BEACH AND DUNE CONDITIONS AT SOUTH PADRE ISLAND, TEXAS
ASSESSMENT AND RECOMMENDATIONS

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Prepared for
Town of South Padre Island
South Padre Island, Texas

January 1993

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Plate 1 (in pocket)

SUMMARY

An investigation of beach and dune conditions on South Padre Island was conducted for the Town of South Padre Island specifically to address two coastal issues, dune management and beach stability. Results of the study were organized and presented to assist City officials in their planning and management of beaches and dunes that are vital to the economy and storm protection of the region. The study demonstrates that beach stability and dune development vary along the island and that management strategies need to be prepared for accreting, stable, and eroding beach segments. Furthermore, the study recognizes the need to begin planning for beach replenishment projects that will be required to maintain recreational beaches along eroding segments of South Padre Island in the future. Recommendations are made regarding the location and restoration of dunes as well as the options for beach replenishment. Also it is recommended that the town initiate a beach-dune monitoring program that will provide a scientific basis for prudent management of the natural resources.

INTRODUCTION

Most sandy beaches worldwide are eroding due to a decrease in sediment supply, a relative rise in sea level, and frequent storms. Even beaches that are currently stable may begin eroding in the near future. South Padre Island (fig. 1) is a low, narrow barrier island that has been frequently inundated during storms. Safe economic development of the island will depend on architectural and structural designs that recognize beach dynamics, changes in sediment supply, rising sea level, and storm surges.

Many coastal communities have construction control lines, dune protection lines, or other types of shore-parallel zones that are based on distances landward of the beach, dune, or vegetation line. As defined in the legal codes, these control lines change position as the beach changes position, so it is necessary to periodically reestablish the position of the control line. The

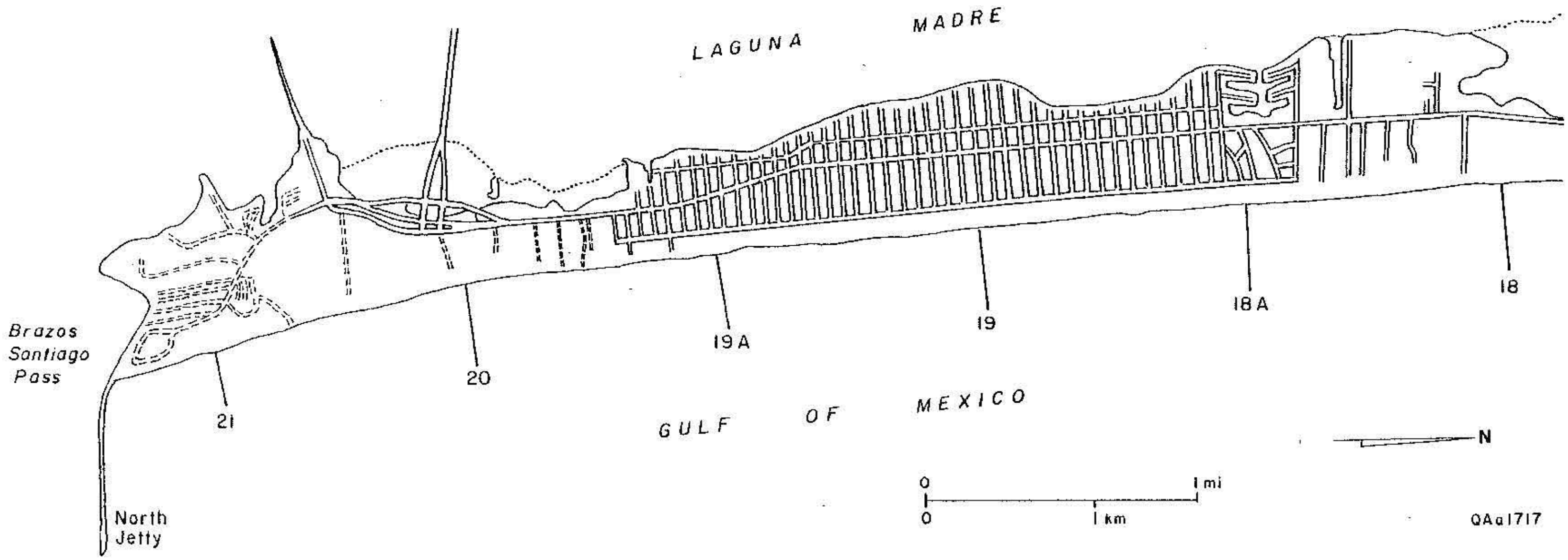

Figure 1. Index map of South Padre Island showing the locations of transects used to summarize shoreline movement.

primary objective of this study was to provide up-to-date information regarding beach and dune conditions on South Padre Island for managing those natural resources, planning and protecting shorefront development, promoting tourism, and minimizing property damage from storms. A secondary objective was to facilitate review of projects planned within or near the beach and dune area and to outline a plan for determining future beach fill requirements.

SHORELINE SOURCES AND THEIR LIMITATIONS

Coastal scientists and coastal property managers need to understand past shoreline changes in order to anticipate where land will be eroded in the future and to predict what the rates of erosion might be. These objectives are best accomplished by using shoreline maps, which provide the basis for understanding the dynamics of the coast. Former shoreline positions can come from several sources, but the most common sources are topographic maps, aerial photographs (Table 1), and ground surveys. All shoreline change analyses involve plotting several shorelines at the same site, comparing the shoreline positions through time, and calculating rates of shoreline movement for several time periods (Stafford, 1971; Leatherman, 1983; Morton, 1991). If coastal managers or property owners are making decisions based on predicted shoreline stability, they should carefully examine the sources of shoreline positions, understand how the shoreline change analysis was conducted, and evaluate the methods used to determine the rate of shoreline movement or to project future shoreline positions.

Topographic Maps and Surveys

The oldest reliable shorelines are preserved on coastal topographic maps commonly referred to as T-sheets (Shalowitz, 1964). Most of these maps were surveyed during the 1800s and the oldest reliable survey of South Padre Island was conducted in 1867 (Table 2). The old topographic maps can be compared with more recent surveys or topographic maps using the geographic coordinates (latitude and longitude) drawn on the original maps.

Table 1. Aerial photographs of South Padre Island used to investigate beach width and dune stability.

	Year	Month	Source	Type
	1991	July	Texas General Land Office	B & W
	1982	July	Texas General Land Office	Color IR
post-Allen	1980	August	Texas General Land Office	B & W
pre-Allen	1980	July	Texas General Land Office	B & W
	1978	December	Texas General Land Office	B & W
	1975	May	Texas General Land Office	Color IR
	1974	June	Texas General Land Office	B & W
	1970	October	National Ocean Service	Color
	1968	July	Texas Highway Department	B & W
post-Beulah	1967	September	Texas Highway Department	B & W
pre-Beulah	1967	June	Corps of Engineers	B & W
	1962	July	Texas General Land Office	B & W

Table 2. Shoreline changes on South Padre Island. Locations of measurement points are shown on Figure 1.

+ accretion
- erosion

Point	Time	Dist. ft.	Rate ft/yr	Time	Dist. ft.	Rate ft/yr	Time	Dist. ft.	Rate ft/yr	Time	Dist. ft.	Rate ft/yr	Time	Dist. ft.	Rate ft/yr	Time	Dist. ft.	Rate ft/yr	Net Time	Net Dist.	Net Rate
18	1867 1937	-1125	-16.1	1937 1960	-175	-7.6	1960 1970	-50	-5.0	1970 1974	-50	-12.5	1974 1982	+46	+5.7	1982 1991	-192	-21.3	1867 1991	-1546	-12.5
18A	"	-1216	-17.4	"	-100	-4.3	"	-50	-5.0	"	0	0	"	-38	-4.7	"	-94	-10.4	"	-1498	-12.1
19	"	-1250	-17.9	"	-50	-2.1	"	-50	-5.0	"	0	0	"	+75	+9.3	"	+3	+.3	"	-1272	-10.3
19A	"	-1250	-17.9	"	+25	+1.1	"	+50	+5.0	"	0	0	"	+26	+3.2	"	+174	+19.3	"	-975	-7.9
20	"	-1200	-17.1	"	+200	+8.7	"	+150	+15.0	"	+125	+31.3	"	-28	-3.5	"	+28	+3.1	"	-725	-5.9
21	"	-1125	-16.1	"	+550	+23.9	"	+<10	+<1.0	"	+50	+12.5	"	+70	+8.7	"	-34	-3.8	"	-479	-3.9

The 1800s topographic maps contain a potential source of error that is not present when aerial photographs are used to detect shoreline changes. This is because the positions of the 1800s shoreline have undergone two corrections, known as the North American Datums of 1927 and 1983 (NAD-27 and NAD-83). These datum corrections have moved the position of the shoreline relative to latitude and longitude coordinates as much as 120 ft (Wade, 1986). The U.S. Coast Survey marked the corrected coordinates on the maps that were used to establish the 1867 shoreline for South Padre Island.

There are both advantages and disadvantages associated with using the old topographic maps for shoreline change analyses. The principal advantage is that the period of record is extended as far back as possible without sacrificing shoreline accuracy. A minor disadvantage is that the documented shoreline changes may be difficult to interpret because information for that period regarding storms and other events affecting the coast is generally lacking. Most coastal scientists think that the longest reliable record of shoreline change will provide the most reliable basis for predicting future changes. This normally means that the oldest reliable shoreline should be used in the shoreline change analysis.

