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HISTORICAL SHORELINE CHANGES IN THE GALVESTON BAY AND SAN ANTONIO BAY SYSTEMS, TEXAS GULF COAST

by

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ABSTRACT

Changes in shoreline position and stability in the Galveston and San Antonio Bay systems since the late 1800's were documented using historical monitoring techniques. This is accomplished by comparing shorelines from topographic charts (dated 1850 to 1860) and aerial photographs (taken in 1929-37, 1956-57, 1974, and 1982), measuring the magnitude (distance) of shoreline movement at specific sites, and 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). Geological interpretations of the maps and photographs are used in conjunction with meteorological data and historical records to explain the important trends revealed in the tabulated shoreline data.

Unprotected sediments forming the margins of these bays are subjected to natural coastal processes and modified by human activities that together cause shoreline movement. These 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 movement by building seawalls and bulkheads and using riprap to dissipate wave energy.

Factors contributing to shoreline changes include (1) regional and worldwide climate, (2) local changes in relative sea-level position, (3) local alterations in sediment supply, (4) storm frequency and intensity, and (5) human activities. Historical data compiled for these various factors indicate that warming temperatures, rising sea level, decreasing sediment supply, recurring severe storms, and ongoing human activities all favor continued erosion of most unprotected bay shorelines.

1.0 INTRODUCTION

Texas bays are bordered by both stable and unstable shorelines that together 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 in size. The cumulative land areas removed through erosion at any time or over several decades are substantial and translate directly to significant economic losses, both to the State and to private landowners. Furthermore, legal questions regarding ownership of property may arise because of shoreline movement, and public and private investments may be jeopardized and real property damaged or destroyed as shoreline positions change. Taken together, the individual and corporate losses are of sufficient magnitude to warrant investigation of shoreline movement.

Shoreline changes in Galveston and San Antonio Bays (fig. 1-1) are attributable to both natural causes and human activities. Regardless of the cause, vast areas of land are being lost in some places and gained in others; accurate estimates of land losses and gains or their equivalent economic value are unavailable because bay shoreline changes have not been systematically investigated. The purpose of this study is (1) to quantify the significant shoreline changes that occurred within the Galveston and San Antonio Bay systems during the past century, (2) to describe the physical processes that cause shoreline movement, and (3) to discuss the anticipated future changes on the basis of long-term historical records and present-day coastal conditions.

General Statement on Shoreline Changes

Shorelines are in a state of erosion, accretion, or are stabilized either naturally or artificially. Erosion produces a net loss in land, accretion produces a net gain in land, and equilibrium conditions produce no net change. Shorelines move in response to a hierarchy of

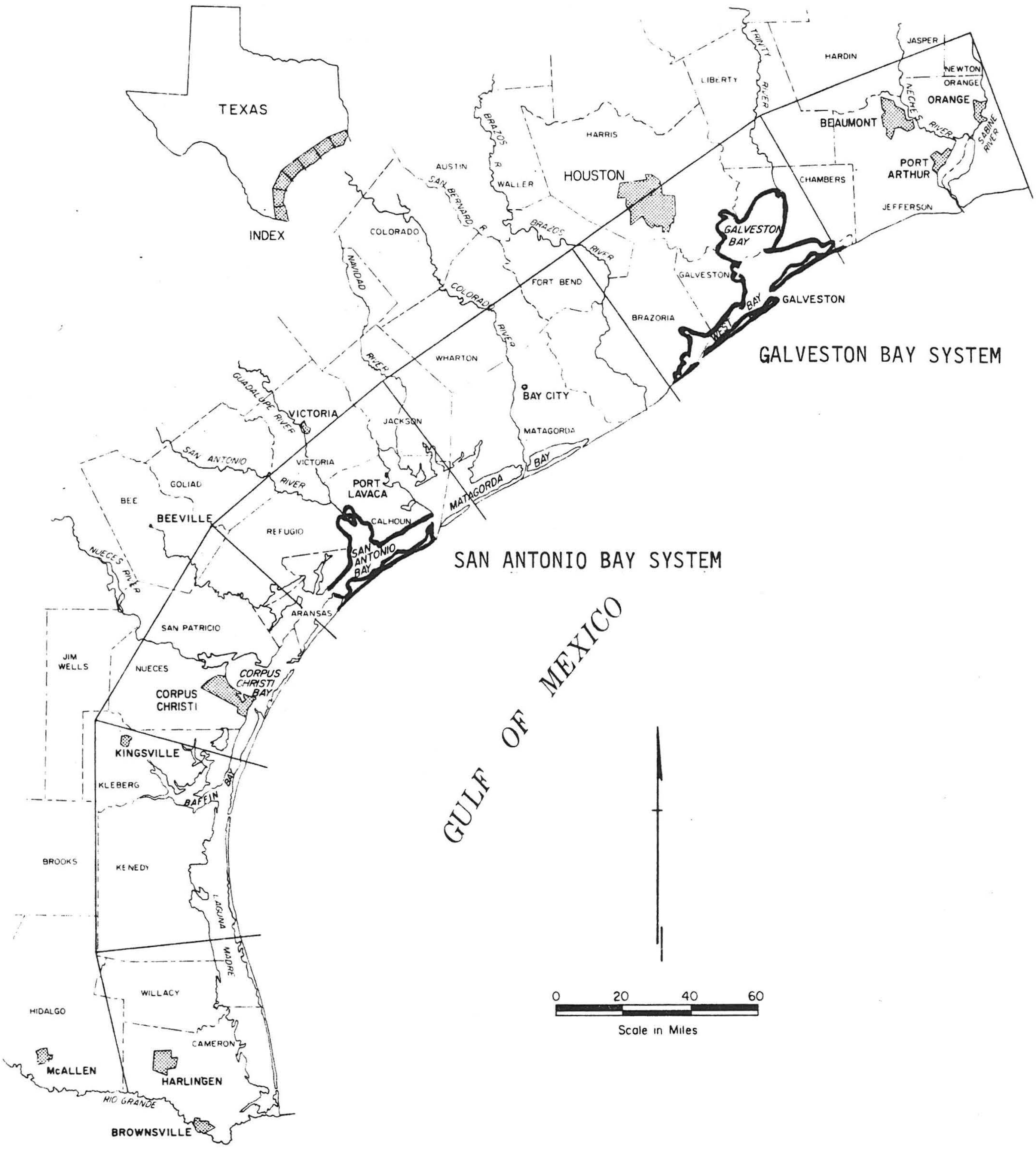


Figure 1-1. The Galveston and San Antonio Bay systems, Texas Gulf Coast.

natural cyclic phenomena including (from lower order to higher order) tides, storms, sediment supply, and relative sea-level changes. Time periods for these cycles range from less than a day to several thousand years. Many shoreline segments undergo both erosion and accretion for lower-order events, no matter what their long-term trends may be. Furthermore, long-term trends can be unidirectional or cyclic; that is, 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 of this historical monitoring program are documenting and quantifying past changes in shoreline position and predicting future changes. Qualitative descriptions of shoreline stability throughout Galveston and San Antonio Bays were previously presented on regional maps of the Texas Coastal Zone (Fisher and others, 1972; McGowen and others, 1976). Because the shoreline conditions published in the present report are more recent and quantitative, they supersede the conditions presented in the previous publications.

2.0 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

Materials used to determine changes in shoreline position are individual near-vertical aerial photographs, photographic mosaics, and topographic charts (Appendix D). Accurate topographic charts dating from 1850, 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 originals are used to establish shoreline position (mean high water) before the early 1930's. Aerial photographs supplemented and later replaced regional topographic surveys in the early 1930's; therefore, subsequent shoreline positions are mapped on individual stereographic photographs and aerial photographic mosaics taken between 1930 and 1982. These photographs show shoreline position based on the sediment-water interface at the time the photographs were taken.

Procedure

The key to detecting shoreline movement is agreement of scale and projection between the original data and the selected map base; U.S. Geological Survey 7.5-minute quadrangle topographic maps (1:24,000, or 1 inch = 2,000 ft) were used for this purpose. 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 interface mapped directly on sequential aerial photographs were optically transferred, with a Saltzman projector, from the topographic charts and aerial photographs onto the common base map. Lines transferred to the base map allow 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 Survey). Shalowitz (1964) described the possible sources of error and the degree of accuracy of these maps. In general, the accuracy of a particular survey is related to its date; recent surveys are more accurate than older surveys. Error can also be introduced by physical changes in material on which the original data appear. However, chart distortions caused by reproduction and changes in atmospheric conditions 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 larger scale photographs, whereas the same boundary can be delineated with less precision on smaller scale photographs. Fortunately, photographs with a scale equal to or larger than the topographic base map were available for this study.

Optical aberration causes the margins of photographs to be slightly distorted. To avoid this distortion, only the central portion of the photographs was used for mapping purposes, and distances between fixed points within the center 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 may introduce apparent anomalies in 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 (albedo effect) and cannot be precisely differentiated; the shoreline is projected through these areas, and therefore, some error may have been introduced. In general, these difficulties were resolved through an understanding of coastal processes and a thorough knowledge of factors that may affect the appearance of shorelines on photographs.

Use of 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 is dependent 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 beach width along most of the Texas bay shorelines substantially reduce the potential difference between mean high water and the sediment-water interface, thus making this source of error negligible in most areas.

The advantage of consecutive mapping of sediment-water interface is the internal consistency from one shoreline type to another, but 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.

Cartographic Procedure

Topographic charts

The topographic charts include a 1-minute grid, along with permanent geographic features, that can assist in transfering the shoreline from chart to base map. Where distortions in the material are present, lakes, stream valleys, meander loops, and the 1-minute latitude and longitude cells controlled rotations and scale adjustments across the charts. In general, areas with many distinctive geographic features provide the most geographic control and have the highest confidence level associated with them.

Aerial photographs

Accuracy of aerial photograph mosaics is similar to topographic charts in that quality is related to vintage; more recent mosaics are more accurate. Photograph negative quality, optical resolution, and techniques of compiling controlled mosaics have improved with time; thus 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. Cartographic procedures do not increase the accuracy of mapping; however, they tend to correct the photogrammetric errors inherent in the original materials, such as distortions and optical aberrations.

Measurements and Calculated Rates

Actual measurements of linear distances on maps can be made to 100th of an inch, which corresponds to 20 ft on maps with a scale of 1 inch = 2,000 ft (1:24,000). This is more precise than the significance of the data warrants. However, problems do arise when rates of change are calculated because (1) time intervals between photographic coverage are not equal; (2) erosion or accretion is assumed constant over the entire time period; and (3) different rates can be obtained at any given point using various combinations of lines.

Perhaps the two most important assumptions made regarding rates of shoreline change are that (1) calculated rates of change are constant over a particular time period and (2) the direction or trend of shoreline change is also invariant over the same time period. If one or both of these assumptions are invalid, then the calculated rates tend to underestimate the actual rates of change.

The problems listed above 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 discussed as follows.

First, periods between mapped shoreline positions commonly were not equal. This may have introduced some sampling bias because of the inability to determine the optimum time interval: an interval that would include not only those periods when the true changes in shoreline position followed the same trend but also when shoreline changes happened at similar rates.

Secondly, the sampling technique commonly fails to show precisely when the reversals in trend occurred. If the trend remains unchanged, then it is still possible to detect variability in the rates of change (acceleration and deceleration), but when 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.

Justification of Methods and Limitations

As shown by the preceding discussion, the methods used in long-term historical monitoring may be slightly imprecise; hence trends and rates of shoreline changes determined from these techniques have limitations. Rates of change are to some degree subordinate in accuracy to trends or direction of change; however, there is no doubt about the significance of the trends of shoreline change documented over more than 100 yr.

Limitations of the methods require that emphasis be placed first on trend of shoreline changes; rates of change are secondary. Although rates of change 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, do the data indicate that 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 D. Additional information was derived from miscellaneous reports prepared by the U.S. Army Corps of Engineers, visits with local landowners, and on-the-ground measurements and observations, including beach profiles, prepared as a part of this investigation.

3.0 FACTORS AFFECTING SHORELINE MOVEMENT

It is impossible to isolate and quantify each of the factors that cause shoreline changes (fig. 3-1). Despite the difficulties, evaluation of the various factors and their interactions is necessary to understand past shoreline changes and to anticipate future changes.

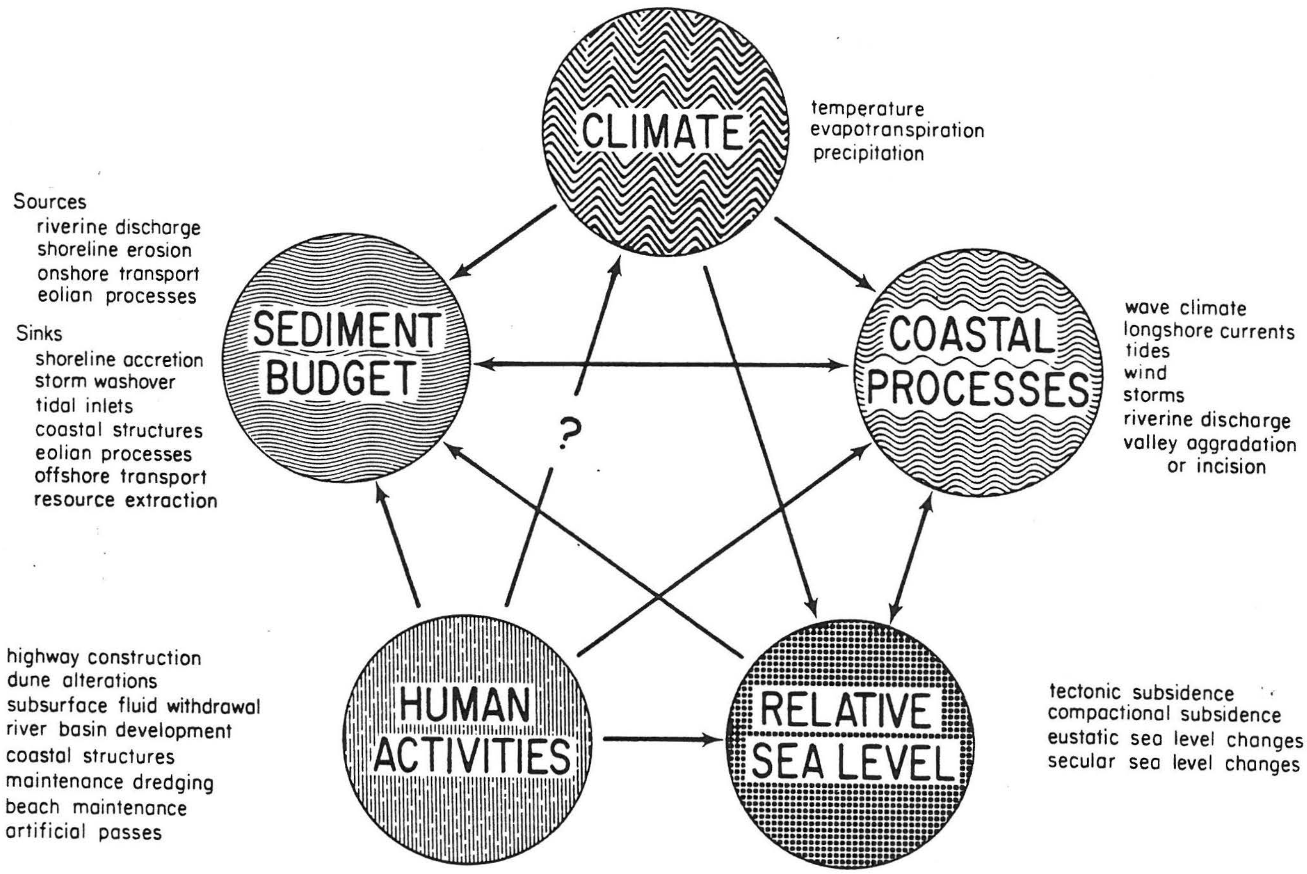


Figure 3-1. Interaction of factors affecting land losses. Arrows point toward the dependent variables: The number of arrows originating from or terminating at a particular factor indicates the relative degree of independence or interaction. For example, human activities are independent of the other factors, 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 today. This is confirmed by the geologic maps by Fisher and others (1972) and McGowen and others (1976), which show that the ancestral Trinity and Guadalupe Rivers were larger and capable of transporting greater volumes of sediment. This decrease in river size, in turn, affected sediment budget primarily by reducing the volume of sediment supplied to the Trinity and Guadalupe deltas as well as to Galveston and San Antonio Bays.

The effects of drought on shoreline changes are also minor and indirect. They cause a slight but perceptible lowering of sea level that may give rise to apparent, rather than actual, accretion. This ephemeral influence is eliminated 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 single factor receiving the most attention in recent years is relative sea-level changes (Hicks, 1978) resulting from natural movement of the Earth's crust (Holdahl and Morrison, 1974), human-induced subsidence (Gabrysch, 1969), and climatic changes (Etkins and Epstein, 1982). At least four factors govern land-sea relationships at the shoreline (fig. 3-1), but only two are significant enough to 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 factor and of less magnitude than 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 based on 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 vertical 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). Tide gauge measurements at Galveston (Swanson and Thurlow, 1973) indicate that compactional subsidence in the Galveston Bay area is substantial.

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 ground-water withdrawal (Gabrysch, 1969). Land-surface subsidence appears to be minor in the San Antonio Bay area but major in the Galveston Bay area and is primarily centered near Baytown (Brown and others, 1974; Ratzlaff, 1980). Continued withdrawal and concomitant dewatering of shales and decline in pore pressures could cause additional decreases in surface elevation and lead to future land losses, especially where volumetrically large 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 around 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), was manifested by reduced riverine discharge and excessive evaporation. These conditions would cause apparent shoreline accretion by lowering the water level. Similarly, the recent rise in sea level (Hicks and Crosby, 1975) may be partly responsible for increased and nearly coastwide shoreline erosion elsewhere.

Sediment Supply

The balance between sediment supply and forces produced by nearshore waves and currents determines shoreline stability. Shorelines accrete when sediment supply exceeds nearshore energy, whereas they erode when sediment supply is deficient. Sediment sources and sinks (fig. 3-1) and coastal processes can be drastically altered by human activities, but none of these factors change appreciably under natural conditions and over periods of several hundred years.

Sources of Sediments

The primary processes and associated sources of bay shoreline sediments in relative order of decreasing 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 during periods 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 coarse-grained material is transported away from the site (downdrift) by longshore currents, while 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 the predominantly fine-grained sediment is permanently removed from the shore. The sand transported alongshore feeds nearby beaches and bay-margin shoals, but the volume of sand added at the expense of bluff retreat is only significant on time scales of hundreds or thousands of years.

The only significant sources of new fluvial sediment in the study areas are the Trinity and Guadalupe Rivers. These rivers deliver terrigenous clastics primarily to Trinity Bay and upper San Antonio Bay and deposit them near the river mouths. Influx of fluvial sand and mud was undoubtedly more important 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 (figs. 3-2, 3-3, and 3-4), have diminished the sediment contribution from both rivers.

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 Galveston and San Antonio Bays shoaled an average of about 1 ft between the late 1800's and the mid 1930's. These bay-margin and bay-center deposits are mostly composed of fine silt and mud (White and others, in press) that settle from suspension and some sand and shell debris that are transported by storms into deeper water where they are incorporated into the muddy sediments by burrowing organisms. Sediments that fill both natural and artificial channels can also be fine grained, but usually they

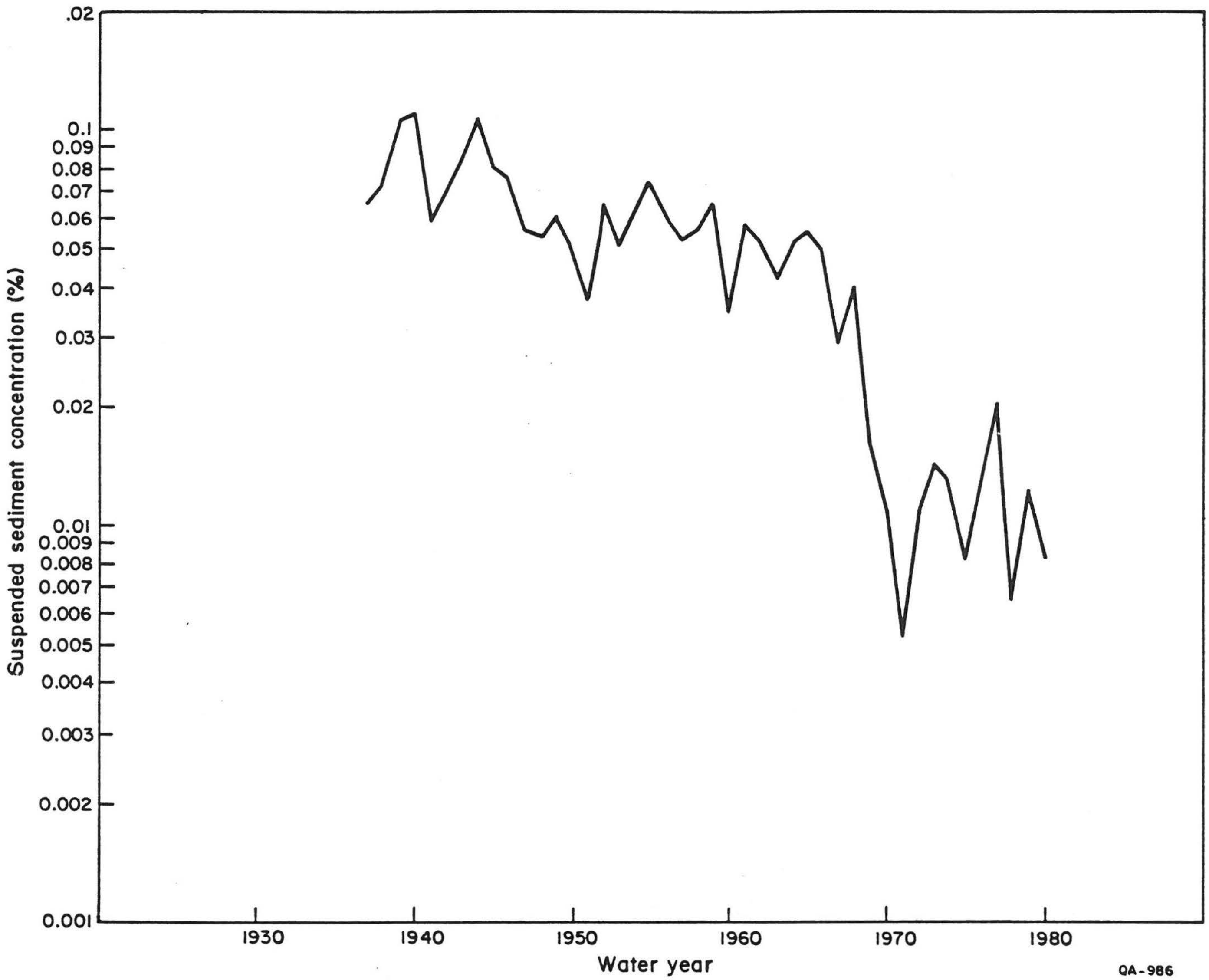


Figure 3-2. Suspended sediment concentraton (by weight) for the Trinity River at Romayor, Texas. Data from the Texas Board of Water Engineers (1961); Texas Water Commission (1964); Texas Water Development Board (1967, 1970, 1974); Texas Department of Water Resources (1979 and unpublished data).

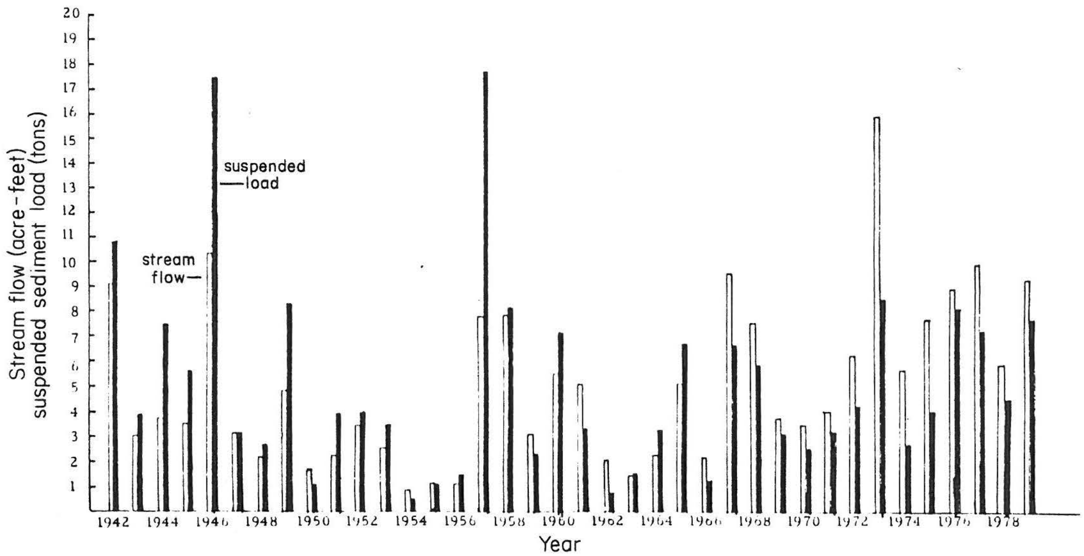


Figure 3-3. Stream flow and suspended load along the San Antonio River at Goliad, Texas.

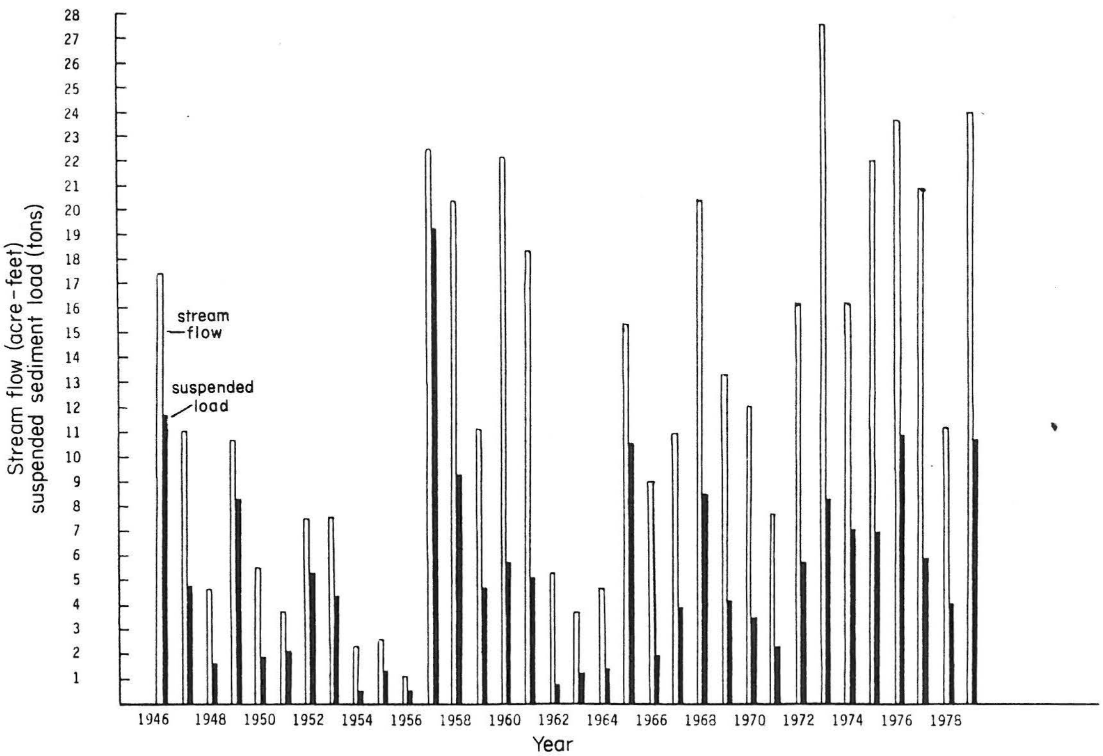


Figure 3-4. Stream flow and suspended load along the Guadalupe River at Victoria, Texas.

contain some sand and gravel-size shell concentrated near the channel base by strong currents. If the fine fraction has been winnowed from the coarse sediments, then the channel fill may be composed mostly of sand with a few mud drapes.

The cumulative losses of coarse material (sand and shell) to deeper water below wave base and away from the shore has a negative effect on sediment budget and leads 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 is dependent, 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 (Appendix C), 67 tropical cyclones have either struck or affected the Texas coast during this century (1900 to 1982). The average of 0.8 storms per yr obtained from these data is similar to the 0.67 per yr 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 Galveston area has an 18-percent probability of experiencing a tropical storm, a 14-percent probability of experiencing a hurricane, and a 4-percent probability of experiencing a catastrophic hurricane.

During storms, high windspeeds and low barometric pressures raise bay levels to extraordinary heights, which may last for several hours or several days. The surge heights and consequently the damage to the beach that occurs during these peak periods depends 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 Galveston Bay have equaled or exceeded 6 ft at least 15 times during the past 146 yr (table 1). Waves superimposed on these water levels overtop beaches, berms, and marshes and dissipate their energy by internal friction (breaking waves), drag (over vegetation or mobile sediment), or they run up against higher elevations such as dunes and bluffs. Under these extreme 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 transfered 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 one-fourth of the shores of the Galveston Bay system have been altered by coastal projects. These projects are clearly responsible for the shoreline changes of greatest magnitude, but it is uncertain whether these activities also 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 quantify because human activities promote imbalances in sediment budget, coastal processes, and relative sea-level conditions (fig. 3-1). 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

Table 1. Maximum hurricane surge heights recorded near Galveston Bay, 1837-1982.

Date	Surge Height (ft)	Location	Reference
1837	5-7	Galveston	U.S. Army Corps of Engineers (1920)
1847	8-10	Galveston channel	U.S. Army Corps of Engineers (1920)
1854	9-10	Galveston channel	U.S. Army Corps of Engineers (1920)
1867	6.6	Galveston channel	U.S. Army Corps of Engineers (1920)
1875	8.3	Galveston	U.S. Army Corps of Engineers (1896)
1886	9.0	Galveston	U.S. Army Corps of Engineers (1920)
1886	6-7	Galveston	U.S. Army Corps of Engineers (1920)
1900	20.0	Galveston	Sugg and others (1971)
1909	10.0	Galveston	Sugg and others (1971)
1915	14.3	Galveston	Sugg and others (1971)
	16.1	Galveston Causeway	Sugg and others (1971)
1919	8.8	Galveston	Price (1956)
	10.0	Anahuac	Sugg and others (1971)
1933	6.0	Galveston	U.S. Army Corps of Engineers (1979)
1942	6.2	Galveston	U.S. Army Corps of Engineers (1979)
1949	7	Galveston	U.S. Army Corps of Engineers (1979)
	8.5	Kemah	U.S. Army Corps of Engineers (1979)
	9	Anahuac	U.S. Army Corps of Engineers (1979)
1961	9.3	Galveston	U.S. Army Corps of Engineers (1979)
	15	Upper Galveston Bay	U.S. Army Corps of Engineers (1979)

effects, whereas many years may pass before the effects of other activities such as subsurface fluid withdrawal, flood control, and sediment impoundment are detected.

Predicting future human impact on the bay shoreline is even more difficult than documenting human influence on historical 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 cause warming of average temperatures, melting of polar ice caps, and raising of 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 (Lamb, 1970), consequently expanding continental ice sheets with attendant lowering of sea level. Regardless of the future consequences, both theories suggest that human activities may eventually alter weather patterns and possibly sea-level position.

4.0 HISTORICAL CHANGES IN THE GALVESTON BAY SYSTEM

The Galveston Bay system includes four major bays--Trinity Bay, Galveston Bay, West Bay, and East Bay (fig. 4-1). Shoreline positions mapped for three time periods (1850-52, 1930, and 1982) indicated whether lengths of shoreline moved bayward, landward, or remained stationary between these periods; the positions were also used to calculate amounts and net rates of shoreline advance or retreat. Supplemental aerial photographs taken in 1956 and 1974 contributed historical information and gave intermediate shoreline positions.

Two methods were used to quantify shoreline changes. First, a shoreline segment for a particular period (for example, Trinity Bay from 1850 to 1930) was divided into lengths of shoreline that moved bayward (accreted), landward (eroded), or showed no net movement (stable). Each length was added to others of its type to obtain the total length of accreting,

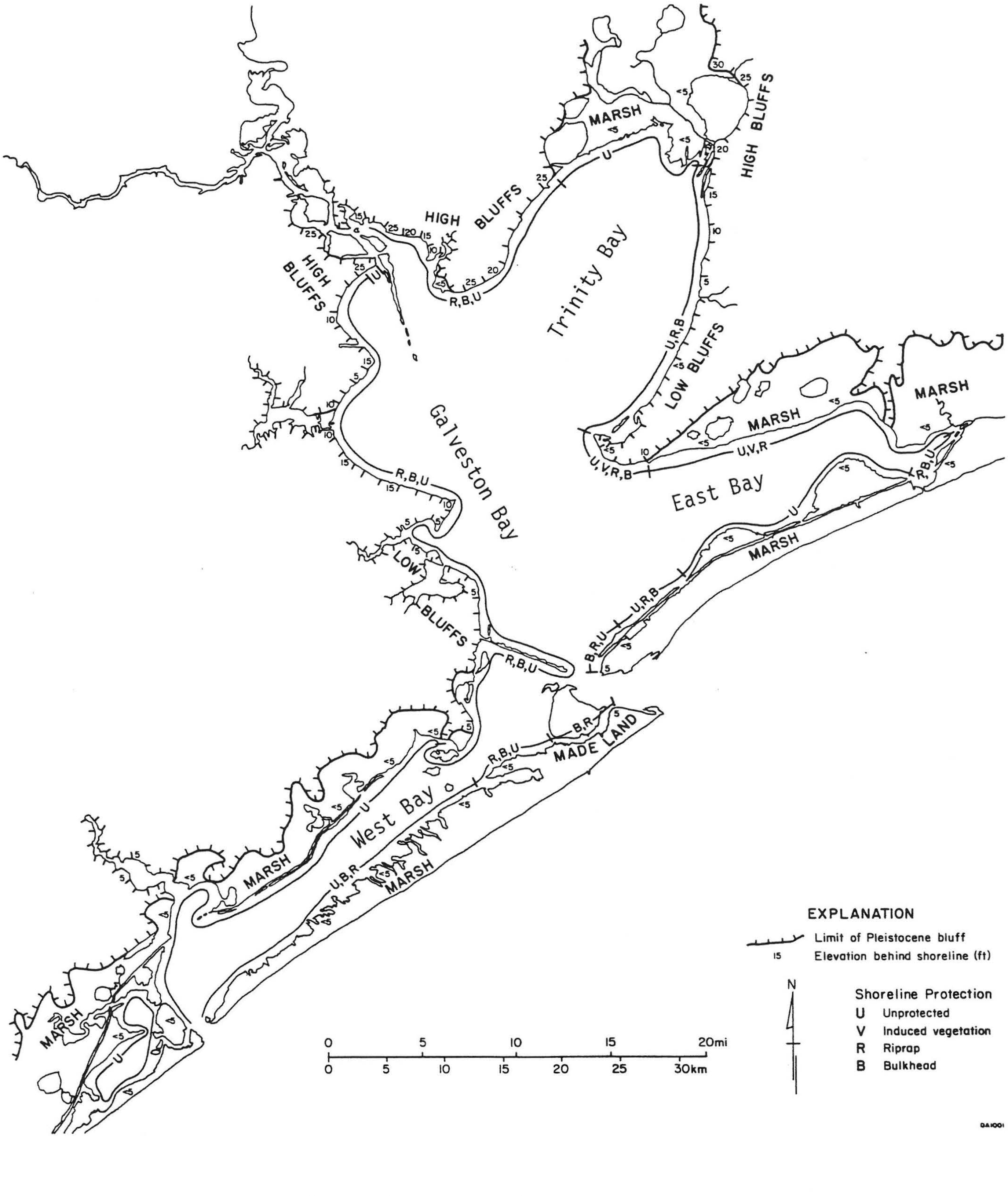


Figure 4-1. Distribution of shoreline types and shoreline protection measures in the Galveston Bay system.

eroding, and stable shoreline by percent. Second, measuring points (stations) were distributed throughout the bays; amounts and rates of shoreline change were measured at these stations. Station spacings (4,000 ft in Trinity Bay, 5,000 ft in all other bays) were selected to maximize interpolation between stations, so that if erosion occurred at two adjacent stations, then erosion could be assumed between those stations. Generalized rates of shoreline change are presented for each bay and period throughout the text; precise dates, measurements, rates, and uncertainties are given in Appendix A.

