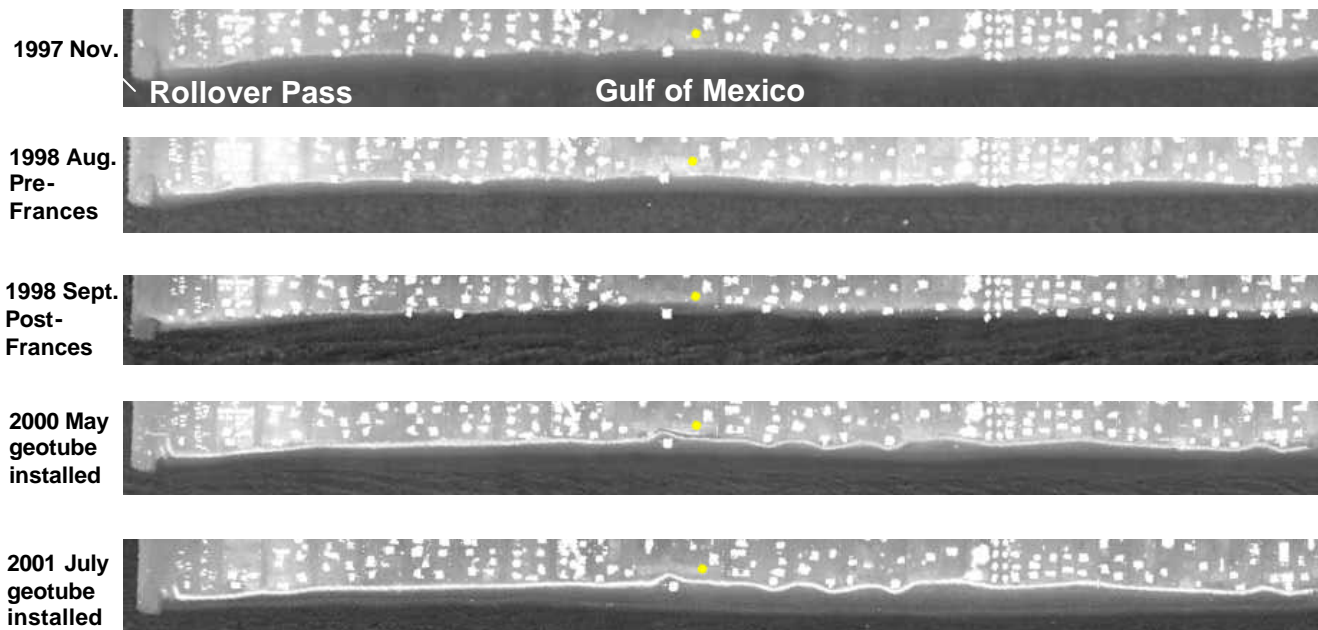


GEOTUBES ALONG THE GULF SHORELINE OF THE UPPER TEXAS COAST: OBSERVATIONS DURING 2001



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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 (geotubes) were installed. The geotubes 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. Geotubes 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. Currently nine separate geotube projects cover a total of 7.3 mi of the Gulf shoreline from Follets Island to High Island.

This study provides a quantitative evaluation of these projects on the basis of observations made during 2001. Three field surveys were conducted that included ground surveys (beach profiles), visual inspection of geotube exposure and damage, and an airborne topographic survey (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 geotube projects in the area. Results, data, and maps are reported on the Bureau of Economic Geology Web site (<http://www.beg.utexas.edu/coastal/geotube.htm>).

The geotubes are intended to serve as temporary storm-surge protection and erosion-control structures. Their effectiveness in protecting against storm surge is untested. Tropical Storm Allison struck the coast in June 2001, but the storm was not a significant event with regard to storm surge and beach erosion. Geotubes are effective only for temporary erosion control, and they will fail when exposed to direct wave attack and undermining. Also during 2001, one of the Treasure Island (on Follets Island) geotubes failed, and holes were found along the Gilchrist West project. To prevent failure it is critical to (1) keep the geotubes 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 did not test the storm-surge-protection function of the geotubes, the storm was largely responsible for eroding sand cover and fully exposing seaward faces of 44% of the combined lengths of the projects, for a total of 14,193 ft. Fair weather and transportation of sand from borrow sites allowed 85% of the geotubes to be covered by November. Because the geotubes 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 been impossible. Besides the Treasure Island projects, the Gilchrist West project on Bolivar Peninsula has been the hardest to maintain. In contrast, the Pirates Beach project on Galveston Island has fared well with respect to keeping a vegetated sand cover. Analysis of pre-Allison data and future monitoring will reveal why.

There has been concern that the geotubes, 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 2001, however, adjacent shorelines had not been affected by the projects. Furthermore, if beaches are nourished in front of the projects, the nourishment sand will erode and supply adjacent beaches. If beaches are not maintained, the geotubes 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 geotubes are forming or will eventually form an unacceptable landward boundary to the public beach. The geotubes do 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 geotubes 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 geotubes 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 geotubes are 21 to 83 ft narrower than they would be if the geotubes and houses seaward of the natural line of vegetation were not there. The largest beach-width difference is along the Pirates Beach project. In some locations, particularly where the geotubes were routed seaward of a house, the beach is impassable during moderately elevated water levels of 2 ft above sea level.

In summary, the geotube projects may be effective for short-term erosion control, but their storm-surge-protection function has yet to be tested. 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.

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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 (geotube) shore protection projects have been constructed. The geotubes consist of sediment-filled sleeves of geotextile fabric with an oval cross section of approximately 12 ft (3.7 m) (Figs. 1, 2). The geotubes rest on a fabric scour apron that has sediment-filled anchor tubes along each edge. Geotubes 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.