Aerial Photographs

Vertical aerial photographs are the most common source of shoreline positions because air photos are much cheaper than ground surveys. The shoreline proxy mapped on aerial photographs is the high water line that separates the wet beach from the dry beach (Stafford, 1971; Morton, 1979; Dolan and Hayden, 1983). The wet beach-dry beach line is not a tidal datum, such as the mean high water line, and it represents the highest water levels occurring immediately before the photographs were taken. Because wave runup is large on low-gradient sandy beaches such as South Padre Island, the high water line on those beaches is sensitive to changes in water level caused by strong winds or unusual tides. As a result, shoreline movement mapped for some sandy beaches may be caused by differences in water levels rather than actual changes in sediment volume. Theoretically, shorelines mapped on aerial photographs could be reconstructed to a specific tidal datum using local correction factors for beach slope and water levels (Stafford, 1971), but in reality, the dynamics of sandy beach profiles preclude making these corrections with much confidence.

The stability of beaches can also be inferred from aerial photographs by monitoring other shoreline proxies, such as the vegetation line and dune line. These boundaries are secondary indicators of shoreline movement that can provide supplementary information about local beach dynamics or can serve as additional ground control for mapping the high water line. These shoreline indicators are more stable than the wet beach-dry beach line since they are not influenced by changes in water level.

Perhaps the most tenuous assumption made regarding aerial photographs is that the photographed shoreline is of an equilibrium beach representing typical or average conditions. This assumption can be verified only indirectly by examining tide gauge records, meteorological reports, and other historical documents that indicate either abnormal conditions or the lack of unusual events preceding the photographic mission.

Beach Profiles

Shoreline movement can also be documented using beach profiles. Beach profiling is a standard field method that involves making repeated measurements at ground-control stations along the beach. These measurements may consist of a single observation, such as dry beach width, or may involve surveying the entire beach surface. Beach profiles require establishing a reference mark from which distances and elevations along a traverse are measured. The reference mark can be a surveyors benchmark or some other stable feature such as the corner of a seawall or sign post.

There are a number of decisions that must be made before a beach is surveyed. The results expected from the survey will determine where and how frequently the survey will be conducted and the type of equipment that will be used. Beach surveys that rely on a tidal datum (mean high water or mean low water) or property boundaries must be conducted by a registered surveyor with expensive equipment. On the other hand, accretion and erosion of the beach can be measured with portable inexpensive equipment as long as the same profile location is reoccupied.

Beach profiles oriented perpendicular to the shoreline (fig. 2) can be obtained with various types of equipment ranging from simple graduated rods and chains (Emery, 1961), to standard stadia rod and level, to a more accurate autotracking geodimeter with a reflecting prism (Birkemier et al., 1991). The more sophisticated techniques offer greater measuring precision, but they also require more field support and data processing equipment, such as computers and specialized software.

A typical shore-normal beach survey yields a one-dimensional profile that represents the relative height of the beach from a fixed reference marker. This profile also displays the position of particular beach features, such as high water line, berm crest, dunes, vegetation line, or a datum intercept such as the National Geodetic Vertical Datum (NGVD). Comparison of subsequent beach surveys yields a two-dimensional cross-sectional area, which represents the amount of beach erosion and deposition that occurred between surveys. A three-dimensional volumetric change in the beach is derived from the profiles by integrating between adjacent cross-sectional areas.

The beach profile is obtained by adding the horizontal distances and corresponding changes in beach elevations and plotting those values on graph paper or entering the data into a computer that has graphics capabilities. Changes in the beach are detected by repeating the surveys at the same site every few months or years and comparing the profiles. Either the sea-level datum or the berm crest can be used to indicate beach movement between consecutive surveys.

There are three sources of error associated with these approaches to estimating beach erosion and deposition. The first is that all of the measurements are made relative to a reference marker. If this marker is lost or damaged, accurate comparison of previous surveys with subsequent surveys would be extremely difficult. The second potential error occurs if subsequent

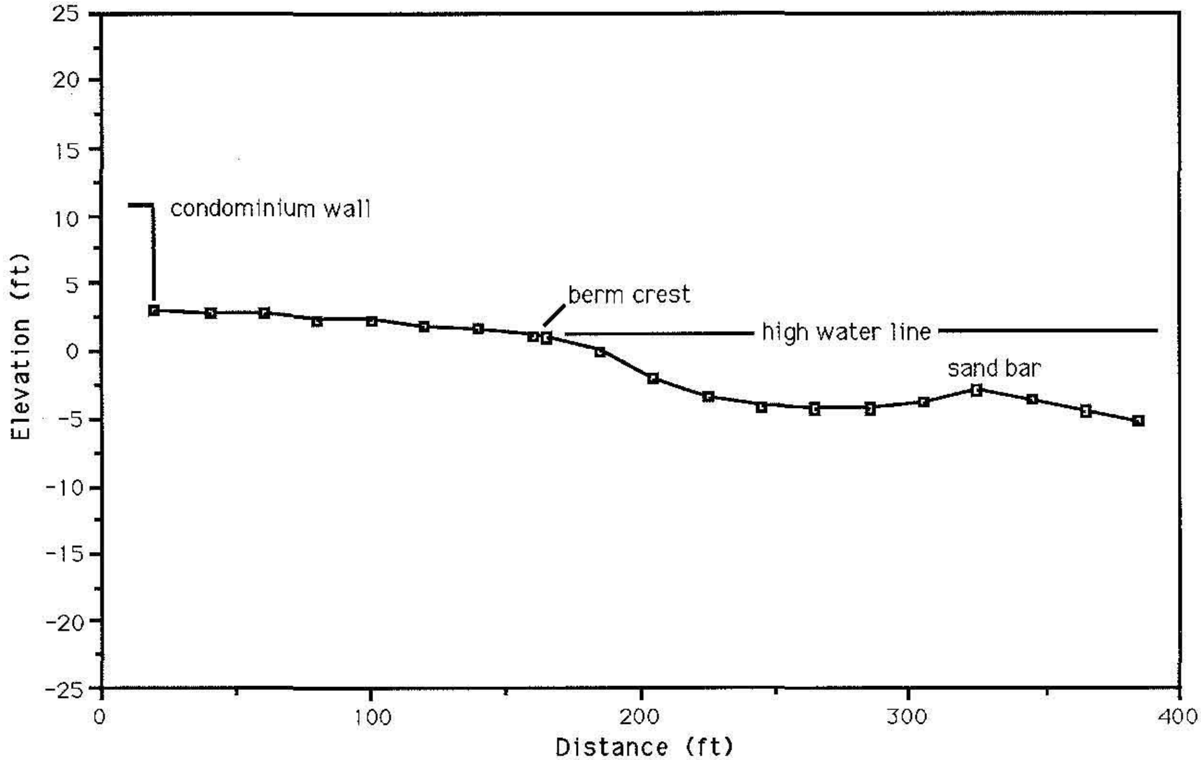

Figure 2. Typical beach profile for the developed part of South Padre Island.

surveys do not follow the same course (compass bearing) as the previous survey. The third potential error involves the calculation of volumetric changes from two-dimensional data. Volumetric changes interpolated from adjacent profiles will be unreliable if the comparisons neglect subtle changes in the beach surface or if the adjacent profiles are widely spaced.

Beach profiles are somewhat limited because (1) they are site specific and do not provide a continuous shoreline position along the coast, (2) it takes several days to conduct extensive surveys, (3) the "permanent" reference markers are commonly destroyed where the beach is either rapidly eroding or subjected to substantial wave penetration during storms, and (4) there can be large errors associated with estimating volumetric changes from inadequate data. Estimates of volumetric beach changes can be significantly improved if the beach is surveyed by an intersecting grid of profiles oriented both perpendicular and parallel to the shoreline. By providing a more accurate representation of the actual beach surface, a grid of profiles can reduce the error that currently is introduced when unknown elevation changes between profiles are ignored or estimated by interpolation.

A primary advantage of beach profiles is that the uncertainties of the wet beach-dry beach line are eliminated and observations of shoreline movement are based on actual field measurements rather than interpreted from aerial photographs. Another advantage of beach profiles is that frequent comparisons yield information about two-dimensional beach changes that can be used to calculate the volume of sediment added to or removed from the beach. These volumetric estimates of sediment movement cannot be accurately derived from aerial photographs.

Profiling is a rapid and inexpensive field method best suited for documenting changes in beach shape and evaluating the magnitude of seasonal or short-term movement in shoreline position. Normally beach profiles are not used to establish long-term trends of shoreline movement because more than 10 years of continuous data are needed before the long-term trend can be established with confidence (Eliot and Clarke, 1989).

GPS Surveys

GPS (Global Positioning System) is an advanced satellite-based electronic surveying technology that is being adapted to measure coastal changes. It will be the field method most widely used to survey beaches in the future. Originally developed by the Department of Defense for military applications, GPS is now used extensively for civilian navigation and surveying (Leick, 1990). A constellation of satellites orbiting in space transmit radio signals that are received by GPS equipment on the ground. Atomic clocks determine how long it takes for the radio signal from each observed satellite to reach the receiver and this information is electronically converted to determine precise geographic positions including latitude, longitude, and elevation.