Shoreline changes occurred for all types of shorelines in the Galveston Bay system. Types of shorelines likely to be found around these bays include low to high clay bluffs, fresh-water to salt-water marshes, sandy slopes, sand and shell beaches, and various types of spoil and made land (fig. 4-1). Shorelines have been protected in a variety of ways, including induced vegetation (commonly Spartina alterniflora), riprap, and bulkheads (fig. 4-1).

Trinity Bay

Trinity Bay is subjected to similar geologic and climatic factors as the other bays in the Galveston Bay system, with the added influence of the Trinity River. This river discharges into northern Trinity Bay, forming the Trinity delta. The bay stretches from Smith Point northward to Lake Anahuac (formerly Turtle Bay), and from there southwestward to Houton Point (fig. 4-2). Sixty-six measuring points were distributed through this bay, including 14 around Lake Anahuac. Average station spacing was 4,000 ft. Shoreline changes were measured between 1851 and 1930, 1930 and 1982, and 1851 and 1982 shorelines, and supplemental shorelines (1956 and 1974) were mapped in areas of greater change.

1851 to 1930

The shores of Trinity Bay (with the exception of the areas near Anahuac and Double Bayou) were largely unsettled in 1930; therefore, most shoreline changes before 1930 must be attributed to natural causes. Over 70 percent of this shoreline occupied a position in 1930 landward of that in 1851, whereas 20 percent of the shoreline accreted during this period. The remainder experienced a net change of less than 25 ft.

Although Trinity Bay shorelines were generally eroding during this period, the highest rates of shoreline change occurred for the accreting portion of the Trinity delta (fig. 4-2). The highest rates of accretion (40 ft/yr) occurred near station 43 on the southern end of the delta; river discharge in other areas near this station caused lower rates of accretion (2 to 12 ft/yr at stations 41, 42, and 44). Erosion was the rule in abandoned parts of the delta, the northeastern portion of the delta in Lake Anahuac recording erosion rates up to 6 ft/yr (stations 36 to 40); erosion rates of 0.5 to 7 ft/yr occurred for the western portion of the delta (stations 45 to 53).

Most of the stations along eastern Trinity Bay (Smith Point to Anahuac) also recorded erosion during this period. Typical erosion rates were less than 5 ft/yr; increased rates up to 10 ft/yr were observed in the Double Bayou area (stations 12 to 14 and 16 to 19) and at Smith Point (station 1). Rates of erosion generally decreased northward from Double Bayou, from 9 ft/yr at station 17 to less than 3 ft/yr at station 23. Erosion rates of less than 2 ft/yr were observed near Anahuac (stations 24 to 26). Decreased erosion rates in this area may be attributed to proximity to a sediment source (Trinity delta) and decreased fetch across Trinity Bay.

Four eastern Trinity Bay stations (4, 5, 7, and 9) recorded accretion during this period. All these stations are on the southern portion of the shoreline, which may be a zone of accumulation for longshore currents generated during strong northerly winds. Rates ranged from 1.5 to 3 ft/yr, the greatest accretion (station 4) occurring in an embayment near Smith Point. Sediment accumulated at the eastern edge of this embayment, allowing marsh expansion at Frankland Point (station 5).

Western Trinity Bay (Houston Point to the Trinity delta) also experienced widespread erosion during this period. Erosion rates ranged from 0.5 to 3.5 ft/yr for stations 56 to 61; however, 1851 shoreline control was poor in this region. Erosion rates were generally higher from Houston Point to Umbrella Point (stations 62 to 66), ranging from 0.6 to 5.7 ft/yr. These

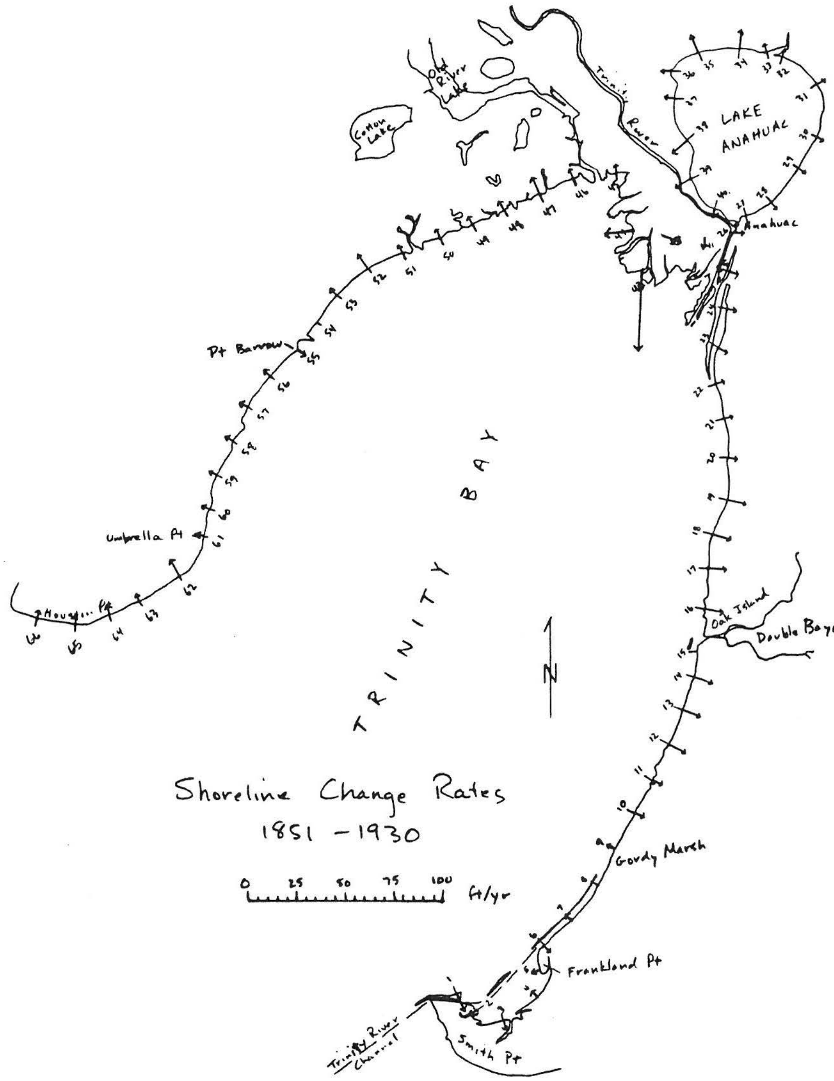


Figure 4-2. Trinity Bay locations, measuring stations, and rates of shoreline change, 1851 to 1930.

stations have a longer wave fetch for the predominant southeasterly winds. Accretion was recorded for a single western Trinity Bay station (station 55). This station occurs on Point Barrow in the discharge area of a small stream.

Throughout the 1851 to 1930 period, Lake Anahuac and Trinity Bay were a continuous body of water (Lake Anahuac was called "Turtle Bay" during that period), connected between Anahuac and the Trinity delta. Turtle Bay became more restricted as the delta prograded southeastward, causing decreased wave energy in Turtle Bay. Nevertheless, all stations in Turtle Bay (stations 27 to 40) recorded erosion during this period. Erosion rates of 1.5 ft/yr or less were observed for southern Turtle Bay (stations 27, 29, and 40), whereas higher erosion rates (2 to 7 ft/yr) were found for northern and eastern portions of the bay. Older Trinity delta sediments form the western shore of Turtle Bay; these deposits eroded at rates of 1.5 to 6 ft/yr.

1930 to 1982

Development and utilization of the Trinity Bay shoreline has accelerated since 1930. Some areas have undergone extensive human modification, such as the Lake Anahuac shoreline. Other areas have remained relatively natural, such as the western flank of the Trinity delta. The most densely populated areas, and consequently the areas in which shoreline change is of greatest concern, include the community of Anahuac along eastern Trinity Bay and several small developments east of Baytown along the western shore of Trinity Bay.

One of the first major projects to directly affect the Trinity Bay shoreline was the dredging of the Trinity River channel on the eastern shore of Trinity Bay. Nearly continuous spoil islands on the bay side of the channel stretched from Smith Point to Anahuac in 1956 (fig. 4-3). Maintenance of this channel was discontinued, allowing the channel to fill and spoil islands to erode. By 1974 most of the islands had disappeared; by 1982, only isolated spoil islands remained to lend some erosion protection to the Smith Point and Double Bayou areas.

Between 1930 and 1956, Turtle Bay and Trinity Bay were separated by Trinity delta progradation and channel dredging and concomitant spoil disposal in Turtle Bay. Also during

Figure 4-3. Wave-cut face of a spoil island along the Trinity River Channel, Trinity Bay.

this period, the Old River ceased to be a tributary of the Trinity River and began direct discharge into Trinity Bay west of the Trinity delta (between stations 46 and 47, fig. 4-4).

For the period 1930 to 1982, 61 percent of the Trinity Bay shoreline experienced net erosion, 23 percent of the shoreline accreted, and the remainder had a net change of less than 25 ft. The Trinity delta was the most rapidly changing feature (fig. 4-4), having both the highest accretion rate (more than 100 ft/yr at station 41) and the highest erosion rate (50 ft/yr at station 39). Two other Trinity delta stations (43 and 44) were in areas of active deposition and recorded marsh expansion rates of 40 and 12 ft/yr, respectively. The northeastern flank of the delta received little sediment and was cut by the Turtle Bay canal; thus erosion was common. Most of the erosion at station 39 occurred between 1956 and 1974; if this was a continuous process, then rates of erosion were in excess of 100 ft/yr.

Despite the protection afforded eastern Trinity Bay by the spoil islands, most stations along this stretch recorded net erosion for the period 1930 to 1982 (fig. 4-5). Erosion rates from Smith Point to Gordy Marsh ranged from no change at station 3 to 5 ft/yr at station 10. Anomalously high erosion rates of 13 to 14 ft/yr occurred near station 11. Rates of erosion of less than 5 ft/yr were observed north and south of Double Bayou (stations 12 to 22), and two stations (15 and 16) recorded no net change. Spoil islands persist from station 23 to Anahuac, protecting marshes formed on dredge spoil adjacent to the pre-channel shoreline. This resulted in apparent accretion rates of 0.5 to 15 ft/yr for stations 23 to 26.

Western Trinity Bay also experienced widespread erosion during this period (fig. 4-6). The highest rates of erosion (6 to 10 ft/yr) occurred west of the Trinity delta (stations 48 to 50) in older Trinity River deposits. Moderate erosion rates of 1 to 3 ft/yr occurred between Point Barrow and Houston Point (stations 57 to 66). Three stations (52, 55, and 64) recorded small amounts of accretion for the period; in each case these were local events.

After its separation from Trinity Bay, Turtle Bay became a fresh-water reservoir (Lake Anahuac) with a surface elevation a few feet above sea level. This separation reduced wave energy in the lake; spoil emplacement related to channel dredging around the circumference of

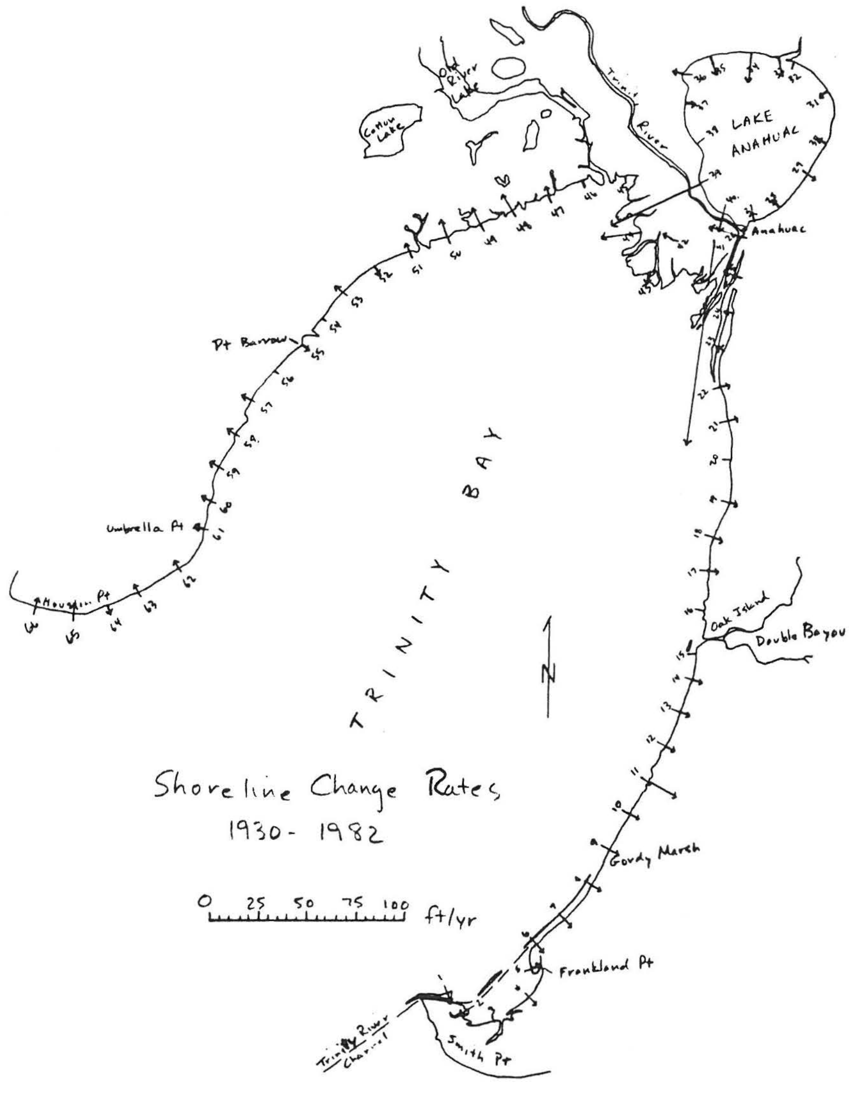


Figure 4-4. Rates of shoreline change for Trinity Bay, 1930 to 1982.

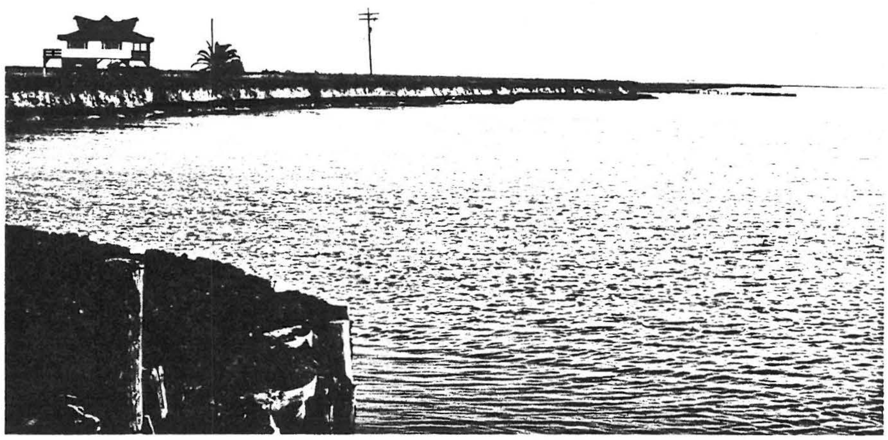


Figure 4-5. Eroding low bluffs along eastern Trinity Bay.

Figure 4-6. Failed bulkhead along western Trinity Bay.

the lake, along with reduced wave energy, caused many Lake Anahuac stations to record accretion for this period. Since completion of the reservoir, however, erosion occurred at many stations where measurements were made. Between 1974 and 1982, stations 33 to 37 recorded no shoreline change; stations 38 to 40 recorded erosion at rates of 6 to 9 ft/yr. Most of this apparent erosion, however, is an artifact of higher lake levels.

Summary, 1851 to 1982

Shoreline changes over the 131-yr period are generally similar to those of the constituent periods. Sixty-seven percent of the Trinity Bay shoreline occupied a position in 1982 landward of its position in 1851, whereas 29 percent of the shoreline experienced net accretion over the same period. Most of the accretion took place in the vicinity of the Trinity delta, and most of the erosion occurred along eastern and western Trinity Bay (fig. 4-7). Rates of erosion were slightly greater for eastern Trinity Bay; 5 stations were in the 5- to 10-ft/yr range, 14 stations in the 0- to 5-ft/yr range, 5 stations reported no net change, and 1 station recorded accretion (less than 1 ft/yr). By comparison, western Trinity Bay had 1 station in the 5- to 10-ft/yr erosion rate range, 19 stations in the 0- to 5- ft/yr range, 1 station recording no net change, and 1 station experiencing accretion at about 3 ft/yr.

The Trinity delta prograded to the south and southeast during this period at rates of about 1 to 40 ft/yr. Areas of nondeposition were commonly retreating, generally at rates of 5 ft/yr or less. Station 39 was an exception, where rapid erosion from 1956 to 1974 produced an average erosion rate for the full period of 11 ft/yr. Despite reduced wave energy and spoil emplacement at the shoreline, the shoreline at Lake Anahuac retreated at most stations during this period, generally at rates less than 5 ft/yr.

Galveston Bay

Shorelines considered here as part of Galveston Bay form an irregular outline (fig. 4-8), beginning at Swan Marsh near Cedar Bayou and including Tabbs Bay, Hogg Island, and the long

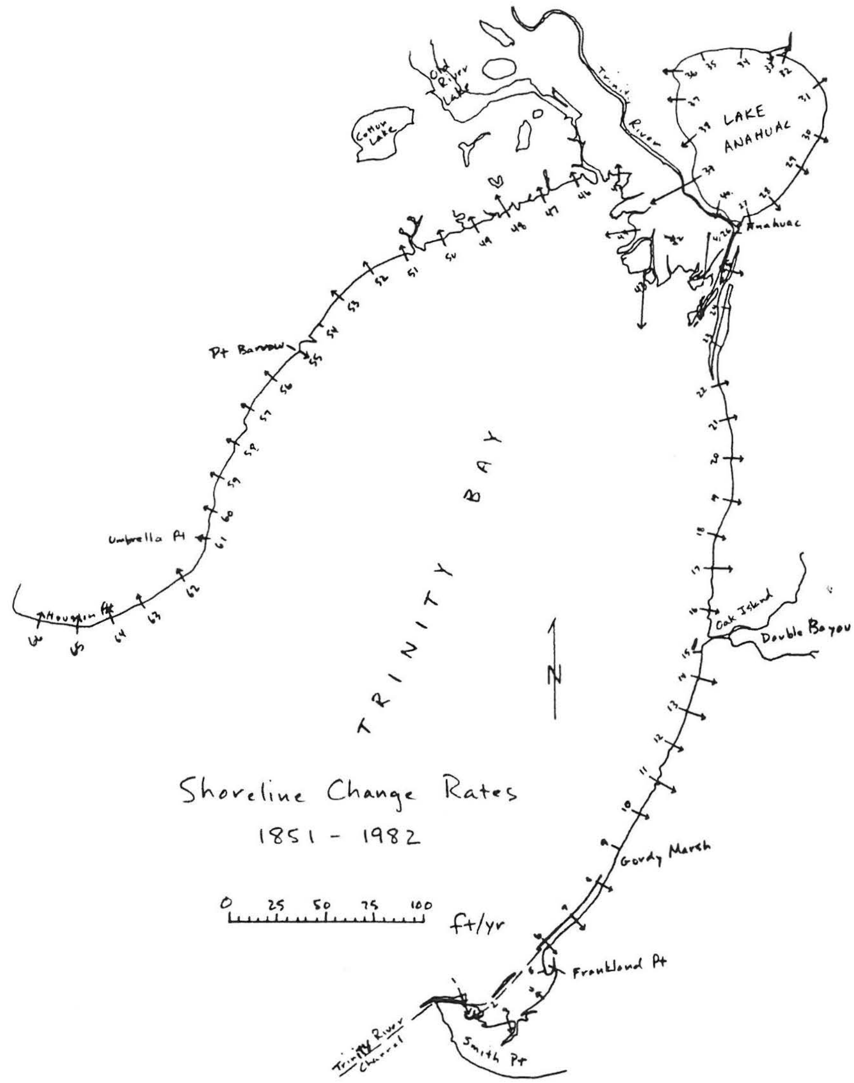


Figure 4-7. Cumulative rates of shoreline change for Trinity Bay, 1851 to 1982.

stretch of shoreline between Morgans Point and Virginia Point. Fifty-eight stations were placed along the shoreline at approximately 5,000-ft intervals, including five stations in Dickinson Bay and nine stations in the Moses Lake - Dollar Bay area. U.S. Coast and Geodetic Survey topographic charts from 1850 and 1851 were the source of the oldest shoreline position; later shoreline positions were obtained from 1930 and 1982 aerial photographs. Supplementary shoreline positions and historical information were taken from 1956 and 1974 aerial photographs.

1850-51 to 1930

The shores of Galveston Bay supported a sparse and scattered population in 1850. However, by 1930 more waterfront development and settlement had occurred around Galveston Bay than has occurred to date on Trinity Bay. Nevertheless, most Galveston Bay shoreline changes before 1930 were largely due to natural processes. Most of these shoreline changes were in a landward direction; 80 percent of the shoreline between Galveston Bay stations 1 and 58 experienced net erosion during this period (fig. 4-8). Twelve percent of the shoreline accreted during this period, and 8 percent had a net change of less than 25 ft.

Only seven stations recorded accretion during the period; three of these occurred between Baytown and Houston Point (stations 1, 3, and 6). Station 1 had the highest rate of natural accretion for Galveston Bay (12 ft/yr). This station recorded the expansion of Swan Marsh behind the Houston Point spit. Minor accretion occurred at stations 3 and 6 (1.6 and 0.3 ft/yr, respectively). Minor erosion (1.5 to 3 ft/yr) was observed in this area at stations 2, 4, and 5. Hydrocarbon production began in the Goose Creek Oil Field before 1930; erosion rates of 13 ft/yr near station 7 in Tabbs Bay record the related disappearance of Thumb Point. This disappearance, coupled with the flooding of nearby Goose Creek with bay waters, indicates that significant subsidence occurred in the area before 1930. Hogg Island stations 8 and 9, on the southern shore of Tabbs Bay, recorded erosion rates for the period of 12 and 2 ft/yr, respectively.

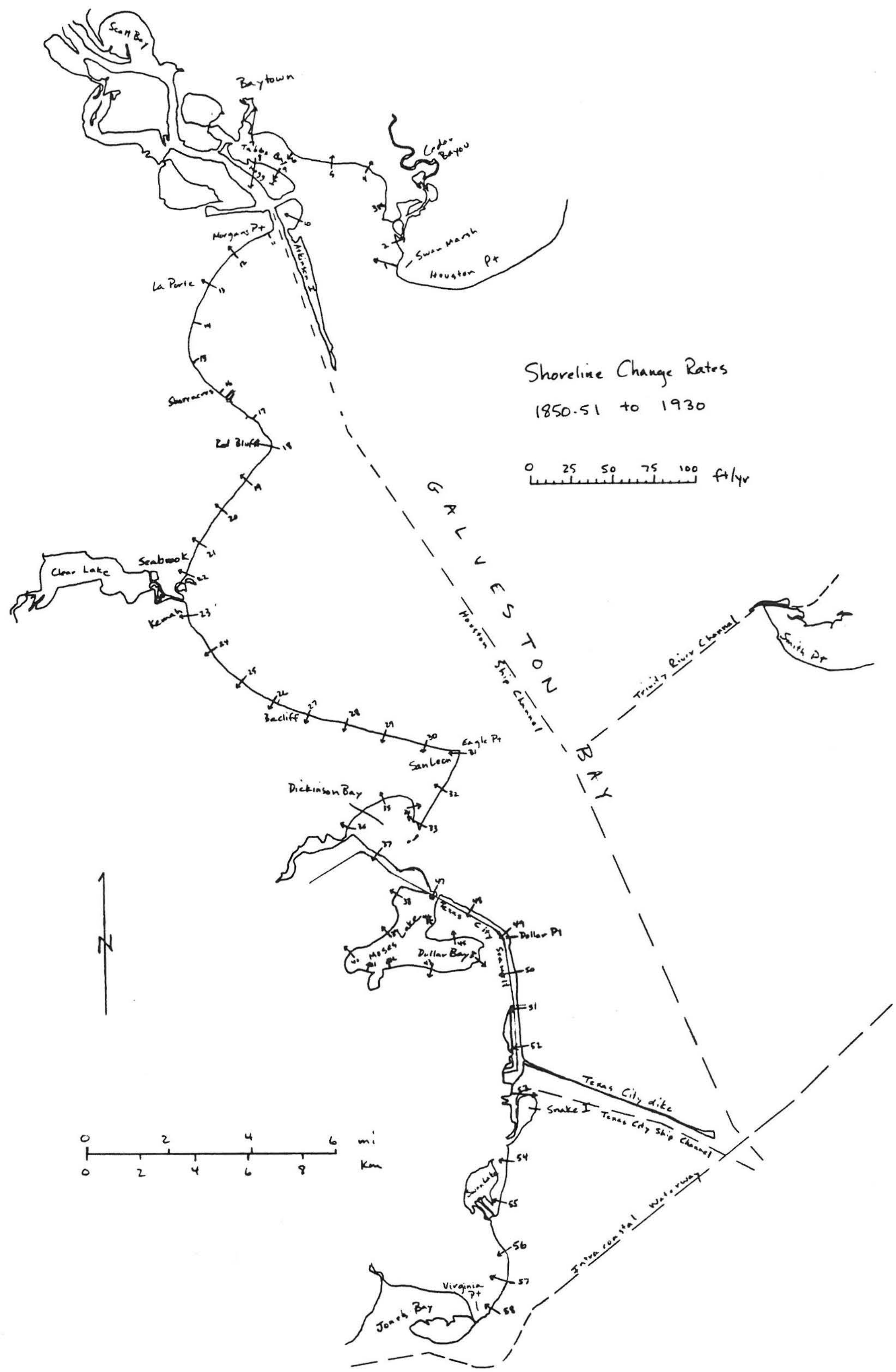


Figure 4-8. Galveston Bay locations, measuring stations, and rates of shoreline change, 1850-51 to 1930.

The Morgans Point - LaPorte area had been signficantly altered from its natural state by 1930. Morgans Point peninsula had been cut by channel dredging (fig. 4-9), and Atkinson Island was created by related spoil disposal. A portion of the bay shoreline near station 11 had been artificially stabilized, resulting in no net shoreline change for that station. The severed portion of Morgans Point underwent erosion at rates greater than 5 ft/yr near station 10, and the unprotected shoreline between Morgans Point and LaPorte (stations 12 and 13) eroded at rates of 3.8 to 4.8 ft/yr. The shoreline between LaPorte and Red Bluff was generally stable during this period; stations 14 to 17 recorded no net change.

Every station between Red Bluff and Dickinson Bay (stations 18 to 33) recorded erosion between 1850 and 1930. Red Bluff eroded at rates of 6 ft/yr near station 18; erosion rates decreased to less than 3 ft/yr in the more protected area southwest of Red Bluff (stations 19 and 20). Erosion rates near the newly settled communities of Seabrook and Kemah (stations 21 to 24) ranged from 0.5 to 2.5 ft/yr, despite discharge from Clear Lake in this area. Rates of erosion increased slightly toward Eagle Point, ranging from 1 to 3 ft/yr for stations 26 to 30. The highest erosion rates for Galveston Bay in this period (7.5 ft/yr) were recorded at station 33. Dickinson Bay eroded at rates of 2 to 3 ft/yr (stations 34 to 37).

Stations 38 to 46 were placed around Moses Lake and Dollar Bay, which are more restricted environments than the open bay. Three of these stations (41, 42, and 46) recorded minor amounts of accretion (1 to 2 ft/yr) caused by marsh expansion. Stations 38 to 40 and 43 to 45 eroded at rates of 0.5 to 4 ft/yr.

By 1930, the Galveston Bay shoreline from Dollar Bay to Virginia Point had been altered somewhat from its natural state. The Texas City dike had been constructed to protect the Texas City Ship Channel, Snake Island was created from ship channel and turning basin spoil, and landfill caused apparent accretion at the Texas City port. More than 1,000 ft of accretion recorded at station 53 were due to this landfill. All other stations between Dollar Bay and Virginia Point recorded erosion, ranging from 2 to 5 ft/yr north of the Texas City dike (stations 47 to 52), and 0.5 to 6 ft/yr south of the dike (stations 54 to 58).

Figure 4-9. Shell berm at Morgans Point, Galveston Bay.

1930 to 1982

The amount of eroding shoreline along Galveston Bay decreased to 68 percent for the period 1930 to 1982, possibly reflecting increased development and greater interest in shoreline protection measures. Twelve percent of the shoreline experienced accretion for this period, in general because of spoil disposal and construction projects. The remaining 20 percent of the shoreline had a net change of less than 25 ft for the period.

The highest rates of erosion were observed for stations 1 and 6 between Baytown and Houston Point (fig. 4-10), at 38 and 26 ft/yr, respectively. Most of the erosion at Swan Marsh (station 1) occurred between 1956 and 1974. Erosion at Evergreen Point (station 6) on Tabbs Bay was caused by subsidence in the Goose Creek Oil Field area. Stations 2 to 5 experienced more moderate erosion at rates of 2 to 5 ft/yr. Despite spoil disposal on the island, Hogg Island (stations 8 and 9) recorded erosion rates of 1 to 5 ft/yr for the period. Spoil emplacement from Houston Ship Channel maintenance dredging caused 750 ft of accretion at Atkinson Island (station 10).

The Morgans Point to Shoreacres stretch of shoreline (stations 11 to 17) was relatively stable during this period; rates of change ranged from 0.5 ft/yr of accretion to 1.5 ft/yr of erosion. Shoreline protection measures (riprap) had been taken by 1974 to prevent erosion at Red Bluff; station 18 at Red Bluff eroded at a rate of 3 ft/yr for this period. Increased erosion (14 ft/yr) was observed at station 19, which was not protected.

Rates of shoreline change for stations 20 to 30 were similar for this period, ranging from no change (stations 22, 24, and 25) to erosion of up to 3 ft/yr (fig. 4-11). The exception was station 28, located east of the cooling water outlet of the Houston Lighting and Power plant. This station experienced rates of erosion of 5 ft/yr. Erosion rates increased from 2.9 ft/yr at Eagle Point (station 31) to 5.8 ft/yr at the Dickinson Bay inlet (station 33). Station 34 in Dickinson Bay recorded no net change, but all other stations in the bay experienced erosion at rates ranging from 2 to 4 ft/yr.

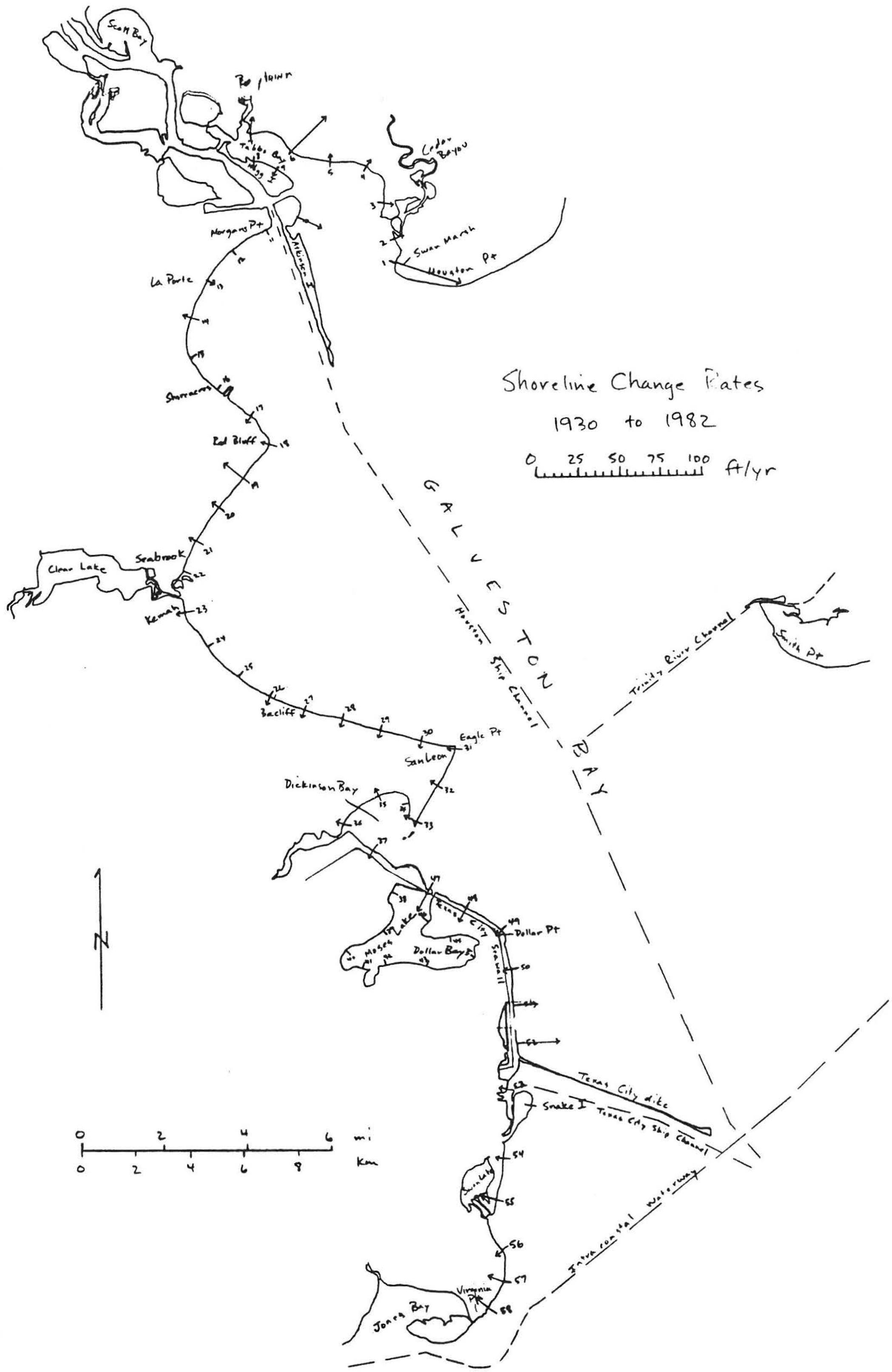


Figure 4-10. Rates of shoreline change for Galveston Bay, 1930 to 1982.

Figure 4-11. Riprap and bulkheads protecting Seabrook, Galveston Bay.

The Texas City Seawall, completed by 1974 (fig. 4-12), extends from Dickinson Bay to Texas City. Stations 47 to 50, located along the present seawall, experienced erosion during the 1930 to 1982 period at rates of 3.5 to 12 ft/yr (fig. 4-13). Landfill associated with construction of the seawall caused apparent accretion of 700 and 1,125 ft at stations 51 and 52, respectively. Erosion occurred during this period for all stations between the Texas City dike and Virginia Point; the highest rates were observed for station 55 at Swan Lake (5 ft/yr), station 57 (9 ft/yr), and station 58 at Virginia Point (5 ft/yr).

Summary, 1850-51 to 1982

Cumulative shoreline changes over this period indicate that nearly all of the Galveston Bay shoreline was subject to long-term erosion. Only 4 of the 58 stations distributed throughout this bay recorded shoreline positions in 1982 bayward of their position in 1850-51 (fig. 4-14). Eighty-five percent of the Galveston Bay shoreline had net erosion for the period, whereas only 11 percent of the shoreline recorded net accretion. The four accreting stations were the result of spoil disposal (station 10), landfill associated with the Texas City Seawall (stations 51 and 52), and the construction of the Texas City port (station 53). No net change was recorded at four stations: station 3 at Cedar Bayou, station 10 at Morgans Point, and stations 15 and 16 near Shoreacres.

