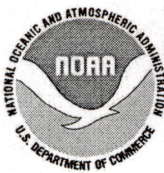# Texas Shoreline Change Project

Gulf of Mexico Shoreline Change from the Brazos River to Pass Cavallo

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Contents

Introduction

In June, Governor Bush signed into law the Coastal Erosion Planning and Response Act (CEPRA). This act provides $15 million over the next 2 years for coastal erosion projects. It authorizes the Texas General Land Office (GLO) to implement a comprehensive coastal erosion response program that can include designing, funding, building, and maintaining erosion projects. The GLO is named in the act as the entity that will monitor shoreline change rates with the assistance of the Bureau of Economic Geology and local governments. Through the Texas Shoreline Change Project (TSCP), the Bureau is working with the GLO to identify and quantify eroding areas. The TSCP is addressing requirements of the CEPRA regarding (1) identification of "critical coastal erosion areas," (2) monitoring of historical shoreline erosion rates, (3) making data accessible on the Internet, and (4) increasing public awareness of coastal erosion issues. The TSCP will be completed in stages according to Gulf of Mexico shoreline segment and bay systems. This report presents an analysis of shoreline change along the Gulf of Mexico Shoreline between the Brazos River and Pass Cavallo (Fig. 1). Other resources provided by the TSCP, including all data used in this report, may be found on the Internet at http://www.beg.utexas.edu/coastal/intro.htm.

Goals of the Texas Shoreline Change Project

The overall goal of the TSCP is to establish a state-of-the-art, regional, shoreline-monitoring and shoreline-change analysis program that will help solve coastal erosion and storm hazard problems along the bay and Gulf shorelines of Texas. When complete the TSCP will

(1) provide the GLO with a comprehensive, up-to-date, digital data base of historical shoreline positions and average annual rates of shoreline change and make the data available to the public through the Internet;

(2) provide a regional framework for conducting local studies related to specific erosion control projects;

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(3) provide data for assessing the susceptibility of the coast to episodic erosion and flooding by storms; and

(4) make available observations on the causes of shoreline change and make them understandable to the general public through the Internet and paper reports.

This report addresses a subset of these goals specifically for the Gulf of Mexico Shoreline between the Brazos River and Pass Cavallo.
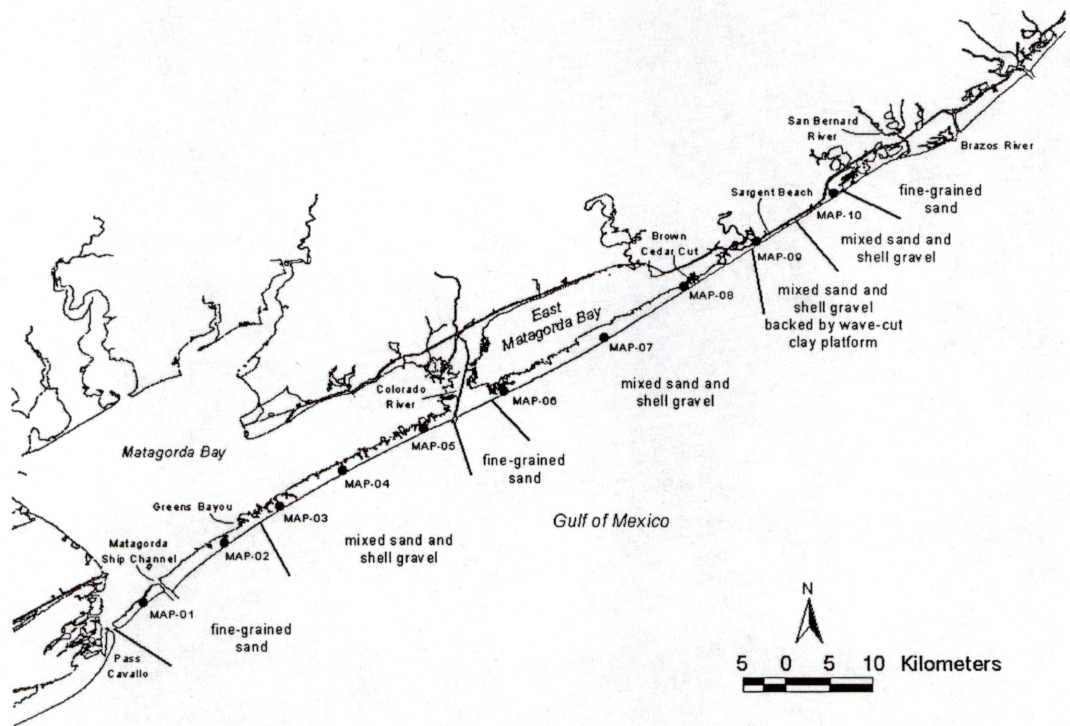

Figure 1. Gulf of Mexico Shoreline from the Brazos River to Pass Cavallo. Sediment characteristics and beach profile locations (i.e., MAP-01) are shown.

The Nature of Shoreline Change

The natural character of sandy beaches is to change shape constantly and to move landward (retreat) or seaward (advance). The changes are caused by changes in the forces that move the sand, namely wind, waves, and currents, and by the supply of sand. Short- and long-term relative sea-level changes also control shoreline movement. The setting of the shoreline and the supply of sand determine how the shoreline changes at a particular location. Setting refers to whether a beach is sheltered from waves, adjacent to a tidal or storm channel, or next to a jetty or seawall, to state a few examples. To understand and predict the rate of change, we need to distinguish between long-term, short-term, and episodic changes and to understand their causes. Long-term change occurs over tens to thousands of years, short-term change refers to movement occurring over several seasons to 5 or 10 years, and episodic change is that which occurs in response to a single storm.

Long-Term Change

We basically understand that it is the changing of sea level relative to the land and the increase and decrease in sand supply to the coast that cause the shoreline to retreat or advance over a period of about 50 years or more. The long-term rise in relative sea level along the upper Texas coast has moved the shoreline by simply inundating it and by shifting the action of waves and currents landward. Relative sea-level rise has also limited sand supply to the coast by drowning ancient river valleys and forming the coastal bays, such as Galveston and Matagorda Bays. Rivers that used to supply sand to the beaches now dump their sand at the heads of these bays where it is kept from reaching the open coast. The natural geologic setting has not much sand left offshore to resupply eroding beaches either. Generally the sand turns to mud less than about 4 km offshore (White et al., 1988, 1989). Thus the natural geological setting of the upper Texas coast has created a shoreline that is low in sand supply and that is undergoing long-term relative sea-level rise. For these reasons, the shoreline will continue to undergo long-term retreat unless human intervention prevails.

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Short-Term Change

Shoreline change that occurs over a few tens of years or less and that may be in the opposite direction of the long-term trend is difficult to understand and predict. These short-term shoreline changes can also be quite variable alongshore. One portion of the coast may be experiencing retreat while just a few kilometers away stable or advancing conditions may prevail. A shoreline that has retreated over the last 100 years may have experienced periods of shoreline advance, and this is the case for various periods and locations along Matagorda Peninsula since the 1930's. It is important, however, for coastal residents to understand that even though a particular beach may have been advancing or stable over the last several years, if it has been retreating for the previous decades, then retreat will eventually resume. An exception to this rule would be if something fundamental, such as a "permanent" increase or decrease in the sand supply, has changed in the system.

Episodic Shoreline Retreat

Shoreline retreat is not always a continuous and steady process with a little more of the beach eroded each year. Tropical storms and hurricanes along the upper Texas coast can move the shoreline more than 30 m landward in a day. There is often dramatic recovery for months and years following a storm, but it is usually incomplete, and the shoreline remains significantly landward of its prestorm position. Even though shoreline change rates are given as annual rates, they must be considered "average" annual rates. A particular shoreline with a long-term retreat rate of 2 m/yr would be expected to be 120 m landward in 60 years. A single storm, however, could cause much of this movement.

Previous Work

Scientists at the Bureau of Economic Geology have been mapping historical shorelines and determining shoreline change rates since the early 1970's. Three Bureau publications that discuss at least portions of the shoreline from the Brazos River to Pass Cavallo precede this work. They are Morton and Pieper, (1975), Morton, et al., (1976), and Paine and Morton, (1989).

Methods

Airborne LIDAR Survey and Extraction of 2000 Shoreline

Airborne LIDAR (LIght Detection and Ranging) surveys of the shoreline from Pass Cavallo to the Brazos River were conducted on May 28 and 29, 2000. Airborne LIDAR is a new technique to obtain highly accurate and detailed topographic measurements of the Earth's surface. LIDAR surveys involve combining a scanning laser, a device that records aircraft motion, and Global Positioning System (GPS) receivers. LIDAR can acquire beach surveys with vertical precision from 8 to 15 cm and data-point spacing less than 1 m. From these data, a shoreline may be extracted for use in shoreline change analyses.

The LIDAR surveys were conducted using an Optech ALTM 1225 instrument. The ALTM was installed in a Cessna 206 single engine airplane operated by the Texas State Aircraft Pooling Board. The GPS ground reference station was installed at Jetty Park at the mouth of the Colorado River. The aircraft was navigated along the shoreline using a video camera with the same look direction as the LIDAR instrument. Four passes were made at altitudes of 450 to 750 m, depending on cloud cover. A swath of data extending about 400 m inland was acquired. This swath covered the shoreline, dunes, and ocean-front structures.

