

Prevailing southeasterly winds (fig. 5) have produced net longshore sediment transport in a counterclockwise direction in northern Corpus Christi Bay and in a clockwise direction in southern Corpus Christi Bay. The result has been the formation of Rincon Point and Indian Point peninsulas during the late Holocene, primarily by spit accretion (fig. 3; fig. 5 for

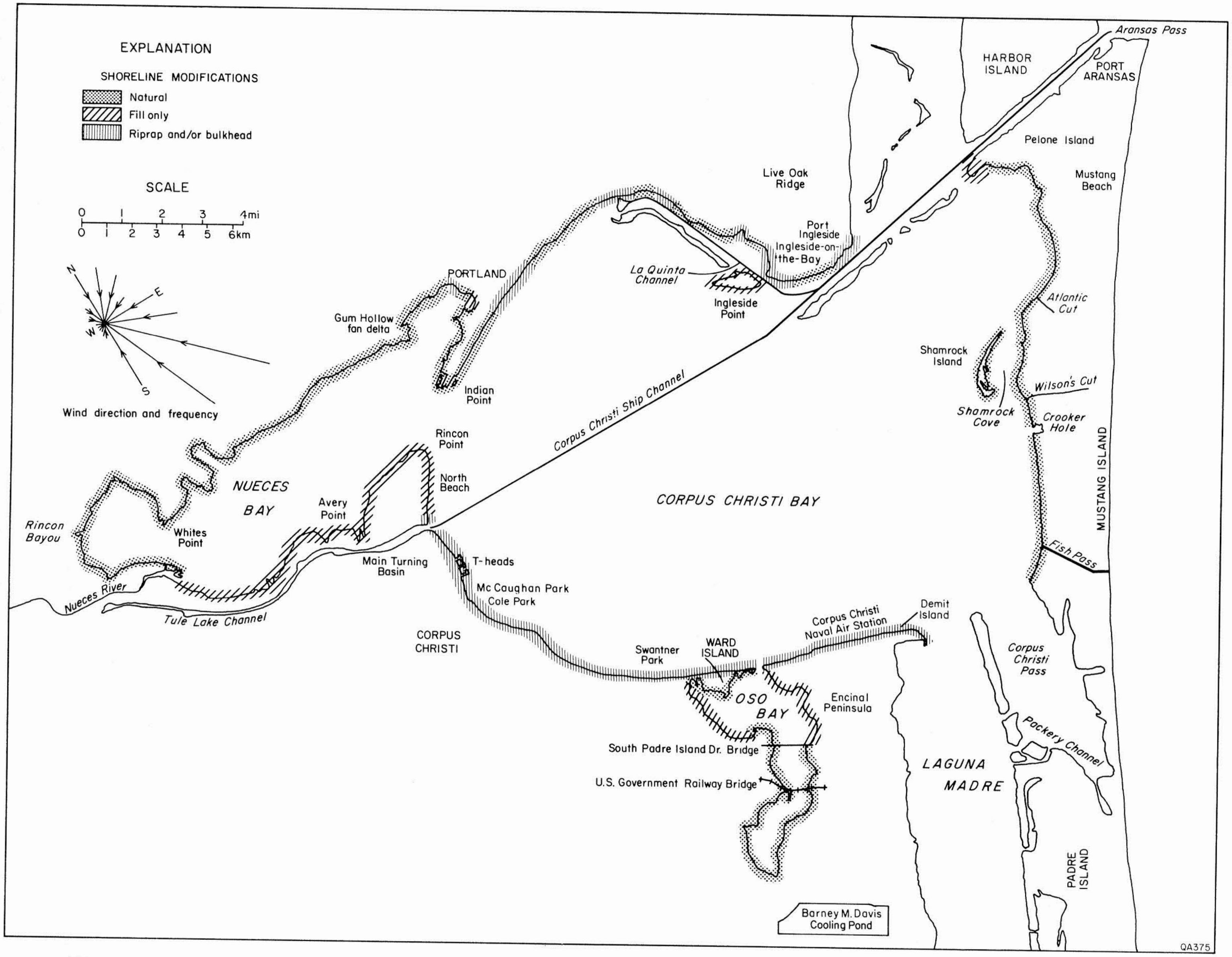

Figure 5. Geographic locations and types of shorelines forming the margins of Corpus Christi, Oso, and Nueces Bays. Wind vectors from Corpus Christi Naval Air Station (1951 to 1960), as shown by Brown and others (1976).

location). Shamrock Island is another late Holocene spit deposit formed by southwesterly directed currents that predominated when a tidal outlet was open in the southeastern part of Corpus Christi Bay.

TYPES OF SHORELINES

Clay bluffs, sandy slopes, marshes, and sand and shell beaches compose the four main types of natural shorelines around Corpus Christi Bay. Altered shorelines include these same shoreline types as well as structurally stabilized shores. Before human alterations, shoreline morphology and composition were chiefly controlled by the regional geology (fig. 3) and local coastal processes. High clay bluffs of Pleistocene mud and sand formed the northern and southern boundaries of Nueces Bay and Corpus Christi Bay and the western margin of Oso Bay (figs. 3 and 5). These bays were separated by baymouth spits (North Beach, Indian Point, shoals adjacent to Ward Island) composed of sand and shell. Mud-rich marshes of the Modern Nueces delta formed the headward margin of Nueces Bay. The bay margin of Mustang Island consisted of sand and shell beaches. The short bay segments near Port Ingleside and the Corpus Christi Naval Air Station most likely were constructed of sand derived from the adjoining Pleistocene barrier-strandplain sand. Sandy slopes along eastern Oso Bay were also associated with the Pleistocene Ingleside sand (fig. 3).

Unstabilized Shorelines

All shorelines composed of unconsolidated sediments and subjected to erosion by the bay waves and nearshore currents are herein considered to be unstabilized. Both natural shorelines and unprotected landfills are included in this category.

Clay Bluffs

Steep bluffs composed of interbedded mud and sand (fig. 6) characterize much of the shoreline along northern Nueces and Corpus Christi Bays, western Oso Bay, and short stretches of southern Corpus Christi Bay. Stiff clay bluffs exhibit the greatest disequilibrium with extant coastal processes and therefore are the most vulnerable to wave attack and undercutting; they are also the most resistant to wave erosion. Elevations of bluffs vary from a few feet to more than 50 ft and generally decrease eastward because of the gentle (≈ 5 ft/mi) gulfward slope of the Coastal Plain. Bluff steepness and corresponding beach width are partly dependent on sediment composition (sand percent), but bluff orientation with respect to predominant wind directions, deep-water fetch across the bay, and presence or absence of intervening land features primarily control bluff morphology. North-, south-, or southeast-facing clay bluffs that are exposed to long wave fetches have steep slopes, whereas sandy bluffs that face other directions or receive protection from promontories have gentler slopes.

Both topographic elevation and wave characteristics complicate bluff shape more along northern Nueces and Corpus Christi Bays than along southern Corpus Christi or western Oso Bays. Large, unimpeded hurricane waves raised to unusually high elevations by storm surge erode the upper levels of the high bluffs and form wave-cut slopes and terraces. Sediment eroded from the bluffs is transported bayward and deposited as broad beaches and bay-margin shoals. These deposits are subsequently reworked by the smaller waves of less intense storms and by the waves generated by the prevailing daily winds.

Bluff orientation with respect to wind direction (fig. 5) probably accounts for the difference in widths between beaches and erosional escarpments. Wide intervening slopes appear along northern Corpus Christi Bay, where weak, low-amplitude waves generated by persistent southeasterly winds cannot remove the planar wave-cut surface and adjacent beach. In contrast, narrow beaches form along southern Corpus Christi Bay because northerly winter waves of moderate size erode the beach and adjoining bay shoals. Elsewhere, the zone of barren or grass-covered sediment at the base of the erosional escarpment is locally controlled by deposition at the mouths of steep-walled, headwardly eroding gullies that transect the tall bluffs. The recently formed Gum Hollow fan delta (McGowen, 1971) is a large deposit of this type. Laterally extensive but narrower berms have also formed in Nueces Bay by coalescing small fans at the bases of numerous gullies and rills scoured into the bluff faces.

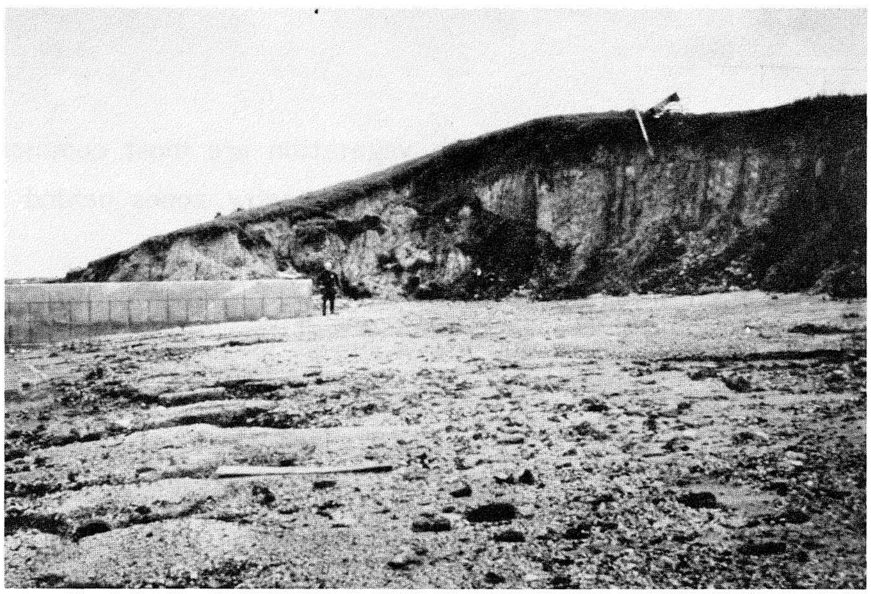

Figure 6. High, nearly vertical clay bluffs of southern Corpus Christi Bay. Photograph by L. Wenger.

Sandy Slopes

Grass- and shrub-covered slopes composed of fine-grained sand and clayey sand commonly grade bayward into sand beaches or merge with barren and marsh-covered sand flats; therefore they are the least distinctive of the principal shoreline types. Prominent sandy slopes are not widespread and occupy only the eastern perimeter of Oso Bay (fig. 7), where they coincide with the landward limit of the Pleistocene Ingleside sand (fig. 3). The slopes are hummocky, have moderate surficial gradients, and are up to 15 ft high.

Figure 7. Sandy slopes of eastern Oso Bay.

Marshes

Bay shorelines partly stabilized by marsh vegetation are most common in Nueces Bay (fig. 8). The marsh vegetation there grows in wave-shadow zones behind spits, in shallow embayments, or in other protected areas of low wave energy.

Before the massive shell dredging during the latter half of this century, water was a few feet deep in the center of Nueces Bay and a few inches deep in the upper reaches near the Nueces River. The extremely shallow depths prevented formation of large erosive waves and promoted extensive growth of marshes fed by nutrients from the river and the sea.

Salt-water marshes grow not only on muddy substrates of the Nueces delta but also on sandy flats throughout Nueces, Corpus Christi, and Oso Bays. A particularly robust stand of marsh in northern Oso Bay is supplied by effluent from the nearby sewage treatment plant.

Figure 8. Broad salt-water marsh (Spartina alterniflora) of the Nueces delta, upper Nueces Bay. Photograph by W. A. White.

Sand and Shell Beaches

Shorelines composed of sand and varying amounts of shell are generally restricted to Corpus Christi Bay along Indian Point (fig. 9), the bayside of Mustang Island, and formerly along North Beach. The beach along Shamrock Island contains the highest concentrations of shell

Figure 9. Low and narrow sand and shell beach of Indian Point.

debris, a mixed assemblage of mollusk species that live in the bay and open Gulf. These low-lying (< 5 ft) shoreline features are commonly backed by salt-water marshes or salt-tolerant grasses that occupy slightly elevated areas and provide some sediment stability.

Perhaps as recently as 100 years ago, many of these sand and shell beaches were at least stable, if not actively accreting. The ridge-and-swale topography associated with some of these bay-margin features marks the positions of older beaches and berms. Some of these former shoreline deposits are now eroding because recent changes in the bay system have altered sediment supply and current patterns.

Made Land

Vast areas of newly created land lie next to the major deep-draft channels in Corpus Christi and southern Nueces Bays (figs. 3 and 10). Excavation, subsequent deepening, and maintenance dredging of the channels supplied the sand and mud that were hydraulically emplaced to form the fill. Broad, low-lying sand flats and higher spoil mounds formed by dredged material are located along the south side of Nueces Bay (Tule Lake Channel and Turning Basin), near Ingleside (La Quinta Channel), and near Port Aransas (Corpus Christi Ship Channel). Indigenous vegetation was planted on some spoil mounds to stabilize the dredged material and to reduce shoaling of adjacent channels (Carl Oppenheimer, personal communication, 1983).

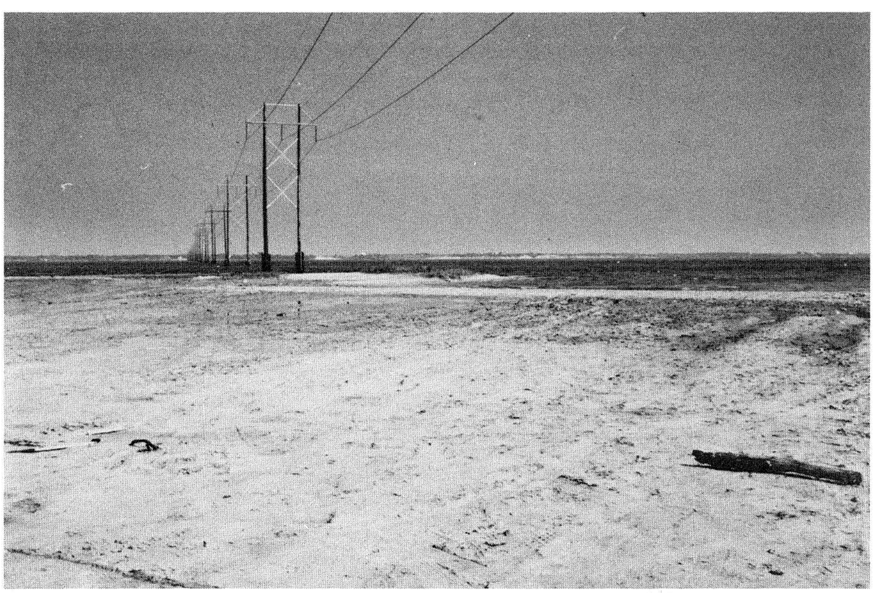

Figure 10. Broad, low-lying flats composed of dredged material (mostly sand), southern Nueces Bay.

Smaller land areas created by activities other than spoil disposal include the Naval Air Station runway extension in northeastern Oso Bay and the Corpus Christi waterfront district near Shoreline Boulevard. These areas, which have been structurally stabilized, are discussed in the following section.

Stabilized Shorelines

Coastal lands are subject to a variety of geological processes and are among the most dynamic areas on Earth. The relative importance of the many agents active along a coastline can fluctuate daily, seasonally, annually, or over a longer term. Because shoreline positions are mainly determined by these changeable coastal processes, shoreline positions also change through time. Several methods have been employed to stabilize transient shorelines, including constructing bulkheads and seawalls, placing rubble (riprap) along the shoreline, and supplying sand to recreational beaches.

Bulkheads and Seawalls

Primarily, bulkheads and seawalls (vertical or near-vertical walls constructed parallel to the shoreline) prevent shoreline retreat by reflecting wave energy that would otherwise impinge upon coastal lands (figs. 11 and 12). Reinforced concrete is the most common construction material; however, wooden and metal bulkheads also exist. Seawalls are generally higher and more laterally extensive than are bulkheads and are designed to reflect wave energy up and away from protected material.