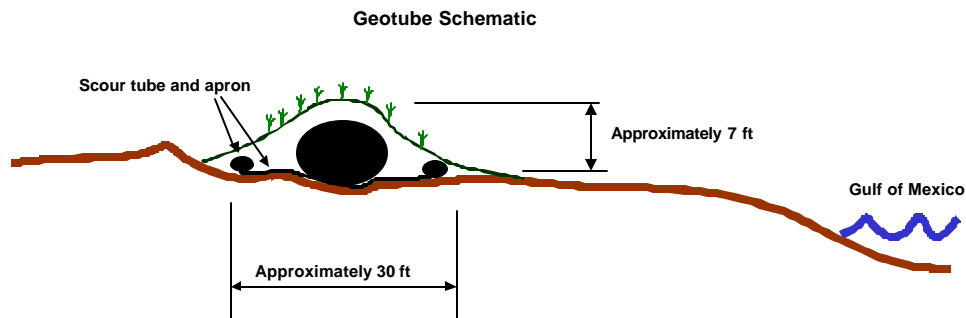


Figure 1. Cross-section schematic of a geotube installation.



Figure 2. Geotube stages.

Since 1998, nine geotube projects have been installed along the Gulf of Mexico Shoreline of Galveston and Brazoria Counties (Figs. 3, 4, 5, 6). As of November 2001, a total of 7.3 mi (11.7 km) of shoreline have the tubes. There is concern that the geotubes may eventually cause the adjacent shorelines to retreat at a higher rate than they would without the geotubes in place. Even if the geotubes 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 geotubes too far seaward or because of natural, long-term shoreline retreat in front of them. This study provides a quantitative evaluation of these extensive geotube 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 geotube projects in the area.

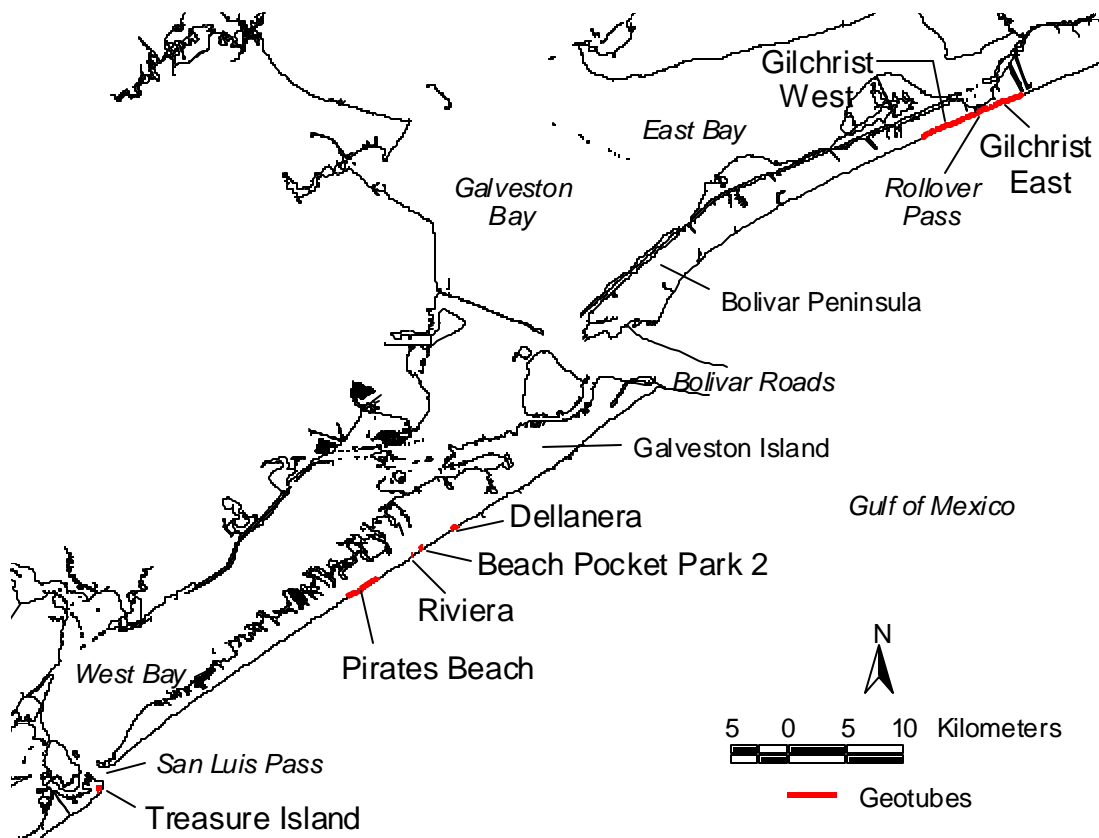


Figure 3. Map of geotubes along the upper Texas Gulf of Mexico shoreline.

Data and results of the geotube 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 geotubes 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.