A potential disadvantage of GPS is the inaccuracy that is introduced by selective availability. This procedure, controlled by the Department of Defense, deliberately degrades the radio signal transmitted by some satellites to prevent unauthorized users from determining precise locations, especially during war. This means that positions obtained by a single GPS receiver will only be within about 300 ft of its actual position. Differential GPS techniques were developed to eliminate the uncertainty introduced by selective availability. In the differential mode of operation, two receivers are used; one stays at a reference point and the other moves about conducting the survey. The reference point is at a location such as a surveying monument or bench mark where the latitude, longitude, and elevation are known.

Beaches are nearly ideal environments for conducting GPS surveys because the field of view with the satellites is largely unobstructed. However, some developed shores may impede or prevent GPS surveys because of interference with the satellite signals. Isolated structures near the beach, such as tall buildings, may cause some minor shading, whereas dense, high-rise developments may entirely block the signal from satellites near the horizon or cause multipath reflections severe enough to invalidate the surveys.

Techniques have been developed to accurately survey beaches by mounting a GPS antenna on a vehicle. Horizontal distances and elevations are recorded as the vehicle drives up and down the beach. An advantage of vehicle-mounted GPS surveys is that they can provide rapid, relatively inexpensive, and repeatable topographic information over long distances with minimal manpower and equipment (Morton et al. 1993).

The entire beach surface between the water line and the dune line can be surveyed using GPS techniques. Shoreline positions can be frequently updated and changes in sediment volume can be determined by comparing the surfaces recorded by repeated surveys of the same beach segment. GPS surveying techniques provide positions without the need for permanent reference marks. Therefore they are particularly well suited for monitoring beaches where the reference marks may be destroyed during a storm.

COMPARING SHORELINE POSITIONS

To many people the words *accuracy* and *precision* have the same meaning and they are often used interchangeably. But to scientists and engineers the words have different meanings as they pertain to shoreline mapping and shoreline change analyses. *Accuracy* involves correctly identifying the long-term trends of shoreline movement (erosion, stability, and accretion), whereas *precision* involves exactness in quantifying both the rates of movement and the variability of those rates. With computers and expensive mapping equipment we can measure the shorelines very precisely and calculate the rates of change to many decimal places, but this high level of precision is meaningless if the shoreline comparisons are not accurate.

To maximize the accuracy of comparing shorelines, many workers plot shorelines from maps and aerial photographs onto large-scale topographic base maps. Measurements of shoreline movement can be made directly from the base maps, or the compiled shorelines can be digitized and entered into a geographic information system (GIS) for additional processing and analysis.

The former shorelines of South Padre Island were digitized and stored in ARC-INFO, which is a GIS used by many organizations and government agencies.

Digital formats and geographic information systems facilitate the comparison and printing of shoreline information; however, computers do not improve the accuracy of the original shoreline positions. Computers can increase the precision of mapping and statistical analyses, but the degree of accuracy depends entirely on the position of the shoreline and its location within the spectrum of shoreline fluctuations.

QUANTIFYING SHORELINE MOVEMENT

Presenting Shoreline Changes

Historical changes in shoreline position are usually presented as maps, in tables (Table 2), and on graphs (figs. 3–9). All three forms of data presentation have advantages and disadvantages compared to the other two. Maps of sequential shoreline positions illustrate shoreline movement as a series of lines that can be compared to determine whether the beach is stable, accreting, or eroding. The map view allows the user to see where the shoreline is relative to other features (buildings, streets, inlets) where the shoreline has been, and to infer where it might be in the future. Shoreline movement can also be expressed in a table that contains the shoreline dates as well as distances and rates of shoreline movement (Table 2). These numerical data quantify what is illustrated on the map and reduce the shoreline movement to an average rate of change expressed in distance per unit time, such as feet/year. Graphs depicting shoreline movement through time illustrate the long-term trends and short-term variability, which also can be used to predict future shoreline positions. These plots contain three fields that represent stability, accretion, and erosion (fig. 3). Data that plot around the zero axis show that the shoreline position has fluctuated but that over the long-term period the beach position has remained nearly unchanged. In contrast, data that plot to the positive or negative side of the graph record long-term accretion or erosion (fig. 3).

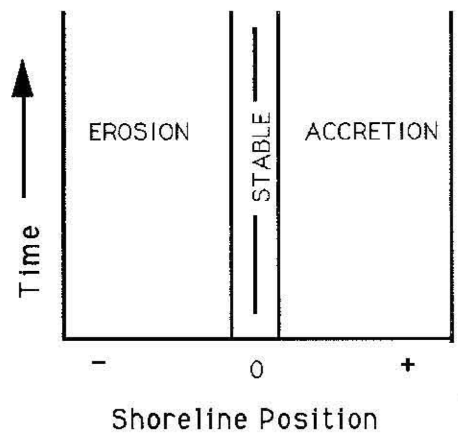

Figure 3. Generalized diagram used to illustrate shoreline movement.

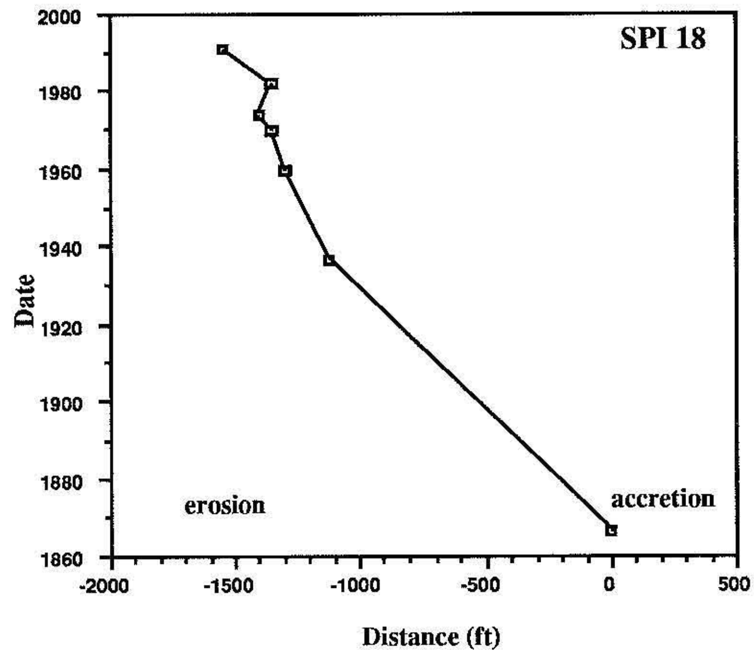

Figure 4. Long-term shoreline movement at transect 18.

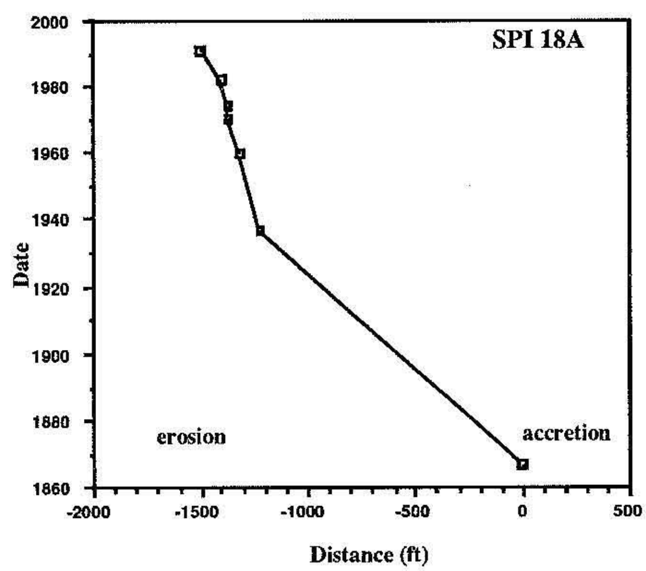

Figure 5. Long-term shoreline movement at transect 18A.

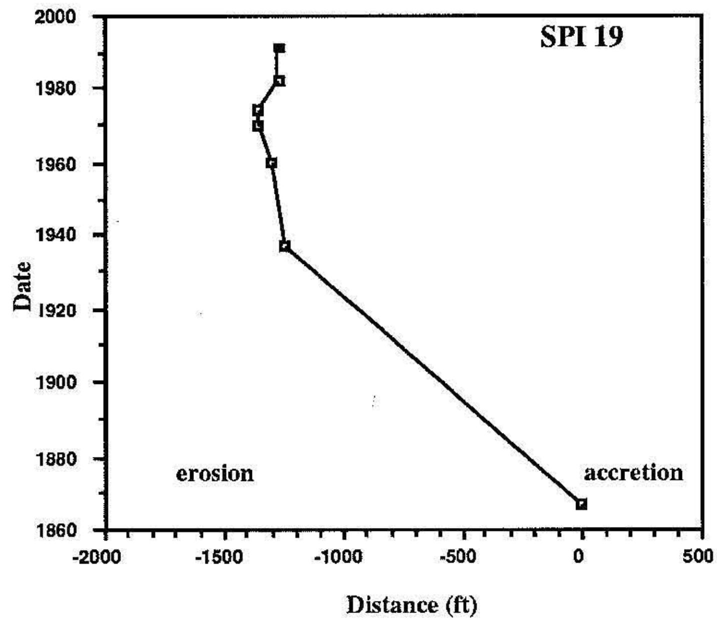

Figure 6. Long-term shoreline movement at transect 19.