Bulkheads and seawalls stop shoreline retreat during the life of the structure. However, wave reflection and water turbulence can erode the seaward toe of a bulkhead or a seawall, increasing the likelihood of its failure. A second disadvantage is the concentration of wave energy at their ends. This causes rapid shoreline retreat if adjacent waterfront property is unprotected. Many bulkheads in the Corpus Christi vicinity have been built lot-by-lot, increasing erosion of adjacent unprotected property. A third disadvantage involves tropical cyclones, infrequent but important agents in shoreline retreat. Along with intense wind and rain, these storms are accompanied by large increases in local sea level (storm surge). Though each storm varies, bay levels have risen to nearly 10 ft above mean sea level for short periods of time (table 1). During periods of extreme wave action and elevated sea level, most bulkheads and some seawalls are overtopped and are thus more prone to failure.

Shoreline stabilization efforts are concentrated on the southern and western shores of Corpus Christi Bay, from the North Beach - Rincon Point area eastward to the Corpus Christi Naval Air Station (fig. 5). Seawalls as high as 10 ft or more above mean sea level protect the northern end of the Corpus Christi Naval Air Station and downtown Corpus Christi. Bulkheads extending only a few feet above sea level are more common between the seawalls. Wall heights and construction materials vary greatly from site to site; however, city-owned park bulkheads are consistent in form and composition.

Figure 11. Low concrete bulkheads backed by consolidated riprap and graded fill at Cole Park, southern Corpus Christi Bay.

Figure 12. The Corpus Christi waterfront protected by a stepped seawall fronting Corpus Christi Bay.

Bulkheads are found at various points around Nueces, Corpus Christi, and Oso Bays. These bulkheads are usually localized and less than 5 ft above sea level. Bulkheads are common on both the Corpus Christi Bay and Nueces Bay sides of Portland, near Ingleside-on-the-Bay on the northeastern shore of Corpus Christi Bay, and surrounding residential, commercial, and oil-field developments on the bay shore of Mustang Island.

Table 1. Maximum hurricane surge heights recorded near Corpus Christi Bay, 1916 to 1982.

Date	Surge height (ft)	Location	Reference
1916	5.9	Corpus Christi	Sugg and others, 1971
1919	11.1	Port Aransas	Sugg and others, 1971
	16.0	Corpus Christi	Sugg and others, 1971
1933 (July)	5.0	Port Aransas	Price, 1956
1933 (August)	4.5	Port Aransas	Bailey, 1933
1933 (September)	8.0	Corpus Christi	Sugg and others, 1971
1945	4.0	Port Aransas	Sumner, 1946
	4.5	Corpus Christi	Sumner, 1946
1961	9.3	Port Aransas	U.S. Army Corps of Engineers, 1962
(Carla)	6.5	Corpus Christi	U.S. Army Corps of Engineers, 1962
1967	8.0	Port Aransas	U.S. Army Corps of Engineers, 1968
(Beulah)	7.3	Corpus Christi	U.S. Army Corps of Engineers, 1968
1970	9.2	Port Aransas	U.S. Army Corps of Engineers, 1971
(Celia)	4.9	Corpus Christi	U.S. Army Corps of Engineers, 1971
1971	3.1	Port Aransas	U.S. Army Corps of Engineers, 1972
(Fern)	3.0	Corpus Christi	U.S. Army Corps of Engineers, 1972
1980	8.9	Port Aransas	U.S. Army Corps of Engineers, 1981
(Allen)	9.4	Corpus Christi	U.S. Army Corps of Engineers, 1981

Riprap

Another common technique used to prevent shoreline retreat is the placement of coarse rubble (riprap) along a shoreline in the zone of wave attack. The random orientation of blocks scatters incident wave energy, reducing the effectiveness of wave attack. Diverse materials, including large rocks, blocks of aggregate, broken pavement, and rubber tires, are used as riprap in the Corpus Christi Bay system (fig. 13). Because these materials are generally readily available and no construction is required, placement of riprap is one of the least expensive methods of shoreline protection.

Riprap is also commonly used in conjunction with other erosion-control structures. Bulkheads, for example, are vulnerable both to undermining caused by a concentration of wave energy at their base and to overtopping during storms. Riprap has been used in some areas in front of and behind bulkheads to increase the life of the structures.

The placement of riprap is less complex than the construction of bulkheads. Thus, riprap is likely to be found in a wider variety of settings around the bays, notably where shoreline control is desired but bulkheads are impractical or economically unfeasible. In southern Corpus Christi Bay, riprap is used lot-by-lot either alone or as protection for bulkheads. Most bulkheads along city parks are fronted and backed by riprap of some type. Although riprap is most common along the southern shores of Corpus Christi Bay, it is locally found throughout the bay system. Other notable concentrations are near Portland and Ingleside-on-the-Bay, along the bay shore of Mustang Island, and at scattered localities in Nueces Bay.

Figure 13. Concrete riprap used as shoreline protection near Ward Island, southern Corpus Christi Bay.

Beach Nourishment

Bulkheads, seawalls, and riprap inhibit shoreline movement by decreasing the amount of wave energy reaching shoreline sediments. Beach nourishment projects differ in that they are an attempt to maintain shoreline position by the addition of material to the littoral system. Continual replenishment is needed because natural processes constantly erode the nourished beaches.

A major beach nourishment project for North Beach was completed by the U.S. Army Corps of Engineers in 1978 (figs. 14 and 15). This area was selected because it has eroded continuously in historical time, even though Rincon Peninsula is an accretionary feature when

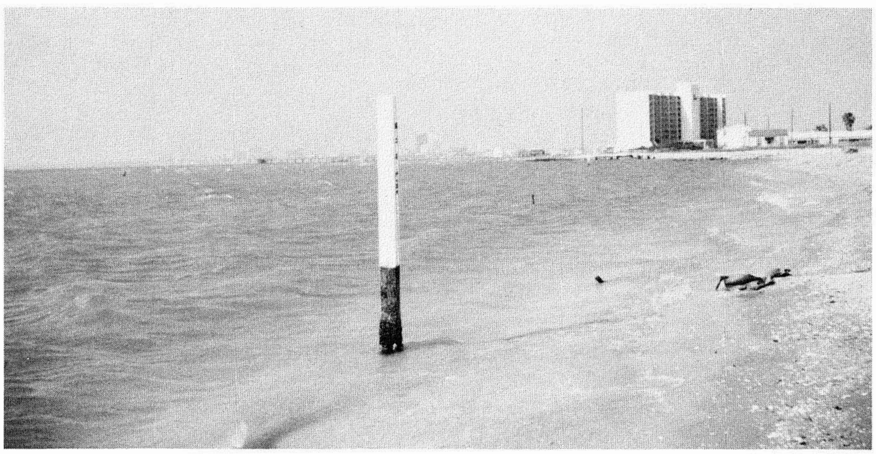

Figure 14. North Beach in 1974 before beach nourishment.

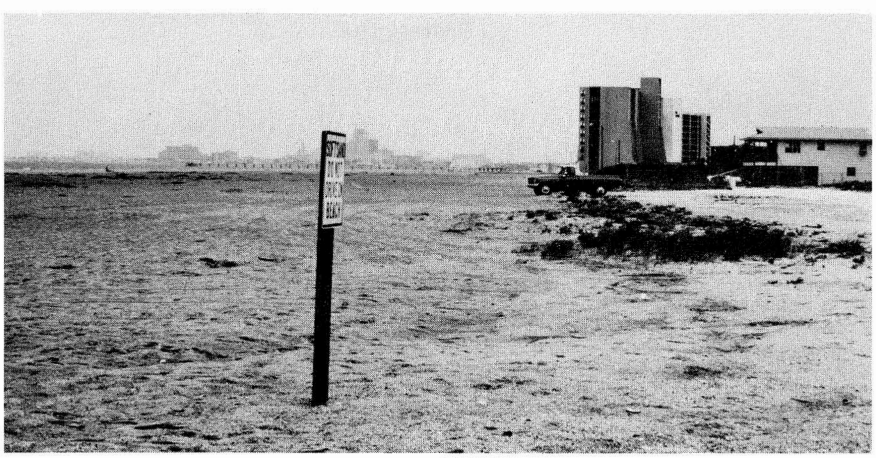

Figure 15. North Beach in 1983 after beach nourishment. Photograph taken from the same location as that of figure 14.

viewed on a geological time scale. To reclaim and nourish North Beach, coarse sand, which covered fill material dredged from Corpus Christi Bay, was imported from the Nueces River (U.S. Army Corps of Engineers, 1974). Material was added to approximately 7,000 ft of shoreline; the restored beach width along this length was 300 to 400 ft (fig. 16). It is estimated that 125,000 yd^3 of cover material will need to be added every 5 years to maintain the beach at its current size (U.S. Army Corps of Engineers, 1974).

Beach nourishment on a smaller scale has been undertaken at McCaughan Park in Corpus Christi, just south of the seawall (fig. 5). In that area, approximately 0.33 mi of beach has been nourished to a width of 70 to 100 ft.

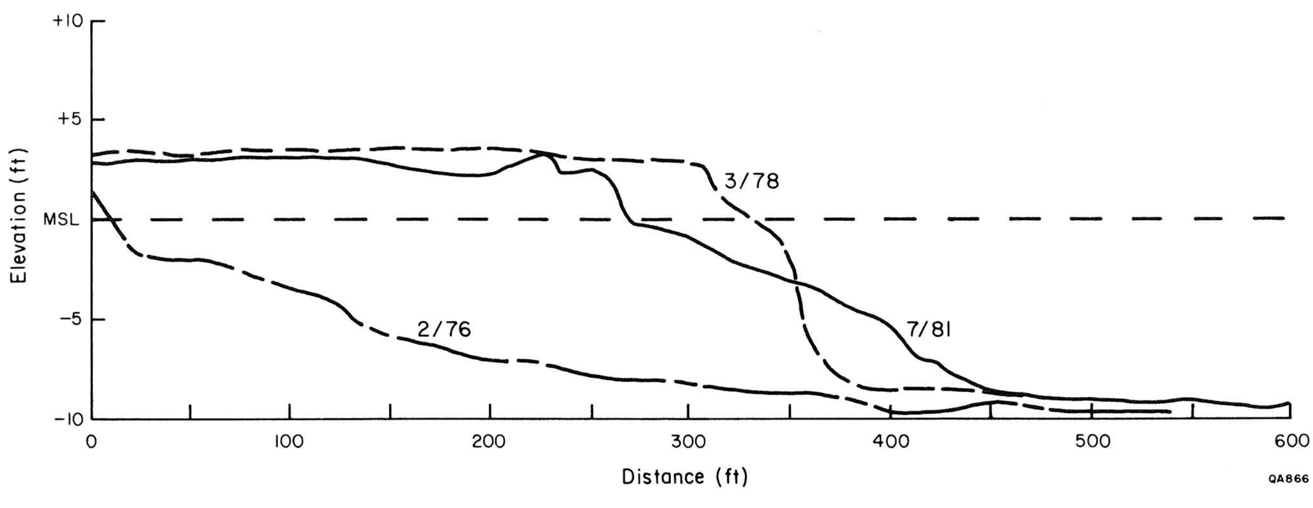

Figure 16. Profiles of North Beach before beach restoration (February 1976), at completion of restoration (March 1978), and in July 1981. Drawn from unpublished data of the Galveston District, U.S. Army Corps of Engineers.

It is impossible to isolate and quantify each cause of shoreline changes (fig. 17). Despite the difficulties, evaluation of as many causes as possible and their interactions is necessary to understand past shoreline changes and to anticipate future changes.

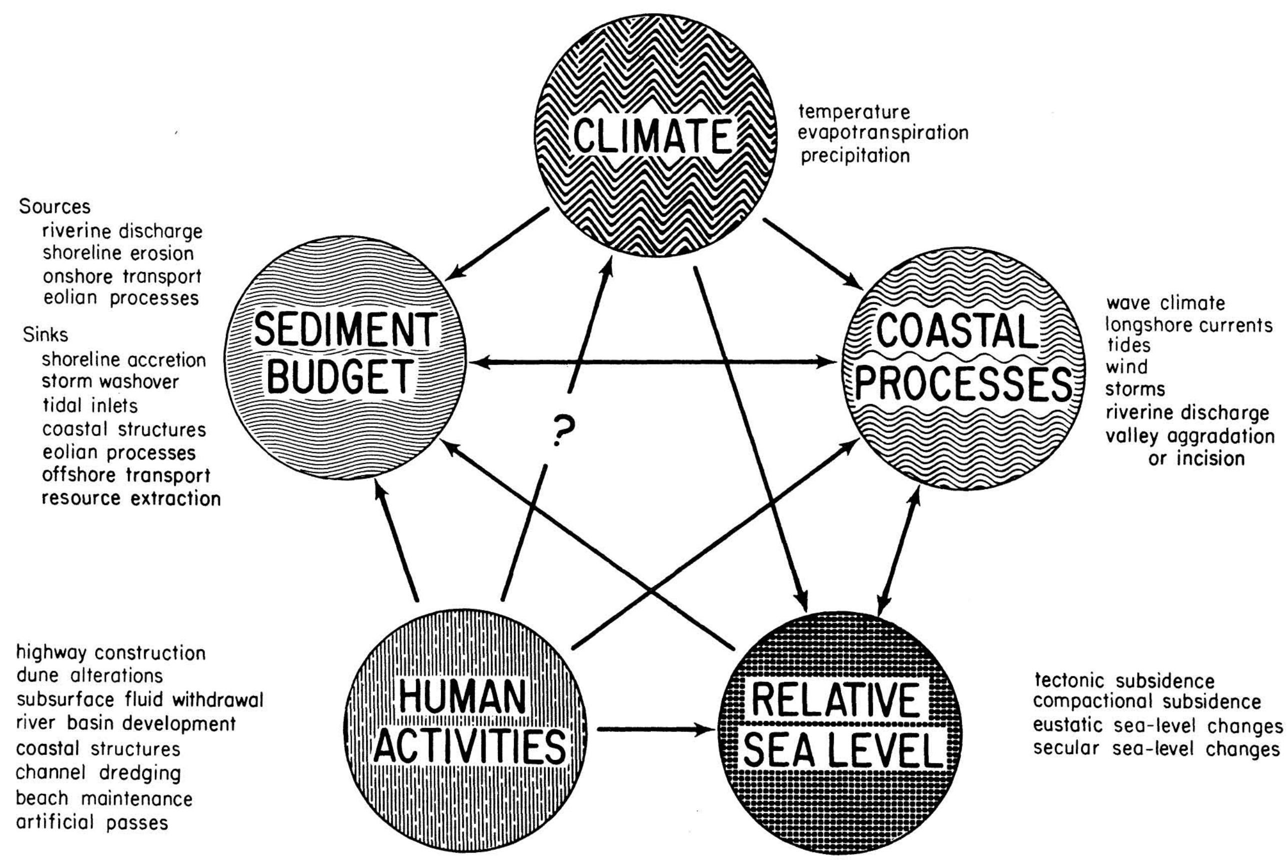

Figure 17. Interaction of factors affecting land losses. Arrows point toward the dependent variables. The number of arrows originating from or terminating at a particular factor indicates the relative degree of independence or interaction. For example, human activities are independent of the other factors, but they affect sediment budget, coastal processes, relative sea-level conditions, and perhaps, climate. From Morton (1977).

Climate

Global changes in climate since the last glacial stage have indirectly affected positions of bay shorelines. In general, temperature was lower (Flint, 1971) and precipitation was greater (Schumm, 1965) at the end of the Pleistocene than at present. The warmer and drier conditions that now prevail indicate that vegetal cover, runoff, and sediment yield have diminished during the past few thousand years.

