
Installation


Covered and vegetated


Exposed


Maintenance

FINAL REPORT

Geotextile Tubes along the Upper Texas Gulf Coast

May 2000 to March 2003

James C. Gibeaut
Tiffany L. Hepner
Rachel Waldinger
John R. Andrews
Rebecca C. Smyth
Roberto Gutierrez

November 2003

Bureau of Economic Geology
Scott W. Tinker, Director
John A. and Katherine G. Jackson School of Geosciences
The University of Texas at Austin
Austin, Texas 78713-8924

QAe7155

FINAL REPORT

Geotextile Tubes along the Upper Texas Gulf Coast

May 2000 to March 2003

James C. Gibeaut
Tiffany L. Hepner
Rachel Waldinger
John R. Andrews
Rebecca C. Smyth
Roberto Gutierrez

A Report of the Texas Coastal Coordination Council pursuant to National Oceanic and Atmospheric Administration Award No. NA07OZ0134, GLO Contract No. 02-493 R

November 2003

Bureau of Economic Geology
Scott W. Tinker, Director
John A. and Katherine G. Jackson School of Geosciences
The University of Texas at Austin
Austin, Texas 78713-8924

Coastal Studies Group

Executive Summary

In September 1998, Tropical Storm Frances caused severe beach and dune erosion along the Gulf shoreline of the southeast Texas coast. This erosion placed many beach houses in danger of being undermined or damaged during subsequent storms and gradual shoreline retreat. To help prevent such damage, shore-parallel geotextile tubes were installed. The tubes are sediment-filled sleeves of geotextile fabric having an oval cross section of approximately 12 ft. They rest on a fabric scour apron that has sediment-filled anchor tubes along each edge. Geotextile tubes are placed in a trench parallel to shore along the back beach or foredunes, and project designs call for sand and natural beach vegetation to cover them. Since 1998, nine separate projects have been installed, and in March 2003 they covered a total of 7.34 mi of the Gulf shoreline from Follets Island to High Island. An additional 709 ft of the tubes have been destroyed.

This study provides a quantitative evaluation of these projects on the basis of observations made from May 2000 to March 2003. Six field surveys were conducted that included ground surveys (beach profiles), visual inspection of geotextile tube exposure and damage plus three airborne topographic surveys (lidar) of the projects and adjacent beaches and dunes. Wave and water-level data were also compiled. Results from this study will aid the design of future erosion-control projects, such as beach nourishment and other geotextile tube projects in the area. Results, data, and maps are reported on a Bureau of Economic Geology Website (http://www.beg.utexas.edu/coastal/geotube.htm).

The geotextile tubes are intended to serve as temporary storm-surge protection and erosion-control structures. Their effectiveness in protecting against storm surge was untested as of March 2003. Tropical Storm Allison struck the coast in June 2001 and Tropical Storm Fay struck in September 2002, but these storms were not significant events with regard to storm surge and beach erosion. The geotextile tubes have been effective for temporary erosion control, but they may fail when exposed to direct wave attack. During Allison and Fay, the geotextile tubes prevented the vegetation line from retreating landward of houses. However, those houses to which the vegetation line would have retreated were probably seaward of the natural line of vegetation at the time the tubes were installed. It is also important to note that, during storms, erosion and vegetation line retreat may occur landward of the geotextile tubes as was observed at the northern Treasure Island project.

During the study period, two of the Treasure Island (on Follets Island) geotextile tubes were destroyed and holes, slumping, and collapsed sections were observed along other projects. To prevent failure it is critical to (1) keep the geotextile tubes covered with sand, (2) maintain a beach in front of them through beach nourishment, and (3) repair holes in the fabric as soon as possible.

Although Allison and Fay did not test the storm-surge-protection function of the geotextile tubes, they were largely responsible for eroding sand cover and fully exposing seaward faces of the tubes. In June 2001, Allison exposed 44% of the combined lengths of the projects for a total of 14,193 ft. Fair weather during the summer of 2001 and transportation of sand from borrow sites allowed 85% of the tubes to be covered by November 2001. In September 2002, Fay exposed 79% of the project lengths for a total of 30,492 ft. The post-Fay survey also revealed that approximately 11,968 ft of the geotextile tube projects suffered damage ranging from small holes to collapsed sections.

The Gilchrist West (Caplen area) project suffered the greatest amount of damage whereas the Pirates Beach and Pocket Park 2 projects had no damage. By March 2003, 69% of the tubes remained uncovered.

Because the geotextile tubes cannot be recovered through natural processes, covering them requires a significant effort. Furthermore, maintaining even a sparse vegetation cover on at least half of the project lengths has not been possible. Besides the Treasure Island projects, the Gilchrist West (Caplen area) project on Bolivar Peninsula has been the hardest to maintain. The primary reason for this is the relatively seaward placement of the tubes causing narrower and lower beaches in front of them and thus less protection than at the other major projects. The Pirates Beach project on Galveston Island has faired relatively well, suffering little or no damage as of March 2003. However, much of the Pirates Beach project was exposed over the 2002/03 winter, and if these conditions prevail, one can expect damage and failure. Tubes exposed by Tropical Storm Allison generally had beaches less than 50-ft wide. Thus beaches need to be at least 50-ft wide to prevent exposure and damage during a mild storm like Allison. A thick and vegetated sand cover on the tubes can partly compensate for a narrower beach.

There has been concern that the geotextile tubes, by preventing erosion and release of landward sand to adjacent beaches, may eventually cause adjacent shorelines to retreat at a higher rate than they otherwise would. As of March 2003, however, adjacent shorelines had not been demonstrably affected by the projects with the possible exception of the Treasure Island north project. If beaches are nourished in front of the projects, the nourishment sand will erode and supply adjacent beaches. If beaches are not maintained, the tubes will be destroyed before adjacent beaches are significantly affected. Even a short-term increase of erosion rate on adjacent beaches, however, could cause problems, and continued monitoring is required.

There has also been concern that the geotextile tubes are forming or will eventually form an unacceptable landward boundary to the public beach. The tubes dramatically alter the geomorphology and sedimentary environment of the beach/dune system. Even when covered by vegetated sand they rise abruptly from the back beach and appear more like earthen dikes than natural dunes or bluffs. In several places the tubes were routed seaward of individual houses or groups of houses, and at one location on Bolivar Peninsula they were routed landward of a house, adding to the unnatural appearance.

Along natural beaches, a coppice mound subenvironment consisting of sparsely vegetated wind-blown sand forms on the back beach seaward of the foredune. This subenvironment is not well developed or does not exist in front of the geotextile tubes because the beaches are not wide enough to provide dry sand for wind transport and to prevent waves and salt spray from inundating the back beach. On the basis of comparisons with adjacent beaches, the beaches in front of the tubes are about 50 ft narrower than they would be if the tubes and houses seaward of the natural line of vegetation were not there. In some locations, particularly where the tubes were routed seaward of a house or group of houses, the beach is impassable during moderately elevated water levels of 2 ft above sea level (1 ft above mean higher high water).

In summary, the geotextile tube projects may be effective for short-term erosion control, but their storm-surge-protection function had yet to be fully tested by March 2003. They are significant engineering structures that have changed and are changing the geomorphic and sedimentary environments of the beach/dune system. Continued maintenance and beach-nourishment projects will be required to mitigate adverse effects on public beaches.

Table of Contents

List of Figures

List of Tables

Introduction

The upper Texas coast was severely eroded during Tropical Storm Frances in September 1998. In response to this erosion and in an effort to prevent further storm damage to structures along the Gulf of Mexico shoreline, geotextile tube shore protection projects have been constructed. The projects consist of sediment-filled sleeves of geotextile fabric with an oval cross section of approximately 12 ft (3.7 m) (Figs. 1, 2). The geotextile tubes rest on a fabric scour apron that has sediment-filled anchor tubes along each edge. Tubes are placed in a trench dug parallel to shore along the back beach or foredunes, and project designs call for sand and natural beach vegetation to cover them.

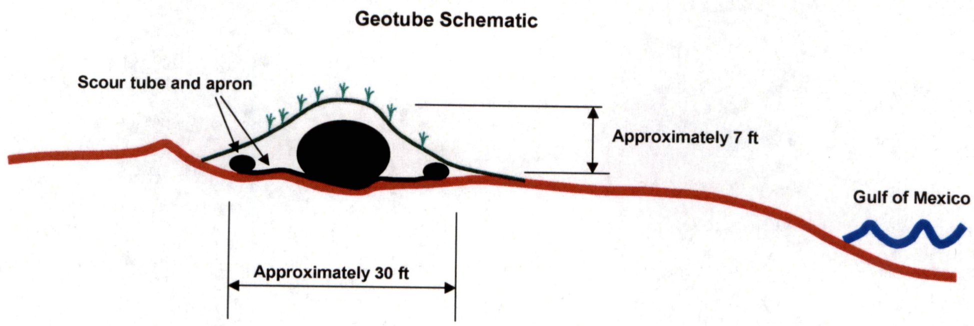


Figure 1. Cross-section schematic of a geotextile tube installation.

Figure 2. Geotextile tube stages.

Since 1998, nine geotextile tube projects have been installed along the Gulf of Mexico Shoreline of Galveston and Brazoria Counties (Figs. 3, 4, 5, 6). As of March 2003, a total of 7.34 mi (11.8 km) of shoreline have the tubes, and 709 ft have been destroyed. There is concern that the geotextile tubes may eventually cause the adjacent shorelines to retreat at a higher rate than they would without the tubes in place. Even if the tubes do not cause changes in the dynamics of the environment, they may eventually form an unacceptable landward boundary to the public beach because of original placement of the tubes too far seaward or because of natural, long-term shoreline retreat in front of them. This study provides a quantitative evaluation of these extensive geotextile tube projects. As more field measurements are acquired, the results will also aid the design of future erosion control projects, such as beach nourishment and other geotextile tube projects in the area.

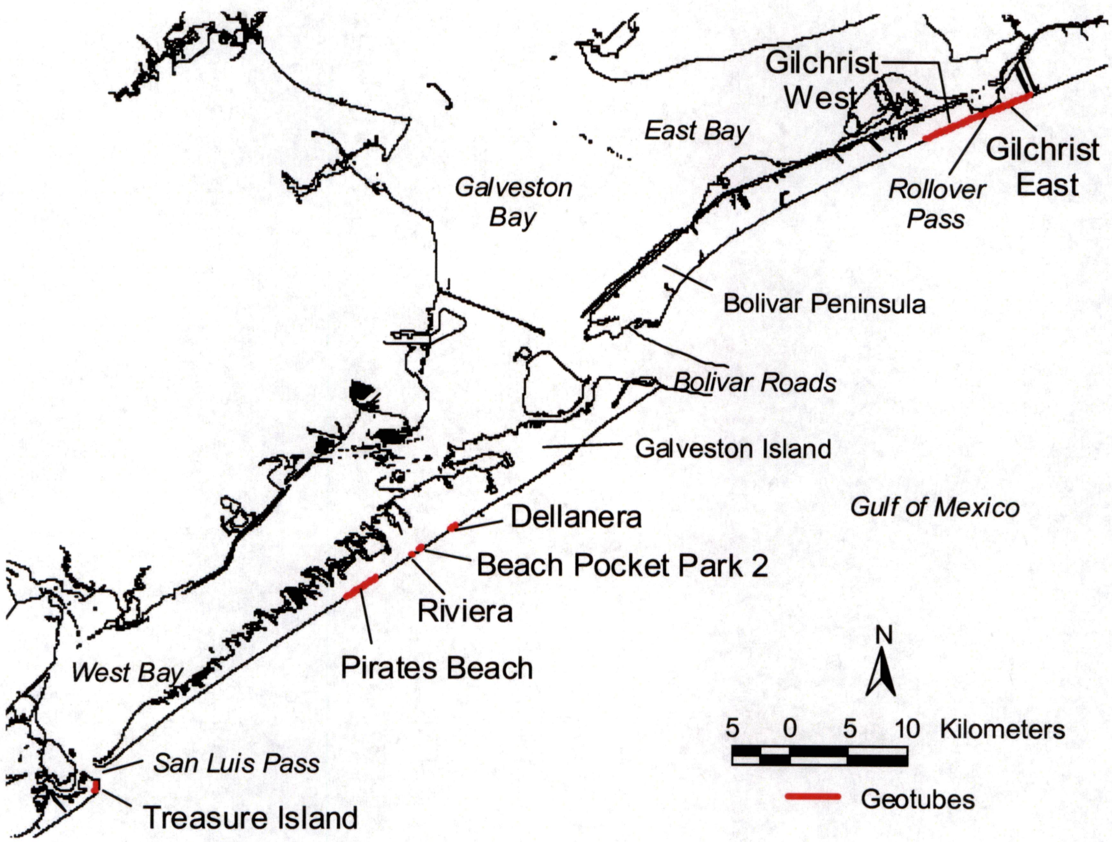


Figure 3. Map of geotextile tubes along the upper Texas Gulf of Mexico shoreline. Note that the Gilchrist West area is also referred to as Caplen and the Gilchrist East area as Gilchrist.

Data and results of the geotextile tube monitoring are presented on the Bureau of Economic Geology's Web page (http://www.beg.utexas.edu/coastal/geotube.htm). Included on this page is a Web-based Geographic Information System (ArcIMS) where the geotextile tube projects are mapped with attributes describing their state at the time of each survey. Photographs and plots of beach profiles are also linked to locations on the map.

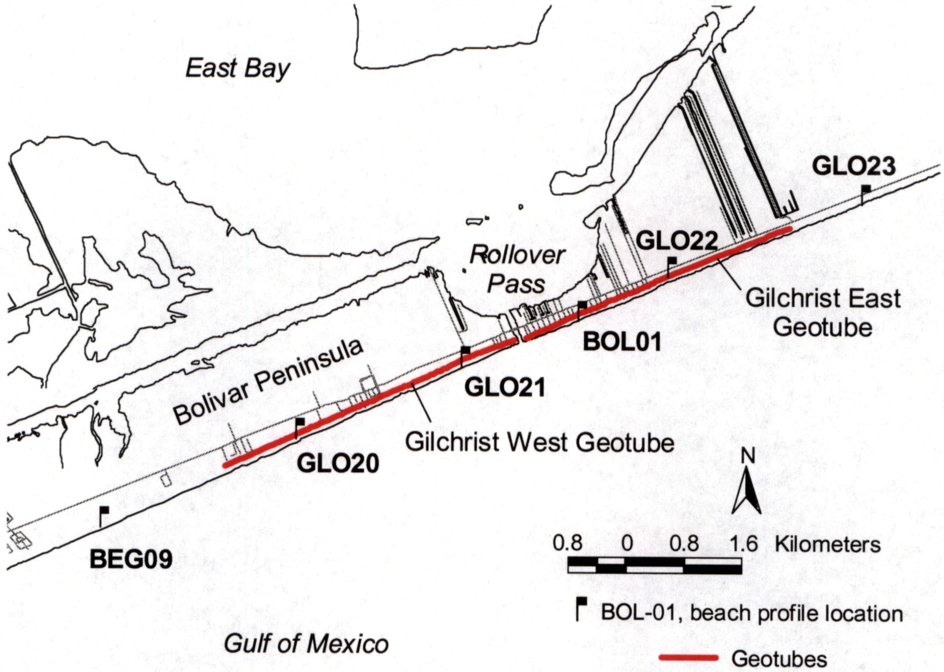


Figure 4. Map of Gilchrist West (Caplen) and Gilchrist East (Gilchrist) geotextile tube projects.

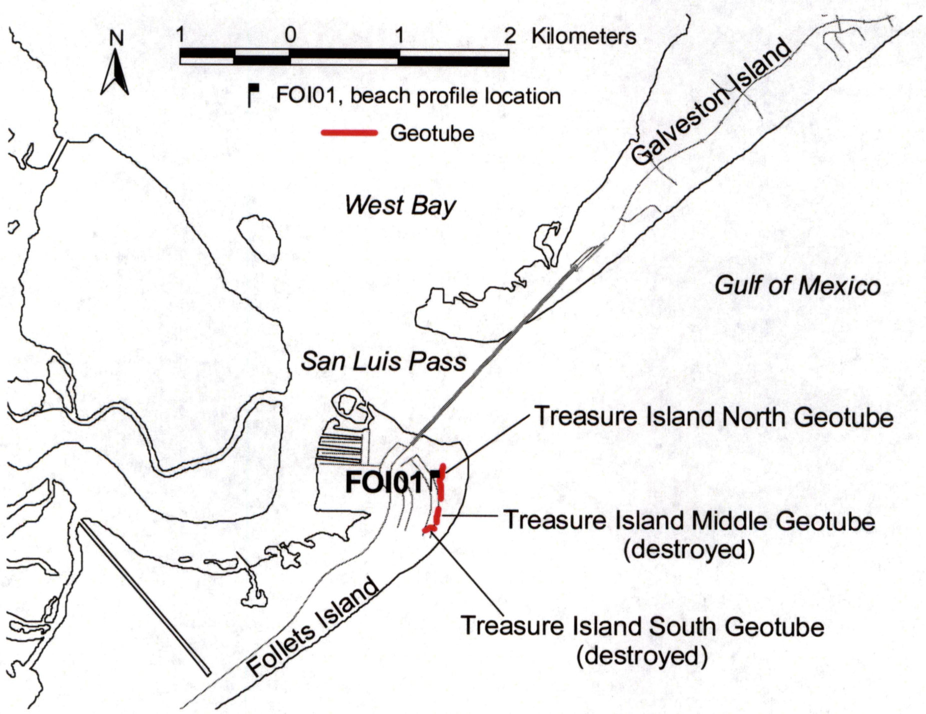


Figure 5. Map of Treasure Island geotextile tube projects.

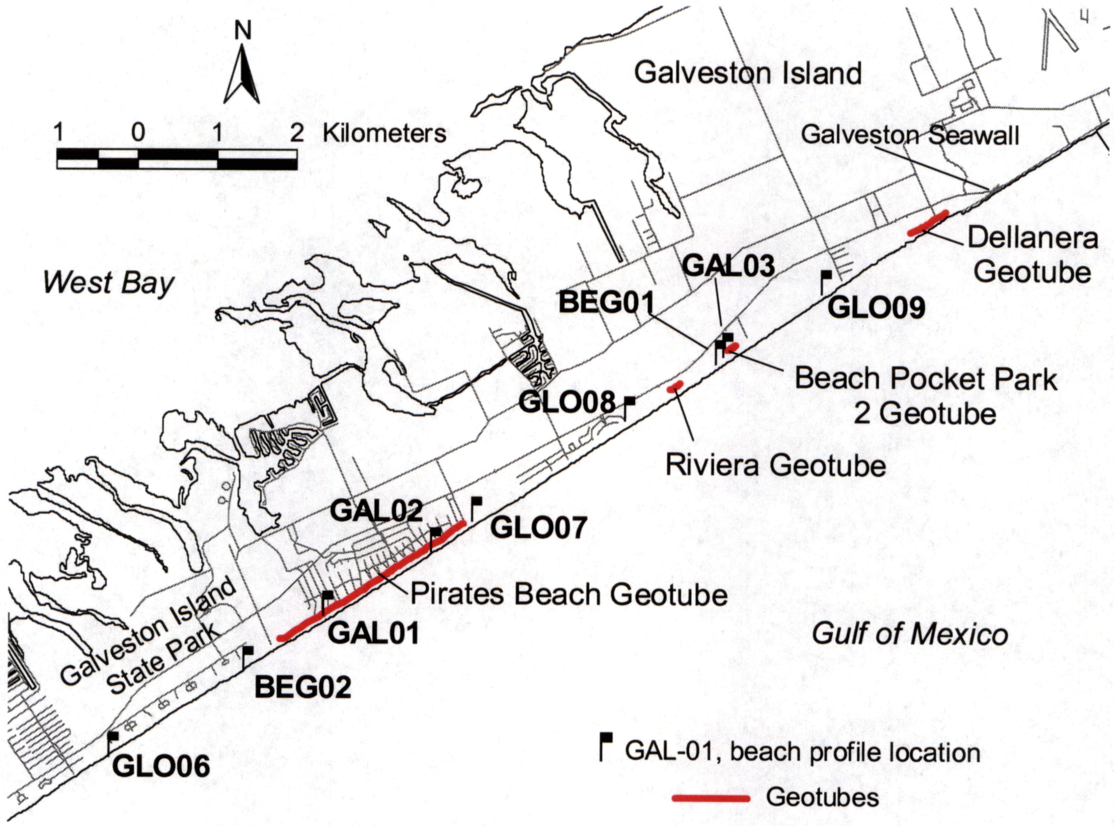


Figure 6. Map of geotextile tube projects along West Beach of Galveston Island.

Methods

Field measurements include beach and dune topography, geotextile tube, foredune, and shoreline positions, tube exposure and damage, vegetation cover, and wave and water levels. From these measurements, the effects of the tubes on the beaches and dunes are evaluated as well as their ability to slow erosion and prevent storm damage.

Beach profiles

Ground-surveyed topographic transects (beach profiles) were conducted at 16 locations between the northeastern end of Follets Island and High Island on Bolivar Peninsula (Figs. 4, 5, 6). Surveys were conducted during June, July, and November in 2001, June and September in 2002, and during March in 2003. The beach profiles are oriented perpendicular to the shoreline and extend from landward of the dunes to wading depth. When repeated frequently, beach profiles can detect short-term changes in morphology, sediment volume, and shoreline position. The ground surveys are also used for checking the accuracy and aiding the interpretation of LIDAR data.

In 1994, the Bureau of Economic Geology (Bureau) established beach profile locations along the southeast Texas coast. These locations have been measured several times since 1994 and eleven of them were found to be in good locations for monitoring the geotextile tube projects. Five additional sites were established to compliment the older survey sites. Sites within and adjacent to the geotextile tube projects were measured.

The approximate coordinates of the new profiles and precise coordinates of the previously established profiles were used to navigate to the profile sites using a real-time differential Global Positioning System (GPS). Temporary survey markers were found at four of the previously established sites. Seven markers were not found because of beach erosion or destruction. At these sites a new temporary marker was installed along the original transect line but farther landward.

The marker of each profile was surveyed using precise differential GPS techniques. The reference GPS station for these surveys is located at the U.S. Coast Guard Station on Galveston Island. A Geodetic Trimble 4000ssi GPS receiver acquired data at each profile site for 1 hour or longer depending on the distance from the reference station and the satellite constellation. GPS data were processed using phase differencing techniques to provide positions of the datum markers with an accuracy of better than 0.787 in (2 cm). Positions are computed in the UTM zone 15 coordinate system using the NAD 83 datum. Vertical measurements are expressed as heights above the reference ellipsoid (HAE). Using the Geoid99 model, HAE heights were converted to orthometric heights relative to NAVD 88. A local mean sea level correction was than applied to the orthometric height based upon vertical information from the bay-side Port Bolivar tide gauge. Profile positions are provided in Appendix A.

Beach profiles were measured using a Sokkia Set 5W Electronic Total Station and a reflecting prism. Vegetation, sediment type, geomorphic features, and the boundary between wet and dry sand were noted along each transect line. Plots of the profiles are referenced to MSL and include designation of the datum marker, vegetation line notations, and location of mean higher high water (MHHW) and 1.97 ft (0.6 m) MSL. The height of MHHW above MSL was determined using data recorded by the open-coast Pleasure Pier tide gauge on Galveston Island.

Geotextile tube condition surveys

Systematic ground observations and photographs of the geotextile tubes were made three times during 2001 (June 11 to 15, July 18 to 20, and November 13 to 14), two times during 2002 (June 11 to 13 and September 17 to 19), and during March 9 to 11, 2003. The purpose of these observations was to determine if the tubes were covered by sand and vegetation and if they were damaged. A differential GPS was used to locate photographs and points along the tubes where conditions changed. The tubes were described with the following characteristics:

Amount of exposure of apron, front, or top of tube (apron, front, and top classified separately)

No exposure: completely covered with sediment
Minor exposure: small areas of fabric are visible in a few places
Partial exposure: fully exposed in intermittent sections
Full exposure: fully and continuously exposed (Fig. 7)

Tube or ultraviolet radiation shroud damage

None: geotextile tube is not damaged or undermined

Yes: some damage

Vegetation cover

Visually estimated percent of vegetation cover including top and front (seaward) but not landward side

An ArcView Geographic Information System (GIS) was used to map the locations and lengths of the tubes with certain conditions. Lines along the seaward edges of the exposed or covered tubes, as mapped using the July 2001 or September 18, 2002 lidar survey (see below), was coded in the GIS according to the condition of the tube. These GIS data are viewable on the Web site (http://www.beg.utexas.edu/coastal/geotube.htm).

Figure 7. Example of fully exposed geotextile tube front and scour apron at the Dellanera project on Galveston Island, July 18, 2001.

Airborne topographic lidar survey

Airborne lidar (LIght Detection and Ranging) surveys of the shoreline from Sabine Pass to Cedar Lakes (southwest of the Brazos River Delta) were conducted May 24, 2000, July 17, 2001, and September 18, 2002. Airborne lidar is a technique to obtain highly accurate and detailed topographic measurements of the Earth's surface. Lidar surveys involve combining a scanning laser, an inertial measurement unit (IMU) to record the aircraft motion, and GPS receivers. Lidar can acquire beach surveys with vertical precision from 5 to 10 cm and data-point spacing less than 1 m. From these data, a shoreline may be extracted for use in shoreline change analysis. These data can also be used to map topographic and geomorphic features such as the geotextile tubes and dunes.

Lidar surveys were conducted using the Bureau's Airborne Lasar Terrain Mapper (ALTM) 1225 instrument manufactured by Optech Inc. The ALTM was installed in a Cessna 206 single engine airplane operated by the Texas State Aircraft Pooling Board. GPS ground reference stations for computing aircraft trajectories were installed at the U.S. Coast Guard Station at Freeport, the Port Bolivar tide gauge, and Sabine Pass Battleground Park. The aircraft was navigated along the shoreline using a video camera with the same field of view as the lidar instrument. At least two passes were flown along the geotextile tube projects. A swath of data extending about 1,640 ft (500 m) inland was acquired. This swath covered the shoreline, foredunes, secondary dunes, and oceanfront structures.

GPS data were processed using National Geodetic Survey kinematic GPS processing software to provide highly accurate aircraft trajectories. The trajectories were then used in combination with laser range data and information from the IMU to compute XYZ positions on the ground. The XYZ data points were compared with ground GPS surveys of roads to remove elevation biases from the lidar data and to make calibration adjustments. After these adjustments, the vertical accuracy of the lidar data points as determined by comparison to GPS ground surveys of roads is 0.328 ft (0.1 m).

Digital elevation models (DEM) with 3.28 ft by 3.28 ft (1 m by 1 m) grids were 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 G99 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. A local MSL correction factor was determined from vertical information from the Gulf side Pleasure Pier tide gauge. Comparison of the height of the water level along the beach, as displayed in the transformed 2001 lidar grid, with the water level recorded by the open-coast tide gauge at Pleasure Pier on Galveston Island during the time of the surveys confirmed the correctness of the transformations and the accuracy of the lidar data. Based upon the examination of ground-surveyed beach profiles 1.97 ft (0.6 m) above mean sea level (MSL) was picked to represent the shoreline. The 1.97 ft (0.6 m) MSL level approximates the position of the upper berm crests and the boundaries between wet and dry sand, which are the features mapped as the shoreline on historical aerial photography. The transformed DEM was contoured and the 1.97 ft (0.6 m) contour line extracted as the shoreline.

Process measurements

Hourly wave and wind information were compiled from the National Data Buoy Center's (NDBC) buoy #42035 approximately 20 mi (32 km) offshore Galveston Entrance. Hourly readings from the open coast tide gauge on the Pleasure Pier in front of the Galveston Seawall were also compiled. The water level (WL) at the tide gauge is computed by smoothing 181, 1-second readings. The standard deviation of these 181 readings is higher during high waves, which cause high-amplitude water-level variations. As expected, therefore, there is a positive correlation of water level standard deviation (WLSD) measured by the tide gauge with the wave heights measured by the buoy. This means the WLSD is a proxy measure of wave energy reaching the shoreline. Periods of greatest beach and dune erosion occur when high WLSD and WLs occur simultaneously. Therefore, the product of WL and WLSD, as measured by the same gauge, is a parameter that indicates the upper reach and energy of wave activity during storms. It is this parameter that is used to gauge the relative erosive power of storms during the monitoring period.

Criteria for assessing geotextile tube performance and effects

Beach width

A primary concern with the geotextile tube projects is that the public beach will be narrower in front of the tubes than it would be without the tubes present. A quantitative technique to compare beach widths, therefore, is required. For this purpose, segments of beaches adjacent to each project on Bolivar Peninsula and Galveston Island were selected for comparison. Beach segments contiguous with the geotextile tube projects and with similar processes and sand supply were selected to represent what the beach width would be if the tubes and houses seaward of the natural line of vegetation were removed. Beach segments used for comparison were selected to have long-term shoreline change rates within ±2 ft/yr (±0.61 m/yr) of the beaches in front of the tubes. Locations within the adjacent comparison beach segments where houses have caused artificial narrowing of the beach and areas where beach access roads have caused artificial widening of the beach are not included. The comparison segments include both vehicular and non-vehicular beaches.

Beach width was measured at transects perpendicular to the shoreline every 16.4 ft (5 m) alongshore. The seaward boundary for computing the width is the 1.97 ft (0.6 m) MSL contour line. This level corresponds to the typical boundary of wet and dry sand as shown in the beach profiles. The lidar maps along Galveston and Bolivar Peninsulas (Gibeaut et al., 2002, Plates 1 and 2) show people parking and using the beach above the 1.97 ft (0.6 m) MSL level (Fig. 8). If the beach is lower than 1.97 ft (0.6 m) MSL, passage and public use is hindered. The landward boundary for computing beach width is the seaward edge of the geotextile tube projects including the sediment cover if present. In the comparison segments, the landward boundary is the seaward toe of the foredune ridge or the base of a scarp/bluff if a foredune ridge is not present (Fig. 8). The foredune ridge is the geomorphic feature the tubes are emulating. Furthermore, the seaward toe of the foredune ridge commonly coincides with the "line of vegetation" defined in the Texas Open Beaches Act. The "line of vegetation" is the landward boundary of the public's easement on Texas beaches.

Increased shoreline retreat adjacent to the geotextile tubes

Along the upper Texas coast, the primary source of beach and dune sand at any given location is that which is eroded from the beaches that are up drift of the location. Any interruption in the alongshore transport or supply of sand will result in increased erosion rates in the down drift direction. Increased erosion of beaches down drift of the geotextile tube projects will occur if there is not adequate beach nourishment or if the tubes do not allow the erosion of sand behind them. Inspection of the alongshore shape of the 1.97 ft (0.6 m) MSL contour line and back beach elevations is used to indicate if beaches adjacent to the tubes are experiencing enhanced erosion rates. A landward deviation of the contour line at the end of the tube or a lower than normal back beach would indicate negative effects.

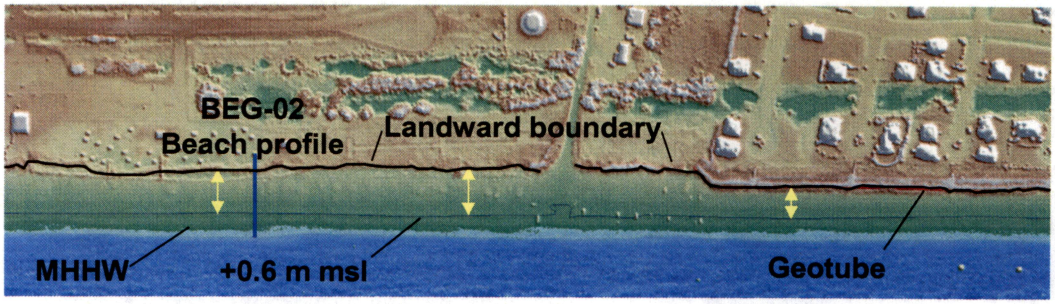


Figure 8. Lidar topographic image (2001) of the southwest end of the Pirates Beach geotextile tube project and the northeast end of Galveston Island State Park. Double-ended arrows demonstrate beach width measurement between the 0.6 m level and the landward boundary.

Storm protection function

A quantitative method for evaluating how well the geotextile tubes serve as storm protection structures has not been devised. Nor has enough data been acquired or severe storms experienced to evaluate this function as of March 2003. With the baseline data collected during 2001, 2002 and early 2003, however, we will be able to at least semi-quantitatively evaluate the effects of the next storm.