A digital elevation model (DEM) with a 1.5 m × 1.5 m grid was constructed from the LIDAR data points. LIDAR data are collected using a GPS reference frame, which means heights are measured relative to an ellipsoid. Heights above the ellipsoid (HAE) must be converted to heights above a sea-level datum before a shoreline can be extracted from the DEM. Therefore, a grid of the GEOID99 geoid model was subtracted from the DEM to transform the HAE grid to a grid that conforms to sea level. Although the transformed grid should be parallel to sea level, it will not necessarily coincide with local sea level. The height of the water level along the beach, as displayed in the transformed grid, was compared with water levels recorded by the open-coast tide gauges at Pleasure Pier on Galveston Island and Bob Hall Pier on north Padre Island during the time of the survey. This comparison allowed the correlation of grid heights to heights relative to a

local tidal datum. Comparison of ground-surveyed beach profiles and the wet/dry line as shown by LIDAR intensity data, which were acquired at the same time as the LIDAR topography data, were used to pick 1 m above mean sea level as the level to represent the shoreline. The transformed DEM was contoured and the +1-m contour line extracted as the shoreline. This shoreline corresponds to earlier shorelines mapped using aerial photography but is much more rigorous in its definition and an order of magnitude more accurate in its position.

Historical Shoreline Mapping

Shorelines from the 1930's, 1956, 1965, 1974, and 1991 were mapped using black-and-white vertical aerial photographs at a scale of 1:24,000 or larger. Mapping shorelines from aerial photographs is a two-step process. First, the shoreline feature is identified and traced on the photograph; second, the shoreline is transferred to a common base map. The shoreline feature used in the photographs was the boundary between wet and dry sand evident by a tonal contrast. This boundary represents the upper reach of the wave swash during the preceding high tide and is less susceptible to daily changes in ocean water levels, which are not related to shoreline changes, than the water line.

Stereo viewing and optical magnification of photographs aided the identification and tracing of the wet/dry boundary on the photographs. After the shorelines were drawn directly on the photographs or on overlays, they were transferred to a common base map. The common base maps are the U.S. Geological Survey, 7.5-minute quadrangle maps that have a scale of 1:24,000. A zoom-transfer scope was used to optically register the photographs and base maps. The shorelines were drawn directly onto the base maps, with only the relatively undistorted central portions of the photographs being used. For this study, the 1974 and 1991 shorelines were mapped from Sargent Beach to Pass Cavallo. Other shorelines were mapped previously by Morton and Pieper (1975) and Morton et al. (1976), and were checked during this study for consistency in interpreting the shoreline feature on the photographs and for accuracy in the transfer to the base map. Crowell et al. (1991) determined that error involved in locating relative positions of shorelines taken from aerial photographs is about 8 m.

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Geographic Information System (GIS)

All shoreline data were compiled into ArcView GIS software. Shorelines that were transferred onto hardcopy base maps from the historical photographs were digitized. The digitized shorelines from the LIDAR survey were also transferred to ArcView. Once in the GIS, the shorelines were compared against each other for consistency. They were also overlain on digital orthophotos produced by the Texas Orthoimagery Program to help determine proper registration. At many base map boundaries, shorelines did not match. This problem is caused by lack of control on one-half of the base map during transfer of the shorelines from the photographs. In some cases, base maps were spliced together to prevent these offsets during the photograph-to-base-map transfer. In other cases, lines were merged across base map boundaries in the GIS. The historical and projected 2060 shorelines may be viewed and downloaded from the Texas Shoreline Change Project Web site (http://www.beg.utexas.edu/coastal/intro.htm).

Calculation of Average Annual Rate of Shoreline Change and Projection of 2060 Shoreline

Shoreline data were exported from ArcView and analyzed by the Shoreline Shape and Projection Program (SSAPP) developed by the Bureau of Economic Geology. SSAPP automatically draws a segmented baseline that follows the trend of the historical shorelines. Transects that intersect the shorelines are constructed perpendicular to this baseline. Distances between the shoreline positions along each transect are determined, and in this study a linear regression model was used to calculate the average annual rate of shoreline change. A baseline segment length of 400 m was used so that shoreline curvature could be adequately defined. Transect spacing was 50 m. The 2060 shoreline was projected along each transect by multiplying the shoreline change rate by 60 years and moving this distance along the transect line away from the 2000 shoreline.

Beach Profiles

From June 27, 2000, to June 30, 2000, topographic ground-survey transects were conducted at 10 locations along the shoreline between the Brazos River and Pass Cavallo (Fig. 1, Appendix). The transects are oriented perpendicular to the shoreline and extend

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from landward of the dunes to about 1.5 m water depth. These transects, or "beach profiles," provide data for checking the accuracy and calibration of LIDAR data. They also provide data on the geomorphology and sediment and vegetation characteristics needed to interpret LIDAR data. The ground surveys can be repeated frequently to detect short-term shoreline changes.

Before the field survey was conducted, transect locations were selected. Ten locations were spaced equally along this stretch of Gulf shoreline with at least one transect on Point Decros between the Matagorda Ship Channel and Pass Cavallo and one on the seawall at Sargent Beach. The approximate coordinates of the selected transects were used with real-time differential GPS to navigate to the proposed transect site.

Two of the monument locations were preexisting monuments established by the United States Army Corps of Engineers. Temporary markers were installed at the other eight locations because there were no stable structures. The reference points for all of the transects were determined by using a GeoExplorer Global Positioning System receiver connected to an Omnistar receiver, which produced differentially corrected position data. Navigation back to the marker locations will be possible using real-time differential GPS. Beach profiles were measured using a Sokkia Set 5W Electronic Total Station and a reflecting prism. Vegetation, sediment type, and geomorphic features were noted along each transect line.

Plots of the transects include designation of the datum marker, vegetation line, wet/dry line, and water line at the time of the survey. Also included on the data plots is the location of approximate mean high water. Mean high water was determined by examining tide gauge data from Pleasure Pier on Galveston Island and Bob Hall Pier on north Padre Island. The tidal data were referenced to mean high water at each location. Approximate location of mean high water on the transects was determined by the offset of the water level from mean high water at the time the position of the water line was obtained for each transect.

Physical Setting

Waves and Tides

The Gulf of Mexico Shore from the Brazos River to Pass Cavallo is a microtidal, wave-dominated coast in the classification of Hayes (1979). Tides are chiefly diurnal, with a diurnal range of 0.65 m at the Pleasure Pier open-coast tide gauge on Galveston Island (Conrad Blucher Institute, Texas A&M University–Corpus Christi, Texas Coastal Ocean Observation Network, http://tcoon.cbi.tamucc.edu/). As determined from 20 years of hindcast data, mean significant wave height (Hs) at a location 40 km southeast of the Colorado River Entrance in 26 m water depth is 1.0 m, with a mean peak wave period (Tp) of 5.7 s (Hubertz and Brooks, 1989, station number 9). The hindcast data show that mean Hs varies from 0.8 m in August to 1.1 m from November through March and 1.2 m in April. Waves from the southeast are the most common, occurring 64% of the time, and have the highest mean Hs of 1.1 m and a mean Tp of 6.1 s.

The hindcast study did not include waves generated by tropical cyclones. The study area, however, is greatly affected by both tropical storms and hurricanes. Tide records from the bay side of Galveston Island show that storm surges exceeded 1.2 m about every 5 years from 1908 to 1983 (Morton and Paine, 1985). In a hurricane hindcast study that included storms occurring from 1956 to 1975, the return interval for a Hs of 5.1 m was determined to be 5 years (Abel et al., 1989, station number 9).

Littoral Drift

The U.S. Army Corps of Engineers (1985) used Summary of Synoptic Meteorological Observations (SSMO) data to estimate littoral drift rates in the study area. Ten years of SSMO data provided deep-water wave statistics that were then transformed to alongshore wave energy flux at 17 locations between Sargent Beach and Sabine Pass. Observational data and a wave gauge verified the wave energy flux determinations. The energy data were converted to littoral drift rates and combined with drift caused by wind-generated currents to determine gross and littoral drift rates and directions. The net overall littoral drift at Sargent Beach was determined to be to the southwest at about

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64,000 m³/yr. Gross transport rate due to waves only was calculated as 249,000 m³/yr. The calculated southwesterly net littoral drift is confirmed by the impoundment of sand on the northeast jetties protecting Matagorda Ship Channel and the Colorado River entrance.

Geologic Evolution

The southeast Texas coast consists of sandy, transgressive and regressive barrier islands, spits, and beaches (Morton, 1979). Transgressive shoreline deposits occur at headlands formed of delta-plain sediments of the Holocene Brazos-Colorado delta and the Pleistocene Trinity delta. Brazos River delta deposits formed a headland between East Matagorda Bay and West Bay of the Galveston Bay system, and the Trinity River delta deposits formed a headland between High Island and Sabine Pass. These headlands probably protruded seaward much more 3,500 years ago, when sea level approached its present level (Frazier, 1974), than they do today (Morton, 1977). Since sea-level "still stand" (3,500 years ago), the headlands eroded and sediment dispersed to the interdeltaic areas, forming prograding spits and regressive barrier islands. This process created the relatively linear shoreline configuration present today (Morton, 1979).

Headland and Modern Delta Shoreline

The beaches and dunes from the Brazos River to Sargent Beach are formed on the ancient Brazos-Colorado deltaic headland. Superimposed on this old headland is the modern Brazos River delta. This delta is an arcuate, wave-dominated delta that protrudes 2 km into the Gulf of Mexico. It began forming in 1929 when the Brazos River was diverted from the Freeport channel to its present location (U.S. Army Corps of Engineers, 1992). No jetties are at this new Brazos River entrance, but the episodic supply of sand to the coast has had a profound impact on shoreline change in the immediate vicinity of the Brazos River and for at least 8 km to the southwest at the San Bernard River entrance. Multiple beach ridges associated with the Brazos River delta progradation, spit progradation and downdrift shoreline offset associated with the San Bernard River entrance, and fine-grained-sand beaches characterize this shoreline. Farther to the southwest toward Sargent Beach, overwash processes prevail and the beaches are mixed

sand and shell gravel. Holocene delta-plain deposits are often exposed in scarps in the Sargent Beach area. In places, mixed sand and shell gravel beaches are backed by a wave-cut clay platform. Profile locations MAP-09 and 10 (Appendix) show small dunes fringing shelly washover platforms. The U.S. Army Corps of Engineers recently constructed a granite rip-rap revetment behind the beach. The revetment is designed to protect the Intra Coastal Waterway when the shoreline retreats and intersects it.