According to Dury (1965), many rivers transported 5 to 10 times more water during the early Holocene than they do today. This is evident on the geologic map by Brown and others (1976), which shows that the ancestral Nueces River was larger and capable of transporting greater volumes of sediment. Decrease in river size, in turn, affected sediment budget primarily by reducing the volume of sediment supplied to the Nueces delta and Nueces Bay. The discharge of Oso Creek, however, was probably not appreciably affected by climatic changes because of the limited size and drainage area of the creek.

The effects of drought on shoreline changes are also minor and indirect. They cause a slight but perceptible lowering of sea level that may promote apparent, rather than actual, accretion. This ephemeral influence stops when normal water levels return after the drought. Real accretion that is attributable to droughts occurs only locally where active sand dunes migrate across the backbarrier flats and advance the bay shoreline toward the mainland. Overall climate is the least important factor when considering long-term historical shoreline changes.

Sea-Level Position

The factor affecting shoreline position receiving the most recent attention is relative sea-level change (Hicks, 1978) resulting from natural movement of the Earth's crust (Holdahl and Morrison, 1974), from human-induced subsidence (Gabrysch, 1969), and from climatic changes (Etkins and Epstein, 1982). At least four conditions govern land-sea relations at the shoreline (fig. 17), but only two significantly influence shoreline changes along the Texas coast. Tectonic subsidence is imperceptible on a historical time scale; eustatic (worldwide) sea-level rise, although documented (Lisitzin, 1974), is probably a minor influence and of less magnitude than are compactional subsidence or local secular sea-level variations.

Compactional Subsidence

Relative sea-level changes have been determined during the past few decades by monitoring mean sea level and establishing trends on the basis of long-term tide gauge measurements (Gutenberg, 1941; Marmer, 1951; Hicks, 1972). Because this method cannot differentiate sea-level rise from land-surface subsidence, Swanson and Thurlow (1973) used statistical techniques to adjust tidal data for the glacial-eustatic component and concluded that the slight rise in sea level recorded along most of the Texas coast is due to compactional subsidence.

A minor rise in sea level caused by compactional subsidence (or any other factor) theoretically can result in considerable landward movement of the shoreline if slopes are sufficiently low (Bruun, 1962). However, both natural beach slopes and tide gauge measurements at Port Aransas (Swanson and Thurlow, 1973) indicate that compactional subsidence in the Corpus Christi area is minor if at all significant.

Natural compaction of the thick sedimentary section that underlies the Coastal Plain and continental shelf can be augmented and actually surpassed by compaction associated with hydrocarbon production (Pratt and Johnson, 1926) and with ground-water withdrawal (Gabrysch, 1969). Land-surface subsidence associated with fluid extraction appears to be minor in the Corpus Christi area and is primarily centered near Clarkwood and southern Nueces Bay (Brown and others, 1974; Ratzlaff, 1980). Continued withdrawal and concomitant dewatering of shales and decline in pore pressures, however, could eventually cause significant decreases in surface elevation and lead to future land losses, especially where substantial production occurs at or near the shoreline.

Secular Variations

Secular sea-level variations, or time-dependent oscillations (Hicks and Crosby, 1975), may also contribute to short-term (years) shoreline changes. For example, anomalous shoreline accretion along parts of the central coast during the mid-1950's was probably related to slightly lower sea-level conditions (Morton and Pieper, 1977). This trend is well illustrated by many tide gauge records throughout the United States (Swanson and Thurlow, 1973; Hicks and Crosby, 1975), including the Galveston and Port Isabel gauges. Most of the state was affected by drought from 1950 to 1956; the most severe drought, between 1954 and 1956 (Lowry, 1959), caused reduced riverine discharge and excessive evaporation from the bays. These conditions prompted apparent shoreline accretion by lowering the water level. Similarly, the recent rise in sea level (Hicks and Crosby, 1975) may have partly caused increased and nearly coastwide shoreline erosion elsewhere.

Sediment Supply

The balance between the sediment supply and the nearshore wave and current forces determines shoreline stability. Shorelines accrete when sediment supply exceeds the erosional capacity of nearshore energy, whereas they erode when sediment supply is deficient relative to nearshore energy. Although sediment sources and sinks (fig. 17) and coastal processes can be drastically altered by human activities, they do not change appreciably under natural conditions over periods of several hundred years.

Sources of Sediments

The primary shoreline processes and the associated sources of bay shoreline sediments in order of importance are (1) redistribution of existing sediments, (2) introduction of terrigenous sediments, (3) deposition of washover fans and flood-tidal deltas, and (4) migration of active backbarrier dunes.

The continuous reworking of bay margins by waves and nearshore currents causes both major and minor shifts in sediment distribution. Minor shifts are largely imperceptible and occur as beach material moves a short distance offshore when waves are slightly higher than normal; much of this material returns to the beach during quiescent periods. In contrast, major shifts in sediment account for the most noticeable long-lasting changes that result in net losses along some shoreline segments. During intense storms, bay shorelines erode, and longshore currents transport coarse-grained material away from the site (downdrift). Meanwhile, the fine-grained material is suspended, transported away from the site, and usually deposited in a slack-water or low-energy environment.

The undercutting and scouring action of waves is particularly devastating to clay bluffs because their predominantly fine-grained sediment is permanently removed from the shore. The sand, transported alongshore, feeds nearby beaches and bay-margin shoals. The volume of sand added at the expense of bluff retreat is, however, significant only over hundreds or thousands of years. For example, the original sand deposits on North Beach and Indian Point were supplied partly by updrift clay-bluff erosion along southern and northern Corpus Christi Bay. Because shoreline alterations in adjacent areas (mainly from channel and bulkhead construction) eliminated this sand supply, these formerly accreting beaches are now eroding.

The only significant source of new fluvial sediment in the study area is the Nueces River, which delivers terrigenous clastic sediments primarily to Nueces Bay near the river mouth. Influx of fluvial sand and mud was undoubtedly greater in volume several hundred years ago than it is today, but natural decreases in precipitation, runoff, and sediment yield, as well as recent reductions in sediment transport (fig. 18), have essentially nullified the sediment contribution from the Nueces River. The diminished sediment load of the river reflects the river-basin development (flood control, surface storage, irrigation); sediment is impounded in reservoirs associated with these upstream projects. Lake Corpus Christi, created with the construction of Mathis Dam in 1929 (Texas Water Development Board, 1967b), decreased sediment concentration downstream of the dam (fig. 18). The enlargement of this reservoir, beginning in 1958 with the completion of Wesley E. Seale Dam, further reduced sediment concentration downstream of Seale Dam. These projects have reduced suspended sediment supplied to Nueces Bay from approximately 750,000 tons/yr in the first half of this century to about 40,000 tons/yr during the period from 1970 to 1980.

Both the volume of sediment delivered to bay shores by storm washover and tidal currents and the areas influenced by these processes are minor. A major washover area on Mustang Island (Corpus Christi Pass, Newport Pass, and Packery Channel) comprises what was previously a natural tidal-inlet/tidal-delta complex that has been modified by storm washover since the inlet closed. The inlet shoaled and became inactive after the Corpus Christi Ship Channel was opened (Price, 1952). Storm waves periodically inundate the washover areas and deposit tongues of sand that project into Corpus Christi Bay and cause perturbations in the shoreline. These are local features, however, and little sediment is added to the littoral drift system.

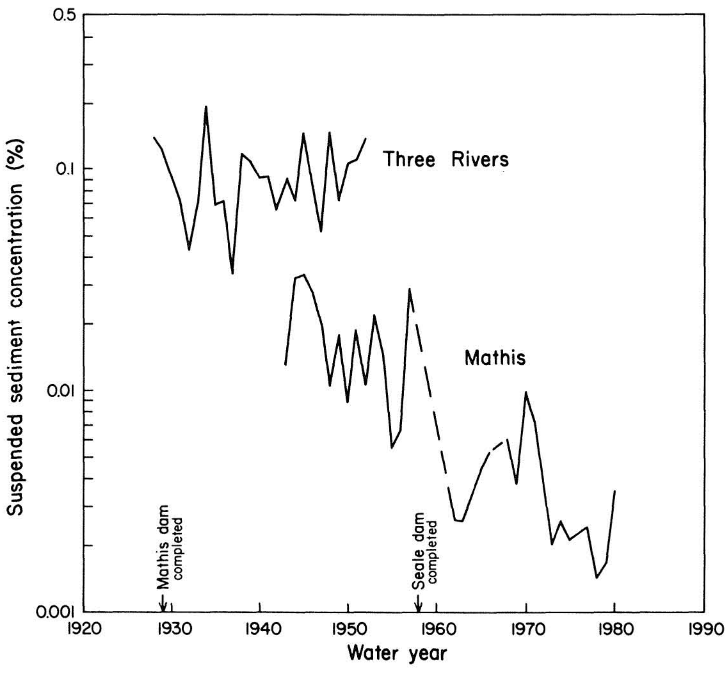

Figure 18. Suspended-sediment concentration (by weight) of the Nueces River at the Three Rivers and Mathis stations. Three Rivers is upstream of Lake Corpus Christi; Mathis is downstream of the lake. No data for dashed segments. Data from Texas Board of Water Engineers (1961), Texas Water Commission (1964), Texas Water Development Board (1967b, 1970, 1974), Texas Department of Water Resources (1979 and unpublished data).

The baymouth bar across Oso Bay is another washover area that was frequently flooded until the highway was elevated and riprap was placed along the shore. Now the areas adjacent to Ward Island receive only minor amounts of sand when bay levels and storm waves overtop the road.

Dune migration, being ephemeral and occurring less frequently than does overwash, is a locally minor source of sediment for the bay shore of Mustang Island. During severe droughts, dune fields north of Corpus Christi Pass become active and migrate across the barrier. This sand, transported by eolian processes, enters the bay, where it nourishes nearby beaches. Unfortunately, the positive effect of sand transport on the bay shoreline is short lived, and its recurrence is both infrequent and unpredictable.

Sediment Sinks

Processes and associated sinks that tend to permanently remove sediment from the nearshore bay system include (1) deposition in the deep bay centers, (2) deposition in artificial and natural channels, (3) containment by coastal structures, and (4) dredging and mining of bay sediment.

Shepard and Moore (1960) reported that Corpus Christi Bay shoaled an average of slightly more than 1 ft between 1868 and 1934. These bay-margin and bay-center deposits are mostly composed of fine silt and mud (White and others, 1983) that settle from suspension and some sand and shell debris that are transported by storms into deeper water, where burrowing organisms incorporate them into the muddy sediments. Sediments that fill both natural and artificial channels can also be fine grained, but usually they contain some sand and gravel-sized shell concentrated near the channel base by strong currents. If the fine fraction has been winnowed from the coarse sediments, the channel fill may be composed mostly of sand and a few mud drapes.

The cumulative losses of coarse material (sand and shell) to deeper water below the wave base and away from the shore negatively affect sediment budget and lead to a deficit in sand supplied to the shoreline. Emplacement of coastal structures and removal of sediment from the bay system by humans also cause deficits in sediment supply.

Storm Frequency and Intensity

Storms are brief, yet they release enormous amounts of energy. They also cause rapid shoreline retreat that commonly results in net losses of land.

The frequency of tropical cyclones depends, in part, on cyclic fluctuations in atmospheric temperature. Hurricane frequency supposedly increases during warm cycles (Dunn and Miller, 1964), but the historical data indicate little variation in frequency. According to summaries based on records of the U.S. Weather Bureau (app. B), 69 tropical cyclones have either struck or affected the Texas coast during this century (1900 to 1983), which averages 0.8 storms per year, similar to the 0.67 storms per year average reported by Hayes (1967). Simpson and Lawrence (1971) used comparable historical data to calculate the probability of storms striking 50-mi segments of the Texas coast. Their data indicate that each year the Corpus Christi - Mustang Island area has a 13-percent probability of undergoing a tropical storm, a 7-percent probability of a mild hurricane, and a 4-percent probability of a catastrophic hurricane.

During storms, high windspeeds and low barometric pressures raise bay levels to extraordinary heights (table 1) that may last from several hours to several days. The surge heights and consequent damage to the beach occurring during these peak periods depend on such factors as direction of storm approach, configuration of the shoreline, shape and slope of the bay bottom, maximum wind velocities, forward speed of the storm, distance from the eye of the storm, stage of astronomical tide, lowest atmospheric pressure, and duration of the storm.

Surge heights in Corpus Christi Bay have equaled or exceeded 4 ft at least 10 times during the past 67 years (table 1). Waves superimposed on these water levels overtop beaches, berms, and marshes. Internal friction (breaking waves), drag (over vegetation or mobile sediment), and obstruction from barriers having higher elevations (such as dunes and bluffs) dissipate wave energy. Under these extreme storm conditions, the bay shores are completely out of equilibrium with the scouring forces. To achieve equilibrium between landforms and physical forces, sediment is eroded and transferred from high-energy to low-energy areas. Where surge heights exceed land elevations (marshes, sand and shell beaches), the dominant transport direction is onshore. Where surge heights are below the land crest (clay bluffs, sandy slopes), the eroded sediment is carried offshore. The sediment transported away from the bay shores by storms accounts for most of the net losses in land area.

Human Activities

Roughly half of the shores of Corpus Christi, Nueces, and Oso Bays have been altered by coastal projects (fig. 5). These projects clearly promote the shoreline changes of greatest magnitude, but it is uncertain whether these activities augment changes coastwide, throughout the entire bay system, or just in adjacent shoreline sectors. Moreover, the components of shoreline changes induced by local, regional, and global influences are difficult to measure because human activities promote imbalances in sediment budget, coastal processes, and relative sea-level conditions (fig. 17). For example, construction of dams and navigation channels, erection of seawalls, bulkheads, and groins, and excavation of sediment all tend to reduce the volume and size of sediment available to the bay shores. Building impermeable structures and mining sediment have immediate, site-specific impacts as well as long-term effects, whereas many years may pass before the effects of other activities such as subsurface fluid withdrawal, flood control, and sediment impoundment are detected.

Dredging ship channels to Corpus Christi and Ingleside and building bulkheads along the southern shore of Corpus Christi Bay began during the early twentieth century and continue today. These and other projects alter natural processes, such as wave refraction and current circulation; their effects on shoreline changes are debatable. It is well known, however, that impermeable structures and deep-draft channels interrupt littoral drift and impound sediment at the expense of beaches downdrift of the projects.

The tremendous volume of sediment that has been and continues to be removed from the bay is indicated by incomplete data for two independent activities--excavation of shell material as an economic resource and maintenance dredging of shipping routes. Records of the Texas Parks and Wildlife Department show that for the first activity, more than 2.5 million yd^3 of shell material were mined from Nueces Bay between 1969 and 1974 (fig. 19). These high rates of shell production could not be sustained for more than two decades, given the limited bay area and mining depths. Nevertheless, the cumulative volume of sediment removed was substantial enough to increase water depths by several feet. Maintenance dredging of navigation channels also removes several hundred thousand cubic yards of sediment annually. Dredging requirements for the Gulf Intracoastal Waterway between Corpus Christi and Baffin Bay average about 200,000 yd^3/yr (U.S. Army Corps of Engineers, 1975). The deeper and longer network of ship channels that cross Corpus Christi Bay has even greater dredging requirements. For example, averages of more than 1 million and 2.5 million yd^3/yr of sediment have been removed from La Quinta and Corpus Christi Ship Channels, respectively, since the late 1940's (U.S. Army Corps of Engineers, unpublished data). These rates include material removed in maintenance

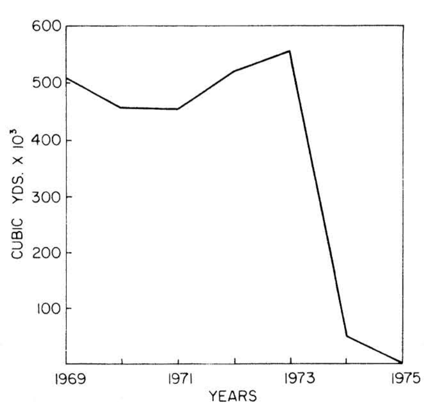

Figure 19. Oystershell extraction in Nueces Bay from 1965 to 1974. Illustration from Kier and White (1978); data from the Texas Parks and Wildlife Department (1969 through 1975).

and deepening of the channels, which are currently 45 ft deep. Both shell production and maintenance dredging contribute to shoreline erosion by allowing for an increase in wave energy, a change in wave-refraction patterns, and a decrease in sediment supply.