The remaining stations recorded erosion for the period. Rates of erosion varied depending on wave fetch, sediment supply, type of shoreline protection (if any), amount of subsidence, and orientation of the shoreline. Long-term erosion rates in the Baytown - Houston Point area ranged from 0 to 11 ft/yr. Hogg Island shorelines retreated at rates of 3 to 8 ft/yr. Low rates of erosion (0 to 3 ft/yr) were observed in the embayment between Morgans Point and Red Bluff; a similar embayment between Red Bluff and Eagle Point experienced comparable erosion rates of 0.5 to 3 ft/yr. Greater rates of erosion were observed on promontories, such as 5 to 6 ft/yr at Red Bluff and 2.5 to 7 ft/yr between Eagle Point and Dickinson Bay. Long-term erosion rates in Dickinson Bay were somewhat lower (1 to 4 ft/yr), probably due to small wave fetch

Figure 4-12. Texas City Seawall and holding ponds, Galveston Bay.

Figure 4-13. Erosion of low bluffs fronting the Texas City Seawall, Galveston Bay.

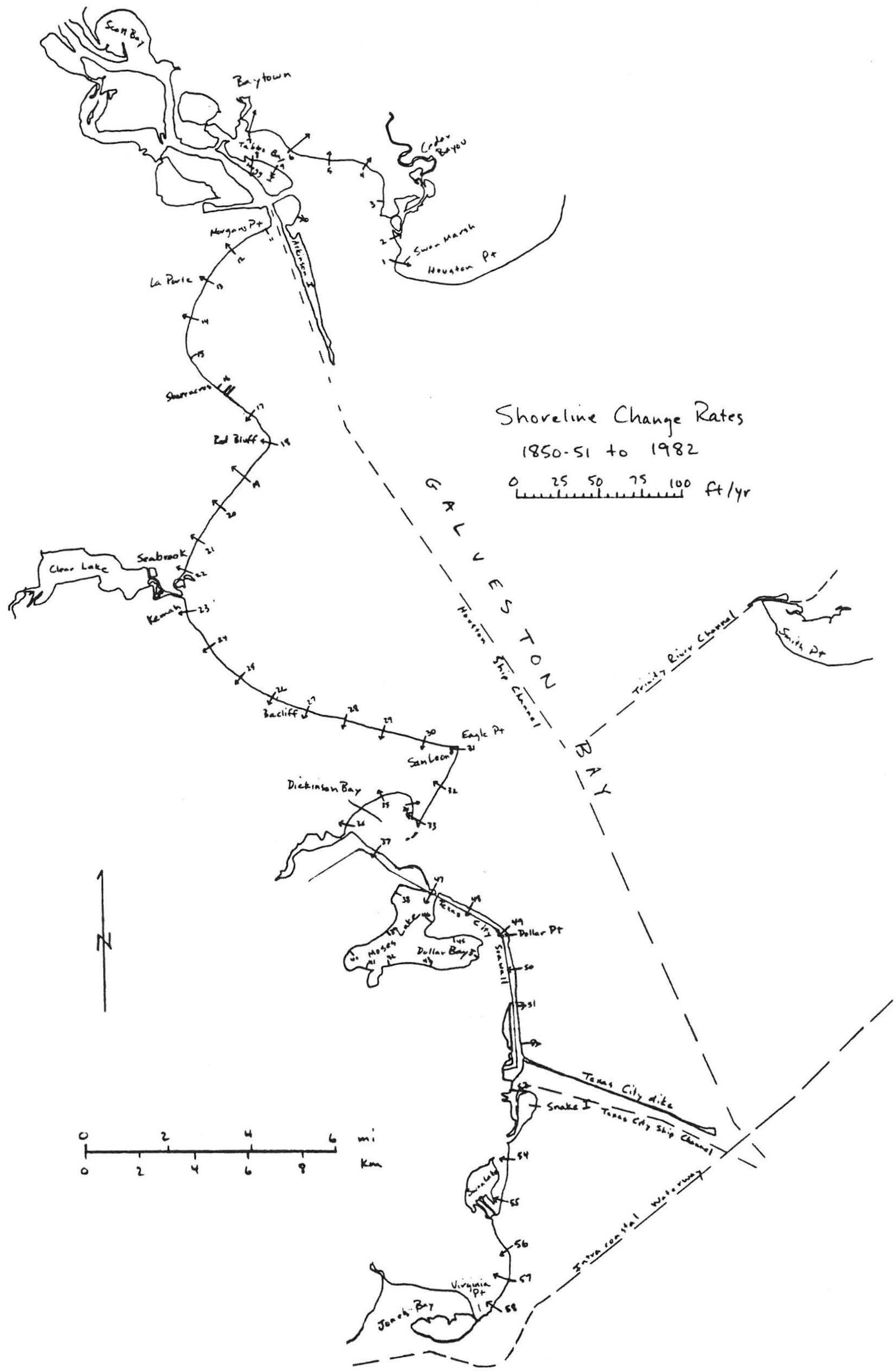


Figure 4-14. Cumulative rates of shoreline change for Galveston Bay, 1850-51 to 1982.

across that bay. Shorelines fronting the Texas City Seawall had erosion rates 3 to 8 ft/yr. Erosion between Snake Island and Virginia Point ranged from 2 to 7 ft/yr during this period.

West Bay

With all of the smaller peripheral bays included as part of West Bay (Jones Bay, Chocolate Bay, Bastrop Bay, Christmas Bay, and Drum Bay), this bay has by far the greatest amount of shoreline of the bays in the Galveston Bay system. The mainland shore of West Bay proper stretches from Virginia Point to San Luis Pass; its southeastern shore is provided by Galveston Island (fig. 4-15). Over 120 measuring points at a point spacing of approximately 5,000 ft, were located in West Bay. Additional stations were placed where this coverage was inadequate.

The earliest shoreline for West Bay was mapped from 1850 to 1852 by the U.S. Coast and Geodetic Survey. This shoreline was compared to later shorelines mapped on 1930 and 1982 aerial photographs. Additional shoreline positions and historical information were obtained from 1956 and 1974 aerial photographs.

1850-52 to 1930

As was the case for all other bays in the Galveston Bay system, West Bay shorelines generally retreated during this period (fig. 4-15). Eighty-five stations recorded net erosion, 9 stations showed no net change, and 28 stations had net accretion. Most of the changes were attributable to natural causes because human modifications affected only a small portion of the West Bay shoreline before 1930. These modifications were concentrated on the eastern end of Galveston Island, from Offatt Bayou eastward to Bolivar Roads.

Movement of water from Galveston Bay into West Bay occurs during cold fronts, when strong northerly winds blow water out of Trinity and East Bays. These water movements have caused spits to form at Wilson Point and Teichman Point. At Wilson Point, shores subjected to the strongest currents (stations 1 and 2) underwent erosion of 3 ft/yr during the 1850 to 1930 period. Deposition occurred in calmer areas on the point (stations 3 and 4), causing accretion

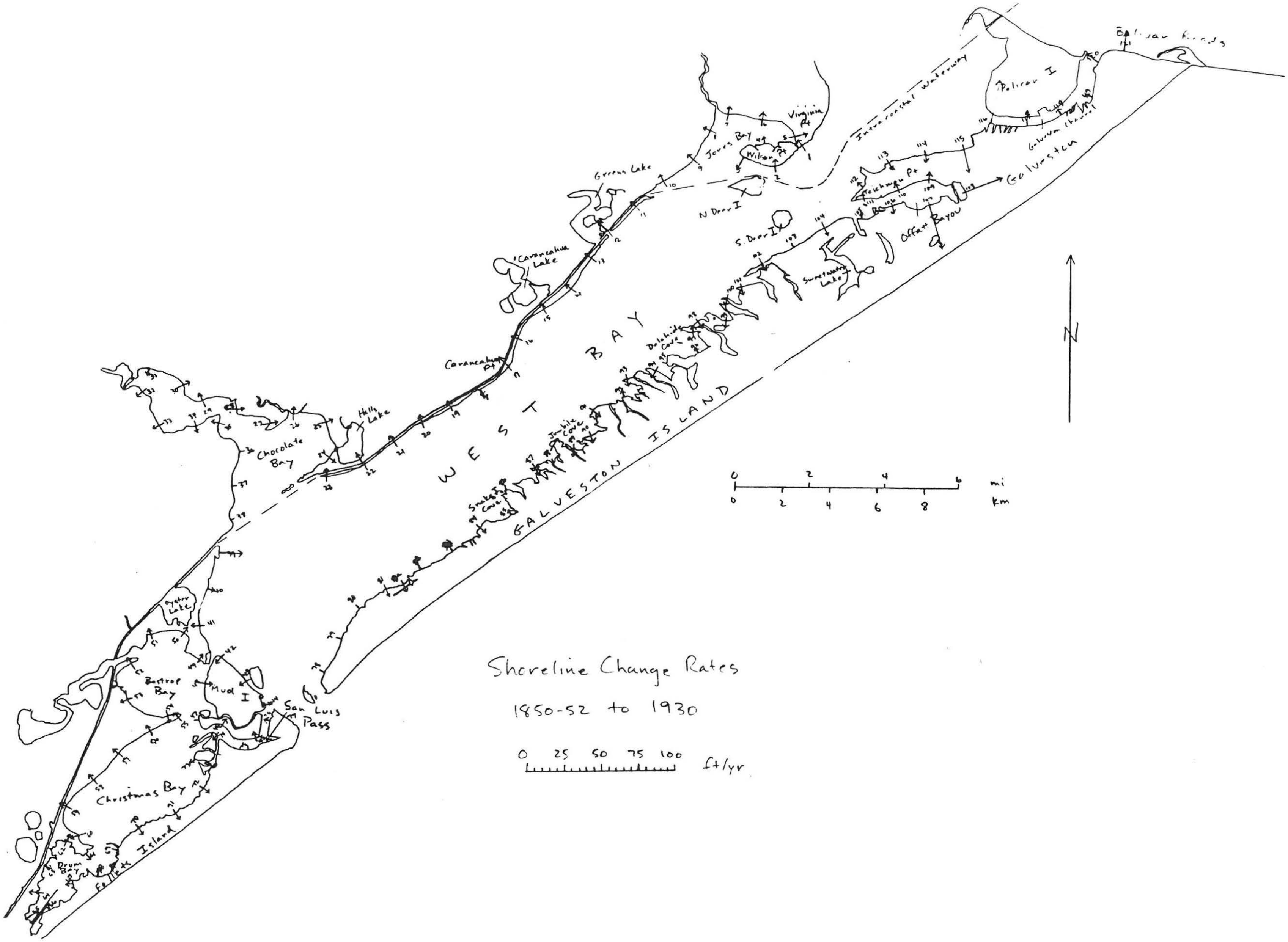


Figure 4-15. West Bay locations, measuring stations, and shoreline change rates, 1850-52 to 1930.

rates in these areas of 3 to 6 ft/yr. The extension of Wilson Point into West Bay pirated part of the bay to form Jones Bay, allowing marsh to form along the mainland shore. This marsh experienced widespread erosion at rates of 2.8 to 3.4 ft/yr (stations 5 to 8).

Erosion was also widespread along the mainland shore of West Bay between Chocolate Bay and Greens Lake. In the Greens Lake - Carancahua Lake area (stations 9 to 17), marshes at the shoreline eroded from 1 to 8 ft/yr. The greatest amount of erosion for this period (8 ft/yr) was recorded at Carancahua Point (station 17). Minor and localized accretion occurred between Carancahua Point and Chocolate Bay; station 18 recorded accretion rates of less than 2 ft/yr. Erosion occurred at all other stations along this stretch, varying from 0.5 to 5.5 ft/yr. The highest value was obtained for station 22 at Halls Lake.

Erosion in the vicinity of station 24 (2.5 ft/yr) on Chocolate Bay narrowed the strip of land separating Chocolate Bay from Halls Lake. Typical erosion rates for the northeastern shore of Chocolate Bay were 1 to 3 ft/yr although the marsh near station 31 advanced at 2 to 3 ft/yr. Stations 32 to 35 in upper Chocolate Bay recorded the erosion of that shoreline; typical rates were 0.5 to 2 ft/yr. Erosion also occurred between stations 36, 37, and 38, but no shoreline change was recorded at these stations.

Erosion became dominant between Chocolate Bay and San Luis Pass, possibly due to increased tidal current erosion. Marsh advanced at stations 39 and 40 (11 and 1.5 ft/yr, respectively), replaced by erosion at stations 41 to 43 (3 to 4.5 ft/yr). The highest rate of natural erosion for this bay (20 ft/yr) was recorded at station 77 on San Luis Pass.

Bastrop, Christmas, and Drum Bays are separated from West Bay by Mud Island. The calmer waters in these bays contributed to generally lower rates of erosion than for West Bay proper; in fact, six of the eight stations located on Drum Bay (the most restricted of these peripheral bays) experienced accretion during this period. Accretion at two of these stations (61 and 65) was caused by channel spoil. Drum Bay stations 62 and 64 eroded 1 ft/yr or less. All Bastrop Bay and northern Christmas Bay stations (48 to 60) recorded erosion of 0.5 to

4.5 ft/yr. Erosion rates of 1 to 4.5 ft/yr were observed on the Folletts Island shore of Christmas Bay.

Galveston Island forms the southeastern boundary of West Bay. Erosion occurred at most Galveston Island stations; in general, erosion was greatest on promontories. Reduced rates of erosion were observed in coves and other protected areas. Between San Luis Pass and Snake Island Cove, the highest rates of erosion (1.5 to 4 ft/yr) occurred at the western end of Galveston Island (stations 78 to 81). Moderate accretion (4.5 to 7 ft/yr) occurred in the vicinity of stations 82 and 83; accretion was also observed at station 85 in Snake Island Cove.

No accretion was observed between Snake Island Cove and Jumbile Cove (stations 86 to 90). Stations located on promontories showed either no change (station 86) or minor erosion (1 to 2 ft/yr, stations 87 and 88). Lower rates of erosion (less than 1 ft/yr) were recorded for Jumbile Cove stations (89 and 90). Stations between Jumbile Cove and Delehide Cove represent a range of environments, from protected (stations 92 and 96) and partially protected (stations 94, 95, and 97) to unprotected (stations 91 and 93). Unprotected stations eroded at rates of 1 to 2.2 ft/yr, partially protected stations eroded at rates less than 1 ft/yr, and shorelines near protected stations accreted at rates of 0.5 to 1.3 ft/yr.

Promontories between Delehide Cove and Offatt Bayou also recorded erosion. Stations 98 and 100 to 104 experienced erosion rates of 0 to 3 ft/yr. The protected shoreline near station 99 eroded at 1.3 ft/yr. Offatt Bayou was altered by excavation for grade raising in Galveston before 1930, but unaltered sections (stations 105, 106, 110, and 111) of the bayou changed little during the period. Rates of change ranged from 0.5 ft/yr of accretion to 3 ft/yr of erosion. Excavation near stations 107, 108, and 109 removed 275 to 2,200 ft of land surrounding the bayou.

Most human modifications around West Bay before 1930 were concentrated in the area between Offatt Bayou and Bolivar Roads. These included dredging of Galveston Channel, spoil deposition at Pelican Island, construction of the Galveston Causeway to Teichman Point, and excavation of Offatt Bayou. Minor accretion (less than 2 ft/yr) occurred on Teichman Point west of the causeway (station 112); artificial accretion of 250 to 2,375 ft occurred along the Galveston Channel with construction of port facilities at Galveston. Erosion of 2 to 11 ft/yr was observed between the causeway and channel (stations 113 to 115).

1930 to 1982

Most of the West Bay shoreline experienced erosion during this period (fig. 4-16), with 67 percent of the shoreline occupying a position in 1982 landward of its position in 1930. In the scattered areas of accretion, human modifications (Intracoastal Waterway spoil and port and residential development) were generally the responsible agents. Accreting shorelines accounted for only 13 percent of the entire West Bay shoreline.

Residential development at Wilson Point before 1974 contributed to the 50 to 175 ft of erosion recorded at stations 2 to 4 along the spit. A channel was cut across Wilson Point before 1956 near its connection to the mainland, reducing the amount of sediment supplied to the spit through longshore drift. Jones Bay stations 6 to 9 also experienced erosion during this period; typical rates were 3 to 4 ft/yr.

The dredging of the Intracoastal Waterway was completed in West Bay by 1956. Between Greens Lake and West Bay, the canal follows the West Bay shoreline and at some points cuts across the mainland. Canal dredging at the shoreline appeared as erosion on 1956 and later photographs, whereas spoil deposited at the shoreline appeared as accretion in later photographs. Accretion recorded at stations 10, 15, 19, 20, and 23 during this period was the result of channel spoil deposition; rates of erosion greater than 5 ft/yr at stations 11a, 12, 14, 17, 18, and 21 occurred where the channel was dredged along the shoreline. More meaningful erosion rates of 0 to 4 ft/yr were common in areas relatively unaffected by dredging. The highest rate of natural erosion observed in this area was 6 ft/yr at station 17 on Carancahua Point.

Typical erosion rates in Chocolate Bay were 0.5 to 4 ft/yr. Higher rates were observed from station 36 to Mud Island (4 to 9 ft/yr); two stations (30 and 32) in upper Chocolate Bay recorded no net change during the period. Erosion increased from Mud Island to San Luis Pass,

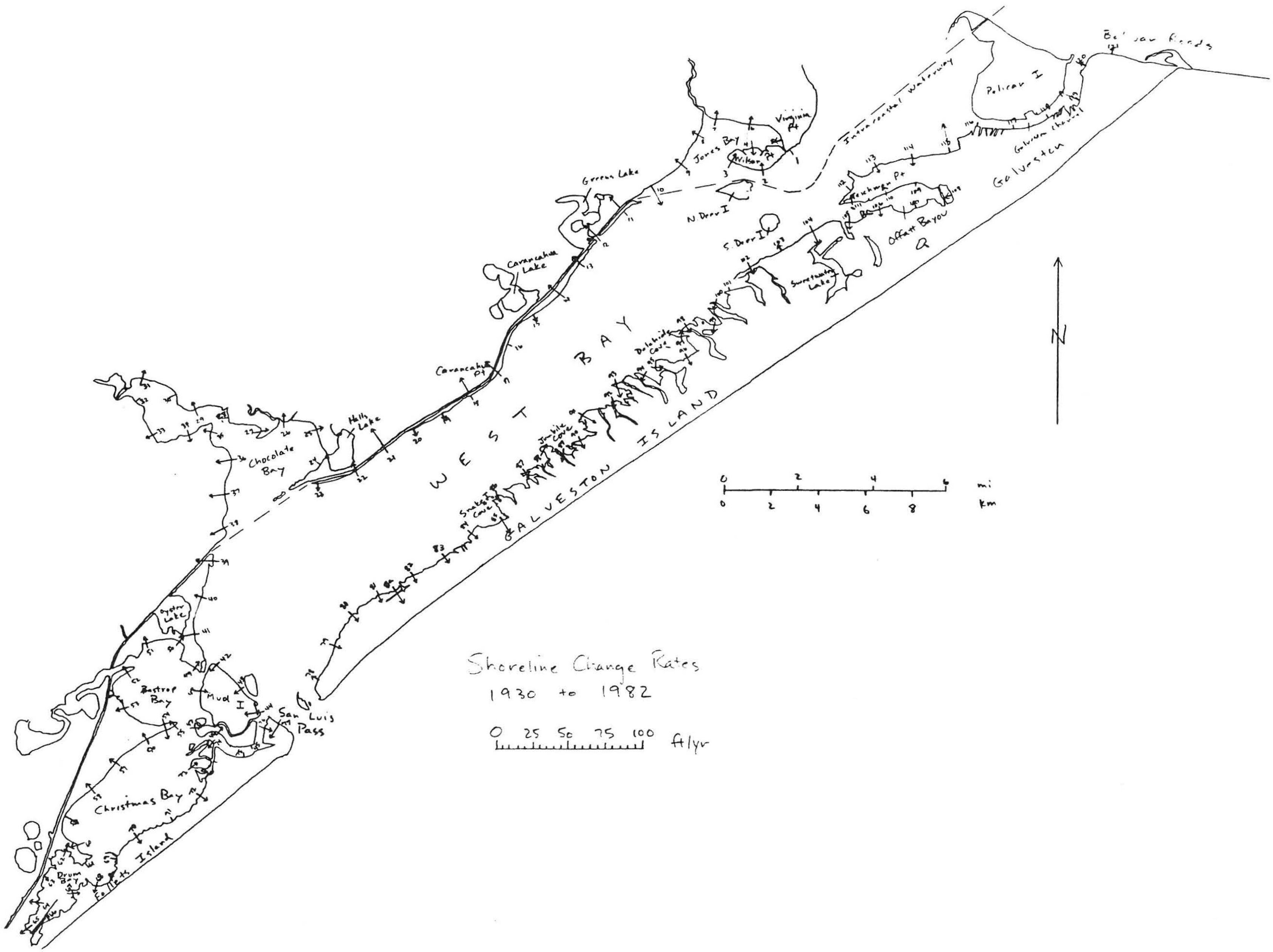


Figure 4-16. Rates of shoreline change for West Bay, 1930 to 1982.

from 2 ft/yr at station 42 to 8 ft/yr at station 44 and 9 ft/yr at station 77, reflecting the increased influence of tidal currents.

Fewer stations in the peripheral bays (Bastrop, Christmas, and Drum Bays) recorded accretion in this period than in the period before 1930. All Bastrop Bay stations (48 to 54) experienced erosion, generally below 4 ft/yr but as high as 6 ft/yr. Intracoastal Waterway spoil accounted for the lone accreting Christmas Bay station (59). Erosion rates in this bay were less than 4.5 ft/yr. One station on Follets Island recorded no net change (station 71). Accretion at two stations in Drum Bay was caused by Intracoastal Waterway spoil. Rates of erosion in this bay were generally lower than those for Christmas and Bastrop Bays, and were below 2.5 ft/yr in all cases.

Scattered development spread to the West Bay shore of western Galveston Island during this period (fig. 4-17). These bulkheaded communities are typically separated by stretches of unprotected marsh (fig. 4-18). Between San Luis Pass and Snake Island Cove, erosion occurred at all stations except station 78, which experienced minor accretion of less than 0.5 ft/yr. Erosion rates in this area were generally 1.5 to 4.5 ft/yr, although marsh in the Bay Harbor development (begun before 1956) receded at rates greater than 10 ft/yr (station 81a). The Sea Isle development near station 83 experienced marsh retreat at 5 ft/yr for the same period. All stations between Snake Island Cove and Jumbile Cove (stations 86 to 90) recorded erosion during this period, at rates of 0.5 to 4.8 ft/yr. Erosion east of Jumbile Cove was greatest on promontories, stations 91 and 93 experiencing erosion rates of 6 to 7 ft/yr. Protected shorelines (stations 92 and 94 to 96) had lesser erosion, at rates between 1 and 4 ft/yr. Promontories east of Delehide Cove (represented by stations 98 and 100) had erosion rates of 3 to 3.5 ft/yr; protected shorelines in the same area (stations 97, 99, and 101) experienced erosion rates of 2 ft/yr or less.

Offatt Bayou shorelines closest to West Bay eroded (1 to 3 ft/yr at stations 105, 106, 110, and 111), whereas stations farther from West Bay either accreted (stations 107 and 108) or remained stable (station 109). Teichman Point spit eroded at rates greater than 3 ft/yr

Figure 4-17. A bulkheaded residential development at Delehide Cove, West Bay.

Figure 4-18. Gangs Bayou marsh, West Bay.

(stations 113 and 114); the shoreline between station 114 and Bolivar Roads experienced apparent accretion in several areas. Accretion in these areas was caused by Galveston port construction.

Summary, 1850-52 to 1982

Measurements made for shorelines of this period confirm that erosion was widespread in West Bay throughout this period (fig. 4-19). Human modifications have affected relatively little of the West Bay shoreline; these effects were generally restricted to eastern Galveston Island commercial development, the Intracoastal Waterway in northern West Bay, and scattered commercial development in the Wilson Point - Virginia Point area and on the bay shore of western Galveston Island. Most large-scale shoreline changes must therefore be attributed to natural causes. Only a few areas accreted naturally in West Bay; these include marsh expansion in highly restricted Drum Bay and some of the protected inlets of western Galveston Island, spit accretion at Wilson Point, and minor accretion near San Luis Pass.

Northern West Bay (Virginia Point to Chocolate Bay) experienced erosion at rates up to 7 ft/yr during the period of record, with the greatest erosion occurring at Carancahua Point. Wilson Point was eroding on the West Bay side and accreting on the Jones Bay side before residential development between 1956 and 1974. Erosion was observed at all Wilson Point stations after development. Erosion around Chocolate Bay was less severe than in West Bay; Chocolate Bay erosion rates were 3 ft/yr or less. Consistently high erosion rates (3 to 15 ft/yr) were observed on the western side of San Luis Pass.

The more restricted bays west of San Luis Pass (Bastrop, Christmas, and Drum Bays) are characterized by less wave energy and thus less severe erosion. In fact, several stations in Drum Bay experienced net accretion over the period, although most of the accretion occurred before 1930.

Most of the West Bay shore of Galveston Island experienced erosion. The most severe erosion (1.5 to 4 ft/yr) occurred on marshy promontories; lesser rates of erosion (1.5 to 2 ft/yr)

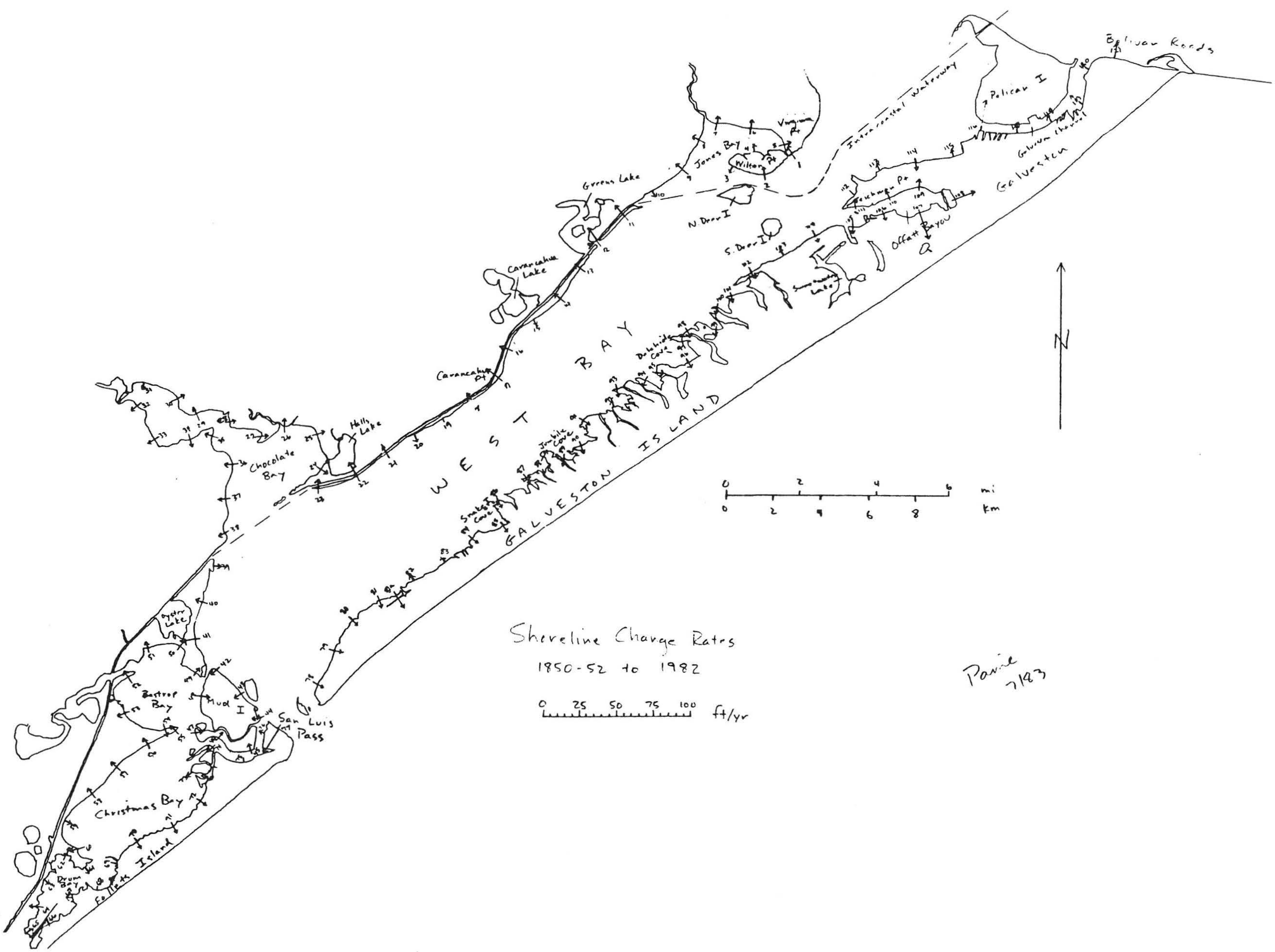


Figure 4-19. Cumulative rates of shoreline change for West Bay, 1850-52 to 1982.

occurred in protected inlets. Much of the West Bay shoreline along eastern Galveston Island has been stabilized.

East Bay

The southern shore of East Bay is formed by Bolivar Peninsula, trending generally northeast from Bolivar Roads (fig. 4-20). The northern shore of the bay stretches from Oyster Bayou to Smith Point. Historical shoreline locations at 55 stations were used to document shoreline changes that occurred between 1850-51 and 1982. These stations were placed approximately 5,000 ft apart.

1850-51 to 1930

Most of the East Bay shoreline (65 percent) experienced erosion during this period; only 21 percent of the shoreline occupied a position in 1930 bayward of its position in 1850-51. The only major engineering project completed by 1930 that could have affected shoreline position in East Bay was the construction of the Bolivar Roads jetties; thus most of the changes during this period were attributable to natural causes.

The most striking shoreline changes for the period in East Bay were at the southwestern tip of Bolivar Peninsula (stations 1 and 2, fig. 4-20), where accretion rates of 11 to 25 ft/yr were recorded. This accretion presumably slowed after the construction of the northern jetty at Bolivar Roads, indicating that accretion rates in this area may have been higher before jetty construction. Widespread erosion during this period occurred along the East Bay shore of Bolivar Peninsula at comparatively lower rates. Erosion between Port Bolivar and Pepper Grove Cove was highest at stations 3 to 5 near Bolivar Roads (8.5 to 10 ft/yr); reduced erosion rates of 0.5 to 7 ft/yr were observed in the slight embayment between Port Bolivar and Pepper Grove Cove (stations 6 to 11). Although this area was somewhat protected, a long northerly fetch across East Bay for these stations produced generally higher erosion rates than for equivalent areas in West Bay.

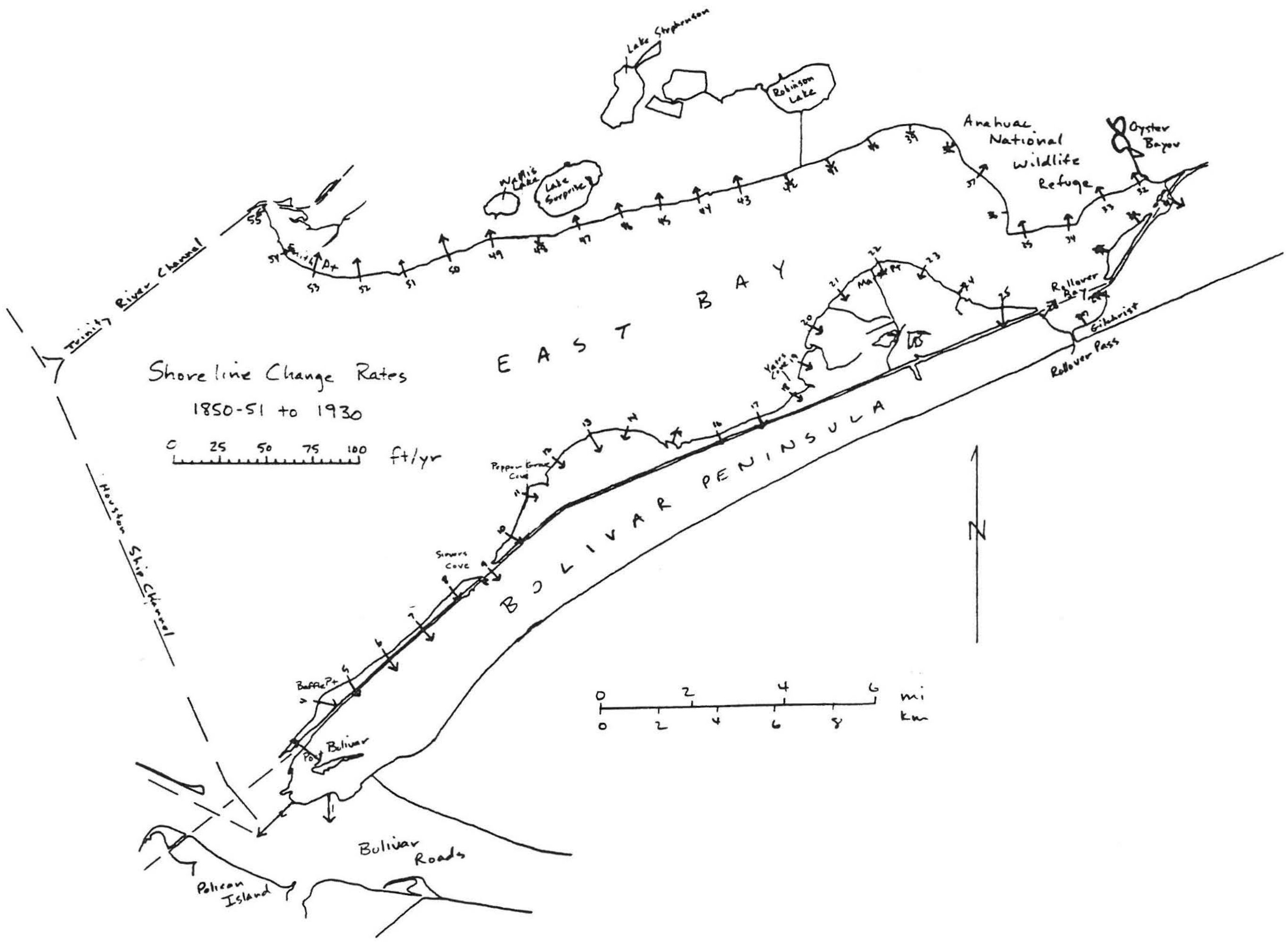


Figure 4-20. East Bay locations, measuring stations, and rates of shoreline change, 1850-51 to 1930.

Wave fetch across East Bay from Bolivar Peninsula decreases northeastward for the strong northerly winds associated with winter cold fronts. Prominent headland marshes near Marsh Point (stations 21 to 23) and east of Pepper Grove Cove (stations 12 to 14) are both subjected to waves generated during these northers. Longer wave fetch at stations 12 to 14 resulted in erosion rates of 2 to 5 ft/yr, whereas reduced wave fetch at stations 21 to 23 caused a reduction in erosion rates to 0.5 to 2 ft/yr. Erosion at rates of 0.5 to 3 ft/yr occurred between these promontories (stations 16 to 19); minor accretion occurred near Little Pasture Bayou (station 24) and in a similar position on the western promontory (station 15). The Rollover Bay area (stations 26 to 30) generally accreted at rates of less than 0.5 to 1 ft/yr, although marsh expansion at station 26 resulted in accretion at 6 ft/yr.

Erosion rates of 0 to 3.8 ft/yr were observed for the area that is now the Anahuac National Wildlife Refuge (stations 32 to 37). Minor accretion at rates of less than 0.5 to 2 ft/yr occurred at stations 38 to 42 as a result of marsh expansion near fresh-water lake discharge areas. Erosion rates generally increased westward from station 43, reflecting increased wave fetch for the predominant southeasterly winds. Lower erosion rates were observed at stations 43 to 47 (1 to 5 ft/yr), whereas increased rates were observed at stations 49 to 53 (3 to 6 ft/yr). Westerly movement of sediment along the northern shore of East Bay from predominant southeasterly winds caused decreased erosion at station 54 (less than 1.5 ft/yr) and accretion at station 55 (greater than 4 ft/yr).