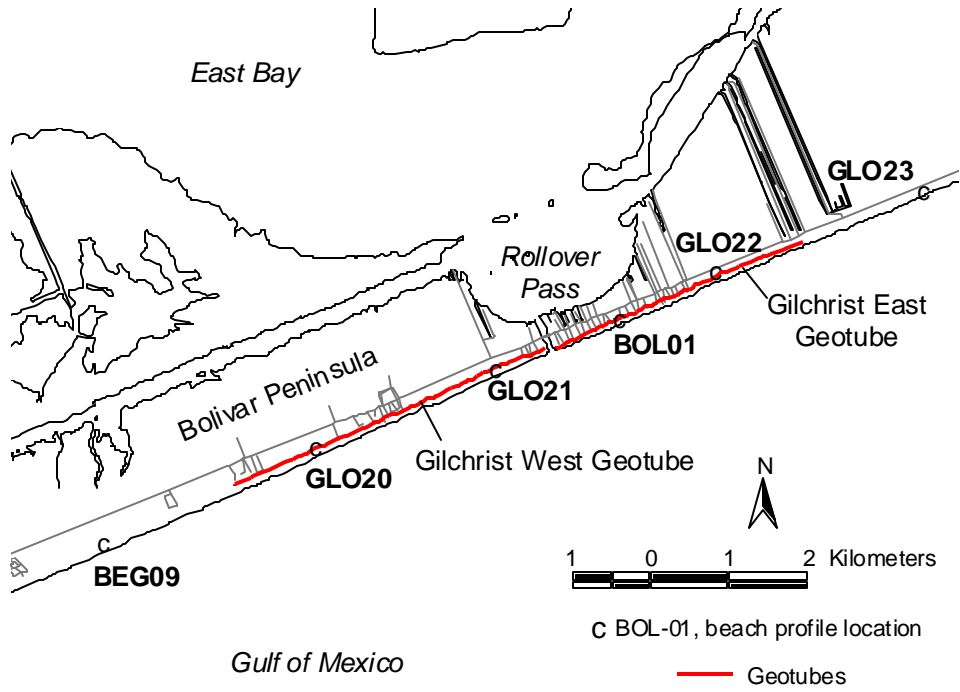


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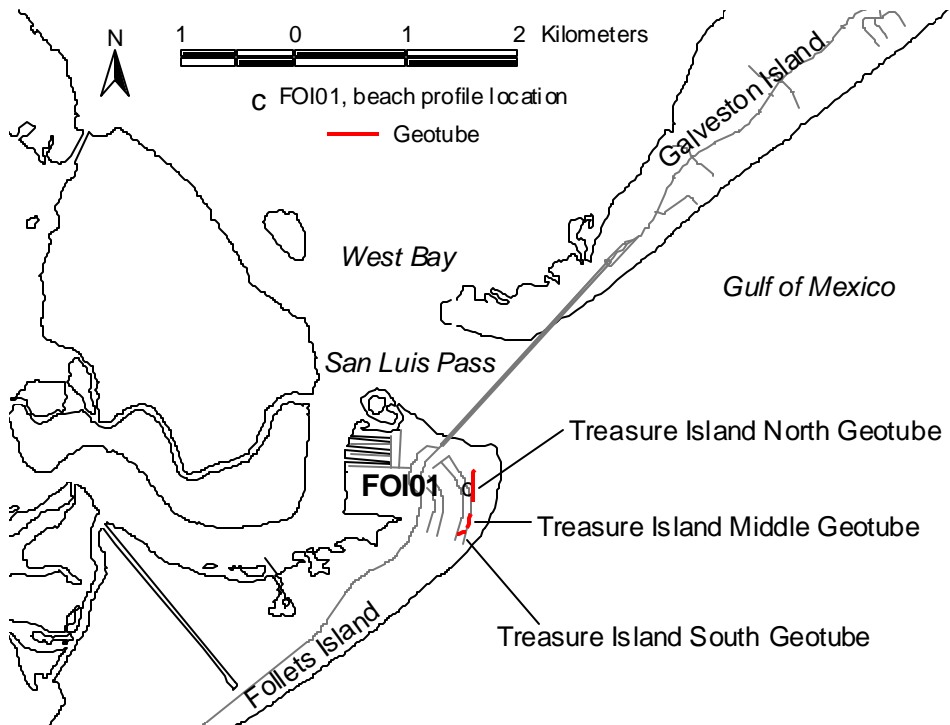


Figure 5. Map of Treasure Island geotube projects.

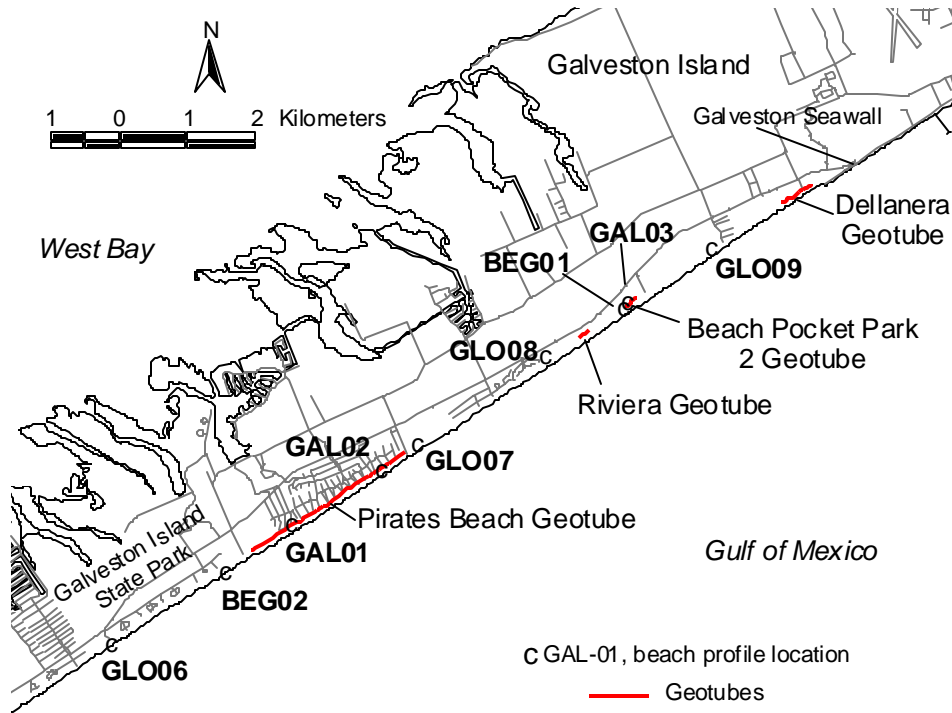


Figure 6. Map of geotube projects on west Galveston Island.