Predicting future human impact on the bay shoreline is more difficult than documenting human influence on past shoreline changes. For example, some scientists have speculated that releasing carbon dioxide and fluorocarbons into the atmosphere from burning fossil fuels and using canned aerosols will cause a greenhouse effect that, in turn, will raise average temperatures, melt polar ice caps, and raise sea level (Emery, 1980; Etkins and Epstein, 1982). Although some meteorological data have been used as evidence to support such a theory, the conclusions are unsubstantiated. Other scientists have used different arguments to suggest that reductions in solar radiation by particulate matter in the atmosphere would cause a cooling effect, consequently expanding continental ice sheets and lowering sea level (Lamb, 1970). Nevertheless, both theories suggest that human activities may eventually alter weather patterns and possibly sea-level position.

HISTORICAL CHANGES

To facilitate discussion, the Corpus Christi Bay system was divided into five segments (fig. 20), composed of northern Corpus Christi Bay (Port Ingleside to Indian Point), southern Corpus Christi Bay (Rincon Point to Encinal Peninsula), eastern Corpus Christi Bay (Mustang Island), Oso Bay, and Nueces Bay. Comparison of shorelines mapped for three time periods (late 1800's, 1930's, and 1982) indicated whether lengths of shoreline moved bayward, landward, or remained stationary between these periods. The shoreline measurements also were used to calculate distances and rates of advance or retreat. Aerial photographs taken between the 1930's and 1982 helped determine more precisely the date of specific shoreline changes.

Two methods were used to quantify shoreline changes. First, a shoreline segment for a particular period (for example, northern Corpus Christi Bay from 1867 to 1930) was divided into lengths of shoreline that moved bayward (accreted), landward (eroded), or showed no net movement (were stable). Each length was added to others of its type to account for the total length of accreting, eroding, and stable shoreline (fig. 21). Second, measuring points (stations) were distributed throughout the bay system (fig. 20), and amounts and rates of shoreline change were measured at these stations. Station spacing was approximately 5,000 ft in Corpus Christi and Nueces Bays. Spacing was irregular, averaging 3,500 ft, in Oso Bay. Rates of shoreline change are presented in figures 22 through 24 and in appendix A.

To place these measurements in proper context, it should be emphasized that Corpus Christi Bay owes its present shape predominantly to wave erosion during the Holocene sea-level

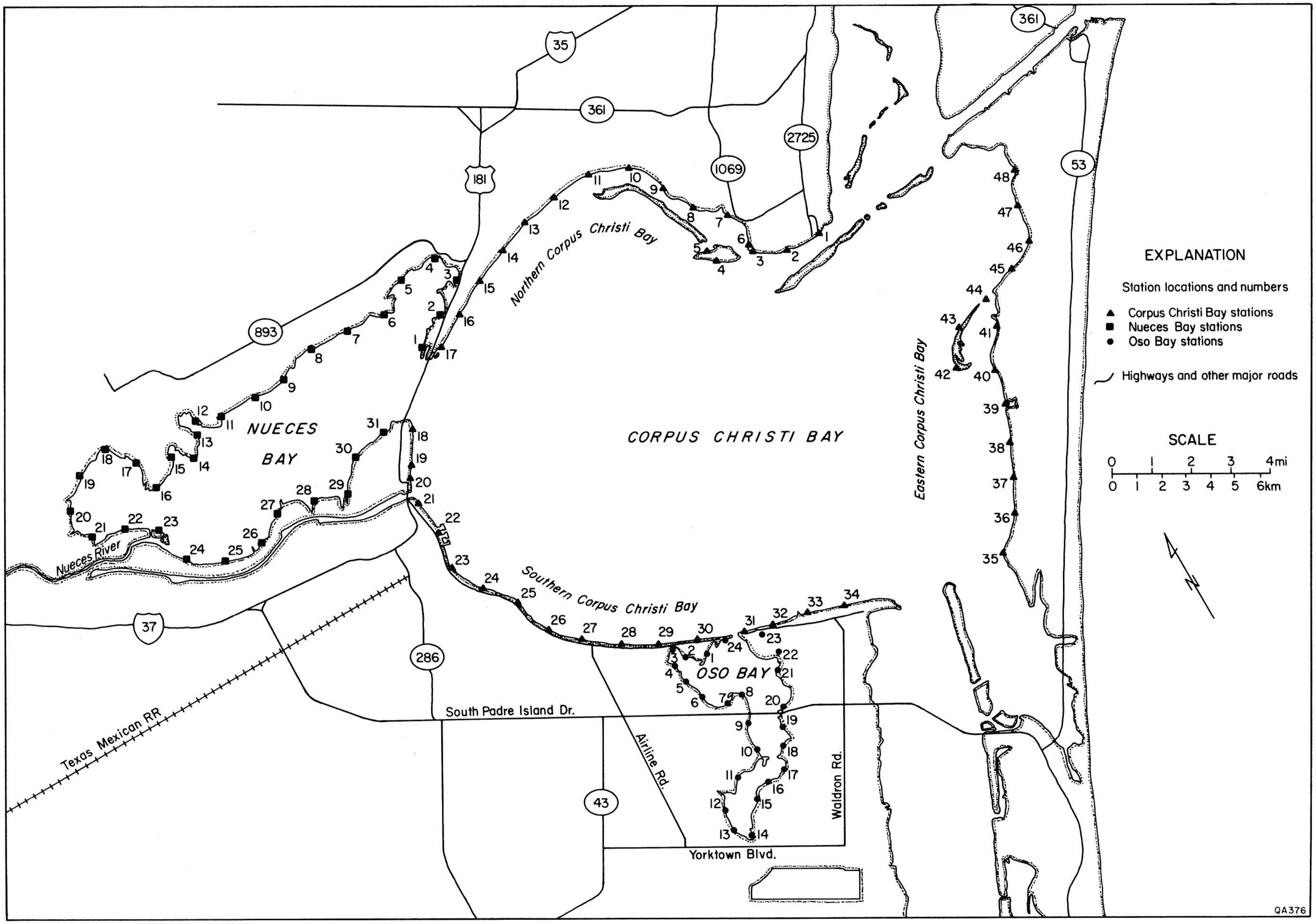

Figure 20. Location of measuring points (stations) in Corpus Christi, Oso, and Nueces Bays.

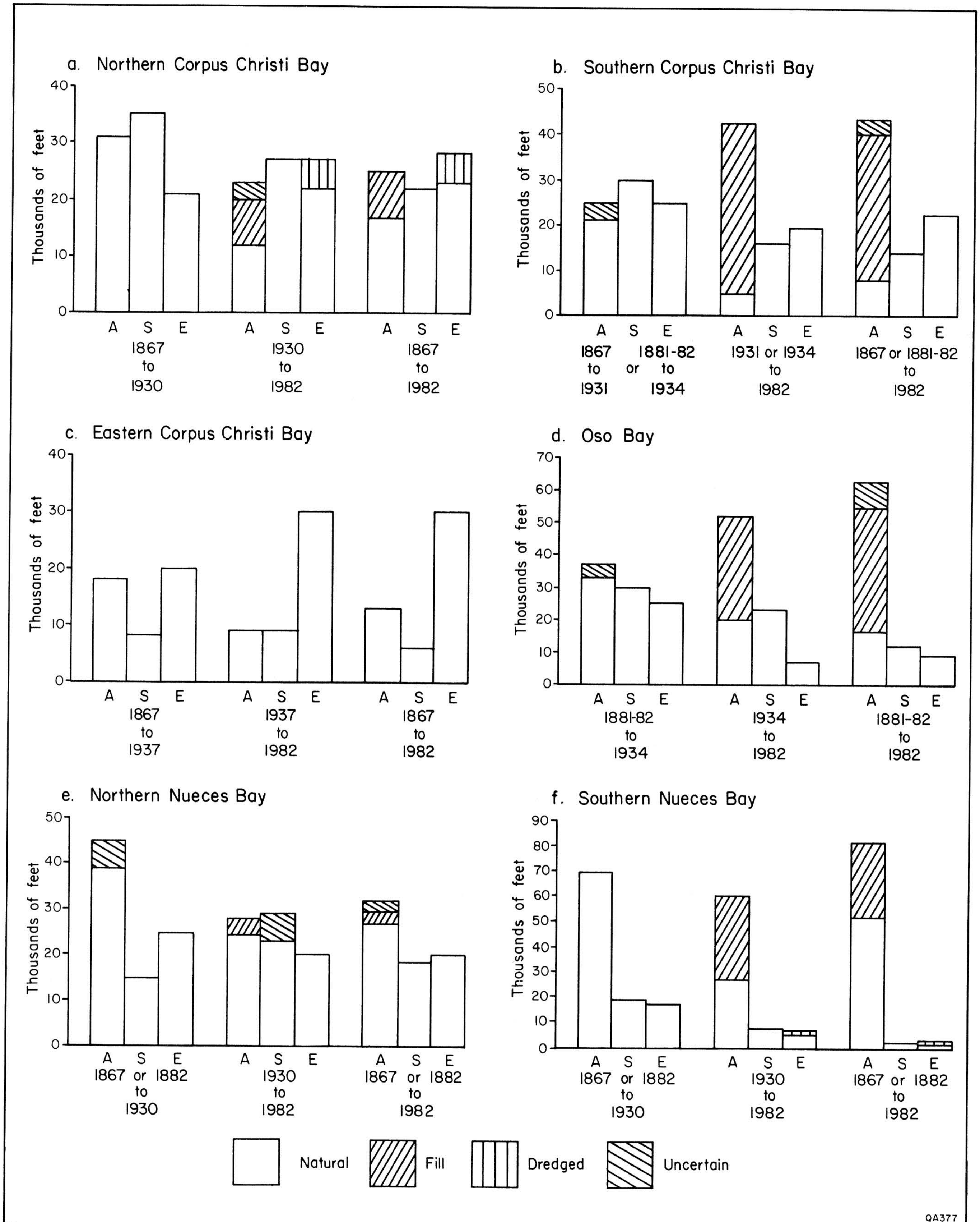

Figure 21. Distribution of accreting (A), stable (S), and eroding (E) shoreline segments for early (late 1800's to 1930's), late (1930's to 1982), and cumulative (late 1800's to 1982) periods.

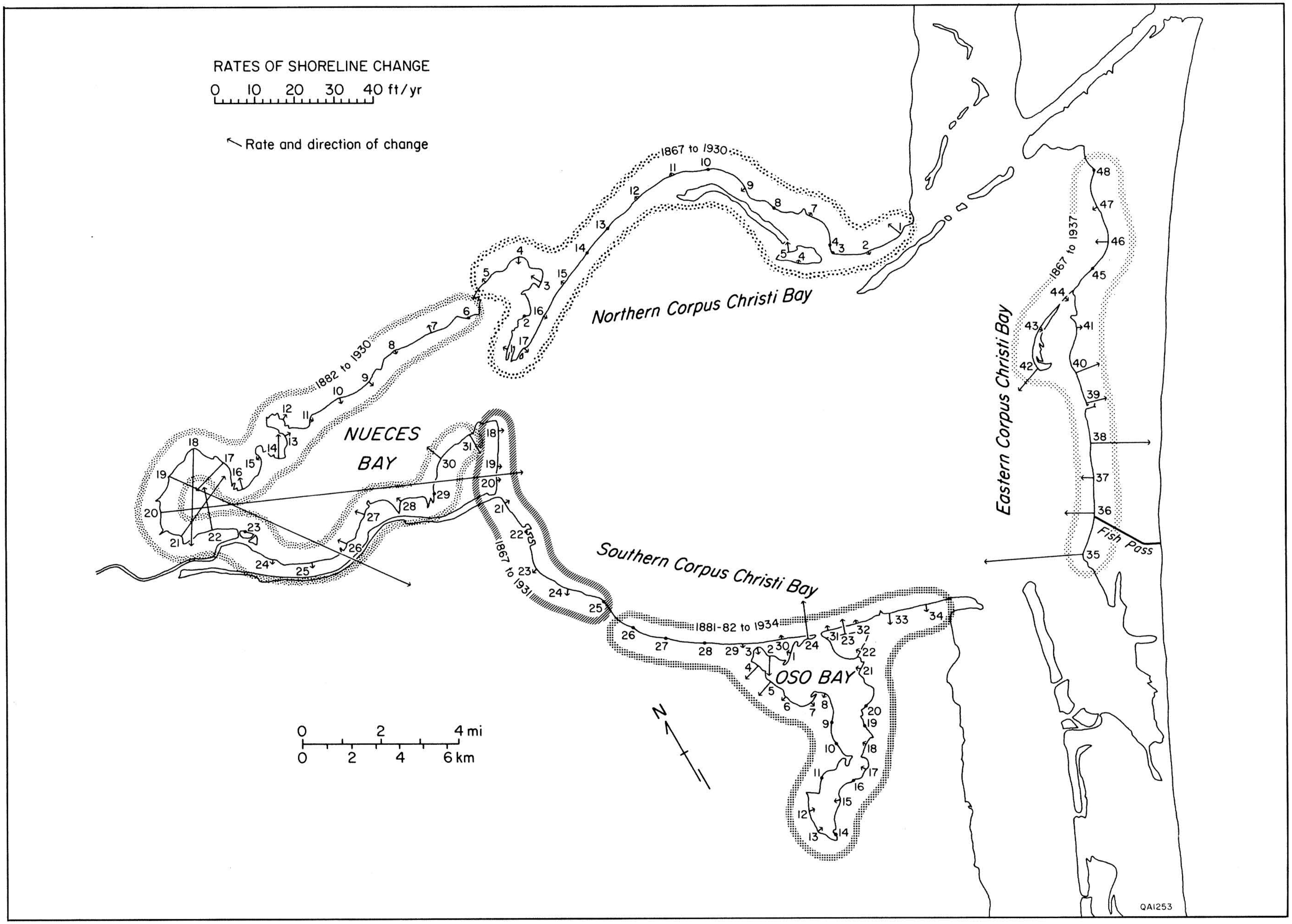

Figure 22. Rates of shoreline change in Corpus Christi, Oso, and Nueces Bays, late 1800's to 1930's.