Results

Water level and wave conditions

Figure 9 is a time series plot of water level (WL), water level standard deviation (WLSD), and the product of WL and WLSD acquired by the open-coast tide gauge at the end of Pleasure Pier in front of the Galveston Seawall. High values for the product of WLSD and WL indicate periods of high-wave energy coincident with high-water levels. Tropical Storms (TS) Josephine, Frances, and Fay are prominent peaks in this plot. Other tropical storms and hurricanes that affected the northern and western Gulf of Mexico caused peaks in the time series, but based on beach profiles and field observations, Gibeaut and Gutierrez (1999) and Gibeaut et al. (2002) determined that prior to 1999 only Tropical Storms Josephine and Frances caused significant dune erosion and vegetation line retreat. Based on the Josephine conditions and the other storms that did not cause significant erosion, it was estimated that the threshold conditions for episodic erosion and vegetation line retreat is a WL that exceeds 2.95 ft (0.9 m) MSL and WLSD that exceeds 0.85 ft (0.26 m) for at least 12 hours. WLSD exceeding 0.85 ft (0.26 m) for 12 hours approximately corresponds to wave heights that exceed 9.84 ft (3 m) for at least 12 hours as measured at offshore buoy #42035.
As described above, the total erosive potential of a storm is a function of how high the WL is elevated (storm surge), the height of waves arriving at the shore (approximated by WLSD), and the duration of the storm. The duration of coincidently high WL and WLSD, as indicated by the product of the WL and WLSD, is an indicator of the relative erosive

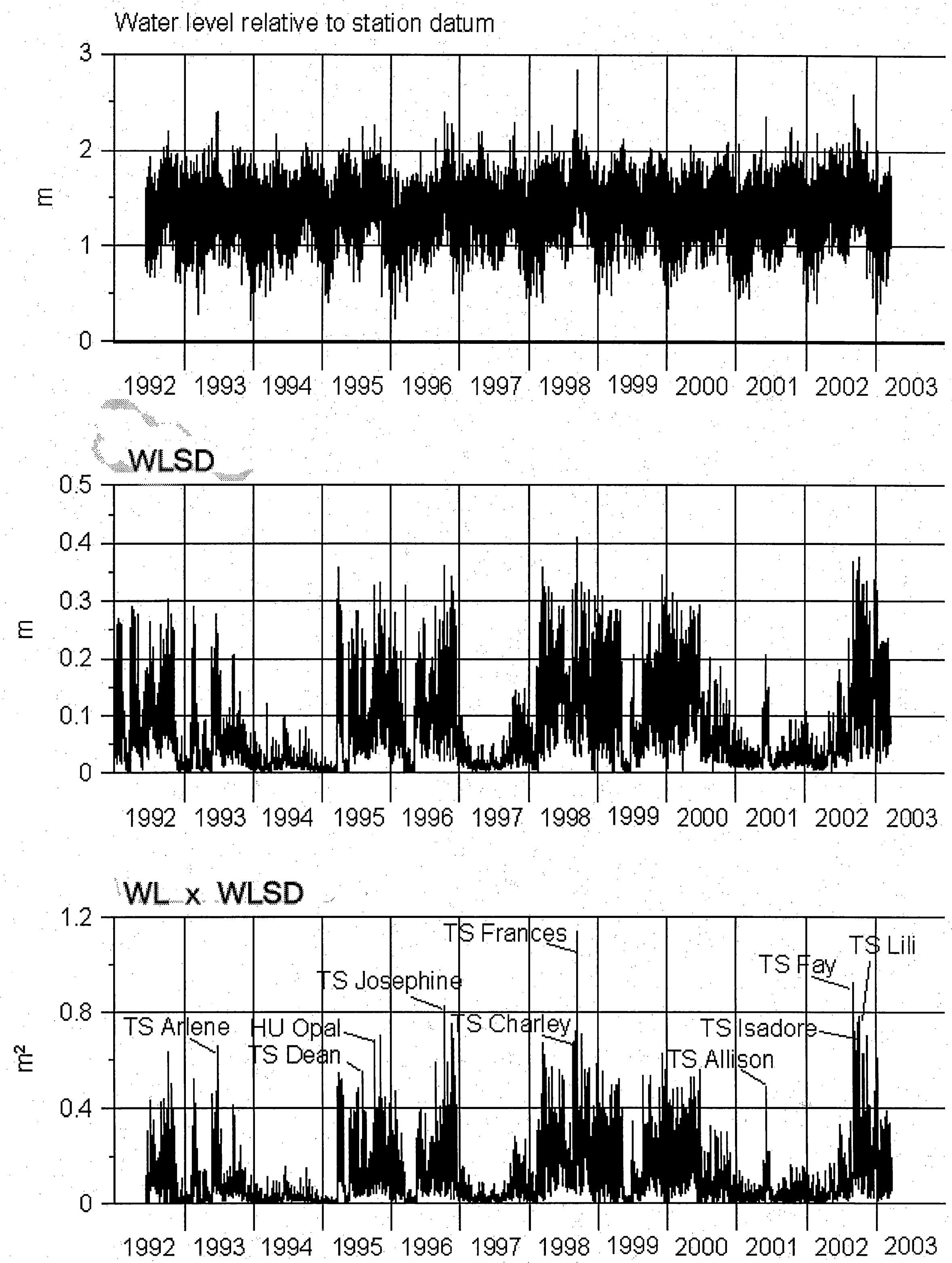


Figure 9. Time series of water level, water level standard deviation (WLSD), and the product of water level (WL) and WLSD from the Pleasure Pier tide gauge.

power of a storm. The mean and standard deviation of the time series (Fig. 9) of WL×WLSD were computed. Extreme conditions are defined as when WL×WLSD exceeds three times the standard deviation above the mean. The extreme value, therefore, is 0.409 m^2. To include the duration of extreme conditions when comparing storms, the WL×WLSD curve was integrated through time to compute the area below the curve and above the level of extreme conditions. This value is called the Extreme Area (EA) and is in units of hour's-meters squared (Table 1). Since the geotextile tubes have been installed and to March 2003, only Tropical Storm Fay in 2002 caused conditions that exceeded TS Josephine's conditions and, therefore, would be expected to cause significant beach/dune erosion (Table 1). TS Allison in June of 2001, however, did have a short-lived peak value of WL×WLSD that was extreme, and this was enough to erode the sand and vegetation cover from the more seaward tubes.

Table 1. Storm Comparison Using Data from Pleasure Pier Tide Gauge

	WL × WLSD		
Storm	Peak (m^2)	Hours > 0.409 (m^2)	Extreme Area (EA) (WL×WLSD Integrated above 0.409) (hr m^2)
TS Dean July 1995	0.546	17	0.94
HU Opal October 1995	0.678	66	6.13
TS Josephine October 1996	0.825	79	12.66
HU Danny July 1997	0.035	0	0
TS Charley August 1998	0.668	30	3.78
TS Frances September 1998	1.138	119	35.96
TS Allison June 2001	0.484	5	0.18
TS Fay September 2002	0.926	81	13.62
HU Isadore September 2002	0.757	72	11.16
HU Lili October 2002	0.783	11	2.32

Tropical Storm Allison

On June 5, 2001, TS Allison made landfall near Freeport, Texas. Figure 10 shows WL, WLSD, and WL×WLSD. WL peaked at 3.12 ft (0.95 m) above MSL, and the highest waves were 13.94 ft (4.25 m), as measured by the NDBC buoy #42035 20 miles offshore of Bolivar Roads. The product of water level and WLSD peaked at only 0.484 m^2 during Allison, considerably less than Tropical Storms Josephine and Frances in 1996 and 1998, respectively (Table 1). Furthermore, extreme conditions lasted only 5 hours to yield an EA of 0.18 hrs-m^2, much less than during Josephine. This analysis shows that TS Allison was not a "threshold" event expected to cause significant dune erosion and vegetation line retreat. Pre- and post-Allison beach profiles at the Galveston Island State Park (BEG02 location, Fig. 6) show that Allison did not cause significant erosion (Fig. 11). At this location, which has no geotextile tubes, the back beach was eroded but significant vegetation remained. A small, sparsely vegetated incipient foredune created with the aid of sand fencing seaward of the foredune ridge, survived.

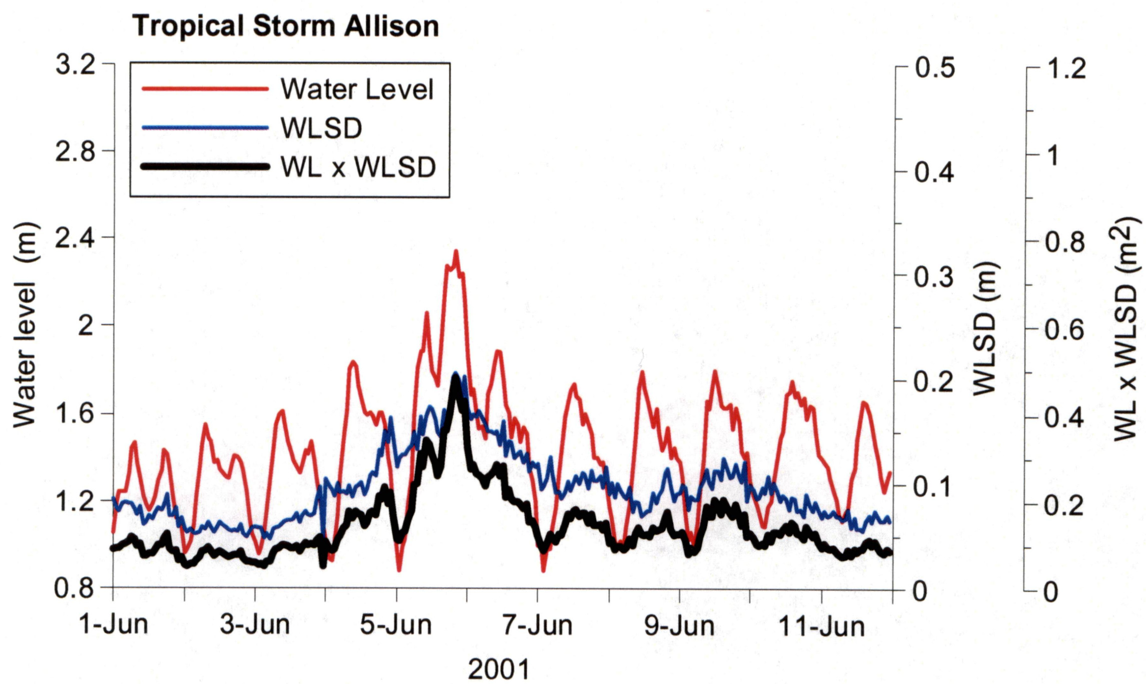


Figure 10. Water level (WL) and wave conditions represented by the water level standard deviation (WLSD) during Tropical Storm Allison. Data recored by the Pleasure Pier tide gauge. WL is relative to the tide station's datum.

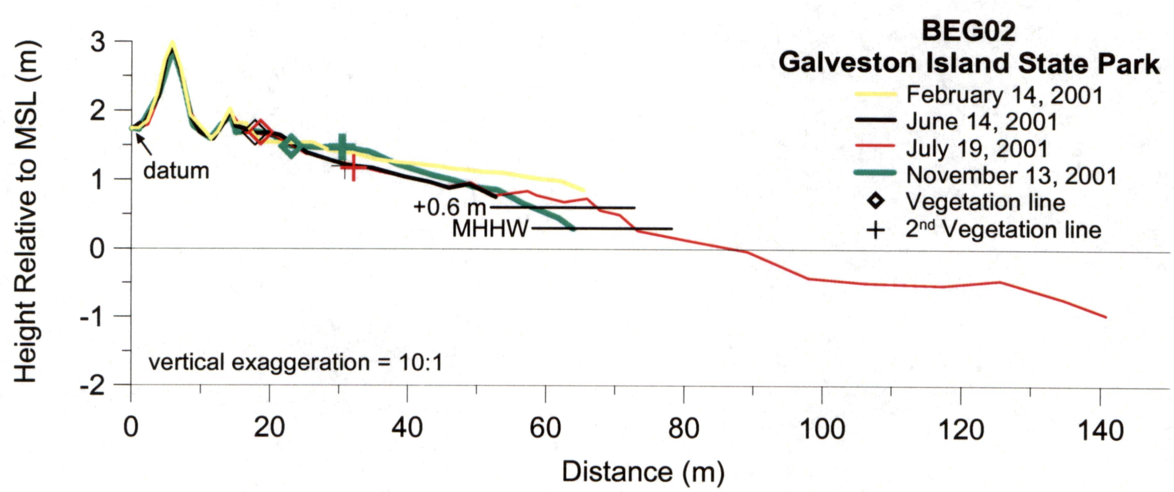


Figure 11. Beach profiles at Galveston Island State Park, location BEG02 (see Fig. 6 for location). The foredune and incipient dune seaward of the foredune survived Tropical Storm Allison in early June, 2001.

Tropical Storm Fay

On the morning of September 7, 2002, Tropical Storm (TS) Fay made landfall near Port O'Connor. The maximum sustained wind speed was 39 kts, and the WL reached 3.9 ft (1.2 m) above MSL at the Pleasure Pier tide gauge. Buoy #42035, measured waves up to 12 ft (3.6 m) high. Figure 12 is a plot of WL, WLSD, and WL×WLSD recorded by the Pleasure Pier tide gauge. Peak WL×WLSD was just above the value reached during TS

Josephine but below the TS Frances level (Table 1). The EA for Fay was also just above the EA for Josephine, but considerably less than for Frances. This is because extreme conditions during Frances lasted 50% longer than they did during Josephine or Fay. The amount of beach erosion and vegetation line retreat caused by Fay in 2002 was similar to that caused by TS Josephine in 1996, but considerably less than what Frances caused in 1998, as would be expected by comparing the EA values.

Beach profiles from the relatively natural BEG-02 beach profile site, gives an indication of the relative severity of erosion caused by Tropical Storms Josephine, Frances, and Fay (Fig. 13). Josephine caused the seaward-most vegetation line to retreat 9 m, but an incipient foredune survived and the primary foredune was untouched. Frances, on the other hand, flattened the incipient dune and foredune and washed over and deposited sand on the back barrier. Frances caused the vegetation line to retreat 20 m. Changes caused by Fay were very similar to those caused by Josephine. A foredune and incipient dune that reformed following Frances in 1998 survived Fay in 2002. Fay partially eroded coppice mounds seaward of a sand fence, but the seaward-most vegetation line did not change position and the vegetation line defining where the vegetation becomes essentially continuous landward retreated only about 8 m (Fig. 13 and BEG02 profiles and photos in Appendix B).

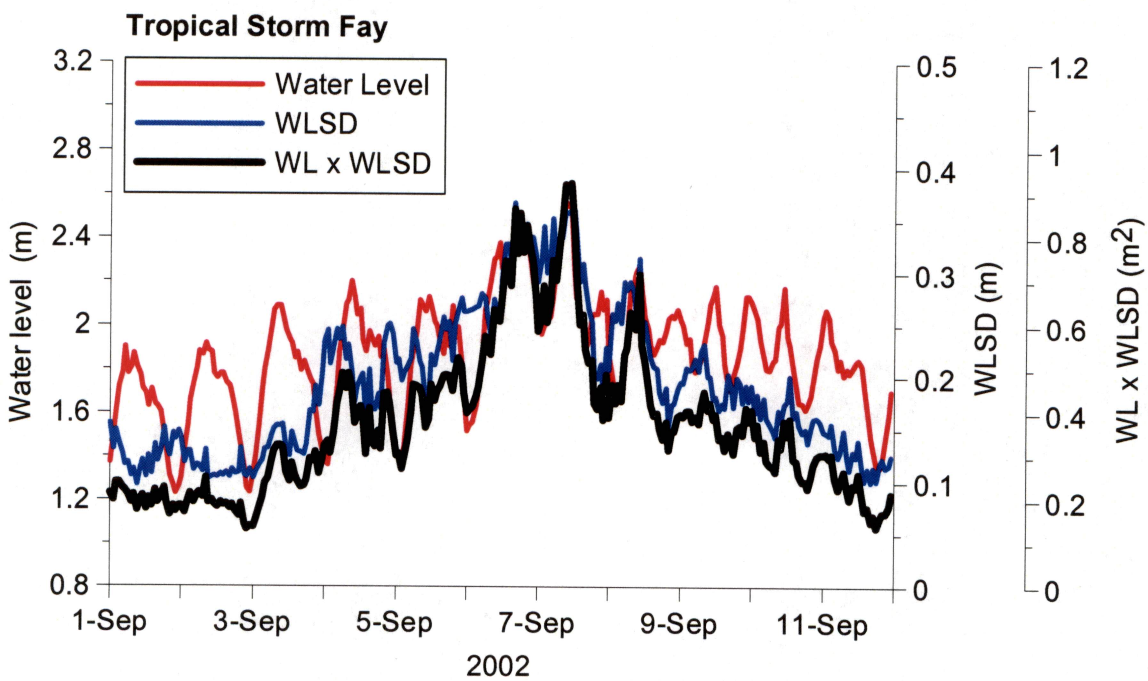


Figure 12. Water level (WL) and wave conditions represented by the water level standard deviation (WLSD) during Tropical Storm Fay. Data recored by the Pleasure Pier tide gauge. WL is relative to the tide station's datum.

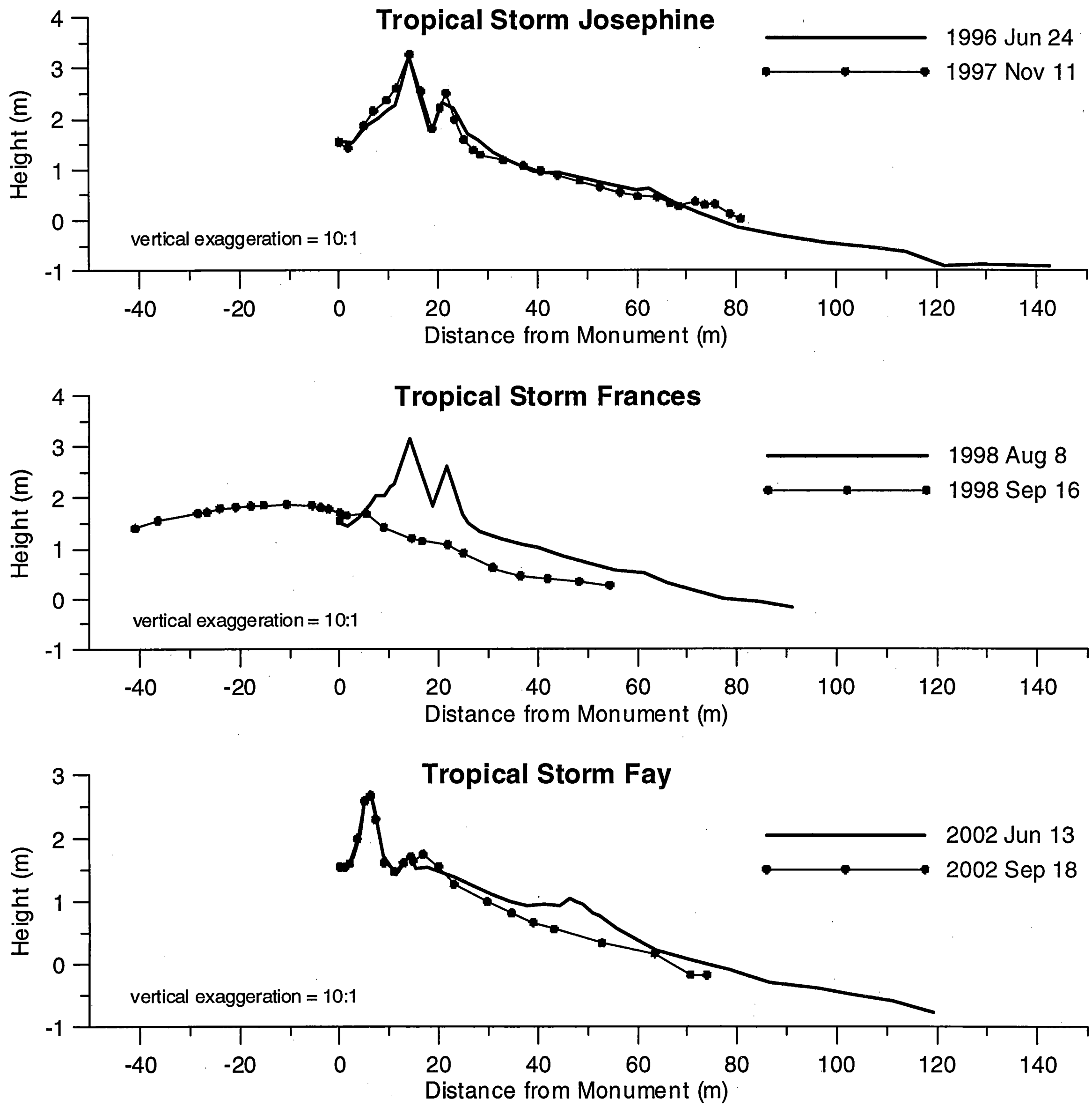


Figure 13. BEG-02 beach profiles from Galveston Island State Park where no geotextile tubes are present (see Fig. 6 for location). Profiles show changes before and after major storms. Tropical Storm Fay caused the same degree of change as Josephine, but Frances completely eroded the foredunes.

Geotextile tube conditions

Table 2 lists the geotextile tube projects installed along the upper Texas coast as of March 2003. Geotextile tube lengths are measured using lidar data acquired in September 2002 and supplemented by the March 2003 ground survey. Appendix B contains all beach profile plots and photographs taken at the profile locations.

Table 3 shows snapshots of the conditions of the geotextile tubes during each field visit. Lengths of sections of tubes where at least the seaward face was fully exposed and sections with little or no vegetation cover are tabulated. The June 2001 survey was conducted seven days after TS Allison. The seaward faces of the tubes were exposed along 44% of their length partly because of erosion at the base of the tubes during Allison. The Gilchrist west project had by far the greatest length and proportion of exposed tubes in June 2001, and the Gilchrist east and west projects on Bolivar Peninsula were more exposed than the Galveston Island projects (Dellanera, Pocket Park 2, Riviera, and Pirates Beach). It is notable that the Pirates Beach project retained most of its sand and vegetation cover even following Allison, but that sand fencing along the seaward face of the project was significantly damaged. Except for the Treasure Island projects, maintenance activities were able to recover most of the exposed geotextile tubes and by November 2001 only 15% of the total length of all projects was exposed (Table 3). The Treasure Island middle and south projects have not retained a sand or vegetation cover during the monitoring period and the north project was mostly exposed by November 2001. The Treasure Island middle project was destroyed by waves and slightly elevated water levels in November 2001.

Table 2: Geotextile tube project lengths as of March 2003.

Geotextile tube Project	Location	Completion Date	Meters	Feet	Miles
Gilchrist east	Bolivar Pen., east of Rollover Pass	Phase 1 (Rollover Pass to Legers Street): May 2000; Phase 3 (Legers Street to Dirty Pelican Pier: July 2001	3,935	12,910	2.44
Gilchrist west	Bolivar Pen., west of Rollover Pass (Caplen)	Phase 1 (Rollover Pass to Martha's Vineyard Road): September 2000; Phase 2 (Martha's Vineyard to Campbell: June 2001	4,341	14,242	2.70
Dellanera	Galveston Isl., West Beach	June 2000	459	1,506	0.29
Pocket Park II	Galveston Isl., West Beach	December 1999	120	394	0.07
Riviera	Galveston Isl., West Beach	January 2001	147	482	0.09
Pirates Beach	Galveston Isl., West Beach	October 1999	2,515	8,251	1.56
Treasure Island north	Follets Isl., San Luis Pass	March 2000	298	978	0.19
Treasure Island middle	Follets Isl., San Luis Pass	March 2000	5 plus 122 destroyed	16 plus 400 destroyed	0.003
Treasure Island south	Follets Isl., San Luis Pass	March 2000	94 all destroyed	308 all destroyed	0
Total			**11,820** plus 216 destroyed	**38,780** plus 709 destroyed	**7.34** plus 0.13 destroyed

Table 3: Exposed and sparsely vegetated geotextile tubes.

	June 2001 (post TS Allison)		July 2001		November 2001	
Project	**Exposed ft/%**	**< 25% veg. ft/%**	**Exposed ft/%**	**< 25% veg. ft/%**	**Exposed ft/%**	**< 25% veg. ft/%**
Gilchrist East	1,670/27	5,079/82	0/0	4,403/52	702/6	7,011/62
Gilchrist West	10,382/73	12,421/87	6,142/43	13,438/95	3,967/28	10,968/77
Dellanera	392/26	761/50	545/36	695/46	207/14	574/38
Pocket Park 2	0/0	499/100	0/0	0/0	0/0	0/0
Riviera	0/0	479/100	0/0	0/0	0/0	0/0
Pirates Beach	791/10	791/10	791/10	791/10	108/1.3	971/12
Treasure Isl. North	285/29	282/29	305/31	305/31	538/55	974/100
Treasure Isl. Middle	417/100	417/100	417/100	417/100	62/100 plus 351 ft destroyed	62/100 plus 351 ft destroyed
Treasure Isl. South	256/100	256/100	256/100	256/100	256/100	256/100
Total	**14,193/44**	**20,985/65**	**8,456/26**	**20,305/59**	**5,778/15 plus 351 ft destroyed**	**20,754/56 plus 351 ft destroyed**

Table 3 continued: Exposed and sparsely vegetated geotextile tubes.

	June 2002		September 2002 (post TS Fay)		March 2003	
Project	**Exposed ft/%**	**< 25% veg. ft/%**	**Exposed ft/%**	**< 25% veg. ft/%**	**Exposed ft/%**	**< 25% veg. ft/%**
Gilchrist East	282/2	4,580/35	8,694/67	8,694/67	6,719/52	10,846/84
Gilchrist West	4,140/29	11,115/78	13,222/93	13,222/93	12,854/90	13,143/92
Dellanera	397/26	587/39	1,506/100	1,506/100	846/56	1,506/100
Pocket Park 2	0/0	0/0	0/0	0/0	0/0	0/0
Riviera	0/0	0/0	486/100	486/100	0/0	482/100
Pirates Beach	0/0	827/10	5,541/67	5,541/67	5,525/67	5,525/67
Treasure Isl. North	978/100	978/100	978/100	978/100	978/100	978/100
Treasure Isl. Middle	66/100 plus 351 ft destroyed	66/100 plus 351 ft destroyed	66/100 plus 351 ft destroyed	66/100 plus 351 ft destroyed	16/100 plus 400 ft destroyed	16/100 plus 400 ft destroyed
Treasure Isl. South	161/100 plus 151 ft destroyed	161/100 plus 151 ft destroyed	308 ft 100% destroyed	308 ft 100% destroyed	308 ft 100% destroyed	308 ft 100% destroyed
Total	**6,023/15 plus 502 ft destroyed**	**18,313/47 plus 502 ft destroyed**	**30,492/79 plus 659 ft destroyed**	**30,800/79 plus 659 ft destroyed**	**26,939/69 plus 708 ft destroyed**	**32,480/84 plus 708 ft destroyed**

In June 2002, 85% of the geotextile tube lengths were still covered, and the length of tube with at least 25% vegetation coverage increased along the Gilchrist East project (Table 3). A portion of the Treasure Island south project, however, had been destroyed. TS Fay in early September exposed 79% of the tubes and completely destroyed what remained of the Treasure Island South project. In addition, approximately 11,968 ft (3,648 m) of the geotextile tube projects suffered damage ranging from small holes to collapsed sections. The Gilchrist West project suffered the greatest amount of damage whereas the Pirates Beach and Pocket Park 2 projects had no damage.

By March 2003, 69% of the tubes remained exposed and only 16% had at least a 25% vegetation cover, less than following TS Fay (Table 3). Also the length of geotextile tubes with damage increased from the September 2002 conditions to a total length of 13,704 ft (4,177 m). Damage remained along the Gilchrist projects, patches and small holes were observed along the Dellanera project, and damage along the Treasure Island north tube included collapsing sections and a mostly destroyed UV shroud. No damage was observed along the Pirates Beach or Pocket Park 2 projects, and the Riviera tube had been recovered with sand by March, 2003.

Beach Width

Figures 14 through 19 are histograms that compare beach widths adjacent to and in front of each project except the Treasure Island projects. The histograms show the distribution of beach width in fractional length of shoreline. For example, figure 14 shows that approximately 82 % (0.82 fraction) of the length of the beach adjacent to the Gilchrist East project was 60- to 80-ft (18.3- to 24.4-m) wide on September 18, 2002. The histograms show that beaches in front of geotextile tubes are generally narrower than beaches adjacent to them. There are, however, portions of the beaches in front of the tubes that are as wide as the narrower portions of the adjacent beaches.

Tables 4 and 5 give the minimum and average beach widths. In July of 2001, average beach widths were narrower in front of the tubes than adjacent to them by 21 to 83 ft (6.4 to 25.3 m) with the Pirates Beach project showing the greatest difference. Except for the Riviera and Pocket Park II projects, the beaches in front of the tubes had minimum beach widths narrow enough to prevent passage during water levels of 1 to 2 ft (0.30 to 0.61 m) above MHHW.

On September 18, 2002 beaches were narrower than they were in July 2001 both adjacent to and in front of the geotextile tube projects (Table 5 and Figs. 14 through 19). All projects except Pocket Park II had places where the beach was impassable during high tide with out having to traverse in the surf or wet sand. As in 2001, average beach widths were narrower in front of the tubes than adjacent to them. However, even though all beaches were narrower in 2002, the differences in beach widths in front of the projects relative to beaches adjacent to the projects were less than in 2001 with the exception of the Dellanera project.

Effect on Adjacent Beaches

Visual inspection of the 1.97 ft (0.6 m) MSL contour line and back beach elevation on the topographic lidar images show that the geotextile tubes have not affected the erosion rates of adjacent beaches (Plates 1, 2) with the minor exception of the beach north of the Treasure Island north project (Plate 3). If adjacent beaches are being affected, we would expect to see a decrease in the effect with distance from the tubes. The morphologies and elevations of the back beach and fore beach portions of the beach profile, however, are similar for sections immediately adjacent to the tubes and for beaches more distal to the tubes.

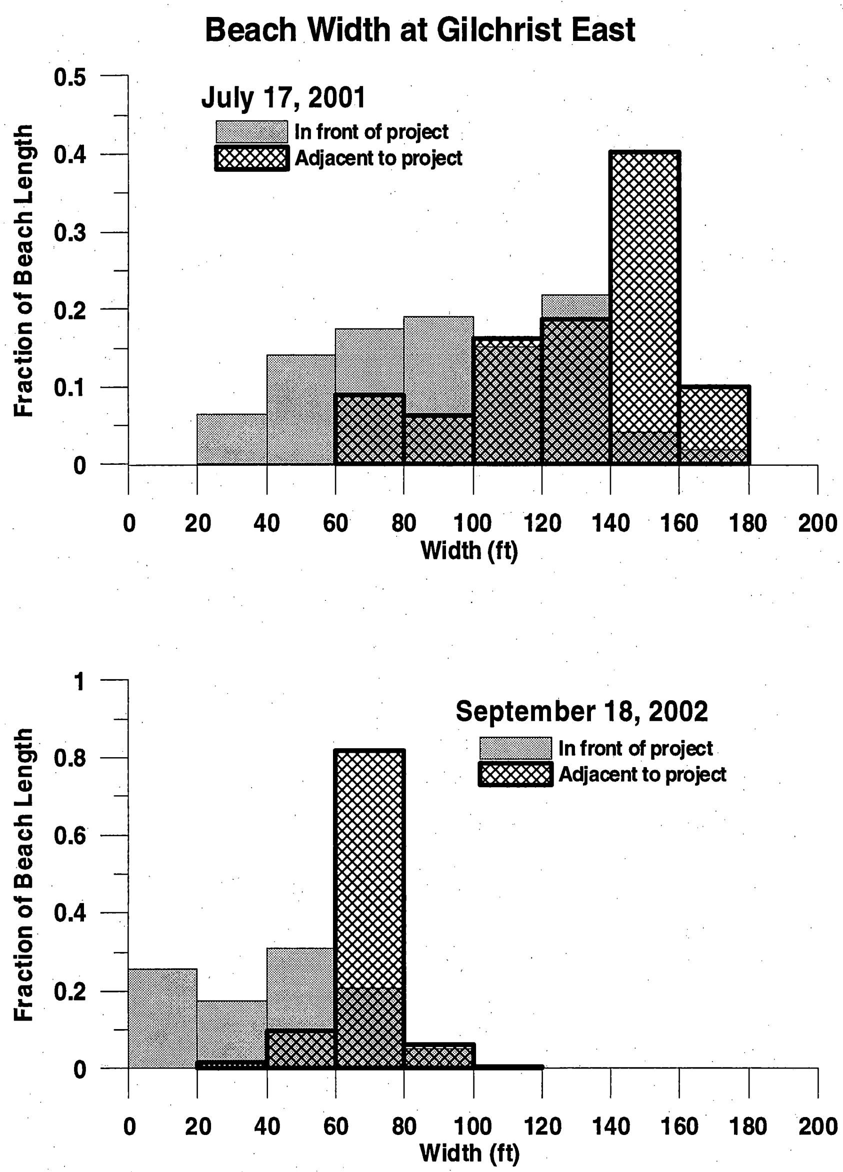


Figure 14. July 2001and September 2002 beach width comparisons shown as fractions of beach length in front of and adjacent to the Gilchrist East (Gilchrist) geotextile tubes.

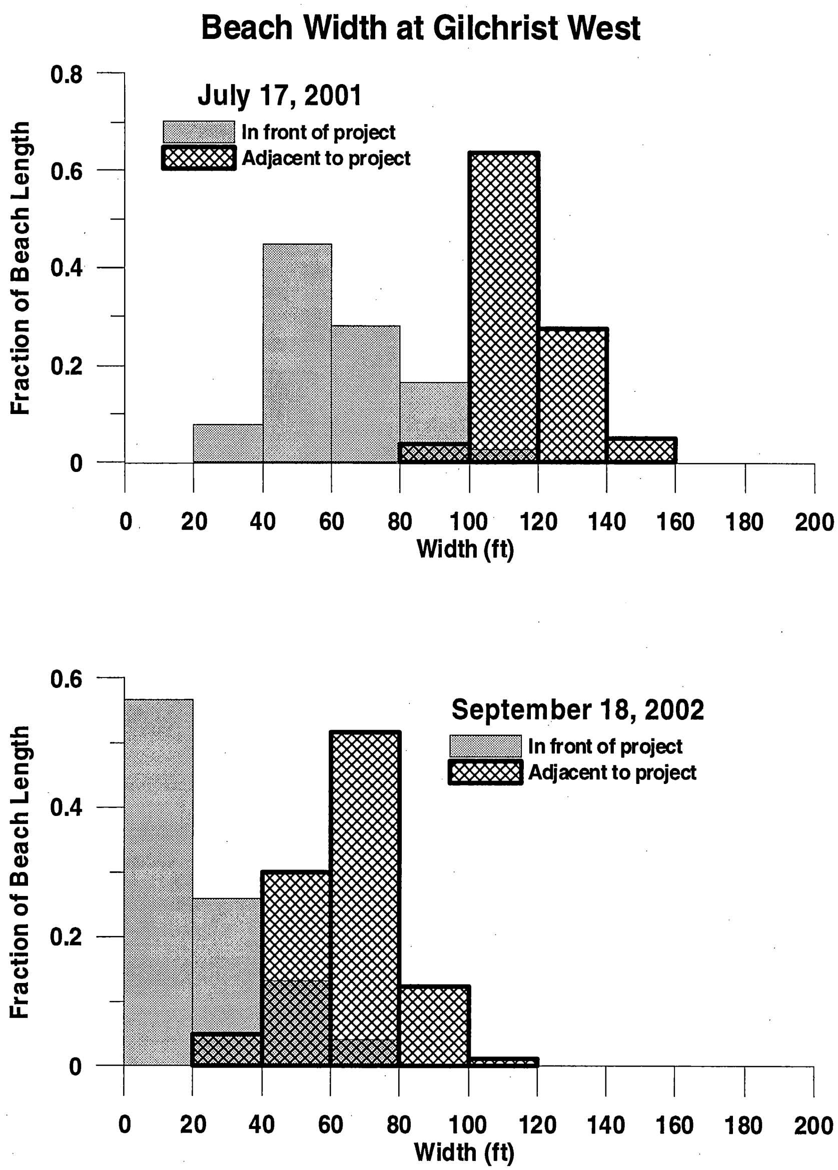


Figure 15. July 2001and September 2002 beach width comparisons shown as fractions of beach length in front of and adjacent to the Gilchrist West (Caplen) geotextile tubes.

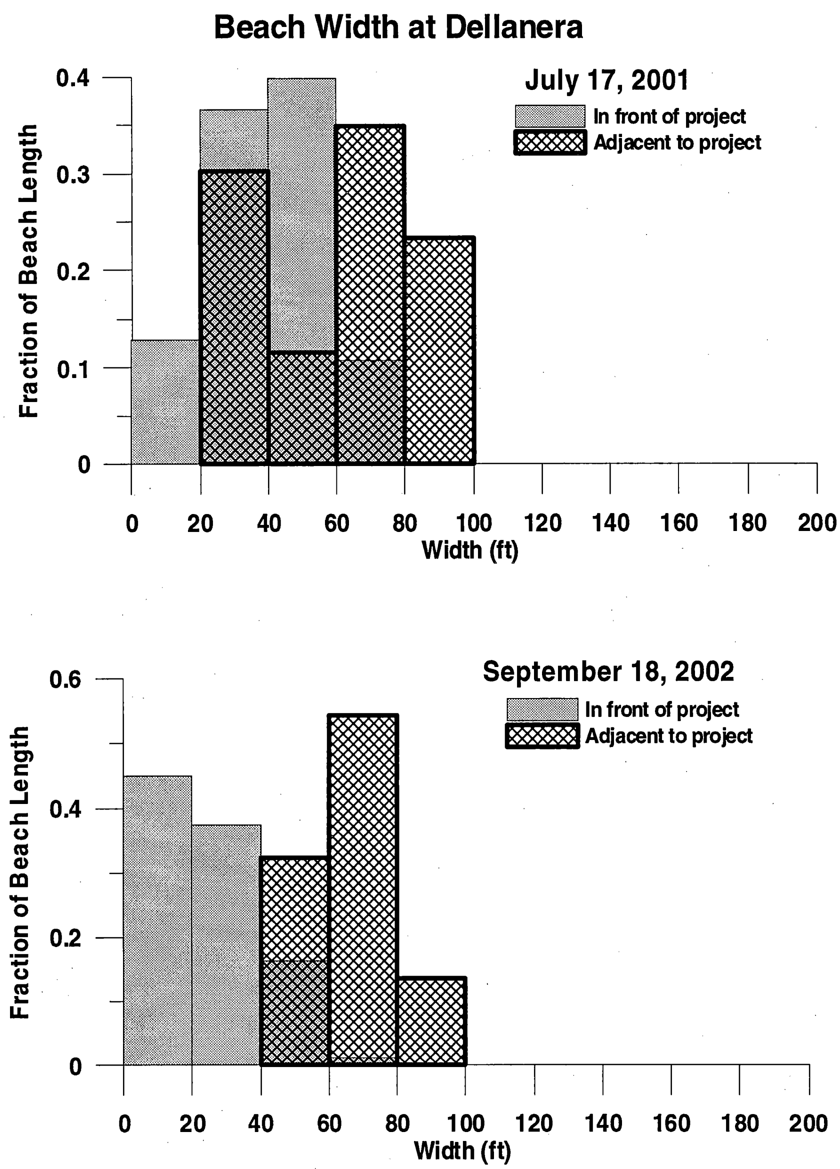


Figure 16. July 2001and September 2002 beach width comparisons shown as fractions of beach length in front of and adjacent to the Dellanera geotextile tubes.