Methods

Field measurements include beach and dune topography, geotube, foredune, and shoreline positions, geotube exposure and damage, vegetation cover, and wave and water levels. From these measurements, the effects of the geotubes 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 three times during 2001 from June 11 to June 15, July 18 to July 20, and November 13 to November 14. 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 geotube projects. Five additional sites were established to compliment the older survey sites. Sites within and adjacent to the geotube 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. Five new profile sites were established within the geotube projects.

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, which approximates mean sea level (MSL). A local mean sea level correction was then 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.

Geotube condition surveys

Systematic ground observations and photographs of the geotubes were made three times during 2001 (June 11 to June 15, July 18 to July 20, and November 13 to November 14). 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 geotubes where conditions changed. The geotubes were described with the following characteristics:

Amount of exposure of apron, front, or top of geotube (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)

Geotube or ultraviolet radiation shroud damage

None: geotube 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 geotubes with certain conditions. A line along the seaward edge of the geotubes, as mapped using the July 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 geotube 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 July 17, 2001. 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 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 analysis. These data can also be used to map topographic and geomorphic features such as the geotubes and dunes.

Lidar surveys were conducted using the Bureau's Airborne Laser Terrain Mapper (ALTM) 1225 instrument developed 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. Four passes were flown between San Luis Pass (northeastern end of Follets Island) and Cedar Lakes. These passes covered the Treasure Island geotube projects, and they were made at altitudes of 1,772-2,297 ft (540-700 m), depending on cloud cover, and an air speed of 95-112 knots between the times of 14:55 and 16:08 Coordinated Universal Time (UTC). Two passes were flown from Bolivar Roads to Sabine Pass between 18:18 and 19:23 UTC. These passes covered the

Gilchrist projects and were made at altitudes of 1,706-2,034 ft (520-620 m) and an air speed of 90-120 knots. Three passes were made at altitudes of 1,657-1,903 ft (505-580 m) between Bolivar Roads and San Luis Pass. The passes covered the projects on Galveston Island and were flown at an air speed of 105-110 knots between 19:53 and 20:35 UTC. 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. Trajectories were computed in the International Terrestrial Reference Frame (ITRF) 97, which uses the GRS80 ellipsoid model. Aircraft trajectories were computed using each base station. For the morning flight (San Luis Pass to Cedar Lakes) the trajectories using the Port Bolivar and Freeport base stations were combined and for the afternoon flight (San Luis Pass to Sabine Pass) the trajectories using the Port Bolivar and Sabine Pass trajectories were combined. 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).

A digital elevation model (DEM) with a 3.28 ft by 3.28 ft (1 m by 1 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 G99SSS 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 bayside Port Bolivar tide gauge. Comparison of the height of the water level along the beach, as displayed in the transformed 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) 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 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 water levels occur simultaneously. Therefore, the product of water level 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 geotube performance and effects

Beach width

A primary concern with the geotube projects is that the public beach will be narrower in front of the geotubes than it would be without the geotubes present. A quantitative technique to compare beach widths, therefore, is required. For this purpose, segments of beaches adjacent to each geotube project on Bolivar Peninsula and Galveston Island were selected for comparison. Beach segments contiguous with the geotube projects and with similar processes and sand supply were selected to represent what the beach width would be if the geotubes 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.

The seaward boundary for computing the beach width is the 1.97 ft (0.6 m) MSL contour line. This level corresponds to the boundary of wet and dry sand as shown in the beach profiles. The lidar maps along Galveston and Bolivar Peninsulas (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 will be hindered. The landward boundary for computing beach width is the seaward edge of the geotube 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 geotubes 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 geotubes

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.

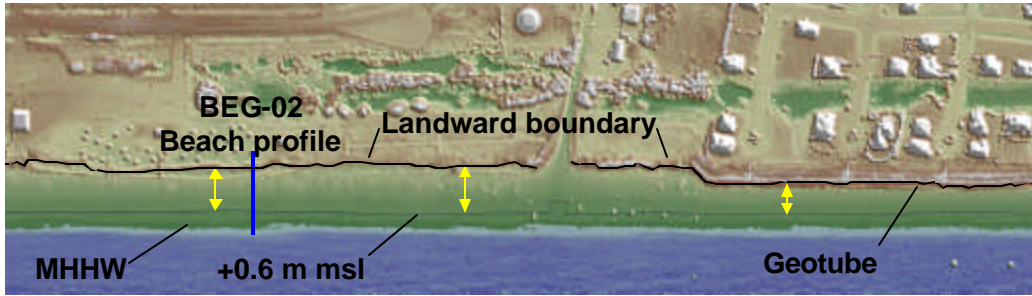


Figure 8. Lidar topographic image of the southwest end of the Pirates Beach geotube project and the northeast end of Galveston Island State Park. Double-ended arrows demonstrate beach width measurement between the 0.6 m level and the landward boundary.

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 geotube projects will occur if there is not adequate beach nourishment and if the geotubes 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 geotubes are experiencing enhanced erosion rates. A landward deviation of the contour line at the end of the geotube or a lower than normal back beach would indicate negative effects.

Storm protection function

A quantitative method for evaluating how well the geotubes serve as storm protection structures has not been devised. Nor has enough data been acquired or severe storms experienced to evaluate this function. With the baseline data collected during 2001, 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, WLS, and the product of water level and WLS 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 WLS and water level indicate periods of high wave energy coincident with high-water levels. TS Josephine and Frances 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, Gibeau and Gutierrez (1999) 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 threshold conditions for episodic erosion and vegetation line retreat are water levels that exceed 2.95 ft (0.9 m) MSL and WLS that

exceeds 0.85 ft (0.26 m) for at least 12 hours. WLS D 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. Furthermore, the product of water level and WLS D exceeds 0.8 m^2 for erosion events.