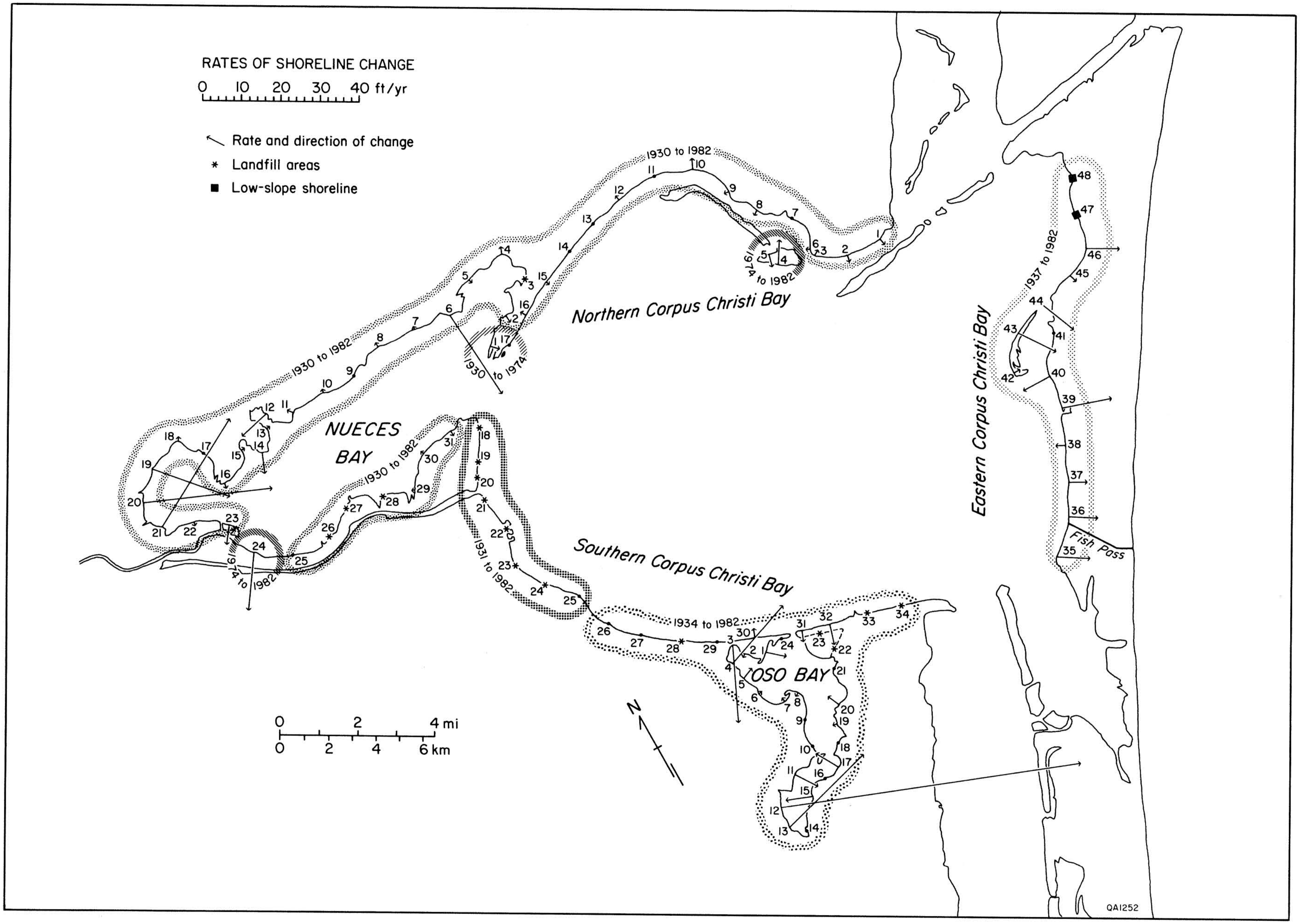

Figure 23. Rates of shoreline change in Corpus Christi, Oso, and Nueces Bays, 1930's to 1982.

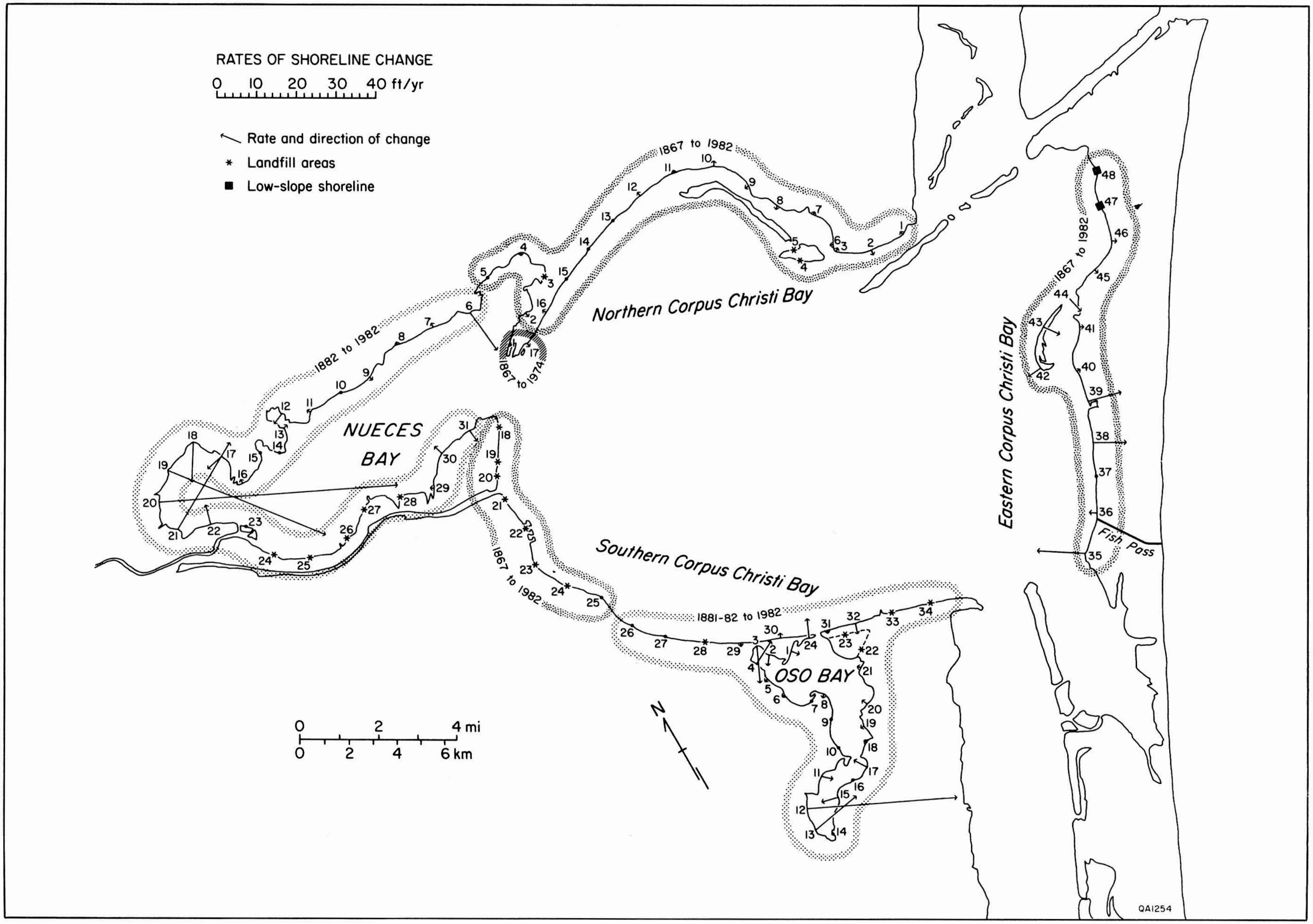

Figure 24. Rates of shoreline change in Corpus Christi, Oso, and Nueces Bays, late 1800's to 1982.

rise and highstand. This erosion transformed the area from an angular, incised river valley (fig. 4) to a nearly circular bay in approximately 10,000 years, or at a probable average long-term erosion rate of about 3 ft/yr.

Northern Corpus Christi Bay

The northern shoreline of Corpus Christi Bay extends from Port Ingleside to Indian Point and includes Corpus Christi Bay stations 1 through 17 (fig. 20). Historical shoreline changes were determined from 1867 topographic maps and from 1930 and 1982 aerial photographs. In addition, 1974 photographs were used to document some recent short-term changes (1974 to 1982) and to supplement incomplete 1982 coverage.

Examination of the geologic map (fig. 3) and wind patterns (fig. 5) assists in understanding the long-term shoreline trends in northern Corpus Christi Bay. Two Holocene spits (Indian Point and Ingleside Point) have formed along this stretch. Ingleside Point formed from sand eroded from Live Oak Ridge (stations 1 to 3) by southeasterly waves and possibly by tidal currents between Corpus Christi and Redfish Bays. This spit is now a spoil island separated from Live Oak Ridge by La Quinta Channel. Before human modification, erosion probably occurred from stations 1 to 3, and accretion at stations 4 and 5. However, the maintenance of Aransas Pass as the dominant tidal pass for Corpus Christi Bay has closed Packery Channel, changing the tidal-current regime in Corpus Christi Bay. In addition, spoil mounds along the Corpus Christi Ship Channel protect Live Oak Ridge from the predominant southeasterly waves. Both modifications tend to reduce erosion at stations 1 to 3 and downdrift spit growth at stations 4 and 5.

Indian Point spit was probably built mostly from sediment supplied by erosion of the shoreline between stations 11 and 15. The shoreline between stations 6 and 10 is nearly parallel to the predominant wind and wave direction and is protected by Ingleside Point and La Quinta Channel spoil mounds; thus severe erosion is not expected along this stretch. Erosion between stations 11 and 15 is facilitated by long southeasterly wave fetch across Corpus Christi Bay. Material eroded from this stretch by southeasterly waves is carried toward Indian Point by longshore currents, causing growth of the Indian Point spit. As Indian Point accretes and the updrift stretch erodes, the shoreline is reoriented more perpendicular to the predominant waves. Dissimilar movement of this shoreline stretch can be expected until reorientation is complete.

1867 to 1930

Only one major human modification (dredging of the Corpus Christi Ship Channel) had begun by 1930; therefore, most shoreline changes for the area and period were due to natural processes. Nearly 35 percent of the 1930 shoreline was bayward of its 1867 position; 24 percent of the 1930 shoreline underwent net erosion compared with its 1867 position (fig. 21a). The rest of the shoreline showed no measurable change during this period.

Shoreline advance or retreat along northern Corpus Christi Bay was generally small. Indicating relative stability, net rates of change were less than 2 ft/yr for all but two measuring stations (fig. 22). The largest amount of shoreline retreat (250 ft) was measured at station 1, which is about 1,000 ft west of a small channel cut into the Ingleside sand before 1930 to establish a dock at Port Ingleside. The most accretion (150 ft) occurred at station 5 on Ingleside Point, a spit building westward from Live Oak Ridge. Local accretion near Donnel Reef (75 ft at station 9) was aided by wave disruption near the reef.

Near Portland, stations 13 and 14 recorded no net change, indicating a stable shoreline for this period. The shoreline at stations 11, 12, and 15 retreated at a rate of less than 0.5 ft/yr, whereas the shoreline at stations 16 and 17 on Indian Point Peninsula accreted slightly, probably as a result of minor updrift erosion.

1930 to 1982

During this period, 36 percent of the northern Corpus Christi Bay shoreline had measurable net erosion, a significant increase from the 1867 to 1930 period (fig. 21a). In addition, spoil and made land accounted for almost half of the shoreline that accreted between 1930 and 1982.

The rate of shoreline advance or retreat was generally less than 2 ft/yr (fig. 23); rates higher than this were found at stations 4, 5, and 10 and were commonly due to discrete events rather than to continuous processes. Net accretion of 875 ft at station 4 and 150 ft at station 5 on Ingleside Point was due to disposal of dredge material, probably from La Quinta Channel. Rapid erosion at these sites (6 ft/yr at station 4, 3 ft/yr at station 5) between 1974 and 1982 attests to the instability of unprotected spoil mounds. Minor accretion at stations 8 and 9 (75 and 50 ft, respectively) was undoubtedly related to the placement of spoil banks along La Quinta Channel. Net erosion of 100 ft at station 3 was related to the dredging of La Quinta Channel in 1956 and 1957, whereas net erosion of 150 ft at station 10 was not clearly related to any single event.

Net rates of shoreline change for the Portland area (stations 13 to 15) were near zero for this period as well. Station 16 on Indian Point Peninsula eroded 100 ft, in contrast to minor accretion between 1867 and 1930. Sediment supplied by updrift erosion was sufficient to offset natural erosion at station 17 and resulted in no net change for that station.

1867 to 1982

Cumulative movements of the shoreline for this 115-year period were similar to those of the constituent periods. Nearly 40 percent of the 1982 northern Corpus Christi Bay shoreline occupied a position landward of that in 1867 (fig. 21a), whereas 33 percent of the shoreline held a position seaward of its 1867 position. One-third of the accreting shoreline consisted of spoil or made land.

At all but two stations, net rates of shoreline change were less than 2 ft/yr (fig. 24). Stations 4 and 5 on Ingleside Point underwent net accretion of 850 and 300 ft, respectively, caused mostly by disposal of dredge material. Before disposal of the dredge material, the shoreline near station 4 was eroding, whereas that near station 5 was accreting. Dominant southeasterly winds form waves that tend to straighten and reorient the northern Corpus Christi Bay shoreline to a northeast-southwest trend; the result was erosion of 25 to 150 ft at stations 10 to 12, stability at stations 13 to 15, and minor accretion at station 17. Station 16 accreted during the early period, but local erosion between 1930 and 1982 left the 1982 shoreline landward of its 1867 position.

Southern Corpus Christi Bay

Shoreline changes between Rincon Point and Demit Island (fig. 20, stations 18 to 34) were documented using topographic maps made between 1867 and 1882 and aerial photographs taken in 1931, 1934, and 1982. Historical information and qualitative shoreline changes were determined from aerial photographs taken between 1934 and 1982.

Holocene bay-margin bars and spits attest to the importance of longshore sand movement in determining shoreline position around southern Corpus Christi Bay (fig. 3). Bluff erosion during heavy rains and high tides contributes sand to the shore; the sand is then carried alongshore, nourishing adjacent stretches of shoreline. In southern Corpus Christi Bay, northerly winds produce waves that tend to move sediment alongshore in a southeasterly direction. These winds are largely responsible for the Demit Island spit and the bar connecting Ward Island with Encinal Peninsula. Conversely, the common easterly and southerly winds tend to move sediment alongshore toward the northwest to form the Rincon Point spit. In summary, the three Holocene accretionary features were caused by erosion of Pleistocene sediments.

Extensive human modifications (two seawalls, a ship channel, bulkheads, and riprap) along the entire southern Corpus Christi Bay shoreline have reduced erosion of the Pleistocene sediments, which in turn reduced the amount of sediment transported alongshore. The results include narrower beaches, decreased bluff protection, and increased erosion in areas such as Rincon Point and Demit Island, which depend on longshore transport of sediment.

Late 1800's to Early 1930's

The earliest time period began and ended at different dates for different segments of southern Corpus Christi Bay (fig. 22) because early topographic charts and 1930's aerial photographs were not completed for the entire bay at the same time. Yet, this inequality does not appreciably affect the results and interpretations if rates of change rather than distances are used for comparison among stations.

Between 1867 and 1931, Corpus Christi grew from a small community of less than 20 blocks near the present-day seawall to a city many times that size. By 1931, agricultural development behind the Pleistocene bluffs stretched from Cole Park eastward to Oso Bay, and a major engineering project (dredging of the Corpus Christi Turning Basin) had breached Rincon Peninsula. In addition, a breakwater protecting the downtown area had been constructed by this time.

In the early 1930's, more than 30 percent of the southern shore of Corpus Christi Bay was measurably landward of its 1800's position (fig. 21b). Net rates of shoreline change were generally less than 2 ft/yr (fig. 22). Four of the seven stations undergoing net accretion were located in the western half of southern Corpus Christi Bay, whereas three of the five stations recording net erosion were in the eastern half of this segment. Stations 18 through 21, which occur in a zone of longshore accumulation from prevailing southeasterly winds (fig. 5), all showed net accretion for the period. Rates of accretion for these stations were as much as 1.2 ft/yr. Among the highest rates of change were those at Encinal Peninsula stations 33 and 34, recording erosion rates of 2.4 and 1.9 ft/yr, respectively. Encinal Peninsula contributes sand to bars connecting it with Ward Island to the west and Demit Island to the east.