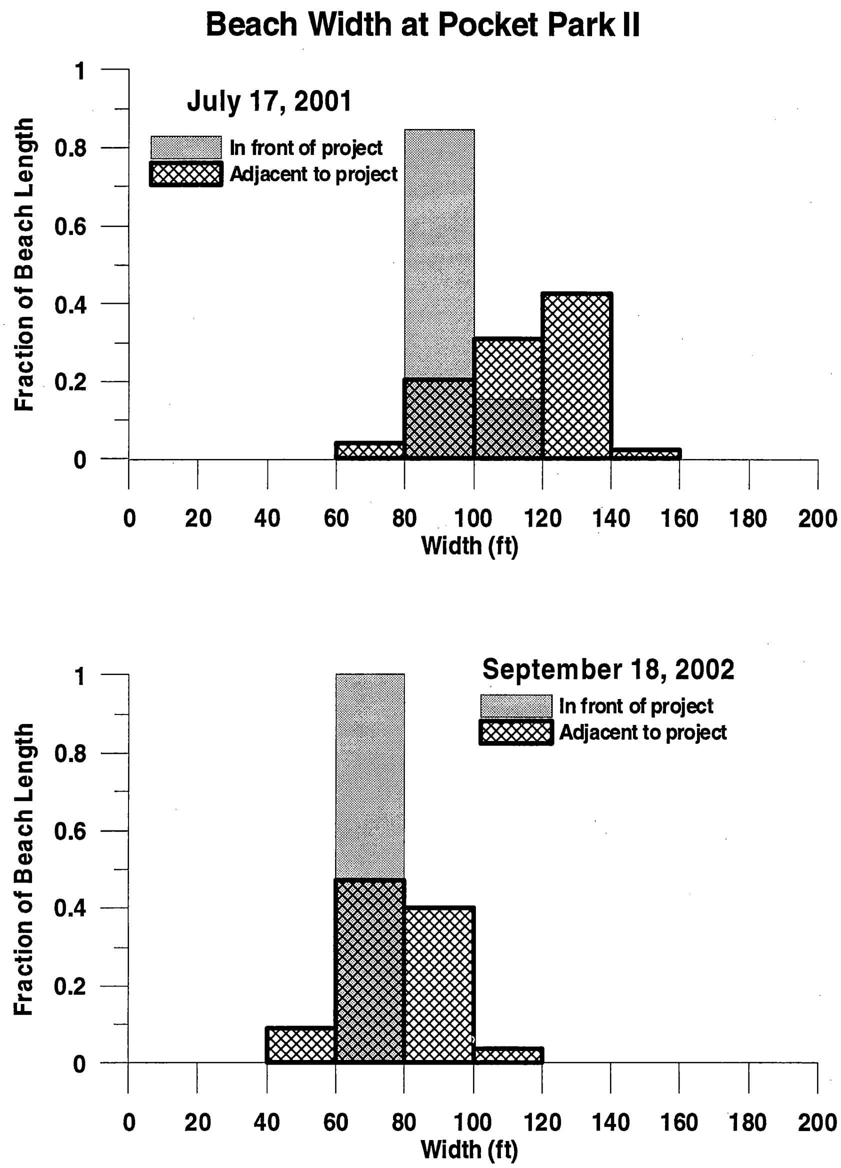


Figure 17. July 2001and September 2002 beach width comparisons shown as fractions of beach length in front of and adjacent to the Pocket Park II geotextile tubes.

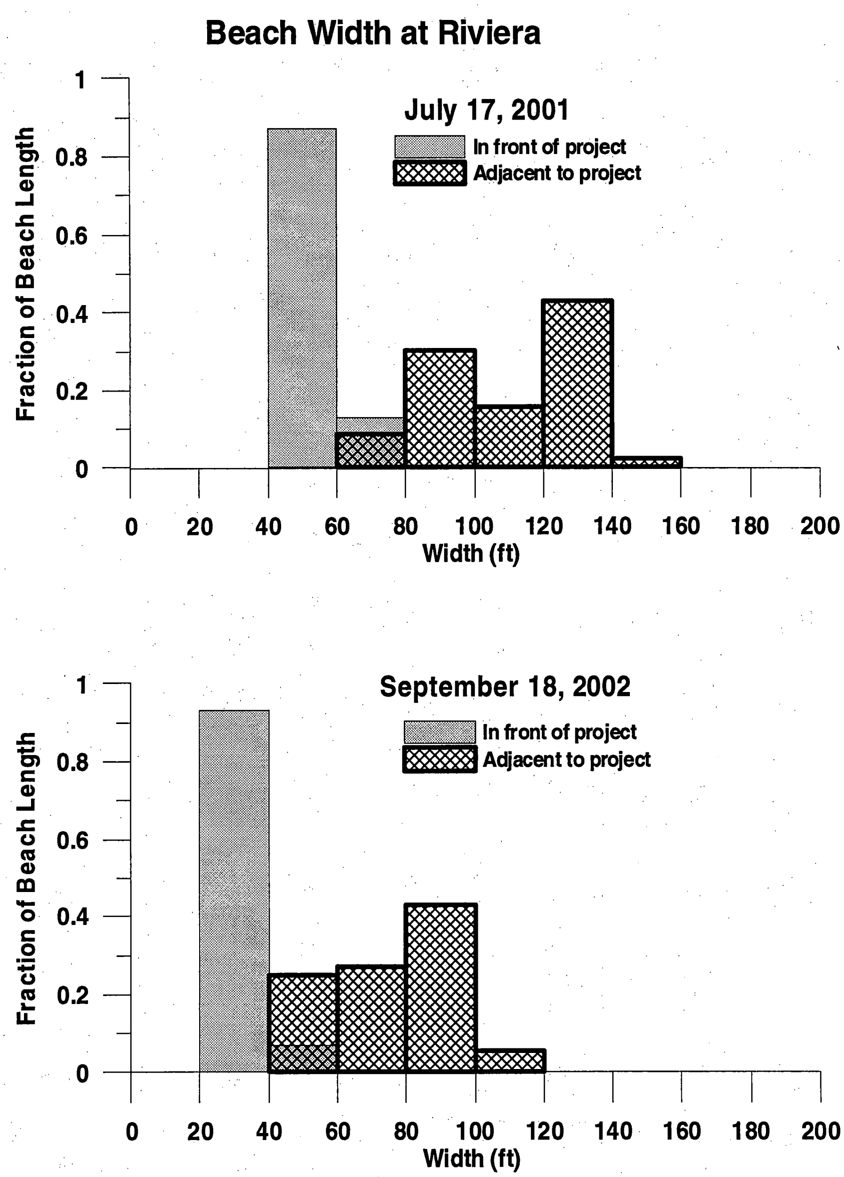


Figure 18. July 2001and September 2002 beach width comparisons shown as fractions of beach length in front of and adjacent to the Riviera geotextile tubes.

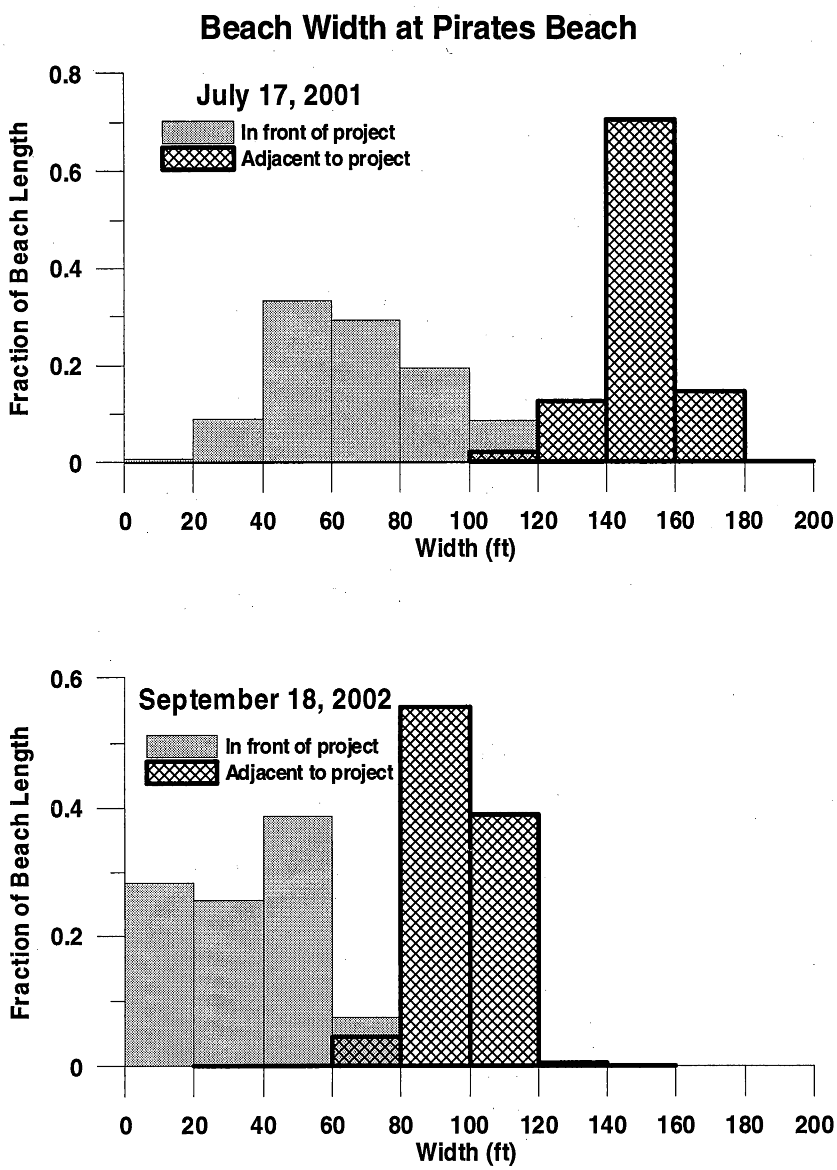


Figure 19. July 2001and September 2002 beach width comparisons shown as fractions of beach length in front of and adjacent to the Pirates Beach geotextile tubes.

Table 4: Comparisons of beach width in front of and adjacent to geotextile tubes July 17, 2001.

Project	Minimum Width (ft)		Average Width (ft)		
	In front	Adjacent	In front	Adjacent	Difference front – adj.
Dellanera	14	28	40	61	-21
Gilchrist east	21	73	93	132	-39
Gilchrist west	22	95	62	117	-55
Pirates Beach	14	101	67	150	-83
Pocket Park II	87	70	92	114	-22
Riviera	50	67	55	110	-55

Table 5: Comparisons of beach width in front of and adjacent to geotextile tubes September 18, 2002.

Project	Minimum Width (ft)		Average Width (ft)		
	In front	Adjacent	In front	Adjacent	Difference front – adj.
Dellanera	3	41	25	66	-41
Gilchrist east	2	31	43	70	-27
Gilchrist west	0	28	22	65	-43
Pirates Beach	1	31	36	97	-61
Pocket Park II	63	48	72	77	-5
Riviera	23	49	31	75	-44

Discussion

Geotextile tube function and maintenance

The geotextile tubes along the Gulf of Mexico shoreline of the upper Texas coast are intended to serve as temporary storm-surge protection and erosion control structures. As of March 2003, their effectiveness in protecting against storm surge was untested and as erosion control structures questionable. Once the beach erodes to the base of the tubes, they become undermined and begin to slump seaward. Direct wave attack on the tubes quickly removes the sand cover, damages the ultraviolet radiation shroud, and causes punctures (Figs. 20, 21, 22, 23, 24, and 25). The length of exposed tube damaged with punctures or having at least partially collapsed sections has been increasing and in March 2003 totaled about 13,700 ft (4,175 m). Damaged UV shrouds were even more prevalent.

Punctures have been observed at all the projects except Pocket Park II and Pirates Beach. The Pocket Park II project retained its sand cover, and the relatively wide beach in front of the tube has protected it from damage. Much of the Pirates Beach project, however, was exposed by TS Fay in September of 2002 and remained exposed over the 2002/03 winter. If these conditions prevail, it is expected the Pirates Beach geotextile tubes will also suffer damage. If beach nourishment does not maintain a beach wide enough to keep the tubes landward of the swash zone, it is expected they will be destroyed by conditions not necessarily reaching the level of tropical storms. This is particularly true in settings with hard debris in the surf zone that can puncture the fabric such as the small riprap at Treasure Island.

Figure 20. Puncture in Gilchrist West (Caplen area) geotextile tube on November 15, 2001.

Figure 21. Seaward scour apron exposed and damaged and patched holes in Dellanera geotextile tube on March 9, 2003.

Figure 22. Tear in Dellanera geotextile tube on June 11, 2002. Some have speculated that this hole was the result of vandalism. It has since been patched

Figure 23. Slumped and collapsed geotextile tube with patched hole near east end of Gilchrist West project (in Caplen) on March 10, 2003. Note completely collapsed section in distance where tube turns seaward.

Figure 24. Collapsed geotextile tube section along west end of Gilchrist West project on September 17, 2002 after Tropical Storm Fay.

Figure 25. Treasure Island middle geotextile tube on July 19, 2001. Except for a short piece in the foreground this section was completely destroyed in November 2001. Note exposed scour apron and damaged UV shroud. Tube has begun to loose its shape and slump seaward in places.

Figure 26. Treasure Island north geotextile tube on March 11, 2003. The UV shroud was almost completely destroyed and erosion had occurred behind the tube with some wind-blown sand deposited between the landward side of the tube and the erosional scarp.

The Treasure Island middle and south projects, which had only narrow beaches in front of the tubes at the time of installation in March 2000, had mostly been destroyed by November 2001 and June 2002, respectively (Figs. 25 and 5, Plate 3). By November 2001 the beach in front of the north tube was eroded allowing direct wave attack on the tube. In March 2003, most of the UV shroud of the north tube had been destroyed, and erosion had occurred landward of the tube (Fig. 26, Plate 3). This shoreline is under the influence of San Luis Pass and has historically undergone dramatic shoreline retreat and advance in response to changes in the sand supply, tidal channels, and offshore shoals. The shoreline along the Treasure Island development is currently in a retreat phase, and the geotextile tubes cannot prevent this natural shoreline adjustment.

TS Allison struck the coast in June 2001, but it was not a significant storm with regard to storm surge and beach erosion. Allison caused elevated water levels and high waves that attacked the bases of the geotextile tubes and removed much of the sand cover on their seaward faces, especially along the Gilchrist West project. Allison conditions, however, did not cause wash over, dune erosion, or significant vegetation line retreat adjacent to the projects. Hence damage to houses behind the tubes would not have been expected even without the tubes present. It is likely, however, that erosion of vegetation to a position landward of some houses behind the tubes would have occurred, which would have placed them on the public beach easement. However, this would be expected only in places where the tubes were installed seaward of houses that were probably on the public easement before tube installation.

TS Fay struck the area in September 2002. Fay caused more erosion than Allison and had about the same erosion potential as TS Josephine in October 1996. However, Fay was much less of a storm with regard to beach and dune erosion than TS Frances in 1998.

Before Fay, it is estimated that less than 15% (6,000 ft) of the tubes were exposed, but after Fay 79% (30,500 ft) were exposed. Fay caused narrowing of beaches in front of and adjacent to the geotextile tube projects and erosion of coppice mounds where they existed on adjacent beaches. As during Allison, however, it is evident that structures behind the geotextile tubes, other than perhaps some of the most seaward structures on the public beach, would not have been damaged by Fay if the tubes had not been present. The line of vegetation, however, would have retreated landward of some houses, but this would be expected only in places where the tubes were installed seaward of houses that were probably on the public easement before tube installation.

The Gilchrist West (Caplen) project has had the greatest length of exposed tube, the narrowest beaches, and has suffered the most damage of the three major projects, which include Gilchrist East and Pirates Beach. Much of the natural beach where the Gilchrist West tubes were installed was characterized by an eroding bluff created by the intersection of the shoreline with a high, relict beach ridge formed thousands of years ago. The tubes were placed along the seaward base of this bluff (see GLO20 beach profiles and photos in Appendix B), where it existed, and the general result was a narrower or lower beach in front of the tubes at the time of installation compared to other projects. This setting has resulted in the shorter life span of the tubes and the fronting beach.

In contrast to the Gilchrist West project where most of the tube was exposed by TS Allison in June 2001, only 10% of the Pirates Beach project was exposed. Before Allison, the Pirates Beach project had sand fencing and vegetated sand in front of the tubes unlike the Gilchrist West project. This additional volume of vegetated sand and a beach wider by about 16 ft (5 m) protected the tubes (Fig. 27). Tubes exposed by TS Allison generally had beaches less than 50-ft wide (15 m). Thus this is the width beaches need to be if the tubes are to retain their sand cover during a mild storm like TS Allison. A thick and vegetated sand cover on the tubes can partly compensate for a narrower beach.

Figure 27. Pirates Beach geotextile tube at GAL01 profile location (see figure 6 for location). This project remained covered and vegetated following Tropical Storm Allison. Note sand fence and lack of coppice mound subenvironment.

Based on beach profile data in this report, it is estimated that 4.78 yd^3 per linear yard of beach length (4 m^3 per 1 m of beach length) is required to cover the seaward face of a geotextile tube. Therefore, it would take about 22,600 yd^3 (17,304 m^3) of sand to cover the 14,193 ft (4,326 m) of tube exposed by Allison in June 2001 and 48,584 yd^3 (37,118 m^3) to cover the 30,492 ft of tube exposed by Fay in September 2002. A medium-sized dump truck with a 15 yd^3 capacity would require 4,745 round trips to deliver this much sand. Most of this sand is needed on the Gilchrist projects. Project designs also call for the tubes to have natural vegetation. Vegetation helps stabilize the sand cover, improves the project's visual appearance, and improves habitat. Even keeping a 25% vegetation cover along the Gilchrist and Dellanera projects, however, has proven difficult (Table 2) and keeping the Pirates Beach project vegetated is becoming difficult as the fronting beach narrows.

Effects of geotextile tubes on the beach/dune system

Along Galveston Island and Bolivar Peninsula, beaches in front of the geotextile tubes are narrower than adjacent beaches (Figs. 14 through 19, Tables 4 and 5). This is because of where the tubes were originally installed and because of shoreline retreat. Shoreline retreat will narrow the beaches in front of the tubes even more if there is not adequate beach nourishment. Tubes were installed farther seaward than the bluffs and foredune ridges on adjacent beaches (Fig. 8, Plates 1 and 2). The seaward edges of the foredune ridges and bluffs correspond with the continuous line of vegetation and are the natural geomorphic features that the geotextile tubes emulate. The continuous line of vegetation forms the landward boundary of the sparsely vegetated coppice mound environment where present and the landward boundary of the public beach easement. The placement of the tubes has created landward boundaries to the beaches that are more seaward than the relatively natural boundaries of adjacent beaches.

Some tube segments were routed seaward of individual houses or groups of houses (Figs. 28, 29, Plates 1 and 2). These areas create particularly narrow beaches that are not passable during times of moderately elevated water levels (1 to 2 ft above MHHW) (Fig. 28). Furthermore, outflow from the drainage pipes along the Pirates Beach project erode channels perpendicular to the shoreline that at times hinder passage (Fig. 30). These drainage pipes, which concentrate flow through the tubes, are required to prevent flooding from rainfall landward of the tubes.

Figure 28. Pirates Beach geotextile tube on November 15, 2001. The tube at this location was routed seaward of the house causing a particularly narrow beach and difficulty in maintaining a sand cover. Water level was about 1 ft (0.3 m) above mean higher high water.

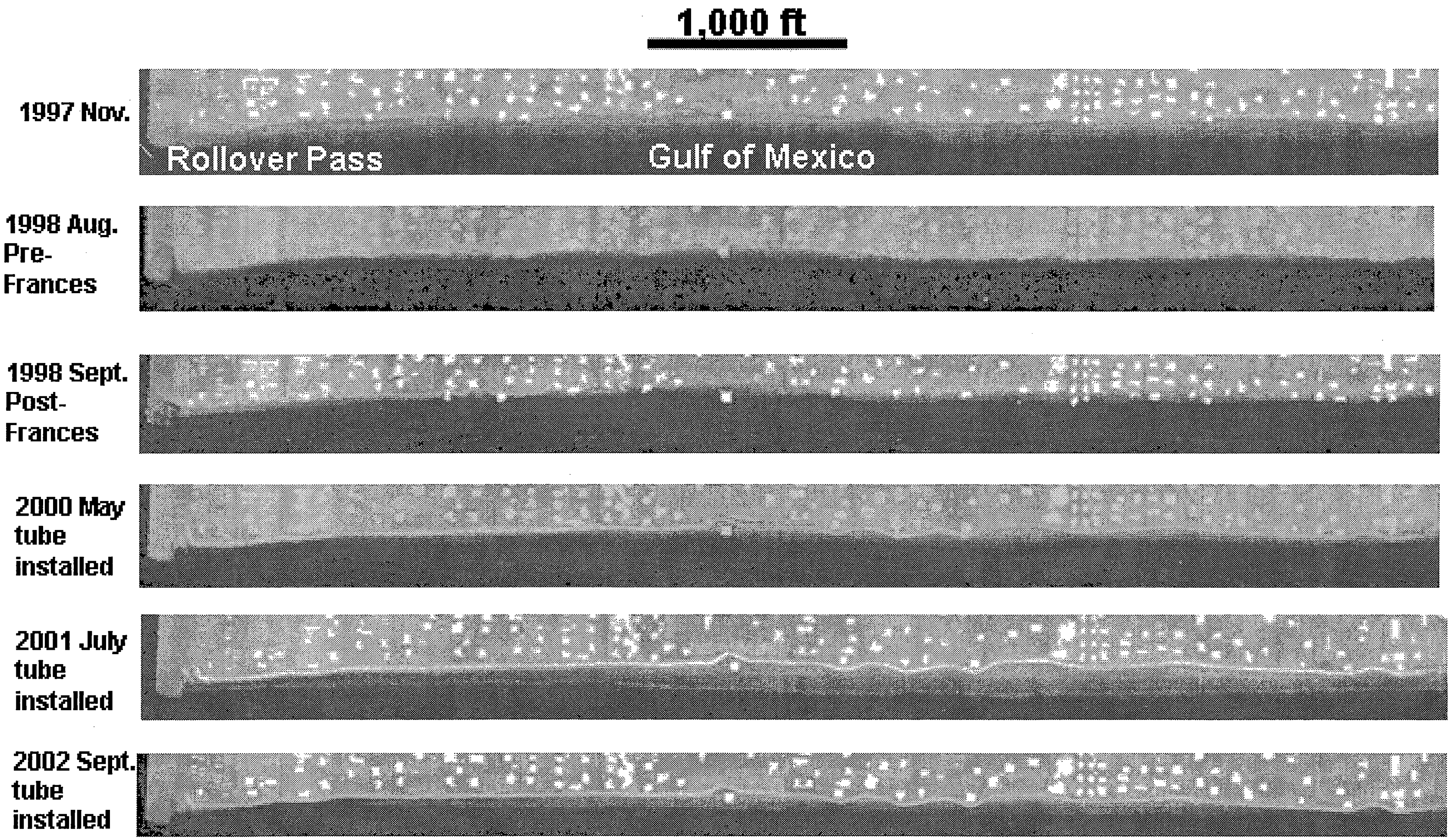


Figure 29. Lidar topographic images of a portion of the Gilchrist East project. Dark areas are low elevation, lighter higher elevation. Geotextile tubes were present during the 2000, 2001, and 2002 surveys. Note how the tubes were routed seaward of some houses and the overall geomorphic impact of the project.

Figure 30. Pirates Beach geotextile tube project on June 14, 2001 after Tropical Storm Allison. Rainfall runoff from Allison flowed through the black street drainage pipe beneath the tube on the right and eroded this channel in the beach.

With regard to geomorphology, geotextile tubes are most congruent where they are placed in front of an eroding bluff such as along portions of the Gilchrist West project (see profile GLO20 in Appendix B). In most areas, however, the tubes have significantly altered the natural geomorphology and have prevented the formation of the coppice mound subenvironment (Fig. 31). This is the case even where the tubes are covered with vegetated sand (Fig. 27). The tubes rise abruptly from the back beach with relief of 1.6 to 6.6 ft (0.5 to 2 m) greater than the natural dune or bluff would (See GLO21 and GLO22 profiles in Appendix B). The covered tubes also lack the complex topography that natural dunes possess and in most places appear more like earthen dikes than wind-formed dunes (Figs. 28, 32 and Plates 1 and 2). If a beach is wide and high enough, vegetation will advance seaward from the dunes, trap wind-blown sand and form irregular and sparsely vegetated coppice mounds on the back beach (Fig. 31).

Coppice mounds are not well developed along beaches where driving is permitted or extensive beach scraping takes place because these activities destroy the colonizing vegetation. They are also poorly developed or not present in front of the geotextile tubes even where driving is not permitted, such as along the Pirates Beach project. Beaches to the northeast of Pirates Beach and beaches in the Galveston Island State Park to the southwest of Pirates Beach have coppice mound areas that are 66 ft (20 m) wide. In front of the project, however, the coppice mound subenvironment does not exist or is poorly developed (Figure 27). This is because the geotextile tube beaches are not wide enough to supply wind-blown sand to the back beach and to keep the back beach out of the swash zone during moderate wave and water level conditions.

For coppice mounds to develop along the upper Texas coast, a beach must be about 70-ft (21-m) wide with the back beach level at least 1.97 ft (0.6 m) above mean sea level. Figure 32 compares beach profiles from a Pirates Beach geotextile tube location and a relatively natural site at Galveston Island State Park in the early spring of 2003. The tube beach is about 3 ft (1 m) lower than the State Park beach. It is unlikely that the tube beach will naturally recover enough to allow coppice mounds to develop or to provide a recreational area equivalent to the State Park.

The profiles in figure 32 are lined up by shifting them horizontally so the foredune and geotextile tube coincide. This was done to emphasize the difference in the beach dimensions; however, it gives the impression that the shoreline is shifted landward at the tube location relative to the State Park. This is not the case. The shoreline along Pirates Beach is generally in a position congruent with the adjacent beaches. However, the geotextile tubes were installed seaward of the adjacent foredune positions which has caused a narrower beach at Pirates Beach. The same situation exists at the other projects; therefore, the primary reason for the geotextile tube beaches being narrower than adjacent beaches during the study period is the original placement of the tubes. This is apparent on the maps of plates 1 and 2 where one can see that the 2000, 2001, and 2002 shorelines are not offset alongshore but that the tubes are set seaward of the adjacent foredunes or bluffs.

Figure 31. Coppice mounds at GLO06 profile location in Galveston Island State Park on September 18, 2002 (see figure 6 for location). There is no geotextile tube at this location. This subenvironment of wind-blown sand and sparse vegetation was eroded but survived Tropical Storm Fay in September 2002. Coppice mounds do not exist or are poorly developed along beaches with geotextile tubes or where structures are on the back beach.

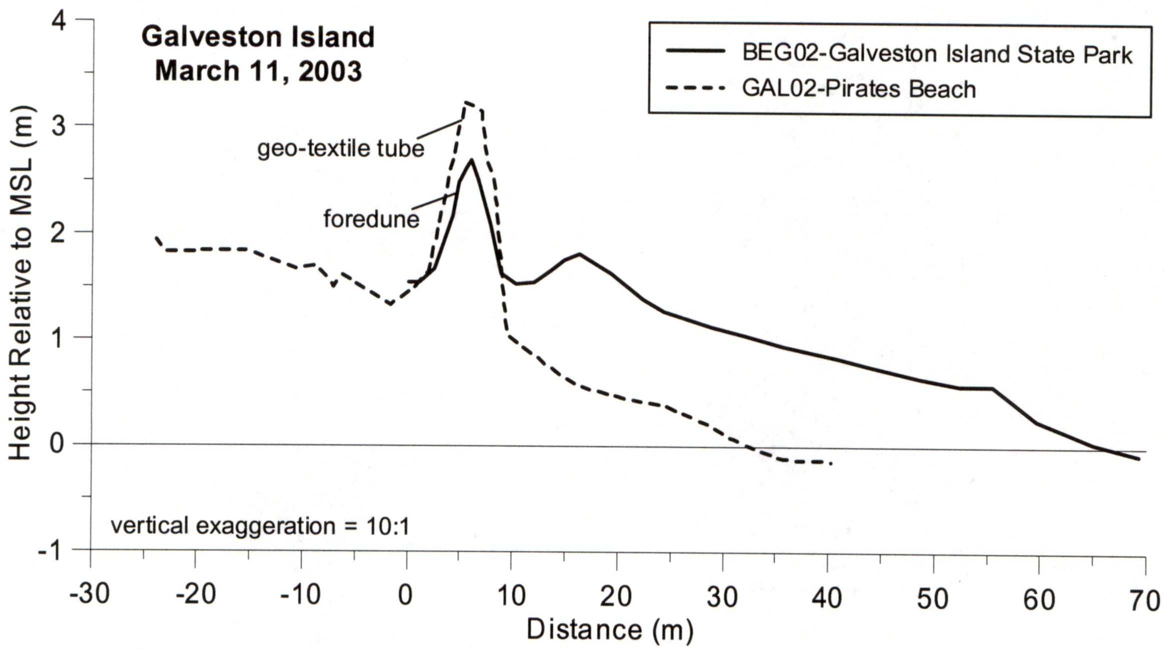


Figure 32. Comparison of beach profiles BEG02 with no geotextile tube and GAL02 in the Pirates Beach geotextile tube project (see Fig. 6 for locations). Profiles are adjusted horizontally to line up the foredune and geotextile tube (see Figs. 33 and 34 for photos).

Figure 33. BEG02 beach profile location in Galveston Island State Park on March 11, 2003. No geotextile tube is at this location. Coppice mounds are present seaward of the sand fence and there is room on the back beach for further mound develop during the summer. This is in contrast to the setting in front of the Pirates Beach tube project shown in figure 34 (see Fig. 6 for location and Fig. 32 for beach profile).

Figure 34. GAL02 beach profile location in the Pirates Beach geotextile tube project on March 11, 2003. There is no coppice mound environment seaward of the tube because the beach is too narrow and too low for vegetation and wind-blown sand to accumulate (see Fig. 6 for location and Fig. 32 for beach profile).

As of March 2003 there was no indication that the geotextile tubes had significantly increased the rate of retreat of adjacent beaches, with the possible exception of the area north of the Treasure Island north project. At this location, the lidar data displayed in Plate 3 shows the shoreline to be offset landward by about 80 ft (25 m) after TS Fay in September 2002. It appears that if the tube had not hindered the erosion of sand behind it, the adjacent beach to the north would have been about 30 ft (10 m) wider for a distance of about 160 ft (50 m) north of the tube.

It is not likely that the tubes will significantly enhance the rate of shoreline retreat in the future. Sand supply to adjacent beaches would be reduced and erosion increased if beaches in front of the tubes completely eroded and the tubes were able to prevent further erosion of the sand behind them. If the beaches in front of the tubes are maintained by nourishment, however, then the nourishment sand will supply adjacent beaches as it is eroded. If the tube beaches are not maintained, the tubes will likely be destroyed before significantly affecting the adjacent beaches. It is important, however, to monitor beaches in the future. Even a small or short-term enhanced rate of erosion along an adjacent beach could cause problems for specific structures.

Conclusions

1. The storm-surge protection function of the geotextile tubes had not been fully tested as of March 2003.
2. The geotextile tubes will fail when exposed to direct wave attack making them useful only for short-term erosion control. This is evident in the failure of the Treasure Island middle project, and in the holes in the tube fabric and collapsed sections along the Gilchrist West project. To prevent failure it is critical to keep the tubes covered with sand, to maintain a beach in front of them, and to repair holes in the fabric as soon as possible. It is also important to note that, during storms, erosion and vegetation line retreat may occur landward of the geotextile tubes as was observed at the northern Treasure Island project.
3. Beaches in front of the geotextile tubes need to be at least 50-ft wide to keep the tubes from being exposed and damaged during a mild storm like TS Allison. A thick and vegetated sand cover on the tubes can partly compensate for a narrower beach.
4. During Tropical Storms Allison and Fay, the geotextile tubes prevented the vegetation line from retreating landward of houses. However, those houses to which the vegetation line would have retreated were probably seaward of the natural line of vegetation at the time the tubes were installed.
5. Because it is under the influence of San Luis Pass, the Treasure Island shoreline is historically dynamic undergoing periods of dramatic retreat and advance. However, net long-term shoreline movement is landward. The shoreline is currently in a retreat phase, and the geotextile tubes cannot stop the movement. Along the northern reach of the Treasure Island North project, erosion has proceeded behind the tubes.
6. Other than the special cases of the Treasure Island projects, the Gilchrist projects have proven to be the most difficult to keep covered with sand. The Gilchrist West project has the highest percentage per project of exposed geotextile tubes and contributes by far the greatest length of exposed and damaged tubes along the upper coast. The primary reason for this is the relatively seaward placement of the tubes causing narrower and lower beaches in front of them and thus less protection than at the other major projects.
7. In June 2001, after Tropical Storm Allison, 44% of the lengths of geotextile tubes were exposed along their seaward faces. Maintenance activity and fair weather conditions allowed the recovering of all but 15% of the project lengths by November 2001. Most of the exposed tubes are along the Gilchrist West project.
8. In September 2002, after Tropical Storm Fay, 79% of the lengths of geotextile tubes were exposed and 69% were still exposed by March 2003.
9. Keeping at least a 25% vegetation cover along the Gilchrist East, Gilchrist West, and Dellanera projects has not been possible.
10. Keeping the geotextile tubes repaired, sand covered, and vegetated requires a significant effort.
11. Beaches in front of the geotextile tubes are narrower than adjacent beaches. This is primarily because the tubes were installed farther seaward than the natural landward boundaries represented by the line of vegetation, foredunes, or bluffs.