On June 5, Tropical Storm Allison made landfall near Freeport, Texas approximately 14 mi southwest of the Treasure Island geotube projects, 30 mi southwest of the Galveston Island projects, and 60 mi southwest of the Gilchrist projects. Figure 10 shows water levels, WLS D, and wave heights measured by the offshore buoy during Allison. The peak water level was 3.12 ft (0.95 m) MSL, the peak WLS D was 0.69 ft (0.21 m), and the peak wave height was 13.94 ft (4.25 m). Wave heights that exceeded 9.84 ft (3 m) coincided with water levels exceeding 2.95 ft (0.9 m) for a period of only 1 hour. Furthermore, the product of water level and WLS D peaked at only 0.5 m^2 during Allison, considerably less than Tropical Storms Josephine and Frances in 1996 and 1998, respectively (Fig. 9). 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 geotubes, 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.

Geotube conditions

Table 1 lists the geotube projects installed along the upper Texas coast. During this study, the Gilchrist East project was completed between the June and November field surveys adding about 2,132 ft (650 m) to the project, and the Treasure Island middle project was destroyed in November. Geotube lengths are measured using lidar data acquired in July and therefore do not reflect the later changes. Appendix B contains all beach profile plots and photographs taken at the profile locations.

Table 2 shows snapshots of the conditions of the geotubes during each field visit. Lengths of sections of geotubes where at least the seaward face was fully exposed and sections with little or no vegetation cover are tabulated. The June survey was conducted seven days after Tropical Storm Allison. The seaward faces of the geotubes were exposed along 44% of their length partly because of erosion at the base of the geotubes during Allison. The Gilchrist west project had by far the greatest length and proportion of exposed geotubes in June, 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 was able to recover most of the exposed geotubes and by November only 15% of the total length of all projects was exposed (Table 2). 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. The Treasure Island middle project was destroyed by waves and slightly elevated water levels in November.

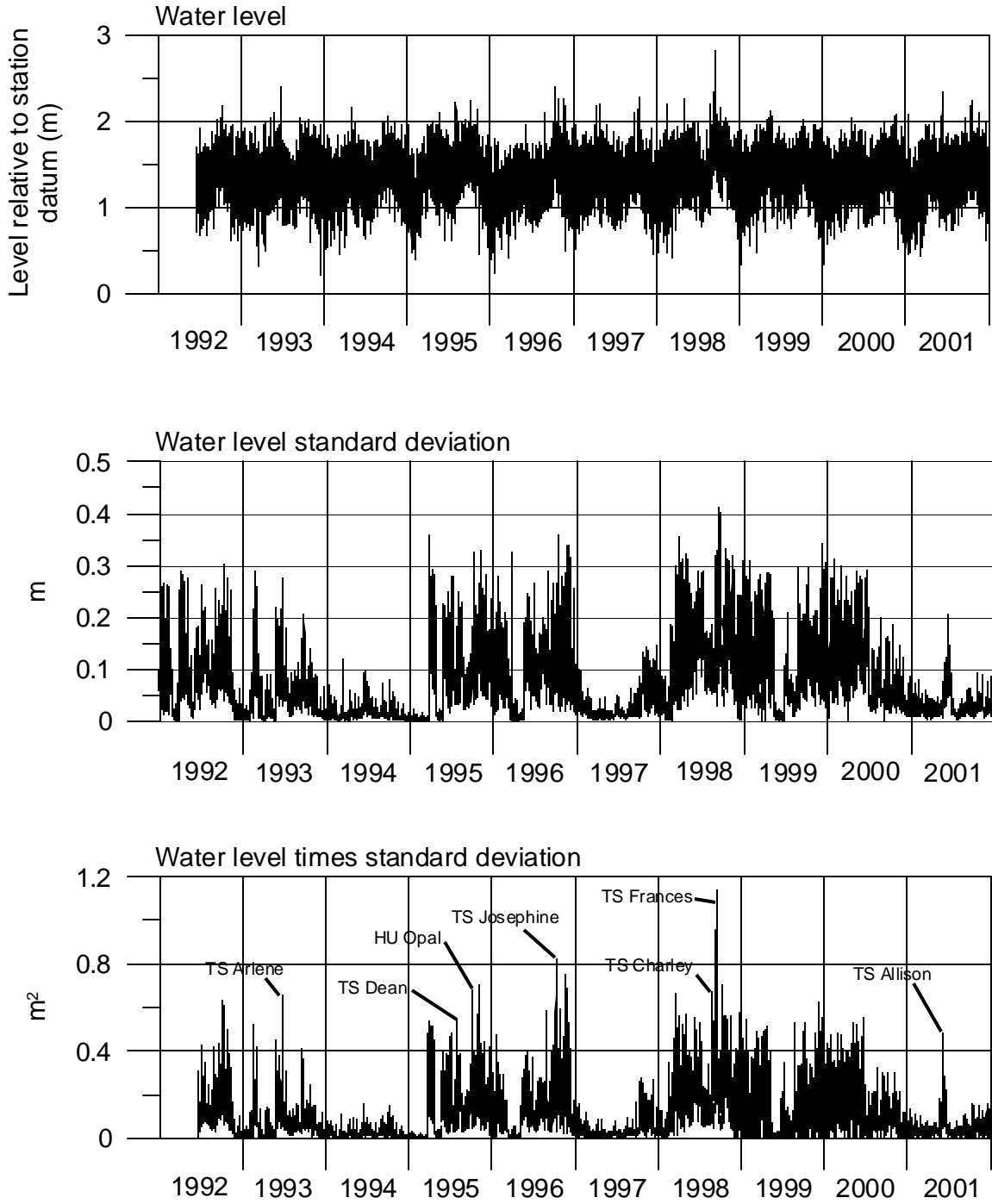


Figure 9. Time series of water level, water level standard deviation (WLSD), and the product of water level and WLSD from the Pleasure Pier tide gauge.