Early 1930's to 1982

Human modifications of the bay bottom and shoreline have been concentrated along the southern shores of Corpus Christi Bay since the 1930's. By 1938, the Corpus Christi Ship Channel had been extended from the Corpus Christi Turning Basin to Avery Point Turning Basin. By 1956, Tule Lake Channel had been cut inland, the downtown area was extended bayward with fill material, the Corpus Christi seawall was in place, the T-heads had been constructed, and the Corpus Christi Naval Air Station occupied the northern end of Encinal Peninsula. The North Beach nourishment project was completed in 1978 (figs. 14, 15, and 16), and by 1982 most of the shoreline between Rincon Point and Encinal Peninsula had been stabilized with riprap, bulkheads, and seawalls (fig. 5).

In 1982, most of the southern Corpus Christi Bay shoreline (54 percent) was bayward of its early 1930's position (fig. 21b). Made land accounted for almost 90 percent of this total. Twenty-five percent of the southern Corpus Christi Bay shoreline occupied a position landward of that in the early 1930's.

Only two stations (31 and 32) underwent net erosion during this period (fig. 23); both were located on the small spit west of Encinal Peninsula. Several stations located approximately midway between Encinal Peninsula and Rincon Peninsula recorded no change. Net accretion of 450 and 400 ft at stations 22 and 23, respectively, was caused by landfill behind the Corpus Christi seawall; landfill at Swantner Park accounts for the 375-ft net accretion at station 28. Landfill associated with the construction of Corpus Christi Naval Air Station moved the shoreline bayward about 300 ft near stations 33 and 34. Net accretion at stations 18, 19, and 20 was due to artificial nourishment of North Beach (figs. 14 and 15), which experienced severe erosion between 1931 and 1974. Profiles completed after the restoration indicate that the beach is currently eroding (fig. 16). The Corpus Christi seawall and the ship channel obstruct northward-moving sediment and probably cause the consistent North Beach erosion. Future artificial nourishment of North Beach will be required to replace the interrupted natural nourishment.

Late 1800's to 1982

Approximately 28 percent of the southern Corpus Christi Bay shoreline occupied a position in 1982 landward of that in the late 1800's, whereas more than 50 percent of the shoreline exhibited net accretion during the same period (fig. 21b). Nevertheless, more than 80 percent of the accreting shoreline had been subject to landfill, and another 8 percent of accretion occurred in an area of uncertain 1800's shoreline location. Most likely, the amount of shoreline undergoing net erosion would increase dramatically if it were not for these two factors.

Four stations (24, 29, 31, and 32) underwent erosion that ranged from net rates of less than 1 ft to about 2 ft/yr (fig. 24). Stations 25 through 27 showed no measurable change, whereas 10 stations accreted 125 ft or more. All stations recording accretion except station 30 were sites of extensive filling, including the North Beach project, the Corpus Christi seawall, Cole Park, Swantner Park, and the Corpus Christi Naval Air Station.

Eastern Corpus Christi Bay

Shorelines mapped along the bay margin of Mustang Island from 1867 topographic charts and 1937 and 1982 aerial photographs were used to determine shoreline changes for eastern Corpus Christi Bay (fig. 20, stations 35 to 48). White and others (1978) reported additional information on historical changes in the Mustang and north Padre Islands area.

Mustang Island is a Holocene barrier island (fig. 3) composed mostly of sand. These sediments are subject to rapid shoreline changes because they have lower elevations and are less consolidated than the bluff-forming Pleistocene fluvial-deltaic sediments found elsewhere around Corpus Christi Bay. Although waves caused by predominant southeasterly winds are not incident to the bay shoreline of Mustang Island, these winds can cause shoreline accretion as dunes migrate across the island and into the bay. Northerly winds cause longshore transport in a southerly direction and promoted the growth of the Shamrock Island spit. Growth of this spit was also possibly aided by tidal currents in Corpus Christi and Redfish Bays before Aransas Pass was artificially maintained as the dominant tidal pass for the area.

1867 to 1937

Before 1937, the only major human modifications near Mustang Island were dredging and jetty construction at Aransas Pass, beginning in the late 1800's (summarized in Morton and Pieper, 1977), and dredging of the Corpus Christi Ship Channel across Harbor Island. These projects directly affected the northeastern end of Mustang Island, but material was not added or removed by fill or dredging on the bay shoreline of Mustang Island between stations 35 and 48.

About 46 percent of the Mustang Island bay shoreline underwent net erosion (fig. 21c), more than any other shoreline segment in the bay system during the same period. Only 18 percent of the shoreline showed no net movement during the period. Furthermore, net rates of change were generally higher on the Mustang Island shoreline than on other bay shoreline segments (fig. 22). Accretion rates of 3 to 25 ft/yr at stations 35 to 37 were probably related to dune migration across southern Mustang Island and to shoaling of Corpus Christi Pass, which was open in 1881-82. Farther north, stations 38 through 41 eroded at rates of 1 to 15 ft/yr. Minor updrift erosion at stations 43 to 45 supplied the rapid net accretion (7 ft/yr) at station 42 on the southwestern tip of Shamrock Island.

The shallow bay bottom along northeastern Mustang Island has an extremely low slope (marine grassflats); thus slight changes in water level produce large lateral displacement of the shoreline. The drought in 1937 possibly caused the observed accretion at stations 46 and 47.

1937 to 1982

Numerous changes related to human activities and natural processes occurred on Mustang Island that directly and indirectly affected bay shoreline position during this period. Natural changes include the extensive growth of vegetation on dunes and barrier flats of southern Mustang Island (White and others, 1978). This spread of vegetation was well underway by 1956, reducing dune migration and sediment supply at the bay shoreline. Human modifications completed by 1956 were the dredging of Wilson's Cut, Croaker Hole, Atlantic Cut across Shamrock Island, and several canals in Shamrock Cove. Hurricane Celia breached Shamrock Island in 1970. Canal dredging across Pelone Island and at Mustang Beach was complete by 1970, and the Corpus Christi Water Exchange Pass (fish pass) was finished in 1972.

In 1982, nearly 62 percent of the shoreline between stations 35 and 48 occupied a position landward of that in 1937 (fig. 21c). This was almost twice as much eroding shoreline than either northern or southern Corpus Christi Bays during the same period. Only two stations (38 and 40) underwent net accretion (fig. 23). Stations 35 through 37 had net accretion during 1867 to 1937, but the shoreline at these stations eroded from 5 to 8 ft/yr between 1937 and 1982. Erosion at stations 36 and 37 was probably due to tidal currents near the fish pass. Assuming all erosion at these stations took place since completion of the pass in 1972, rates of erosion averaged 20 to 30 ft/yr. Erosion of 575 ft at station 39 occurred when Croaker Hole was dredged. Shamrock Island stations 42 through 45 had net erosion rates of 2 to 10 ft/yr, possibly owing to subsidence and a decrease in sediment supplied by southerly longshore currents. Stations 47 and 48 showed large net erosion rates, an effect of submergence rather than of lateral erosion.

1867 to 1982

In 1982, about 61 percent of the shoreline was located landward of its 1867 position, making eastern Corpus Christi Bay an area of widespread shoreline retreat (fig. 21c). In addition, the magnitude of shoreline-position change caused by natural processes is consistently larger here than in other parts of the bay system (fig. 24).

For the 115-year period, only three stations (35, 36, and 42) underwent net accretion. Stations 35 and 36 accreted sufficiently during drought conditions before 1937 to offset erosion between 1937 and 1982. Net rates of erosion at stations 43 and 44 on Shamrock Island increased from less than 1 ft/yr from 1867 to 1937 to about 10 ft/yr from 1937 to 1982, resulting in average net erosion rates from 1867 to 1982 of about 4 ft/yr. Sediment supplied to the tip of Shamrock Island was insufficient to prevent erosion between 1937 and 1982, reversing the accretion observed between 1867 and 1937. Extreme land loss at station 48 (2,250 ft) was due to submergence rather than to erosion.

Oso Bay

Many promontories and embayments characterize the shoreline of Oso Bay and make the regular placement of measuring stations impractical. Instead of systematic and unbiased station placement, station locations were selected to provide an even distribution of stations in various bay environments. The total length of Oso Bay shoreline is approximately 85,000 ft; the 24 stations selected (fig. 20) give an average station spacing of about 3,500 ft. Shoreline changes for Oso Bay were determined from 1881-82 topographic charts and from 1934 and 1982 aerial photographs.

The western shore of Oso Bay is formed by low bluffs of Pleistocene clay and sand, the eastern shore by low bluffs of the Pleistocene Ingleside sand, and the northern shore by a

Holocene sandbar connecting Ward Island and Encinal Peninsula (fig. 3). The most rapid shoreline changes occur along the bar because it is relatively unconsolidated, poorly vegetated, and susceptible to inundation during storms and cold fronts. Most of Oso Bay is characterized by low rates of shoreline change partly because of limited wave fetch, shallow water throughout the bay, and little fluvial influx from Oso Creek. Oso Bay is not significantly wider than the valley cut by ancestral Oso Creek during a Pleistocene sea-level lowstand (fig. 4), indicating that Oso Bay has not eroded greatly since the Holocene sea-level rise and highstand.

1881-82 to 1934

Before 1934, only a few human modifications had affected Oso Bay. These included road construction connecting Corpus Christi and Encinal Peninsula across the mouth of Oso Bay, bridge construction across the upper reaches of the bay, and a small water impoundment near western Oso Bay.

Percentages of stable, accreting, and eroding shoreline were approximately equal during this early period (fig. 21d). With a few exceptions, rates of net accretion and erosion were both 2 ft/yr or less (fig. 22). Rates of net accretion greater than 2 ft/yr occurred only at station 2 on Ward Island. This area receives sediment during inundation of the sandbar between Oso and Corpus Christi Bays. Net erosion greater than 2 ft/yr occurred at stations 4 and 5 in western Oso Bay and at station 23, located in an active washover area.

1934 to 1982

Major and minor human modifications have changed the position of the Oso Bay shoreline since 1934. Although no major changes occurred in the area between 1934 and 1938, by 1958 the runway at Corpus Christi Naval Air Station had been extended into Oso Bay, the South Padre Island Drive bridge and a railway bridge had been built across the bay, sewage disposal had begun in western Oso Bay, and bay filling associated with oil-field activities had begun. Discharge of saline water from Laguna Madre into Oso Bay through the Barney Davis cooling pond began in 1974.

In October 1973, Oso Creek (the major tributary of Oso Bay) had its largest flood since the 1919 hurricane. More than 20,000 acre-ft of water flowed down the creek, to constitute more than two-thirds of the total Oso Creek discharge for the 1974 water year (U.S. Geological Survey, 1975). This flood carried large quantities of material from the watershed and deposited approximately 0.6 mi^2 (370 acres) of new subaerial and subaqueous sediment at the southern end of Oso Bay. By 1982, some of this sediment had been transported northward to partly fill embayments south of the railway bridge. Much of this northerly transport was probably caused by an even greater flood, that of Hurricane Allen in August 1980. Total discharge of water at Oso Creek during this storm was approximately 28,000 acre-ft (U.S. Geological Survey, 1981).

In 1982, 64 percent of the bay shoreline was bayward of its 1934 position (fig. 21d). If accretion from fill and new sediment is subtracted, then only about 25 percent of the bay shoreline showed net accretion. The amount of shoreline having net erosion decreased to less than 10 percent.

Net rates of shoreline change calculated for the 1934-1982 period showed larger fluctuations in magnitude than for the 1881-82 to 1934 period (fig. 23). Exceptionally large amounts of accretion occurred at stations 3, 4, 12, 13, 22, and 23. Station 3 is in an active washover area, station 4 is the site of marsh growth promoted by sewage disposal, stations 12 and 13 are in the area of 1973 flood deposition, and stations 22 and 23 are landfill sites for the Corpus Christi Naval Air Station. High rates of accretion (nearly 6 ft/yr) occurred at stations 11, 15, and 17; these stations are in former embayments now being filled by the natural transport of sediment deposited at the head of Oso Bay during the 1973 flood. Station 8, located on a promontory within the bay, recorded net erosion of less than 2 ft/yr.

1881-82 to 1982

Changes in shoreline position over this 100-year period generally reflect changes that have occurred since 1934. There was more accreting shoreline over the 100-year period than during the 1934-to-1982 period (fig. 21d), indicating that fill and new sediment occupied areas that were previously stable or eroding. Only about 10 percent of the bay shoreline, a value significantly less than that for the 1881-82-to-1934 period, occupied a position in 1982 landward of its position in 1881-82. Net rates of change were generally smaller for the 100-year period than for 1934 to 1982 (compare figs. 23 and 24), indicating that most of the significant shoreline changes took place during the period 1934 to 1982. In addition, only one station recording erosion in the period 1881-82 to 1934 also recorded erosion in the period 1934 to 1982. Four stations had net erosion for the 100-year period; rates were 1 ft/yr or less.

Nueces Bay

The earliest shoreline position for Nueces Bay was determined from an 1867 topographic chart that depicted the eastern part of Nueces Bay near Portland (fig. 22, stations 1 to 5). The early shoreline position for the rest of the bay was taken from an 1882 topographic chart. Later shoreline positions were mapped from 1930 and 1982 aerial photographs.

Nueces Bay is shallower, has a shorter wave fetch, and receives more fluvial sediment than Corpus Christi Bay. Each of these factors either reduces erosion or causes accretion, implying that Nueces Bay is not as susceptible to shoreline erosion as is Corpus Christi Bay.

The shores of Nueces Bay are formed by low Holocene spits (Rincon Point and Indian Point), by moderate to high Pleistocene clay bluffs, and by a low Holocene marsh near the mouth of the Nueces River (fig. 3). Most rapid rates of change were observed during marsh growth promoted by delta progradation at the head of Nueces Bay; high rates of change were also found along Rincon Point and Indian Point, which are subject to inundation during storms.

Late 1800's to 1930

Changes in shoreline position were mostly caused by natural processes, though by 1930, dredging of the Corpus Christi Turning Basin had resulted in spoil disposal into Nueces Bay along Rincon Peninsula. From the late 1800's to 1930, Portland had grown from a single house to a small community; by 1930, roads had been established north and south of the bay, and agricultural development had spread over the Pleistocene fluvial-deltaic deposits.

More than 50 percent of the 1930 Nueces Bay shoreline held a position bayward of its position in 1867 and 1882 (figs. 21e, f). Laterally extensive accretion in the form of marsh progradation occurred in the Rincon Bayou - Whites Point vicinity, near the mouth of the Nueces River. Net rates of shoreline change for the bay as a whole were generally 2 ft/yr or less, with some exceptions (fig. 22). High net rates of accretion occurred in the area of active marsh progradation (stations 17 through 22). Rates of accretion for these stations ranged from 10 to 90 ft/yr. High net rates of erosion (>5 ft/yr) occurred at station 14 and at Rincon Point (station 31).

1930 to 1982

After 1930, effects of human modifications joined those of natural processes as important in the positioning of the Nueces Bay shoreline. Between 1930 and 1938, spoil from the dredging of Avery Point Turning Basin was deposited along the southern shore of Nueces Bay. Spoil from the dredging of the Tule Lake Channel had been placed along the southern shore of the bay by 1958; spoil and reworked spoil stretched from the mouth of the Nueces River to Rincon Peninsula at this time. Extensive oil-field development, including the creation of islands and peninsulas to support oil-field equipment, had begun near Whites Point. In addition, the construction of a major highway across Rincon Peninsula and Indian Point Peninsula required the placement of fill material in the Portland area. Gum Hollow fan delta prograded into Nueces Bay during the flooding associated with Hurricane Beulah in 1967 (McGowen, 1971). By 1971, spoil from the dredging of the Tule Lake Channel had been placed near the mouth of the Nueces River.

In areas of little human modification, such as northern Nueces Bay, the lengths of accreting, eroding, and stable shoreline were approximately equal (fig. 21e). However, the 1982 shoreline of southern Nueces Bay occupied a position mostly bayward of its position in 1930 (fig. 21f). Approximately half of the shoreline accretion in southern Nueces Bay resulted from spoil disposal; marsh growth in western Nueces Bay was the other significant contributor.