12. Some geotextile tube segments were routed seaward of individual houses or groups of houses and departed from a shore-parallel orientation. These areas create particularly narrow beach segments that are not passable during times of moderately elevated water levels of 1 to 2 ft (0.30 to 0.61 m) above mean higher high water.
13. After rainfall, outflows from street drainage pipes along the Pirates Beach project erode channels perpendicular to the beach that at times hinder passage along the beach.
14. Geotextile tubes alter the natural geomorphology of the beach/dune system and have hindered the formation of coppice mounds and natural dunes.
15. The geotextile tubes have not enhanced erosion rates on adjacent beaches with the possible exception of the Treasure Island north project. If the beaches in front of the tubes are not nourished with sand from outside the littoral system, then there may be a small enhancement of erosion of adjacent beaches until the tubes are destroyed by wave action.

References

Gibeaut, J. C., Gutiérrez, Roberto, and Hepner, Tiffany, 2002, Threshold conditions for episodic beach erosion along the southeast Texas coast: Gulf Coast Association of Geological Societies Transactions, v. 52, p. 323–335.

Gibeaut, J. C., Hepner, T. L., Waldinger, R., Andrews, J. R., Smyth, R. C., and Gutierrez, R., 2002, Geotubes along the Gulf shoreline of the upper Texas coast: observations during 2001: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the Texas Coastal Coordination Council pursuant to National Oceanic and Atmospheric Administration Award No. NA970Z0179, 24 p. + appendices.

Gibeaut, J. C., and Gutiérrez, Roberto, 1999, Dune and beach dynamics in Galveston County, Texas, 1994 to 1998: critical information for coastal management: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the Texas Coastal Coordination Council, pursuant to National Oceanic and Atmospheric Administration Award No. NA770Z0202, 34 p. + apps.

Appendix A: Beach Profile Positions

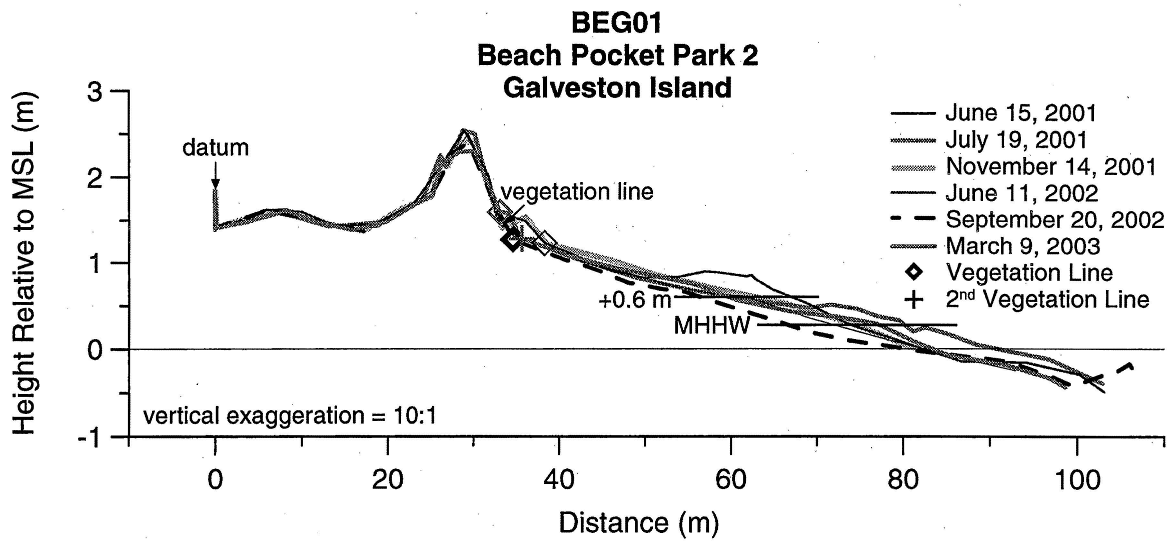
Geotextile tube profile marker coordinates (UTM, NAD 83)

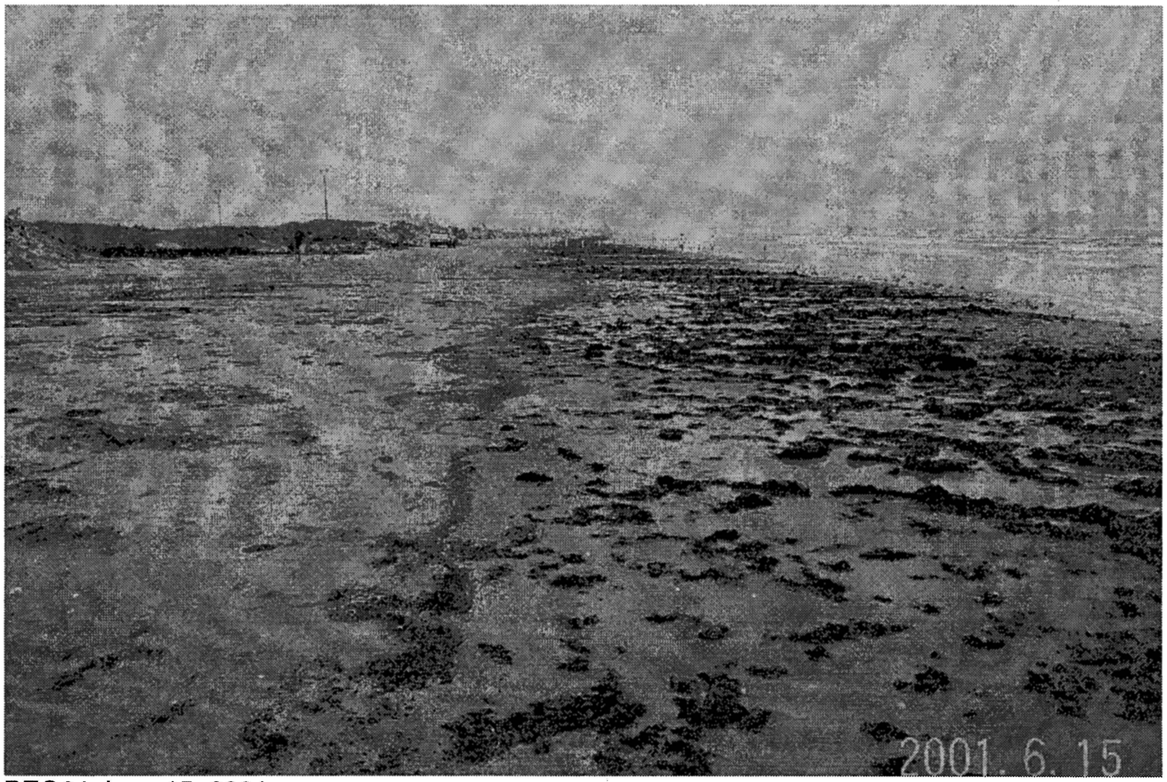
Name	Lat deg., min., sec.	Long deg., min., sec.	Easting (m)	Northing (m)	HAE (m)	Geoid Corr. (m)	Orthometric Height (m)	Local Mean Sea Level Height (m)*	Azimuth (True)	Datum Feature
BEG01	29 13 36.48216	94 53 48.18554	315646.750	3234603.858	-24.526	-26.483	1.957	1.844	144.5	orange stake
BEG02	29 11 38.50200	94 57 06.60400	310255.200	3231059.160	-24.570	-26.412	1.842	1.729	143.5	corner concrete slab
BEG09	29 29 04.13400	94 33 28.69200	348950.310	3262691.490	-24.120	-26.72	2.600	2.487	156.5	Orange stake
BOL01	29 30 39.19755	94 29 26.97214	355505.009	3265515.946	-24.345	-26.741	2.396	2.283	160.9	Orange stake
FOI01	29 04 27.39310	95 07 26.45246	293244.022	3218077.630	-25.056	-26.311	1.255	1.142	97.3	Orange stake
GAL01	29 11 59.57123	94 56 32.39297	311163.070	3231692.950	-23.736	-26.417	2.681	2.568	155.2	fire hydrant
GAL02	29 12 24.48297	94 55 47.41969	312390.472	3232439.838	-24.366	-26.422	2.056	1.943	148.2	concrete curb
GAL03	29 13 39.17440	94 53 45.31781	315725.530	3234685.488	-24.376	-26.439	2.063	1.950	146.2	corner concrete slab
GLO06	29 11 05.67840	94 58 01.80875	308720.010	3230074.029	-24.056	-26.405	2.349	2.236	142.5	orange stake
GLO07	29 12 35.99739	94 55 30.28728	312859.025	3232786.716	-24.096	-26.425	2.329	2.216	141.5	orange stake
GLO08	29 13 14.59334	94 54 26.42201	314603.252	3233946.744	-23.036	-26.434	3.398	3.285	144.5	fire hydrant
GLO09	29 14 03.52156	94 53 04.00811	316853.092	3235417.045	-24.076	-26.443	2.367	2.254	143.5	orange stake
GLO20	29 29 44.38813	94 31 49.46133	351646.106	3263878.565	-23.575	-26.728	3.153	3.040	154.0	orange stake
GLO21	29 30 18.04174	94 30 25.75880	353913.668	3264885.105	-24.395	-26.735	2.340	2.227	154.0	orange stake
GLO22	29 30 59.89016	94 28 41.60542	356734.656	3266137.334	-25.605	-26.749	1.144	1.031	155.5	orange stake
GLO23	29 31 33.75012	94 27 04.45168	359363.480	3267146.689	-24.885	-26.762	1.877	1.764	157.5	orange stake

*Local mean sea level correction is -0.113 m and is applied to the orthometric height.

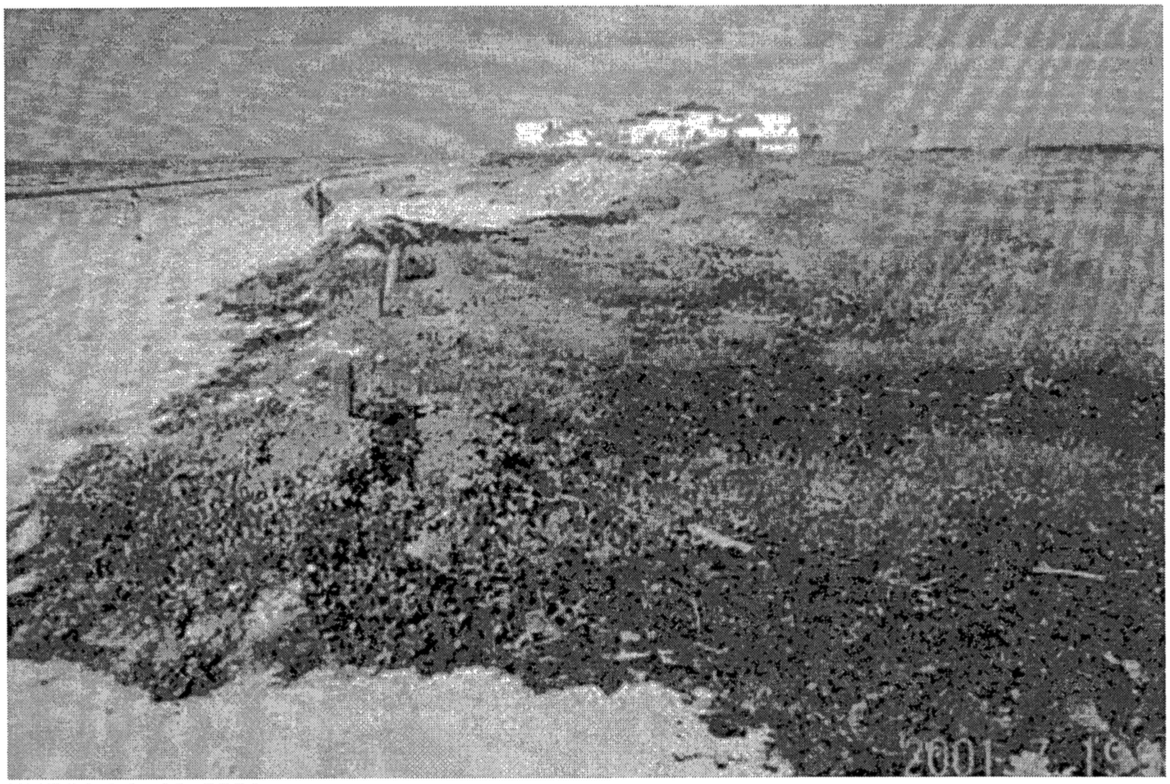
Appendix B: Plots and Photographs of Beach Profiles

Profiles are in alphabetical order. See figures 4, 5, and 6 or plates 1, 2, and 3 for locations.