Matagorda Peninsula Shoreline

Matagorda Peninsula from Sargent Beach to Pass Cavallo is a low-lying transgressive barrier spit that has been modified by the maintenance of navigation channels at the Colorado River entrance and the Matagorda Ship Channel. In 1929, the removal of a log jam on the Colorado River allowed a delta to prograde across East Matagorda Bay. In 1936, a channel dredged across the peninsula allowed the river to discharge directly to the Gulf of Mexico (McGowen and Brewton, 1975). In 1990, the U.S. Army Corps of Engineers completed the construction of jetties on each side of the river entrance and dredged a 61-m-wide, 4.6-m-deep entrance channel. The northeast jetty extends 610 m offshore and has a weir section adjacent to the beach that allows littoral sand to pass into an impoundment basin (U.S. Army Corps of Engineers, 1992). Sand caught in the basin is periodically dredged and placed on the beach southwest of the entrance. In 1993, the U.S. Army Corps of Engineers constructed a diversion channel that directs the flow of the Colorado River into East Matagorda Bay. The former river channel is now a navigation channel connected with the Intra Coastal Waterway.

The construction of the Matagorda Ship Channel across Matagorda Peninsula began in 1962. The entrance channel dredging and jetty construction were completed in 1966. The jetties on each side extend about 975 m seaward from the preconstruction shoreline. The entrance channel extends 6,096 m offshore and is designed to be 91 m wide and 11.6 m deep. Pass Cavallo is a natural entrance separating Matagorda Peninsula from Matagorda Island to the southwest. The construction of the ship channel, however, has affected Pass Cavallo's stability, and it is undergoing shoaling.

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The entire peninsula is subject to complete inundation during tropical storms and to channeled washover. Roughly 45 storm washover channels have been mapped. These storm washover areas and channels are sites that will most likely reactivate during future storms. There are two areas along the peninsula that are less susceptible to washover than the rest. These are from the Matagorda Ship Channel to about 10 km northeast and from the Colorado River to about 5 km northeast. Sand accumulation against the Matagorda Ship Channel jetty is partly responsible for the formation of wide and high dunes, which prevent washover (see beach profile MAP-02). Northeast of the Colorado River entrance, two dune lines have formed probably in response to sediment supplied by the Colorado River. In these areas of relatively abundant sand supply and less washover activity the beaches are fine-grained sand (Fig. 1). Where washover is relatively common, the beaches are mixed sand and shell gravel, and the beach profile typically consists of a small dune fringing a washover platform (see beach profile MAP-07). There are two storm surge/tidal inlet channels that are open often and long enough after storms to be named on published maps. These channels are called Greens Bayou and Brown Cedar Cut. Both of them were closed during the 2000 survey, but an unnamed channel 4 km northeast of Brown Cedar Cut was open (Fig. 1).

Average Annual Rate of Shoreline Change

The purpose of calculating the average annual rate of shoreline change is to provide an indication of likely future changes. Therefore, shorelines from a time before permanent and significant engineering changes were made are not used in the calculation. From Pass Cavallo to Green's Bayou, only the 1974, 1991, and 2000 shorelines are used in the calculation. The significant alteration of the sediment budget by the construction of the Matagorda Ship Channel in the 1960's and its likely permanence precludes using earlier shorelines. Rates along the remaining shoreline from Greens Bayou to the Brazos River are calculated using 1930's, 1950's, 1965, 1974, 1991, and 2000 shorelines. Shorelines earlier than 1930 are not used because of the significant changes in sediment budgets brought about by the alterations of the Brazos and Colorado Rivers, as just described. The 1990 jetty construction at the Colorado River entrance will not

significantly affect long-term shoreline change because of the periodic sediment bypassing. Therefore, shorelines prior to 1990 are used in this area.

Figure 2 is a plot of the long-term average annual rate of shoreline change. High shoreline advance rates northeast of Pass Cavallo are related to spit progradation toward the southwest as the pass shoals. Just to the northeast and adjacent to the southwest jetty of the Matagorda Ship Channel, however, the shoreline is retreating at a rate of about 4.5 m/yr. Adjacent to the northeast jetty, the shoreline is advancing about 7.5 m/yr. The rate of shoreline advance decreases away from the jetty toward the northeast to Greens Bayou. From Greens Bayou to 2.6 km southwest of the Colorado River, the shoreline is retreating at a rate of 0.5 m/yr to about 2 m/yr. There is a broad area in the middle of this shoreline segment with a lower retreat rate that is not directly related to engineering structures. Southwest of the Colorado River the shoreline displays long-term advance. This advance is at least partly related to sediment supplied by the river, sand bypassing across the entrance jetties, and wave sheltering by the jetties and offshore bathymetry.

Northeast of the Colorado River the shoreline is relatively stable and even shows long-term advance in an area 13 km to the northeast. From that point toward the northeast, retreat rates increase to more than 4 m/yr. They remain at about 4 m/yr from 8 km southwest of Brown Cedar Cut to just northeast of the "cut," where they increase dramatically to more than 8 m/yr along Sargent Beach. This alongshore pattern of shoreline retreat does not appear to be directly related to engineering activities. Spikes at Brown Cedar Cut and the unnamed cut are caused by the opening and closing of these ephemeral channels. Shoreline change rates are not reliable at these locations.

From Sargent Beach to the Brazos River, shoreline retreat chances to shoreline advance of more than 21 m/yr. This trend has been caused largely by the influx of sand from the diversion of the Brazos River in 1929. Shoreline change rates in the vicinity of the new delta are not as reliable as elsewhere because the system is still adjusting to the new sediment supply.
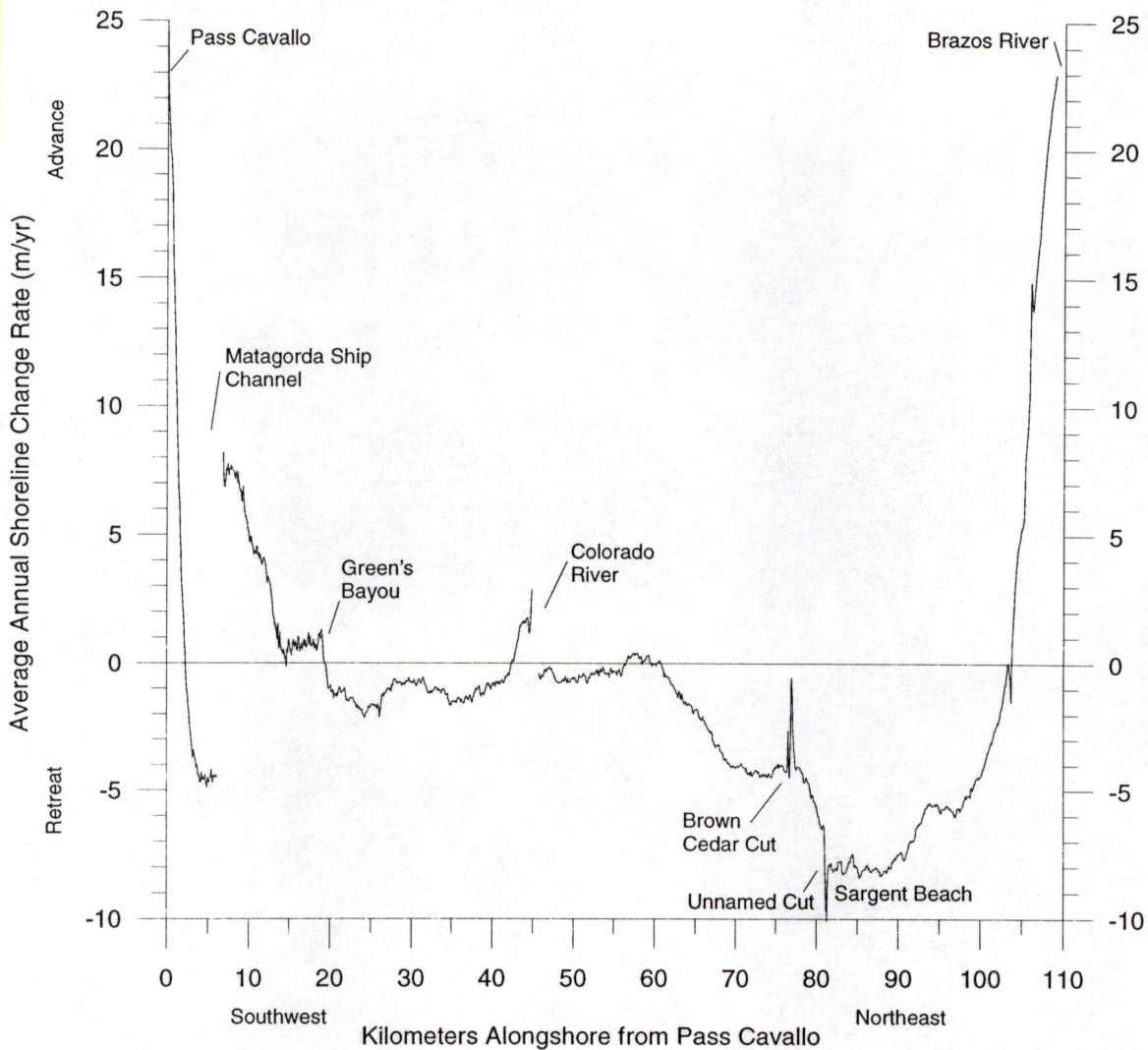
Figure 2. Long-term average annual rate of shoreline change.