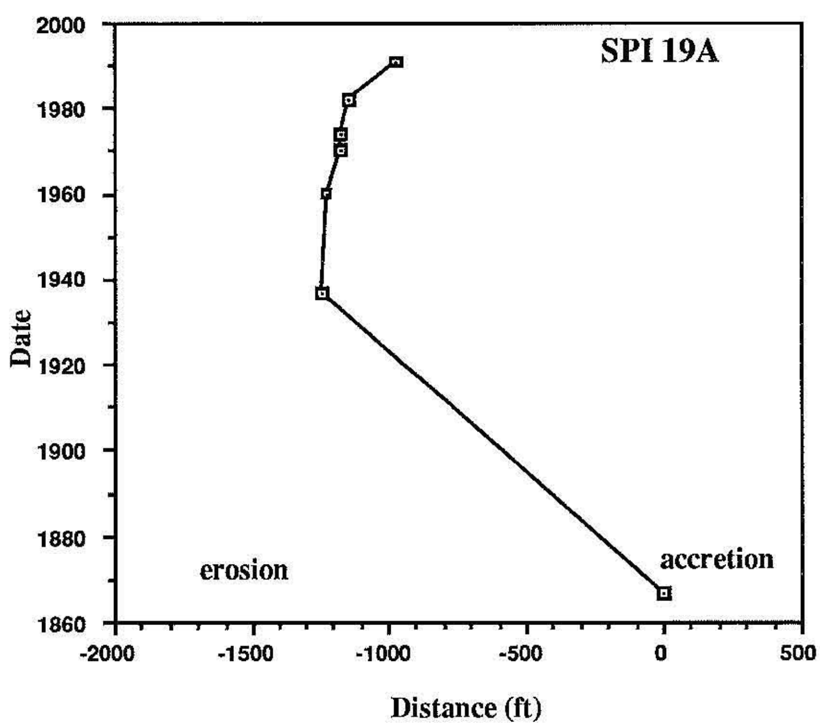

Figure 7. Long-term shoreline movement at transect 19A.

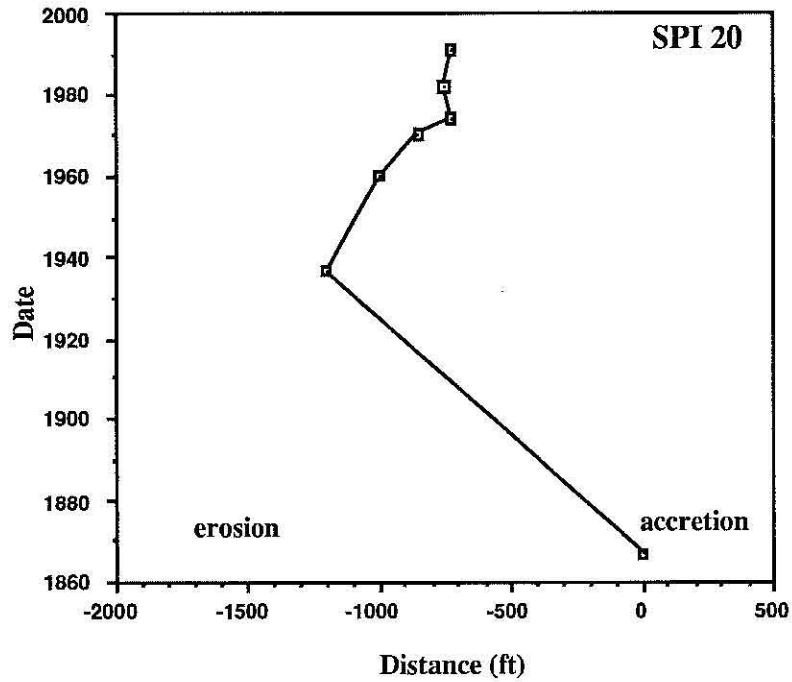

Figure 8. Long-term shoreline movement at transect 20.

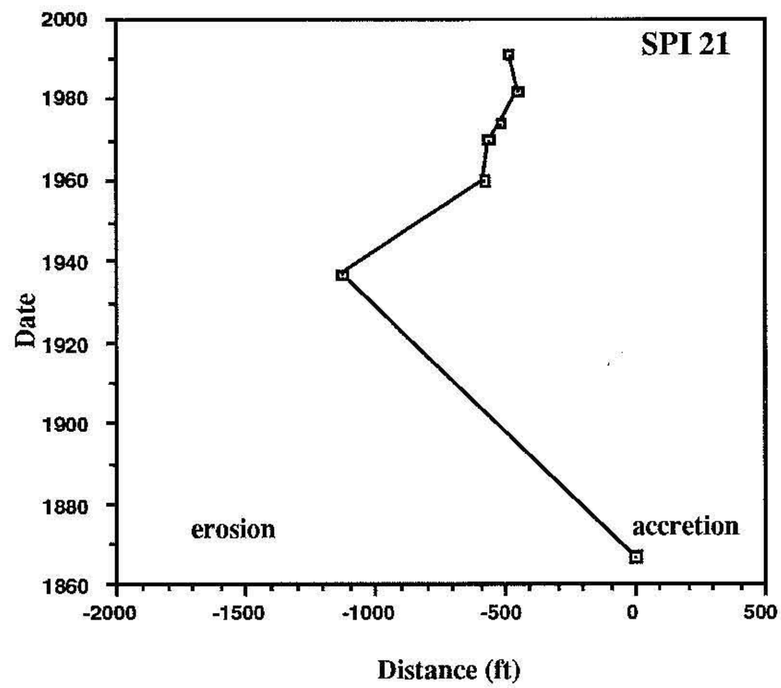

Figure 9. Long-term shoreline movement at transect 21.

Interpreting Graphical Displays

Shoreline positions derived from maps, aerial photographs, or ground surveys represent individual points in a spectrum of shoreline movement. Most studies of shoreline changes are normally based on five to eight shoreline positions spanning as much as 150 yr (figs. 3–9). Studies of that duration typically employ two distinctly different data densities. The lowest data density is for the first 100 yr when shoreline movement is determined from two or three maps and air photos. In contrast, most of the shoreline movement data were collected during the past 50 yr and the highest data densities are available for the past 30 yr. The increased number of shoreline positions since 1960 provides a better measure of the short-term beach fluctuations and a way of distinguishing the long-term trend from the short-term fluctuations.

Plots of cumulative shoreline movement versus time at representative beach transects (figs. 3–9) commonly illustrate different rates of movement or reversals in the direction of shoreline movement. The shape and slope of the line connecting a series of shoreline positions can also be used to interpret the relative rate of change and to predict future shoreline positions. Nearly vertical line segments indicate very slow changes whereas flatter line segments indicate more rapid changes.

These plots also provide a basis for fitting statistically derived regression curves that can be used to predict future changes. These time-space plots of cumulative shoreline movement are useful for visualizing the long-term trend and for recognizing unusual departures from the trend (figs. 3–9). These irregularities in shoreline movement can often be explained in terms of physical processes or human activities.

Distinguishing the actual trend of shoreline movement from "noisy" data is facilitated when the trend is uniform and the rate of change is so large that it cannot be confused by high-frequency beach cyclicity. On the other hand, this task of differentiation is extremely difficult for relatively stable beaches that experience large seasonal fluctuations and that are in transition with regard to reversals in long-term trend. This is especially true for some dynamic sandy beaches that were stable or accreting on geological time scales but are beginning to erode as a result of both natural and human-induced decreases in sediment supply and a rise in relative sea level (Morton, 1979).

Analytical problems associated with nonuniform and nonlinear shoreline changes are illustrated in figures 6–9, which show trend reversals that can be explained by examining historical documents and evaluating coastal processes. In figures 8 and 9, the rate of landward retreat of the shoreline between 1867 and 1937 is similar to the long-term erosion trend for this coastal compartment before navigation projects altered the littoral system. The reversal in trend at 1937 is the result of jetty construction at Brazos Santiago Pass that caused rapid outbuilding of the shoreline near the jetties. In this example, the 1991 shoreline is still far landward of the 1867 shoreline, but the most recent trend is accretion. Calculated net rates of change would erroneously indicate long-term erosion when clearly the most recent trend and predicted future trend is accretion.

Calculating Rates of Change and Future Predictions

Two assumptions are made when shoreline movement is analyzed, regardless of the sources of shoreline positions. First is the assumption that the state of shoreline stability does not change during each monitoring period. This assumption requires continuous beach erosion, accretion, or stability throughout the entire monitoring period without any reversals in trend. The second assumption is that the rates of change are also constant for the same period. This assumption rules out accelerations or decelerations in shoreline movement. If either or both of these assumptions is incorrect, the calculated rates of change probably underestimate the actual rates of change for the period of interest (Morton, 1978).