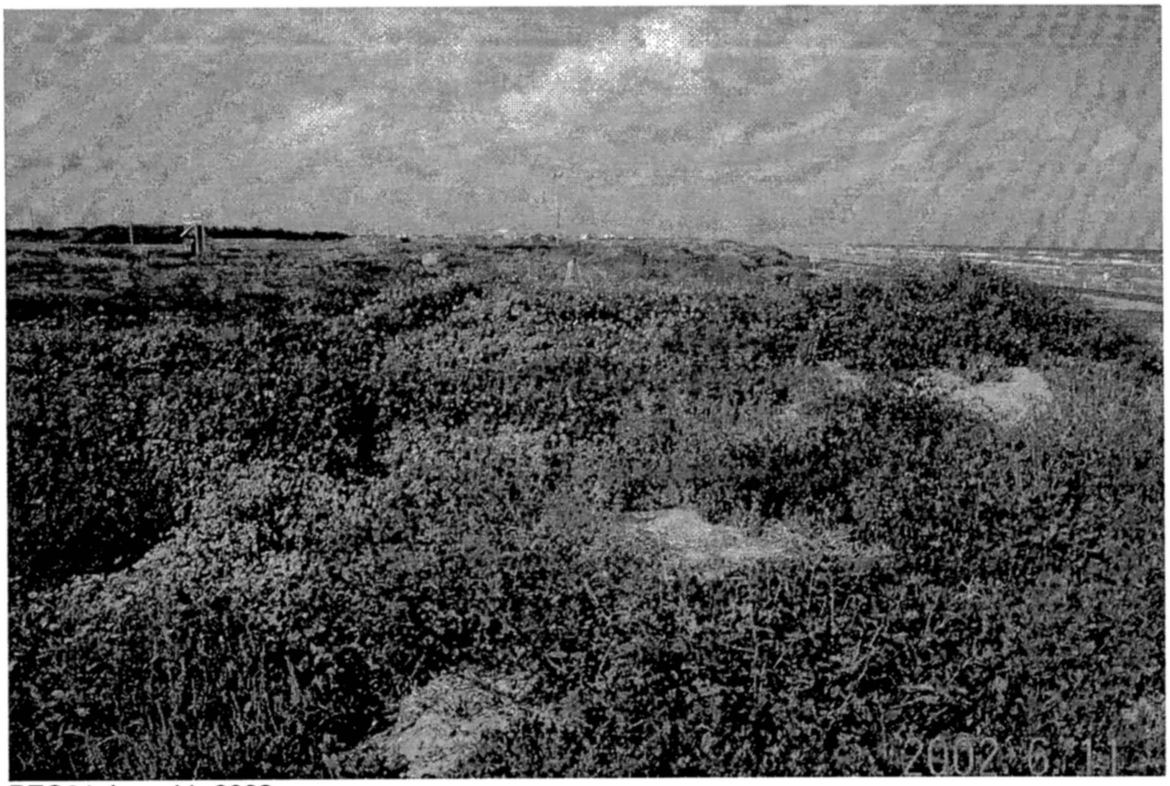


BEG01 June 15, 2001



BEG01 July 19, 2001

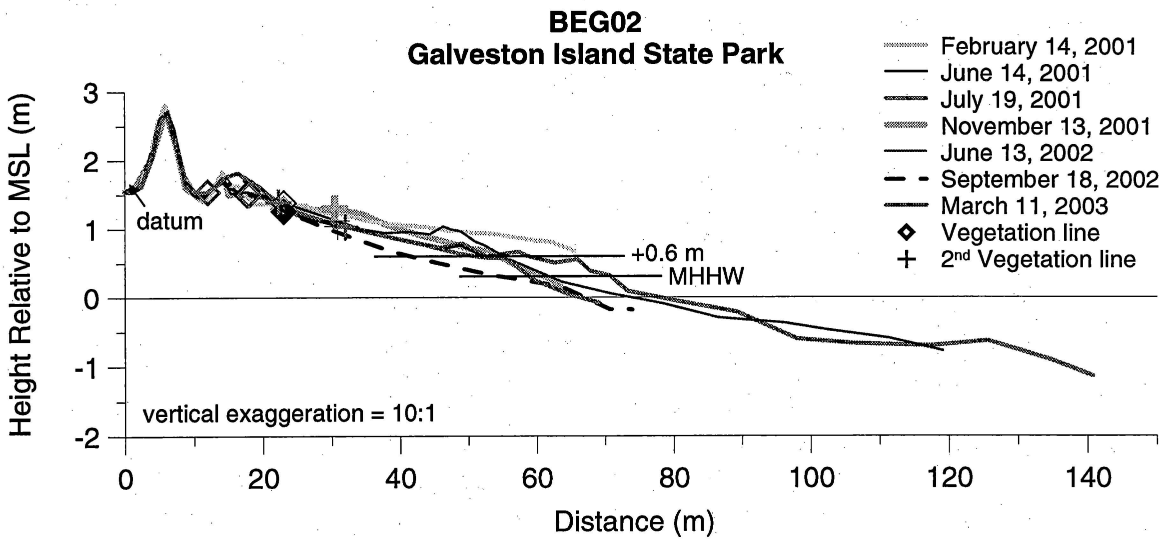
BEG01 November 14, 2001

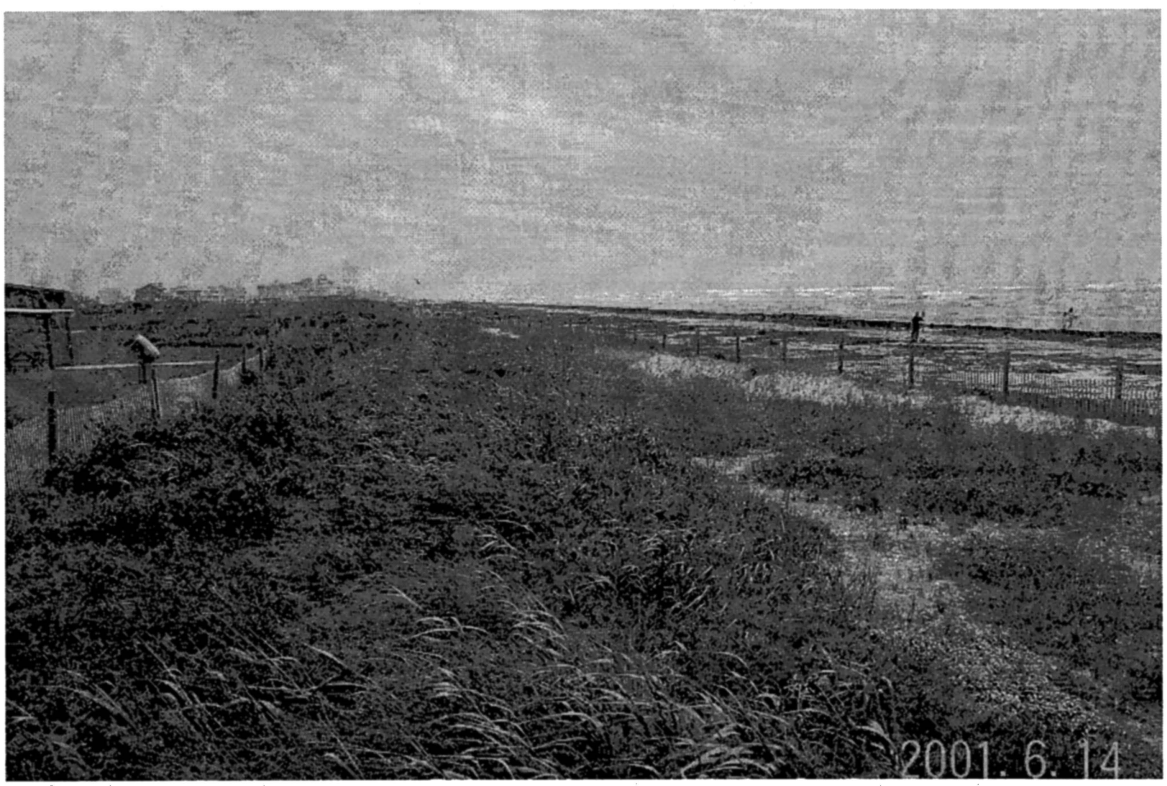


BEG01 June 11, 2002

BEG01 September 20, 2002

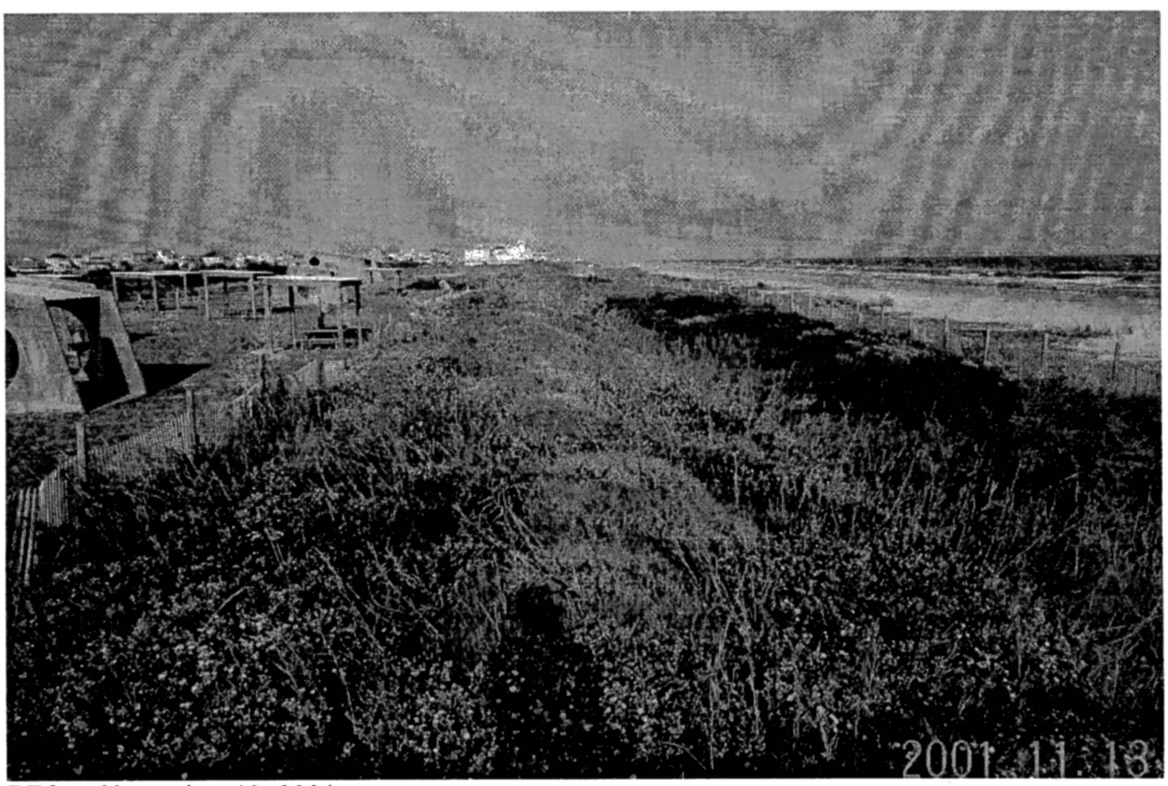
BEG01 March 9, 2003



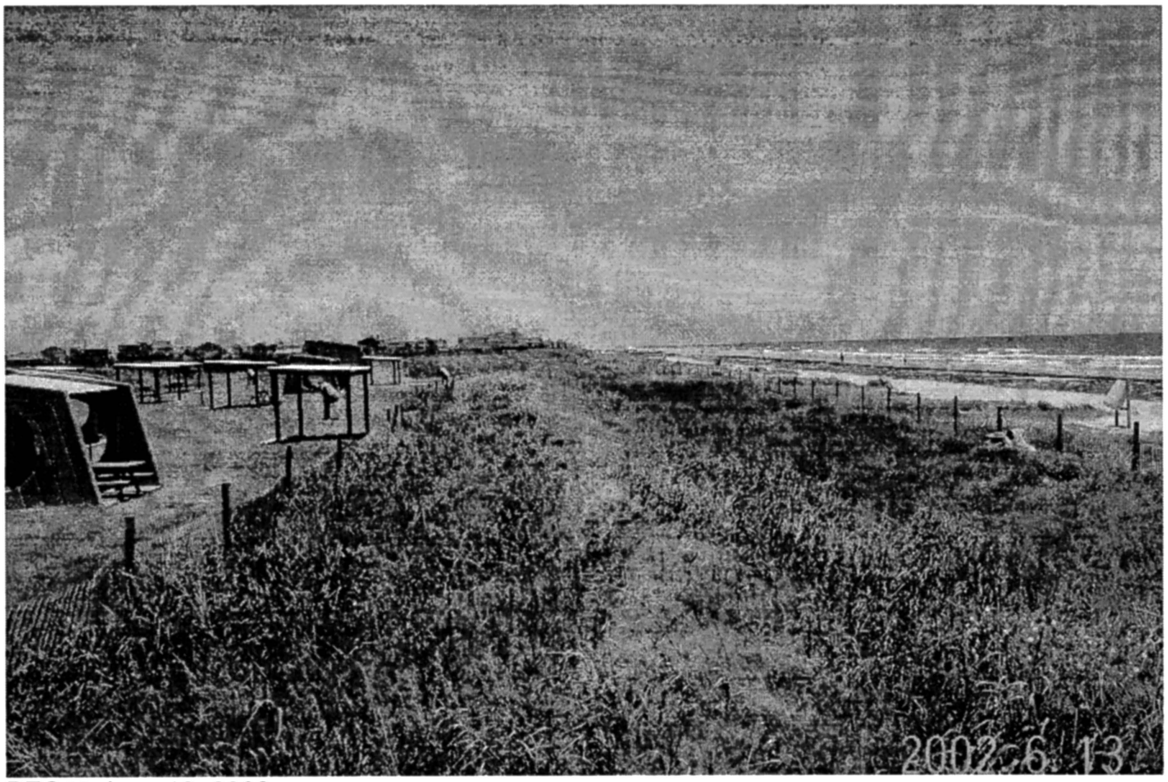


BEG02 June 14, 2001

BEG02 July 19, 2001

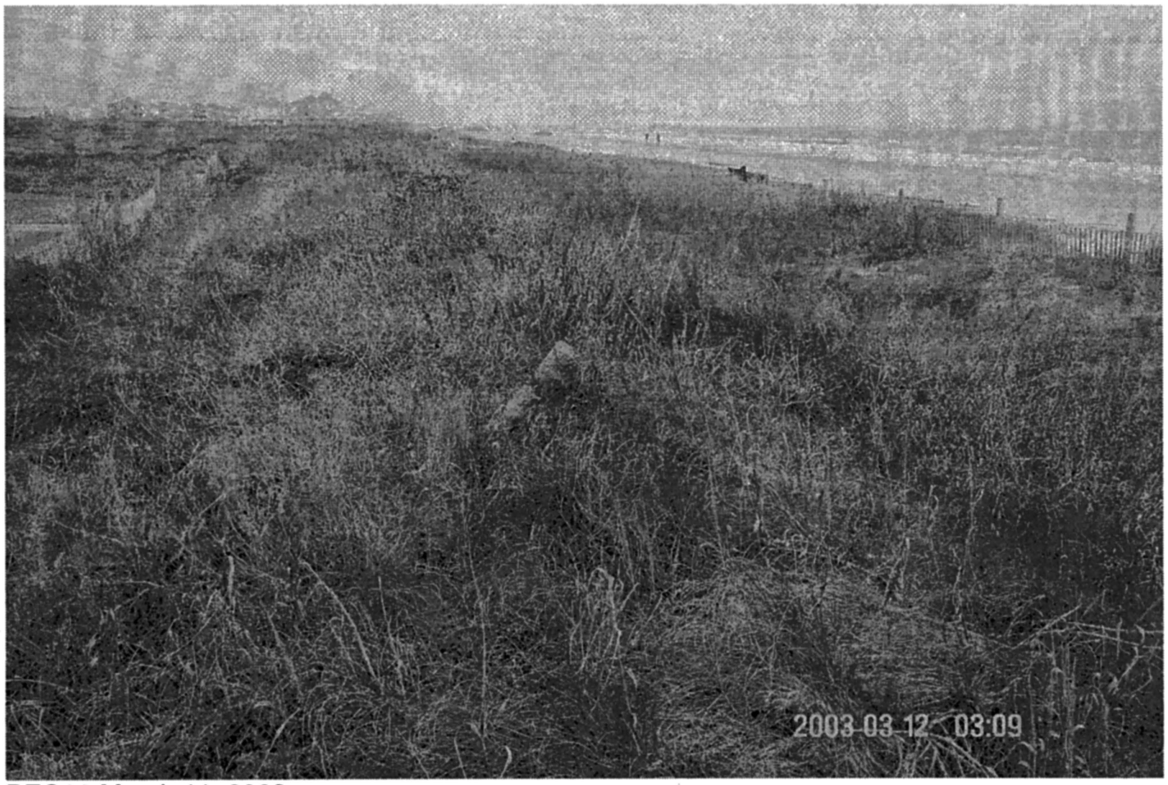


BEG02 November 13, 2001

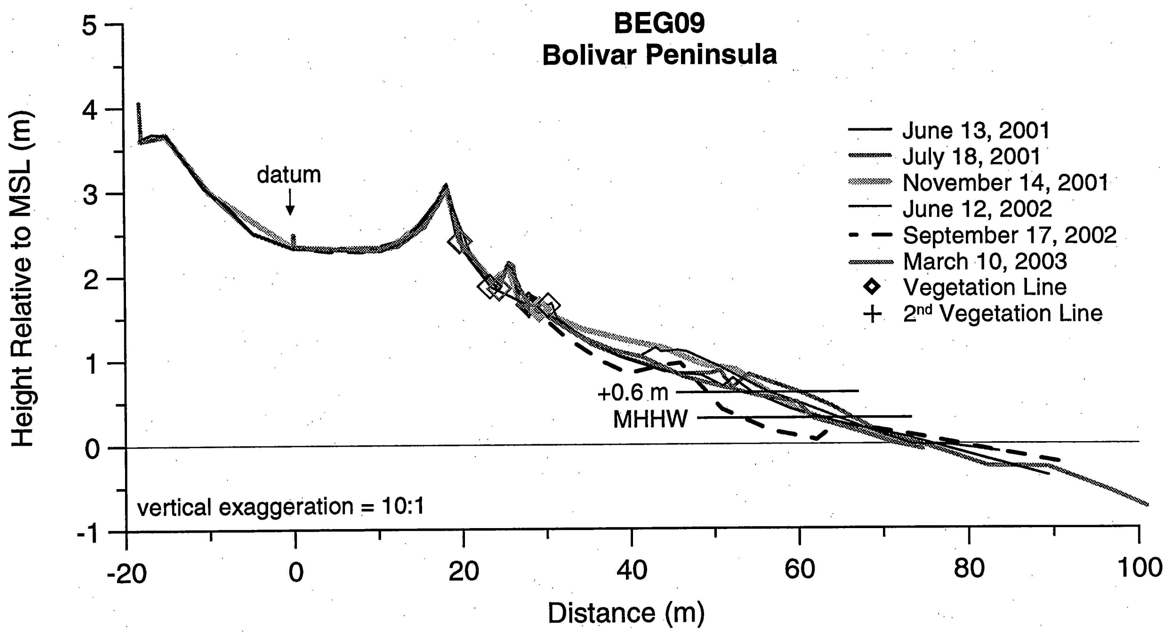


BEG02 June 13, 2002

BEG02 September 18, 2002

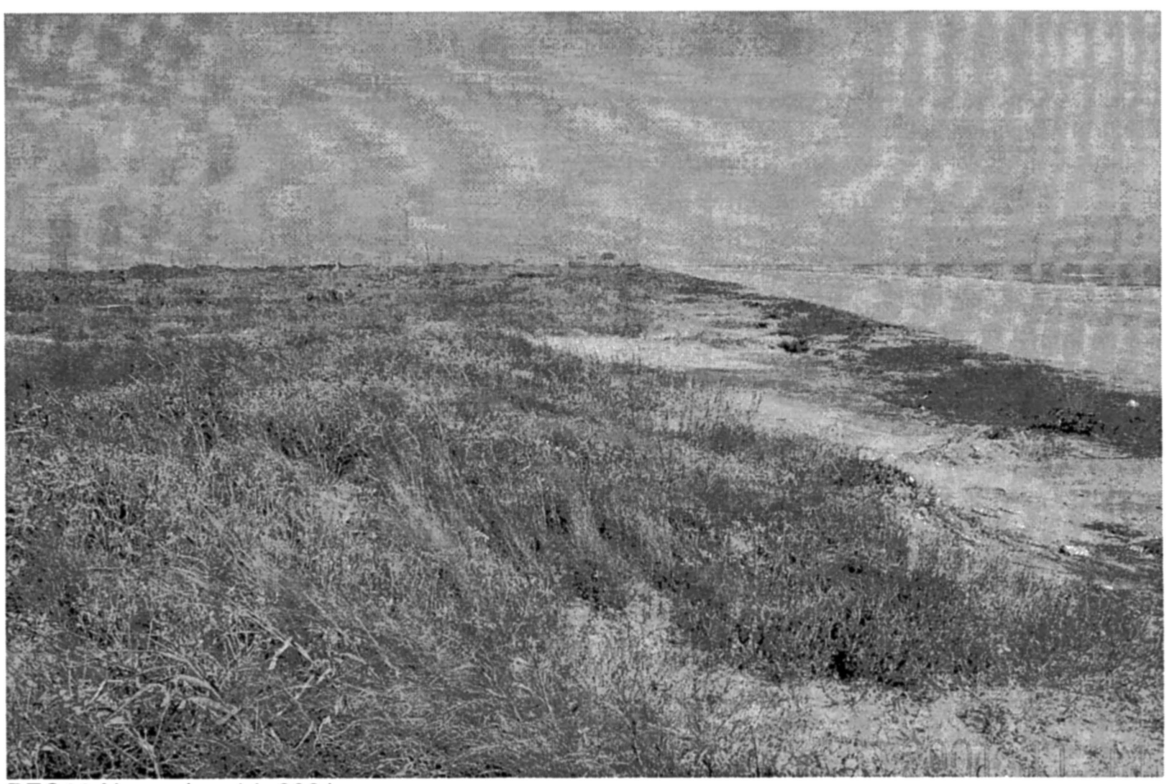


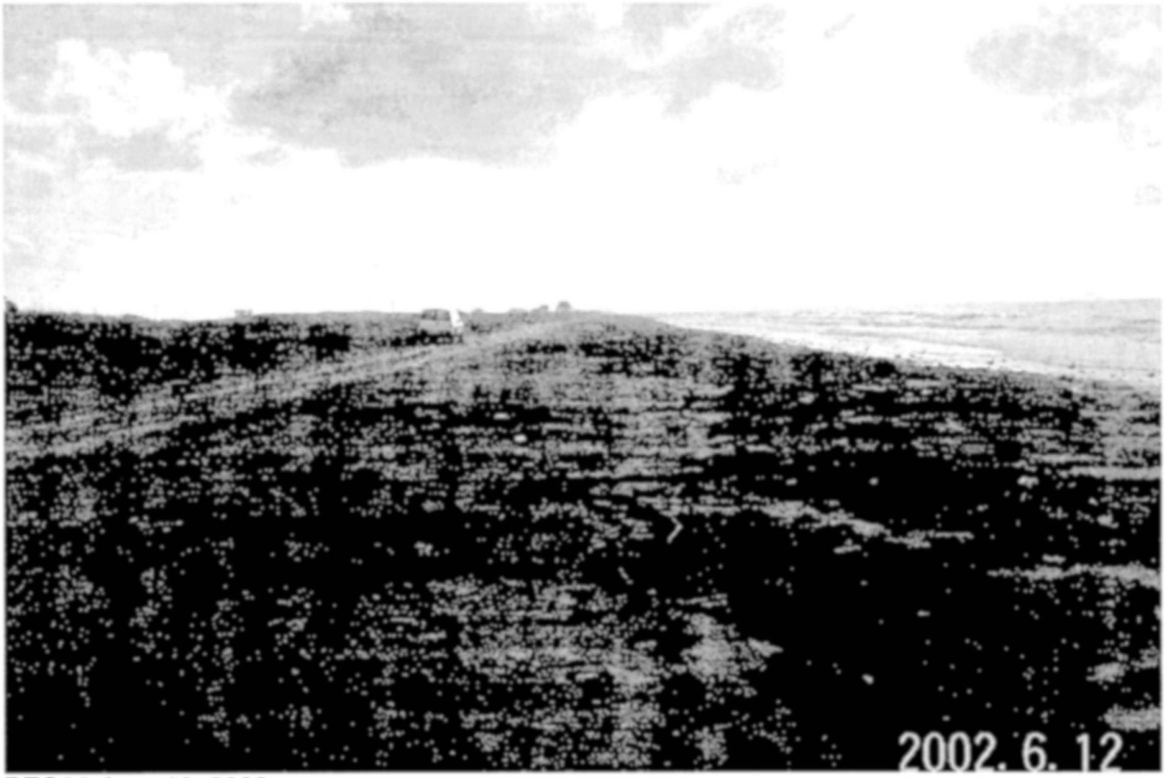
BEG02 March 11, 2003



BEG09 June 13, 2001

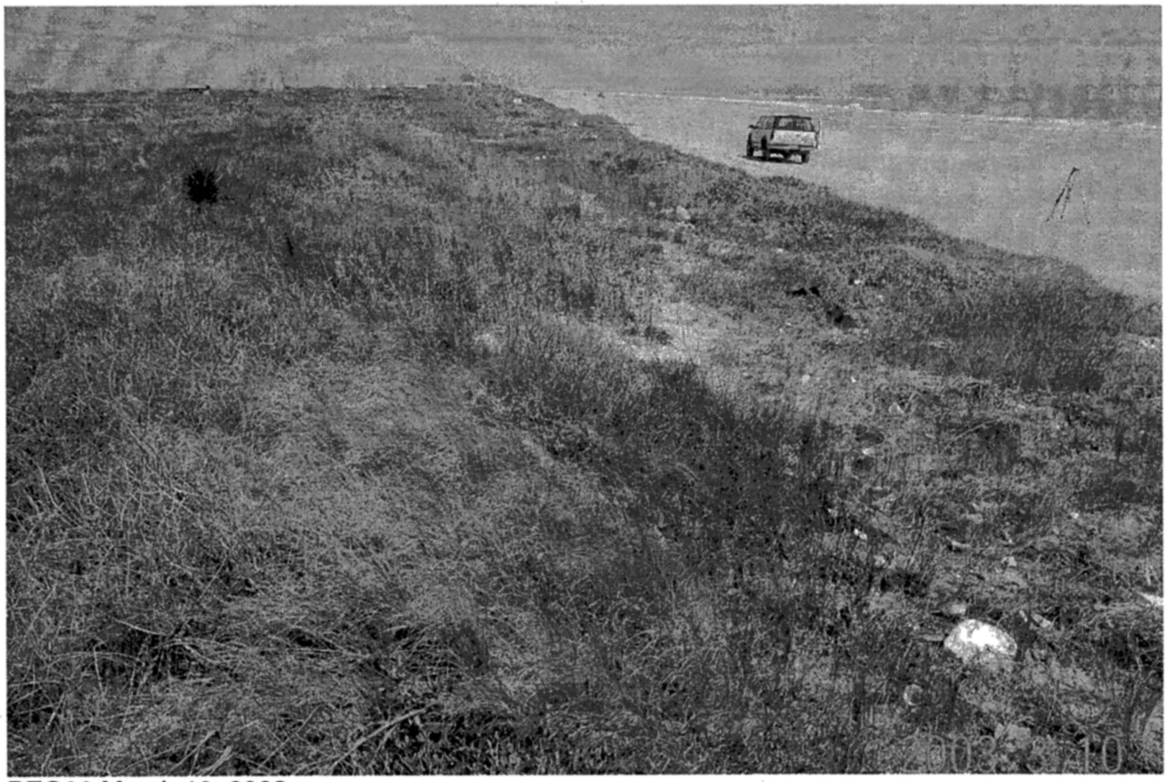
BEG09 July 18, 2001


BEG09 November 14, 2001

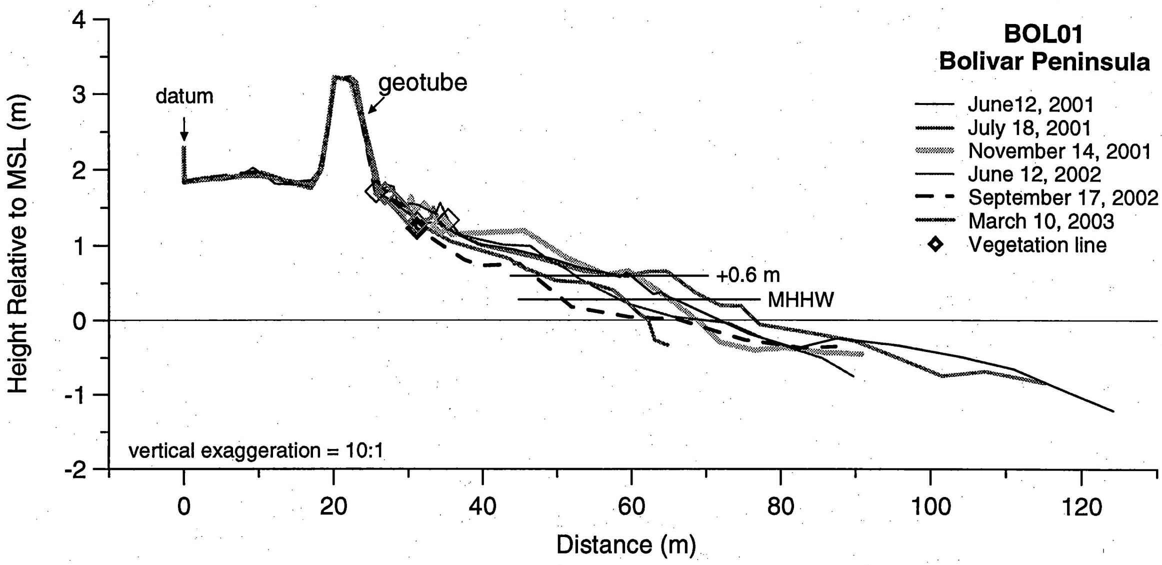


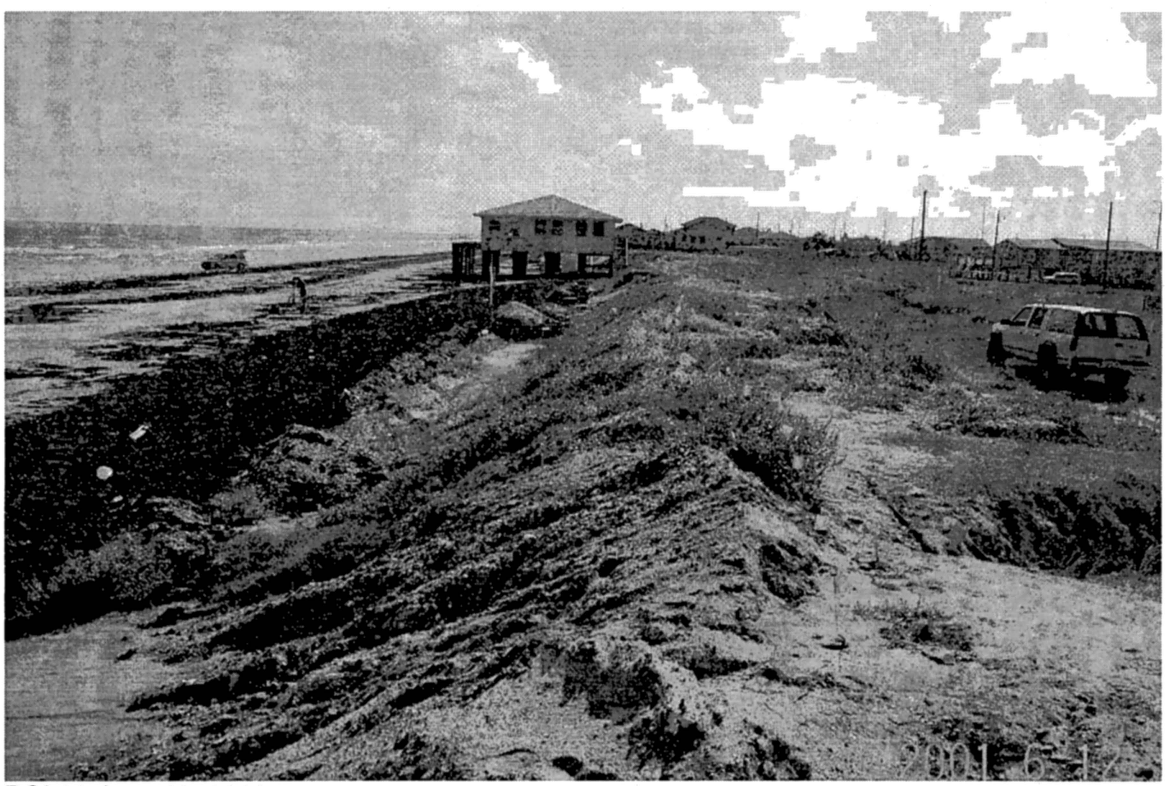
BEG09 June 12, 2002

BEG09 September 17, 2002



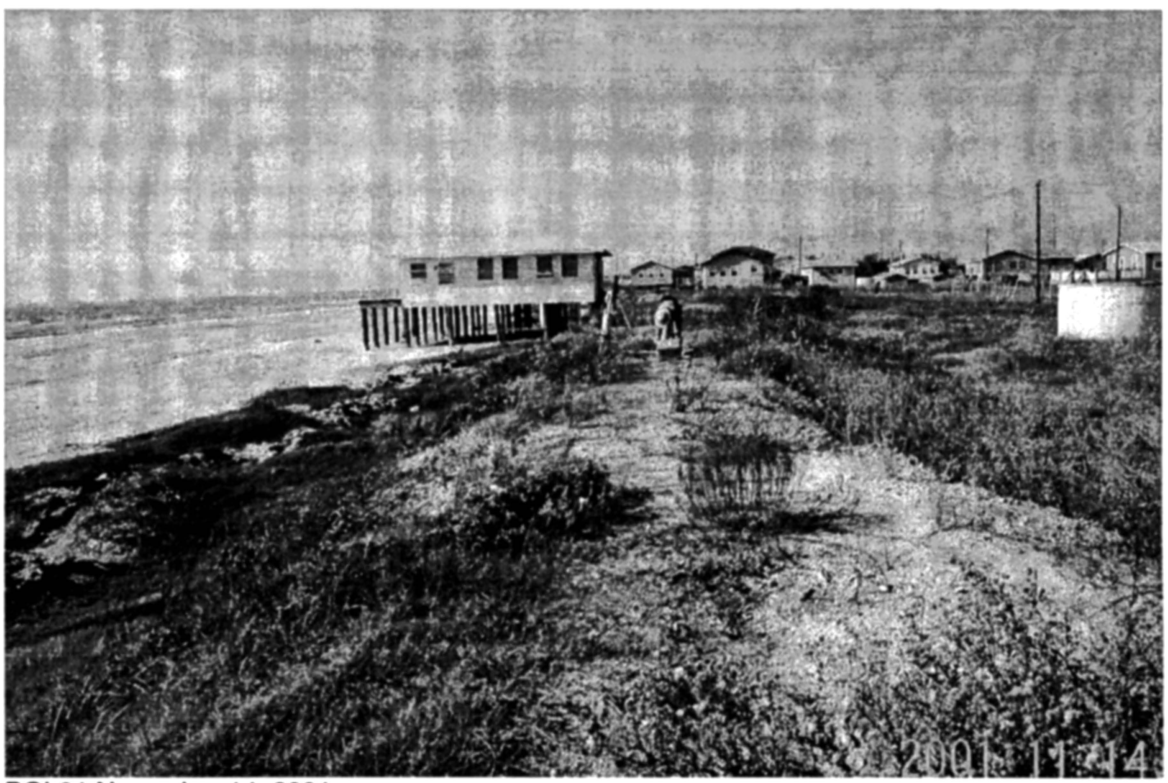
BEG09 March 10, 2003



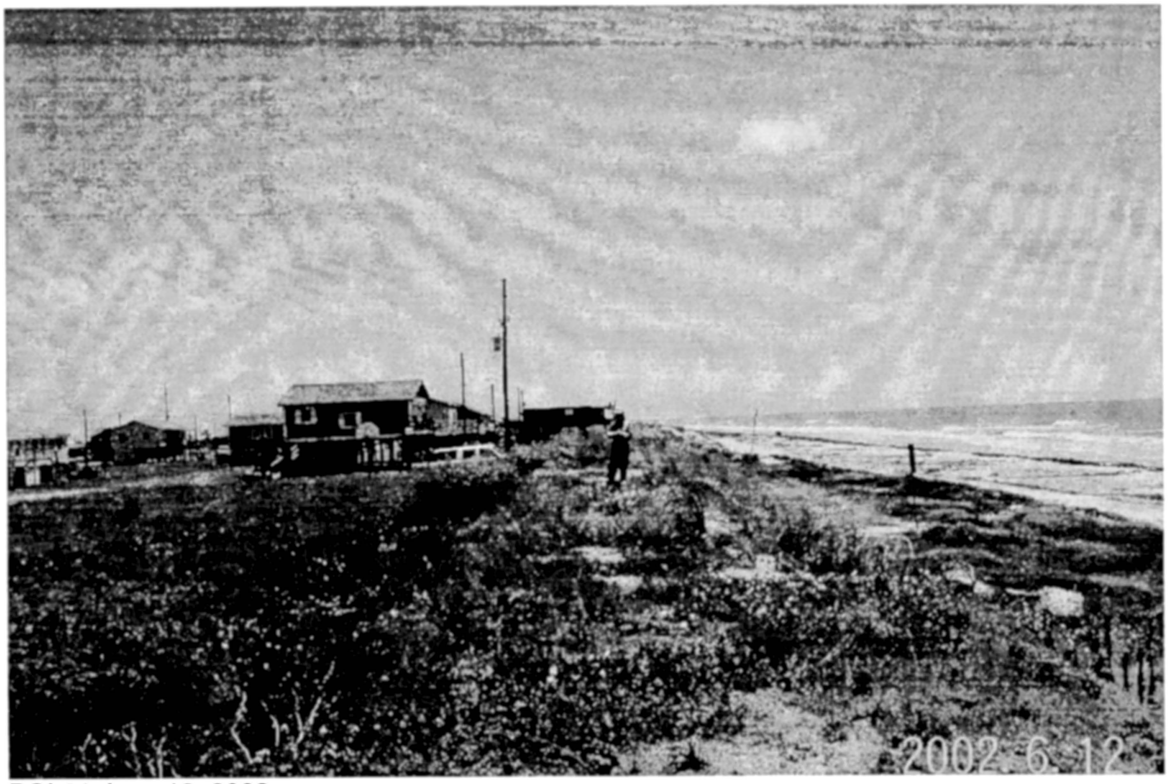


BOL01 June 12, 2001

BOL01 July 18, 2001

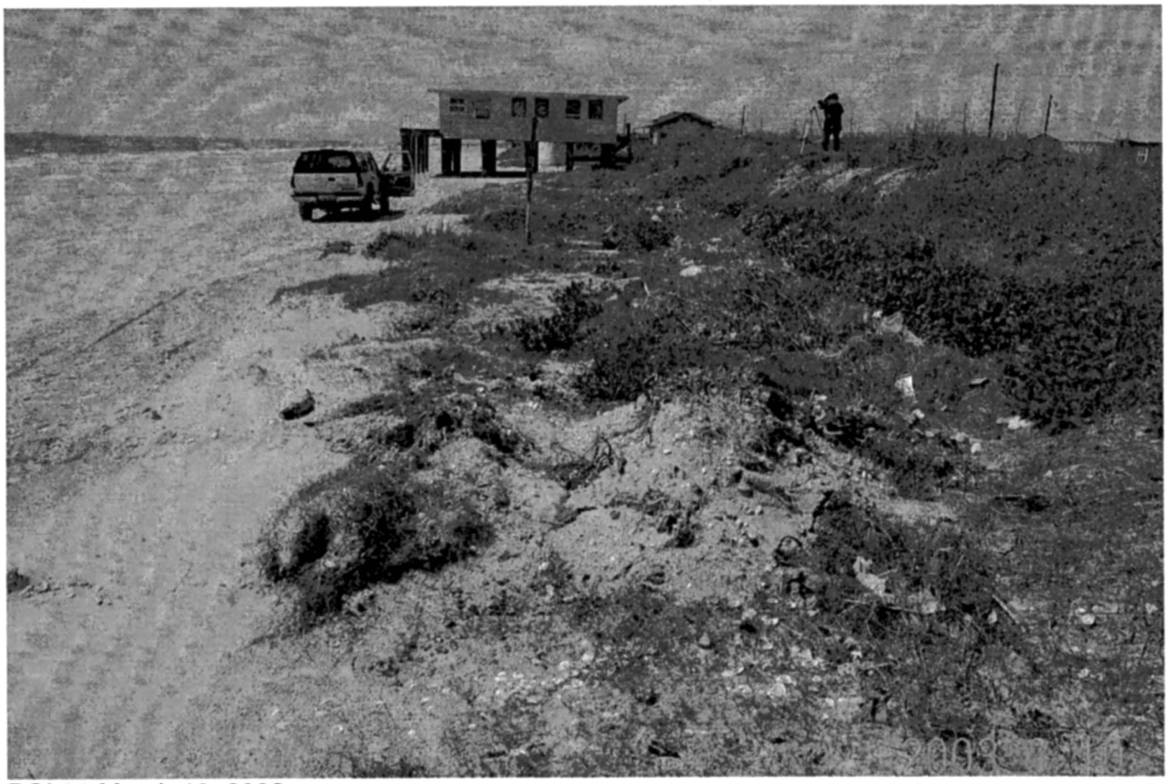


BOL01 November 14, 2001

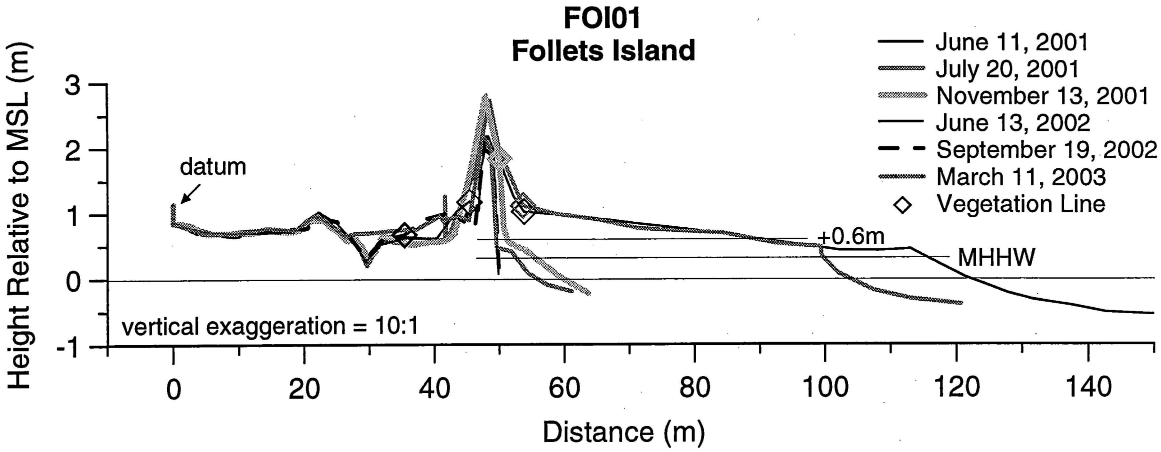


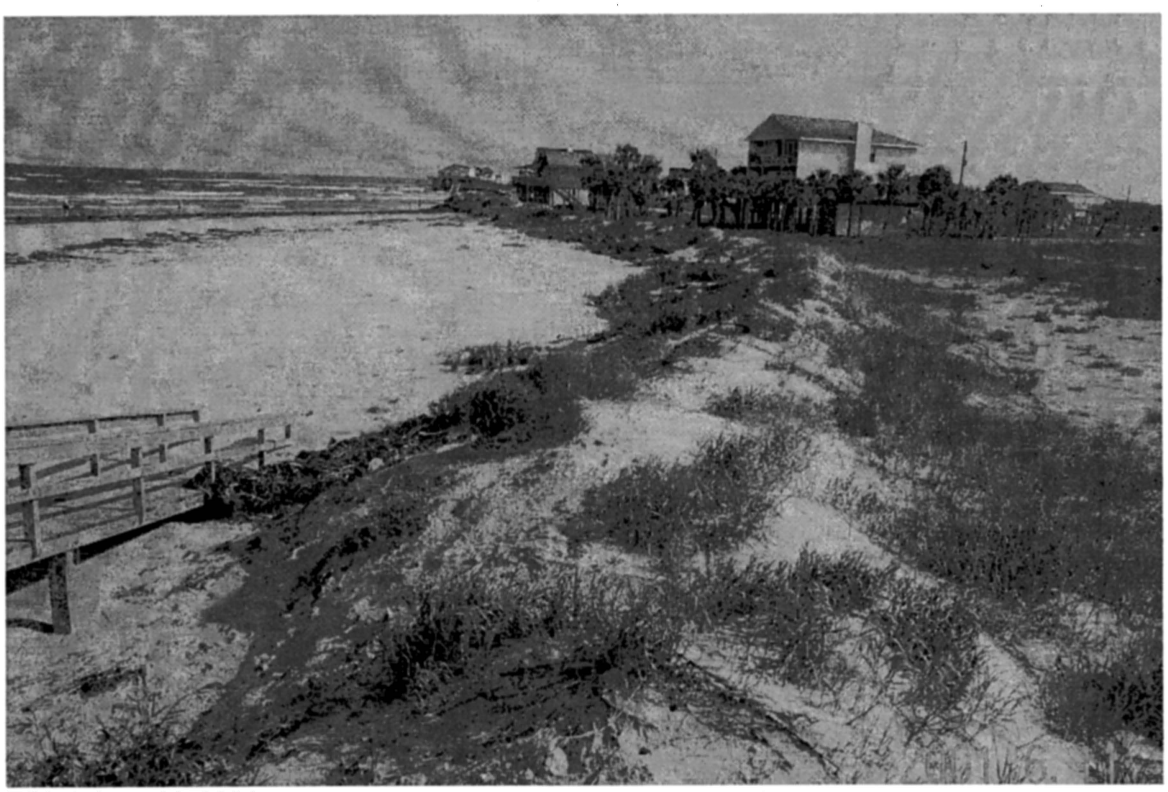