Discussion and Conclusions

There are several scales of alongshore variability in the average annual rate of shoreline change. Engineering modifications at the Matagorda Ship Channel, the Colorado River, and the Brazos River cause the largest alongshore shifts in shoreline change by "permanently" (time scale of 50 years or more) altering the sediment budget. The diversion of the Brazos River in 1929 and the dredging of the Colorado River to allow discharge into the Gulf of Mexico for the period from 1936 to 1993 have supplied sand and caused shoreline advance in the downdrift (southwest) direction. The jetties at Matagorda Ship Channel have caused dramatic shoreline advance on the updrift

(northeast) side but retreat on the downdrift (southwest) side. From 1956 to 2000 there was 751 hectares (1,858 acres) of land gained, all of which is related to engineering modifications. During this same period, however, there was 1,150 hectares (2,843 acres) of land lost, which means there was a net loss of 399 hectares (985 acres). The land loss is related to the downdrift effect of the Matagorda Ship Channel jetties and the overall naturally erosional state of the coast. Shoreline retreat, which will intersect the Sargent Beach revetment/seawall in approximately 20 years, will cause a reduction in sand supply to downdrift beaches, and enhanced shoreline retreat will be the result.

There are smaller amplitude alongshore variations in the rate of shoreline change that are not directly related to engineering structures. The 10-km stretch of shoreline with a relatively lower retreat rate between the Matagorda Ship Channel and the Colorado River is an example (Fig. 2). These variations may be caused by wave refraction patterns or geologic setting. Future research should address these patterns.

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Appendix

Plots of beach profiles and data tables.

MAP-01 (Matagorda Peninsula)
27 June 2000 (1040)

vegetation line
wet/dry line
water line (1150)
~mean high water
datum

vertical exaggeration=10:1

MAP-02 (Matagorda Peninsula)
28 June 2000 (1114)

vegetation line
wet/dry line
water line (1206)
~mean high water
datum

vertical exaggeration=10:1

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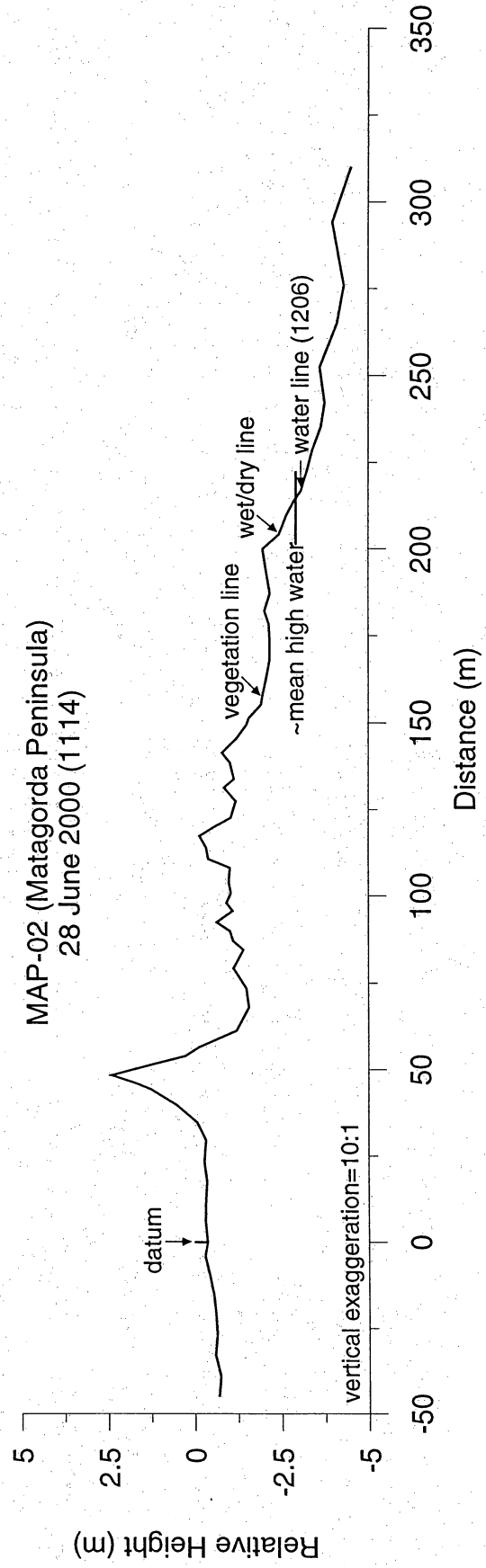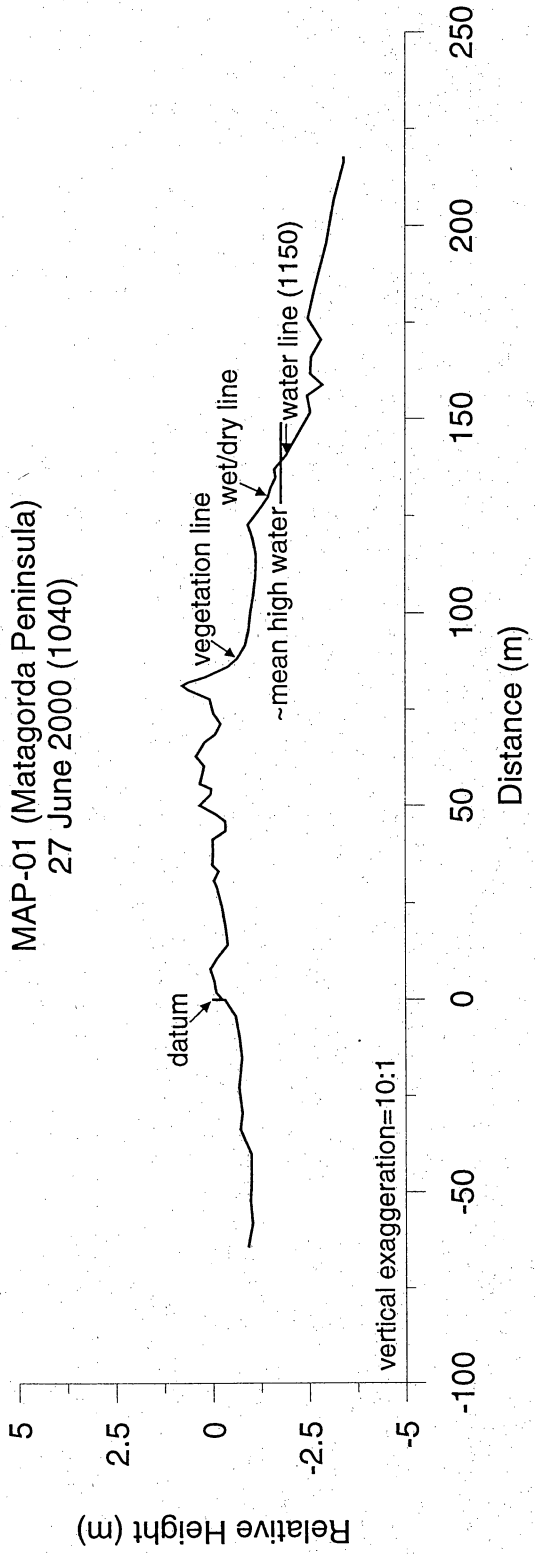
MAP01   Datum Latitude: 28° 24' 42.33078" N
           Datum Longitude: 96° 21' 12.08681" W
           Azimuth: 146° True North

X (m)	Z (m)	Beach feature	X (m)	Z (m)	Beach feature
-63.95	-0.92		71.26	-0.22	
-58.10	-1.03		73.90	-0.05	
-52.27	-0.98		77.67	0.05	
-46.23	-1.00		80.05	0.61	dune crest
-40.32	-1.00		81.12	0.75	
-33.80	-0.72		81.95	0.62	
-29.33	-0.77		83.37	0.17	
-22.88	-0.68		86.05	-0.41	vegetation line
-15.29	-0.76		88.11	-0.65	
-9.60	-0.69		91.59	-0.86	
-4.39	-0.60		95.58	-0.95	
-0.10	-0.33		100.12	-1.01	
0.00	0.00	datum	104.76	-1.08	
0.03	-0.25		109.88	-1.14	
1.84	-0.11		114.87	-1.14	
4.91	-0.05		119.33	-1.06	
7.92	0.05		122.62	-0.93	berm crest
10.75	-0.13		127.11	-1.27	
14.23	-0.40		129.79	-1.46	wet/dry line
18.89	-0.34		132.15	-1.53	
24.06	-0.26		134.76	-1.65	
28.92	-0.13		136.86	-1.61	berm crest
30.77	-0.05		138.76	-1.78	~mhw
33.08	-0.17		140.43	-1.93	water line
34.77	-0.01		146.03	-2.24	
37.76	-0.03		151.56	-2.55	
41.27	-0.02		155.83	-2.47	
43.41	-0.36		158.74	-2.87	
45.82	-0.34		161.64	-2.56	
47.63	-0.10		166.00	-2.58	
49.97	0.31		170.48	-2.84	
52.79	0.03		175.98	-2.50	
54.22	0.01		184.77	-2.69	
55.55	0.31		195.37	-2.97	
60.08	0.20		206.59	-3.17	
62.76	0.41		216.38	-3.43	
66.51	0.19		217.39	-3.42	
68.51	-0.08				

MAP02   Datum Latitude: 28° 28' 17.39698" N
            Datum Longitude: 96° 15' 24.91151" W
            Azimuth: 148° True North