Coastal managers want to know the optimum period for monitoring beaches. Considering the diversity and dynamics of open coasts, it is not possible to determine this without some knowledge of local beach dynamics. Such decisions must be based on local factors including frequency of storms, overall rate of erosion, seasonal differences in beach shape, and economic considerations. Data obtained from long-term shoreline monitoring should be used to establish the beach stability for a particular shoreline segment. If the beach shape or trend of shoreline movement has not changed over the entire period of record and if for geological reasons that trend can be expected to continue, then the monitoring interval is not extremely critical unless the area is being rapidly developed. If, however, long-term shoreline monitoring indicates numerous reversals in trend, then the frequency of reversals might suggest an appropriate interval for future beach monitoring.

Net rates of shoreline change, based on the entire monitoring period (Table 2), are commonly calculated to summarize the overall direction and speed of shoreline movement. Net rates of change are useful for characterizing long-term trends and for establishing average rates of change, but calculations based on net shoreline changes clearly are not the best predictors of future changes. This is because the net change is a straight-line average determined by the first and most recent shoreline positions (figs. 4–9). The net change analysis does not provide for irregular changes in beach position (figs. 8 and 9) that are reported for many coastal areas.

COASTAL EROSION MODELS

Model Definitions

Now that coastal erosion and land loss are identified as important social issues, questions are asked about how much land will be lost in the future, where the shoreline will be at some particular time, which communities will be threatened by land loss, and how much land will be flooded if sea level continues to rise. To answer these questions, several methods (models) have been developed that project shoreline positions based on assumptions regarding past shoreline changes and estimated rates of future sea-level rise. It should be remembered that all the predictive models are limited because they are unable to anticipate significant changes in the factors that cause or control shoreline movement and therefore their forecasts may not be very accurate. Despite the uncertainties involved in the model results, some planners may want to use them because they provide a basis for making decisions that will influence future use and development of the coast.

Models that estimate future land loss can be either qualitative or quantitative. Non-quantitative predictions of coastal evolution and future shoreline positions are based on a general understanding of how nearshore environments respond to changing oceanic conditions. Geological and historical evidence clearly demonstrate that a rapid rise in sea level will cause narrowing of barrier islands, accelerate migration of transgressive barriers, convert uplands to wetlands, enlarge flood plains, and increase the area that would be inundated by storms of historical record.

Quantitative predictions of future coastal erosion and land loss rely on either *statistical models, geometric models*, or *deterministic models*. Even though all of these models have the same goal, they are based on completely different assumptions and input data. For example, statistical models do not attempt to understand the causes of shoreline change. Instead, they depend on making observations for such a long period that reliable projections can be made on the basis of historical records. Geometric models emphasize how beach slopes and shapes control profile evolution in response to increased water levels. Deterministic (numerical) models simulate sequences of events expressed as equations that represent observed physical conditions and processes. Even the deterministic models rely on statistical data such as wave characteristics, average beach profiles, and average sizes of beach sand. All of the analyses presented in Table 2 and in figures 4–9 use the statistical approach.

Statistical Models

Simple statistical models are used to reduce long-term historical shoreline change data to a single value (rate of change) that is then extrapolated to estimate future shoreline positions.

Dolan et al. (1991) summarized the most common linear analyses of shoreline movement and described the advantages and disadvantages of each technique.

Computer graphics programs can convert shoreline dates and positions to scatter diagrams (figs. 4–9) and also generate regression curves and equations representing the best statistical fit. When used properly, the least-squares equations are particularly helpful because they can be used to estimate a future shoreline position when the date (year 2050) or elapsed time (next 50 yr) is specified.

None of the linear time-averaging techniques used to analyze historical shoreline movement and to calculate rates of change are appropriate if actual trend reversals occur during the period of record (figs. 8 and 9). In those cases where trend reversals have occurred, the period of the most recent trend should be used for predictive purposes.

Projections of historical data are easy to make and understand but their predictive capabilities can be severely limited because (1) input data are empirical, site specific, and not broadly applicable because of morphological variability and diversity of coastal settings, (2) the analyses assume uniform (linear) shoreline responses even though they may be irregular (nonlinear), (3) statistical analyses can be strongly biased by data clusters and single anomalous shoreline positions, and (4) physical processes summarized in historical shoreline change records may not adequately represent future conditions. The most severe limitation of historical projections is that they are incapable of accurately predicting future responses if some factor is drastically altered. Predictions of climatic changes (Hoffman et al., 1983; National Research Council, 1987; 1990) clearly indicate that the rate of sea-level rise will probably accelerate and other factors such as sediment supply, and storm activity could invalidate the extrapolation of even recent erosion rates.

GEOLOGIC HISTORY OF SOUTH PADRE ISLAND

South Padre Island is a narrow, low-profile transgressive barrier that owes its origin to marine flooding and erosion of the Rio Grande delta. Climatically related reductions in sediment supply and subsidence of the delta plain during the past few thousand years have caused landward retreat of the Gulf shoreline and attendant formation of a flanking barrier-lagoon system. The modern migrating barrier overlies the foundered delta and is separated from the modern delta plain by Laguna Madre. Geomorphic analysis of aerial photographs and sub-bottom surveys of the inner continental shelf reveal that South Padre Island has experienced a long but sporadic history of migration. The entire landform abruptly moves landward during major storms and remains relatively stable during non-storm periods.

The landward migration of the barrier island is partly driven by a relative rise in sea level that has been recorded at tide gauges since the turn of the century (fig. 10). All the tide gauges in Texas show the same general variations in sea level that coincide with droughts and periods of abnormally high rainfall. They also show the relative rise in sea level averaging 3.3 and 6.3 mm/yr at Port Isabel and Galveston, respectively (Hicks et al., 1983). This rate of rise is about 3 to 4 times greater than the worldwide rise in sea level, which averages about 1.5 to 2 mm/yr (Gornitz and Lebedeff, 1987). Most of the relative rise in sea level along the northern Gulf of Mexico is caused by subsidence of the land surface (Swanson and Thurlow, 1973).

At the southern extremity of South Padre Island is Brazos Santiago Pass, a natural inlet that allows tidal exchange between the Gulf of Mexico and Laguna Madre. Jetty construction at Brazos Santiago Pass in 1935 altered wave refraction patterns, which resulted in erosion of sand stored offshore in the ebb-tidal delta. Sand eroded from the ebb-tidal delta was transported onshore, causing beach accretion on both sides of the inlet and stabilizing what had been an eroding segment of South Padre Island (Morton and Pieper, 1975; Paine and Morton, 1989).

Gradients of the shoreface and inner continental shelf are steeper off South Padre Island than at other sites along the Texas coast. The shoreface and inner shelf are covered with sand that

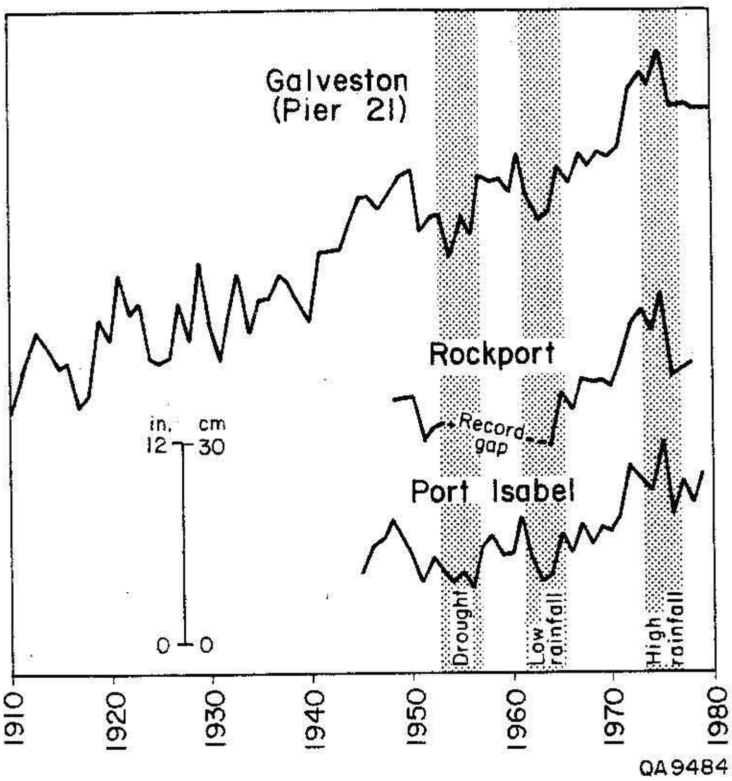

Figure 10. Records of tide gauges along the Texas coast.

is periodically transported onshore and blown landward to form dunes. Because the shoreline is oriented north-south and the winds generally blow from the southeast, littoral drift is normally to the north and waves approach the coast at a high angle. These conditions frequently cause migration of sand bars alongshore and make the shoreline irregular. At times during the winter, strong winds from the north drive littoral currents to the south. Also the counterclockwise circulation of hurricane winds drives littoral currents to the south. It is during these major flow events that sand accumulates on the north side of the jetty at Brazos Santiago Pass.

North of the developed area the island is characterized by a series of closely spaced washover channels and fans that lie about 3 ft above sea level and are devoid of vegetation because they are frequently flooded. These barren washover zones are separated by sparsely vegetated accretion mounds and dunes that locally increase the surface elevation.