1930 to 1982

The major human modifications affecting shoreline positions in East Bay during this period included the Bolivar Roads jetties and the Intracoastal Waterway. Other modifications were made (oilfield canals, shoreline protection measures, and a tidal exchange pass), but they were localized and affected only the shoreline in their immediate vicinity. Most of the shoreline in East Bay (76 percent) experienced erosion for the period, whereas only 12 percent accreted. The remainder showed no perceptible change.

With the Bolivar Roads jetties in place by 1930, southwestward migration of Bolivar Peninsula ceased. Heavy ship channel traffic and channelization of Bolivar Roads undoubtedly contributed to the erosion of the tip of Bolivar Peninsula, where extreme erosion at rates up to 17 ft/yr was recorded (fig. 4-21). The Intracoastal Waterway was cut along the East Bay shore of Bolivar Peninsula by 1956; removal of material at the shoreline moved the shoreline back at some places, whereas spoil deposited at the shoreline resulted in apparent accretion in other areas. Accretion of 75 to 375 ft at stations 3, 5, 6, and 7 near Baffle Point was caused by spoil placement. Erosion at 4 ft/yr was observed after the spoil was deposited (station 5 recorded 75 ft of erosion between 1956 and 1974). Baffle Point (station 4) was unaffected by dredging and spoiling; this area eroded at 13 ft/yr.

Erosion was observed for all stations from Sievers Cove to Rollover Bay (stations 8 to 25). Higher erosion rates (4 to 6 ft/yr) occurred on the Pepper Grove Cove promontory (stations 12 to 14) than in the area near Marsh Point (2 to 3 ft/yr at stations 21 to 23). Longer northerly wave fetch apparently caused this discrepancy. Stations between these promontories (stations 15 to 20) recorded erosion rates of 1 to 5 ft/yr. Higher than normal erosion was observed near the site of the Sun Oil Company canal at Marsh Point.

Artificial accretion was observed at stations 26 and 27 in Rollover Bay. Accretion at station 26 (75 ft) was due to development along the Intracoastal Waterway, and approximately 100 ft of accretion at station 27 was caused by construction at Gilchrist (fig. 4-22). Low rates of erosion (less than 1.5 ft/yr) occurred at stations 28 and 29. Intracoastal Waterway spoil accounted for apparent shoreline stability at station 30 and 125 ft of accretion at station 31.

There were no stations along the northern shore of East Bay (stations 32 to 55) that experienced accretion during this period. Anahuac National Wildlife Refuge shoreline (stations 32 to 38) eroded at rates of 0 to 3 ft/yr. Along the northern shore, rates of erosion generally increased westward; rates of erosion for stations 39 to 48 ranged from 1 to 4 ft/yr, whereas the range of erosion rates for stations 49 to 55 was 2.5 to 8 ft/yr.

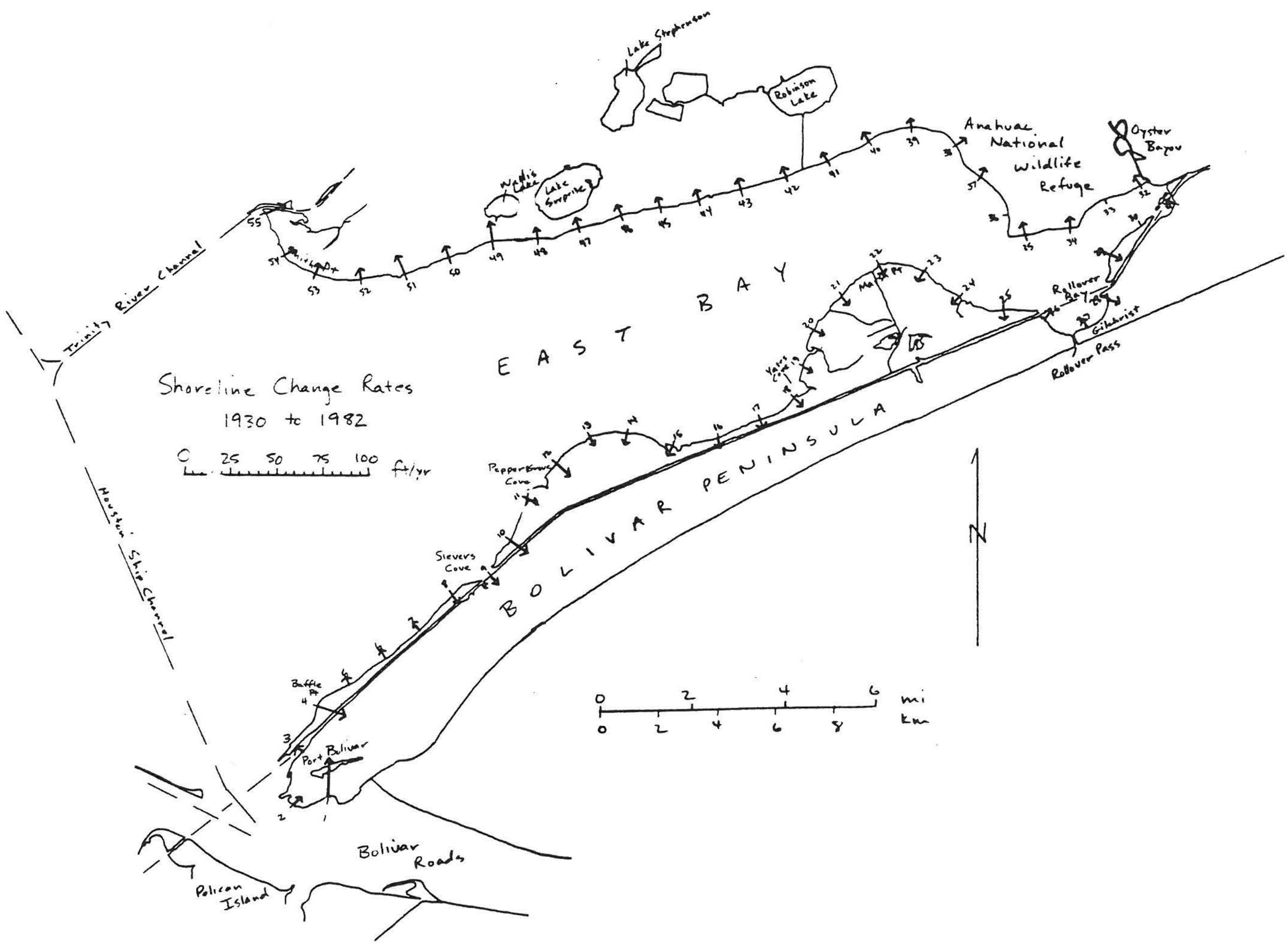


Figure 4-21. Rates of shoreline change for East Bay, 1930 to 1982.

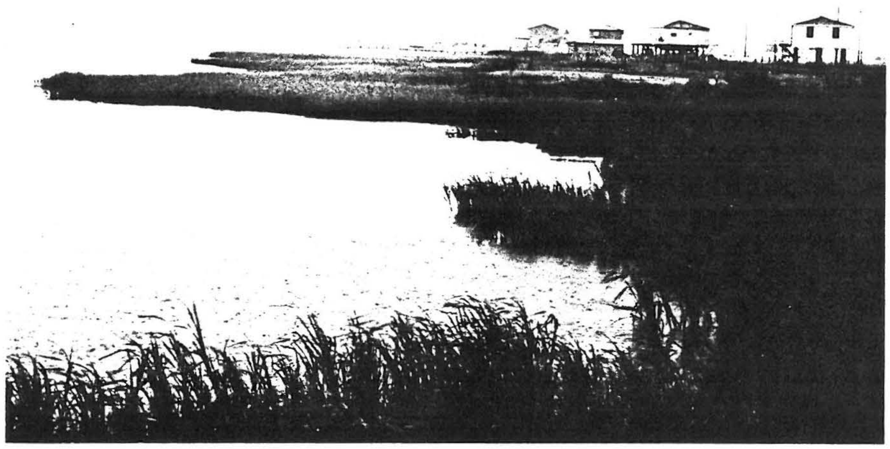


Figure 4-22. Development near East Bay shoreline at Gilchrist.

Summary, 1850-51 to 1982

For the period of record, 85 percent of the East Bay shoreline experienced net erosion. Only 11 percent accreted during this period, whereas the remainder experienced no measurable change. Human modifications that had the most visible effects on shoreline position in this area were the Bolivar Roads jetties and the Intracoastal Waterway. The jetties interrupted southwesterly longshore drift along Bolivar Peninsula, impeding the propagation of Bolivar Peninsula. The tip of Bolivar Peninsula experienced net accretion for the period; however, no accretion occurred after jetty construction. Significant shoreline disturbance also occurred during Intracoastal Waterway dredging and concomitant spoil disposal along the East Bay shore of Bolivar Peninsula.

All but four stations along the southern shore of East Bay recorded erosion during this period (fig. 4-23). The highest erosion rates were observed at Baffle Point (10 ft/yr); other stations had erosion rates of 1 to 5 ft/yr. In general, erosion decreased toward the east, reflecting decreased northerly fetch and wave energy. Observed accretion was due to marsh expansion near one station, whereas other stations experienced artificial accretion due to construction or spoil disposal.

Land that is now included in the Anahuac National Wildlife Refuge consistently eroded at rates of 0 to 3 ft/yr. This erosion has been slowed along a portion of the shoreline through the use of riprap and induced vegetation along the shoreline (fig. 4-24). Most other areas along the northern shore of East Bay also eroded, erosion rates generally increasing westward. Early accretion at the Smith Point spit was nearly offset by later erosion; station 55 recorded minor net accretion for the period of record. Marsh expansion in the Robinson Lake area before 1930 was offset by erosion between 1930 and 1982, causing only two stations in that area to record net erosion. Erosion rates observed between Smith Point and Robinson Lake ranged from 1 to 6 ft/yr.

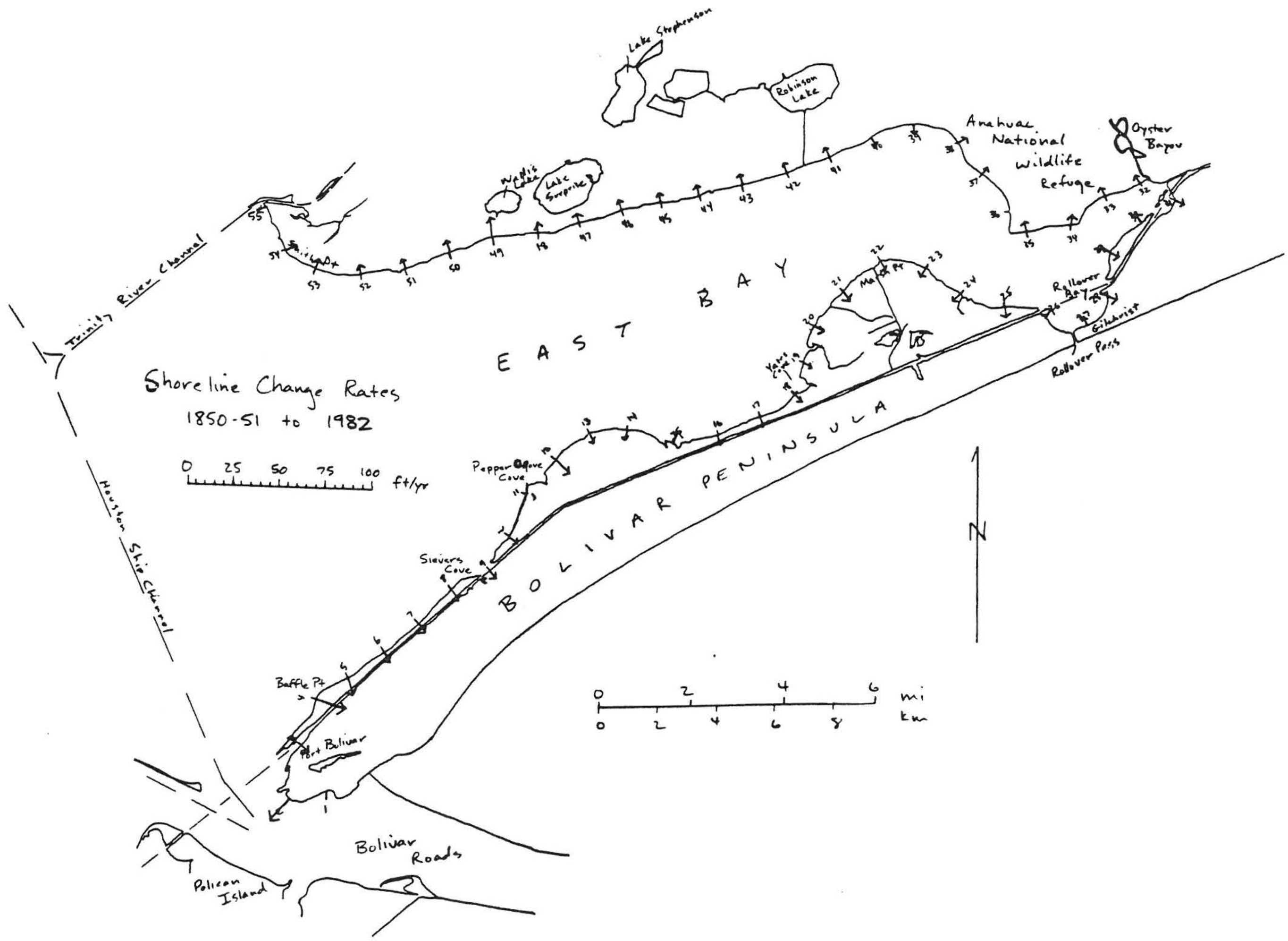


Figure 4-23. Cumulative rates of shoreline change for East Bay, 1850-51 to 1982.

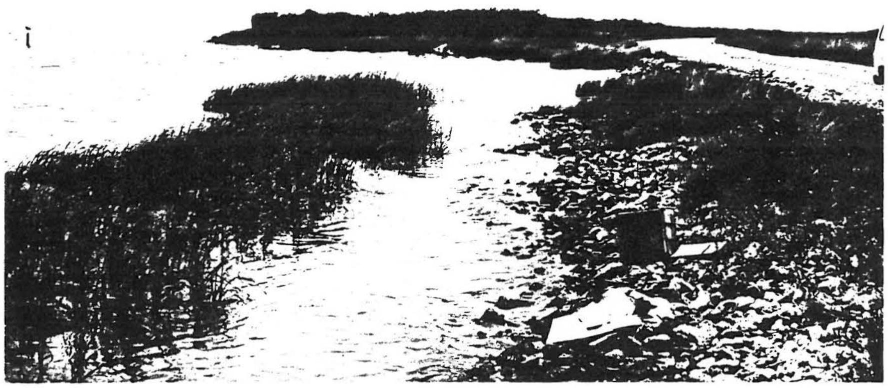


Figure 4-24. Riprap and Spartina alterniflora protecting Anahuac National Wildlife Refuge shoreline, East Bay.

5.0 HISTORICAL CHANGES IN THE SAN ANTONIO BAY SYSTEM

The San Antonio Bay System, located along the central Texas coast (fig. 1-1), is defined in this report by the following bays and estuaries: San Antonio, Espiritu Santo, Mesquite, Ayres, Hynes, Guadalupe, and Shoalwater Bays, and Mission and Pringle Lakes (fig. 5-1). The most common types of natural shorelines in this bay system are: (1) clay bluffs (fig. 5-2), (2) sandy slopes (fig. 5-3), (3) marshes (figs. 5-4 and 5-5), and (4) sand and shell beaches and berms (figs. 5-6 and 5-7). Excluding areas altered by human activities, shoreline morphology and composition are chiefly controlled by regional geology and local coastal processes. High clay bluffs of Pleistocene fluvial-deltaic mud and sand form much of the eastern and part of the western boundaries of San Antonio Bay. Sandy slopes along shores of western San Antonio Bay are associated with the Pleistocene barrier-strandplain system known as the Ingleside sand. Marshes and sand and shell berms characterize much of the shoreline along Matagorda Island as well as smaller natural islands along the mainland shores of Espiritu Santo, Mesquite, and Ayres Bays. Shorelines along the Modern-Holocene bayhead delta at the head of San Antonio Bay consist primarily of marshes, sand and shell berms, and tidal flats.

Between 1930 and 1982, human modifications occurred at many locations in the San Antonio Bay System. The most extensive modifications were the dredging of the Intracoastal Waterway and the Victoria Channel. Extensive dredged spoil islands line both channels. Other modifications include shoreline stabilization efforts such as emplacing wooden or cement bulkheads (fig. 5-8), terracing the shore with cement bags (fig. 5-9), and armoring the shore with riprap.

For discussion purposes, the San Antonio Bay System has been subdivided into six major segments. With reference to figure 5-1, the subdivisions are (1) the bay shoreline of Matagorda Island from near the air force base at the eastern end of the island to Cedar Bayou at the western end (stations 1 to 55, fig. 5-1); (2) the inland shorelines of Mesquite and Ayres Bays, including a portion of San Antonio Bay (stations 56 to 76); (3) the western shoreline of

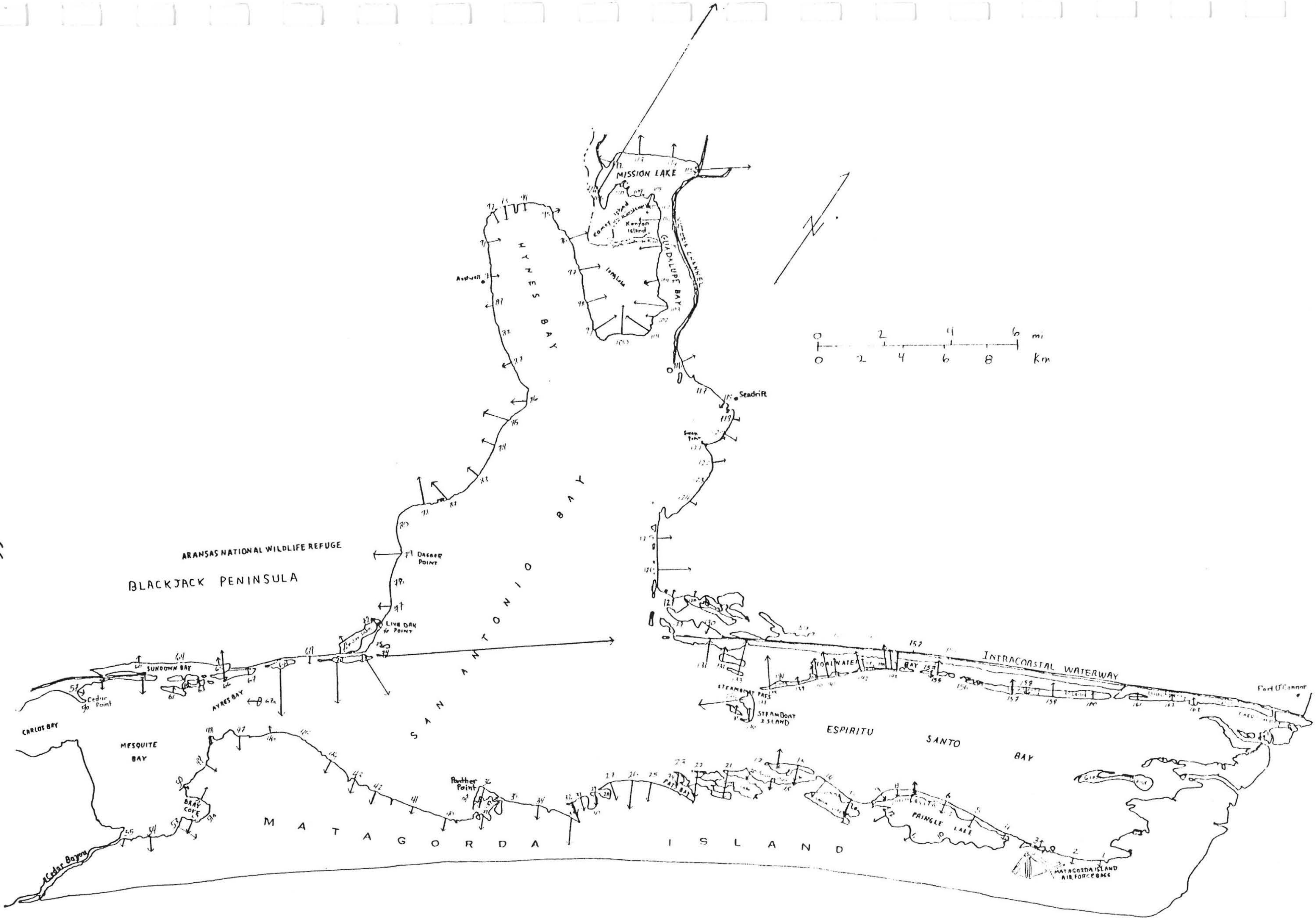


Figure 5-1. Station-location and vector-diagram map of the San Antonio Bay System for the period 1930-37 to 1974-82. Vectors at stations (numbered) indicate the relative rates and directions of movement (whether eroding or accreting) of the shoreline. Vectors are based on data presented in Appendix B.

Figure 5-2. Clay bluffs on the western shore of San Antonio Bay near Austwell.

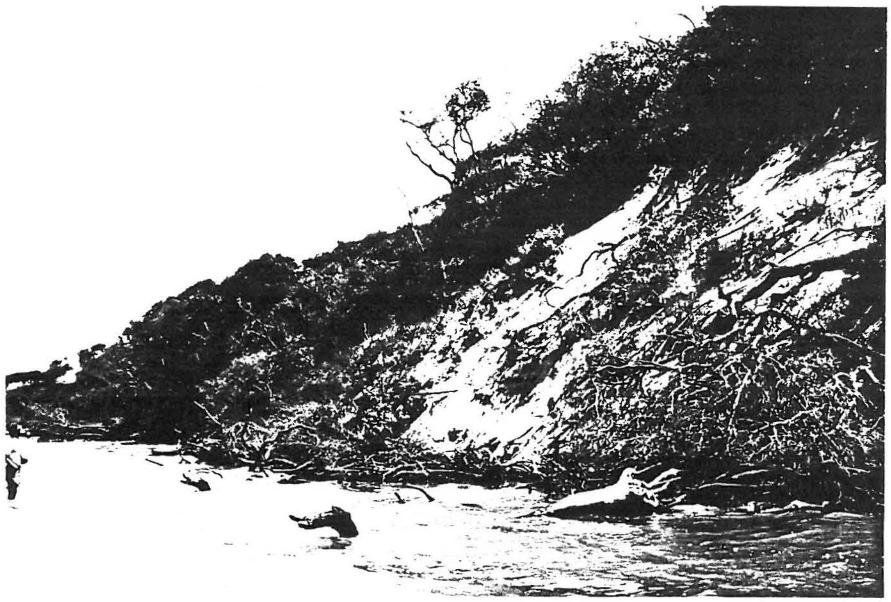


Figure 5-3. Sandy slope on the western shore of San Antonio Bay at Dagger Point, Aransas National Wildlife Refuge.

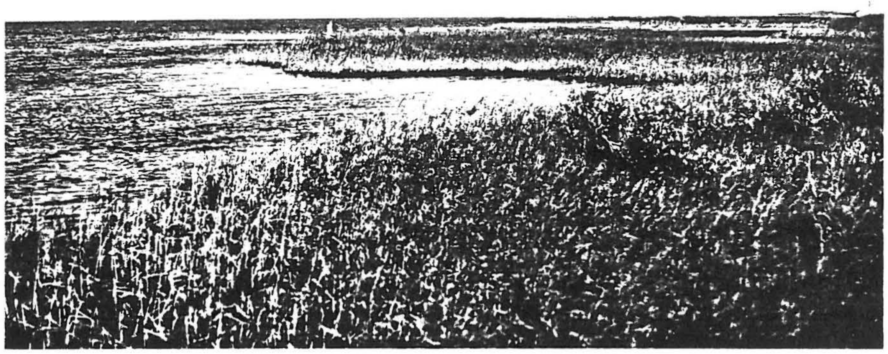


Figure 5-4. Spartina alterniflora marsh along the shoreline of Matagorda Island Air Force Base.

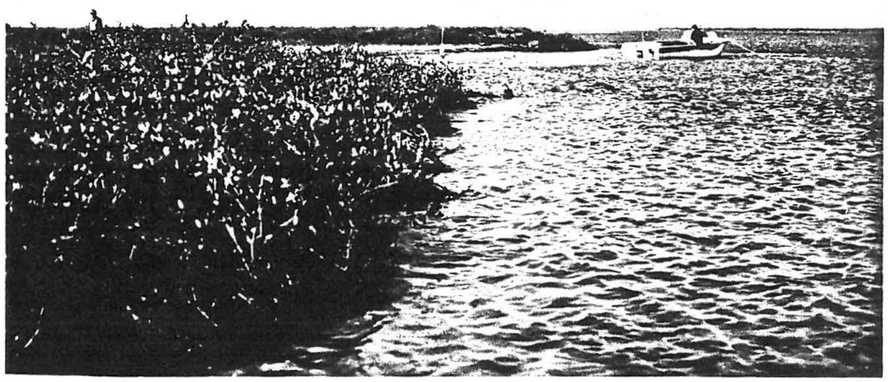


Figure 5-5. Mangrove marsh along an island shoreline in Espiritu Santo Bay near Pass Cavallo.

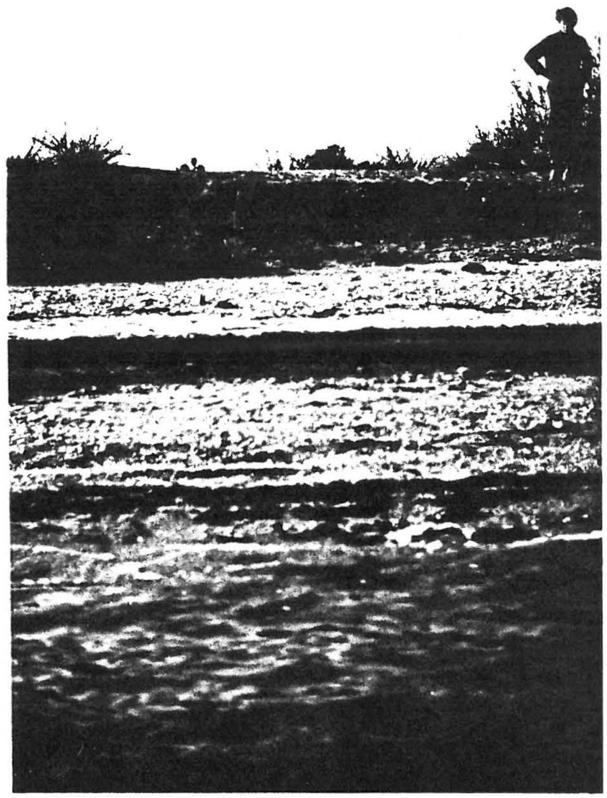


Figure 5-6. Storm berm composed predominantly of shell material along the Matagorda Island - Espiritu Santo Bay shoreline.

Figure 5-7. Shell beach and berm on Vanderveer Island (a spit along the bay shoreline of Matagorda Island). Uprooted Yucca and other shrubs are evidence of erosion.

Figure 5-8. Cement bulkhead along the eastern shore of San Antonio Bay south of Seadrift.

Figure 5-9. Shoreline terraced with Portland Cement bags along the eastern shore of San Antonio Bay south of Seadrift.

San Antonio Bay from Live Oak Point to a point about 1.5 mi northeast of Austwell (stations 77 to 91); (4) the Modern-Holocene bayhead delta including the Guadalupe Delta, and the inland shores of Hynes Bay and Mission Lake (stations 92 to 115); (5) the eastern shore of San Antonio Bay from near the mouth of Victoria Channel to the Intracoastal Waterway (ICWW) (stations 116 to 130); and (6) the mainland shores of Espiritu Santo Bay from near Steamboat Pass to Dewberry Island (stations 131 to 163).

Mapped shoreline positions for the mid 1800's, 1930's, 1958 (for selected areas), 1974, and 1982, were transferred to USGS 7.5-minute topographic base maps, and compared to determine those shorelines that were accreting, eroding, or remaining stationary through time.

To quantify shoreline changes, almost 170 stations were selected around the entire bay complex (fig. 5-1). Usually, stations are spaced about 5,000 ft (1,500 m) apart. At each of the stations, shoreline changes were quantified by measuring the direction and magnitude of change in shoreline positions for a given time period (based on dates of historical maps and photographs). Rates of shoreline change at each measured station were calculated, when possible, for the following time periods: (1) 1859/60 to 1930/37, (2) 1930/37 to 1974, (3) 1974 to 1982, (4) 1930/37 to 1982 (rate for period of photographic record), and (5) 1859/60 to 1982 (rate for period of record). In selected map areas, shorelines were also mapped on 1958 photographs, primarily to provide additional information on more "recent" rates of change. It should be noted that some photographs of the San Antonio Bay System were taken during the latter part of 1929 (November) and the latter part of 1957 (December). Because they were taken near the end of these years, for purposes of discussion and quantification of shoreline changes in this report, these photographs are cited as being 1930 and 1958 photographs. The distances and rates of change are presented in Appendix B. These rates that are based in part on the 1958 photographs were selectively included in the Appendix.

Following is a discussion of the historical shoreline changes that have occurred along the six-shoreline subdivisions (listed above) for the San Antonio Bay System. For simplification, the discussion will focus on three major periods--1859/60 to 1930/37, 1930/37 to 1982, and 1959/60 to 1982.

Bay Shoreline of Matagorda Island (Stations 1-55)

The bay shoreline of Matagorda Island stretching from near Matagorda Island Air Force Base to Cedar Bayou (stations 1-55) contacts the waters of Espiritu Santo, San Antonio, and Mesquite Bays. The depositional framework of the bay shore of the island includes at least three major, although inactive, washover fans, and a large, compound, recurved spit (Vanderveer Island) (fig. 5-10). Many smaller spits have developed, in part, from washover deposit modification. Generally, the direction of sediment movement along much of this shoreline is from east to west, probably due primarily to the effect of longshore currents set up by waves generated from north and northeasterly winds (fig. 5-11). The ridges formed on Vanderveer Island during spit accretion have recorded the direction of sediment movement (fig. 5-10). Panther Point, the tip of a strongly recurved spit, also reflects this east to west sediment migration until recurvature occurs to the south in alignment with the north northwest south southeast orientation of Panther Reef. Numerous other features along the bay shore of Matagorda Island reflect the east to west movement of sediments. There appears to be some variation or at least moderation of this drift direction toward Ayres and Mesquite Bays and near the tidal influence of Cedar Bayou.

Most of the bay shoreline along Matagorda Island is composed of either shell berms and ridges (fig. 5-6) or marshes (fig. 5-4). Common in the marsh areas are numerous circular to elliptical-shaped bodies of water and tidal flats in a wide range of sizes. Not much of the shoreline has been modified through human activity except for a few minor segments near Matagorda Island Air Force Base and an area near the west end of the island where a dike/road complex parallels the shoreline. Also a few channels have been dredged into some of the small embayments and lakes that occur along shore.

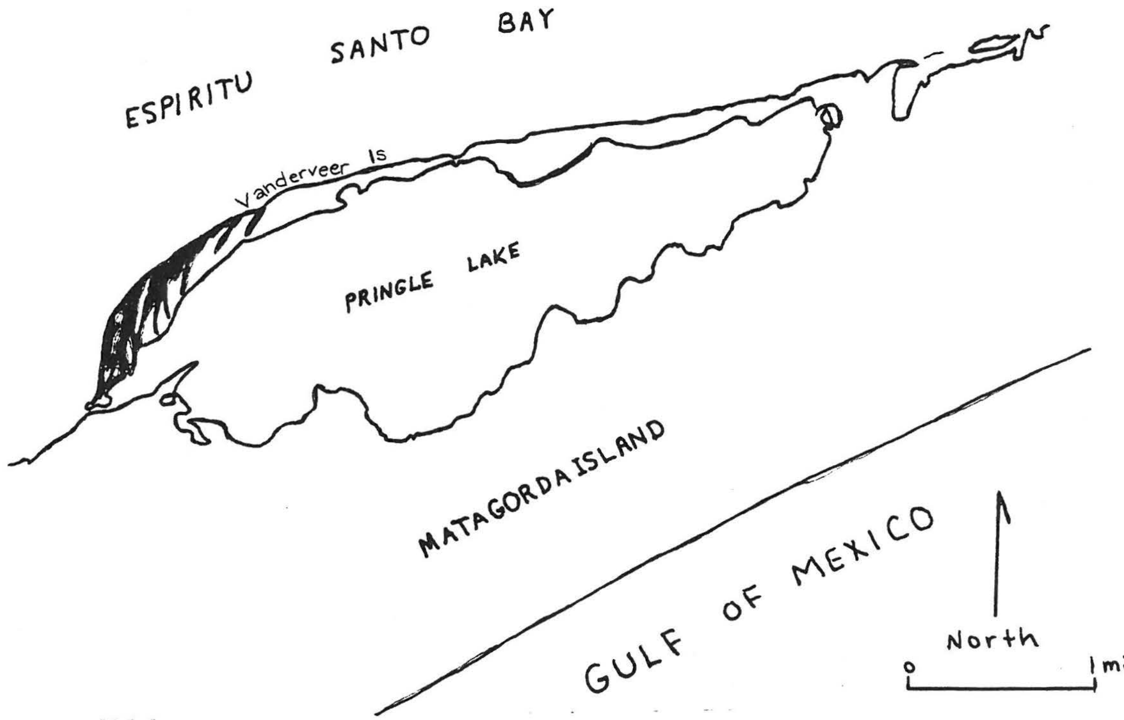


Figure 5-10. Accretionary ridges, shown in black, along the compound spit--Vanderveer Island.

1859 to 1937

During this period, no measureable human modifications had occurred along the shore of Matagorda Island, so changes are related solely to natural processes.

About 70 percent of the 55 stations measured along this shoreline either registered erosion or no change. Of this 70 percent, about 75 percent of the stations were on shorelines experiencing erosion. Stations on accreting shorelines made up about 30 percent of the total number of stations.

The magnitudes of erosion, or retreat, ranged from a maximum of 310 ft at stations 5 and 13, to a minimum of 20 ft at station 3. Erosion rates were from a high of almost 4 ft/yr to a low of less than 0.5 ft/yr. Accretion occurred at 15 stations, ranging from 840 ft at station 33 to 30 ft at stations 9 and 48; the respective rates are 10.8 ft/yr and 0.4 ft/yr.

The changes were essentially predictable. Most of the stations undergoing erosion were along high-energy shorelines of Espiritu Santo, San Antonio, and Mesquite Bays, which are unprotected from waves and currents set up by north and northeasterly winds. Stations that show no change and those that show accretion were typically in more protected embayments, or areas of lower energy with respect to wave and current activity. The high magnitude of accretion at station 33 is due to the buildup of a narrow marsh promontory at this station. Although this is in a protected embayment, this accretionary rate of 10.8 ft/yr is not typical of this shore.

1937 to 1982

Between 1937 and 1982, almost 80 percent of the shorelines at measured stations retreated, about 15 percent remained stationary, and about 5 percent accreted (fig. 5-1). Those shorelines undergoing the highest rates of erosion were along shores susceptible to wave attack from open bay waters during "northers." Shorelines that eroded at slower rates, remained stable, or accreted were in inlets or embayments protected from wave and current attack during advancing polar fronts.

The highest rates of erosion were at stations 14, 15, 21, 22, 25, 26, 27, 33, 36, and 53, all registering rates of more than 5 ft/yr. The rate of erosion of 6.4 ft/yr at station 33, however, is misleading (fig. 5-1). This station is located in a protected embayment in Cedar Lake, and the rate is atypical for the shorelines in this embayment. This anomaly was produced by the erosion of a small promontory that was mapped on the 1937 photograph. On either side of this station the shoreline changes do reflect erosion, but at much lower rates. All the other stations listed above but one, station 53, are along shorelines susceptible to attack by waves approaching from the north and northeast. Station 53 is located along a westward facing shore near Cedar Bayou in Mesquite Bay. Natural processes affecting this shore include flood-tidal currents in Cedar Bayou. However, dredging a small channel/harbor complex as well as building a dike/road system, both completed before 1956, probably have also contributed to displacement of the shore islandward. Only stations 3, 7, 16, 17, and 46 depict accretion. Station 3 is in an area of spoil disposal near Matagorda Air Force Base. Station 7 is along the shore of Vanderveer Island, which is a spit along which sediment is generally eroded (fig. 5-7) and transported down current to the west (fig. 5-10). Station 7 remained relatively stationary between 1937 and 1974, perhaps in large part due to a vegetation-stabilized storm berm (Josephine Motte) that slowed erosion. Accretion occurred between 1974 and 1982 because of the movement down drift of a mass of sediment (sand and shell) that extended the shore bayward between 1974 and 1982. The resulting accretion, then, appears to be only a temporary reversal along this erosional shoreline. Stations 16 and 17 also owe their accretion to movement of sediment along shore. The source of the sediment appears to be a ridge located up drift that is eroding. Also, this deposition may be due in part to recurvature of the spit. At station 17, accretion (based on 1974 to 1982 record) and spit growth have connected the spit to a chain of islands.