Net rates of shoreline change in Nueces Bay were generally less than 2 ft/yr for both accreting and eroding shorelines (fig. 23). Six stations in northeastern Nueces Bay (2, 4, 7, 8, 10, and 11) had net erosion, including two in the Portland vicinity. In contrast, only three stations in northeastern Nueces Bay underwent net accretion; high net rates of accretion at stations 3 and 6 are due to landfilling and the rapid progradation of the Gum Hollow fan delta, respectively. Stations 19 through 21 showed net rates of accretion of 20 to 30 ft/yr related to marsh growth in western Nueces Bay. Net erosion was recorded along the northern flanks of subaerial Nueces River deltaic deposits. High rates of net accretion were found at stations 24 through 28, primarily caused by spoil disposal.

Late 1800's to 1982

For northern Nueces Bay, about 45 percent of the 1982 shoreline held a position bayward of its late 1800's position (fig. 21e). In contrast, 93 percent of the shoreline in southern Nueces Bay occupied a 1982 position bayward of its 1882 position (fig. 21f). Spoil disposal and rapid marsh progradation in southern Nueces Bay caused this disparity.

Net rates of both accretion and erosion for most bay environments were less than 2 ft/yr (fig. 24). More stations recorded net erosion than net accretion in northeastern Nueces Bay, which lacked widespread marsh growth and landfill. Extremely high net rates of accretion were recorded in western Nueces Bay during marsh progradation; aerial photographs taken in 1959, 1971, and 1974 show that marsh progradation stopped between 1930 and 1959. High net rates of accretion at several stations in southern Nueces Bay were caused by spoil disposal.

Storm Effects

> The *Caller* has always contended that Corpus Christi, with its beautiful high bluff, is the only really safe place on the coast of Texas, and we are more convinced of this fact now than ever. It is the only seaport city with high ground, and where there is not the least danger of being swept into the sea.
>
> --*Corpus Christi Caller*, August 29, 1886

These lines were written in reaction to news of the second destruction of Indianola in 11 years. Before its abandonment in 1886, Indianola was one of Texas' largest ports. Unfortunately, it occupied low ground on the southern shore of Matagorda Bay, and devastation was mainly caused by high bay-water levels (storm surge) and winds associated with tropical cyclones.

The Pleistocene bluffs bordering parts of Corpus Christi, Oso, and Nueces Bays have elevations sufficient to withstand inundation from storm surge; however, the bluffs and other coastal lands in the Corpus Christi Bay area are not invulnerable to the effects of tropical cyclones. The bluffs are undercut, so they collapse during periods of elevated bay water; minor tropical storms can inundate low-lying areas (North Beach, Mustang Island, Indian Point Peninsula, and Ward Island).

The bluffs east of Portland illustrate that bluff erosion and retreat occur even behind stable shorelines. In this area, erosion of the 25- to 30-ft high bluffs has produced steep bluff faces adjacent to gently bayward-sloping beach sediments (fig. 25). Shoreline position is relatively stable in this area; indeed, stations 13 and 14 east of Portland show no measurable shoreline change between 1930 and 1982. During the same period, however, the base of the bluff near these stations retreated 125 ft, 40 ft of which occurred between 1974 and 1982. The

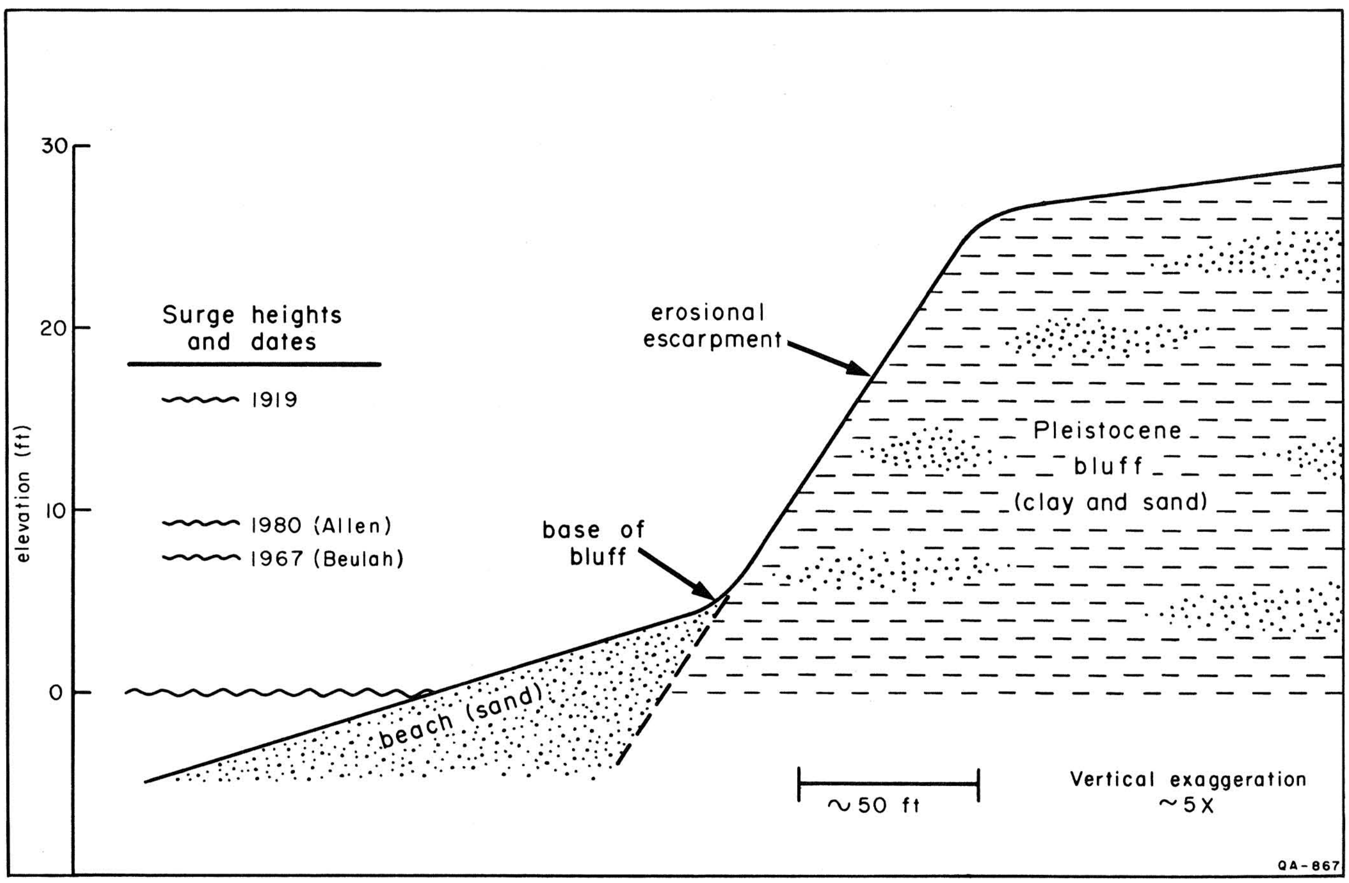

Figure 25. Generalized bay-margin morphology, northern Corpus Christi Bay. Also shown are bay water levels during the 1919, 1967, and 1980 hurricanes.

base of the bluff is at an elevation of about 5 ft; thus widespread erosion of the bluff by wave action would occur only during periods of elevated bay levels, as during tropical cyclones. During Hurricane Allen (1980), for example, bay levels peaked at 8 ft and exceeded 5 ft for more than 24 hours (fig. 26); this hurricane was responsible for most of the 1974 to 1982 retreat. Several hurricanes have caused bay water levels to exceed 5 ft in this century (table 1), resulting in most of the bluff retreat.

Hurricanes are common on the Texas coast (app. B). Shoreline changes associated with these storms depend mostly on storm-surge height; higher surges generally cause greater shoreline change. Hurricanes having the most significant effect in the Corpus Christi Bay area include those of August 1916, September 1919, September 1933, September 1961 (Carla), September 1967 (Beulah), August 1970 (Celia), and August 1980 (Allen). Many other tropical

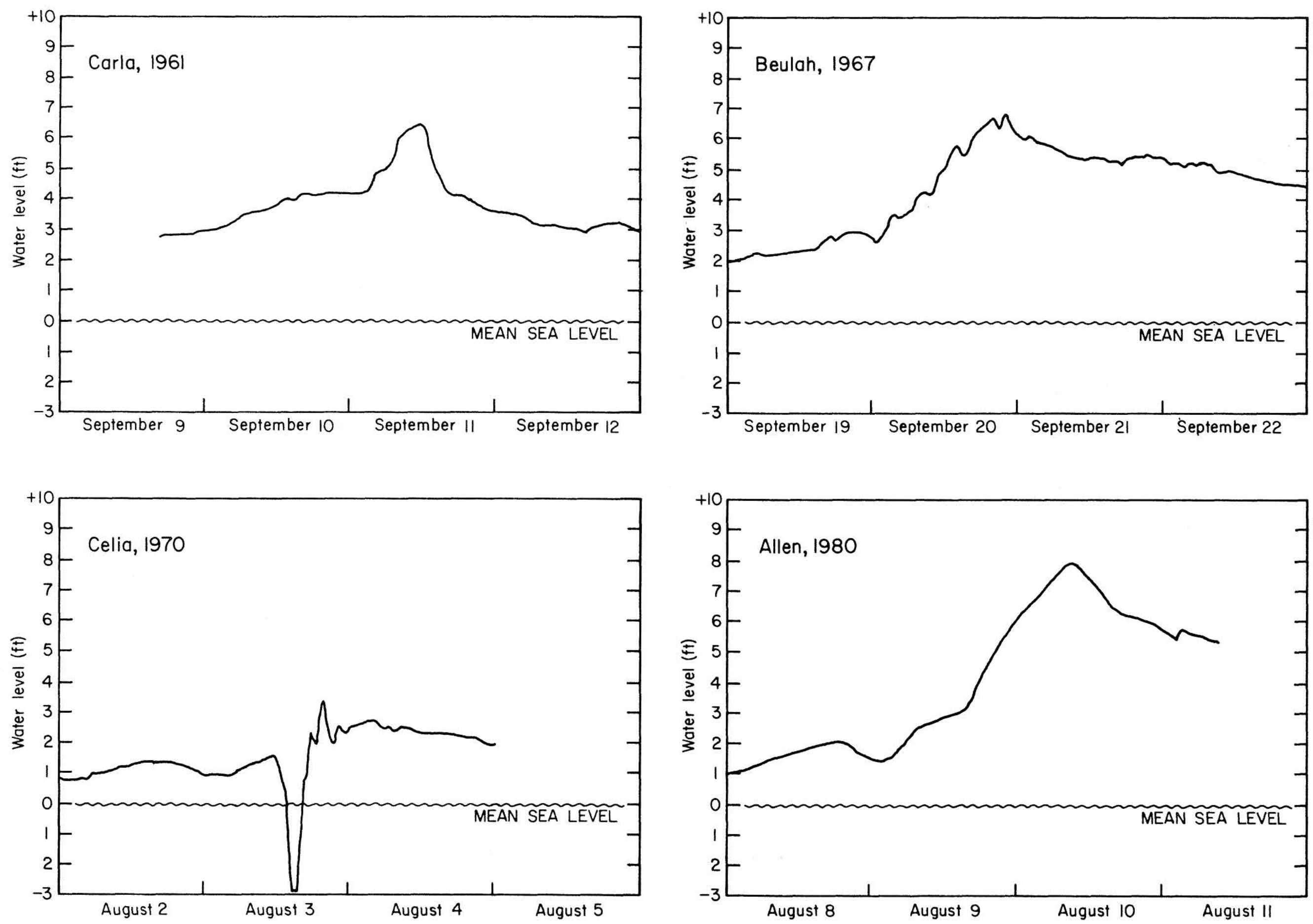

Figure 26. Storm-surge hydrographs for Hurricanes Carla, Beulah, Celia, and Allen recorded at Corpus Christi. Data from U.S. Army Corps of Engineers (1962, 1968, 1972, 1981).

storms have affected the area to varying degrees, depending on intensity and size of the storm, distance from the storm's eye, and position with respect to the eye. In general, storms striking south of Corpus Christi Bay raise bay water level in this area higher than do storms making landfall north of the bay, primarily owing to the counterclockwise wind circulation in northern hemisphere hurricanes.

The first recorded hurricane that affected the shoreline of Corpus Christi Bay was in 1868. This storm submerged waterfront lots, washed property into the bay, and destroyed several houses seaward of the Nueces Hotel in Corpus Christi (Price, 1956a). An 1874 storm that struck near what was then Indianola washed a schooner onto North Beach and caused an estimated 6-ft tide and an unspecified amount of shoreline erosion (Price, 1956a). The October 1880 hurricane was the next reported storm to produce significant shoreline erosion (Price, 1956b). The 1875 hurricane that destroyed Indianola apparently caused no damage in the Corpus Christi Bay area.

Although the high winds and nearby landfall of the August 1916 hurricane considerably damaged man-made structures in the Corpus Christi Bay area (Carr, 1967), storm surge was not commensurate with the intensity of the storm. Peak water level reported at Corpus Christi was 5.9 ft (table 1), which probably caused only minor shoreline erosion. The relatively low bay levels during this storm led residents to expect nothing worse during the September 1919 hurricane, which was slightly less intense than the 1916 storm. However, extremely high water levels, reaching 16 ft in Corpus Christi Bay, accompanied the 1919 storm (table 1). In addition to the loss of at least 284 lives, all Corpus Christi businesses located below the bluffs were damaged or destroyed (U.S. Army Corps of Engineers, 1979), North Beach eroded 250 ft (Price, 1956a), and Corpus Christi Bay bluffs near Portland and Corpus Christi retreated as much as 100 ft (Bartlett, 1919) during the 1919 storm. This is one of only six "extreme" hurricanes to strike the Texas coast since 1900 and is considered one of the four severest Texas hurricanes (Carr, 1967).

Three hurricanes were felt in the Corpus Christi Bay area in 1933, but erosion was reported for only the September storm. Bay levels were at 8 ft during this storm (table 1). Streets cracked as the Corpus Christi bluffs eroded, damaging bluff terraces constructed by the City of Corpus Christi (*Corpus Christi Caller-Times*, 1933). The next major hurricane to affect the bay area was Carla in 1961; reported bay levels ranged from 6.5 to more than 9 ft (table 1). This storm extensively damaged the jetties at Port Aransas and inundated North Beach (U.S. Army Corps of Engineers, 1962). Hurricane Beulah (1967) is known more for its great amounts of rainfall, though bay levels were again high enough to inundate North Beach. Hurricane Celia (1970), a small hurricane that intensified rapidly as it approached the Texas coast, made landfall at Aransas Pass. Significant gulf surge was reported at Port Aransas (table 1), but bay levels were raised to only about 5 ft. Most destruction during this storm was caused by its extremely high winds. Hurricane Allen (1980) was potentially the most powerful hurricane to strike the Texas coast this century, but the storm rapidly weakened as it approached land. The weakened storm went inland north of Brownsville, nevertheless causing considerable damage in the Corpus Christi Bay area. Bluff retreat in Corpus Christi's Cole Park ranged from no change to 55 ft and averaged 25 ft (City of Corpus Christi, unpublished data, 1983). In addition, more than 6,000 ft^2 of land was lost from North Beach, translating to an average shoreline retreat of only 1 ft over the length of the beach. More than 20,000 yd^3 of beach material formerly above mean sea level were, however, transported below mean sea level during this storm (U.S. Army Corps of Engineers, unpublished data, 1983), resulting in a generally lower beach (fig. 16).