The density of vegetation on the dunes, and thus their stability, is related to the climate of the area. The climate of South Texas is semiarid because the moisture released to the atmosphere by evapotranspiration greatly exceeds precipitation. In this area of low rainfall, salt-water marshes are rare, grasses are the climax vegetation on the barrier islands, and large active dunes cover the landscape, signifying the importance of dry blowing sand. Because rainfall is low, the area is susceptible to prolonged droughts such as those recorded in the 1930s and 1950s. The droughts weaken or kill the vegetation and create large active dune fields. From a coastal erosion perspective, these fields of active dunes represent a large volume of sand that is derived from the beach, blown across the barrier island, and deposited in the adjacent lagoon.

STATUS OF BEACHES AND DUNES, SOUTH PADRE ISLAND

Beach Stability

The most recent beach stability trends on South Padre Island were determined by comparing shoreline positions in 1982 and 1991 (Table 2). The most recent shoreline (1991) was also compared to former shorelines previously published by the Bureau of Economic Geology

(Morton and Pieper, 1975; Paine and Morton, 1989). The results of all three of the studies show that the southern end of South Padre Island is experiencing erosion, stability, or accretion depending on location with respect to the jetties at Brazos Santiago Pass. The most recent trends are similar to those established by the previous studies.

The shoreline movement data for South Padre Island are summarized in Table 2 and in figures 4–9. To facilitate comparisons, the measurement points used to illustrate shoreline movement (fig. 1, Table 2) have the same numbers as those published in the previous reports (Morton and Pieper, 1975; Paine and Morton, 1989). Although the measurement points are drawn on a map, they can be related to adjacent ground features as follows: (18) Andy Bowie Park south beach access road, (18A) Parade Drive, (19) Oleander Street, (19A) Pompano Street, (20) Saida Towers, and (21) Isla Blanca Park.

The plots of cumulative shoreline movement (figs. 4–9) illustrate the long-term trends and any reversals in shoreline movement that are opposite to the long-term trend. These plots also illustrate changes in the rates of shoreline movement. When examined in their proper numerical order along the coast, the plots reveal a history of shoreline changes that can be explained in terms of physical processes and human activities. At each transect there is a reversal in the trend or a change in the rate of shoreline movement after 1937. These adjustments in beach stability are related to jetty construction at Brazos Santiago Pass in 1935 and the trapping of sand by the jetties. The north jetty acts like a large terminal groin that causes sand deposition near the jetty and prevents transport of sand farther to the south.

Plots of cumulative shoreline movement at transects 18 and 19A (figs. 4 and 5) indicate continuous beach erosion for all periods of observation. Retreat of this beach segment has averaged about 12 ft/yr (Table 2), which is slower than the rates of erosion observed between 1867 and 1937. Transects 19 and 19A are in the transition zone where the beach was eroding before 1937, but since then it has been relatively stable or slightly accreting (figs. 6 and 7). For any given time period the beach at these sites may erode or accrete slightly, but the overall response has been one of dynamic equilibrium. This means that the shoreline has generally fluctuated around an average position. An exception to this trend is observed at transect 19A where the most recent shoreline movement (1982–1991) is anomalous rapid accretion (fig. 7). This anomaly is caused by the onshore migration of a sand bar and it does not signify an overall increase in sediment volume on that segment of the beach. Transects 20 and 21 also document a reversal in trend from erosion to accretion about 1937 and then moderate rates of accretion since then (figs. 8 and 9). The minor erosion recorded between 1982 and 1991 at transect 21 (fig. 9) is an ephemeral anomaly caused by a bar trough and does not represent a reversal in the trend of shoreline movement.

The only physical field evidence of beach erosion on South Padre Island is near transect 18A where a short section of a failed seawall remains. When it was built in 1962, this seawall was 1,500 ft long and 8 ft high. It was the second seawall built at the site and the beach was at the seawall when it was built (Morton, 1988). Now the beach is about 75 ft landward of the wall and the wall is acting like a small breakwater with an attached tombolo. When this part of the wall collapses or is removed, there will be no clear evidence of erosion on the beach.

The dry-beach width between the water and the dunes can also be used as an indicator of beach stability. This feature was measured at three undeveloped sites (Sea Vista, Kingfish Street, and Jupiter Lane) on five sets of aerial photographs taken between 1962 and 1991 (Table 3). The dry beach at Sea Vista ranges in width from 200 to 400 ft and is consistently the widest for any undeveloped segment of South Padre Island. At Kingfish Street dry-beach width is intermediate in value and ranges from 150 to 250 ft; however, at Jupiter Lane the beach is only 125 to 200 ft wide (Table 3). Comparing the alongshore dimensions, average dry-beach width decreases from 300 ft at Sea Vista to about 155 ft at Jupiter Lane. The northward decrease in average beach width is a result of long-term beach erosion and the orientation of the shoreline with respect to the building line. These dimensions provide average beach widths that can be used for designing beach replenishment projects.

Table 3. Dry-beach widths at undeveloped beach-front sites on South Padre Island.

Date	Sea Vista	Kingfish St.	Venus Ln.
July 1962	400	175	150
June 1967	200	150	125
May 1975	200	150	150
Dec. 1978	High water erosional phase		
July 1980	400	250	200
July 1991	200	175	125
Average	300	190	150

Dune Conditions

The oldest reliable topographic maps (1867) and aerial photographs (1937) all show that the dunes on South Padre Island were discontinuous and separated by washover channels before the island was developed. The two types of eolian dune complexes that form landward of the backbeach north of the city are the same as those that existed before the southern part of the island was developed. Stable foredune clusters up to 25 ft high are moderately well vegetated but discontinuous because washover channels create wide breaks in the dunes. These hummocky dunes occur in oval-shaped clusters that form the highest barrier elevations. These stable clusters of dunes also constrict storm floodwaters that flow through adjacent washover channels.

The second type of dunes are low, relatively young dunes that have accumulated since the last large storm. These low dunes form small fields of unstable sand near the shoreline after the washover channels are filled at their Gulf entrances. These sparsely vegetated to unvegetated active dunes attain heights from 3 to 15 ft and migrate at high angles to the barrier under the influence of northward eolian transport. Most of the active dunes are completely destroyed by severe hurricanes and they represent nearly all of the sand that is deposited on the lagoon side of the island in the washover fans.

Most of the foredunes on South Padre Island in the developed areas were either removed by construction or prevented from accumulating by beach scraping. An exception is the older dune cluster preserved just north of Isla Blanca Park. These foredunes have grown larger as a result of sand supplied from the accreting beach.

The beaches of South Padre Island are frequently scraped to remove the organic debris and inorganic litter that continuously washes in from the Gulf of Mexico. At different times, the sand and litter removed from the beach have been dumped in the surf zone or stored in the backbeach area. The sand and refuse placed in the backbeach have formed large, partly vegetated mounds that are located mainly in undeveloped areas between the buildings with seawalls. In 1980, Hurricane Allen obliterated the low mounds and accumulations of sand up to the seawalls and slightly landward of the walls where they terminated at undeveloped property. The existing mounds of sand have been constructed since then. The accumulation of sand has come from the removal of beach debris as well as the scraping of sand from in front of the seawalls to provide easy access to the beach.

The unobstructed paths from the seawalls to the Gulf of Mexico are also potential conduits for storm waters that normally would be blocked or at least impeded by the natural dunes of a barrier island. The large volume of sand stockpiled in the mounds between the buildings represents the equivalent of a substantial dune ridge that would protect the seawalls and buildings from storm damage. In South Carolina, the only beach-front structures that survived Hurricane Hugo were sheltered by large dunes. All of the seawalls in the storm impact area were overtopped and either extensively damaged or destroyed (Thieler and Young, 1991). Hurricane Allen was a much weaker storm than Hugo and yet it damaged or destroyed nearly all of the seawalls on South Padre Island. As in South Carolina, storm damage can be minimized by constructing dunes that are either high enough to prevent overtopping by storm waves or are wide enough that they are not completely eroded during the storm.

Distances were also measured between the seawalls and seaward edges of the sand mounds on South Padre Island (Plate 1 and Table 4). This was done to compare the sand mound distance with dry-beach widths and to determine the optimum position of dune reconstruction in those areas where dunes are absent. The sand mounds extend from 50 ft to 300 ft seaward of the seawalls and most of the distances are between 200 and 250 ft. The distances that the mounds extend from the seawalls are related to beach stability. The widest mounds of stockpiled sand are to the south where the beach is accreting or stable (Plate 1), whereas the distances decrease northward because the beach is eroding and narrower.

Table 4. Distances from seawalls to recommended dune reconstruction line and to Gulf edge of sand banks, South Padre Island.