Accretion at station 46 may be due in part to the construction of a road/dike complex sometime before 1956. However, this area is also somewhat protected by the orientation of the shore and a rather broad shallow shelf that slows and dissipates waves from the north and northeast.

Summary, 1859 to 1982

The net direction of changes along Matagorda Island for the period of record (1859 to 1982) are similar to the period 1937 to 1982, at least in overall direction, although the net distances of change are considerably less (fig. 5-11). Approximately 75 percent of the stations experienced erosion, about 10 percent reflected no change, and about 15 percent experienced accretion. Rates of erosion ranged from 4.3 ft/yr to 0.2 ft/yr. The average rate was about 1.9 ft/yr. Station 22, which had the highest rate of erosion, is located on a small island (spit) near the junction of Espiritu Santo and San Antonio Bays. Generally, rates were highest between stations 4 through 36 (Panther Point), which are the shores along Espiritu Santo to mid San Antonio Bay. Beyond this point (west of Panther Point), the shoreline swings bayward, marking the largest washover fan complex on Matagorda Island. Along this shoreline, rates of erosion are somewhat lower. Parts of this shore have been stabilized to some degree by the road/dike system built along the shoreline sometime before 1956. Erosion at stations 53, 54, and 55 is perhaps related to flood-tidal currents and storm tides that surge through Cedar Bayou. Part of the stability of this large fan complex is undoubtedly due to a shallow offshore (landward) shelf, which is vegetated with marine grasses, and which was aggraded in part by hurricane washover processes when this fan was active. Also, the size of the washover fan has restricted the fetch of north winds.

Washover channels that cross Matagorda Island and supplied sediment to the fans in the past are inactive. Because the washover channels are closed, sediments are no longer being supplied to the fans during storms. The storm berms, eolian mounds, and overwash deposits locally provide a source of sediment to minimize erosion and contribute to local stability of the shoreline. Although a few shoreline segments in the more protected embayments and lakes

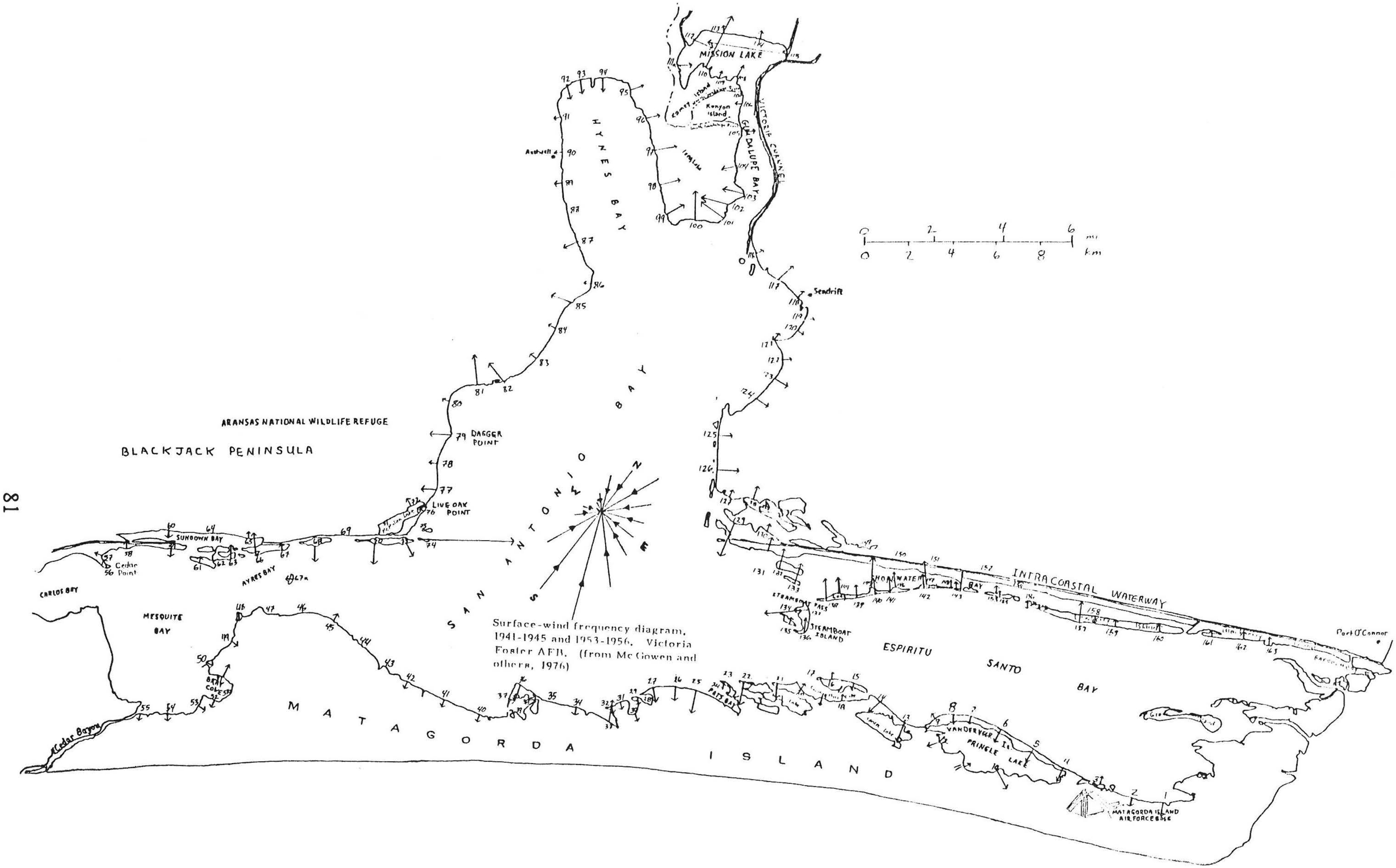


Figure 5-11. Station-location and vector-diagram map of the San Antonio Bay System for the period 1859-60 to 1974-82. Vectors indicate relative rates and directions of movement (whether eroding or accreting) of the shoreline at the numbered stations. Vectors are based on data presented in Appendix B.

have been stable or slightly accretionary, the primary Matagorda Island - bay shoreline is undergoing systematic erosion.

Mainland Shorelines of Mesquite and Ayres Bays

This shoreline segment extends from Cedar Point in Mesquite Bay (station 56) eastward along the Intracoastal Waterway and Blackjack Peninsula to near Live Oak Point (station 76) on the edge of San Antonio Bay (fig. 5-1). Although there are natural islands, oyster reefs, and peninsulas along this shore, it has been largely modified by dredging of the Intracoastal Waterway between 1938 and 1940. Shorelines include marshes, shrub- and tree-vegetated ridges, and sand and shell berms. This area also includes a chain of dredged-spoil deposits that line the Intracoastal Waterway. Extensive salt-water marshes occupy an area between the Intracoastal Waterway and the Ingleside barrier-strandplain sand of Blackjack Peninsula. Oyster reefs are major components of the Mesquite Bay and Ayres Bay System, virtually enclosing each of these water bodies. Three major reefs, which form chains of islands, are each more than two miles in length. The reefs are a source of shell material that characterizes much of the shoreline.

1860 to 1930

No measurable human modifications had occurred in this area during the period 1859 to 1930. Thus, shoreline changes are the result of natural causes. Of the 21 stations that transect shorelines mapped on 1860 maps and 1930 photographs, about half (50 percent) experienced erosion, and half, no change (30 percent) and accretion (20 percent). Of the 11 stations along which erosion was measured, rates ranged from 9.0 to 0.6 ft per year. The highest rate of erosion of 9.0 ft/yr occurred at station 74. This erosion rate is not unexpected because the shoreline faces east northeast toward San Antonio Bay. This shoreline is along a salt-water-marsh island or peninsula (in 1860) that separates San Antonio Bay from a smaller body of water (McMullen Lake; fig. 5-1).

One of the highest rates of erosion (4.1 ft/yr) occurred at station 57, which is near Cedar Point along the western shore of Mesquite Bay. Erosion occurs along a shoreline marked by a curved vegetated ridge and berm that parallels the shore. The high rate of erosion in this semi-protected area, characterized by a well-developed and vegetation-stabilized berm, is somewhat unexpected. Possibly, the energy of waves and currents approaching from the east is focused by the parabolic shape of the small embayment to produce currents that flow in a counter-clockwise direction under normal conditions.

Another relatively high rate of erosion (4.3 ft/yr) occurred on a promontory (station 68) near the junction of San Antonio and Mesquite Bays. The remaining erosional stations that exceeded a rate of at least 2 ft/yr occur along island shores that face the open waters of San Antonio, Ayres, and Mesquite Bays and are afforded little protection from waves generated by south to easterly winds and landward-moving tropical cyclones.

The erosion of 2.1 ft/yr at station 66 occurred in conjunction with the retreat of a southwesterly projecting spit that was breached between 1860 and 1930, leaving a "flying-spit" (island) at the detached end.

Most of the stations experiencing accretion or stability were along more protected shores. One that experienced no change, and that is atypical for the shore along which it occurs, is station 76. This one occurs along a marshy, east northeast facing shoreline along San Antonio Bay. At this particular station, the 1860 and 1937 shorelines coincide with each other, but alongshore on either side of this station the 1930 shoreline is landward of the 1860 line, indicating retreat. This particular area apparently received some sediment from the Ingleside sand to the north. The sediment formed a curved, southwestward projecting peninsula that was connected to Blackjack Peninsula (Ingleside sand) in 1860. By 1930 the small peninsula had been breached by a channel that connects San Antonio Bay to McMullen Lake. A small delta developed at the mouth of the channel in McMullen Lake, suggesting the general direction of sediment movement is southwestward.

1930 to 1982

A major human modification along this shore was the dredging of the Intracoastal Waterway in 1938 to 1940. Spoil was deposited mostly along the gulfward side of the channel on marshland or in submerged lands forming islands. The effects of the spoil disposal can be seen in the number of stations that registered accretion or stability (no change) (fig. 5-1). At the 22 stations measured, 60 percent of the shorelines either accreted or experienced no change, and 40 percent underwent erosion.

The most extensive accretion occurred at station 74, where deposition of spoil produced a peninsula parallel to the waterway, projecting the shoreline outward into San Antonio Bay 3,500 ft beyond the position of the 1930's shoreline. Of the 8 remaining stations that showed accretion, all but station 69 owe their accretion to dredged-spoil disposal. Station 69, located along a marsh shoreline north of the Intracoastal Waterway station experienced accretion of less than 1 ft/yr. A levee constructed parallel to and immediately inland from the shoreline, as well as a vegetated ridge oriented normal to the shoreline, may have contributed to the marsh accretion.

The stations showing no change were 56, 62, 64, and 72. With the exception of station 56, most are along protected and relatively stable shorelines. Station 56 at Cedar Point is in a more dynamic area. The shoreline at this station experienced accretion between 1930 and 1974, and offsetting erosion from 1974 to 1982.

The most extensive erosion occurred at station 66 where the shoreline retreated 350 ft --a rate of 6.7 ft/yr. The peninsula at this station (in 1860), which was breached before 1930, continued to retreat between 1930 and 1982. The only other station recording more than 3 ft of erosion was station 76, which is along the shoreline of San Antonio Bay and is susceptible to erosion by waves set up by northeasterly winds blowing across the bay. Other stations where shorelines experienced erosion generally are along unprotected shores in Mesquite and Ayres Bay. The erosion at station 65, which is along a somewhat protected shore, may be due in part to wakes from boat traffic on the Intracoastal Waterway.

Summary, 1860 to 1982

Cumulative changes for this 122-yr period (fig. 5-11) generally mimic the trends set by the two earlier blocks of time. Eleven stations, or about half, documented net erosion, eight net accretion, and three no net change. The highest net erosion (4.1 ft/yr) was recorded at station 66. The erosion, as noted above, occurred in conjunction with the breaching of a spit that was present in 1860. Only one other station reflected net erosion in excess of 2 ft/yr; it was station 63, where the shoreline retreated at a rate of 2.6 ft/yr. Stations with an erosional rate of between 1 and 2 ft include 57, 58, 61, 67a, and 76.

Net accretion occurred at stations 59, 60, 68, 70, 73, and 74. Disposal of dredged spoil was the principal cause of accretion. Of the three stations reflecting no change in shoreline position, only one, station 69, actually underwent a change in position--first experiencing erosion of 40 ft between 1860 and 1930, then offsetting accretion between 1930 and 1974. No measurable change occurred between 1974 and 1982.

Generally, stations documenting erosion were along unprotected shores of San Antonio, Mesquite, and Ayres Bays. Stations where shorelines experienced accretion were in areas of dredged-spoil disposal, and stations where shorelines remained unchanged were along more protected shores in shallow, fetch-limited embayments.

Western Shoreline of San Antonio Bay

The western shoreline of San Antonio Bay includes relatively steep, high sandy bluffs (fig. 5-3) near vertical clay cliffs (fig. 5-2), salt-water marshes, and one area of relatively low (in elevation) accretionary ridge and swale topography composed of shell berms separated by linear brackish to fresh marshes. The sandy shores coincide with the valley-truncated Ingleside barrier-strandplain sand, the clay bluffs with Pleistocene fluvial-deltaic deposits, and the ridge and swale topography with a Modern-Holocene accretionary deposit that developed in a shallow embayment along the shoreline of the Ingleside sand.

Lying immediately offshore are several linear oyster reefs that are oriented essentially parallel to each other and normal to prevailing southeast winds. These normally shallow subaqueous reefs form ridges and shoals at angles of about 45° with the shoreline.

Sixteen stations (76 through 91; fig. 5-1) were measured along this shoreline to quantify changes.

1859-60 to 1930

All stations except 1 (station 83) recorded erosion between 1860 and 1930. Distances and rates of retreat ranged from 440 ft and 6.3 ft/yr to 30 ft and 0.4 ft/yr. The average rate of erosion was about 2.2 ft/yr. The maximum rates of erosion occurred at stations 81 and 82. Both stations are located along the accretionary shoreline feature mentioned above. Other stations that experienced erosion of more than 2 ft/yr included 77, 79, 80, 85, 87, 89, and 91.

The shoreline at station 83, the only station registering accretion, advanced bayward at the modest rate of 1.1 ft/yr. Accretion near station 83 may be related to transport of sediment along shore from the erosional area at stations 81 and 82 to the south. It is also possible that the accretion reflects a temporary bayward displacement of the shoreline occurring in conjunction with bluff slumping and sediment accumulation producing short-term shoreline advance in an area undergoing long-term erosion.

1930 to 1982

The erosional trends along the western shoreline of San Antonio Bay established between 1859/60 to 1930 continued during this period (1930 to 1982) for all stations but two; stations 90 and 91, north of Austwell, experienced accretion of 40 ft (0.8 ft/yr) and 180 ft (3.5 ft/yr), respectively (fig. 5-1). Stations to the south, however, eroded at rates from a high of 7.1 ft/yr to a low of 0.8 ft/yr. The high rate of 7.1 ft/yr occurred at station 79, Dagger Point, where the shoreline retreated 370 ft during this 52-yr period. Dagger Point, a unique feature, is a promontory or headland, composed of live-oak-stabilized sand dunes with elevations about 50 ft above mean sea level. Evidence of erosion in this area includes a steeply sloping sandy bluff along the base of which are numerous dead trees that have succumbed to the retreating shoreline (fig. 5-3). The dunes in this area have probably produced the promontory and appear to be a massive source of sand for nourishment of the shores down current. The fact that Dagger Point is a bayward projecting point contributes to the erosion rate as it is susceptible to attack by waves from the south, southeast, east, and northeast. Refraction of the approaching wave trains focuses energy on the promontory (fig. 5-12). Wrack from a house, located near station 79, destroyed by Hurricane Carla in 1961, affords some shore protection in this area (fig. 5-13). An oyster reef and reef-flank deposit offshore from Dagger Point may have some effect on wave refraction and dissipation, but its exact role in these processes has not been examined.

Three other stations registered rather high rates of erosion of over 6 ft/yr during this time period; they are stations 81, 82, and 85. Stations 81 and 82 as mentioned above are along the relict accretionary ridge and swale shoreline feature north of Dagger Point. Station 85 is farther north along a marsh that developed at the base of a bluff composed of Pleistocene fluvial-deltaic sediments. Erosion of the bluff and Pleistocene deposits apparently was in part responsible for the deposition of a fan delta on which the marsh developed. The marsh has been erosional since 1859; erosion may have been accelerated by construction of a small harbor near this station sometime before 1957. Small peninsulas constructed as part of the harbor may cause some refraction of waves approaching from the northeast, east, or southeast. Boat traffic into and out of the harbor may also contribute to the erosion. It is not known whether fill material was extracted from the vicinity of station 85, which could be another factor contributing to shoreline retreat.

Accretion at station 91 was apparently related to channelizing of a gully, which accelerated development of a fan-delta marsh in this area.

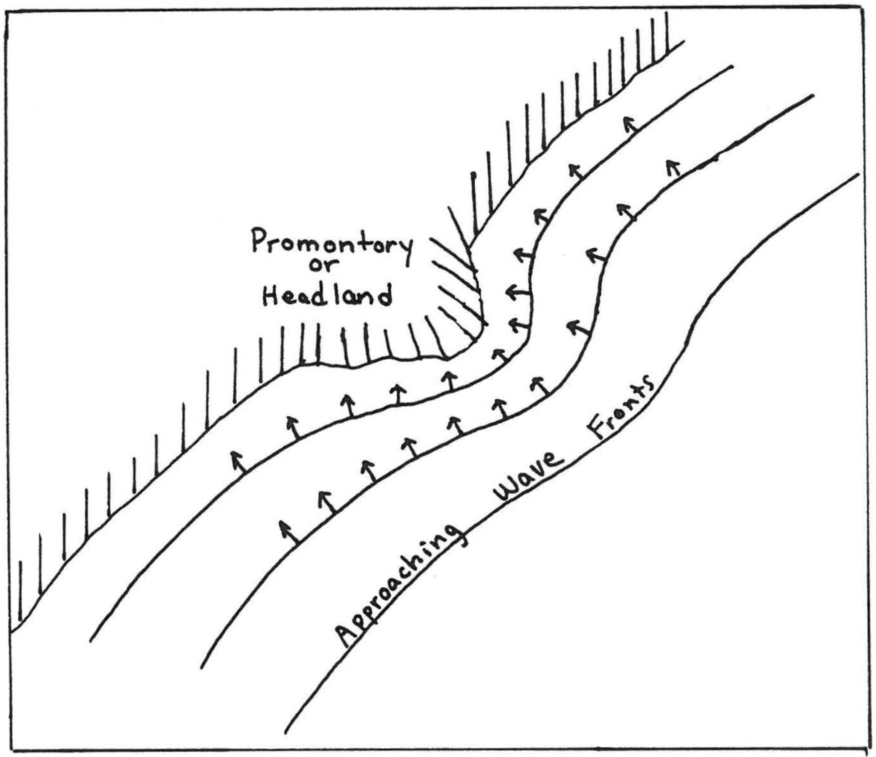


Figure 5-12. Wave refraction along a promontory. Waves approaching a promontory or headland are slowed by shallower water and refracted, thereby focusing more energy on the headland and accelerating erosion. This phenomenon was noted by D. W. Johnson in 1919.

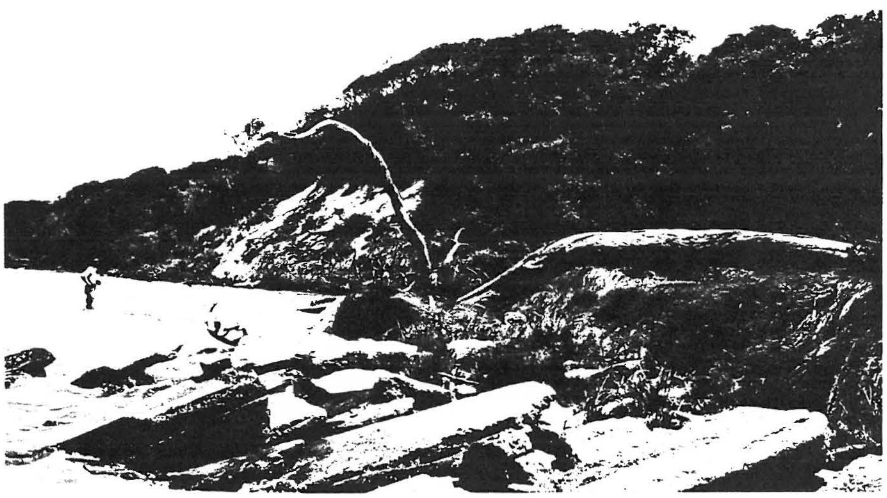


Figure 5-13. Wrack from house near Dagger Point destroyed by Hurricane Carla. (Photograph from Aransas National Wildlife Refuge interpretive station.)

Summary, 1859-60 to 1982

The dominant net trend along the western shore of San Antonio Bay was erosional, as documented by the fact that the shoreline at all 16 measured stations retreated or moved landward (fig. 5-11). Compared with rates between 1930 and 1982, net rates were lower at all stations except 3. The net rate at station 81 was 6.2 ft/yr, the same as for the previous period. At stations 87 and 89, the net rate was 2.1 and 1.9 ft/yr, respectively--an increase of about 1 ft/yr over the 1930 to 1982 rate. These higher net rates were, of course, caused by higher rates during the period 1859 to 1930.

Other stations with relatively high net erosion rates were 82 (5.2 ft/yr), 79 (4.6 ft/yr), and 85 (4.1 ft/yr). Each of these stations experienced high rates of erosion between 1930 and 1982. The accretionary feature intersected by stations 81 and 82 has experienced systematic erosion since 1860. The average net retreat of all stations along this shoreline segment was 265 ft for a rate of about 2.2 ft/yr.

The Modern-Holocene Bayhead Delta Shoreline

This shoreline segment includes the northwestern (inland) shorelines of Hynes Bay and Mission Lake and the shoreline along the Guadalupe Delta. This entire section is composed of Modern-Holocene fluvial-deltaic sediments deposited at the head of San Antonio Bay.

Station numbers along which quantitative measurements were made are 92 to 115 (fig. 5-1). The inclusion of one substation (111b) yields a total of 25 stations overall.

1860 to 1930

Three stations, 92, 93, and 94, are along an abandoned beach-ridge strandplain (Donaldson and others, 1970). Two of these stations (92 and 93) experienced accretion and the third erosion. This particular shoreline, at the head of Hynes Bay, apparently lies in an area of converging currents (Donaldson and others, 1970), which contributed to the formation of a broad promontory or bulge along the 1860 shoreline. This broad rounded promontory, intersected by station 94, retreated 410 ft (perhaps as a result of the westward migration and narrowing of the promontory) between 1860 and 1930. The rate of erosion was 5.8 ft/yr at station 94. Adjacent stations 92 and 93 advanced at magnitudes of 320 and 290 ft, or at rates of 4.5 and 4.1 ft/yr, respectively.

Along the Guadalupe Delta shoreline, the trend was one of loss of land or erosion from stations 95 to 104--an area coincident with an abandoned delta lobe (Donaldson and others, 1970). Rates of erosion in this area apparently caused by a combination of compactional subsidence, submergence, and erosion, range from a high of 9.7 ft/yr at station 102 to a low of 1.7 ft/yr at station 96. Six of the 10 stations, along this subsection of the delta, experienced erosion at rates above 5 ft/yr.

At stations 105 through 110, there was a gain in land as all six stations showed accretion. This prograding shoreline apparently was supplied with sediment from active delta distributaries--the North and South branches of the Guadalupe River (fig. 5-1). Experiencing some of the highest rates of accretion were those shorelines near the mouths of these distributaries. The shoreline at station 105 prograded at a rate of 9.2 ft/yr, and at station 107 at a rate of 6.6 ft/yr. However, the highest rate of accretion occurred at station 110, where the 1930 shoreline was 1,800 ft beyond the 1859 shoreline, for a rate of advance, or progradation, of 25.4 ft/yr. Undoubtedly there was an active distributary channel supplying this northern lobe of the Guadalupe Delta. Although the distributary was inactive by 1930, the relict natural levees constructed along the channel are visible on the 1930 photographs. Other accretionary stations--106, 108, and 109--advanced at rates from 0.9 ft/yr to 5.2 ft/yr.

Along western and northwestern shorelines of Mission Lake, stations 111a and 114 experienced erosion, while the remaining stations (112, 113, and 115) experienced accretion. The accretion was in large part due to the expansion of marshes along the edge of this shallow protected water body of Mission Lake. Most of the accretion occurred near the mouths of inactive distributary channels, under normal conditions functioning as tidal channels, but perhaps the channels were reactivated during periods of valley flooding. During these times, sediments would be contributed to this shallow estuary.

The 1,090 ft (15.4 ft/yr) retreat of the shoreline at station 111a is not clearly explainable because this station is also near the mouth of a relict distributary channel that could have contributed sediment resulting in accretion. Two factors that possibly led to the erosion are (1) the shoreline being at the southwest end of the long axis of Mission Lake and therefore being susceptible to erosion by waves and elevated water levels produced by steady, strong northeasterly winds and (2) the shoreline possibly being scoured by currents moving along the tidal channel (inactive distributary channel) that discharges along (parallel to) this shoreline. Erosion at the other station (114) where erosion occurred was at a low rate of less than 1 ft/yr.

1930 to 1974-1982

Two significant human modifications occurred along this shoreline segment during this time period. One was the dredging of Traylor Cut in 1935, which diverted most of the discharge of the Guadalupe River into the southwestern part of Mission Lake. The other was the construction of the Victoria Channel, between 1951 and 1960 (J. C. Trahan, U.S. Army Corps of Engineers, personal communication, 1983), along the northeastern shores of Guadalupe Bay and Mission Lake. Photographs taken in 1982 were not available for stations 93 through 96; so the time frame covering this area is 1930 to 1974.

The abandoned beach-ridge strandplain (Donaldson and others, 1970) at the head of Hynes Bay accreted from 50 to 110 ft at the three measured stations (92, 93, and 94) (fig. 5-1). The rate of accretion was highest at station 93 (2.3 ft/yr) and lowest at station 94 (1.1 ft/yr). The small peninsula that projects southeastward from the shore between stations 93 and 94 developed during this time period. Donaldson and others (1970) noted that in 1929 an island was present about 700 ft offshore from the abandoned beach-ridge plain. According to Donaldson and others (1970), the island was at the nodal point of the two primary currents that supply sediments to the mud flats and shell berms. The island retreated landward as the shoreline advanced bayward, producing a small peninsula when the former island became attached to the mainland shore (fig. 5-14). Although the stations along this beach-ridge plain experienced accretion between 1930 and 1974, all three stations, 92-94, have experienced more recent short-term erosion (between 1958 and 1974 for stations 93 and 94 and between 1974 and 1982 for station 92). Examination of this shoreline in the field provided some evidence, such as an erosional shell berm and exposed shrub and marsh-grass roots, that this shoreline has recently retreated, at least along some stretches.

Stations measured along the Guadalupe Delta (stations 95 through 111) reflected an erosional shoreline, with the exceptions of stations 110 and 111, where the shoreline accreted, and station 109, where the shoreline was stable. Rates of erosion ranged from 9.2 to 1.9 ft/yr. The average rate was about 5 ft/yr. With the exception of station 102, which had the lowest rate, stations along the delta shoreline extending into San Antonio Bay documented the highest rate of retreat. Erosion was less than 5 ft/yr at stations located along Guadalupe Bay and the southeastern shore of Mission Lake. The shore at station 110 on Mission Lake experienced accretion of 80 ft--a rate of 1.5 ft/yr.

A reversal in the erosional trend of the Guadalupe Delta occurred in the area of stations 111a and 111b, near the mouth of Traylor Cut. The opening of Traylor Cut in 1935 led to the formation of a rapidly prograding subdelta in the southeast corner of shallow Mission Lake. At station 111a, the shoreline prograded 1,510 ft at a rate of 29 ft/yr and at station 111b, 3,350 ft at a rate of 64.4 ft/yr (fig. 5-1). The rate of progradation had slowed between 1958 and 1974 perhaps in part because of a logjam on the Guadalupe River. After the logjam was removed in the mid-1970's, this small lobe of the Guadalupe Delta prograded at over 150 ft per year until 1982. The development of this small delta is illustrated in figure 5-15.

Stations along the northwestern shore of Mission Lake (stations 112 through 115) reflected erosion at rates of from 2.1 ft/yr at station 112 to 16 ft/yr at station 115. The retreat at this latter station was apparently in part related to the construction of the Victoria Channel along this shoreline.

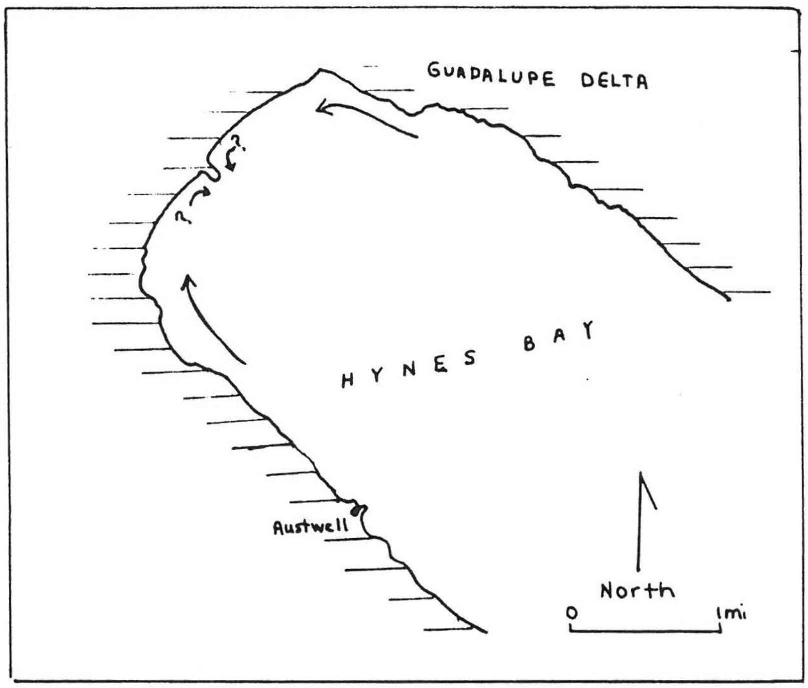


Figure 5-14. Converging currents, depicted by arrows, in Hynes Bay. Wave trains generated by prevailing southeasterly winds may produce littoral currents (by wave refraction along the opposite shorelines) that converge at the head of the bay.

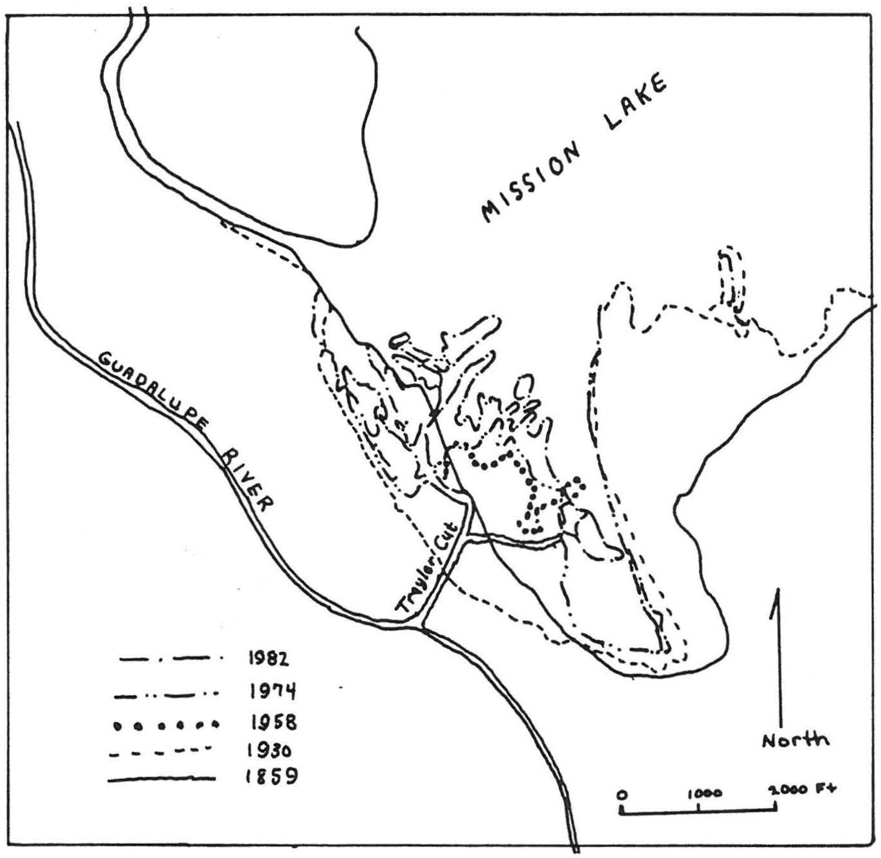


Figure 5-15. Historical shoreline changes of the Traylor Cut lobe of the Guadalupe Delta.

Summary, 1859 to 1982

Net cumulative changes ranged from accretion at stations along the abandoned beach-ridge plain at the head of Hynes Bay (stations 92-94) to erosion of most of the Guadalupe Delta along Hynes Bay, San Antonio Bay, and most of Guadalupe Bay (stations 95 through 106), to accretion of the delta along Mission Lake (stations 107 to 112) (fig. 5-11). Stations 113 and 114 along the inland shore of Mission Lake registered net erosion, while station 115 registered accretion.

The highest rates of erosion occurred along the Guadalupe Delta at stations 100 through 103, where rates were about 6 ft/yr or higher. Distributary channels that in the past supplied these parts of the delta with sediments have been abandoned throughout historic time (Donaldson and others, 1970). Through compactional subsidence and submergence and wave attack, the major part of the delta is retreating.

The relatively high rates of accretion occurring between 1859 and 1930 near the mouths of the North and South Guadalupe Rivers produced net accretion at stations 105 and 107. These stations, however, experienced erosion between 1930 and 1982 as a result of the construction of Traylor Cut, which diverted most of the discharge of the Guadalupe River away from the North and South branches. These distributary channels have become less active, and sediment discharged at their mouths is insufficient to keep pace with compactional subsidence and erosion of the shoreline.

The extensive accretion at station 110 between 1859 and 1930 gave this station the highest cumulative accretion rate of 15.3 ft/yr. However, comparisons of 1974 and 1982 shorelines indicate no measurable change. This is in marked contrast to stations 111a and 111b, where progradation, or shoreline advance, occurred at rates of 175 and 150 ft/yr between 1974 and 1982. The cumulative rate at station 111 from 1859 to 1982, though, was less than at station 110 because of the offsetting erosion that occurred at station 111 between 1859 and 1930.

Along the inland shore of Mission Lake, station 112, although more recently undergoing short-term (1970 to 1982) erosion, had net accretion of 650 ft (5.3 ft/yr). Stations 113 and 114 had net erosion of between 1 and 2 ft/yr. The large amount of accretion that was measured at station 115 for the period 1859 to 1930 gave this station net accretion of 2,650 ft (21.5 ft/yr), which more than offset the recent (1930 to 1982) loss of land in this area.

Eastern Shoreline of San Antonio Bay

This shoreline segment extends from near the mouth of Victoria Channel in San Antonio Bay to the Intracoastal Waterway. Fifteen stations (numbers 116 to 130) were measured along this shoreline (fig. 5-1). Because of the extensive modifications made by dredging of Victoria Channel and the disposal of dredged spoil along the entire length of the eastern shore of Guadalupe Bay, no quantitative measurements were made along this stretch of shoreline.