X (m)	Z (m)	Beach feature	X (m)	Z (m)	Beach feature
-44.72	-0.70		110.51	-0.41	
-39.04	-0.75		113.75	-0.36	
-32.87	-0.60		117.18	-0.17	dune crest
-26.76	-0.64		119.70	-0.56	
-20.97	-0.61		122.51	-1.06	
-15.55	-0.56		127.28	-1.21	
-10.00	-0.45		131.19	-0.87	
-4.06	-0.31		133.70	-1.16	
-0.06	-0.38		138.41	-1.05	
0.00	0.00	datum	141.25	-0.82	dune crest
0.04	-0.37		145.47	-1.23	
5.67	-0.32		149.35	-1.52	
11.30	-0.34		151.23	-1.58	
17.65	-0.37		155.16	-1.93	
23.43	-0.29		157.45	-1.97	vegetation line
29.50	-0.35		162.81	-2.08	
34.64	-0.08		167.98	-2.18	
39.66	0.51		173.19	-2.19	
44.17	1.25		178.22	-2.15	
46.05	1.70		181.97	-2.03	berm crest
48.24	2.40		186.96	-2.19	
51.34	1.26		192.71	-2.09	
53.95	0.25		199.78	-1.99	berm crest
56.48	-0.15		203.94	-2.45	wet/dry line
61.31	-1.23		209.41	-2.66	
67.94	-1.58		213.37	-2.86	
73.45	-1.50		214.10	-2.91	~mhw
79.14	-1.14		216.58	-3.08	water line
84.39	-1.42		222.49	-3.25	
86.92	-1.14		228.40	-3.40	
89.81	-1.04		235.27	-3.65	
92.24	-0.66		242.13	-3.76	
95.55	-1.12		252.28	-3.61	
97.82	-0.95		264.89	-4.10	
100.64	-1.07		275.79	-4.31	
103.68	-1.01		294.00	-3.98	
107.92	-1.04		309.73	-4.50	

MAP-03 (Matagorda Peninsula)
28 June 2000 (1352)

vegetation line

wet/dry line

water line (1434)

~mean high water

datum

vertical exaggeration=10:1

Relative Height (m)

Distance (m)

MAP-04 (Matagorda Peninsula)
28 June 2000 (1610)

vegetation line

wet/dry line

water line (1640)

~mean high water

datum

vertical exaggeration=10:1

Relative Height (m)

Distance (m)

21
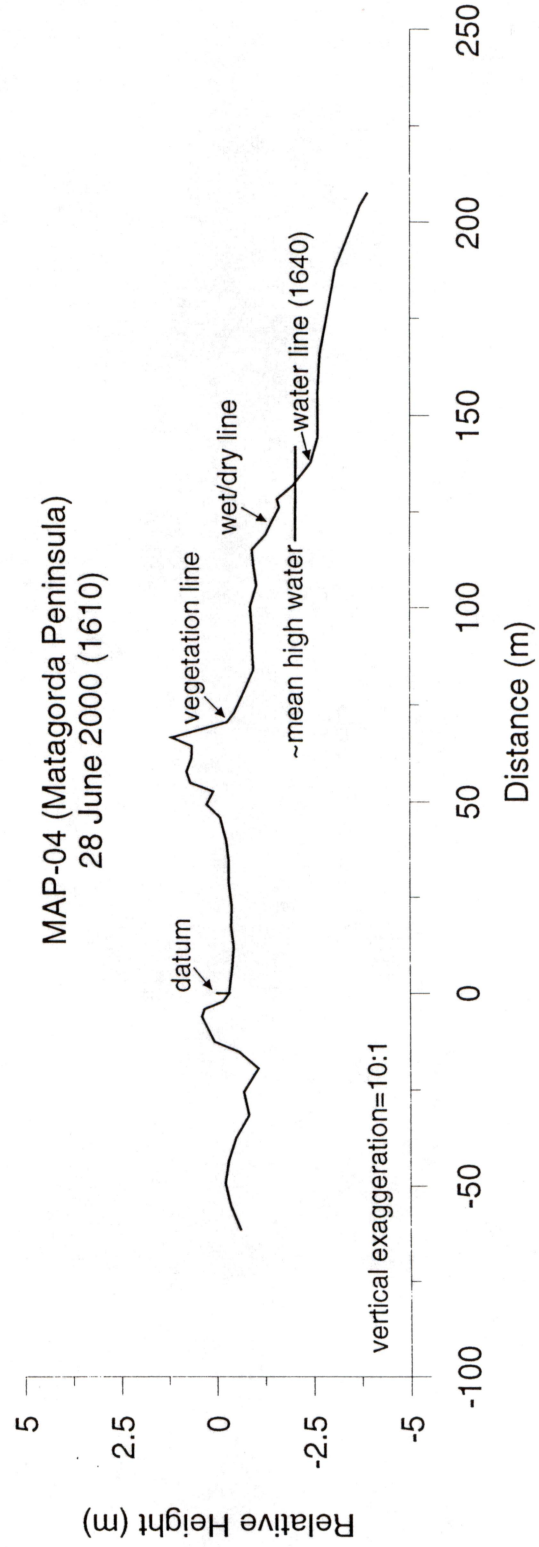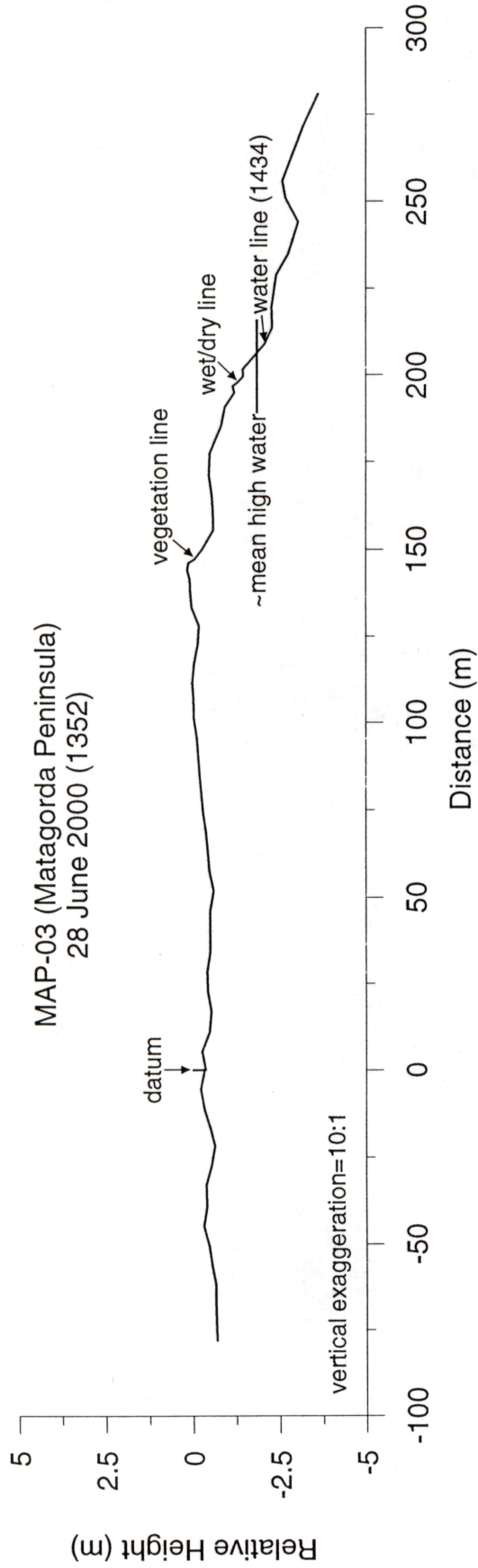
MAP03   Datum Latitude: 28° 30' 26.27398" N
Datum Longitude: 96° 11' 25.14888" W
Azimuth: 150° True North

X (m)	Z (m)	Beach feature	X (m)	Z (m)	Beach feature
-78.17	-0.69		111.66	-0.01	
-72.80	-0.68		117.05	-0.06	
-67.42	-0.66		122.69	-0.17	
-61.77	-0.66		128.03	-0.20	
-56.51	-0.56		133.39	0.00	
-50.85	-0.48		138.25	0.05	
-44.87	-0.32		141.27	0.06	
-39.08	-0.41		144.07	0.14	
-33.01	-0.39		146.14	0.10	
-27.25	-0.55		147.22	-0.08	vegetation line
-21.76	-0.64		150.10	-0.31	
-16.94	-0.52		155.52	-0.62	
-11.43	-0.34		160.67	-0.61	
-5.57	-0.23		165.40	-0.58	
-0.02	-0.35		171.01	-0.49	
0.00	0.00	datum	177.36	-0.51	berm crest
0.03	-0.38		185.12	-0.84	
5.30	-0.28		190.64	-0.96	berm crest
11.02	-0.49		194.73	-1.23	
16.88	-0.55		196.62	-1.18	berm crest
22.68	-0.44		197.78	-1.33	wet/dry line
28.44	-0.43		199.43	-1.47	
34.13	-0.52		201.53	-1.47	berm crest
40.01	-0.52		205.43	-1.80	
46.09	-0.52		205.89	-1.84	~mhw
51.88	-0.62		208.89	-2.10	water line
57.64	-0.49		213.59	-2.31	
63.01	-0.45		219.66	-2.29	
68.49	-0.40		228.92	-2.43	
73.93	-0.32		234.86	-2.77	
79.35	-0.27		244.04	-3.05	
84.75	-0.22		250.87	-2.70	
90.51	-0.18		255.76	-2.60	
95.88	-0.14		271.66	-3.20	
101.30	-0.06		280.82	-3.61	
106.58	-0.05				

MAP04   Datum Latitude: 28° 32' 30.98611" N
Datum Longitude: 96° 06' 52.75765" W
Azimuth: 152° True North