Site	Description of Area	Distance to to Rec. Dune Line	Distance to Gulf Edge
1	Sea Vista 1 & 2 to Sheraton	25 ft.	150 ft.
2	Sheraton to Bridgepoint	50 ft.	200 ft.
3	Bridgepoint to Saida Towers	70 ft.	250 ft.
4	Saida Towers to Radisson	70 ft.	225 ft.
5	Breakers to dune front	80 ft.	200 ft.
6	Summit to dune front	dunes in place	300 ft.
7	Sunchase to dune front	90 ft.	200 ft.
8	Sangria to Padre South	dunes in place	210 ft.
9	Padre South to Marisol	75 ft.	225 ft.
10	Marisol to Regency	75 ft.	200 ft.
11	Regency to dune front	dunes in place	200 ft.
12	Suntide I to dune front	0 ft.	110 ft.
13	Aquarius to Padre Grand	35 ft	200 ft.
14	Edgewater to LaPlaya	25 ft.	200 ft.
15	Surf to Ocean Vista	25 ft.	150 ft.
16	Ocean Vista to Suntide III	25 ft.	125 ft.
17	Suntide III to Beach House	0 ft.	125 ft.
18	Beach House to Seamist	10 ft.	100 ft.
19	Palms to Castaways	dunes in place	150 ft.
20	Seville to Seagull	15 ft.	150 ft.
21	Seagull to Seabreeze I	25 ft.	100 ft.
22	Suntide II to Executive Nautilus	0 ft.	50 ft.
23	Executive Nautilus to Ocean View	0 ft.	100 ft.

DUNE RESTORATION OPTIONS

The main objectives of this task were to determine the optimum siting of reconstructed dunes and to make recommendations regarding the locations and types of dune restoration activities. The first objective was accomplished by examining predevelopment and recent aerial photographs and measuring average beach width for each beach segment. The measurements of predevelopment beach width were then compared with beach width measured on the 1991 aerial photographs (Plate 1) and observed on the ground. Judging from the natural dry-beach widths (Table 3) and the locations of low, young dunes in 1978 and 1980 (pre-Allen), the foredune complex should be constructed where the sand naturally accumulates and at least 200 ft landward of the high water line (Plate 1).

The most successful dune reconstruction projects take advantage of the sand-transporting capacity of the wind and the natural locations of sand accumulation. This means that the dunes may need to be reconstructed near the seawalls or slightly farther seaward depending on the stability of the beach. Constructing an artificial dune ridge too far seaward of the natural dune location is an invitation for failure since storm waves would easily erode the sand ridge. More important to dune stability is the continued supply of sand after the initial ridge is constructed. If the initial ridge is too far seaward of the natural dune line, then the dry-beach width will be too narrow to provide additional sand for dune growth. Failed dune ridges and beaches too narrow for dune development can be observed on the West Beach of Galveston Island (Morton and Paine, 1985).

It has been suggested that leaving a gap between the dune ridge and seawalls might allow dune overtopping by storm waves and thus cause more structural damage than if the ridge was constructed next to the walls. However, the primary reason for constructing the dune ridge next to the seawalls is that the ridge will be farther from storm waves and more beach and dune sand would be available for erosion before the supply of dune sand is exhausted.

There is a surplus of sand at the southern end of South Padre Island (between the jetty and transect 19) and a deficit farther to the north (between transects 19 and 18) and it appears that these conditions will persist in the foreseeable future. To utilize this locally abundant sand supply, beach scraping should be conducted so that sand is systematically transferred to the north. The cumulative volume of each beach scraping would supplement the natural sand accumulation once the artificial ridge is established. It is clear that the volume of sand moving onshore is sufficient to maintain a foredune complex. The total volume of sand removed from in front of the buildings and the width of the storage mounds is much greater than most foredune ridges that are able to withstand storm waves. However, the sand mounds are oriented perpendicular to the beach rather than being parallel to it.

There are several approaches that could be used on South Padre Island to combine beach maintenance operations with the natural processes so that a protective dune ridge is formed. The most expensive but quickest solution would be to redistribute the sand stored in the mounds forming a continuous ridge in a single season. This would require trucks and loaders to haul the sand from the mounds and to place it in the gaps between the mounds. The least expensive but slowest dune restoration effort would be to supplement the natural accumulation of sand with the sand and organic debris scraped from the beach. Another solution would be to concentrate dune restoration efforts at those sites that are most vulnerable to storm damage either because the beach is narrow or the buildings lack adequate structural protection. After Hurricanes Beulah and Allen, the foundations of some beach-front buildings on South Padre Island were undermined as a result of beach erosion. This same type of destruction has been observed after every major storm along the Gulf Coast or East Coast of the United States. A moderately large dune ridge could prevent or reduce this type of storm excavation and potential structural damage. By targeting structures at risk, the maximum temporary protection could be achieved with the least expenditure for dune restoration.

To provide the maximum protection from large waves and strong currents, the dune complex should eventually be about 10 to 12 ft high (above sea level) and about 75 to 100 ft wide at the base. These dimensions and attendant sand volume should survive most large storms and minimize the beach-front damage most frequently caused by direct wave attack (failed seawalls, destroyed swimming pools). Dunes this size will require adequate walkovers to prevent vegetation damage and weakening of the dunes by heavy pedestrian traffic. Dune walkover locations and dimensions should be coordinated with the master plans for dune restoration. They should be built at all entrances to the beach including private developments and points of public access. Walkovers should be high enough and long enough so they are not buried by migrating sand and will not interfere with the formation of new dunes.

Dune management policies for South Padre Island should encourage the stabilization of dune sand and prevent the removal of or interference with accumulated sand. Several methods have been developed to stabilize barren dunes and recently accumulated sand with grass plantings, organic mulches, and sand fences. Some of these dune stabilization techniques were tested and verified on the foredunes of Padre Island (Dahl et al., 1974; Dahl and Goen, 1977). The Texas General Land Office (1991) has prepared a manual that identifies the native dune plants in Texas and summarizes planting techniques and maintenance of transplanted vegetation. The manual also contains practical information on the use of sand barriers to attract sand and describes several designs for the construction of dune walkovers.

The location and methods used to create an artificial dune ridge would need to comply with policies adopted by the Texas General Land Office (TGLO). The proposed TGLO regulations may influence plans to reestablish a dune ridge along the southern part of the developed area where the sand may naturally accumulate more than 20 ft seaward of the seawalls. Extending a natural dune or filling in gaps between adjacent dunes is allowed under the existing regulations, but this provision probably would not apply to the large sand mounds constructed on South Padre Island that project far out on the beach and are less than 200 ft landward of the normal high water line. As previously stated, it would not be advantageous to build an artificial dune ridge that far out on the beach because the dune ridge would block the onshore transport of sand.

BEACH REPLENISHMENT OPTIONS

Sources of Sand

There are three local sources of beach quality sand that are suitable for nourishment of beaches on South Padre Island. One source is the material periodically dredged from the Gulf entrance to the Brownsville Ship Channel. This is probably the best source of sand for replenishment of South Padre Island beaches because most of the sediment is compatible with the beach sand, the dredging occurs frequently and will continue indefinitely, and disposal of dredged sand would provide the lowest cost method of placing sand on the beach. Maintenance dredging of the Ship Channel every few years by the Corps of Engineers could provide enough beach-replenishment sand so that additional sources would not be necessary to maintain the desired beach width. Utilizing the material provided by maintenance dredging would require advance planning of the sand volume needed and the locations where the sand would be placed. The beach replenishment design could be determined by the anticipated volume of sand that would be dredged from the channel. Records of past maintenance dredging at Brazos Santiago Pass (U.S. Army Corps of Engineers, 1992) could provide a basis for determining the composition and amount of dredged material and how frequently it would be available for beach replenishment.

The seafloor off South Padre Island, in the Gulf of Mexico, is a second locally available source of sand for beach replenishment. Foundation borings and surface sediment samples of the inner continental shelf show that thick sand deposits are located in about 50 ft of water (Morton and Price, 1987). Additional studies are needed to assess the quantity and quality of the offshore sand deposits and the potential environmental impacts of sand excavation, but preliminary data indicate an abundant supply of fine sand that would be compatible with existing beach sand. Sediment samples from Laguna Madre suggest that some material would be adequate for beach replenishment, depending on the location and depth of extraction. But not all of the material in Laguna Madre is suitable for beach replenishment because lagoon sediments typically contain some mud and shells that reduce the quality of the fill material. Sediment samples taken from Tompkins Channel along the lagoon side of the island in 1992 indicate a high proportion of mud at some sites (Shiner, Moseley and Associates, 1992). Muddy sediments either from Laguna Madre or nearby navigation channels could be used to build up the beaches of South Padre Island if it was later covered with beach-quality sand in the final stage of the project. Two-stage beach-replenishment projects are used at other coastal sites when adequate supplies of beach-quality sand are unavailable or if the two-stage design reduces the overall cost of the project. A disadvantage of this technique is the mud that is suspended in the ocean during the project and possible exposure of mud and shell on the beach after a storm.

The third local source of sand for South Padre Island is the island itself. Large volumes of sand are stored in the dune fields north of the developed area. This sand is entirely suitable for beach fill but it would be expensive to haul it from the mining site to the beach. Furthermore, mining of sand on barrier islands in Texas is restricted by State law and a large-scale sand mining operation would probably be prohibited.

Beach Replenishment Strategies

Several strategies can be employed to maintain the beaches of South Padre Island while at the same time reducing the costs of beach replenishment. One strategy would be to use the natural northward transport of littoral drift to feed the eroding part of the beach. The surplus of sand near Brazos Santiago Pass is already reducing the erosion rate at the northern end of the developed area, and additional sand placed in the transition zone could serve as a feeder beach for the eroding segment. This strategy would reduce the volume of sand placed on the beach at any one time and lower the cost of each replenishment, but it might also require more frequent replenishment to mitigate the erosion.