Shoreline types along the eastern shore of San Antonio Bay include (1) overhanging wave-cut clay bluffs (fig. 5-16) that transect Pleistocene fluvial-deltaic deposits, (2) gently sloping, vegetated shores, (3) marshes, and (4) human-modified shores ranging from those that have been bulkheaded or stabilized with riprap, to those that have been modified by channel construction.

1859 to 1930

Eighty percent, or 12 of the 15 stations measured indicated erosion during this period. Of the three remaining stations, two had no measurable change, and one registered accretion. Rates of erosion ranged from a high of 10.4 ft/yr at station 117 to a low of 0.4 ft/yr at station 120. The average rate of erosion was 3.2 ft/yr. Most of the stations recording the highest rates of retreat (stations 117, 118, 123, 125, and 126) are located along stretches of shore unprotected from waves and wind tides produced by southerly winds. The exception is station 123, where erosion can be attributed more to northerly winds, which elevate waters along this shore during passage of polar air masses.

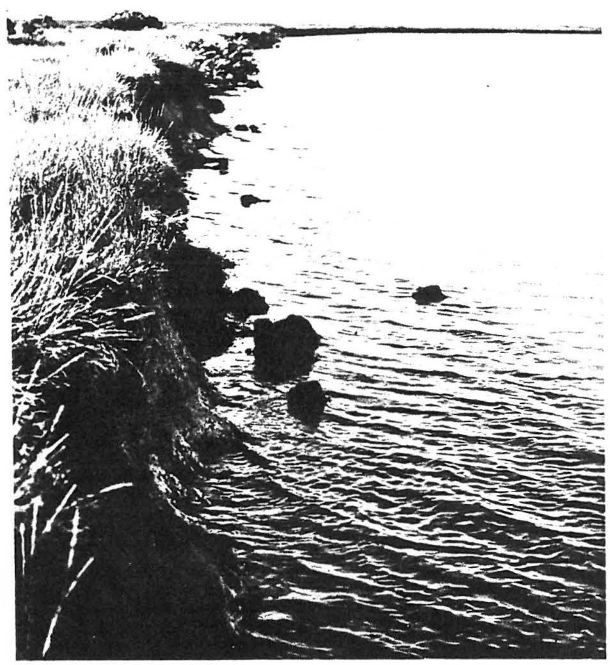


Figure 5-16. Overhanging clay bluff along the eastern shore of San Antonio Bay near station 124 (fig. 5-1).

Although measurement at station 121 (Swan Point) reflected no change, the shoreline along Swan Point is more dynamic than this station suggests, as is noted in a following section.

Countering the erosional trend displayed by most measured stations, station 129 registered 1,120 ft of accretion between 1859 and 1930. This station is on a relatively protected marshland. The overall shape of this marshland area as depicted by the shoreline positions on the 1859 map, however, is substantially different from its shape as shown in the 1930 photographs. There is a possibility that the 1859 survey map is in error, and therefore the magnitude and rate of accretion at station 129 should be viewed with suspicion.

1930 to 1982

Several human modifications occurred along this shoreline between 1930 and 1982, including dredging of Victoria Channel as well as a branch channel to Seadrift, where two boat basins, or harbors, were constructed as well as channels associated with a recreational/community development. Also, various shoreline stabilization and protection projects were undertaken by public and private interests. The most extensive shore stabilization project occurred at Seadrift, where a vertical cement bulkhead approximately 3 to 4 ft high and about 3,000 ft long (fig. 5-17) was constructed in 1961 (Seadrift public officials, personal communication, 1983). Station 118, which intersects this bulkhead, is the only station along this eastern shore of San Antonio Bay registering a bayward advance of the shoreline (fig. 5-1). Apparently in conjunction with construction of the bulkhead, the shoreline was graded bayward approximately 60 ft primarily by leveling a nearly vertical erosional clay bluff that previously characterized this area.

Ten of the remaining 14 stations experienced erosion during this period. Magnitudes of shoreline retreat ranged from 430 ft at station 126 to 20 ft at station 128. Loss of land at stations 125 and 126, the two stations having the highest rate of retreat, is related mostly to the construction of Victoria Channel between 1957 and 1960. Short-term (1974 to 1982) erosion

Figure 5-17. Cement bulkhead constructed in 1961 along the shoreline of San Antonio Bay at Seadrift.

rates of more than 10 ft/yr recorded at these two stations are probably related to a combination of channel maintenance dredging, channel boat traffic, and natural processes.

Another station having a relatively high rate of erosion of 4.4 ft/yr was station 121 at Swan Point. Most stations in the more protected embayments on either side of Swan Point also experienced erosion but at lower rates.

Four stations, 117, 123, 129, and 130, registered no measurable change. All of these but station 117 are in somewhat protected areas. Station 117 is along a shoreline where individual property owners have employed some partially successful shoreline stabilization techniques such as bulkheading.

Summary, 1859 to 1982

About 95 percent of the stations along the eastern shoreline of San Antonio Bay registered net erosion during this 123-yr period (fig. 5-11). Two stations, 117 and 126, had rates of more than 5 ft/yr, six stations had rates ranging from about 2 to almost 4 ft/yr, and six stations had rates of from 1.1 to 1.7 ft/yr. Only one station, 129, registered accretion, all of which occurred between 1859 and 1930; but as mentioned earlier, the accretion at this station is suspect.

The high rate of retreat of 6.0 ft/yr recorded at station 117 is an artifact of the 10.4 ft/yr rate established between 1859 and 1930. From 1930 to 1982, this station registered no measurable change, indicating the retreat of the shoreline had diminished apparently in part by shore protection measures implemented by property owners. But the slowdown may also be, in part, related to natural adjustments in shoreline alignment caused by the earlier period of erosion. The 1859 shoreline curved outward toward San Antonio Bay, forming a broad promontory which retreated landward until 1930.

Although the shoreline at station 118 registered net erosion of 1.7 ft/yr during this period, it has been stabilized by the bulkhead (fig. 5-17) described above.

Stations 119 and 120, although located along a shoreline relatively protected from waves produced by the dominant wind regimes, are not protected from storm tides and waves, and have retreated at a rate of about 1 to 1.5 ft/yr. Swan Point and spoil islands offshore from these stations offer some protection. Boat traffic to and from boat basins may have contributed some to the retreat, but it is not possible to quantify how much.

Station 121, which intersects Swan Point, had a net rate of retreat of about 2 ft/yr. Figure 5-18, depicting the historical shorelines along Swan Point, shows that the spit at the tip of the promontory migrated or rotated clockwise toward Seadrift from 1930 to 1982.

Net rates of erosion ranged from 1.1 to 2.4 ft/yr at stations 122 through 124. Evidence of erosion at station 124 includes an overhanging wave-cut clay bluff at the base of which are vegetated clumps of soil that have fallen as the bluff is undermined (fig. 5-16), principally when bay water is blown against this shoreline by strong northerly winds.

Stations 125 and 126 registered the highest rates of retreat of 3.8 and 5.5 ft/yr, respectively. The principal cause of retreat was the construction of Victoria Channel.

Stations 127, 128, and 130 are along somewhat protected marshland shorelines. Rates of retreat ranged from a high of 2.3 ft/yr at station 128 to a low of 1.1 ft/yr at station 130. The retreat at station 128 occurred principally between 1859 and 1930.

Mainland Shorelines of Espiritu Santo Bay

This segment covers primarily the shorelines of natural islands that are present along the western and northern shores of Espiritu Santo Bay. The mainland shoreline has been modified by construction of the Intracoastal Waterway between 1938 and 1940. Only a few stations selected for quantitative measurements are located on the mainland shore along the Intracoastal Waterway. Measured stations extend from near Steamboat Pass to Dewberry Island and encompass stations 131 through 163 (fig. 5-1).

Shoreline types are, primarily, salt-water marshes and sand and shell berms, although gentle sloping clay and sand substrates line portions of the mainland shore along the Intracoastal Waterway. The major natural islands along this shoreline are Steamboat Island, Long Island, Dewberry Island, and Blackberry Island (fig. 5-1). Much of this chain of elongate

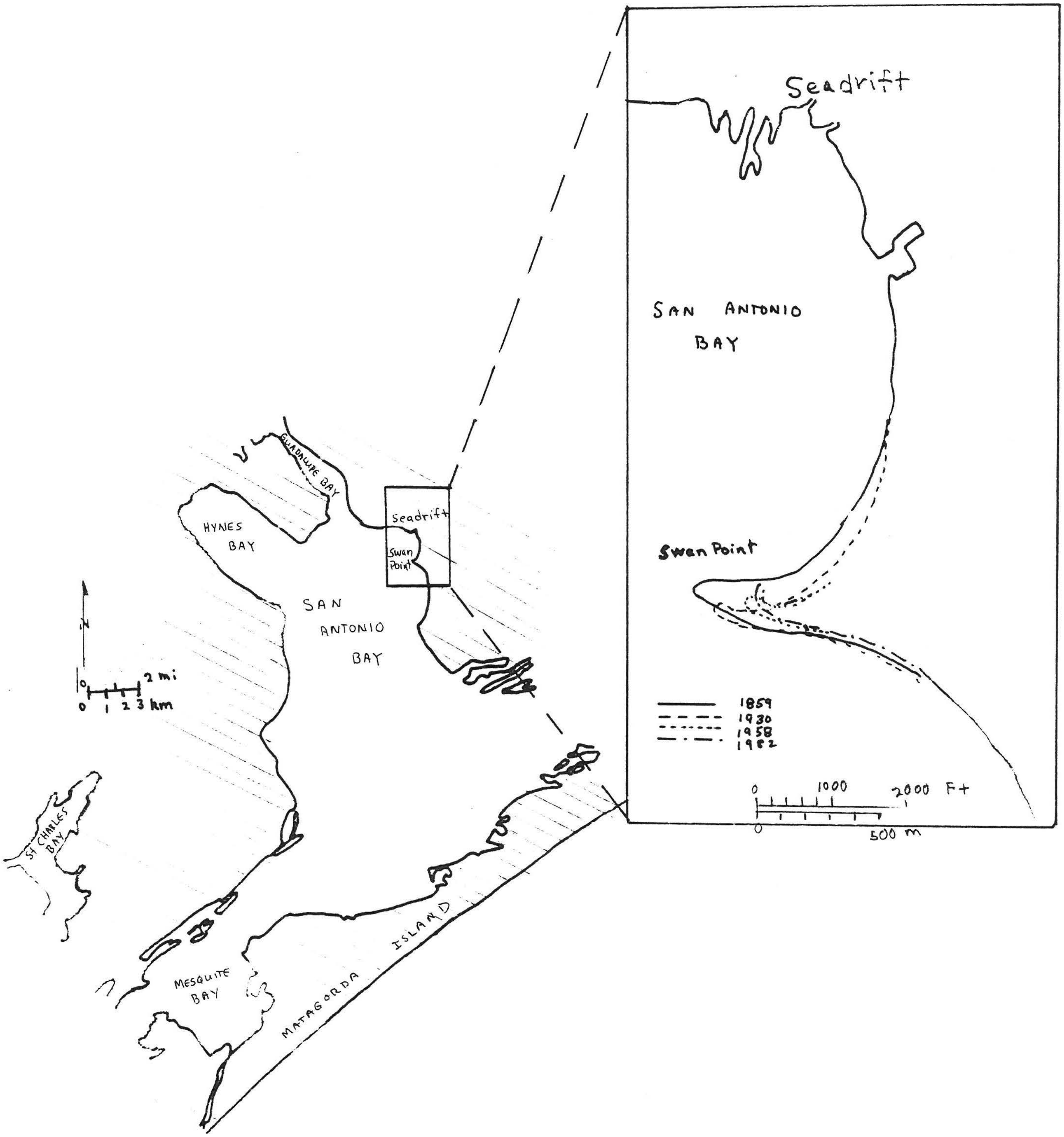


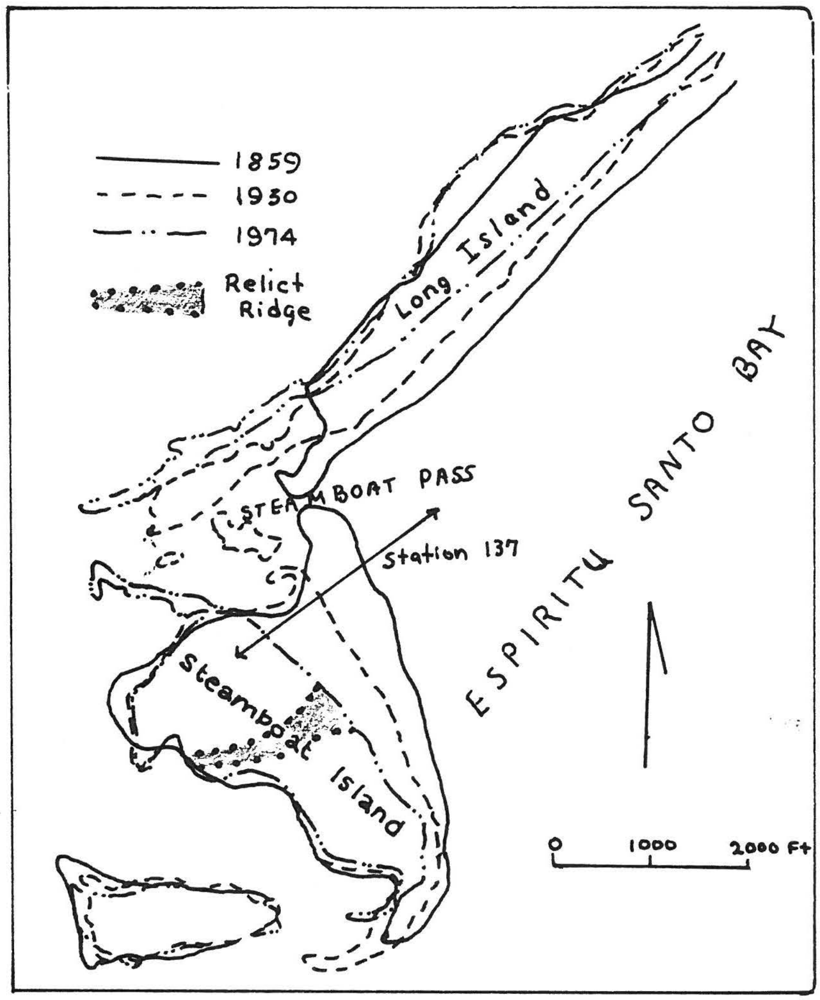
Figure 5-18. Historical changes of Swan Point, 1859 to 1982. Note the clockwise rotation of the spit from 1930 to 1982.

narrow islands, especially Long Island, appears to be part of a natural spit that accreted, from northeast to southwest, before historical time. The islands form a barrier between Shoalwater and Espiritu Santo Bays. An elongate ridge on Steamboat Island that is parallel to Long Island suggests that these two islands may have been connected in the past. Today, they are separated by a natural channel--Steamboat Pass (fig. 5-1).

1859 to 1930

During this 71-yr period, about 55 percent of the stations registered erosion, 35 percent accretion, and 10 percent no change. Those undergoing erosion were generally located along shorelines facing the open waters of Espiritu Santo or San Antonio Bays. Magnitudes and rates of retreat ranged from 560 ft and 7.9 ft/yr at station 137, to 20 ft and 0.3 ft/yr at station 158. Stations registering erosion of at least 3 ft/yr include 132, 137, 138, 139, 140, and 157. All of these stations but one (station 132) are on shorelines susceptible to wave attack during winter storms when strong winds from the northeast and east blow down the length of Espiritu Santo Bay. Station 137, which registered the highest rate of erosion of all stations, is on the eastward facing shoreline of Steamboat Island. Near this station is Steamboat Pass, which separates Long Island from Steamboat Island. In 1859 the Pass was less than 200 ft wide; by 1930 it was more than 1,000 ft wide at this same location. An island and recurved spit that had formed along the pass to the west in 1930 apparently were the down-current remnants of the promontories that were almost connected in 1859 (fig. 5-19). These changes suggest that relatively strong currents flow through the pass during the passage of polar air masses, which are normally accompanied by strong northerlies. Also, the pass and flanking shorelines on Long and Steamboat Islands are susceptible to the effects of currents and waves generated in Espiritu Santo Bay by prevailing southeasterly winds.

Station 136, which is along the southeastern end of Steamboat Island, also registered erosion, but at the slower rate of 2.3 ft/yr. The shoreline at this station retreated 160 ft.



5-19. Historical changes of Steamboat Island and Steamboat Pass near the eastern end
itu Santo Bay.

With the exception of station 148, stations from 142 to 156 either registered accretion or no change (at 2 stations). All these stations except 155 and 156, which registered the lowest amount of accretion, are located in areas protected from the open water of Espiritu Santo Bay. Several of the stations (144, 145, 146, and 147), which recorded some of the most extensive accretion, ranging from 770 ft to 310 ft, are located on what are possibly washover fans deposited on the mainland side of Long Island by surging storm tides that produced channels or breaches in the island. Sediments were washed through these channels, creating the fans. The erosion of Long Island along the Espiritu Santo Bay shoreline and its accretion along the Shoalwater Bay shoreline produce a retreating island that is similar to a transgressive barrier island along the Gulf.

1930 to 1974-82

The Intracoastal Waterway was dredged along the mainland shoreline during this period, and a continuous spoil-island ridge was created along the bay side of the channel. Two branch channels cut the spoil ridge and connect the waterway with Espiritu Santo Bay between stations 143 and 155, and between stations 160 and 161. Changes in shorelines of the spoil islands were not quantified in this area (eastern shoreline of Espiritu Santo Bay). Thus, stations 131 through 163 intersect shorelines of natural islands and in a few cases shorelines along the mainland side of the Intracoastal Waterway (fig. 5-1). The stations along the waterway are 149 to 152 and 154. Because the dredging of the canal and disposal of spoil greatly modified the shore, a cumulative or net change beyond 1930 was not determined for these stations (149 to 152 and 154). Short-term changes between 1974 and 1982, however, were measured.

It should be noted that 1982 photographs were not available for some stations (135 to 139) in the Steamboat Island area. Photographs taken in 1974 were used instead.

Approximately 80 percent of the stations recorded erosion, 10 percent accretion, and 5 percent no change. These percentages include short-term changes (1974 to 1982) at five stations. The highest rate of erosion occurred at station 137, where the eastward shoreline of

Steamboat Island retreated 690 ft during the period 1930 to 1974. The rate of retreat at this station was about 16 ft/yr, which is almost twice the rate recorded at any other station. Other stations marking shorelines that eroded at rates of more than 5 ft/yr include stations 131 (6.0 ft/yr), 133 (8.5 ft/yr), 138 (9.1 ft/yr), 141 (7.1 ft/yr), and 142 (5.4 ft/yr). Stations with more than 3 ft/yr include 132 (3.8 ft/yr), 140 (4.2 ft/yr), 143 (4.6 ft/yr), and 157 (3.1 ft/yr). As in the preceding period, those stations recording the highest rates of retreat are located along shores generally unprotected from the open water of Espiritu Santo and San Antonio Bays. The rates decrease to the east along Dewberry and Blackberry Islands.

The trend of retreating shorelines in the vicinity of Steamboat Pass that was established during the period 1850 to 1930 continued to 1974. The island that had formed in the pass in 1930 was eroded away by 1974. Westward projecting spits along Steamboat Island and Long Island lined the pass (fig. 5-19).

Grass Island along the northern shore of Steamboat Pass (at its western end) continued to retreat at rates of between 3.8 and 8.5 ft/yr (stations 131, 132, and 133). Stations marking the highest rates of retreat on Long Island were generally those near its western end, which curves southward into Espiritu Santo Bay toward Steamboat Pass.

Much of the 240-ft retreat (4.6 ft/yr) at station 143 was caused by a navigation channel that connects to the Intracoastal Waterway just northeast of this station. The tips of Long Island on both sides of the channel have retreated or migrated (forming recurved spits) landward along the channel. The rapid change is related to the channel and associated waves, tidal currents, and boat traffic that the channel supports.

During the period 1974 to 1982, shorelines measured at stations 149 to 152 and 154, along the mainland shore of the Intracoastal Waterway, eroded at rates of greater than 5 ft/yr during this short-term period. Most of the erosion is attributed to boat traffic on the Intracoastal Waterway.

Stations that accreted or registered no change between 1930 and 1982 are located along the more protected shores of shallow, fetch-limited Shoalwater Bay, except for station 134 located along the protected shore of western Steamboat Island. The greatest amount of shoreline advance was registered at station 148, located on the landward side of Long Island on Shoalwater Bay. The movement landward of the shoreline a distance of 280 ft at this station is associated with the landward migration of Long Island. This migration was caused by the dredged channel that connects Espiritu Santo to the Intracoastal Waterway. As mentioned above, station 143, which is on the Espiritu Santo Bay shore across Long Island from station 148, eroded or retreated by about 240 ft, which also reflects the migration of the island near the channel. In other words, the entire tip of the island migrated landward as sediment was eroded from the bayward side and deposited on the landward side.

Summary, 1859 to 1974-82

Net historical changes generally follow the trends established between 1859 to 1930 and 1930 to 1974/82. For the 28 stations where long-term changes were determined (5 stations, 149 to 152 and 154, were considered only over the short term because of the Intracoastal Waterway), 21 recorded net erosion and 7 net accretion. Rates of erosion ranged from a high of almost 11 ft/yr at station 137 on Steamboat Island to a low of 0.3 ft/yr at station 135, which is on a smaller island to the west of and under the protective "wings" (spits projecting southwestward) of Steamboat Island (fig. 5-11). The westward retreat of the shoreline at station 137, for a distance of 1,250 ft between 1859 and 1974, makes it the fastest eroding shoreline in the entire San Antonio - Espiritu Santo Bay System. Figure 5-19 illustrates the systematic retreat of this northeastern shoreline of Steamboat Island.

The next highest rate of erosion occurred at station 138, which is along the shoreline of Long Island next to Steamboat Pass. The shoreline at this station retreated 630 ft at a rate of 5.5 ft/yr.

With this rate in mind, it is interesting to theorize how long ago Long Island may have been connected to the relict ridge on Steamboat Island. In the discussion above, it was proposed that this relict ridge is a past tip of the Long Island spit. The ridge is about 2,500 ft southeast of the 1859 shoreline depicting the tip of Long Island. Assuming that the rate of retreat of Long Island has been about 5 to 6 ft/yr as recorded at station 138, Long Island would have been connected to this ridge about 400 or 500 yrs before the 1859 survey was conducted, or about 500 to 600 yrs before the present (fig. 5-19).

Other stations documenting net shoreline erosion of at least 3 ft/yr are 131 (3.5 ft/yr), 132 (4.3 ft/yr), 133 (5 ft/yr), 139 (3.0 ft/yr), 140 (3.7 ft/yr), 141 (4.0 ft/yr) and 157 (4.6 ft/yr). These stations are mostly located either along Grass Island northwest of Steamboat Pass or along the western half of Long Island, which curves southward into Espiritu Santo Bay. Stations registering lower rates of erosion are along more protected shores on the eastern half of Long Island, along naturally protected shores west of Steamboat Island, and along much of Dewberry and Blackberry Islands.

Recording net accretion are the stations located along the Shoalwater Bay shoreline of Long Island (stations 144 to 148 and 153). Station 156 is the only station on a shoreline facing Espiritu Santo that registered net accretion although it was only for a distance of 60 ft at a rate of 0.5 ft/yr. Erosion of the tip of the Island possibly supplied some of the sediment that produced accretion at station 156.

6.0 CONCLUSIONS

Except for major shoreline advances associated with spoil disposal and minor accretion adjacent to coastal structures, human activities tend to contribute to shoreline erosion. The widespread alteration of shorelines coupled with decreased and disrupted sediment supply, minor relative sea-level rise, and frequent, intense storms is essentially insurmountable. Furthermore, there is no evidence that suggests a long-term reversal in any trend of the major causal factors that promote shoreline erosion. In fact, some studies such as 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 additive effects of the principal forces, it appears that most unprotected shorelines in the Galveston and San Antonio Bay Systems will continue to retreat landward in response to natural erosional conditions that were mainly established before the 1800's, have continued since then, and are likely to persist into the foreseeable future.

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APPENDIX A

HISTORICAL SHORELINE CHANGES IN THE GALVESTON BAY SYSTEM.

TRINITY BAY

STATION	PERIOD	PERIOD LENGTH(YR)	DISTANCE (FT)	RATE (FT/YR)	RATE UNCERTAINTY (FT/YR)
1	1851 - 1930	79	-750	-9.49	0.32
	1930 - 1982	52	-100	-1.92	0.48
	1851 - 1982	131	-850	-6.49	0.19
2	1851 - 1930	79	-150	-1.90	0.32
	1930 - 1982	52	-125	-2.40	0.48
	1851 - 1982	131	-275	-2.10	0.19
3	1851 - 1930	79	-150	-1.90	0.32
	1930 - 1982	52	0	0.00	0.48
	1851 - 1982	131	-150	-1.15	0.19
4	1851 - 1930	79	225	2.85	0.32
	1930 - 1982	52	-100	-1.92	0.48
	1851 - 1982	131	125	0.95	0.19
5	1851 - 1930	79	125	1.58	0.32
	1930 - 1982	52	-125	-2.40	0.48
	1851 - 1982	131	0	0.00	0.19
6	1851 - 1930	79	-150	-1.90	0.32
	1930 - 1982	52	-75	-1.44	0.48
	1851 - 1982	131	-225	-1.72	0.19
7	1851 - 1930	79	150	1.90	0.32
	1930 - 1982	52	-225	-4.33	0.48
	1851 - 1982	131	-75	-0.57	0.19
8	1851 - 1930	79	0	0.00	0.32
	1930 - 1982	52	-25	-0.48	0.48
	1851 - 1982	131	-25	-0.19	0.19
9	1851 - 1930	79	150	1.90	0.32
	1930 - 1982	52	-150	-2.88	0.48
	1851 - 1982	131	0	0.00	0.19
10	1851 - 1930	79	-250	-3.16	0.32
	1930 - 1982	52	-250	-4.81	0.48
	1851 - 1982	131	-500	-3.82	0.19
11	1851 - 1930	79	-300	-3.80	0.32
	1930 - 1982	52	-700	-13.46	0.48
	1851 - 1982	131	-1000	-7.63	0.19
12	1851 - 1930	79	-475	-6.01	0.32
	1930 - 1982	52	-125	-2.40	0.48
	1851 - 1982	131	-600	-4.58	0.19

TRINITY BAY

STATION	PERIOD	PERIOD LENGTH(YR)	DISTANCE (FT)	RATE (FT/YR)	RATE UNCERTAINTY (FT/YR)
13	1851 - 1930	79	-525	-6.65	0.32
	1930 - 1956	26	-50	-1.92	0.96
	1956 - 1974	18	-75	-4.17	1.39
	1974 - 1982	8	-50	-6.25	3.13
	1851 - 1982	131	-700	-5.34	0.19
14	1851 - 1930	79	-800	-10.13	0.32
	1930 - 1956	26	-25	-0.96	0.96
	1956 - 1974	18	-150	-8.33	1.39
	1974 - 1982	8	-50	-6.25	3.13
	1851 - 1982	131	-1025	-7.82	0.19
15	1851 - 1930	79	0	0.00	0.32
	1930 - 1956	26	-75	-2.88	0.96
	1956 - 1974	18	0	0.00	1.39
	1974 - 1982	8	75	9.38	3.13
	1851 - 1982	131	0	0.00	0.19
16	1851 - 1930	79	-500	-6.33	0.32
	1930 - 1982	52	0	0.00	0.48
	1851 - 1982	131	-500	-3.82	0.19
17	1851 - 1930	79	-725	-9.18	0.32
	1930 - 1982	52	-50	-0.96	0.48
	1851 - 1982	131	-775	-5.92	0.19
18	1851 - 1930	79	-450	-5.70	0.32
	1930 - 1982	52	-50	-0.96	0.48
	1851 - 1982	131	-500	-3.82	0.19
19	1851 - 1930	79	-400	-5.06	0.32
	1930 - 1982	52	-100	-1.92	0.48
	1851 - 1982	131	-500	-3.82	0.19
20	1851 - 1930	79	-375	-4.75	0.32
	1930 - 1982	52	0	0.00	0.48
	1851 - 1982	131	-375	-2.86	0.19
21	1851 - 1930	79	-325	-4.11	0.32
	1930 - 1982	52	-50	-0.96	0.48
	1851 - 1982	131	-375	-2.86	0.19
22	1851 - 1930	79	-175	-2.22	0.32
	1930 - 1982	52	-25	-0.48	0.48
	1851 - 1982	131	-200	-1.53	0.19
23	1851 - 1930	79	-225	-2.85	0.32
	1930 - 1982	52	225	4.33	0.48
	1851 - 1982	131	0	0.00	0.19

TRINITY BAY

STATION	PERIOD	PERIOD LENGTH(YR)	DISTANCE (FT)	RATE (FT/YR)	RATE UNCERTAINTY (FT/YR)
24	1851 - 1930	79	-50	-0.63	0.32
	1930 - 1982	52	50	0.96	0.48
	1851 - 1982	131	0	0.00	0.19
25	1851 - 1930	79	-150	-1.90	0.32
	1930 - 1982	52	25	0.48	0.48
	1851 - 1982	131	-125	-0.95	0.19
26	1851 - 1930	79	-75	-0.95	0.32
	1930 - 1982	52	850	16.35	0.48
	1851 - 1982	131	775	5.92	0.19
27	1851 - 1930	79	-50	-0.63	0.32
	1930 - 1982	52	25	0.48	0.48
	1851 - 1982	131	-25	-0.19	0.19
28	1851 - 1930	79	-125	-1.58	0.32
	1930 - 1982	52	75	1.44	0.48
	1851 - 1982	131	-50	-0.38	0.19
29	1851 - 1930	79	-50	-0.63	0.32
	1930 - 1982	52	-50	-0.96	0.48
	1851 - 1982	131	-100	-0.76	0.19
30	1851 - 1930	79	-175	-2.22	0.32
	1930 - 1982	52	75	1.44	0.48
	1851 - 1982	131	-100	-0.76	0.19
31	1851 - 1930	79	-225	-2.85	0.32
	1930 - 1982	52	50	0.96	0.48
	1851 - 1982	131	-175	-1.34	0.19
32	1851 - 1930	79	-225	-2.85	0.32
	1930 - 1982	52	0	0.00	0.48
	1851 - 1982	131	-225	-1.72	0.19
33	1851 - 1930	79	-150	-1.90	0.32
	1930 - 1974	44	375	8.52	0.57
	1974 - 1982	8	0	0.00	3.13
	1851 - 1982	131	225	1.72	0.19
34	1851 - 1930	79	-600	-7.59	0.32
	1930 - 1974	44	600	13.64	0.57
	1974 - 1982	8	0	0.00	3.13
	1851 - 1982	131	0	0.00	0.19
35	1851 - 1930	79	-500	-6.33	0.32
	1930 - 1974	44	500	11.36	0.57
	1974 - 1982	8	0	0.00	3.13
	1851 - 1982	131	0	0.00	0.19

TRINITY BAY

STATION	PERIOD	PERIOD LENGTH(YR)	DISTANCE (FT)	RATE (FT/YR)	RATE UNCERTAINTY (FT/YR)
36	1851 - 1930	79	-125	-1.58	0.32
	1930 - 1974	44	-125	-2.84	0.57
	1974 - 1982	8	0	0.00	3.13
	1851 - 1982	131	-250	-1.91	0.19
37	1851 - 1930	79	-325	-4.11	0.32
	1930 - 1974	44	175	3.98	0.57
	1974 - 1982	8	0	0.00	3.13
	1851 - 1982	131	-150	-1.15	0.19
38	1851 - 1930	79	-450	-5.70	0.32
	1930 - 1974	44	125	2.84	0.57
	1974 - 1982	8	-125	-15.63	3.13
	1851 - 1982	131	-450	-3.44	0.19
39	1851 - 1930	79	-400	-5.06	0.32
	1930 - 1974	44	-2400	-54.55	0.57
	1974 - 1982	8	-100	-12.50	3.13
	1851 - 1982	131	-2900	-22.14	0.19
40	1851 - 1930	79	-100	-1.27	0.32
	1930 - 1974	44	-175	-3.98	0.57
	1974 - 1982	8	-150	-18.75	3.13
	1851 - 1982	131	-425	-3.24	0.19
41	1851 - 1930	79	200	2.53	0.32
	1930 - 1982	52	5375	103.37	0.48
	1851 - 1982	131	5575	42.56	0.19
42	1851 - 1930	79	200	2.53	0.32
	1930 - 1982	52	-125	-2.40	0.48
	1851 - 1982	131	75	0.57	0.19
43	1851 - 1930	79	3175	40.19	0.32
	1930 - 1982	52	225	4.33	0.48
	1851 - 1982	131	3400	25.95	0.19
44	1851 - 1930	79	975	12.34	0.32
	1930 - 1982	52	850	16.35	0.48
	1851 - 1982	131	1825	13.93	0.19
45	1851 - 1930	79	-40	-0.51	0.32
	1930 - 1974	44	0	0.00	0.57
	1974 - 1982	8	0	0.00	3.13
	1851 - 1982	131	-40	-0.31	0.19
46	1851 - 1930	79	-325	-4.11	0.32
	1930 - 1974	44	0	0.00	0.57
	1851 - 1974	123	-325	-2.64	0.20

TRINITY BAY

STATION	PERIOD	PERIOD LENGTH(YR)	DISTANCE (FT)	RATE (FT/YR)	RATE UNCERTAINTY (FT/YR)
47	1851 - 1930	79	-425	-5.38	0.32
	1930 - 1956	26	25	0.96	0.96
	1956 - 1974	18	-50	-2.78	1.39
	1851 - 1974	123	-450	-3.66	0.20
48	1851 - 1930	79	-275	-3.48	0.32
	1930 - 1956	26	-275	-10.58	0.96
	1956 - 1974	18	-175	-9.72	1.39
	1851 - 1974	123	-725	-5.89	0.20
49	1851 - 1930	79	-250	-3.16	0.32
	1930 - 1956	26	-50	-1.92	0.96
	1956 - 1974	18	-150	-8.33	1.39
	1974 - 1982	8	-125	-15.63	3.13
	1851 - 1982	131	-575	-4.39	0.19
50	1851 - 1930	79	-100	-1.27	0.32
	1930 - 1956	26	-150	-5.77	0.96
	1956 - 1974	18	-150	-8.33	1.39
	1851 - 1974	123	-400	-3.25	0.20
51	1851 - 1930	79	-175	-2.22	0.32
	1930 - 1956	26	100	3.85	0.96
	1956 - 1974	18	-225	-12.50	1.39
	1974 - 1982	8	-75	-9.38	3.13
	1851 - 1982	131	-375	-2.86	0.19
52	1851 - 1930	79	-575	-7.28	0.32
	1930 - 1956	26	250	9.62	0.96
	1956 - 1974	18	-100	-5.56	1.39
	1974 - 1982	8	75	9.38	3.13
	1851 - 1982	131	-350	-2.67	0.19
53	1851 - 1930	79	-75	-0.95	0.32
	1930 - 1956	26	0	0.00	0.96
	1956 - 1974	18	-100	-5.56	1.39
	1974 - 1982	8	0	0.00	3.13
	1851 - 1982	131	-175	-1.34	0.19
54	1851 - 1930	79	0	0.00	0.32
	1930 - 1956	26	0	0.00	0.96
	1956 - 1982	26	0	0.00	0.96
	1851 - 1982	131	0	0.00	0.19
55	1851 - 1930	79	250	3.16	0.32
	1930 - 1956	26	75	2.88	0.96
	1956 - 1982	26	50	1.92	0.96
	1851 - 1982	131	375	2.86	0.19