X (m)	Z (m)	Beach feature	X (m)	Z (m)	Beach feature
-61.22	-0.62		61.22	0.63	
-55.12	-0.37		64.29	0.63	
-49.28	-0.23		66.51	1.16	
-43.43	-0.32		70.45	-0.29	vegetation line
-37.39	-0.51		72.76	-0.48	
-31.54	-0.84		78.48	-0.74	
-25.48	-0.71		83.85	-0.97	
-19.47	-1.09		89.44	-0.94	
-15.14	-0.59		94.73	-0.93	
-12.53	0.05		100.14	-0.89	
-9.15	0.23		105.82	-1.06	
-6.10	0.37		110.83	-0.98	
-4.16	0.31		115.12	-0.95	berm crest
-2.13	-0.18		119.01	-1.29	
-0.01	-0.34		121.48	-1.41	wet/dry line
0.00	0.00	datum	126.08	-1.64	
0.05	-0.34		128.24	-1.58	berm crest
6.55	-0.42		131.73	-1.98	
11.89	-0.45		132.24	-2.02	~mhw
17.25	-0.39		137.76	-2.45	water line
22.79	-0.41		144.35	-2.63	
28.67	-0.34		152.12	-2.63	
34.26	-0.33		156.30	-2.63	
39.83	-0.27		165.77	-2.70	
45.86	-0.10		174.59	-2.86	
49.27	0.24		187.86	-3.10	
52.60	0.07		204.25	-3.73	
54.84	0.66		207.33	-3.91	
57.71	0.77				

MAP-05 (Matagorda Peninsula)
28 June 2000 (1745)

vegetation line

wet/dry line

water line (1825)

~mean high water

datum

vertical exaggeration=10:1

MAP-06 (Matagorda Peninsula)
29 June 2000 (1010)

vegetation line

wet/dry line

water line (1100)

~mean high water

road   datum

vertical exaggeration=10:1

24
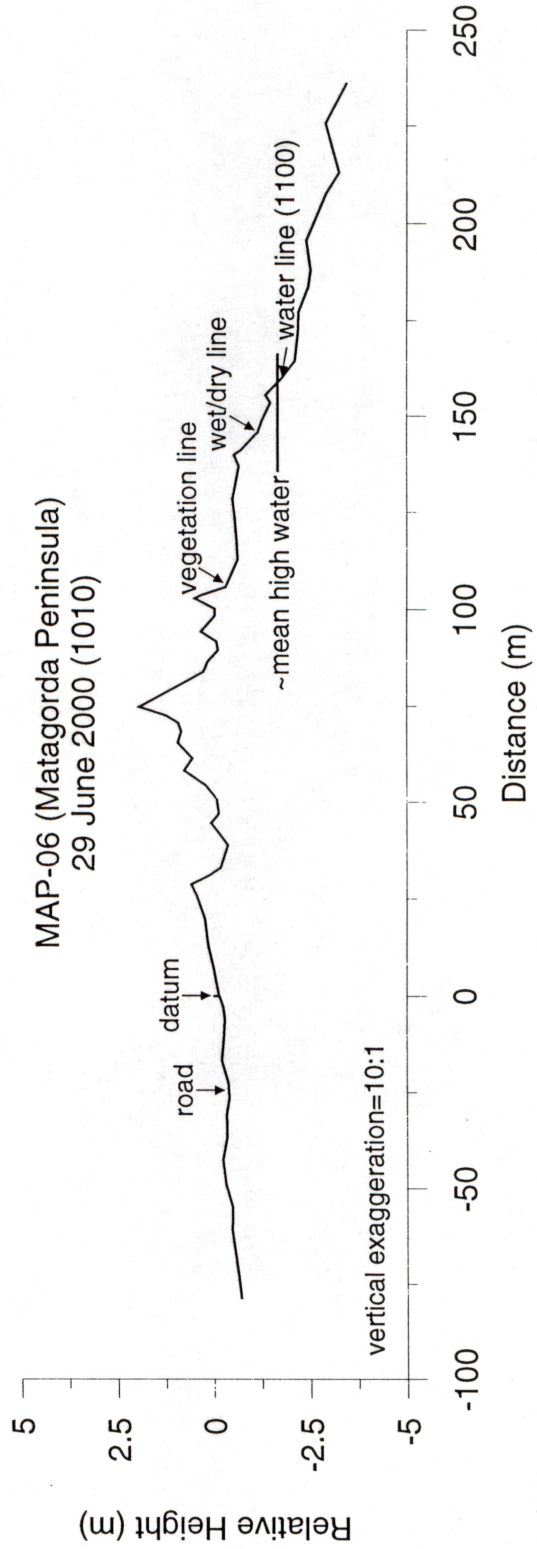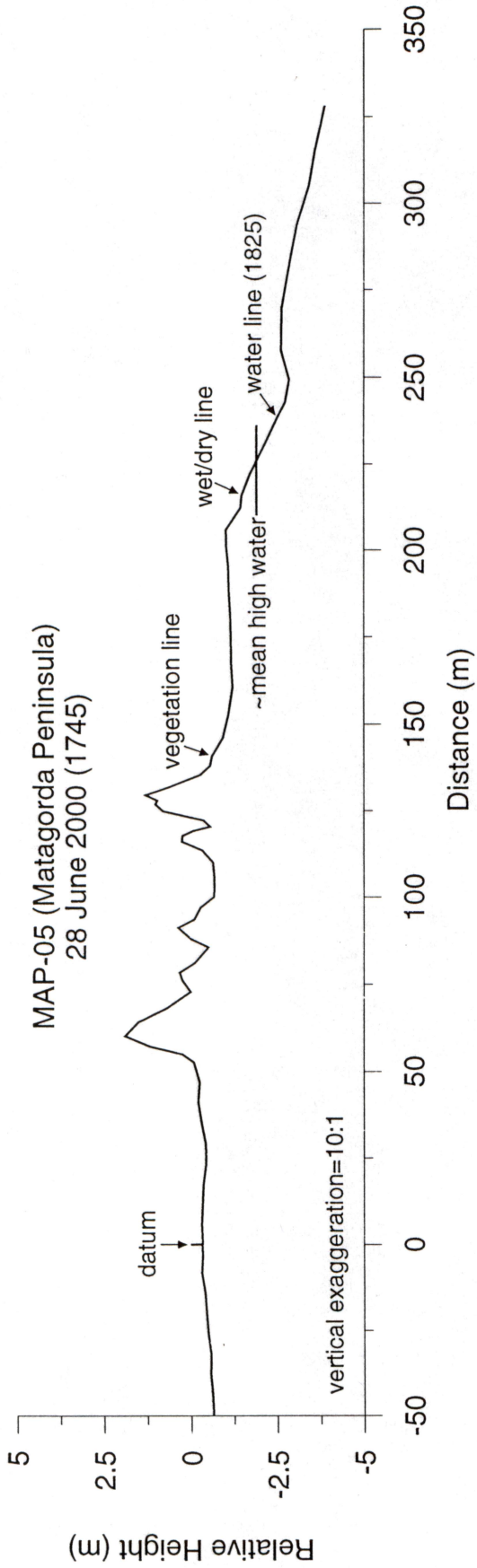
MAP05   Datum Latitude: 28° 35' 00.03843" N
Datum Longitude: 96° 01' 05.98699" W
Azimuth: 160° True North

X (m)	Z (m)	Beach feature	X (m)	Z (m)	Beach feature
-49.66	-0.64		116.02	0.24	
-43.75	-0.61		117.69	0.22	dune crest
-37.96	-0.57		119.14	-0.08	
-32.06	-0.58		120.41	-0.56	
-26.25	-0.50		122.20	-0.38	
-20.01	-0.46		124.91	0.78	
-14.03	-0.41		126.89	1.00	
-8.25	-0.32		127.94	0.95	
-3.13	-0.35		129.57	1.28	
-0.04	-0.33		131.83	0.61	
0.00	0.00	datum	135.42	-0.28	
0.09	-0.34		138.01	-0.58	
5.83	-0.31		140.80	-0.63	vegetation line
11.51	-0.34		146.13	-0.94	
17.26	-0.36		152.58	-1.10	
23.24	-0.45		160.50	-1.23	
28.94	-0.44		167.20	-1.18	
34.84	-0.32		173.90	-1.18	
41.06	-0.22		181.09	-1.16	
46.89	-0.26		188.01	-1.12	
52.65	-0.09		194.95	-1.11	
54.99	0.24		200.91	-1.04	
57.21	1.17		205.83	-1.03	berm crest
60.24	1.88		212.21	-1.46	
64.20	1.49		215.78	-1.49	wet/dry line
68.18	0.68		221.91	-1.73	berm crest
72.83	-0.01		227.20	-1.99	~mhw
76.08	0.23		227.61	-2.01	
78.34	0.31		231.54	-2.20	
81.18	-0.13		238.34	-2.52	water line
85.58	-0.52		242.72	-2.74	
87.94	-0.02		249.23	-2.86	
91.21	0.35		257.66	-2.63	
93.61	-0.11		269.81	-2.64	
97.05	-0.29		283.55	-2.89	
100.15	-0.68		293.79	-3.08	
105.36	-0.69		305.10	-3.42	
110.04	-0.66		315.18	-3.59	
113.54	-0.34		327.84	-3.87	

MAP06   Datum Latitude: 28° 37' 11.89520" N
               Datum Longitude: 95° 55' 18.81184" W
               Azimuth: 155° True North