Direct placement of sand on the eroding segment is the most effective strategy to achieve specific beach dimensions. The advantage of the direct approach is that all the sand would be used to reestablish beach width and provide additional storm protection. A disadvantage of the technique is the long distance from Brazos Santiago Pass and the additional costs associated with booster pumps and pipes that would be required to place the sand on the beach. A moderately long slurry pipe from Brazos Santiago Pass could also cause minor disruption of recreational activities all along the pipe, which would extend most of the length of the developed area. Some dredges are designed to get near the shore and they have pumpout capabilities that can be used to place sand directly on the beach (Bruun and Willekes, 1992). However, this technique would require the use of very shallow draft dredges that may not be available in the Gulf of Mexico.

A relatively old technique, to take beach-quality sand dredged from ship channels and return it to the littoral system in a submerged berm, is being modified and improved by the Corps of Engineers. This indirect beach nourishment technique is being used in preference to the formerly accepted disposal method, which was to dump the dredged sand in deeper water in the Gulf of Mexico where it was unavailable to replenish nearby beaches. One test site of the submerged berm concept is off South Padre Island (McLellan, 1990). In January 1989, approximately 220,000 yd^3 of sand dredged from Brazos Santiago Pass and the Brownsville Ship Channel was placed in a submerged berm. The berm construction site was located about one mile north of the jetties because bottom-drifter surveys and other oceanographic information indicated that the sand could be transported northward and onshore to feed the beaches of South Padre Island. When completed, the berm was about 3,500 ft long and parallel to the shoreline in about 28 ft of water. Final height of the berm crest was about 4 ft above the seafloor or at a water depth of about 24 ft. Although the project design called for placement of the sand in shallower water depths, the hopper dredge used for the work had a loaded draft that prevented it from unloading in water less than 28 ft. Nearshore surveys conducted immediately after the berm was constructed showed initial onshore movement but the results of subsequent surveys are inconclusive because of the short history of the project.

Construction of a sand berm at water depths less than 15 ft would probably be much more successful for beach nourishment on South Padre Island than a berm constructed below the limit of fairweather wave base. The berm in 28 ft of water may provide some minor storm protection, but even greater protection could be achieved by direct placement of sand on the beach or construction of a berm in much shallower water.

BEACH AND DUNE MONITORING PROGRAM

Only a few studies of beach replenishment projects have been conducted where the original design and expected durability of the replenished beach were compared with what actually happened. The findings reported by Leonard et al. (1990) suggest that coastal engineers may be optimistic about how long replenishment projects will last before additional sand is needed to maintain a recreation beach. Underestimating the volume and frequency of beach replenishment has profound economic implications for local communities that are attempting to fund beach maintenance operations entirely on their own or with financial assistance from the Corps of Engineers. The inability to accurately predict the durability of replenished beaches is a result of limited field data and an incomplete understanding of how replenished beaches differ from natural beaches. Experience has shown that replenished beaches typically adjust to wave energy by rapidly losing volume. Some of this adjustment is related to wave sorting of the beach fill and removal of material that is generally finer than the natural beach sand. Overfilling is a technique used to compensate for the anticipated losses related to initial adjustment of the beach profile.

It has also been suggested that replenished beaches erode faster than natural beaches because the underwater profile is steeper after the fill has been added. Faster erosion reduces the durability of replenished beaches and requires renourishment more frequently than originally expected. Several beach nourishment projects on the East coast of the United States have only lasted a few months because strong winter storms eroded the beach and transferred the sand offshore. Similar risks are present in the Gulf of Mexico where a beach replenishment project could be destroyed in one year by a hurricane.

Too often, predictions about beach stability are made without the benefit of sufficient supporting evidence. Beach replenishment involves placing a large volume of sand and making the beach wider if not higher than it was before the project. Beach profiling typically is unable to provide accurate volumetric estimates of beach changes because the field measurements are of the exposed (subaerial) beach and not the more dynamic part which is under water (subaqueous). The lack of information about the subaqueous gains and losses in sand is one of the reasons why the behavior of replenished beaches is so uncertain. In the past the general approach to beach replenishment has been to conduct the project and then to try to understand the environmental impacts and economic implications. Today the operating philosophy of most coastal managers and scientists is to collect data before a replenishment project that will at least answer some of the fundamental questions about beach stability so that overly optimistic predictions about the success of beach replenishment can be avoided.

Avoiding unrealistic expectations for beach replenishment projects on South Padre Island means collecting site specific data on beach processes and fluctuations in beach volume. Systematic profiling of both the subaerial and subaqueous beach will be necessary to design a successful beach replenishment project. Several years of monthly data are needed to estimate the durability of replenished beaches and to determine the anticipated frequency of replenishment.

The present study represents the first step in developing an ongoing beach and dune monitoring program for South Padre Island. Continuation of this effort will require beach and dune surveying as well as periodic updating of shoreline position.

Task 1. Establish a beach and dune surveying program—The important decisions that need to be made before initiating the surveying program are summarized in Table 5. GPS surveys, coupled with GIS, are rapidly becoming the preferred method of monitoring the shore and relating that information to other spatial attributes such as property lines, buildings, utilities, roads, and environmentally sensitive areas.

Beach and dune surveying should be conducted frequently (monthly) during at least two nonstorm years so that the seasonal variability of beach elevation and volume can be established;

Table 5. Important decisions to make before establishing a beach and dune monitoring program. The options are ranked depending on the objectives and expected results of the monitoring program. The ranking progresses from a simple comparison of beach width to complete surveys of the beach surface suitable for three-dimensional estimates of volumetric changes.

A. Type of reference markers or baseline control- Existing uncontrolled features such as seawalls and sign posts, or controlled features such as surveyed stations and geodetic benchmarks.

B. Type of beach monitoring equipment- Compass and tape measure, graduated rods and chain, theodolite, electronic total station, Global Positioning System (GPS).

C. Type of beach survey- Dry beach width, beach profiles, tidal datum (mean high water line), or entire beach surface including subaqueous as well as subaerial profiles.

D. Frequency of beach surveys- Annual, semi-annual, or monthly depending on inferred beach stability and anticipated information requirements.

E. Training of personnel who are responsible for collecting field data.

F. Training of personnel who are responsible for analyzing and storing beach survey data (comparative profiles or surfaces), preparing shoreline change maps, tables, graphs, calculating volumetric changes, and determining sediment budgets.

G. Frequency of reporting the status of beaches and dunes- Annual or biannual reports on beaches (seasonal variability and storm response) and dunes (stability and extent of vegetation).

then at least once a year to maintain a record of annual fluctuations. The annual surveys should be conducted about the same time each year, usually in the summer. Summer surveys are conducted for two reasons: (1) it is the time of year when the beach reaches its maximum width as a result of onshore sand transport and (2) surveys conducted near the first part of August also have the potential of recording the prestorm conditions if a hurricane strikes. These measurements are critical to estimate beach losses and recovery from a storm.

Task 2. Update shoreline positions—This task requires several steps that are performed in sequence. The same sequence was followed for the current study of beach stability: (1) acquire the most recent low-altitude aerial photographs and map the shoreline; (2) transfer the most recent shoreline to a stable base and compare with the previous shoreline; (3) measure the distances between consecutive shorelines at selected transects and calculate the rates of change; (4) prepare representative plots of cumulative shoreline movement versus time; and (5) summarize beach stability for each beach segment.

Mapping from aerial photographs only needs to be done about every five to ten years unless the area is dramatically altered by a hurricane or some activity near the beach causes major changes in either coastal processes or sediment budget. Shoreline mapping is an independent way of keeping track of beach erosion and reestablishing control lines for regulatory and permitting purposes. When beach surveys are conducted with GPS equipment and processed in a GIS, they can provide rapid updates of shoreline position and projections of the 10-, 30-, and 60-year construction hazard zones that have been proposed by Federal Emergency Management Agency.

Specific recommendations for restoring dunes and stabilizing the beach of South Padre Island are made throughout the report and are summarized in Table 6. The recommendations emphasize beach and dune management activities that are currently regarded as the optimum practices for balancing the long-term demands for recreation, storm protection, and aesthetics. The costs of these activities are justifiable considering the importance of the beach-dune system to the local economy and the consequences of improper management, which can be observed along segments of the East Coast of the United States.

Table 6. Summary of recommendations for restoring dunes and maintaining beaches on South Padre Island

Dune Restoration

1. Prepare a dune restoration plan that will eventually provide a continuous dune complex high enough and wide enough to survive most storms.
2. Initiate construction of the foredune complex where sand naturally accumulates in the backbeach.
3. Promote the initial stabilization of barren sand in front of the seawalls using grass plantings, organic mulches, and sand fences.
4. Encourage the construction of dune walkovers at all entrances to the beach, including private developments and points of public access.

Beach Stabilization

1. Eliminate the removal of sand from in front of the seawalls and buildings.
2. Use the wet-beach scraping operations to progressively transfer sand from south to north.
3. Plan for and initiate an ongoing beach monitoring program that addresses seasonal fluctuations in beach volume, including the subaerial beach and shallow subaqueous beach.
4. Investigate the feasibility and costs of periodically placing sand dredged from navigation channels directly on the beach rather than in a submerged berm.
5. Encourage the Corps of Engineers to dispose of surplus dredged sand in relatively shallow water (<15 ft) so that it will provide better storm protection and possibly migrate onshore.

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