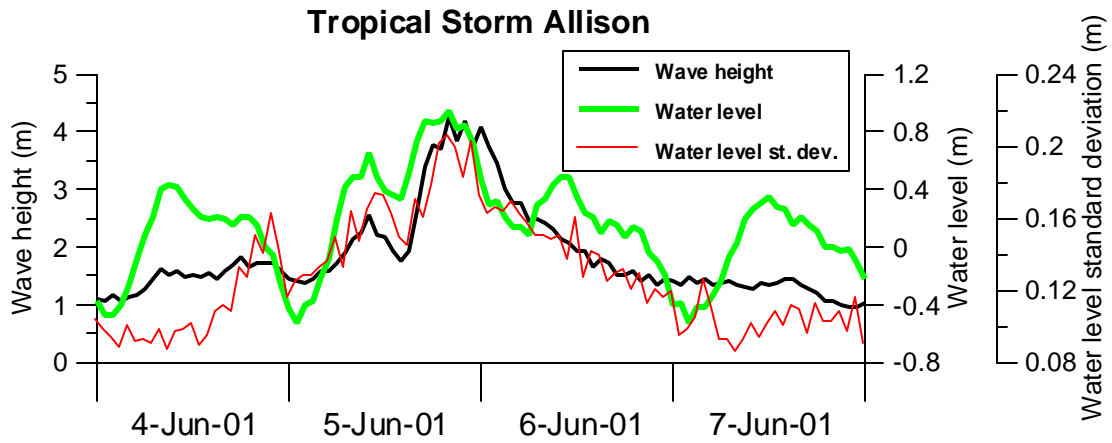


Figure 10. Water level and wave conditions during Tropical Storm Allison. Water level and Water level standard deviation (WLSD) measured at Pleasure Pier tide gauge. Wave heights measured by National Data Buoy Center buoy #42035 located 20 miles offshore Galveston.

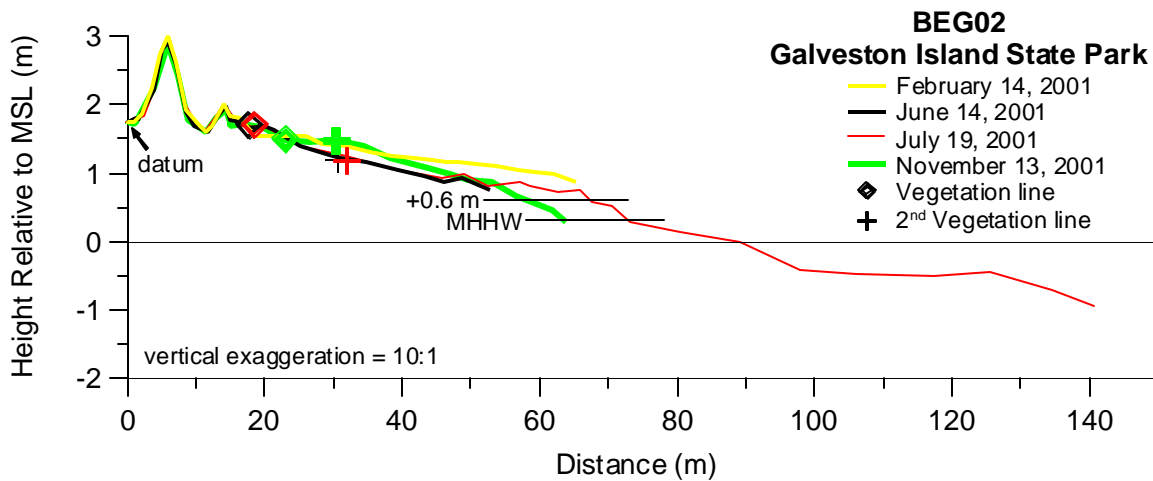


Figure 11. Beach profiles at Galveston Island State Park, location BEG02 (see Fig. 6 for location). The foredune and incipient dune seaward of the foredune survived Tropical Storm Allison in early June, 2001.

Table 1: Geotube project lengths as of July 17, 2001.

Geotube Project	Location	Completion Date	Meters	Feet	Miles
Dellanera	Galveston Isl., West Beach	June 2000	459	1,506	0.285
Gilchrist east	Bolivar Pen., east of Rollover Pass	Phase 1 (Rollover Pass to Legers Street): September 2000; Phase 3 (Legers Street to Dirty Pelican Pier: July 2001	3,446	11,306	2.141
Gilchrist west	Bolivar Pen., west of Rollover Pass	Phase 1 (Rollover Pass to Martha's Vineyard Road): September 2000; Phase 2 (Martha's Vineyard to Campbell: June 2001	4,339	14,236	2.696
Pirates Beach	Galveston Isl., West Beach	October 1999	2,499	8,199	1.553
Pocket Park II	Galveston Isl., West Beach	December 1999	152	499	0.094
Riviera	Galveston Isl., West Beach	January 2001	146	479	0.091
Treasure Island middle	Follets Isl., San Luis Pass	March 2000	127	417	0.079
Treasure Island north	Follets Isl., San Luis Pass	March 2000	299	981	0.186
Treasure Island south	Follets Isl., San Luis Pass	March 2000	78	256	0.048
Total			11,545	37,879	7.173

Table 2: Exposed and sparsely vegetated geotubes.