X (m)	Z (m)	Beach feature	X (m)	Z (m)	Beach feature
-78.61	-0.71		78.28	1.29	
-72.62	-0.65		79.35	1.09	
-66.91	-0.57		83.90	0.26	
-60.91	-0.49		86.51	0.14	
-54.89	-0.49		89.44	-0.12	
-48.79	-0.31		91.69	-0.08	
-42.60	-0.24		94.29	0.33	
-36.70	-0.35		96.09	0.16	
-30.60	-0.34		98.36	-0.04	
-26.49	-0.41		100.08	-0.04	
-22.54	-0.38		102.77	0.49	dune crest
-16.68	-0.22		103.52	0.33	
-10.74	-0.27		105.71	-0.31	
-5.97	-0.29		106.41	-0.35	vegetation line
-2.76	-0.25		112.78	-0.64	
-0.07	-0.15		118.28	-0.60	
0.00	0.00	datum	123.34	-0.56	
0.02	-0.14		128.37	-0.50	
6.95	-0.01		136.78	-0.67	
13.31	0.15		139.81	-0.54	berm crest
19.88	0.23		141.08	-0.73	
25.69	0.44		145.12	-1.10	
28.77	0.58		145.65	-1.16	wet/dry line
31.10	0.11		148.76	-1.27	berm crest
33.17	-0.20		153.34	-1.48	
38.89	-0.37		155.42	-1.36	berm crest
42.00	-0.14		158.41	-1.64	~mhw
44.51	0.05		159.90	-1.78	water line
46.96	-0.14		164.40	-2.12	
50.71	-0.09		171.58	-2.19	
54.23	0.20		177.14	-2.21	
58.16	0.77		183.66	-2.46	
61.28	0.55		187.86	-2.51	
65.41	0.94		195.52	-2.41	
68.25	0.84		207.50	-2.92	
70.54	0.92		212.95	-3.25	
72.47	1.24		225.60	-2.91	
74.72	1.95		235.89	-3.44	

MAP-07 (Matagorda Peninsula)
29 June 2000 (1248)

vegetation line
wet/dry line
water line (1327)
~mean high water
road
datum
vertical exaggeration=10:1

Relative Height (m)
Distance (m)

MAP-08 (Matagorda Peninsula)
29 June 2000 (1458)

vegetation line
wet/dry line
water line (1547)
~mean high water
datum
vertical exaggeration=10:1

Relative Elevation (m)
Distance (m)

27
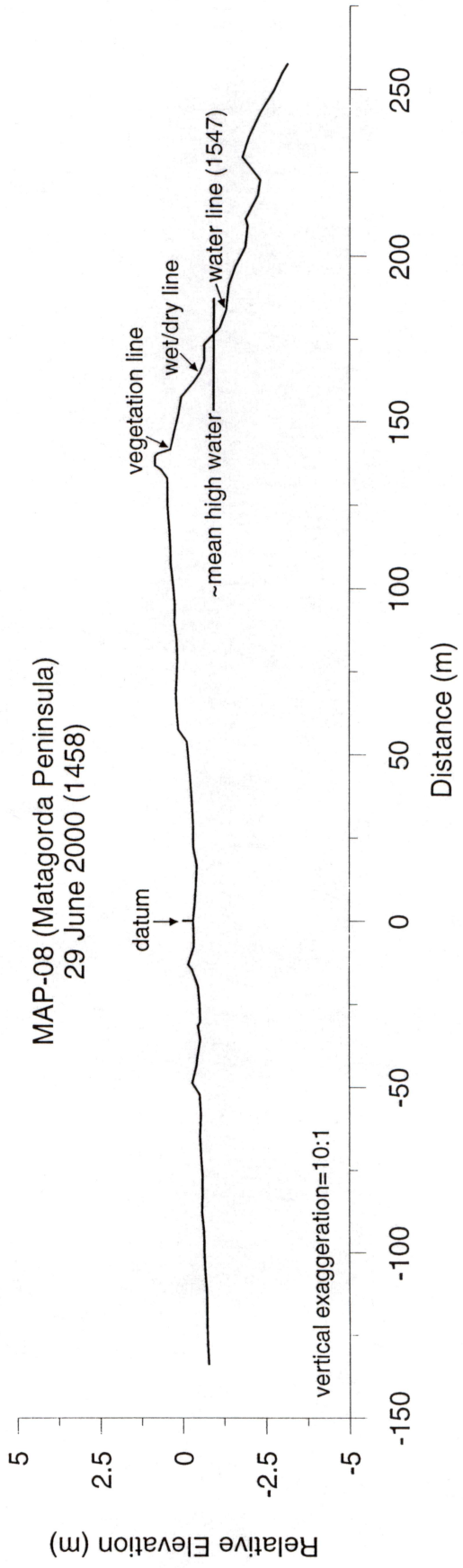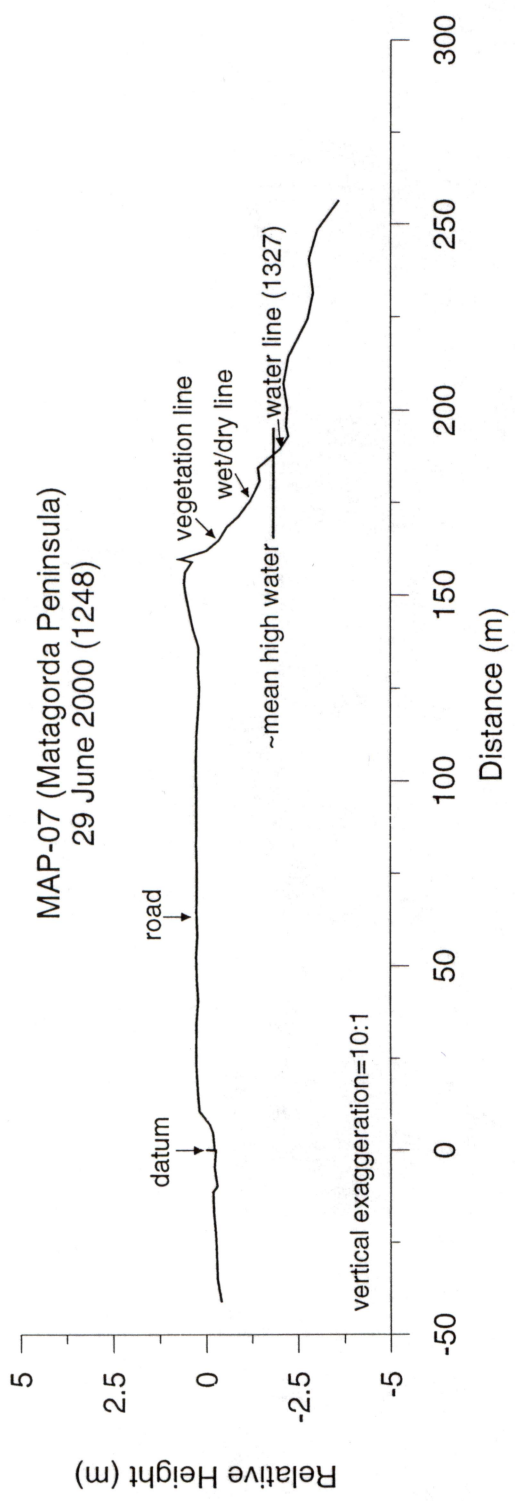
MAP07   Datum Latitude: 28° 40' 20.96790" N
         Datum Longitude: 95° 48' 06.67428" W
         Azimuth: 152° True North

X (m)	Z (m)	Beach feature	X (m)	Z (m)	Beach feature
-40.90	-0.40		118.39	0.20	
-34.89	-0.30		124.61	0.17	
-28.80	-0.28		130.47	0.21	
-22.86	-0.26		135.86	0.20	
-16.89	-0.21		141.19	0.36	
-11.27	-0.20		146.64	0.47	
-9.68	-0.30		150.43	0.55	
-4.71	-0.22		153.17	0.58	
-0.04	-0.26		156.01	0.56	
0.00	0.00	datum	158.74	0.37	
0.05	-0.23		159.62	0.70	dune crest
4.65	-0.19		161.86	-0.02	
6.85	-0.09		164.61	-0.35	vegetation line
10.51	0.18		168.26	-0.57	berm crest
16.07	0.23		171.12	-0.89	
22.84	0.27		174.33	-1.12	
28.09	0.26		175.40	-1.21	wet/dry line
34.84	0.25		178.52	-1.36	
40.48	0.21		180.87	-1.47	
46.04	0.25		184.33	-1.42	
52.23	0.26		187.72	-1.81	~mhw
58.32	0.23		189.46	-2.01	water line
61.67	0.24		192.96	-2.24	
64.46	0.25		195.60	-2.18	
70.36	0.24		200.41	-2.21	
75.85	0.24		207.03	-2.12	
82.41	0.26		214.09	-2.24	
88.84	0.25		224.28	-2.76	
95.03	0.25		231.33	-2.91	
100.38	0.27		240.43	-2.80	
106.14	0.26		248.37	-3.03	
112.22	0.26		256.08	-3.58	

MAP08   Datum Latitude: 28° 43' 22.00497" N
         Datum Longitude: 95° 42' 23.41616" W
         Azimuth: 152° True North

X (m)	Z (m)	Beach feature	X (m)	Z (m)	Beach feature
-133.71	-0.78		73.59	0.17	
-128.32	-0.76		79.16	0.16	
-122.82	-0.74		84.38	0.18	
-116.87	-0.74		89.54	0.25	
-111.22	-0.73		94.87	0.24	
-105.66	-0.68		99.90	0.29	
-99.76	-0.66		105.15	0.34	
-93.84	-0.65		107.04	0.36	
-87.81	-0.59		111.88	0.38	
-82.19	-0.61		116.94	0.41	
-76.62	-0.61		120.95	0.43	
-70.68	-0.57		124.60	0.47	
-64.87	-0.53		129.75	0.47	
-58.60	-0.55		132.69	0.47	
-52.30	-0.51		135.40	0.68	
-48.78	-0.29		136.59	0.85	
-43.49	-0.42		139.40	0.85	foredune crest
-41.09	-0.45		140.27	0.76	
-35.69	-0.54		141.44	0.38	vegetation line
-31.56	-0.46		146.62	0.27	
-30.33	-0.54		151.95	0.13	
-25.10	-0.52		157.27	0.05	berm crest
-19.57	-0.47		161.62	-0.32	
-14.48	-0.28		164.64	-0.53	wet/dry line
-13.06	-0.17		168.12	-0.66	
-7.67	-0.34		173.19	-0.66	berm crest
-2.70	-0.33		175.74	-0.89	~mhw
-0.02	-0.32		178.29	-1.12	
0.00	0.00	datum	183.57	-1.30	water line
0.05	-0.32		191.17	-1.38	
5.26	-0.37		196.81	-1.59	
11.06	-0.41		202.60	-1.88	
16.68	-0.44		209.04	-1.95	
22.14	-0.33		211.06	-1.89	
27.53	-0.33		218.04	-2.26	
33.01	-0.31		222.67	-2.33	
38.44	-0.27		229.44	-1.80	
44.22	-0.22		235.39	-1.98	
50.26	-0.17		242.75	-2.33	
53.76	-0.12		249.70	-2.74	
57.41	0.14		254.75	-2.97	
62.66	0.18		257.39	-3.13	
68.22	0.20				