BOL01 June 12, 2002

BOL01 September 17, 2002



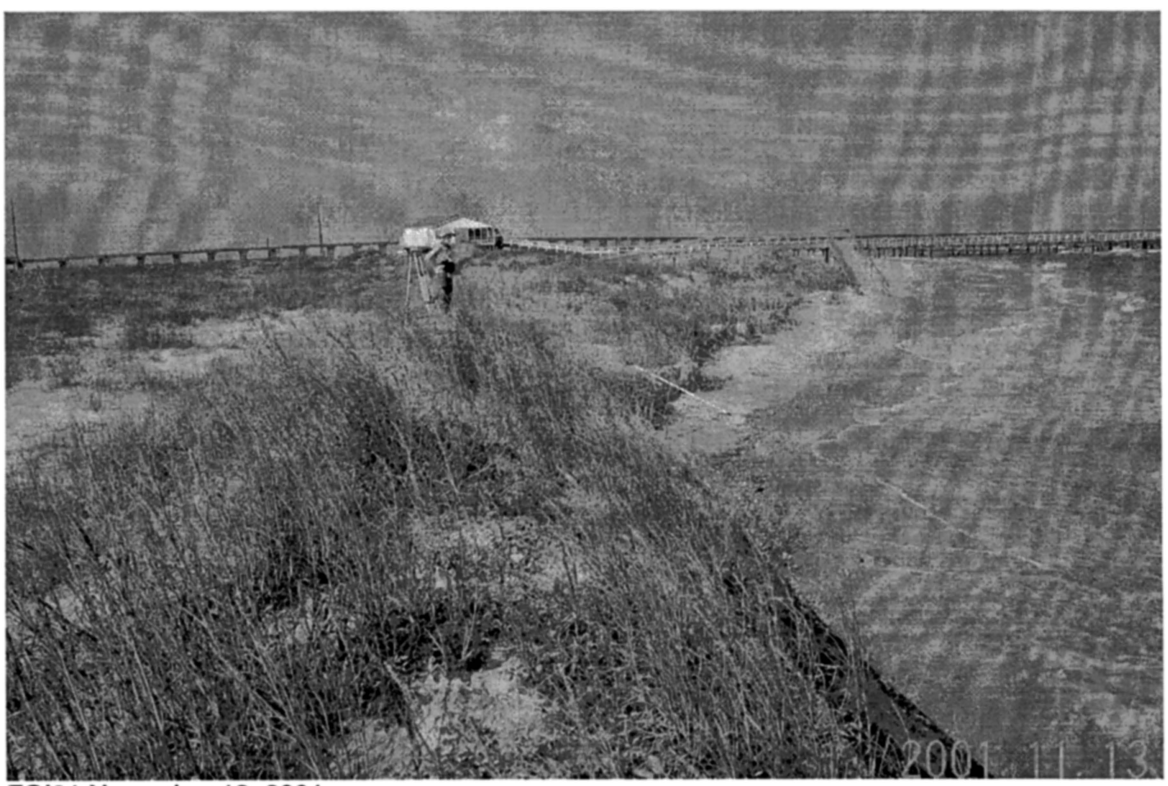
BOL01 March 10, 2003





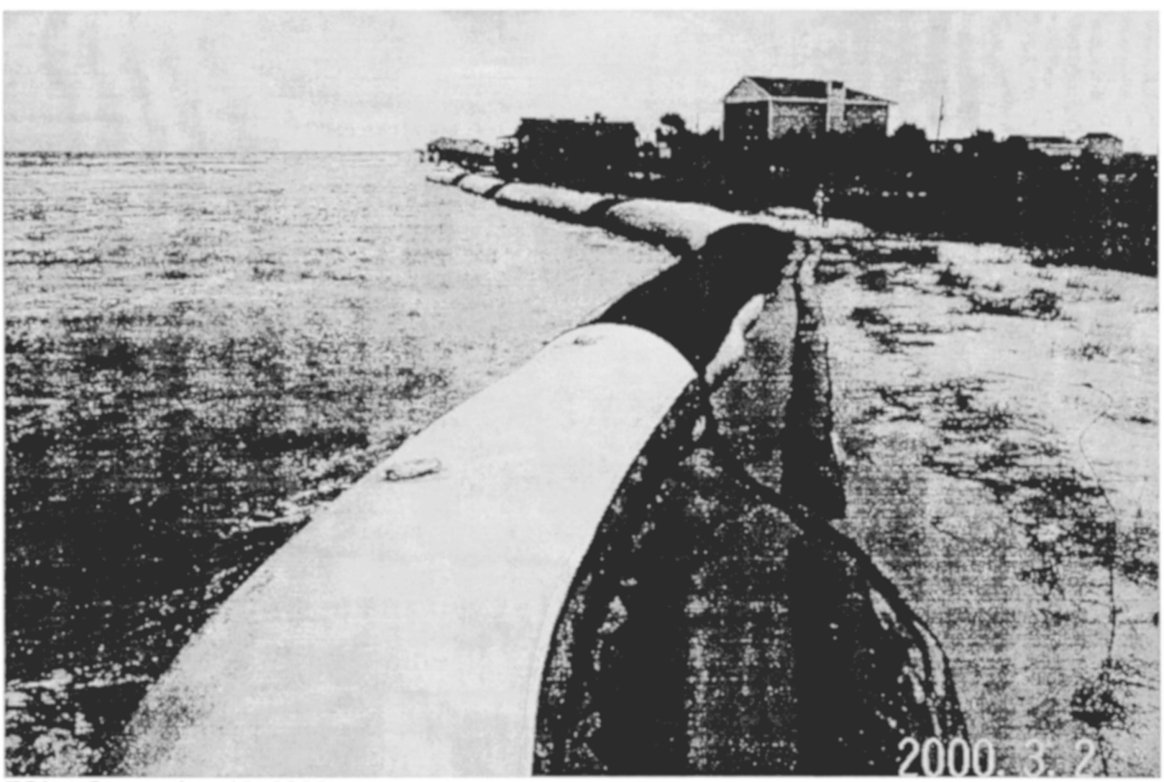
FOI01 June 11, 2001

FOI01 July 20, 2001



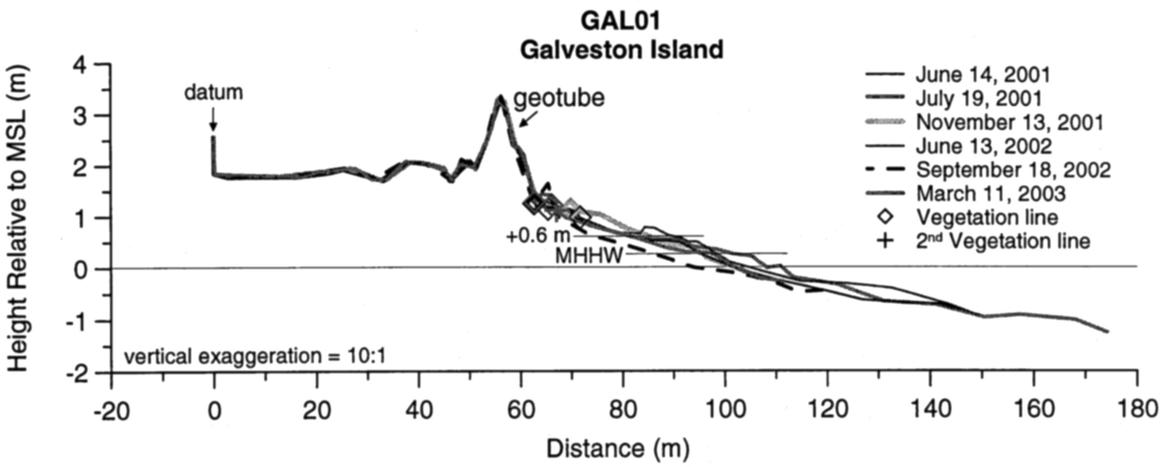
FOI01 November 13, 2001

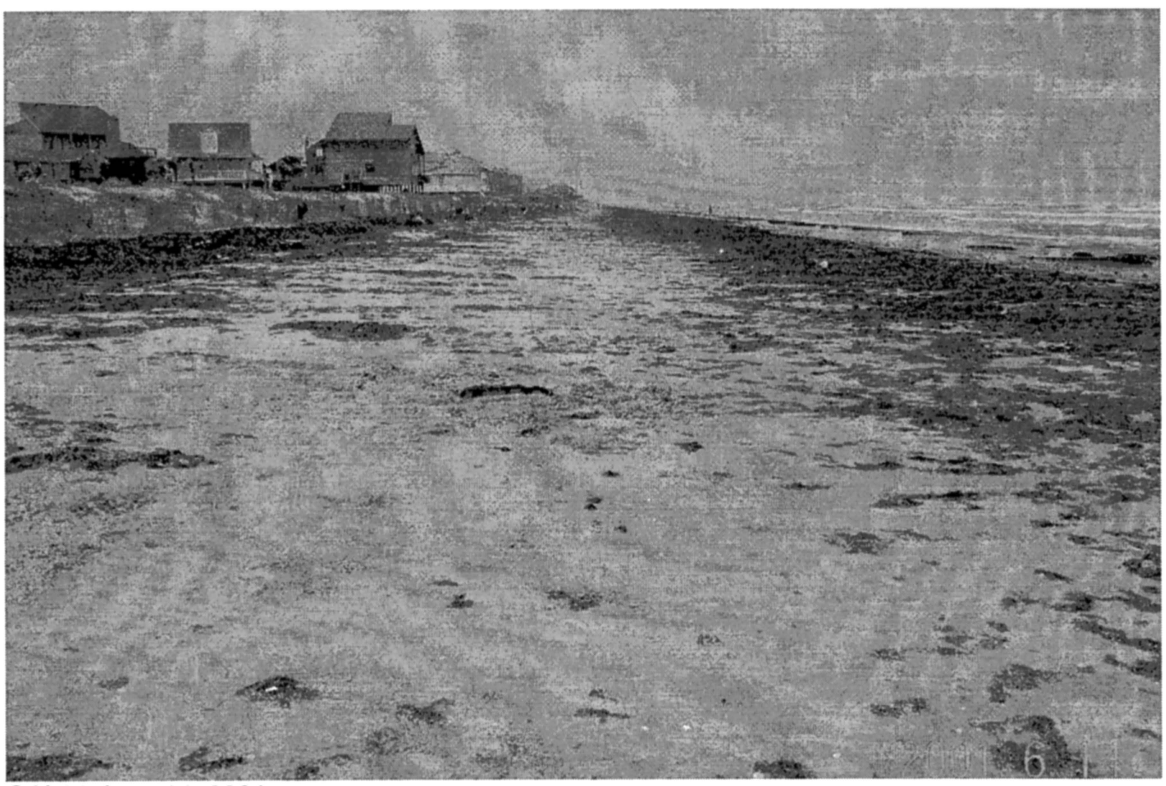
FOI01 June 13, 2002



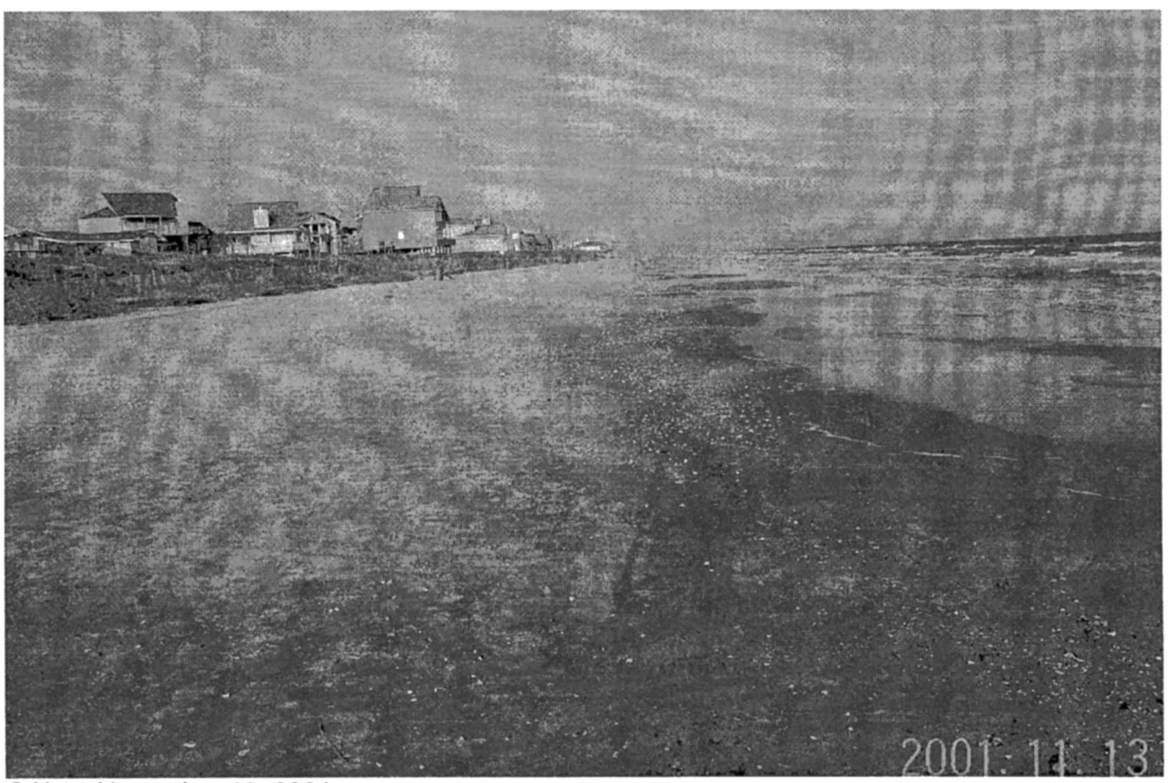
FOI01 September 19, 2002

FOI01 March 11, 2003




GAL01 June 14, 2001

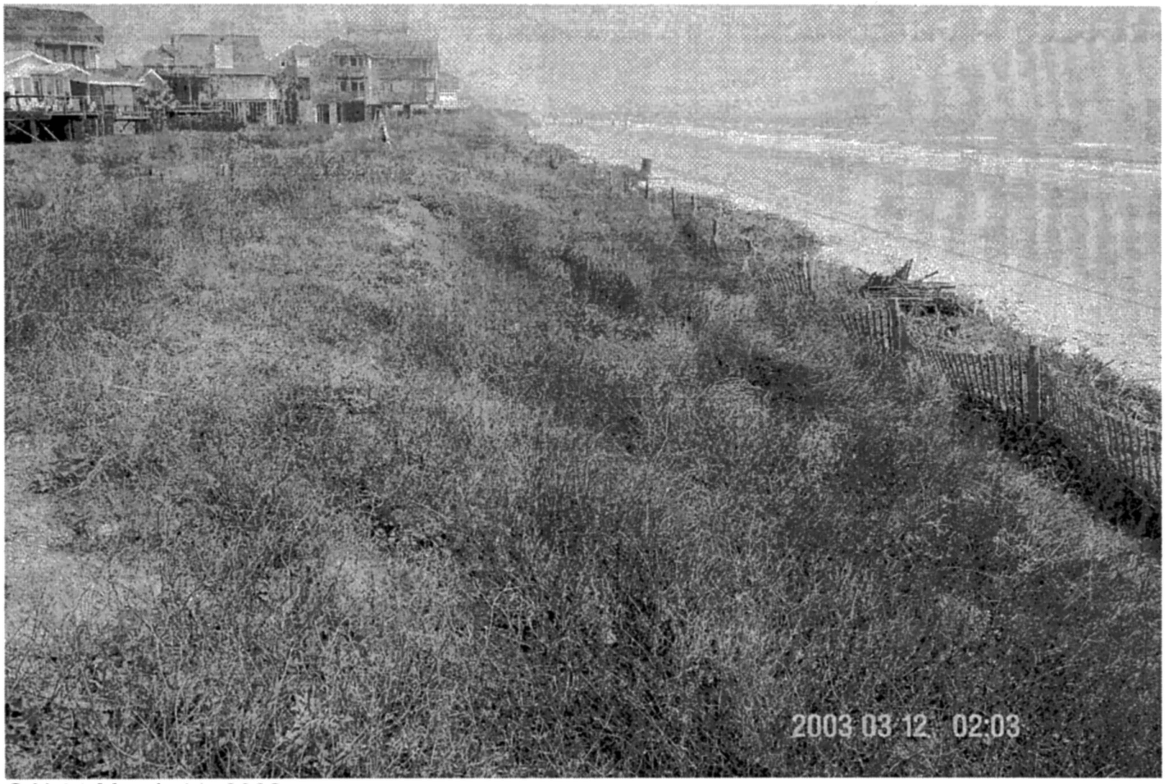
GAL01 July 19, 2001



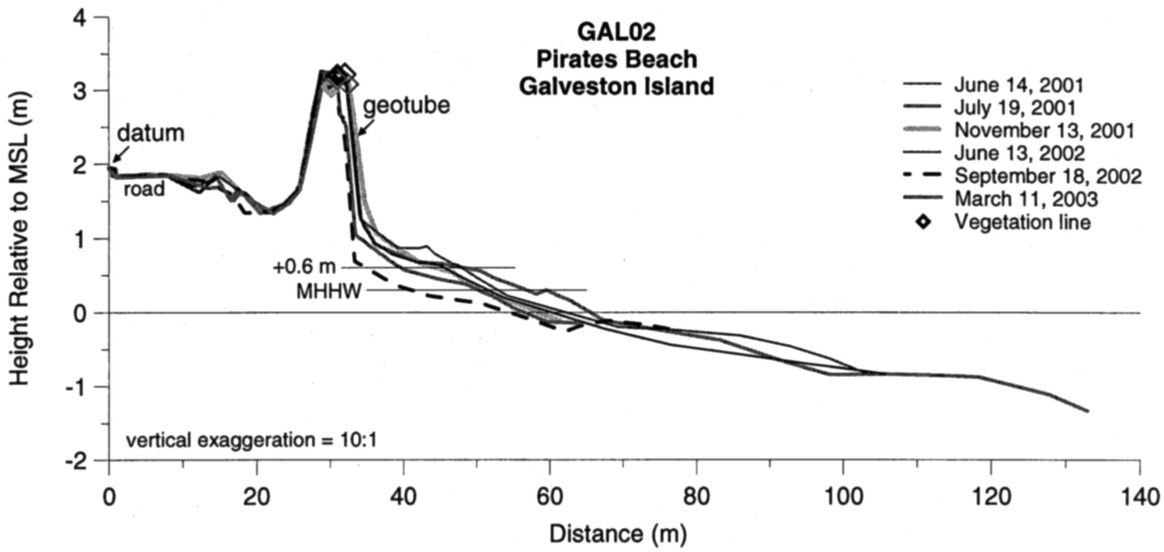
GAL01 November 13, 2001

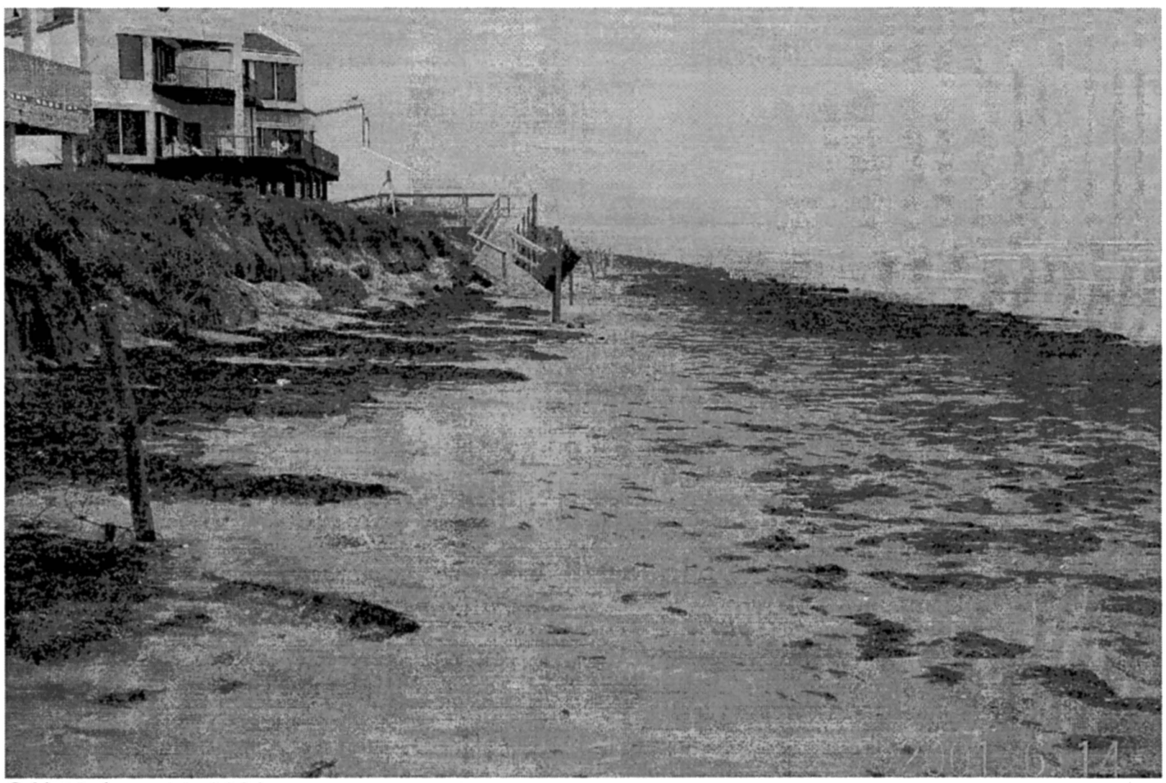
GAL01 June 13, 2002


GAL01 September 18, 2002



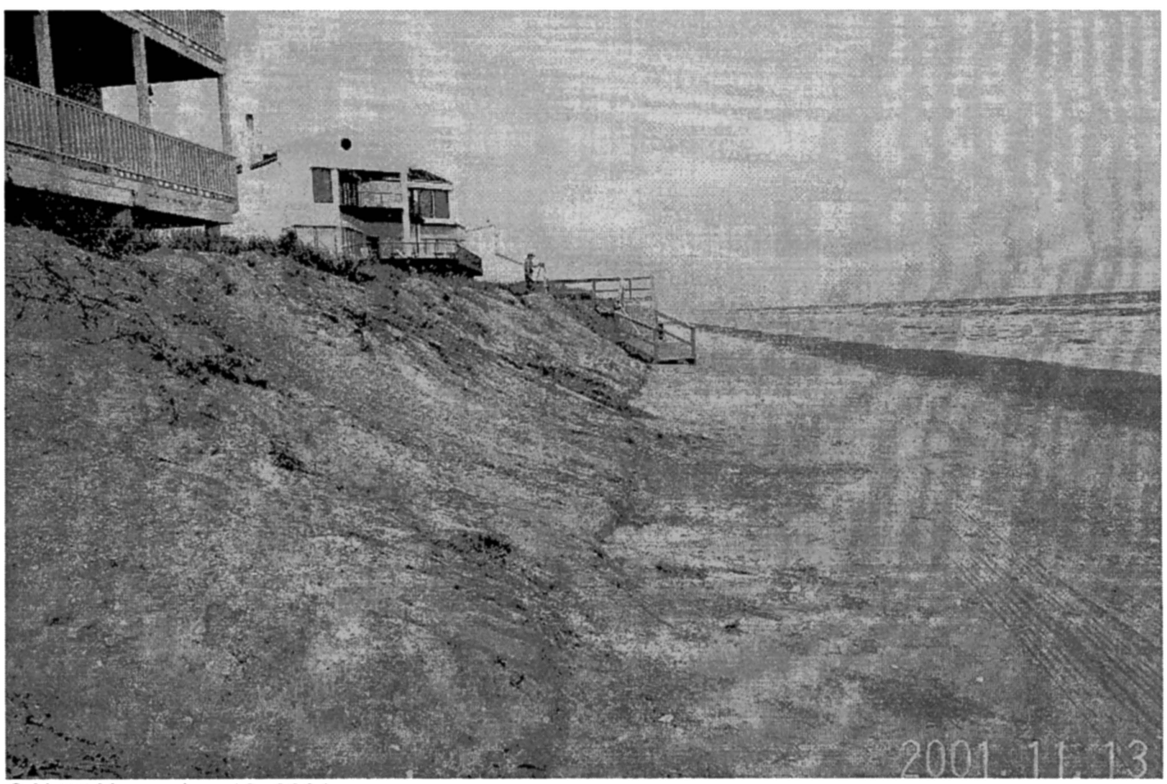
GAL01 March 11, 2003



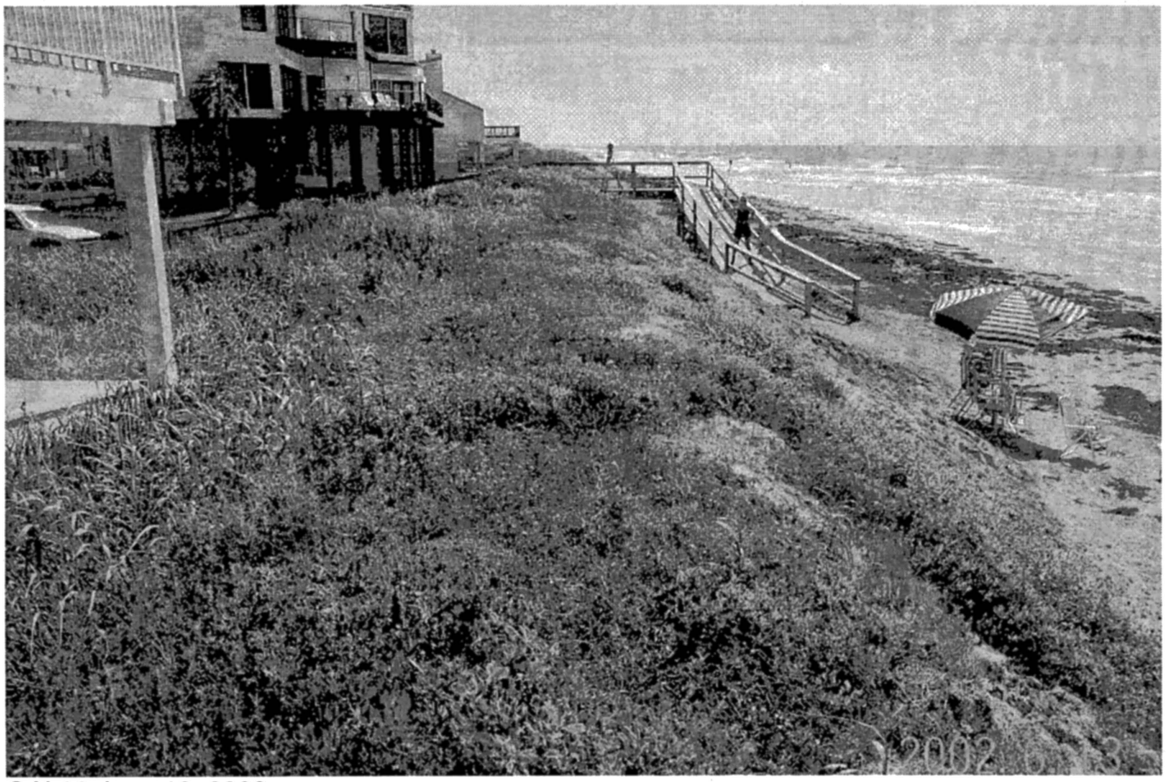


GAL02 June 14, 2001

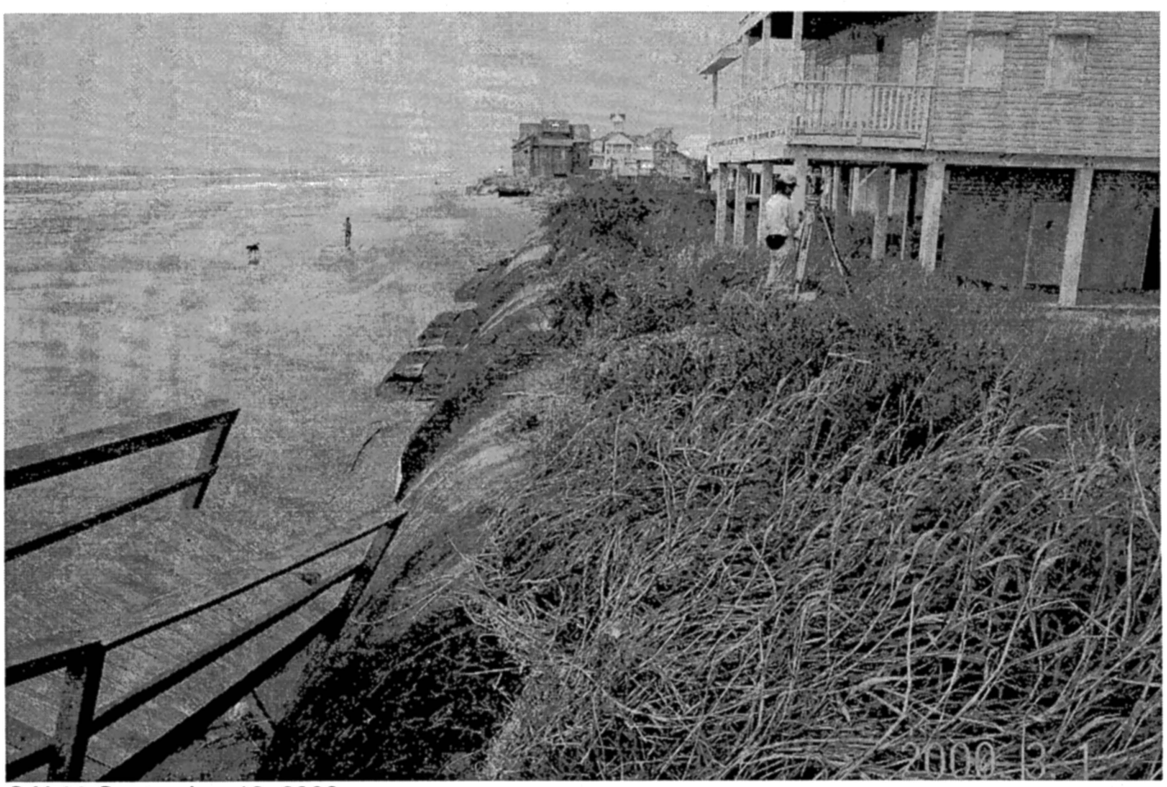

GAL02 July 19, 2001



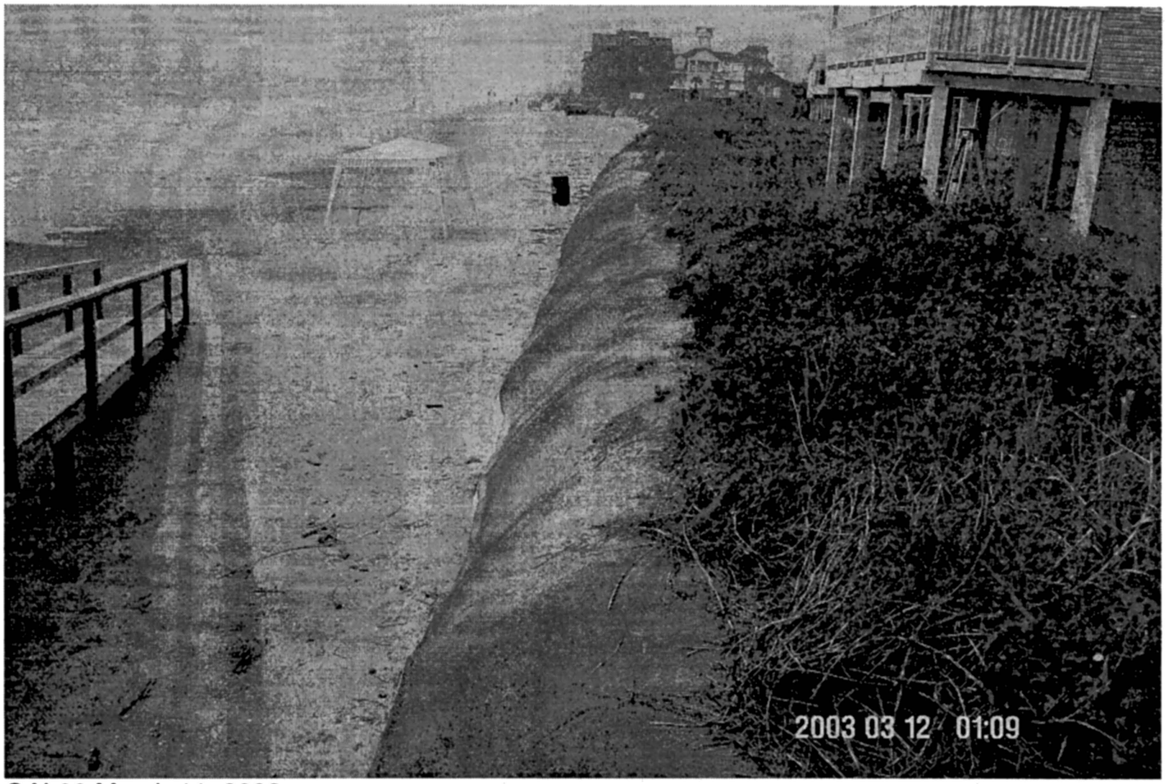
GAL02 November 13, 2001



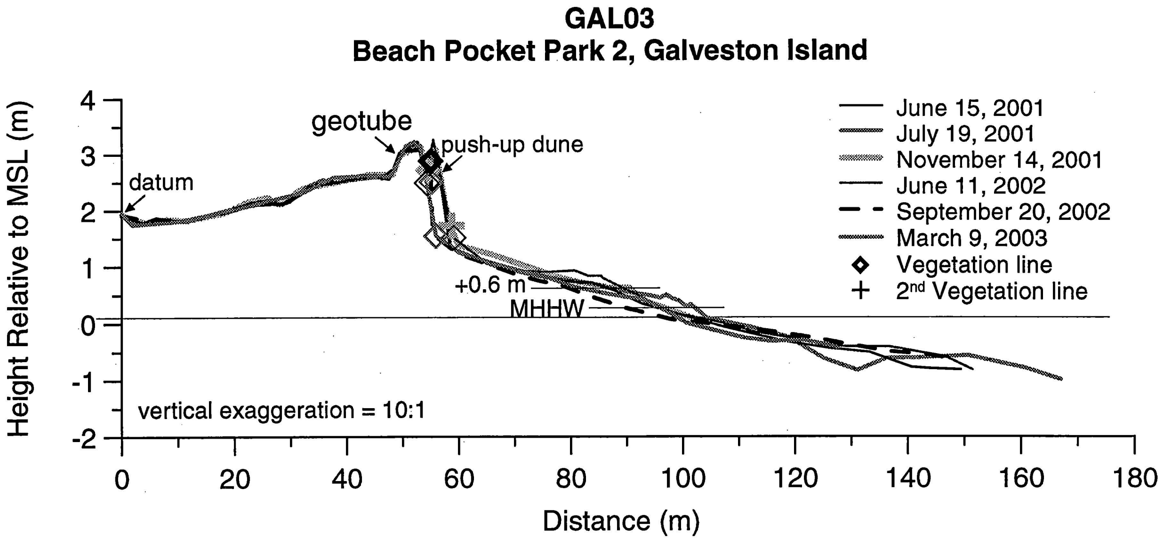
GAL02 June 13, 2002

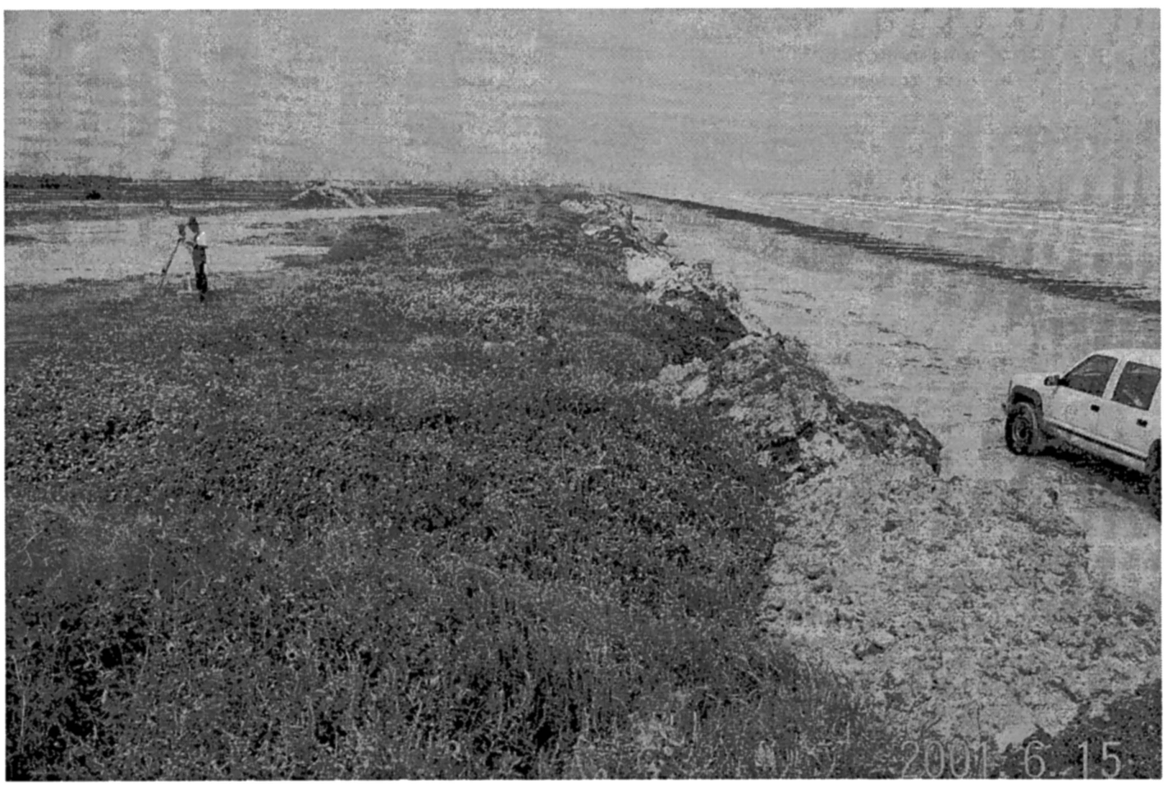


GAL02 September 18, 2002

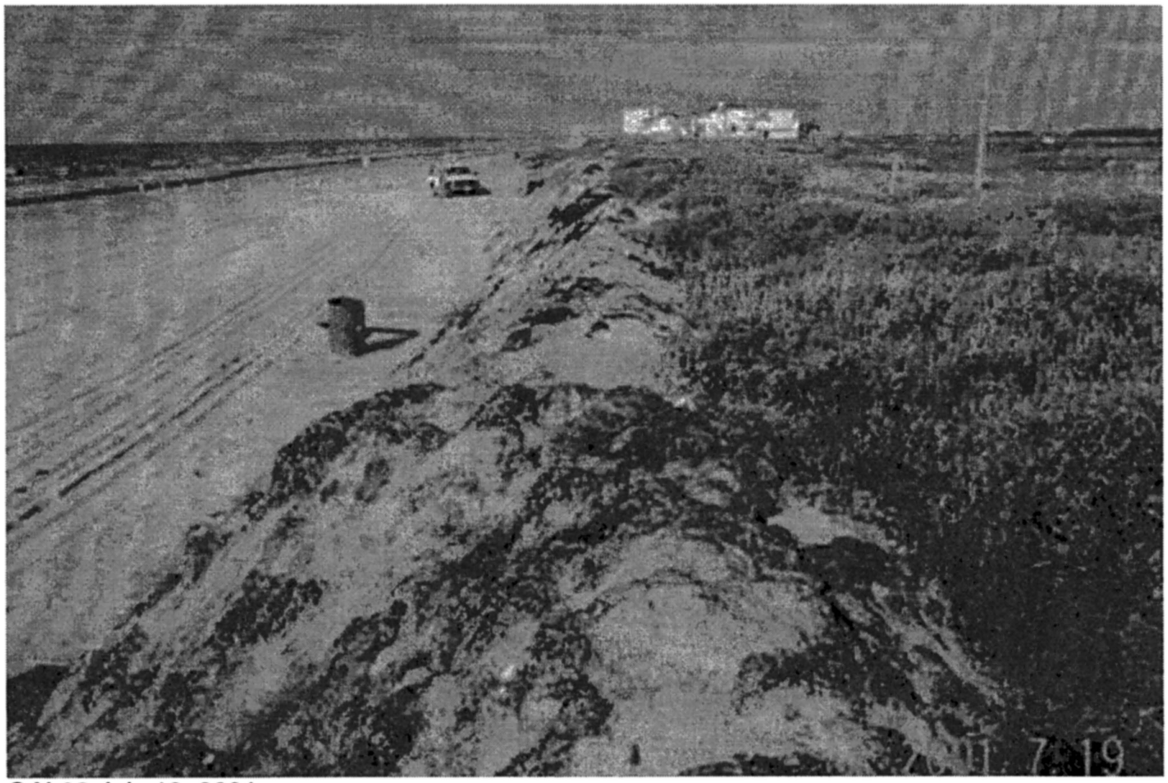


GAL02 March 11, 2003

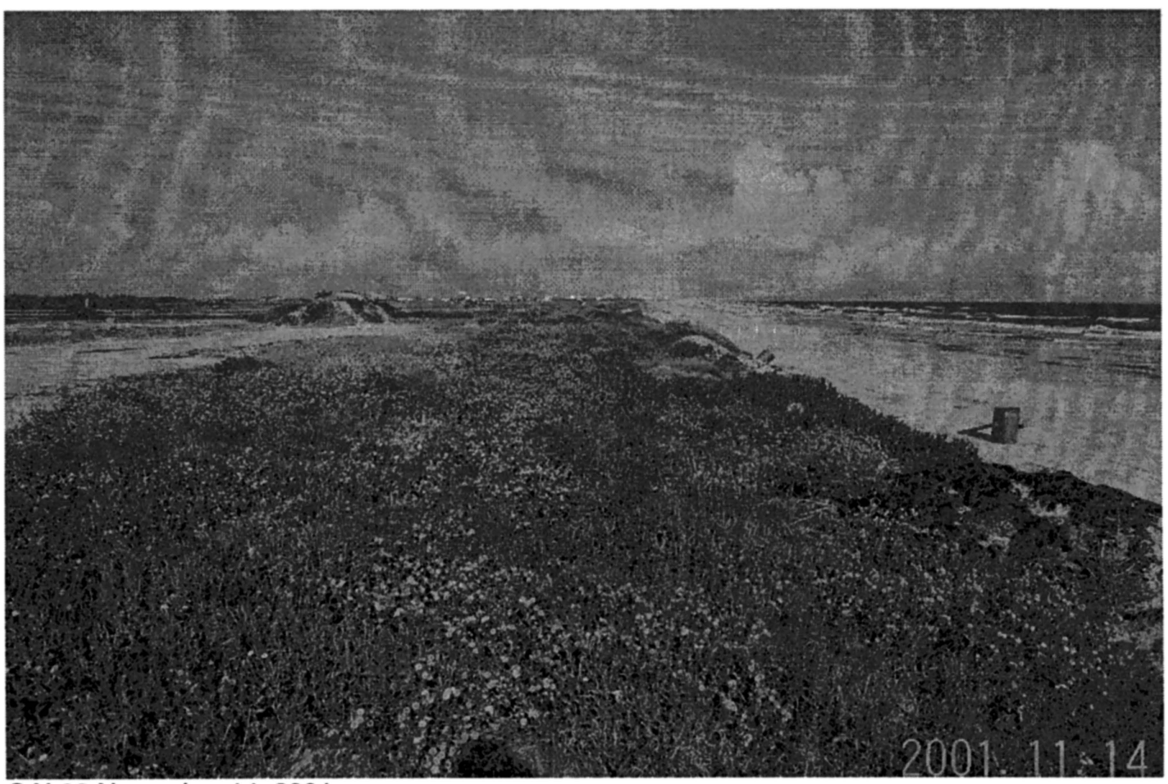




GAL03 June 15, 2001