Project	June 2001		July 2001		November 2001	
	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. Middle	417/100	417/100	417/100	417/100	destroyed	destroyed
Treasure Isl. North	285/29	282/29	305/31	305/31	538/55	974/100
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	20,754/56

Beach Width

Figures 12 and 13 are histograms that compare beach widths adjacent to and in front of each project except the Treasure Island projects. The histograms are shown in relative frequency of locations spaced 16.40 ft (5 m) alongshore. For example, figure 12A shows that approximately 40 % (0.4 relative frequency) of the length of the beach is 140 to 160 ft (42.7 to 48.8 m) wide adjacent to the geotubes. The histograms show that beaches in front of geotubes are generally narrower than beaches adjacent to them. There are, however, portions of the beaches in front of the geotubes that are as wide as the narrower portions of the adjacent beaches. Table 3 gives the minimum and average beach widths. Average beach widths are narrower in front of the geotubes 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 geotubes have minimum beach widths narrow enough to prevent passage during water levels of 1 to 2 ft (0.30 to 0.61 m) above MHHW.

**Table 3: Comparisons of beach width in front of and adjacent to geotubes
July 17, 2001.**

Project	Minimum Width (ft)		Average Width (ft)		Difference front – adj.
	In front	Adjacent	In front	Adjacent	
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

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 (Plates 1 and 2) show that the geotubes have not affected the erosion rates of adjacent beaches. If adjacent beaches were being affected, we would expect to see a decrease in the effect with distance from the geotubes. 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 geotubes and for beaches more distal to the geotubes.

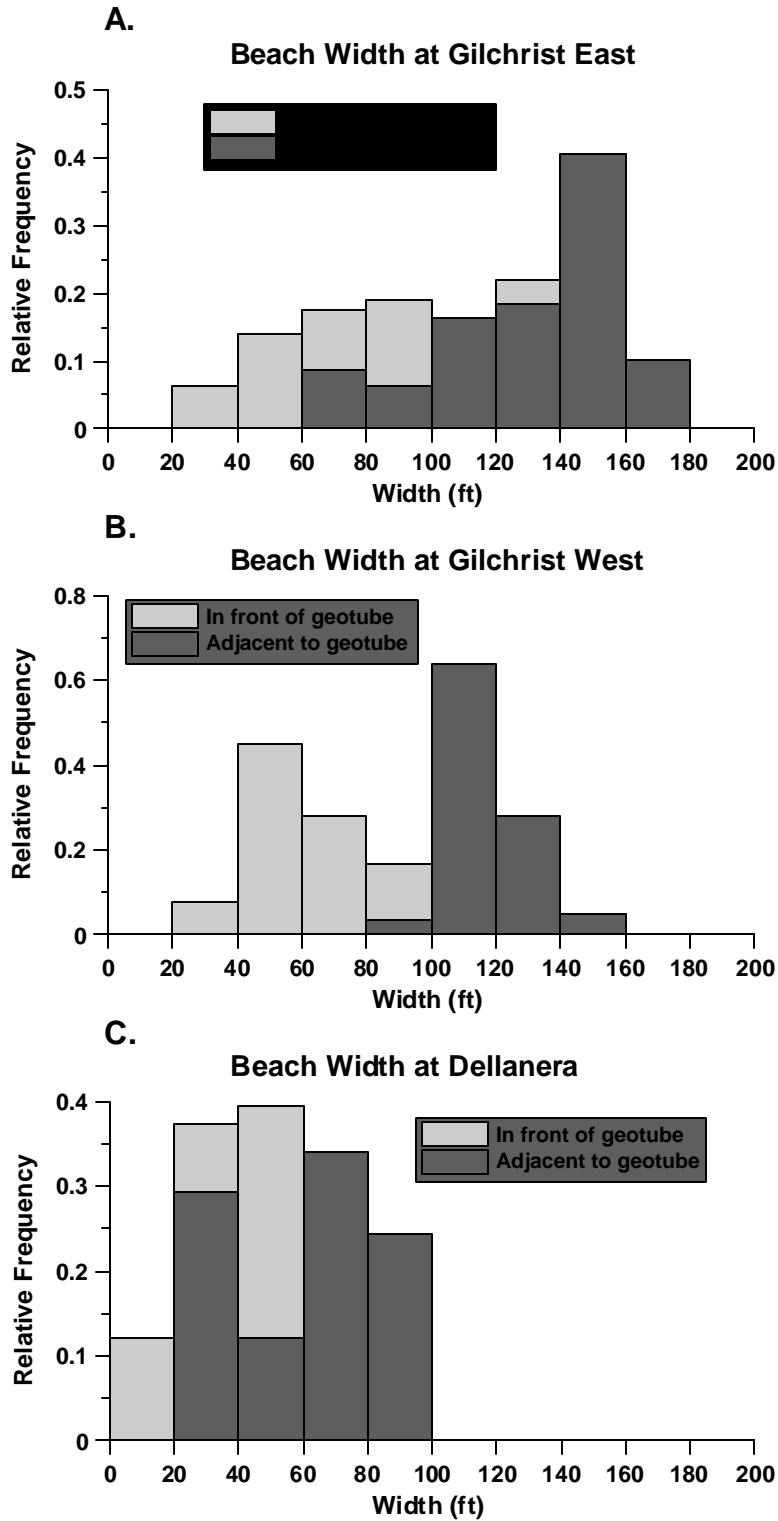


Figure 12. July 2001 beach width comparison shown as relative frequency of transects spaced every 16.4 ft (5 m) alongshore in front of and adjacent to the designated geotubes: (A) Gilchrist east; (B) Gilchrist west; (C) Dellanera.