MAP-09 (Sargent Beach)
30 June 2000 (0943)

road datum vegetation line
wet/dry line
~water line(1030)
~mean high water

vertical exaggeration=10:1

Relative Height (m)

Distance (m)

MAP-10 (Sargent Beach)
30 June 2000 (1248)

road vegetation line 1
vegetation line 2
wet/dry line
water line (1335)
~mean high water

datum

vertical exaggeration=10:1

Relative Height (m)

Distance (m)

30
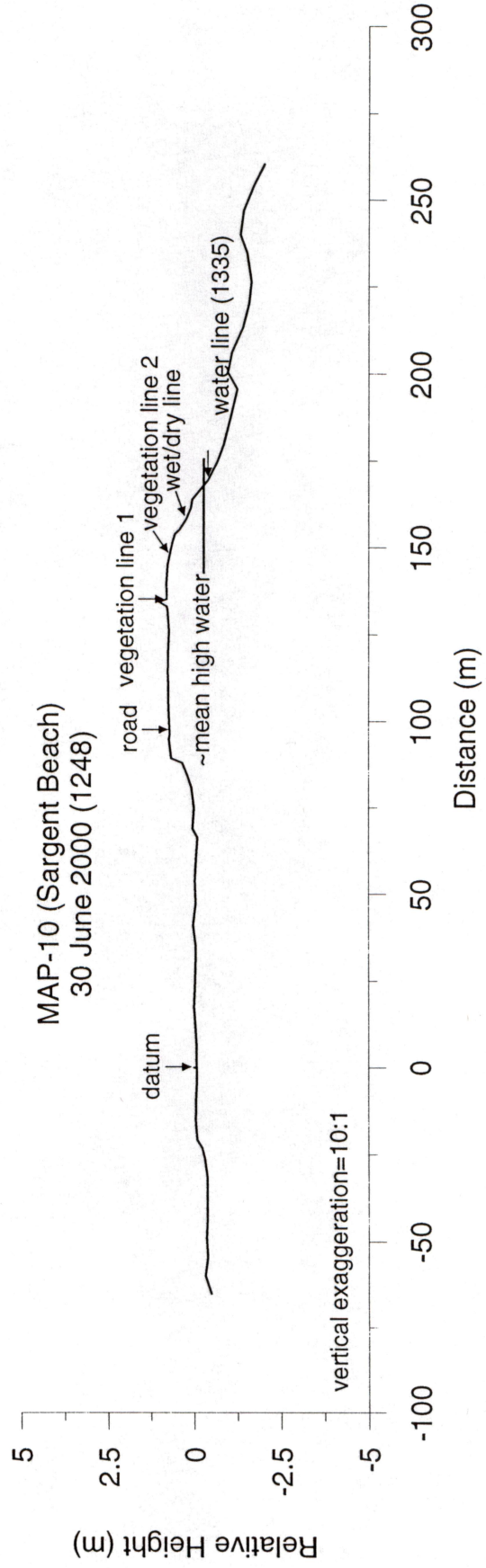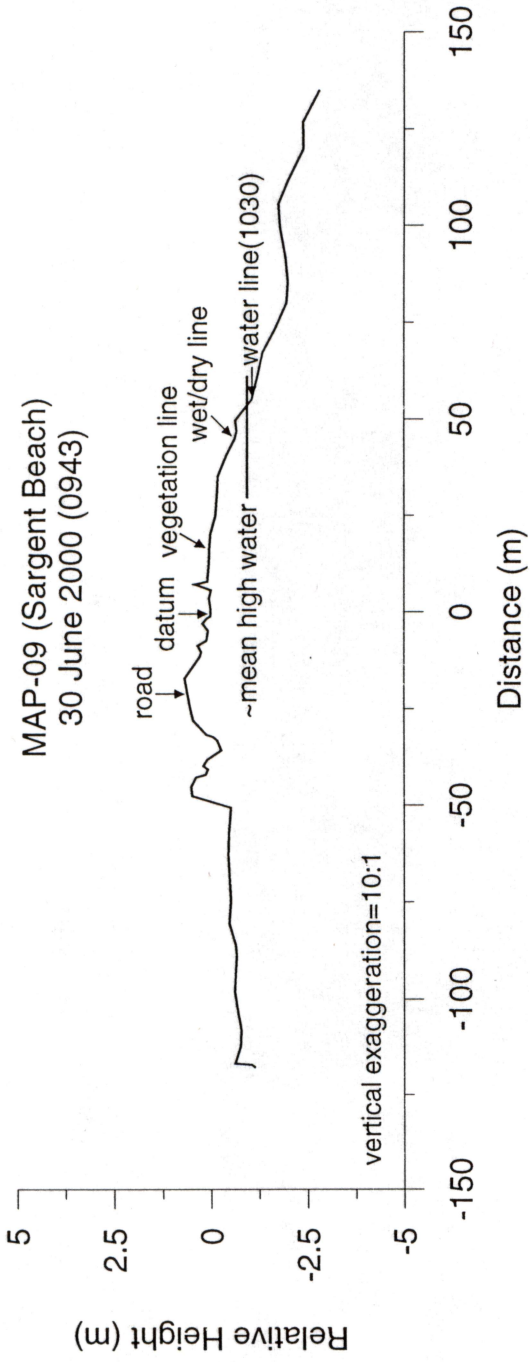
MAP09

Datum Latitude:	28° 46' 04.63613" N
Datum Longitude:	95° 37' 09.40009" W
Azimuth:	155° True North

X (m)	Z (m)	Beach feature	X (m)	Z (m)	Beach feature
-7.34	0.11		134.74	-2.81	
-8.75	0.34		126.75	-2.39	
-10.38	0.24		119.74	-2.39	
-11.60	0.28		111.65	-2.00	
-17.11	0.67		105.48	-1.75	
-24.47	0.54		99.37	-1.80	
-28.05	0.46		91.45	-1.95	
-31.74	0.11		85.31	-2.01	
-32.28	-0.06		79.96	-1.96	
-33.22	-0.16		73.34	-1.68	
-35.79	-0.28		67.21	-1.35	
-38.21	0.09		61.08	-1.22	
-39.89	0.19		55.03	-1.06	water line
-40.78	0.08		54.01	-0.98	~mhw
-42.08	0.13		49.67	-0.64	
-42.91	0.38		46.74	-0.68	
-45.25	0.51		44.82	-0.63	wet/dry line
-47.72	0.49		40.25	-0.41	
-50.68	-0.52		35.16	-0.19	
-54.40	-0.49		30.19	-0.17	
-57.02	-0.46		24.77	-0.13	
-62.83	-0.45		19.96	0.01	
-68.63	-0.48		16.10	0.03	vegetation line
-74.77	-0.52		12.73	0.04	
-80.49	-0.48		7.82	0.08	
-86.13	-0.64		7.04	0.40	
-88.91	-0.67		5.56	-0.01	
-92.02	-0.65		3.36	0.04	
-98.09	-0.61		0.44	0.00	
-103.85	-0.71		0.00	0.00	datum
-107.81	-0.78		-0.52	0.00	
-112.08	-0.76		-1.14	0.00	
-116.77	-0.63		-1.82	0.10	
-117.14	-1.06		-3.03	0.21	
-117.68	-1.12		-4.92	0.06	

MAP10   Datum Latitude: 28° 48' 57.25661" N
         Datum Longitude: 95° 31' 40.19478" W
         Azimuth: 148° True North

X (m)	Z (m)	Beach feature	X (m)	Z (m)	Beach feature
-64.83	-0.50		105.28	0.73	
-59.79	-0.33		110.31	0.73	
-54.52	-0.40		113.75	0.75	
-48.75	-0.37		120.00	0.75	
-43.13	-0.39		125.80	0.72	
-37.41	-0.39		131.71	0.76	
-31.66	-0.39		132.95	0.78	
-26.19	-0.32		134.21	1.01	dune crest
-23.16	-0.24		135.04	0.78	
-20.74	-0.10		135.11	0.78	vegetation line
-15.33	-0.05		139.77	0.80	
-9.30	-0.07		144.77	0.76	
-3.61	-0.09		147.64	0.70	vegetation line
-0.06	-0.09		151.35	0.62	
0.00	0.00	datum	153.78	0.54	berm crest
0.03	-0.08		155.06	0.40	
5.96	-0.08		157.99	0.22	wet/dry line
11.72	-0.05		161.25	0.08	
17.50	-0.01		163.68	0.04	berm crest
23.38	-0.04		167.84	-0.32	~mhw
29.07	-0.05		169.33	-0.42	water line
34.99	-0.06		174.77	-0.68	
41.09	0.02		179.45	-0.86	
47.25	-0.05		187.35	-1.06	
53.85	-0.03		195.47	-1.25	
60.21	-0.07		200.27	-0.98	
66.32	-0.11		206.16	-1.10	
68.89	0.04		213.20	-1.42	
74.78	0.00		220.02	-1.59	
80.81	0.07		226.27	-1.66	
84.18	0.18		234.52	-1.53	
87.90	0.34		239.79	-1.34	
89.19	0.65		246.83	-1.44	
94.72	0.72		253.93	-1.72	
96.20	0.70		260.19	-2.03	
99.29	0.71				