TRINITY BAY

STATION	PERIOD	PERIOD LENGTH(YR)	DISTANCE (FT)	RATE (FT/YR)	RATE UNCERTAINTY (FT/YR)
56	1851 - 1930	79	-50	-0.63	0.32
	1930 - 1956	26	0	0.00	0.96
	1956 - 1982	26	0	0.00	0.96
	1851 - 1982	131	-50	-0.38	0.19
57	1851 - 1930	79	-250	-3.16	0.32
	1930 - 1956	26	-50	-1.92	0.96
	1956 - 1982	26	-25	-0.96	0.96
	1851 - 1982	131	-325	-2.48	0.19
58	1851 - 1930	79	-125	-1.58	0.32
	1930 - 1956	26	-100	-3.85	0.96
	1956 - 1982	26	0	0.00	0.96
	1851 - 1982	131	-225	-1.72	0.19
59	1851 - 1930	79	-175	-2.22	0.32
	1930 - 1956	26	-150	-5.77	0.96
	1956 - 1982	26	0	0.00	0.96
	1851 - 1982	131	-325	-2.48	0.19
60	1851 - 1930	79	-275	-3.48	0.32
	1930 - 1956	26	-100	-3.85	0.96
	1956 - 1982	26	0	0.00	0.96
	1851 - 1982	131	-375	-2.86	0.19
61	1851 - 1930	79	-275	-3.48	0.32
	1930 - 1956	26	-50	-1.92	0.96
	1956 - 1982	26	0	0.00	0.96
	1851 - 1982	131	-325	-2.48	0.19
62	1851 - 1930	79	-450	-5.70	0.32
	1930 - 1982	52	-50	-0.96	0.48
	1851 - 1982	131	-500	-3.82	0.19
63	1851 - 1930	79	-300	-3.80	0.32
	1930 - 1982	52	-25	-0.48	0.48
	1851 - 1982	131	-325	-2.48	0.19
64	1851 - 1930	79	-225	-2.85	0.32
	1930 - 1982	52	25	0.48	0.48
	1851 - 1982	131	-200	-1.53	0.19
65	1851 - 1930	79	-350	-4.43	0.32
	1930 - 1982	52	-50	-0.96	0.48
	1851 - 1982	131	-400	-3.05	0.19
66	1851 - 1930	79	-50	-0.63	0.32
	1930 - 1982	52	-150	-2.88	0.48
	1851 - 1982	131	-200	-1.53	0.19

EAST BAY

STATION	PERIOD	PERIOD LENGTH(YR)	DISTANCE (FT)	RATE (FT/YR)	RATE UNCERTAINTY (FT/YR)
1	1850 - 1930	80	900	11.25	0.31
	1930 - 1982	52	-900	-17.31	0.48
	1850 - 1982	132	0	0.00	0.19
2	1850 - 1930	80	1950	24.38	0.31
	1930 - 1982	52	-100	-1.92	0.48
	1850 - 1982	132	1850	14.02	0.19
3	1850 - 1930	80	-725	-9.06	0.31
	1930 - 1982	52	100	1.92	0.48
	1850 - 1982	132	-625	-4.73	0.19
4	1850 - 1930	80	-675	-8.44	0.31
	1930 - 1956	26	-200	-7.69	0.96
	1956 - 1974	18	-375	-20.83	1.39
	1974 - 1982	8	-125	-15.63	3.13
	1850 - 1982	132	-1375	-10.42	0.19
5	1850 - 1930	80	-775	-9.69	0.31
	1930 - 1956	26	150	5.77	0.96
	1956 - 1974	18	-75	-4.17	1.39
	1974 - 1982	8	0	0.00	3.13
	1850 - 1982	132	-700	-5.30	0.19
6	1851 - 1930	79	-550	-6.96	0.32
	1930 - 1982	52	225	4.33	0.48
	1851 - 1982	131	-325	-2.48	0.19
7	1851 - 1930	79	-550	-6.96	0.32
	1930 - 1982	52	375	7.21	0.48
	1851 - 1982	131	-175	-1.34	0.19
8	1851 - 1930	79	-350	-4.43	0.32
	1930 - 1982	52	-25	-0.48	0.48
	1851 - 1982	131	-375	-2.86	0.19
9	1851 - 1930	79	-150	-1.90	0.32
	1930 - 1982	52	-125	-2.40	0.48
	1851 - 1982	131	-275	-2.10	0.19
10	1851 - 1930	79	-275	-3.48	0.32
	1930 - 1956	26	-100	-3.85	0.96
	1956 - 1974	18	-125	-6.94	1.39
	1974 - 1982	8	-75	-9.38	3.13
	1851 - 1982	131	-575	-4.39	0.19
11	1851 - 1930	79	-50	-0.63	0.32
	1930 - 1956	26	-100	-3.85	0.96
	1956 - 1974	18	-100	-5.56	1.39
	1974 - 1982	8	-50	-6.25	3.13
	1851 - 1982	131	-300	-2.29	0.19

EAST BAY

STATION	PERIOD	PERIOD LENGTH(YR)	DISTANCE (FT)	RATE (FT/YR)	RATE UNCERTAINTY (FT/YR)
12	1851 - 1930	79	-350	-4.43	0.32
	1930 - 1956	26	-150	-5.77	0.96
	1956 - 1974	18	-150	-8.33	1.39
	1974 - 1982	8	-25	-3.13	3.13
	1851 - 1982	131	-675	-5.15	0.19
13	1851 - 1930	79	-400	-5.06	0.32
	1930 - 1956	26	-75	-2.88	0.96
	1956 - 1974	18	-25	-1.39	1.39
	1974 - 1982	8	-100	-12.50	3.13
	1851 - 1982	131	-600	-4.58	0.19
14	1851 - 1930	79	-150	-1.90	0.32
	1930 - 1956	26	-125	-4.81	0.96
	1956 - 1974	18	-75	-4.17	1.39
	1974 - 1982	8	-50	-6.25	3.13
	1851 - 1982	131	-400	-3.05	0.19
15	1851 - 1930	79	150	1.90	0.32
	1930 - 1982	52	-100	-1.92	0.48
	1851 - 1982	131	50	0.38	0.19
16	1851 - 1930	79	-125	-1.58	0.32
	1930 - 1982	52	-125	-2.40	0.48
	1851 - 1982	131	-250	-1.91	0.19
17	1851 - 1930	79	-175	-2.22	0.32
	1930 - 1956	26	-75	-2.88	0.96
	1956 - 1974	18	-125	-6.94	1.39
	1974 - 1982	8	-50	-6.25	3.13
	1851 - 1982	131	-425	-3.24	0.19
18	1851 - 1930	79	-250	-3.16	0.32
	1930 - 1956	26	-25	-0.96	0.96
	1956 - 1974	18	-100	-5.56	1.39
	1974 - 1982	8	0	0.00	3.13
	1851 - 1982	131	-375	-2.86	0.19
19	1851 - 1930	79	-50	-0.63	0.32
	1930 - 1982	52	-125	-2.40	0.48
	1851 - 1982	131	-175	-1.34	0.19
20	1851 - 1930	79	-100	-1.27	0.32
	1930 - 1982	52	-50	-0.96	0.48
	1851 - 1982	131	-150	-1.15	0.19
21	1851 - 1930	79	-150	-1.90	0.32
	1930 - 1982	52	-125	-2.40	0.48
	1851 - 1982	131	-275	-2.10	0.19

EAST BAY

STATION	PERIOD	PERIOD LENGTH(YR)	DISTANCE (FT)	RATE (FT/YR)	RATE UNCERTAINTY (FT/YR)
22	1851 - 1930	79	-75	-0.95	0.32
	1930 - 1982	52	-150	-2.88	0.48
	1851 - 1982	131	-225	-1.72	0.19
23	1851 - 1930	79	-50	-0.63	0.32
	1930 - 1982	52	-100	-1.92	0.48
	1851 - 1982	131	-150	-1.15	0.19
24	1851 - 1930	79	100	1.27	0.32
	1930 - 1982	52	-125	-2.40	0.48
	1851 - 1982	131	-25	-0.19	0.19
25	1851 - 1930	79	-400	-5.06	0.32
	1930 - 1982	52	-150	-2.88	0.48
	1851 - 1982	131	-550	-4.20	0.19
26	1851 - 1930	79	500	6.33	0.32
	1930 - 1982	52	75	1.44	0.48
	1851 - 1982	131	575	4.39	0.19
27	1851 - 1930	79	50	0.63	0.32
	1930 - 1982	52	100	1.92	0.48
	1851 - 1982	131	150	1.15	0.19
28	1851 - 1930	79	25	0.32	0.32
	1930 - 1982	52	-75	-1.44	0.48
	1851 - 1982	131	-50	-0.38	0.19
29	1851 - 1930	79	25	0.32	0.32
	1930 - 1982	52	-75	-1.44	0.48
	1851 - 1982	131	-50	-0.38	0.19
30	1851 - 1930	79	100	1.27	0.32
	1930 - 1982	52	0	0.00	0.48
	1851 - 1982	131	100	0.76	0.19
31	1851 - 1930	79	-225	-2.85	0.32
	1930 - 1982	52	125	2.40	0.48
	1851 - 1982	131	-100	-0.76	0.19
32	1851 - 1930	79	-75	-0.95	0.32
	1930 - 1982	52	-50	-0.96	0.48
	1851 - 1982	131	-125	-0.95	0.19
33	1851 - 1930	79	-125	-1.58	0.32
	1930 - 1982	52	0	0.00	0.48
	1851 - 1982	131	-125	-0.95	0.19
34	1851 - 1930	79	-25	-0.32	0.32
	1930 - 1982	52	-50	-0.96	0.48
	1851 - 1982	131	-75	-0.57	0.19

EAST BAY

STATION	PERIOD	PERIOD LENGTH(YR)	DISTANCE (FT)	RATE (FT/YR)	RATE UNCERTAINTY (FT/YR)
35	1851 - 1930	79	-125	-1.58	0.32
	1930 - 1982	52	-150	-2.88	0.48
	1851 - 1982	131	-275	-2.10	0.19
36	1851 - 1930	79	0	0.00	0.32
	1930 - 1974	44	0	0.00	0.57
	1851 - 1974	123	0	0.00	0.20
37	1851 - 1930	79	-300	-3.80	0.32
	1930 - 1974	44	-50	-1.14	0.57
	1851 - 1974	123	-350	-2.85	0.20
38	1851 - 1930	79	50	0.63	0.32
	1930 - 1974	44	-125	-2.84	0.57
	1851 - 1974	123	-75	-0.61	0.20
39	1851 - 1930	79	150	1.90	0.32
	1930 - 1982	52	-75	-1.44	0.48
	1851 - 1982	131	75	0.57	0.19
40	1851 - 1930	79	150	1.90	0.32
	1930 - 1982	52	-75	-1.44	0.48
	1851 - 1982	131	75	0.57	0.19
41	1851 - 1930	79	100	1.27	0.32
	1930 - 1956	26	0	0.00	0.96
	1956 - 1974	18	-100	-5.56	1.39
	1974 - 1982	8	-50	-6.25	3.13
	1851 - 1982	131	-50	-0.38	0.19
42	1851 - 1930	79	25	0.32	0.32
	1930 - 1956	26	-75	-2.88	0.96
	1956 - 1974	18	-25	-1.39	1.39
	1974 - 1982	8	-75	-9.38	3.13
	1851 - 1982	131	-150	-1.15	0.19
43	1851 - 1930	79	-50	-0.63	0.32
	1930 - 1982	52	-100	-1.92	0.48
	1851 - 1982	131	-150	-1.15	0.19
44	1851 - 1930	79	-250	-3.16	0.32
	1930 - 1982	52	-100	-1.92	0.48
	1851 - 1982	131	-350	-2.67	0.19
45	1851 - 1930	79	-375	-4.75	0.32
	1930 - 1982	52	-25	-0.48	0.48
	1851 - 1982	131	-400	-3.05	0.19
46	1851 - 1930	79	-250	-3.16	0.32
	1930 - 1982	52	-175	-3.37	0.48
	1851 - 1982	131	-425	-3.24	0.19

EAST BAY

STATION	PERIOD	PERIOD LENGTH(YR)	DISTANCE (FT)	RATE (FT/YR)	RATE UNCERTAINTY (FT/YR)
47	1851 - 1930	79	-50	-0.63	0.32
	1930 - 1956	26	-50	-1.92	0.96
	1956 - 1974	18	-100	-5.56	1.39
	1974 - 1982	8	-25	-3.13	3.13
	1851 - 1982	131	-225	-1.72	0.19
48	1851 - 1930	79	50	0.63	0.32
	1930 - 1956	26	-100	-3.85	0.96
	1956 - 1974	18	-50	-2.78	1.39
	1974 - 1982	8	-50	-6.25	3.13
	1851 - 1982	131	-150	-1.15	0.19
49	1851 - 1930	79	-375	-4.75	0.32
	1930 - 1956	26	-225	-8.65	0.96
	1956 - 1974	18	-125	-6.94	1.39
	1974 - 1982	8	-75	-9.38	3.13
	1851 - 1982	131	-800	-6.11	0.19
50	1851 - 1930	79	-500	-6.33	0.32
	1930 - 1956	26	0	0.00	0.96
	1956 - 1974	18	-100	-5.56	1.39
	1974 - 1982	8	-25	-3.13	3.13
	1851 - 1982	131	-625	-4.77	0.19
51	1851 - 1930	79	-250	-3.16	0.32
	1930 - 1982	52	-350	-6.73	0.48
	1851 - 1982	131	-600	-4.58	0.19
52	1851 - 1930	79	-525	-6.65	0.32
	1930 - 1956	26	-200	-7.69	0.96
	1956 - 1974	18	0	0.00	1.39
	1974 - 1982	8	50	6.25	3.13
	1851 - 1982	131	-675	-5.15	0.19
53	1851 - 1930	79	-250	-3.16	0.32
	1930 - 1956	26	-150	-5.77	0.96
	1956 - 1974	18	-25	-1.39	1.39
	1974 - 1982	8	0	0.00	3.13
	1851 - 1982	131	-425	-3.24	0.19
54	1851 - 1930	79	-100	-1.27	0.32
	1930 - 1956	26	-125	-4.81	0.96
	1956 - 1974	18	-100	-5.56	1.39
	1974 - 1982	8	-25	-3.13	3.13
	1851 - 1982	131	-350	-2.67	0.19
55	1851 - 1930	79	350	4.43	0.32
	1930 - 1956	26	-225	-8.65	0.96
	1956 - 1974	18	-50	-2.78	1.39
	1974 - 1982	8	0	0.00	3.13
	1851 - 1982	131	75	0.57	0.19

GALVESTON BAY

STATION	PERIOD	PERIOD LENGTH(YR)	DISTANCE (FT)	RATE (FT/YR)	RATE UNCERTAINTY (FT/YR)
1	1851 - 1930	79	950	12.03	0.32
	1930 - 1982	52	-1975	-37.98	0.48
	1851 - 1982	131	-1025	-7.82	0.19
2	1851 - 1930	79	-250	-3.16	0.32
	1930 - 1982	52	-175	-3.37	0.48
	1851 - 1982	131	-425	-3.24	0.19
3	1851 - 1930	79	125	1.58	0.32
	1930 - 1982	52	-125	-2.40	0.48
	1851 - 1982	131	0	0.00	0.19
4	1851 - 1930	79	-125	-1.58	0.32
	1930 - 1982	52	-175	-3.37	0.48
	1851 - 1982	131	-300	-2.29	0.19
5	1851 - 1930	79	-200	-2.53	0.32
	1930 - 1982	52	-250	-4.81	0.48
	1851 - 1982	131	-450	-3.44	0.19
6	1851 - 1930	79	25	0.32	0.32
	1930 - 1982	52	-1375	-26.44	0.48
	1851 - 1982	131	-1350	-10.31	0.19
7	1851 - 1930	79	-1050	-13.29	0.32
	1930 - 1982	52	-400	-7.69	0.48
	1851 - 1982	131	-1450	-11.07	0.19
8	1851 - 1930	79	-950	-12.03	0.32
	1930 - 1982	52	-50	-0.96	0.48
	1851 - 1982	131	-1000	-7.63	0.19
9	1851 - 1930	79	-150	-1.90	0.32
	1930 - 1982	52	-250	-4.81	0.48
	1851 - 1982	131	-400	-3.05	0.19
10	1851 - 1930	79	-450	-5.70	0.32
	1930 - 1982	52	750	14.42	0.48
	1851 - 1982	131	300	2.29	0.19
11	1851 - 1930	79	0	0.00	0.32
	1930 - 1982	52	0	0.00	0.48
	1851 - 1982	131	0	0.00	0.19
12	1851 - 1930	79	-300	-3.80	0.32
	1930 - 1982	52	0	0.00	0.48
	1851 - 1982	131	-300	-2.29	0.19
13	1851 - 1930	79	-375	-4.75	0.32
	1930 - 1982	52	25	0.48	0.48
	1851 - 1982	131	-350	-2.67	0.19

GALVESTON BAY

STATION	PERIOD	PERIOD LENGTH(YR)	DISTANCE (FT)	RATE (FT/YR)	RATE UNCERTAINTY (FT/YR)
14	1851 - 1930	79	0	0.00	0.32
	1930 - 1982	52	-75	-1.44	0.48
	1851 - 1982	131	-75	-0.57	0.19
15	1850 - 1930	80	0	0.00	0.31
	1930 - 1982	52	0	0.00	0.48
	1850 - 1982	132	0	0.00	0.19
16	1850 - 1930	80	0	0.00	0.31
	1930 - 1982	52	0	0.00	0.48
	1850 - 1982	132	0	0.00	0.19
17	1850 - 1930	80	0	0.00	0.31
	1930 - 1982	52	-50	-0.96	0.48
	1850 - 1982	132	-50	-0.38	0.19
18	1850 - 1930	80	-475	-5.94	0.31
	1930 - 1982	52	-150	-2.88	0.48
	1850 - 1982	132	-625	-4.73	0.19
19	1850 - 1930	80	-100	-1.25	0.31
	1930 - 1982	52	-725	-13.94	0.48
	1850 - 1982	132	-825	-6.25	0.19
20	1850 - 1930	80	-200	-2.50	0.31
	1930 - 1982	52	-150	-2.88	0.48
	1850 - 1982	132	-350	-2.65	0.19
21	1850 - 1930	80	-100	-1.25	0.31
	1930 - 1982	52	-25	-0.48	0.48
	1850 - 1982	132	-125	-0.95	0.19
22	1850 - 1930	80	-175	-2.19	0.31
	1930 - 1982	52	0	0.00	0.48
	1850 - 1982	132	-175	-1.33	0.19
23	1850 - 1930	80	-200	-2.50	0.31
	1930 - 1982	52	-25	-0.48	0.48
	1850 - 1982	132	-225	-1.70	0.19
24	1850 - 1930	80	-125	-1.56	0.31
	1930 - 1982	52	0	0.00	0.48
	1850 - 1982	132	-125	-0.95	0.19
25	1850 - 1930	80	-50	-0.63	0.31
	1930 - 1982	52	0	0.00	0.48
	1850 - 1982	132	-50	-0.38	0.19
26	1850 - 1930	80	-75	-0.94	0.31
	1930 - 1982	52	-50	-0.96	0.48
	1850 - 1982	132	-125	-0.95	0.19

GALVESTON BAY

STATION	PERIOD	PERIOD LENGTH(YR)	DISTANCE (FT)	RATE (FT/YR)	RATE UNCERTAINTY (FT/YR)
27	1850 - 1930	80	-100	-1.25	0.31
	1930 - 1982	52	-50	-0.96	0.48
	1850 - 1982	132	-150	-1.14	0.19
28	1850 - 1930	80	-75	-0.94	0.31
	1930 - 1982	52	-250	-4.81	0.48
	1850 - 1982	132	-325	-2.46	0.19
29	1850 - 1930	80	-250	-3.13	0.31
	1930 - 1982	52	-75	-1.44	0.48
	1850 - 1982	132	-325	-2.46	0.19
30	1850 - 1930	80	-175	-2.19	0.31
	1930 - 1982	52	-25	-0.48	0.48
	1850 - 1982	132	-200	-1.52	0.19
31	1850 - 1930	80	-200	-2.50	0.31
	1930 - 1982	52	-150	-2.88	0.48
	1850 - 1982	132	-350	-2.65	0.19
32	1850 - 1930	80	-150	-1.88	0.31
	1930 - 1982	52	-200	-3.85	0.48
	1850 - 1982	132	-350	-2.65	0.19
33	1850 - 1930	80	-600	-7.50	0.31
	1930 - 1982	52	-300	-5.77	0.48
	1850 - 1982	132	-900	-6.82	0.19
34	1850 - 1930	80	-175	-2.19	0.31
	1930 - 1982	52	0	0.00	0.48
	1850 - 1982	132	-175	-1.33	0.19
35	1850 - 1930	80	-150	-1.88	0.31
	1930 - 1982	52	-150	-2.88	0.48
	1850 - 1982	132	-300	-2.27	0.19
36	1850 - 1930	80	-125	-1.56	0.31
	1930 - 1982	52	-100	-1.92	0.48
	1850 - 1982	132	-225	-1.70	0.19
37	1850 - 1930	80	-250	-3.13	0.31
	1930 - 1982	52	-225	-4.33	0.48
	1850 - 1982	132	-475	-3.60	0.19
38	1850 - 1930	80	-200	-2.50	0.31
39	1850 - 1930	80	-200	-2.50	0.31
40	1850 - 1930	80	-75	-0.94	0.31
41	1850 - 1930	80	100	1.25	0.31

GALVESTON BAY

STATION	PERIOD	PERIOD LENGTH(YR)	DISTANCE (FT)	RATE (FT/YR)	RATE UNCERTAINTY (FT/YR)
42	1850 - 1930	80	175	2.19	0.31
43	1850 - 1930	80	-150	-1.88	0.31
44	1850 - 1930	80	-50	-0.63	0.31
45	1850 - 1930	80	-350	-4.38	0.31
46	1850 - 1930	80	100	1.25	0.31
47	1850 - 1930	80	-375	-4.69	0.31
	1930 - 1982	52	-625	-12.02	0.48
	1850 - 1982	132	-1000	-7.58	0.19
48	1850 - 1930	80	-150	-1.88	0.31
	1930 - 1982	52	-500	-9.62	0.48
	1850 - 1982	132	-650	-4.92	0.19
49	1850 - 1930	80	-250	-3.13	0.31
	1930 - 1982	52	-175	-3.37	0.48
	1850 - 1982	132	-425	-3.22	0.19
50	1850 - 1930	80	-400	-5.00	0.31
	1930 - 1982	52	-225	-4.33	0.48
	1850 - 1982	132	-625	-4.73	0.19
51	1850 - 1930	80	-225	-2.81	0.31
	1930 - 1982	52	700	13.46	0.48
	1850 - 1982	132	475	3.60	0.19
52	1850 - 1930	80	-325	-4.06	0.31
	1930 - 1982	52	1125	21.63	0.48
	1850 - 1982	132	800	6.06	0.19
53	1850 - 1930	80	1150	14.38	0.31
	1930 - 1982	52	-50	-0.96	0.48
	1850 - 1982	132	1100	8.33	0.19
54	1850 - 1930	80	-150	-1.88	0.31
	1930 - 1956	26	-25	-0.96	0.96
	1956 - 1974	18	-150	-8.33	1.39
	1974 - 1982	8	-25	-3.13	3.13
	1850 - 1982	132	-350	-2.65	0.19
55	1850 - 1930	80	-225	-2.81	0.31
	1930 - 1956	26	-25	-0.96	0.96
	1956 - 1974	18	-75	-4.17	1.39
	1974 - 1982	8	-175	-21.88	3.13
	1850 - 1982	132	-500	-3.79	0.19

GALVESTON BAY

STATION	PERIOD	PERIOD LENGTH(YR)	DISTANCE (FT)	RATE (FT/YR)	RATE UNCERTAINTY (FT/YR)
56	1850 - 1930	80	-175	-2.19	0.31
	1930 - 1956	26	-200	-7.69	0.96
	1956 - 1974	18	0	0.00	1.39
	1974 - 1982	8	-25	-3.13	3.13
	1850 - 1982	132	-400	-3.03	0.19
57	1850 - 1930	80	-450	-5.63	0.31
	1930 - 1956	26	-400	-15.38	0.96
	1956 - 1974	18	75	4.17	1.39
	1974 - 1982	8	-150	-18.75	3.13
	1850 - 1982	132	-925	-7.01	0.19
58	1850 - 1930	80	-50	-0.63	0.31
	1930 - 1956	26	-275	-10.58	0.96
	1956 - 1974	18	0	0.00	1.39
	1974 - 1982	8	0	0.00	3.13
	1850 - 1982	132	-325	-2.46	0.19

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STATION	PERIOD	PERIOD LENGTH(YR)	DISTANCE (FT)	RATE (FT/YR)	RATE UNCERTAINTY (FT/YR)
1	1850 - 1930	80	-250	-3.13	0.31
	1930 - 1982	52	0	0.00	0.48
	1850 - 1982	132	-250	-1.89	0.19
2	1850 - 1930	80	-250	-3.13	0.31
	1930 - 1982	52	-50	-0.96	0.48
	1850 - 1982	132	-300	-2.27	0.19
3	1850 - 1930	80	450	5.63	0.31
	1930 - 1982	52	-175	-3.37	0.48
	1850 - 1982	132	275	2.08	0.19
4	1850 - 1930	80	225	2.81	0.31
	1930 - 1982	52	-100	-1.92	0.48
	1850 - 1982	132	125	0.95	0.19
5	1850 - 1930	80	-475	-5.94	0.31
	1930 - 1982	52	100	1.92	0.48
	1850 - 1982	132	-375	-2.84	0.19
6	1850 - 1930	80	-225	-2.81	0.31
	1930 - 1956	26	-125	-4.81	0.96
	1956 - 1974	18	-25	-1.39	1.39
	1974 - 1982	8	-25	-3.13	3.13
	1850 - 1982	132	-400	-3.03	0.19
7	1850 - 1930	80	-225	-2.81	0.31
	1930 - 1956	26	-225	-8.65	0.96
	1956 - 1974	18	0	0.00	1.39
	1974 - 1982	8	0	0.00	3.13
	1850 - 1982	132	-450	-3.41	0.19
8	1851 - 1930	79	-225	-2.85	0.32
	1930 - 1956	26	75	2.88	0.96
	1956 - 1974	18	-200	-11.11	1.39
	1974 - 1982	8	-100	-12.50	3.13
	1851 - 1982	131	-450	-3.44	0.19
9	1851 - 1930	79	-175	-2.22	0.32
	1930 - 1956	26	-50	-1.92	0.96
	1956 - 1974	18	-125	-6.94	1.39
	1974 - 1982	8	0	0.00	3.13
	1851 - 1982	131	-350	-2.67	0.19
10	1851 - 1930	79	-375	-4.75	0.32
	1930 - 1982	52	575	11.06	0.48
	1851 - 1982	131	200	1.53	0.19
11	1851 - 1930	79	-300	-3.80	0.32
	1930 - 1982	52	575	11.06	0.48
	1851 - 1982	131	275	2.10	0.19

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STATION	PERIOD	PERIOD LENGTH(YR)	DISTANCE (FT)	RATE (FT/YR)	RATE UNCERTAINTY (FT/YR)
11A	1851 - 1930	79	-300	-3.80	0.32
	1930 - 1982	52	-375	-7.21	0.48
	1851 - 1982	131	-675	-5.15	0.19
12	1851 - 1930	79	-500	-6.33	0.32
	1930 - 1982	52	-500	-9.62	0.48
	1851 - 1982	131	-1000	-7.63	0.19
13	1851 - 1930	79	-325	-4.11	0.32
	1930 - 1982	52	-150	-2.88	0.48
	1851 - 1982	131	-475	-3.63	0.19
14	1851 - 1930	79	-225	-2.85	0.32
	1930 - 1982	52	-275	-5.29	0.48
	1851 - 1982	131	-500	-3.82	0.19
15	1851 - 1930	79	-50	-0.63	0.32
	1930 - 1982	52	275	5.29	0.48
	1851 - 1982	131	225	1.72	0.19
16	1851 - 1930	79	-200	-2.53	0.32
	1930 - 1974	44	50	1.14	0.57
	1974 - 1982	8	-50	-6.25	3.13
	1851 - 1982	131	-200	-1.53	0.19
17	1851 - 1930	79	-600	-7.59	0.32
	1930 - 1956	26	-175	-6.73	0.96
	1956 - 1974	18	-50	-2.78	1.39
	1974 - 1982	8	-75	-9.38	3.13
	1851 - 1982	131	-900	-6.87	0.19
18	1851 - 1930	79	125	1.58	0.32
	1930 - 1982	52	350	6.73	0.48
	1851 - 1982	131	475	3.63	0.19
18A	1851 - 1930	79	125	1.58	0.32
	1930 - 1982	52	-425	-8.17	0.48
	1851 - 1982	131	-300	-2.29	0.19
19	1851 - 1930	79	-200	-2.53	0.32
	1930 - 1982	52	200	3.85	0.48
	1851 - 1982	131	0	0.00	0.19
20	1852 - 1930	78	-50	-0.64	0.32
	1930 - 1982	52	100	1.92	0.48
	1852 - 1982	130	50	0.38	0.19
21	1852 - 1930	78	-50	-0.64	0.32
	1930 - 1982	52	-575	-11.06	0.48
	1852 - 1982	130	-625	-4.81	0.19

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STATION	PERIOD	PERIOD LENGTH(YR)	DISTANCE (FT)	RATE (FT/YR)	RATE UNCERTAINTY (FT/YR)
22	1852 - 1930	78	-425	-5.45	0.32
	1930 - 1982	52	-225	-4.33	0.48
	1852 - 1982	130	-650	-5.00	0.19
23	1852 - 1930	78	-125	-1.60	0.32
	1930 - 1982	52	100	1.92	0.48
	1852 - 1982	130	-25	-0.19	0.19
24	1852 - 1930	78	-200	-2.56	0.32
	1930 - 1982	52	0	0.00	0.48
	1852 - 1982	130	-200	-1.54	0.19
25	1852 - 1930	78	-150	-1.92	0.32
	1930 - 1982	52	-125	-2.40	0.48
	1852 - 1982	130	-275	-2.12	0.19
26	1852 - 1930	78	-125	-1.60	0.32
	1930 - 1982	52	-200	-3.85	0.48
	1852 - 1982	130	-325	-2.50	0.19
27	1852 - 1930	78	-100	-1.28	0.32
	1930 - 1982	52	-25	-0.48	0.48
	1852 - 1982	130	-125	-0.96	0.19
28	1852 - 1930	78	-50	-0.64	0.32
	1930 - 1982	52	0	0.00	0.48
	1852 - 1982	130	-50	-0.38	0.19
29	1852 - 1930	78	-250	-3.21	0.32
	1930 - 1982	52	-50	-0.96	0.48
	1852 - 1982	130	-300	-2.31	0.19
30	1852 - 1930	78	-50	-0.64	0.32
	1930 - 1982	52	0	0.00	0.48
	1852 - 1982	130	-50	-0.38	0.19
31	1852 - 1930	78	200	2.56	0.32
	1930 - 1982	52	-75	-1.44	0.48
	1852 - 1982	130	125	0.96	0.19
32	1852 - 1930	78	-175	-2.24	0.32
	1930 - 1982	52	0	0.00	0.48
	1852 - 1982	130	-175	-1.35	0.19
33	1852 - 1930	78	-175	-2.24	0.32
	1930 - 1982	52	-200	-3.85	0.48
	1852 - 1982	130	-375	-2.88	0.19
34	1852 - 1930	78	-100	-1.28	0.32
	1930 - 1982	52	-75	-1.44	0.48
	1852 - 1982	130	-175	-1.35	0.19

STATION	PERIOD	PERIOD LENGTH(YR)	DISTANCE (FT)	RATE (FT/YR)	UNCERTAINTY (FT/YR)
35	1852 - 1930	78	-25	-0.32	0.32
	1930 - 1956	26	-200	-7.69	0.96
	1956 - 1982	26	0	0.00	0.96
	1852 - 1982	130	-225	-1.73	0.19
36	1852 - 1930	78	0	0.00	0.32
	1930 - 1956	26	-150	-5.77	0.96
	1956 - 1974	18	0	0.00	1.39
	1974 - 1982	8	-125	-15.63	3.13
	1852 - 1982	130	-275	-2.12	0.19
37	1852 - 1930	78	0	0.00	0.32
	1930 - 1956	26	-275	-10.58	0.96
	1956 - 1974	18	-75	-4.17	1.39
	1974 - 1982	8	-25	-3.13	3.13
	1852 - 1982	130	-375	-2.88	0.19
38	1852 - 1930	78	0	0.00	0.32
	1930 - 1956	26	-100	-3.85	0.96
	1956 - 1974	18	-75	-4.17	1.39
	1974 - 1982	8	-100	-12.50	3.13
	1852 - 1982	130	-275	-2.12	0.19
39	1852 - 1930	78	850	10.90	0.32
	1930 - 1956	26	-100	-3.85	0.96
	1956 - 1974	18	-125	-6.94	1.39
	1974 - 1982	8	-175	-21.88	3.13
	1852 - 1982	130	450	3.46	0.19
40	1852 - 1930	78	100	1.28	0.32
	1930 - 1956	26	-25	-0.96	0.96
	1956 - 1974	18	-75	-4.17	1.39
	1974 - 1982	8	-100	-12.50	3.13
	1852 - 1982	130	-100	-0.77	0.19
41	1852 - 1930	78	-350	-4.49	0.32
	1930 - 1956	26	-25	-0.96	0.96
	1956 - 1974	18	-325	-18.06	1.39
	1974 - 1982	8	-125	-15.63	3.13
	1852 - 1982	130	-825	-6.35	0.19
42	1852 - 1930	78	-300	-3.85	0.32
	1930 - 1956	26	0	0.00	0.96
	1956 - 1974	18	0	0.00	1.39
	1974 - 1982	8	-100	-12.50	3.13
	1852 - 1982	130	-400	-3.08	0.19
43	1852 - 1930	78	-225	-2.88	0.32
	1930 - 1956	26	-150	-5.77	0.96
	1956 - 1974	18	-75	-4.17	1.39
	1974 - 1982	8	-25	-3.13	3.13
	1852 - 1982	130	-475	-3.65	0.19

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STATION	PERIOD	PERIOD LENGTH(YR)	DISTANCE (FT)	RATE (FT/YR)	RATE UNCERTAINTY (FT/YR)
44	1852 - 1930	78	100	1.28	0.32
	1930 - 1982	52	-425	-8.17	0.48
	1852 - 1982	130	-325	-2.50	0.19
45	1852 - 1930	78	-300	-3.85	0.32
	1930 - 1982	52	0	0.00	0.48
	1852 - 1982	130	-300	-2.31	0.19
46	1852 - 1930	78	-75	-0.96	0.32
	1930 - 1982	52	-25	-0.48	0.48
	1852 - 1982	130	-100	-0.77	0.19
47	1852 - 1930	78	0	0.00	0.32
	1930 - 1982	52	-125	-2.40	0.48
	1852 - 1982	130	-125	-0.96	0.19
48	1852 - 1930	78	-50	-0.64	0.32
	1930 - 1982	52	-25	-0.48	0.48
	1852 - 1982	130	-75	-0.58	0.19
49	1852 - 1930	78	-225	-2.88	0.32
	1930 - 1956	26	-100	-3.85	0.96
	1852 - 1982	130	-325	-2.50	0.19
50	1852 - 1930	78	-150	-1.92	0.32
	1930 - 1956	26	-100	-3.85	0.96
	1852 - 1982	130	-250	-1.92	0.19
51	1852 - 1930	78	-200	-2.56	0.32
	1930 - 1982	52	-150	-2.88	0.48
	1852 - 1982	130	-350	-2.69	0.19
52	1852 - 1930	78	-250	-3.21	0.32
	1930 - 1982	52	-200	-3.85	0.48
	1852 - 1982	130	-450	-3.46	0.19
53	1852 - 1930	78	-350	-4.49	0.32
	1930 - 1956	26	25	0.96	0.96
	1956 - 1974	18	-50	-2.78	1.39
	1974 - 1982	8	-50	-6.25	3.13
	1852 - 1982	130	-425	-3.27	0.19
54	1852 - 1930	78	-250	-3.21	0.32
	1930 - 1956	26	-100	-3.85	0.96
	1956 - 1974	18	-200	-11.11	1.39
	1974 - 1982	8	0	0.00	3.13
	1852 - 1982	130	-550	-4.23	0.19
55	1852 - 1930	78	-250	-3.21	0.32
	1930 - 1982	52	-75	-1.44	0.48
	1852 - 1982	130	-325	-2.50	0.19