CONCLUSIONS

Except for major shoreline advances promoted by spoil disposal and minor accretion adjacent to man-made coastal structures, human activities in and near Corpus Christi Bay tend to initiate or accelerate shoreline erosion. The cumulative impact of widespread alteration of shorelines, of reduction and disruption of sediment supply, of minor elevation of sea level, and of frequent intense storms is essentially insurmountable because each contributes to shoreline retreat. Furthermore, no evidence suggests a long-term reversal in these trends that promote shoreline erosion. In fact, some studies, such as that of Gornitz and others (1982), have demonstrated that worldwide magnitudes and rates of shoreline recession will increase if sea-level rise maintains or exceeds a pace comparable to that of the past few decades. Considering the cumulative and mostly additive effects of these principal forces, most unprotected shorelines in Corpus Christi Bay probably will continue to retreat landward in response to natural erosional conditions that were established mainly before the 1800's, have continued since then, and are likely to persist.

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APPENDIX A

Summary of historical shoreline changes in Corpus Christi, Nueces, and Oso Bays. Distances were measured to the nearest 25 ft. Rates were calculated as distance divided by years; error associated with rates is defined as ± 25 ft divided by the number of years represented in the measurement. Asterisk denotes distances with distorted rates of change, caused by landfill or other unusual circumstances.

Corpus Christi Bay

Station	Dates	Distance (ft)	Rate (ft/yr)	Dates	Distance (ft)	Rate (ft/yr)	Dates	Distance (ft)	Rate (ft/yr)
1	1867 to 1930	-250	-4.0	1930 to 1982	+100	+1.9	1867 to 1982	-150	-1.3
2	"	+25	<+0.5	"	+100	+1.9	"	+125	+1.1
3	"	0	0	"	-100	-1.9	"	-100	-0.9
4	"	-25	<-0.5	"	+875*	spoil	"	+850*	spoil
5	"	+150	+2.4	"	+150*	"	"	+300*	"
6	"	0	0	"	+50	+1.0	"	+50	<+0.5
7	"	-50	-0.8	"	0	0	"	-50	<-0.5
8	"	0	0	"	+75	+1.4	"	+75	+0.7
9	"	+75	+1.2	"	+50	+1.0	"	+125	+1.1
10	"	0	0	"	-150	-2.9	"	-150	-1.3
11	"	-25	<-0.5	"	0	0	"	-25	<-0.5
12	"	-25	<-0.5	"	-75	-1.4	"	-100	-0.9
13	"	0	0	"	0	0	"	0	0
14	"	0	0	"	0	0	"	0	0
15	"	-25	<-0.5	"	+25	+0.5	"	0	0
16	"	+25	<+0.5	"	-100	-1.9	"	-75	-0.7

Corpus Christi Bay (cont.)

Station	Dates	Distance (ft)	Rate (ft/yr)	Dates	Distance (ft)	Rate (ft/yr)	Dates	Distance (ft)	Rate (ft/yr)
17	"	+75	+1.2	1930 to 1974	0	0	1867 to 1974	+75	+0.7
18	1867 to 1931	+75	+1.2	1931 to 1982	+50*	landfill	1867 to 1982	+125*	landfill
19	"	+50	+0.8	"	+225*	"	"	+275*	"
20	"	+50	+0.8	"	+250*	"	"	+300*	"
21	"	+75	+1.2	"	+175*	"	"	+250*	"
22	"	0	0	"	+450*	"	"	+450*	"
23	"	-75	-1.2	"	+400*	"	"	+325*	"
24	"	-125	-2.0	"	+75*	"	"	-50*	"
25	"	0	0	"	0	0	"	0	0
26	1881-82 to 1934	0	0	1934 to 1982	0	0	1881-82 to 1982	0	0
27	"	0	0	"	0	0	"	0	0
28	"	0	0	"	+375*	landfill	"	+375*	landfill
29	"	-50	-1.0	"	0	0	"	-50	-0.5
30	"	+25	+0.5	"	+100	+2.1	"	+125	+1.3
31	"	+75	+1.4	"	-125	-2.6	"	-50	-0.5
32	"	+25	+0.5	"	-250	-5.2	"	-225	-2.3
33	"	-125	-2.4	"	+325*	landfill	"	+200*	landfill
34	"	-100	-1.9	"	+275*	"	"	+175*	"
35	1867 to 1937	+1,750	+25.0	1937 to 1982	-375	-8.3	1867 to 1982	+1,375	+12.0

Corpus Christi Bay (cont.)

Station	Dates	Distance (ft)	Rate (ft/yr)	Dates	Distance (ft)	Rate (ft/yr)	Dates	Distance (ft)	Rate (ft/yr)
36	1867	+550	+7.9	1937 to 1982	-325	-7.2	1867 to 1982	+225	+2.0
37	"	+225	+3.2	"	-225	-5.0	"	0	0
38	"	-1,050	-15.0	"	+100	+2.2	"	-950	-8.3
39	"	-375	-5.4	"	-575	-12.8	"	-950	-8.3
40	"	-425	-6.1	"	+350	+7.8	"	-75	-0.7
41	"	-100	-1.4	"	0	0	"	-100	-0.9
42	"	+525	+7.5	"	-75	-1.7	"	+450	+3.9
43	"	-25	<-0.5	"	-475	-10.6	"	-500	-4.3
44	"	-25	<-0.5	"	-450	-10.0	"	-475	-4.1
45	"	0	0	"	-100	-2.2	"	-100	-0.9
46	"	+200	+2.9	"	-375	-8.3	"	-175	-1.5
47	"	+50	+0.7	"	-725*	tidal flat	"	-675*	tidal flat
48	"	0	0	"	-2,250*	"	"	-2,250*	"

Oso Bay

Station	Dates	Distance (ft)	Rate (ft/yr)	Dates	Distance (ft)	Rate (ft/yr)	Dates	Distance (ft)	Rate (ft/yr)
1	1881-82 to 1934	-50	-1.0	1934 to 1982	+250	+5.2	1881-82 to 1982	+200	+2.0
2	"	+275	+5.3	"	+25	+0.5	"	+300	+3.0
3	"	+100	+1.9	"	+950	+19.8	"	+1,050	+10.5
4	"	-225	-4.3	"	+925	+19.3	"	+700	+7.0

Oso Bay (cont.)

Station	Dates	Distance (ft)	Rate (ft/yr)	Dates	Distance (ft)	Rate (ft/yr)	Dates	Distance (ft)	Rate (ft/yr)
5	1881-82 to 1934	-225	-4.3	1934 to 1982	+150	+3.1	1881-82 to 1982	-75	-0.8
6	"	-75	-1.4	"	+50	+1.0	"	-25	-0.3
7	"	-50	-1.0	"	+50	+1.0	"	0	0
8	"	-50	-1.0	"	-50	-1.0	"	-100	-1.0
9	"	0	0	"	0	0	"	0	0
10	"	0	0	"	0	0	"	0	0
11	"	0	0	"	+300	+6.3	"	+300	+3.0
12	"	+75	+1.4	"	+3,700	+77.1	"	+3,775	+37.8
13	"	+75	+1.4	"	+1,275	+26.6	"	+1,350	+13.5
14	"	0	0	"	0	0	"	0	0
15	"	+100	+1.9	"	+325	+6.8	"	+425	+4.3
16	"	0	0	"	0	0	"	0	0
17	"	+75	+1.4	"	+325	+6.8	"	+400	+4.0
18	"	+25	+0.5	"	0	0	"	+25	<+0.5
19	"	0	0	"	+50	+1.0	"	+50	+0.5
20	"	0	0	"	+175	+3.6	"	+175	+1.8
21	"	+50	+1.0	"	0	0	"	+50	+0.5
22	"	+25	+0.5	"	+4,050*	landfill	"	+4,075*	landfill
23	"	-200	-3.8	"	+3,675*	"	"	+3,475*	"
24	"	-500	-9.4	"	0	0	"	-500	-5.0

Nueces Bay

Station	Dates	Distance (ft)	Rate (ft/yr)	Dates	Distance (ft)	Rate (ft/yr)	Dates	Distance (ft)	Rate (ft/yr)
1	1867 to 1930	+75	+1.2	1930 to 1974	-100	-2.3	1867 to 1974	-25	< -0.5
2	"	0	0	1930 to 1982	-100	-1.9	1867 to 1982	-100	-0.9
3	"	+175	+2.8	"	+1,200*	landfill	"	+1,375*	landfill
4	"	+125	+2.0	"	-100	-1.9	"	+25	< +0.5
5	"	-50	-0.8	"	+50	+1.0	"	0	0
6	1882 to 1930	0	0	"	+1,250	+24.0	1882 to 1982	+1,250	+12.5
7	"	-100	-2.1	"	-25	-0.5	"	-125	-1.3
8	"	+25	+0.5	"	-50	-1.0	"	-25	< -0.5
9	"	+50	+1.0	"	0	0	"	+50	+0.5
10	"	+50	+1.0	"	-50	-1.0	"	0	0
11	"	+25	+0.5	"	-100	-1.9	"	-75	-0.8
12	"	-75	-1.6	"	+425	+8.2	"	+350	+3.5
13	"	+75	+1.6	"	+25	+0.5	"	+100	+1.0
14	"	-300	-6.3	"	+300	+5.8	"	0	0
15	"	-25	-0.5	"	+25	+0.5	"	0	0
16	"	-150	-3.1	"	+75	+1.4	"	-75	-0.8
17	"	+475	+9.9	"	0	0	"	+475	+4.8
18	"	+1,100	+22.9	"	-75	-1.4	"	+1,025	+10.3

Nueces Bay (cont.)

Station	Dates	Distance (ft)	Rate (ft/yr)	Dates	Distance (ft)	Rate (ft/yr)	Dates	Distance (ft)	Rate (ft/yr)
19	1882 to 1930	+3,200	+66.7	1930 to 1982	+1,075	+20.7	1882 to 1982	+4,275	+42.7
20	"	+4,400	+91.7	"	+1,700	+32.7	"	+6,100	+61.0
21	"	+900	+18.8	"	+1,675	+32.2	"	+2,575	+25.8
22	"	+525	+10.9	"	-25	-0.5	"	+500	+5.1
23	"	--	--	"	-250	-4.8	"	--	--
24	"	-50	-1.0	"	+3,300*	spoil	"	+3,250*	spoil
25	"	-75	-1.6	"	+2,750*	"	"	+2,675*	"
26	"	+100	+2.1	"	+3,025*	"	"	+3,125*	"
27	"	+100	+2.1	"	+4,875*	"	"	+4,975*	"
28	"	+50	+1.0	"	+3,600*	"	"	+3,650*	"
29	"	0	0	"	+50	+1.0	"	+50	+0.5
30	"	+200	+4.2	"	+25	+0.5	"	+225	+2.3
31	"	-250	-5.2	"	-75	-1.4	"	-325	-3.2

APPENDIX B

Tropical cyclones affecting the Texas coast, 1854 to 1983 (compiled from Tannehill, 1956; Dunn and Miller, 1964; Cry, 1965; intensity classification from Dunn and Miller, 1964).

	Maximum winds (mph)	Minimum central pressures (inches)
Minor:	Less than 74	Above 29.40
Minimal:	74 to 100	29.01 to 29.40
Major:	101 to 135	28.01 to 29.00
Extreme:	136 and higher	28.00 or less

Year	Area	Intensity
1854	Galveston southward	major
1857	Port Isabel	?
1866	Galveston	minimal
1867	Galveston southward	major
1868	Corpus Christi	minimal
1871	Galveston	minor
1871	Galveston	minimal
1872	Port Isabel	minimal
1874	Indianola	minimal
1874	Lower coast	minor
1875	Indianola	extreme
1876	Padre Island	?
1877	Entire coast	minimal
1879	Upper coast	minor
1880	Lower coast	major
1880	Sargent	?
1880	Brownsville	major
1881	Lower coast	minimal
1885	Entire coast	minimal
1886	Upper coast	minor
1886	Entire coast	extreme
1886	Lower coast	minimal
1886	Upper coast	minimal
1887	Brownsville	minimal
1888	Upper coast	minimal
1888	Upper coast	minor
1891	Entire coast	minimal
1895	Lower coast	minor
1895	Lower coast	minor
1897	Upper coast	minimal
1898	Upper coast	minor
1900	Upper coast	extreme
1901	Upper coast	minor
1902	Corpus Christi	minimal
1908	Brownsville	?
1909	Lower coast	minor
1909	Velasco	major
1909	Lower coast	minimal
1910	Lower coast	minor
1910	Lower coast	minimal
1912	Lower coast	minimal
1913	Lower coast	minor
1915	Upper coast	extreme
1916	Lower coast	extreme
1918	Sabine Pass	minimal
1919	Corpus Christi	extreme
1921	Entire coast	minimal
1921	Lower coast	minor
1922	South Padre Island	minor
1925	Lower coast	minor
1929	Port O'Connor	minimal
1931	Lower coast	minor
1932	Freeport	major
1933	Lower coast	minor
1933	Matagorda Bay	minor
1933	Brownsville	major
1933	Brownsville	minimal
1934	Rockport	minimal
1934	Entire coast	minor
1936	Port Aransas	minimal
1936	Lower coast	minor
1938	Upper coast	minor
1940	Upper coast	minimal
1940	Upper coast	minor
1941	Matagorda	minimal
1941	Upper coast	minimal
1942	Upper coast	minimal
1942	Matagorda Bay	major
1943	Galveston	minimal
1943	Upper coast	minor
1945	Central Padre Island	minor
1945	Middle coast	extreme
1946	Port Arthur	minor
1947	Lower coast	minor
1947	Galveston	minimal
1949	Freeport	major
1954	South of Brownsville	minor
1955	Corpus Christi	minimal
1957	Beaumont	minor
1957	Sabine Pass	minimal
1958	Extreme southern coast	minimal
1958	Corpus Christi	minimal
1959	Galveston	minimal
1960	South Padre Island	minor
1961	Palacios	extreme
1963	High Island	minimal
1964	Sargent	minor
1967	Mouth Rio Grande	major
1968	Aransas Pass	minor
1970	Corpus Christi	major
1970	High Island	minor
1971	Aransas Pass	minimal
1973	High Island	minor
1978	Padre Island	minor
1979	Central coast	minor
1980	South Padre Island	major
1980	Galveston Island	minor
1982	Upper coast	minor
1983	Galveston Island	major
1983	South Padre Island	minor

APPENDIX C

Materials and Sources

Topographic maps used to determine shoreline position.

Date	Name	Source
1867	#1043, Corpus Christi Bay, Texas	National Oceanic and Atmospheric Administration (NOAA)
1867	#1044, Corpus Christi Bay, Texas	NOAA
1882	#1513, Nueces Bay, Texas	NOAA
1881-82	#1626, Shores of Laguna Madre, Texas	NOAA

Aerial photographs used to determine shoreline position. Asterisk indicates photographs on which measurements were based.

Date	Name	Source
February 1930 to April 1937	* Black-and-white mosaics, 1:24,000	Tobin Research, Inc.
November 1938	Black-and-white mosaics, 1:31,680	U.S. Department of Agriculture
January and February 1940	Black-and-white mosaics, 1:63,360	U.S. Department of Agriculture
January 1956	Black-and-white mosaics, 1:20,000	U.S. Department of Agriculture
December 1958 and January and February 1959	Black-and-white mosaics, 1:24,000	Tobin Research, Inc.
October 1971	Black-and-white mosaics, 1:48,000	Tobin Research, Inc.
June 1974	* Black-and-white, 1:24,000	General Land Office of Texas
June and July 1982	* False-color infra-red, 1:24,000	General Land Office of Texas

U.S. Geological Survey 7.5-minute quadrangle maps used to construct base maps.

Annaville, Texas
Aransas Pass, Texas
Corpus Christi, Texas
Crane Islands, Texas
Gregory, Texas
Odem, Texas
Oso Creek NE, Texas
Port Aransas, Texas
Port Ingleside, Texas
Portland, Texas
Taft, Texas