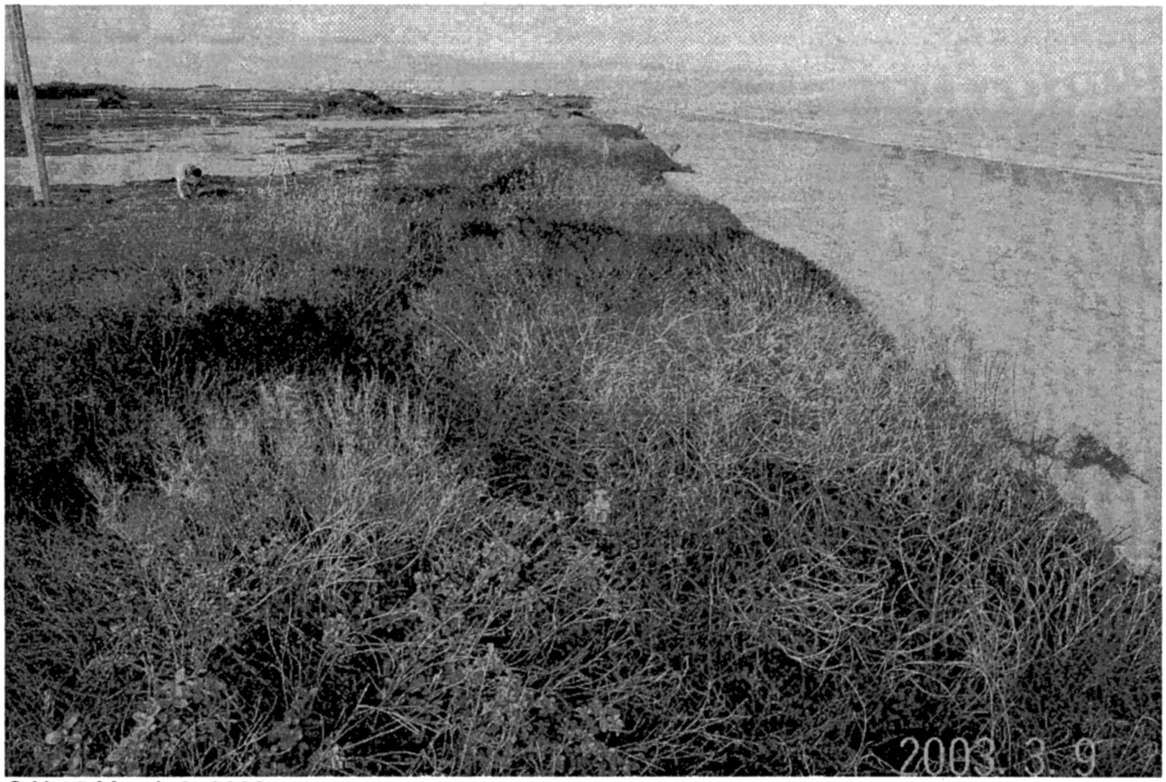
GAL03 July 19, 2001



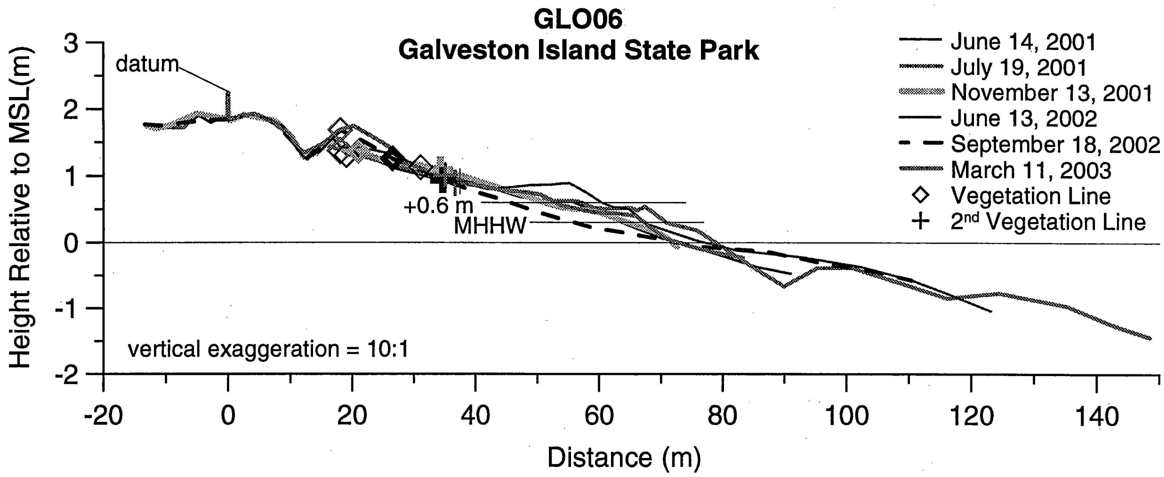
GAL03 November 14, 2001

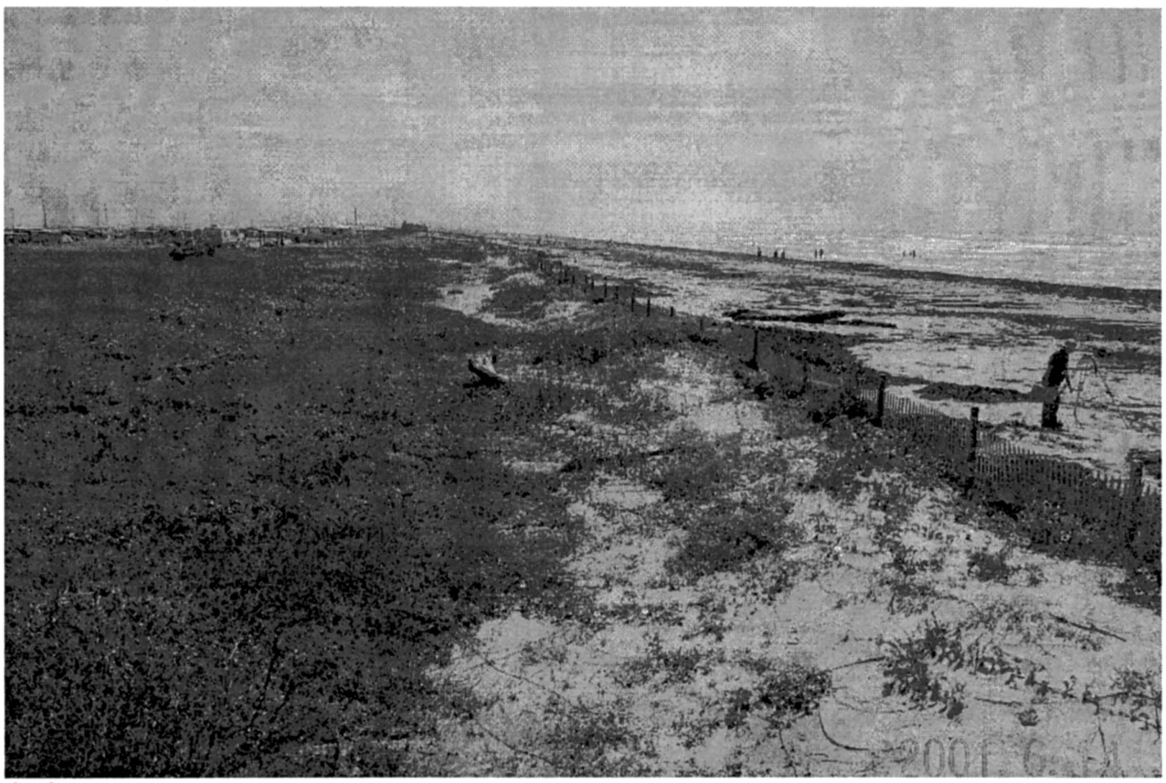
GAL03 June 11, 2002

GAL03 September 20, 2002

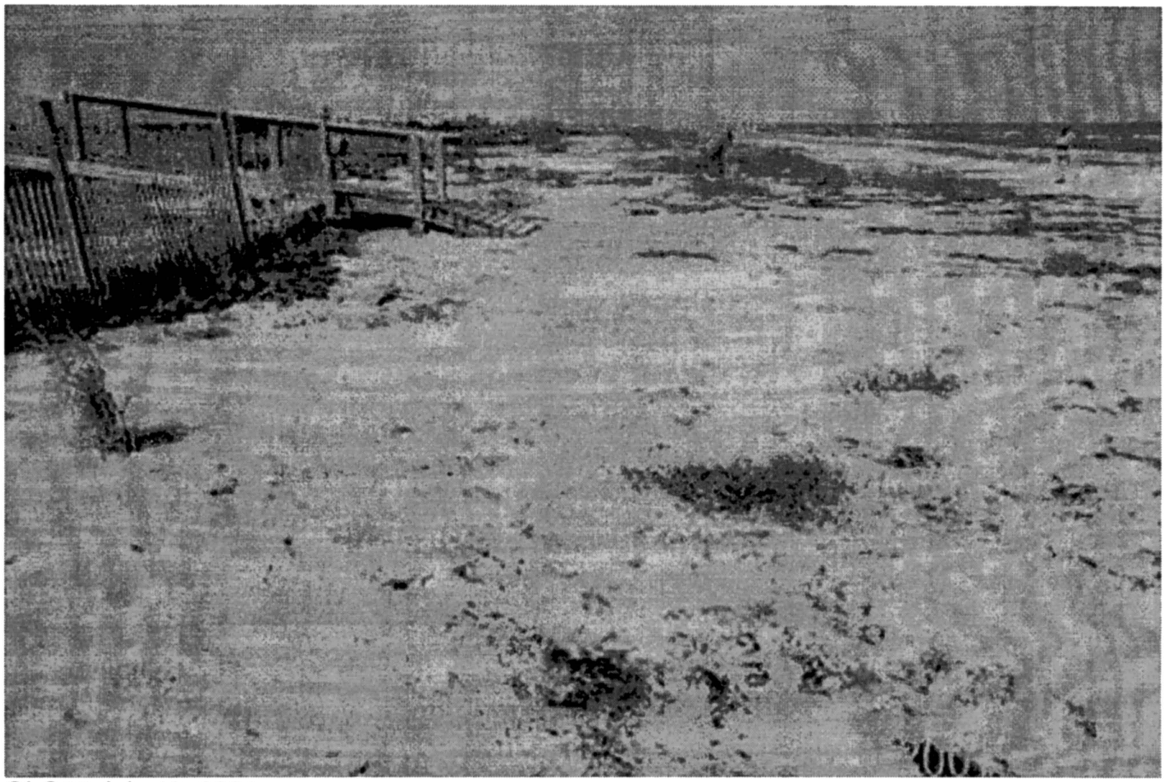


GAL03 March 9, 2003

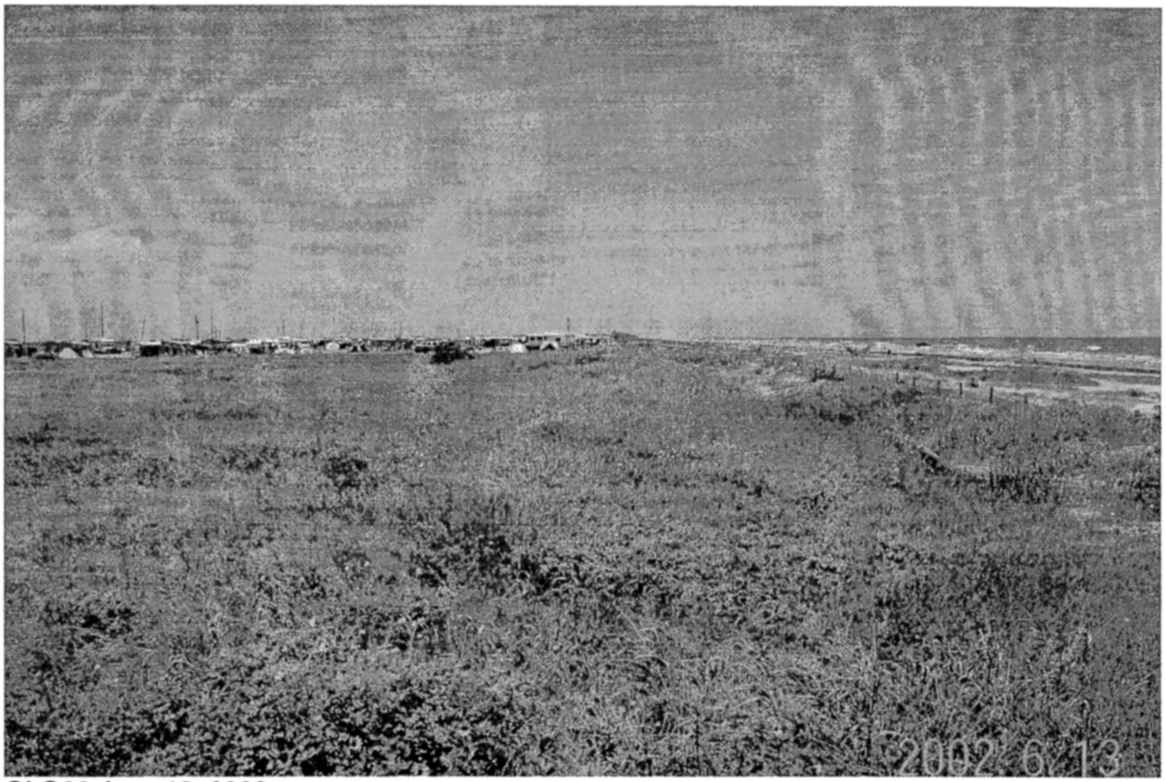




GLO06 June 14, 2001


GLO06 July 19, 2001

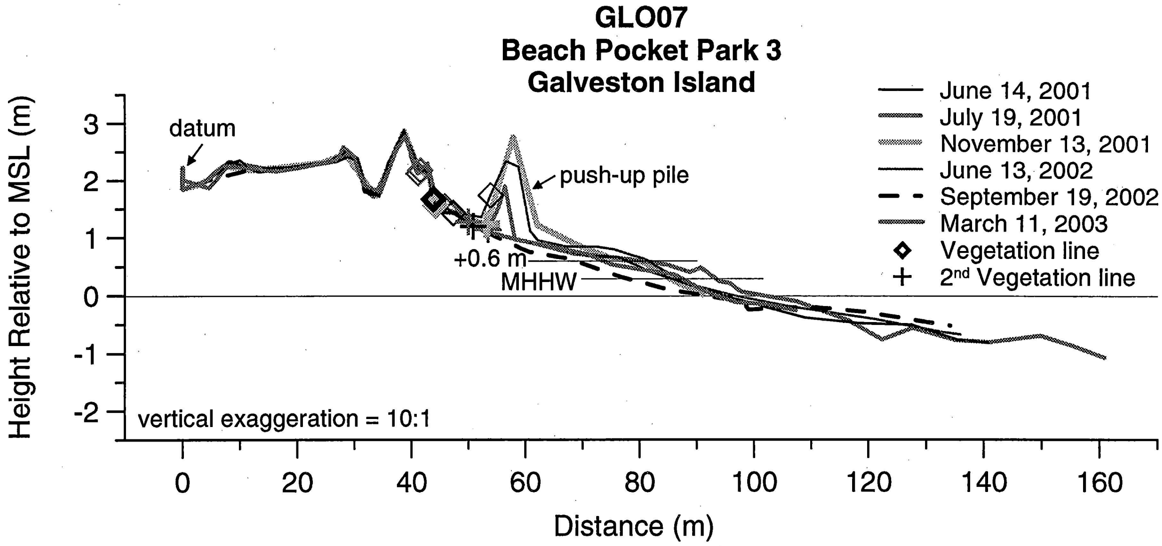

GLO06 November 13, 2001

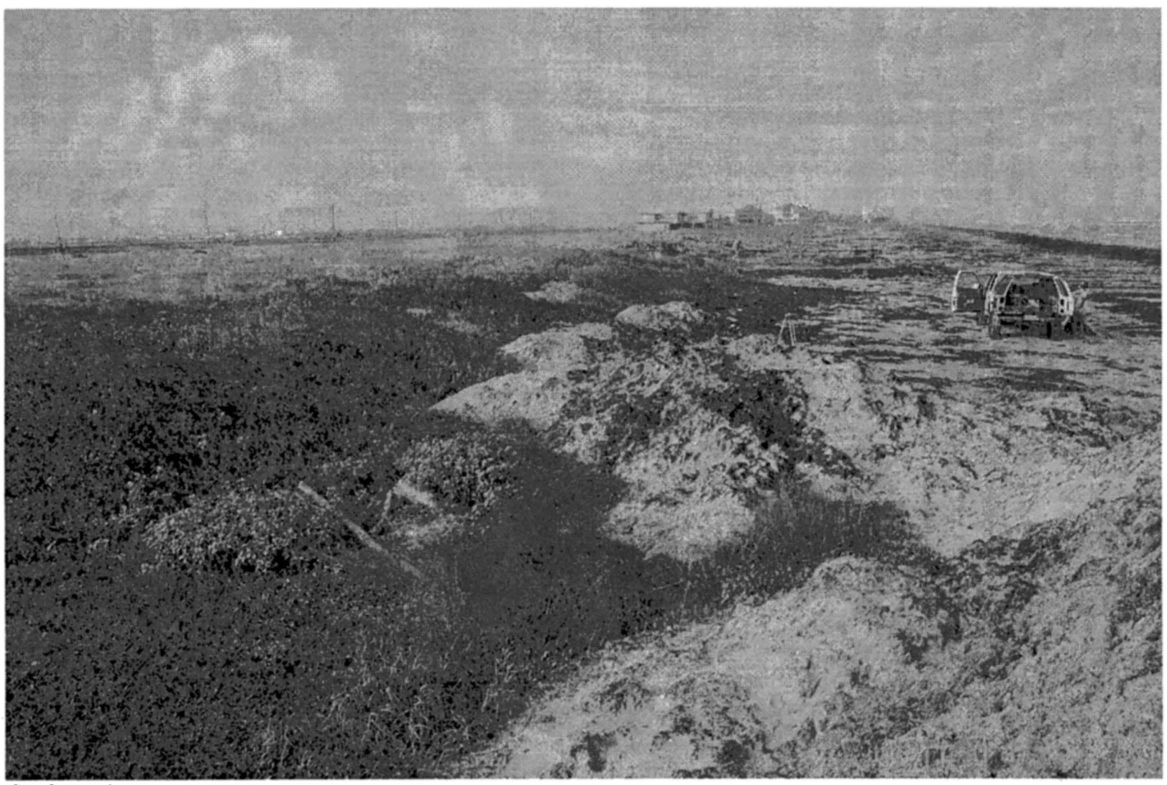


GLO06 June 13, 2002

GLO06 September 18, 2002

GLO06 March 11, 2003

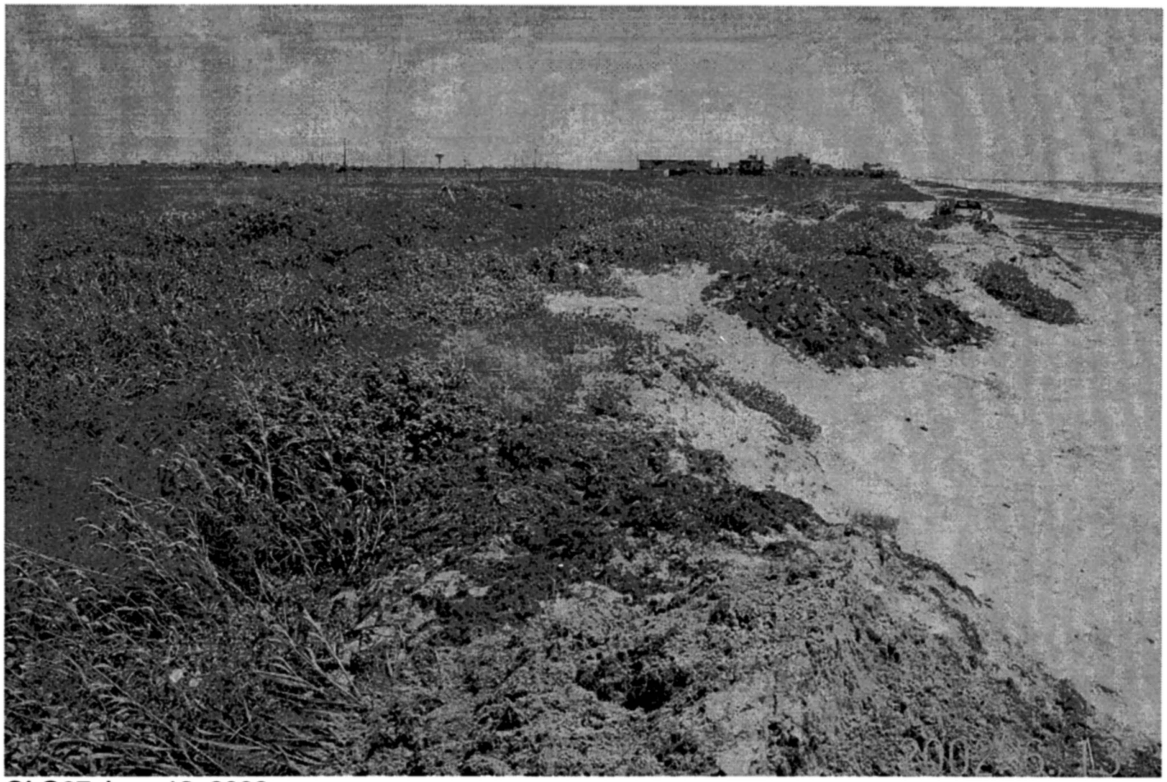




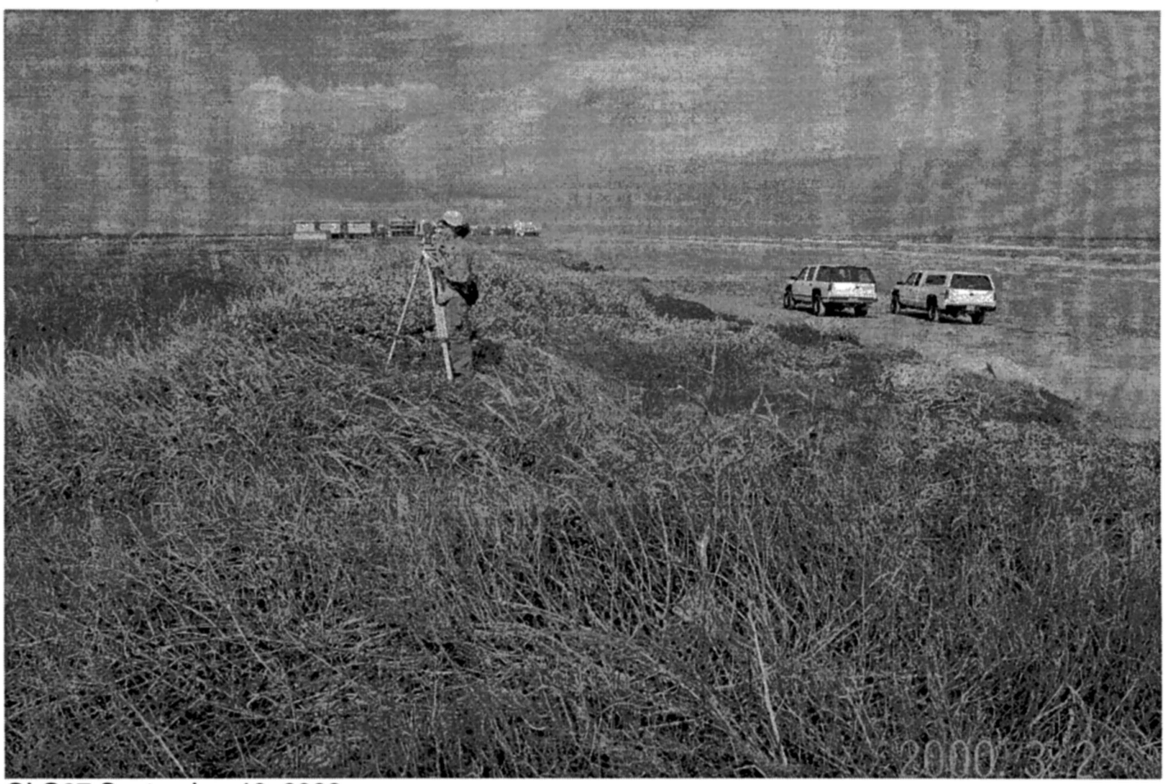
GLO07 June 14, 2001

GLO07 July 19 2001

GLO07 November 13, 2001

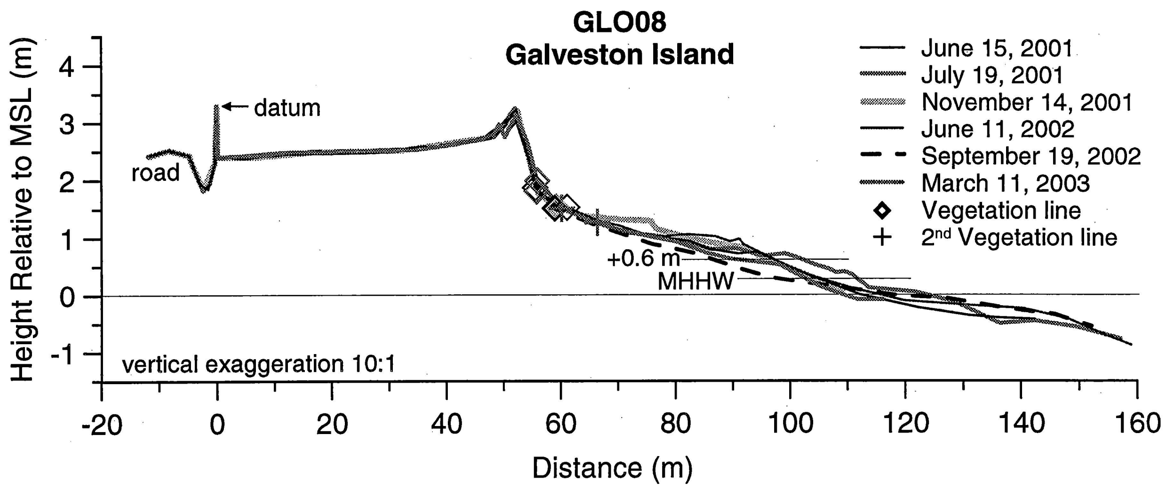


GLO07 June 13, 2002



GLO07 September 19, 2002

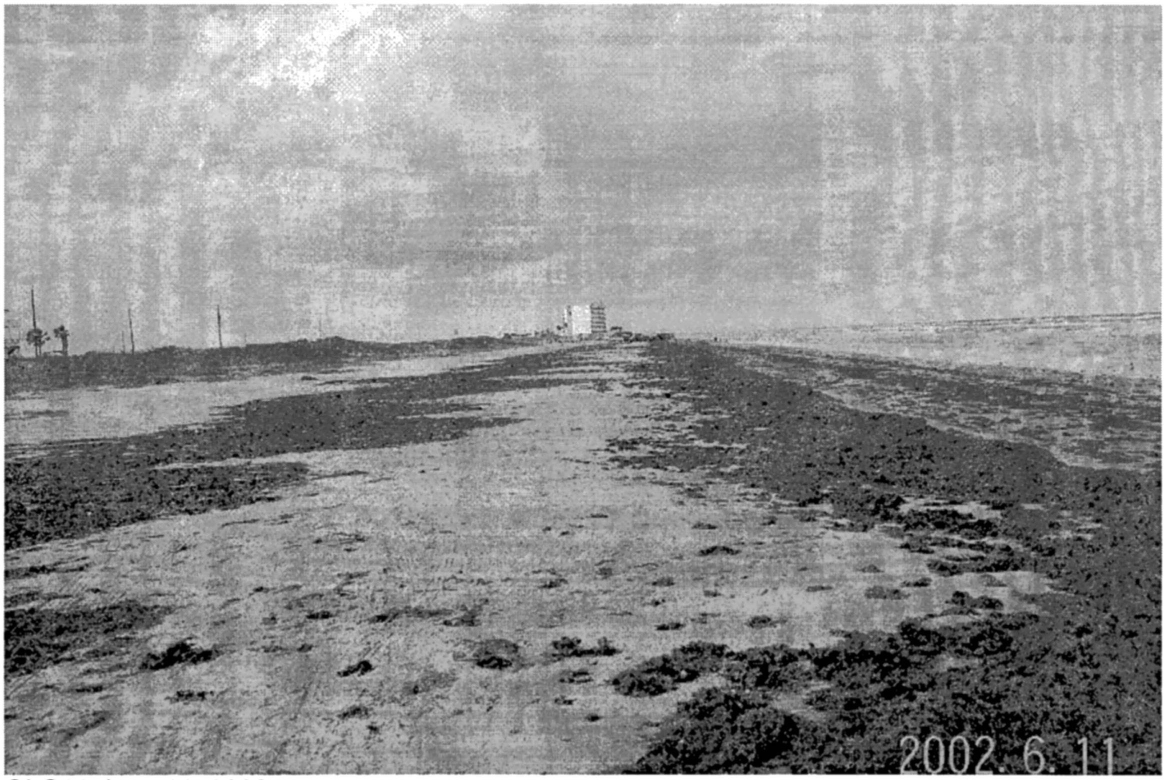
GLO07 March 11, 2003



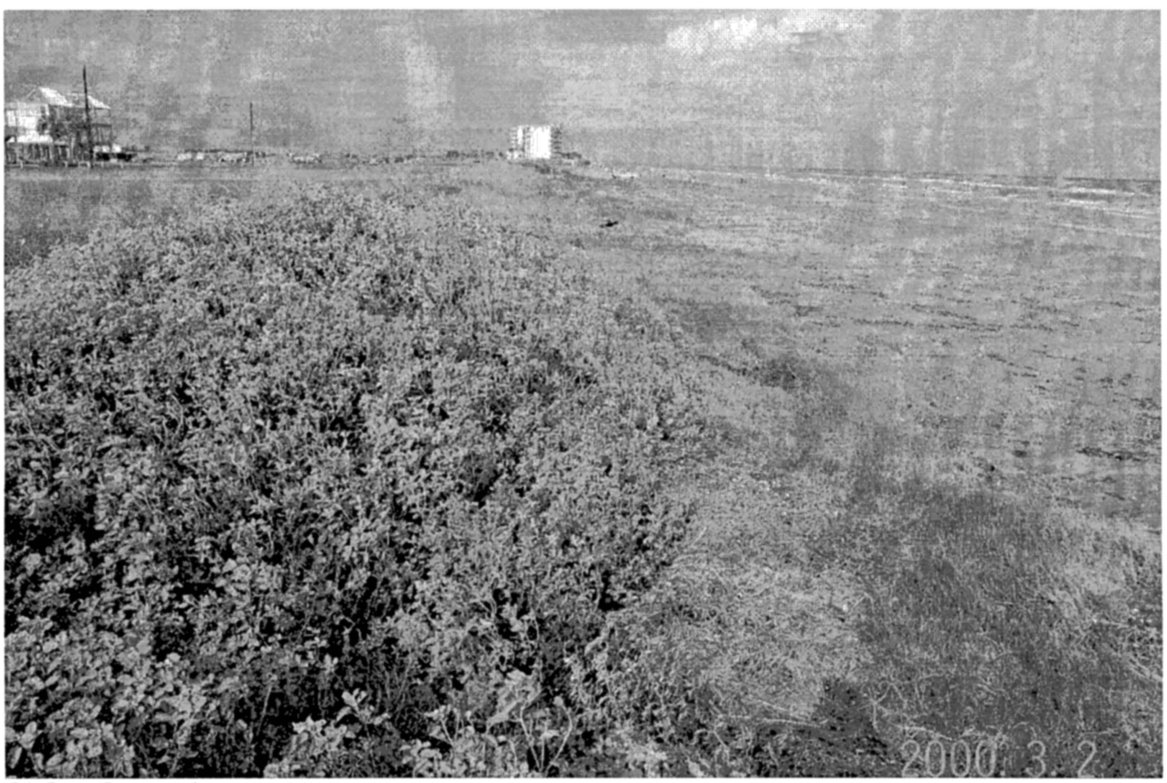
GLO08 June 15, 2001

GLO08 July 19, 2001

GLO08 November 14, 2001

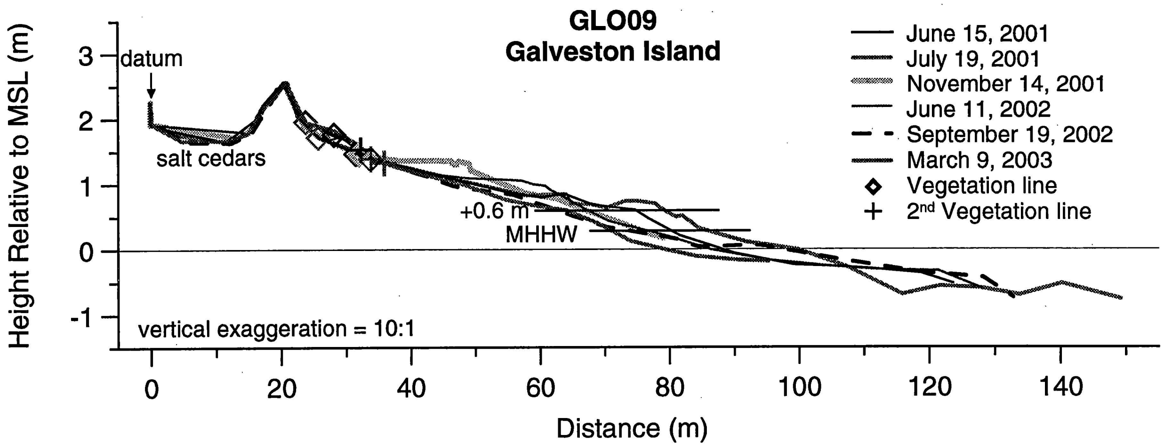


GLO08 June 11, 2002

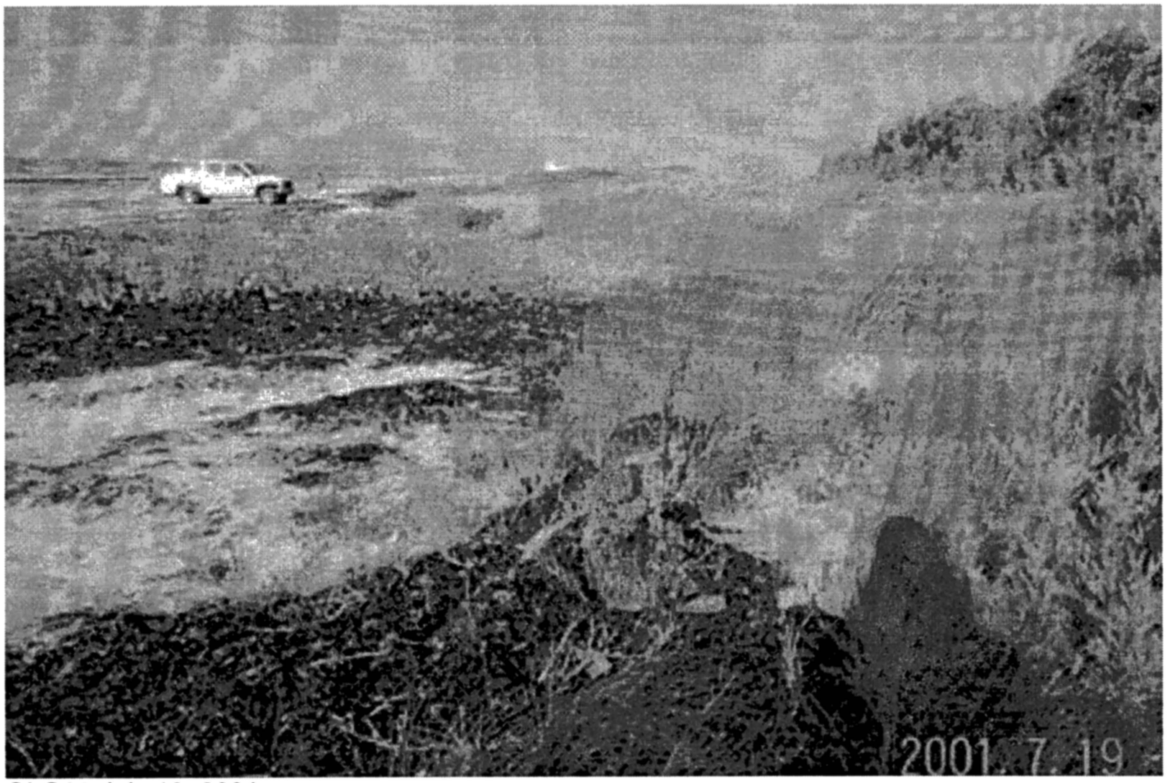


GLO08 September 19, 2002

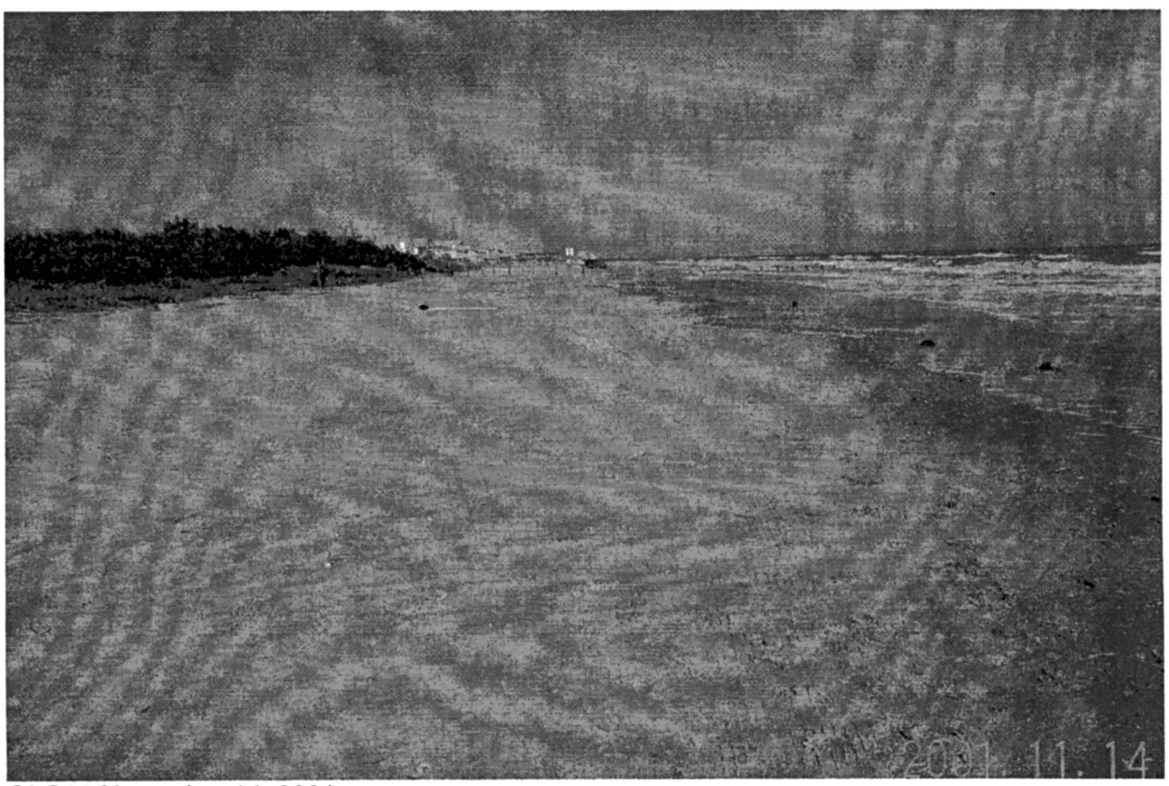
GLO08 March 11, 2003



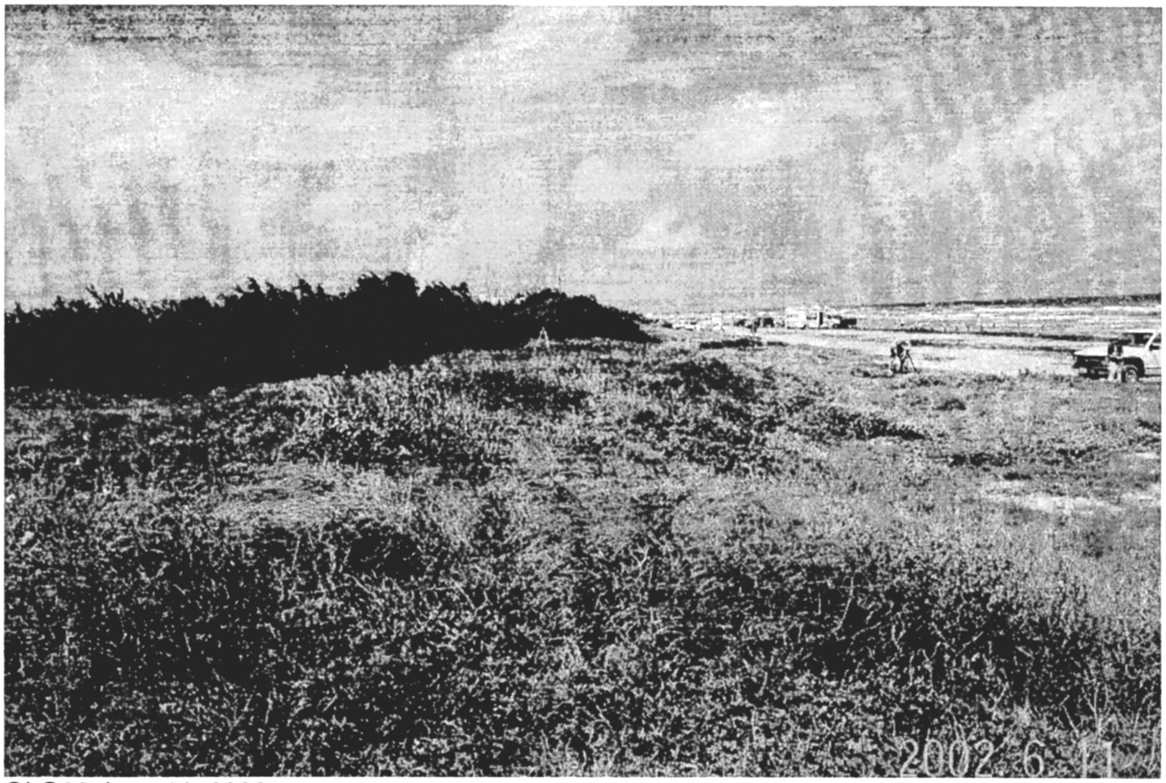