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STATION	PERIOD	PERIOD LENGTH(YR)	DISTANCE (FT)	RATE (FT/YR)	RATE UNCERTAINTY (FT/YR)
56	1852 - 1930	78	-125	-1.60	0.32
	1930 - 1982	52	-125	-2.40	0.48
	1852 - 1982	130	-250	-1.92	0.19
57	1852 - 1930	78	-250	-3.21	0.32
	1930 - 1982	52	-25	-0.48	0.48
	1852 - 1982	130	-275	-2.12	0.19
58	1852 - 1930	78	-75	-0.96	0.32
	1930 - 1982	52	-25	-0.48	0.48
	1852 - 1982	130	-100	-0.77	0.19
59	1852 - 1930	78	-50	-0.64	0.32
	1930 - 1982	52	325	6.25	0.48
	1852 - 1982	130	275	2.12	0.19
60	1852 - 1930	78	-175	-2.24	0.32
	1930 - 1982	52	-75	-1.44	0.48
	1852 - 1982	130	-250	-1.92	0.19
61	1852 - 1930	78	150	1.92	0.32
	1930 - 1974	44	0	0.00	0.57
	1852 - 1982	130	150	1.15	0.19
62	1852 - 1930	78	-100	-1.28	0.32
	1930 - 1956	26	-25	-0.96	0.96
	1852 - 1982	130	-125	-0.96	0.19
63	1852 - 1930	78	125	1.60	0.32
	1930 - 1982	52	200	3.85	0.48
	1852 - 1982	130	325	2.50	0.19
64	1852 - 1930	78	-50	-0.64	0.32
	1930 - 1982	52	-125	-2.40	0.48
	1852 - 1982	130	-175	-1.35	0.19
65	1852 - 1930	78	500	6.41	0.32
	1930 - 1982	52	-75	-1.44	0.48
	1852 - 1982	130	425	3.27	0.19
66	1852 - 1930	78	25	0.32	0.32
	1930 - 1982	52	25	0.48	0.48
	1852 - 1982	130	50	0.38	0.19
67	1852 - 1930	78	100	1.28	0.32
	1930 - 1982	52	-25	-0.48	0.48
	1852 - 1982	130	75	0.58	0.19
68	1852 - 1930	78	100	1.28	0.32
	1930 - 1982	52	-100	-1.92	0.48
	1852 - 1982	130	0	0.00	0.19

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STATION	PERIOD	PERIOD LENGTH(YR)	DISTANCE (FT)	RATE (FT/YR)	RATE UNCERTAINTY (FT/YR)
69	1852 - 1930	78	0	0.00	0.32
	1930 - 1982	52	0	0.00	0.48
	1852 - 1982	130	0	0.00	0.19
70	1852 - 1930	78	-350	-4.49	0.32
	1930 - 1982	52	-100	-1.92	0.48
	1852 - 1982	130	-450	-3.46	0.19
71	1852 - 1930	78	-200	-2.56	0.32
	1930 - 1982	52	0	0.00	0.48
	1852 - 1982	130	-200	-1.54	0.19
72	1852 - 1930	78	-100	-1.28	0.32
	1930 - 1982	52	-100	-1.92	0.48
	1852 - 1982	130	-200	-1.54	0.19
73	1852 - 1930	78	150	1.92	0.32
	1930 - 1982	52	-75	-1.44	0.48
	1852 - 1982	130	75	0.58	0.19
74	1852 - 1930	78	-200	-2.56	0.32
	1930 - 1982	52	-175	-3.37	0.48
	1852 - 1982	130	-375	-2.88	0.19
75	1852 - 1930	78	0	0.00	0.32
	1930 - 1982	52	0	0.00	0.48
	1852 - 1982	130	0	0.00	0.19
76	1852 - 1930	78	250	3.21	0.32
	1930 - 1982	52	-175	-3.37	0.48
	1852 - 1982	130	75	0.58	0.19
77	1852 - 1930	78	-1550	-19.87	0.32
	1930 - 1982	52	-450	-8.65	0.48
	1852 - 1982	130	-2000	-15.38	0.19
78	1852 - 1930	78	NA	NA	0.32
	1930 - 1982	52	25	0.48	0.48
	1852 - 1982	130	NA	NA	0.19
79	1852 - 1930	78	NA	NA	0.32
	1930 - 1982	52	-75	-1.44	0.48
	1852 - 1982	130	NA	NA	0.19
80	1852 - 1930	78	NA	NA	0.32
	1930 - 1956	26	0	0.00	0.96
	1956 - 1982	26	-125	-4.81	0.96
	1852 - 1982	130	NA	NA	0.19

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STATION	PERIOD	PERIOD LENGTH(YR)	DISTANCE (FT)	RATE (FT/YR)	RATE UNCERTAINTY (FT/YR)
81	1852 - 1930	78	-200	-2.56	0.32
	1930 - 1956	26	-325	-12.50	0.96
	1956 - 1982	26	100	3.85	0.96
	1852 - 1982	130	-425	-3.27	0.19
81A	1852 - 1930	78	-100	-1.28	0.32
	1930 - 1956	26	-50	-1.92	0.96
	1956 - 1982	26	-500	-19.23	0.96
	1852 - 1982	130	-650	-5.00	0.19
82	1852 - 1930	78	525	6.73	0.32
	1930 - 1956	26	-100	-3.85	0.96
	1956 - 1982	26	-100	-3.85	0.96
	1852 - 1982	130	325	2.50	0.19
83	1852 - 1930	78	350	4.49	0.32
	1930 - 1956	26	-250	-9.62	0.96
	1956 - 1982	26	0	0.00	0.96
	1852 - 1982	130	100	0.77	0.19
84	1852 - 1930	78	-150	-1.92	0.32
	1930 - 1956	26	-50	-1.92	0.96
	1956 - 1982	26	-75	-2.88	0.96
	1852 - 1982	130	-275	-2.12	0.19
85	1851 - 1930	79	225	2.85	0.32
	1930 - 1982	52	-350	-6.73	0.48
	1851 - 1982	131	-500	-3.82	0.19
86	1851 - 1930	79	0	0.00	0.32
	1930 - 1982	52	-250	-4.81	0.48
	1851 - 1982	131	-250	-1.91	0.19
87	1851 - 1930	79	-100	-1.27	0.32
	1930 - 1982	52	-100	-1.92	0.48
	1851 - 1982	131	-200	-1.53	0.19
88	1851 - 1930	79	-175	-2.22	0.32
	1930 - 1982	52	-25	-0.48	0.48
	1851 - 1982	131	-200	-1.53	0.19
89	1851 - 1930	79	-50	-0.63	0.32
	1930 - 1982	52	-225	-4.33	0.48
	1851 - 1982	131	-275	-2.10	0.19
90	1851 - 1930	79	-25	-0.32	0.32
	1930 - 1982	52	-200	-3.85	0.48
	1851 - 1982	131	-225	-1.72	0.19
91	1851 - 1930	79	-100	-1.27	0.32
	1930 - 1982	52	-350	-6.73	0.48
	1851 - 1982	131	-450	-3.44	0.19

WEST BAY

STATION	PERIOD	PERIOD LENGTH(YR)	DISTANCE (FT)	RATE (FT/YR)	RATE UNCERTAINTY (FT/YR)
92	1851 - 1930	79	100	1.27	0.32
	1930 - 1982	52	-50	-0.96	0.48
	1851 - 1982	131	50	0.38	0.19
93	1851 - 1930	79	-175	-2.22	0.32
	1930 - 1956	26	-175	-6.73	0.96
	1956 - 1974	18	-25	-1.39	1.39
	1974 - 1982	8	-125	-15.63	3.13
	1851 - 1982	131	-500	-3.82	0.19
94	1851 - 1930	79	-50	-0.63	0.32
	1930 - 1982	52	-100	-1.92	0.48
	1851 - 1982	131	-150	-1.15	0.19
95	1851 - 1930	79	0	0.00	0.32
	1930 - 1956	26	-25	-0.96	0.96
	1956 - 1982	26	-100	-3.85	0.96
	1851 - 1982	131	-125	-0.95	0.19
96	1851 - 1930	79	50	0.63	0.32
	1930 - 1982	52	-200	-3.85	0.48
	1851 - 1982	131	-150	-1.15	0.19
97	1851 - 1930	79	-50	-0.63	0.32
	1930 - 1982	52	-100	-1.92	0.48
	1851 - 1982	131	-150	-1.15	0.19
98	1851 - 1930	79	-250	-3.16	0.32
	1930 - 1956	26	-50	-1.92	0.96
	1956 - 1982	26	-125	-4.81	0.96
	1851 - 1982	131	-425	-3.24	0.19
99	1851 - 1930	79	-100	-1.27	0.32
	1930 - 1982	52	-75	-1.44	0.48
	1851 - 1982	131	-175	-1.34	0.19
100	1851 - 1930	79	-125	-1.58	0.32
	1930 - 1982	52	-150	-2.88	0.48
	1851 - 1982	131	-275	-2.10	0.19
101	1851 - 1930	79	-100	-1.27	0.32
	1930 - 1982	52	0	0.00	0.48
	1851 - 1982	131	-100	-0.76	0.19
102	1851 - 1930	79	-150	-1.90	0.32
	1930 - 1982	52	-125	-2.40	0.48
	1851 - 1982	131	-275	-2.10	0.19

WEST BAY

STATION	PERIOD	PERIOD LENGTH(YR)	DISTANCE (FT)	RATE (FT/YR)	RATE UNCERTAINTY (FT/YR)
103	1851 - 1930	79	0	0.00	0.32
	1930 - 1956	26	0	0.00	0.96
	1956 - 1974	18	0	0.00	1.39
	1974 - 1982	8	25	3.13	3.13
	1851 - 1982	131	25	0.19	0.19
104	1851 - 1930	79	-100	-1.27	0.32
	1930 - 1956	26	-150	-5.77	0.96
	1956 - 1974	18	-50	-2.78	1.39
	1974 - 1982	8	-75	-9.38	3.13
	1851 - 1982	131	-375	-2.86	0.19
105	1851 - 1930	79	50	0.63	0.32
	1930 - 1982	52	-125	-2.40	0.48
	1851 - 1982	131	-75	-0.57	0.19
106	1851 - 1930	79	-100	-1.27	0.32
	1930 - 1982	52	-150	-2.88	0.48
	1851 - 1982	131	-250	-1.91	0.19
107	1851 - 1930	79	-2200	-27.85	0.32
	1930 - 1982	52	25	0.48	0.48
	1851 - 1982	131	-2175	-16.60	0.19
108	1851 - 1930	79	-1925	-24.37	0.32
	1930 - 1982	52	125	2.40	0.48
	1851 - 1982	131	-1800	-13.74	0.19
109	1851 - 1930	79	-275	-3.48	0.32
	1930 - 1974	44	0	0.00	0.57
	1851 - 1982	131	-275	-2.10	0.19
110	1851 - 1930	79	-150	-1.90	0.32
	1930 - 1956	26	-75	-2.88	0.96
	1851 - 1982	131	-225	-1.72	0.19
111	1851 - 1930	79	-250	-3.16	0.32
	1930 - 1982	52	-50	-0.96	0.48
	1851 - 1982	131	-300	-2.29	0.19
112	1851 - 1930	79	125	1.58	0.32
	1930 - 1982	52	NA	NA	0.48
	1851 - 1982	131	NA	NA	0.19
113	1851 - 1930	79	350	4.43	0.32
	1930 - 1982	52	-175	-3.37	0.48
	1851 - 1982	131	175	1.34	0.19
114	1851 - 1930	79	-300	-3.80	0.32
	1930 - 1982	52	-175	-3.37	0.48
	1851 - 1982	131	-475	-3.63	0.19

WEST BAY

STATION	PERIOD	PERIOD LENGTH(YR)	DISTANCE (FT)	RATE (FT/YR)	RATE UNCERTAINTY (FT/YR)
115	1850 - 1930	80	-850	-10.63	0.31
	1930 - 1982	52	900	17.31	0.48
	1850 - 1982	132	50	0.38	0.19
116	1850 - 1930	80	2375	29.69	0.31
	1930 - 1982	52	0	0.00	0.48
	1850 - 1982	132	2375	17.99	0.19
117	1850 - 1930	80	625	7.81	0.31
	1930 - 1982	52	0	0.00	0.48
	1850 - 1982	132	625	4.73	0.19
118	1850 - 1930	80	350	4.38	0.31
	1930 - 1982	52	0	0.00	0.48
	1850 - 1982	132	350	2.65	0.19
119	1850 - 1930	80	250	3.13	0.31
	1930 - 1982	52	775	14.90	0.48
	1850 - 1982	132	1025	7.77	0.19
120	1850 - 1930	80	425	5.31	0.31
	1930 - 1982	52	25	0.48	0.48
	1850 - 1982	132	450	3.41	0.19
121	1850 - 1930	80	975	12.19	0.31
	1930 - 1982	52	100	1.92	0.48
	1850 - 1982	132	1075	8.14	0.19

APPENDIX B. Summary of Historical Changes, San Antonio Bay System.

Point	Time	Dist. ft	Rate ft per yr	Time	Dist. ft	Rate ft per yr	Time	Dist. ft	Rate ft per yr	Time	Dist. ft	Rate ft per yr	Net Time	Net Dist.	Net Rate
1	1857-1937	-220	-2.7	1937-1974			1974-1982			1937-1982	-40	-0.6	1857-1982	-260	-2.1
2	"	-160	-2.0	"			"			"	-20	-0.5	"	-180	-1.4
3	"	-20	-0.2	"			"			"	+40	+0.9	"	+20	+0.2
4	1859-1937	-180	-2.3	"			"			"	-80	-1.8	1859-1982	-260	-2.1
5	"	-310	-3.9	"	-160	-4.4	"	0	0	"	-160	-3.6	"	-470	-3.8
6	"	-300	-3.8	"	-130	-3.0	"	0	0	"	-130	-3.0	"	-430	-3.5
7	"	-140	-1.8	"	0	0	"	+30	+3.8	"	+30	+0.7	"	-110	-0.9
8	"	-160	-2.0	"	-40	-2.0	"	-50	-6.3	"	-90	-2.0	"	-250	-2.0
9	"	+30	+0.4	"	-20	-0.6	"	0	0	"	-20	-0.5	"	+10	+0.1
10	"	+540	+6.8	"	0	0	"	0	0	"	0	0	"	+540	+4.3
11	"	-30	-0.4	"	0	0	"	-70	-8.8	"	-70	-1.6	"	-100	-0.8
12	"	+380	+4.8	"	-100	-2.8	"	0	0	"	-100	-2.3	"	+280	+2.3
13	"	-310	-3.9	"	-210	-5.8	"	0	0	"	-210	-4.8	"	-520	-4.2
14	"	-200	-2.5	"	-220	-6.1	"	-40	-5.0	"	-260	-5.9	"	-460	-3.7
15	"	0	0	"	-160	-4.4	"	-90	-11.3	"	-250	-5.7	"	-250	-2.0
16	"	+40	+0.5	"	-20	-0.6	"	+200	+25	"	+180	+4.0	"	+220	+1.8
17	"			"			"	+150	+18.8	"			"		
18	"	-140	-1.8	"	0	0	"	0	0	"	0	0	"	-140	-1.1
19	"	+190	+2.4	"	-20	-0.6	"	-20	-2.5	"	-40	-0.9	"	+150	+1.2
20	"	-60	-0.8	"	0	0	"	-40	-5.0	"	-40	-0.9	"	-100	-0.8
21	"	-80	-1.0	"	-280	-7.8	"	0	0	"	-280	-6.4	"	-360	-2.9
22	"	-240	-3.0	"			"			"	-290	-6.6	"	-530	-4.3
23	"	+150	+1.9	"	-100	-2.7	"	-80	-10	"	-180	-4.0	"	-30	-0.2
24	"	0	0	"			"			"	-60	-1.2	"	-60	-0.5
25	"	-280	-3.6	"	-180	-4.9	"	-50	-6.3	"	-230	-5.1	"	-510	-4.1
26	"	0	0	"	-320	-8.6	"	0	0	"	-320	-7.1	"	-320	-2.6
27	"	-130	-1.7	"	-230	-6.2	"	-30	-3.8	"	-260	-5.8	"	-390	-3.2
28	"	0	0	"	0	0	"	0	0	"	0	0	"	0	0
29	"	-70	-0.9	"	-140	-3.8	"	0	0	"	-140	-3.1	"	-210	-1.7
30	"	-110	-1.4	"	0	0	"	0	0	"	0	0	"	-110	-0.9
31	"	0	0	"	-140	-3.8	"	0	0	"	-140	-3.1	"	-140	-1.1
32	"	-30	-0.4	"	-110	-3.0	"	0	0	"	-110	-2.4	"	-140	-1.1
33	"	+840	+10.8	"	-370	-10.0	"	+80	+10	"	-290	-6.4	"	+550	+4.5
34	"	+70	+0.9	"	-150	-4.1	"	0	0	"	-150	-3.3	"	-80	-0.7
35	"	0	0	"	0	0	"	0	0	"	0	0	"	0	0
36	"	0	0	"	-260	-7.0	"	0	0	"	-260	-5.8	"	-260	-2.1
37	"	0	0	"	-50	-1.4	"	0	0	"	-50	-1.1	"	-50	-0.4
38	"	+230	+2.9	"	-70	-1.9	"	0	0	"	-70	-1.6	"	+160	+1.3
39	"	+100	+1.3	"	-100	-2.7	"	0	0	"	-100	-2.2	"	0	0
40	"	-80	-1.0	"	-100	-2.7	"	0	0	"	-100	-2.2	"	-180	-1.5
41	"	-40	-0.5	"	-90	-2.4	"	0	0	"	-90	-2.0	"	-130	-1.1
42	"	0	0	"	-110	-3.0	"	0	0	"	-110	-2.4	"	-110	-0.9
43	"	+40	+0.5	"	-150	-4.1	"	0	0	"	-150	-3.3	"	-110	-0.9
44	"	+70	+0.9	"	-120	-3.2	"	+25	+3.1	"	-145	-3.2	"	-75	-0.6
45	"	+60	+0.9	"	0	0	"	0	0	"	0	0	"	+60	+0.5
46	1860-1937	-90	-1.2	"	+90	+2.4	"	0	0	"	+90	+2.0	1860-1982	0	0
47	"	+110	+1.4	"	-110	+3.0	"	0	0	"	-110	-2.4	"	0	0
48	"	+30	+0.4	"	-90	-2.4	"	0	0	"	-90	-2.0	"	-60	-0.5
49	"	-50	-0.6	"	-170	-4.6	"	0	0	"	-170	-3.8	"	-220	-1.8
50	"	-60	-0.8	"	-60	-1.6	"	0	0	"	-60	-1.3	"	-120	-1.0
51	"	-160	-2.1	"	-100	-2.7	"	0	0	"	-100	-2.2	"	-260	-2.1
51a	"	0	0	"	0	0	"	0	0	"	0	0	"	0	0
52	"	+80	+1.0	"	-100	-2.7	"	0	0	"	-100	-2.2	"	-20	-0.2
53	"	+40	+0.5	"	-240	-6.5	"	0	0	"	-240	-5.3	"	-200	-1.6

Point	Time	Dist. ft	Rate ft per yr	Time	Dist. ft	Rate ft per yr	Time	Dist. ft	Rate ft per yr	Time	Dist. ft	Rate ft per yr	Net Time	Net Dist.	Net Rate
54	1860-1937	-70	-0.9	1937-1974	-120	-3.2	1974-1982	-50	-6.3	1937-1982	-170	-3.8	1860-1982	-240	-2.0
55	"	-120	-1.6	"	-40	-1.1	"	-50	-6.3	"	-90	-2.0	"	-210	-1.7
56	1860-1930	-130	-1.9	1930-1974	+100	+1.9	"	-100	-12.5	1930-1982	0	0	"	-130	-0.2
57	"	-290	-4.1	"	+60	+1.3	"	0	0	"	+60	+1.2	"	-230	-1.9
58	"	-160	-2.3	"	+20	+0.5	"	0	0	"	+20	+0.4	"	-120	-1.1
59	"	+20	+0.3	"	+200	+4.5	"	0	0	"	+200	+3.8	"	+220	+1.8
60	"	+260	+3.7	"			"			"	-30	-0.6	"	+230	+1.9
61	"	-140	-2.0	"	-40	-0.9	"	0	0	"	-40	-0.8	"	-180	-1.5
62	"	0	0	"	0	0	"	0	0	"	0	0	"	0	0
63	"	-220	-3.1	"	-100	-2.3	"	0	0	"	-100	-1.9	"	-320	-2.6
64	"	0	0	"	0	0	"	0	0	"	0	0	"	0	0
65	"	+60	+0.9	"	-80	-1.8	"	0	0	"	-80	-1.5	"	-20	-0.2
66	"	-150	-2.1	"	-310	-7.0	"	-40	-5.0	"	-350	-6.7	"	-500	-4.1
67	"	0	0	"	-40	-0.9	"	0	0	"	-40	-0.8	"	-40	-0.3
67a	"	0	0	"	-120	-2.7	"						1860-1974	-120	-1.1
68	"	-300	-4.3	"	+720	+16.4	"	-50	-6.2	"	+670	+12.9	1860-1982	+370	+3.0
69	"	-40	-0.6	"	+40	+0.9	"	0	0	"	+40	+0.8	"	0	0
70	"	+190	+2.7	"	+490	+11.1	"	+40	+5.0	"	+530	+10.2	"	+720	+5.9
71	"	0	0	"	-80	-1.8	"	0	0	"	-80	-1.5	"	-80	-0.7
72	"	-100	-1.4	"	0	0	"	0	0	"	0	0	"	-100	-0.8
73	"	-210	-3.0	"	+600	+13.6	"	-40	-5.0	"	+560	+10.8	"	+350	+2.9
74	"	-630	-9.0	"	+3,470	+78.9	"	+30	+3.8	"	+3,500	+67.3	"	+2,870	+23.5
75	"			"			"	+300	+37.5				"		
76	"	0	0	"	-160	-3.6	"	0	0	"	-160	-3.1	"	-160	-1.3
77	"	-190	-2.7	"	-30	-0.7	"	-80	-10.0	"	-110	-2.1	"	-300	-2.5
78	"	-80	-1.1	"	0	0	"	0	0	"	0	0	"	-80	-0.7
79	"	-190	-2.7	"	-240	-5.5	"	-130	-16.3	"	-370	-7.1	"	-560	-4.6
80	"	-170	-2.4	"	0	0	"	0	0	"	0	0	"	-170	-1.4
81	"	-440	-6.3	"	-240	-5.5	"	-80	-10.0	"	-320	-6.2	"	-760	-6.2
82	"	-270	-3.9	"	-320	-7.3	"	-40	-5.0	"	-360	-6.9	"	-630	-5.2
83	1859-1930	+80	+1.1	"	-160	-3.6	"	0	0	"	-160	-3.1	1859-1982	-80	-0.7
84	"	-100	-1.4	"	-120	-2.7	"	0	0	"	-120	-2.3	"	-220	-1.8
85	"	-180	-2.5	"	-270	-6.1	"	-60	-7.5	"	-330	-6.3	"	-510	-4.1
86	"	-30	-0.4	"	0	0	"	-110	-13.8	"	-110	-2.1	"	-140	-1.1
87	"	-200	-2.8	"	0	0	"	-60	-7.5	"	-60	-1.2	"	-260	-2.1
88	"	+30	+0.4	"			"			"	-70	-1.3	"	-40	-0.3
89	"	-190	-2.7	"	-40	-0.9	"	0	0	"	-40	-0.8	"	-230	-1.9
90	"	-120	-1.7	"	+40	+0.9	"	0	0	"	+40	+0.8	"	-80	-0.7
91	"	-210	-3.0	"	+180	+4.1	"	0	0	"	+180	+3.5	"	-30	-0.2
92	"	+320	+4.5	"	+140	+3.2	"	-30	-3.4	"	+110	+2.1	"	+430	+3.5
93	"	+290	+4.1	1930-1958	+140	+5.0	1958-1974	-40	-2.5	1930-1974	+100	+2.3	1859-1974	+390	+3.4
94	"	-410	-5.8	"	+180	+6.4	"	-130	-8.1	"	+50	+1.1	"	+360	+3.1
95	"	-320	-4.5	1930-1974	-60	-1.4				"			"	-380	-3.3
96	"	-120	-1.7	"	-180	-4.1				"			"	-300	-2.6
97	"	-380	-5.4	"	-280	-6.4	1974-1982	0	0	1930-1982	-280	-5.4	1859-1982	-660	-5.4
98	"	-380	-5.4	"	-180	-4.1	"	-80	10.0	"	-260	-5.0	"	-640	-5.2
99	"	-220	-3.1	"	-320	-7.2	"	-40	-5.0	"	-360	-6.9	"	-580	-4.7
100	"	-400	-5.6	"	-300	-6.8	"	-110	-13.8	"	-410	-7.9	"	-810	-6.6
101	"	-530	-7.5	"	-440	-10.0	"	0	0	"	-440	-8.5	"	-970	-7.9
102	"	-690	-9.7	"	-100	-2.3	"	0	0	"	-100	-1.9	"	-790	-6.4
103	"	-240	-3.4	"	-480	-10.9	"	0	0	"	-480	-9.2	"	-720	-5.9
104	"	-150	-2.1	"	-150	-3.4	"	-30	-3.8	"	-180	-3.5	"	-330	-2.7
105	"	+580	+9.2	"	-160	-3.6	"	-60	-7.5	"	-220	-4.2	"	+360	+2.9
106	"	+60	+0.9	"	-240	-5.5	"	0	0	"	-240	-4.6	"	-180	-1.5
107	"	+470	+6.6	"	-240	-5.5	"	0	0	"	-240	-4.6	"	+230	+1.9
108	"	+440	+5.2	"	-160	-3.6	"	0	0	"	-160	-3.1	"	+280	+2.3

Point	Time	Dist. ft	Rate ft per yr	Time	Dist. ft	Rate ft per yr	Time	Dist. ft	Rate ft per yr	Time	Dist. ft	Rate ft per yr	Net Time	Net Dist.	Net Rate
109	1859-1930	+120	+1.7	1930-1974	0	0	1974-1982	0	0	1930-1982	0	0	1859-1982	+120	+1.0
110	"	+1,800	+25.4	"	+80	+1.8	"	0	0	"	+80	+1.5	"	+1,880	+15.3
111a	"	-1,090	-15.4	"	+110	+2.5	"	+1,400	+175	"	+1,510	+29	"	+420	+3.4
111b	"			"	+2,150	+48.9	"	+1,200	+150	"	+3,350	+64.4			
112	"	+760	+10.7	"	+100	+2.2	"	-210	-26.3	"	-110	-2.1	"	+650	+5.3
113	"	+40	+0.6	"	-260	-5.9	"	0	0	"	-260	-5.0	"	-220	-1.8
114	"	-60	-0.9	"	-30	-0.6	"	-100	-12.5	"	-130	-2.5	"	-190	-1.5
115	"	+3,480	+49.0	"	-830	-18.9	"	0	0	"	-830	-16.0	"	+2,650	+21.5
116	"	-80	-1.1	"	-150	-3.4	"	0	0	"	-150	-2.9	"	-230	-1.9
117	"	-740	-10.4	"	0	0	"	0	0	"	0	0	"	-740	-6.0
118	"	-270	-3.8	"	+60	+1.4	"	0	0	"	+60	+1.2	"	-210	-1.7
119	"	-130	-1.8	"	-50	-1.8	"	0	0	"	-50	-1.0	"	-180	-1.5
120	"	-30	-0.4	"	-110	-2.5	"	0	0	"	-110	-2.1	"	-140	-1.1
121	"	0	0	"	-230	-5.1	"	0	0	"	-230	-4.4	"	-230	-1.9
122	"	0	0	"	-130	-3.0	"	0	0	"	-130	-2.5	"	-130	-1.1
123	"	-300	-4.2	"	-40	-0.9	"	+40	+5	"	0	0	"	-300	-2.4
124	"	-200	-2.8	"	-50	-1.1	"	-40	-5	"	-90	-1.7	"	-290	-2.4
125	"	-230	-3.2	"	-150	-3.4	"	-80	-10	"	-150	-2.9	"	-460	-3.8
126	"	-250	-3.5	"	-290	-6.6	"	-140	-17.5	"	-430	-8.2	"	-680	-5.5
127	"	-120	-1.7	"	-30	-0.7	"	0	0	"	-30	-0.6	"	-150	-1.2
128	"	-260	-3.7	"			"			"	-20	-0.4	"	-280	-2.3
129	"	+1,120	+15.7	"	0	0	"	0	0	"	0	0	"	+1,120	+9.1
130	"	-130	-1.8	"	0	0	"	0	0	"	0	0	"	-130	-1.1
131	"	-120	-1.7	"	-210	-4.8	"	-100	-12.5	"	-310	-6.0	"	-430	-3.5
132	"	-330	-4.6	"	-200	-4.5	"	0	0	"	-200	-3.8	"	-530	-4.3
133	"	-180	-2.5	"	-390	-8.5	"	-50	-6.3	"	-440	-8.5	"	-620	-5.0
134	"	-130	-1.8	"	0	0	"	0	0	"	0	0	"	-130	-1.1
135	"	0	0	"	-30	-0.7	"			"			1859-1974	-30	-0.3
136	"	-160	-2.3	"	-110	-2.5	"			"			"	-270	-2.3
137	"	-560	-7.9	"	-690	-15.7	"			"			"	-1,250	-10.9
138	"	-230	-3.2	"	-400	-9.1	"			"			"	-630	-5.5
139	"	-280	-3.9	"	-70	-1.6	"			"			"	-210	-3.0
140	"	-230	-3.2	"	-130	-3.0	"	-90	-11.2	"	-220	-4.2	1859-1982	-450	-3.7
141	"	-120	-1.7	"	-220	-5.0	"	-150	-18.8	"	-370	-7.1	"	-490	-4.0
142	"	+20	+0.3	"	-280	-6.4	"	0	0	"	-280	-5.4	"	-260	-2.1
143	"	0	0	"	-80	-1.8	"	-160	-20	"	-240	-4.6	"	-240	-2.0
144	"	+350	+4.9	"	0	0	"			"			1859-1974	+350	+3.0
145	"	+770	+10.8	"	+800	+0.7	"	0	0	"	+30	+0.6	1859-1982	+800	+6.5
146	"	+310	+4.4	"	+100	+2.3	"	+30	+3.4	"	+130	+2.5	"	+440	+3.6
147	"	+560	+7.9	"	+30	+0.7	"	0	0	"	+590	+0.6	"	+590	+4.8
148	"	-100	-1.4	"	+180	+4.1	"	+100	+12.5	"	+280	+5.4	"	+180	+1.5
149	"	+190	+2.7	"			"	-40	-5.0	"			"		
150	"	0	0	"			"	-70	-8.8	"			"		
151	"	+400	+5.6	"			"	-50	-6.3	"			"		
152	"	+100	+1.4	"			"	-70	-8.8	"			"		
153	"	+140	+2.0	"	-140	-3.2	"	+70	+8.8	"	-70	-1.3	"	+70	+0.6
154	"	+530	+7.4	"			"	-70	-8.8	"			"		
155	"	+60	+0.8	"	-60	-1.4	"	-90	-11.3	"	-150	-2.9	"	-90	-0.7
156	"	+60	+0.8	"	0	0	"	0	0	"	0	0	"	+60	+0.5
157	"	-400	-5.6	"			"			"	-160	-3.1	"	-560	-4.6
158	"	-20	-0.3	"			"			"	-50	-1.0	"	-70	-0.6
159	1857-1930	-40	-0.5	"			"			"	-110	-2.1	1857-1982	-150	-1.2
160	"	-30	-0.4	"			"			"	-100	-1.9	"	-130	-1.0
161	"	-80	-1.1	"			"			"	-90	-1.7	"	-170	-1.4
162	"	-30	-0.4	"			"			"	-50	-1.0	"	-80	-0.6
163	"	-120	-1.6	"			"			"	-50	-1.0	"	-170	-1.4

APPENDIX C

Tropical cyclones affecting the Texas coast 1854-1982
(compiled from Tannehill, 1956; Dunn and Miller, 1964; Cry, 1965).

Intensity Classification from Dunn and Miller

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

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

APPENDIX D

Materials and Sources

Galveston Bay System

Topographic maps used in the determination of shoreline position.

Date	Name	Source
1850	#282, Galveston harbor and city	National Oceanic and Atmospheric Administration (NOAA)
1850	#283, Galveston Bay	NOAA
1850	#298, Red Fish Bar	NOAA
1851	#328, Galveston West Bay and part of Galveston Island	NOAA
1851	#329, Galveston East Bay and part of Bolivar Peninsula	NOAA
1851	#330, Galveston Bay	NOAA
1851	#331, Galveston Bay	NOAA
1852	#374, Galveston West Bay, Galveston Island, and Chocolate Bay	NOAA
1852	#375, Texas Coast from San Luis to Jupiter	NOAA

Aerial photographs used in the determination of shoreline position. Asterisk indicates photography on which measurements were based.

Date	Name	Source
April 1930 to November 1930	* Black-and-white mosaics, 1:24,000	Tobin Research, Inc.
December 1938 to February 1939	Black-and-white mosaics, 1:31,680	U.S. Department of Agriculture
February to December 1941	Black-and-white mosaics, 1:63,360	U.S. Department of Agriculture
September 1942	Black-and-white mosaics, 1:63,360	U.S. Army Corps of Engineers

March and April 1952	Black-and-white mosaics, 1:63,360	U.S. Department of Agriculture
February 1956	Black-and-white mosaics, 1:63,360	U.S. Department of Agriculture
August and October 1956	* Black-and-white mosaics, 1:24,000	Tobin Research, Inc.
June 1974	* Black-and-white 1:24,000	General Land Office of Texas
June and July 1982	* Color infrared 1:24,000	General Land Office of Texas

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

Anahuac, Texas
Bacliff, Texas
Caplen, Texas
Christmas Point, Texas
Cove, Texas
Flake, Texas
Frozen Point, Texas
Galveston, Texas
High Island, Texas
Hoskins Mound, Texas
Lake Como, Texas
Lake Stephenson, Texas
La Porte, Texas
League City, Texas
Morgans Point, Texas
Oak Island, Texas
Port Bolivar, Texas
San Luis Pass, Texas
Sea Isle, Texas
Smith Point, Texas
Texas City, Texas
The Jetties, Texas
Umbrella Point, Texas
Virginia Point, Texas

San Antonio Bay System

Topographic maps used in the determination of shoreline positions.

Date	Name	Source
1859	#767, Map of part of San Antonio Bay and vicinity Texas	National Oceanic and Atmospheric Administration (NOAA)
1860	#828, St. Charles Bay/San Antonio Bay Texas	NOAA
1859	#1030, Map of part of Matagorda Island Texas	NOAA
1860	#787, 2nd Chain to Long Reef Texas	NOAA
1857	#644, Matagorda Island and the Shore of the SW end of Matagorda Bay, State of Texas	NOAA

1859	#766, Map of Part of Espiritu Santo and San Antonio Bays and Vicinity Texas	NOAA

Aerial photographs used in the determination of shoreline position. Asterisk indicates photography on which measurements were based.

Date	Type	Source
Nov. 1929 to March 1937	*Black-and-white mosaics, 1:24,000	Tobin Research, Inc.
Dec. 1957	Black-and-white mosaics, 1:24,000 *(selected measurements)	Tobin Research, Inc.
June and Nov. 1974	Black-and-white stero pair 1:24,000 *(selected measurements)	General Land Office of Texas
Nov. 1979	Color-infrared 1:66,000	Environmental Protection Agency
June to Sept. 1982	*Color-infrared stero pair 1:24,000	General Land Office of Texas

U.S. Geological Survey 7.5-minute quadrangle maps used in the construction of base maps

Austwell, Texas
Long Island, Texas
Mesquite Bay, Texas
Mosquito Point, Texas
Pass Cavallo SW, Texas
Port O'Connor, Texas
Panther Point, Texas
Seadrift, Texas
Seadrift NE, Texas
St. Charles Bay, Texas
St. Charles Bay SE, Texas
Tivoli SE, Texas