GLO09 June 15, 2001



GLO09 July 19, 2001



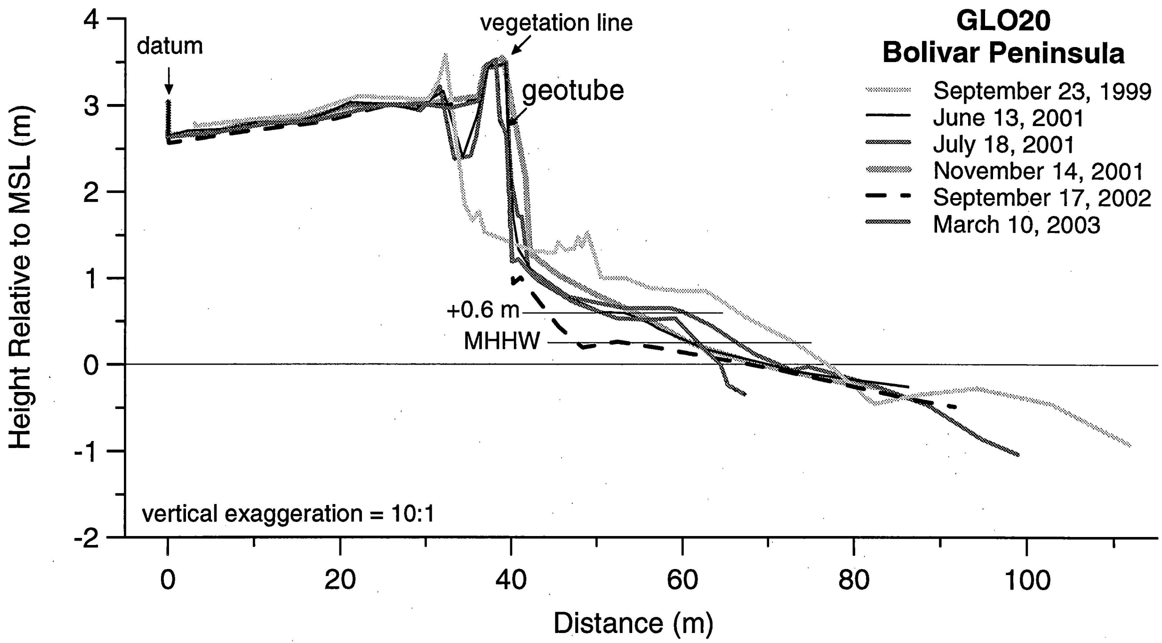
GLO09 November 14, 2001



GLO09 June 11, 2002

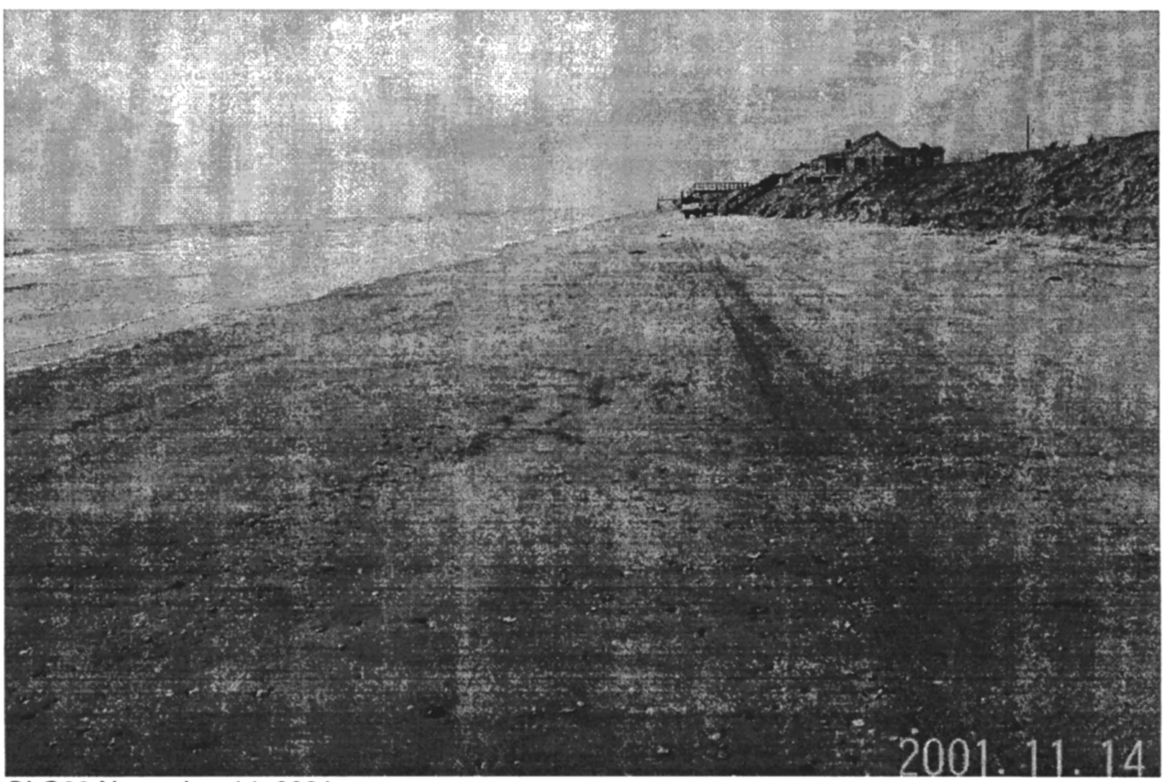
GLO09 September 20, 2002


GLO09 March 9, 2003

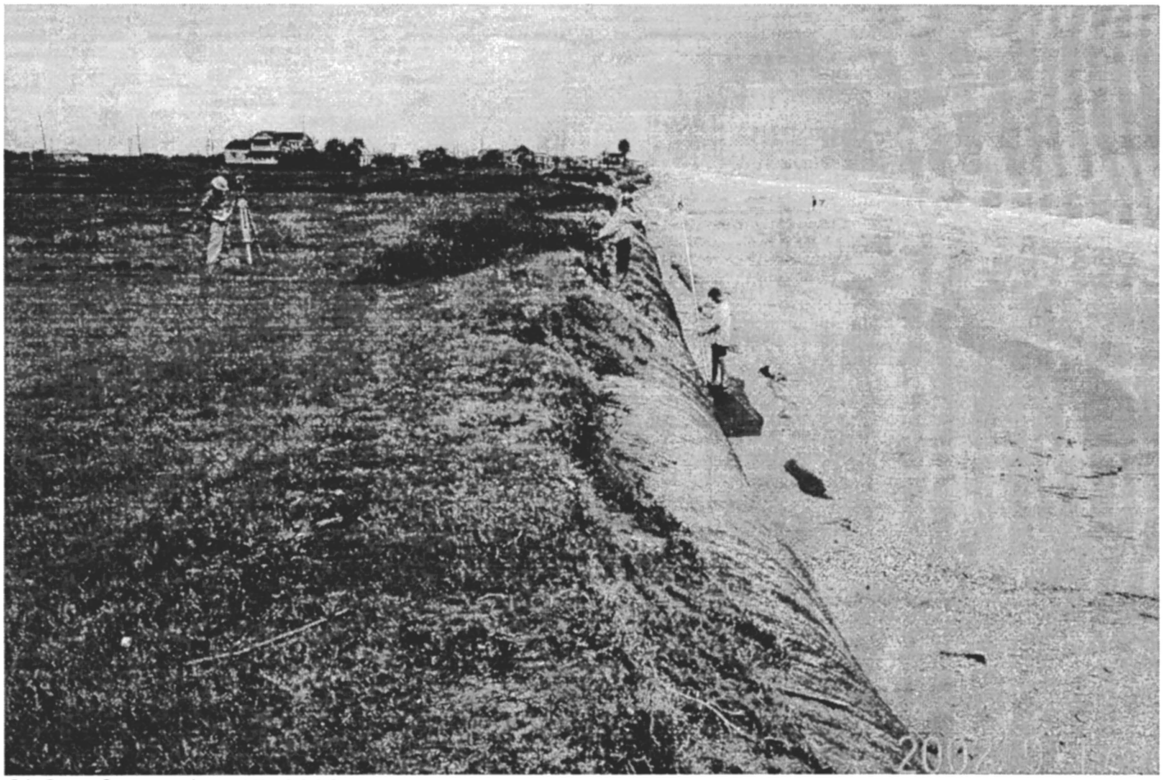


GLO20 June 13, 2001

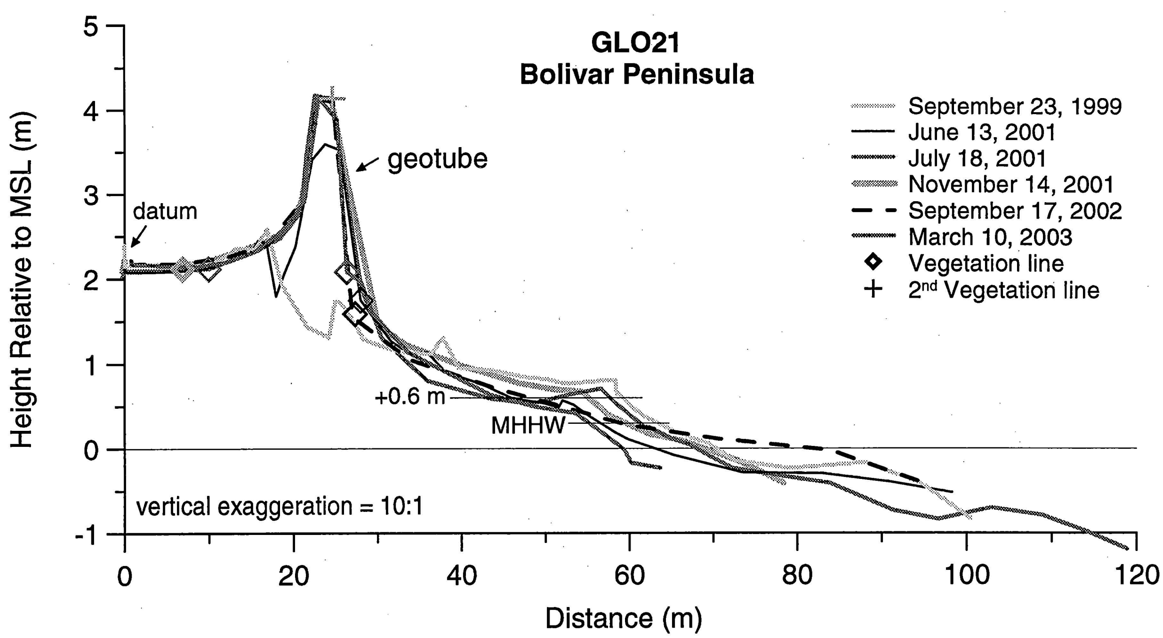
GLO20 July 18, 2001



GLO20 November 14, 2001


GLO20 September 17, 2002


GLO20 March 10, 2003

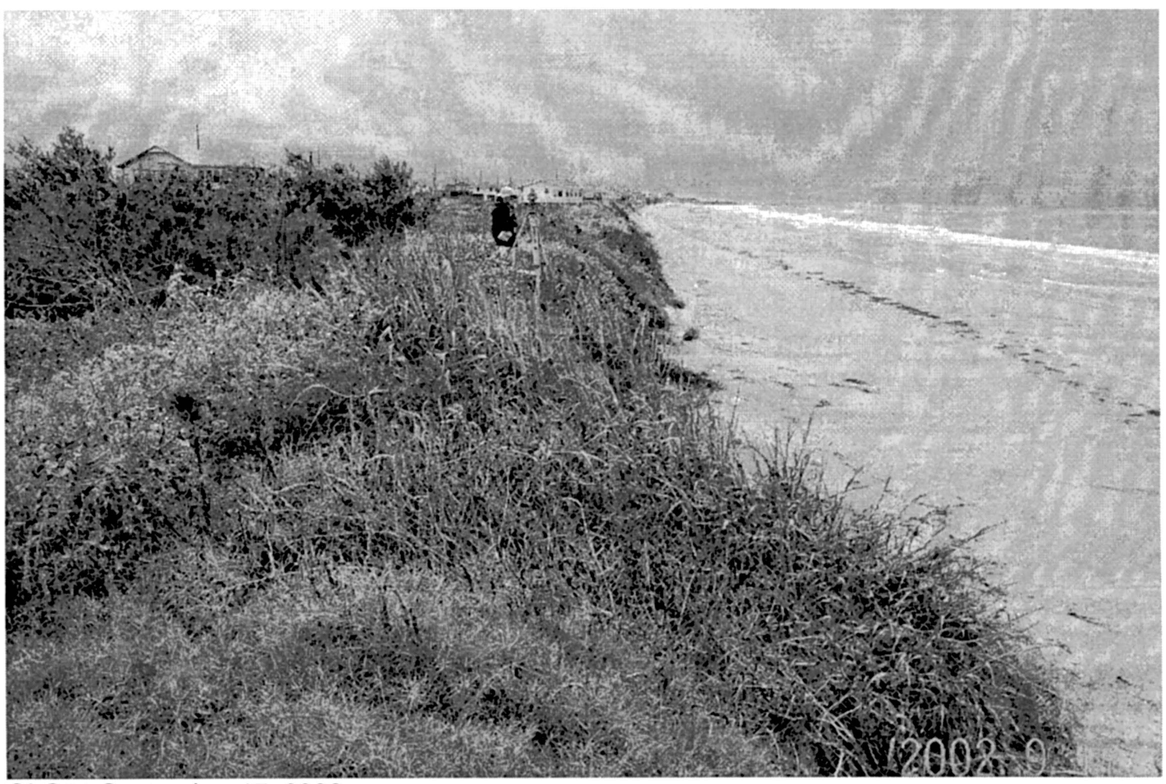


GLO21 September 23, 1999

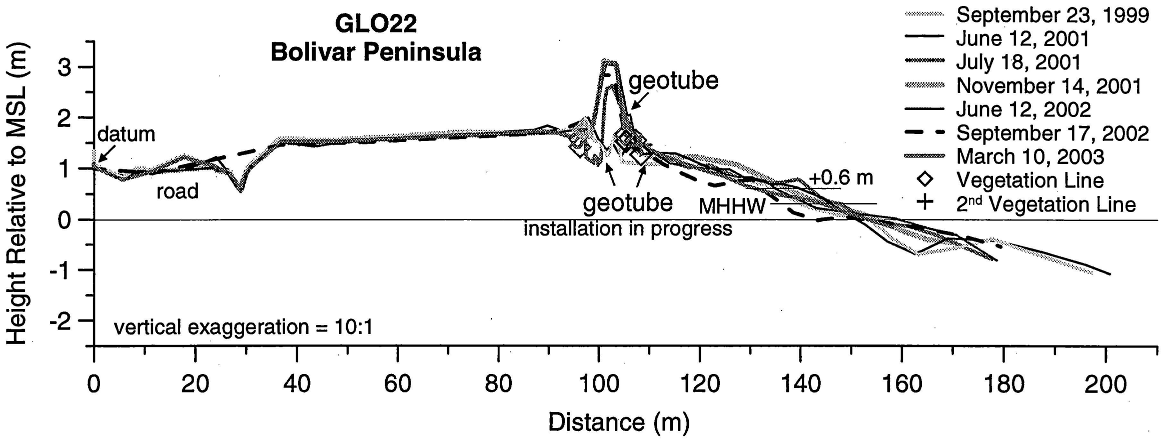
GLO21 June 13, 2001


GLO21 July 18, 2001

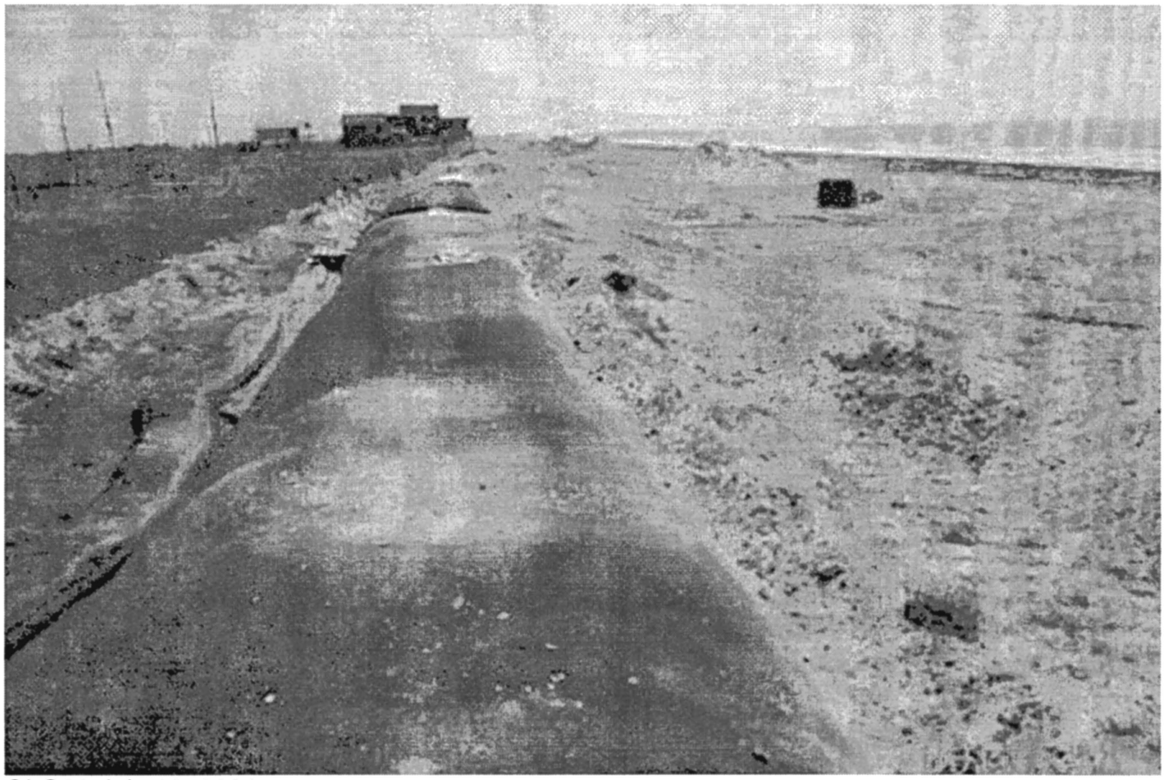

GLO21 November 14, 2001


GLO21 September 17, 2002

GLO21 March 10, 2003

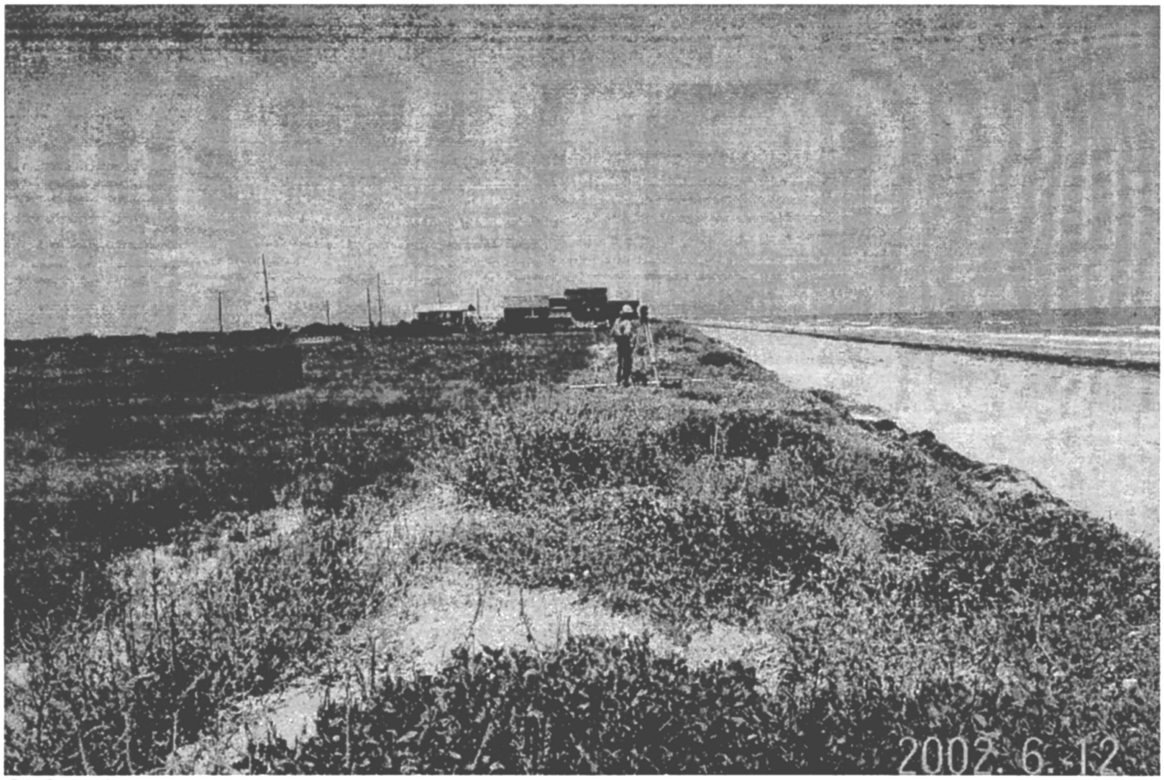


GLO22 June 12, 2001



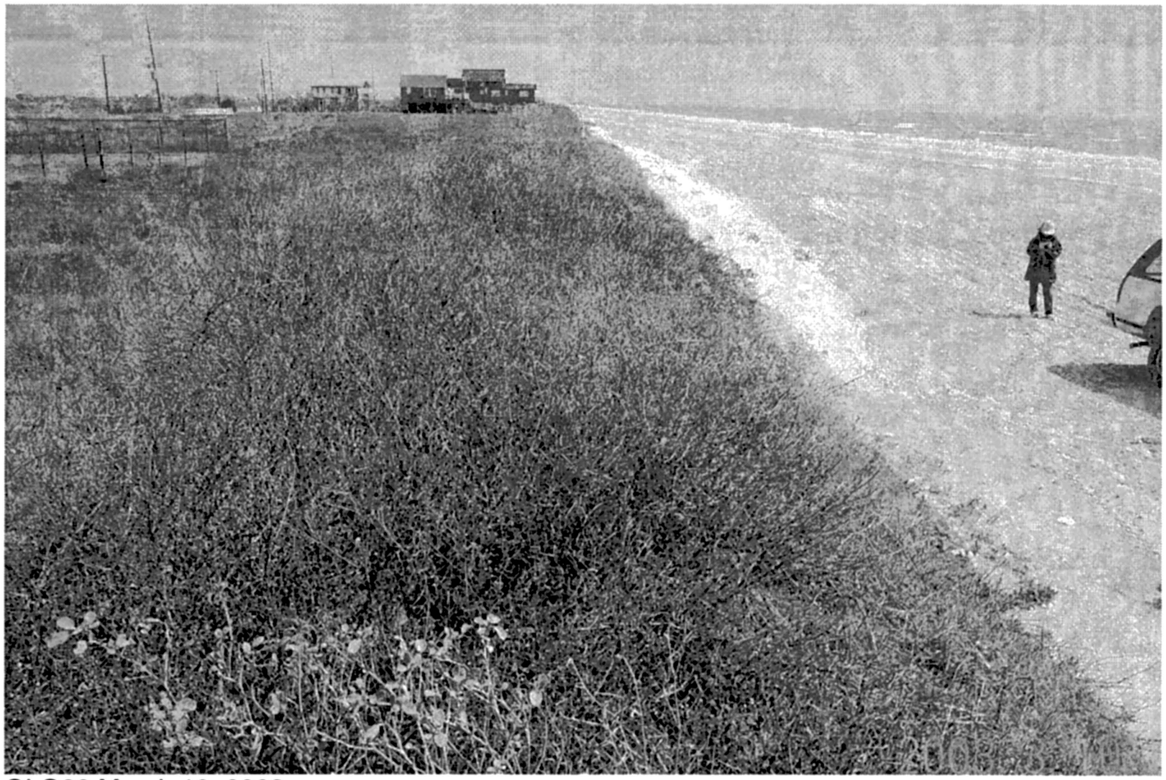
GLO22 July 18, 2001

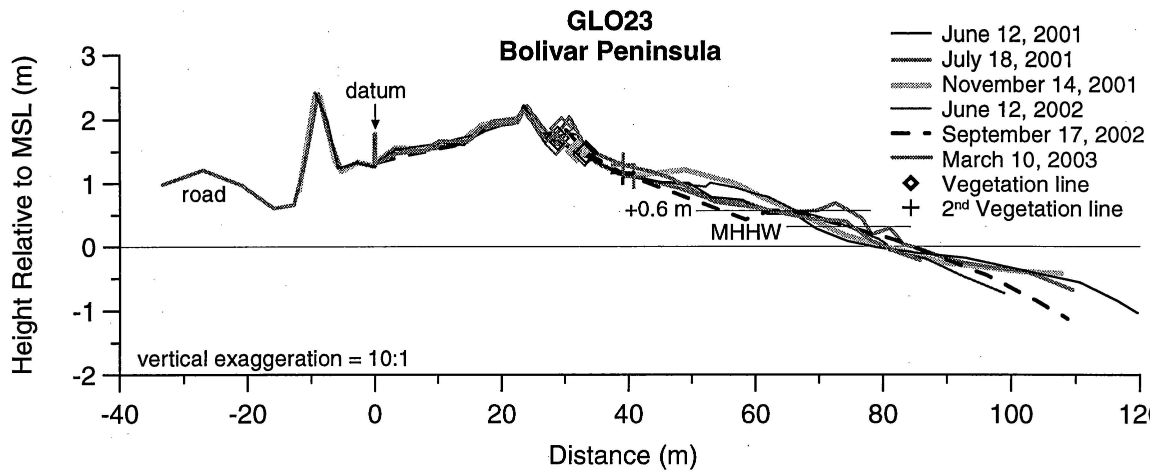
GLO22 November 14, 2001



GLO22 June 12, 2002

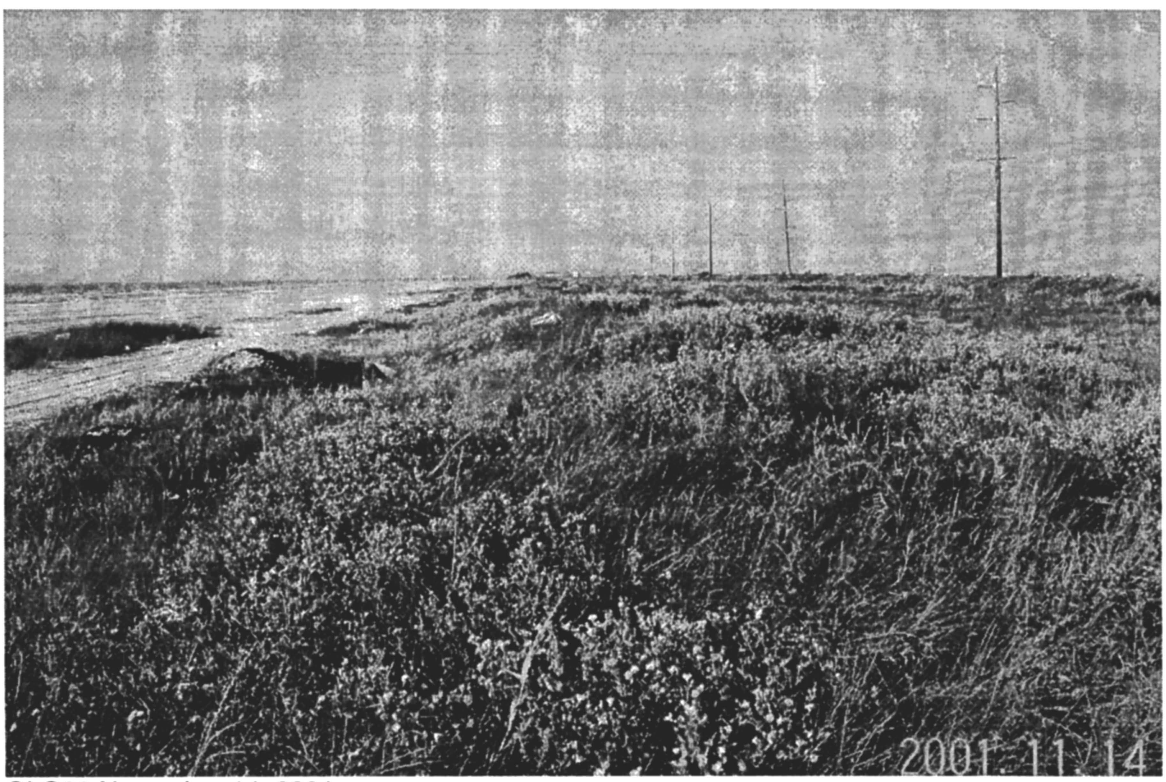
GLO22 September 17, 2002


GLO22 March 10, 2003

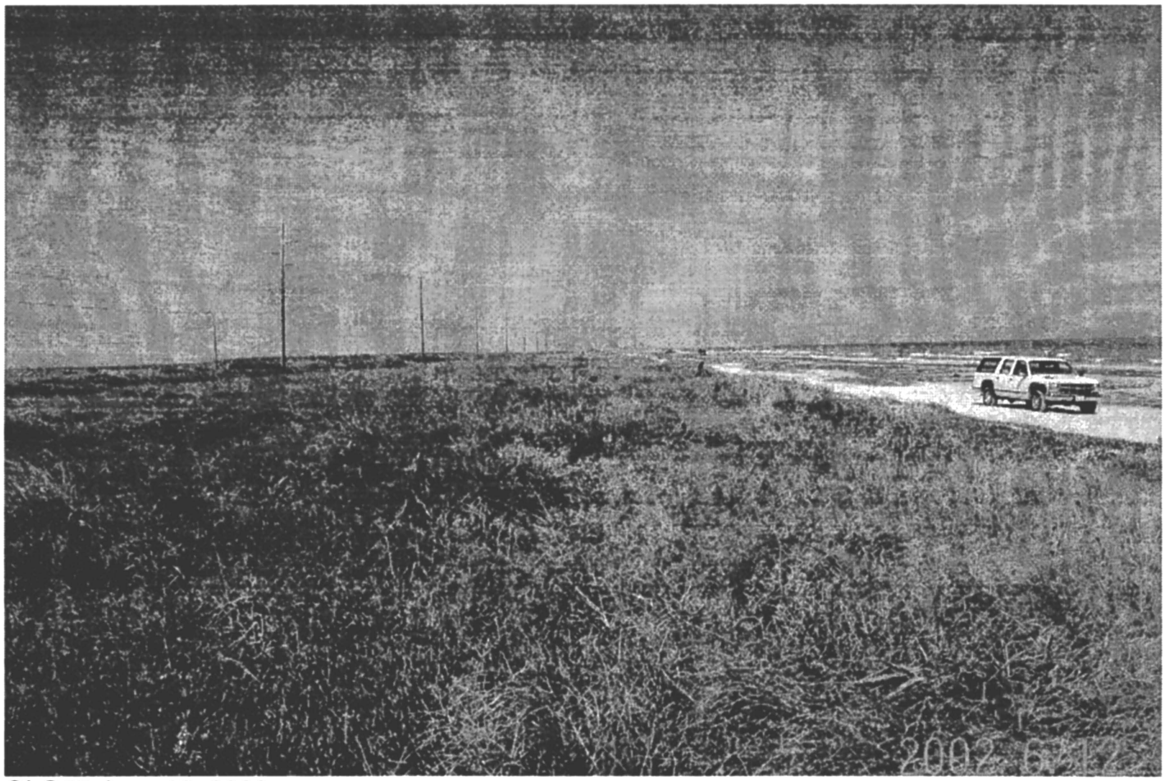


GLO23 June 12, 2001

GLO23 July 18, 2001



GLO23 November 14, 2001



GLO23 June 12, 2002

GLO23 September 17, 2002

GLO23 March 10, 2003