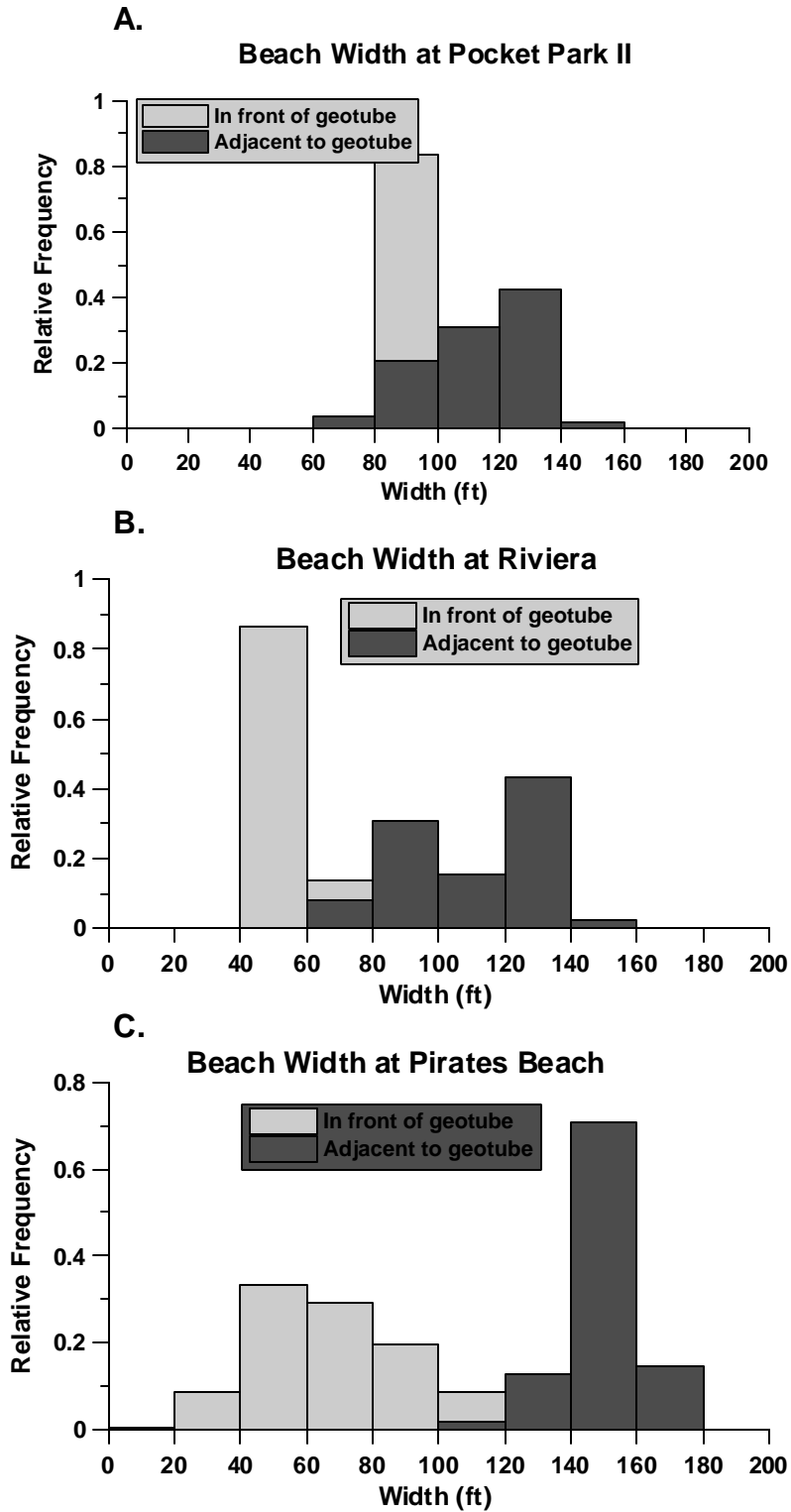


Figure 13. July 2001 beach width comparison shown as relative frequency of transects spaced every 16.4 ft (5 m) alongshore in front of and adjacent to the designated geotubes: (A) Pocket Park II; (B) Riviera; (C) Pirates Beach.

Discussion

Geotube function and maintenance

The geotubes along the Gulf of Mexico shoreline of the upper Texas coast are intended to serve as temporary storm-surge protection and erosion control structures. Their effectiveness in protecting against storm surge is untested and as erosion control structures is questionable. Once the beach erodes to the base of the geotubes, 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. Punctures have been observed at the Gilchrist West project, and the Treasure Island middle project was completely destroyed (Figs. 14 and 15). If beach nourishment does not maintain a beach wide enough to keep the geotubes 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 14. Treasure Island middle geotube 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.



Figure 15. Puncture in Gilchrist West geotube on November 15, 2001.

In July there were no beaches in front of the Treasure Island middle project (Fig. 14), most of the south project, and the southern part of the north project; the bases of the geotubes were at the MHHW line (Plate 3). By November the remaining beach in front of the north geotube was eroded allowing direct wave attack on the tube. 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 geotubes cannot prevent this natural shoreline adjustment.

Tropical Storm Allison struck the coast in June, 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 geotubes 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 geotubes would not have been expected even without the geotubes present. It is likely, however, that erosion of vegetation to a position landward of some houses behind the geotubes would have occurred, which would have placed them on the public beach easement. However, this would be expected only in places where the geotubes were installed seaward of houses that were probably on the public easement before geotube installation (Plates 1 and 2).

It is notable that most of the seaward faces of the Gilchrist West geotubes were exposed following Allison, but only 10% of the Pirates Beach project was exposed. This disparity occurred even though these projects had nearly the same width of beach in front of them in July (Table 3). Before Allison, however, the Pirates Beach project had sand fencing and vegetated sand in front of the geotubes unlike the Gilchrist West project (Fig. 16). This additional volume of vegetated sand and possibly the presence of nearshore

bars, which attenuate wave energy arriving at the beach, offshore of the Pirates Beach project protected the geotubes. It is also possible that the pre-Allison beach in front of the Pirates Beach project was wider than in front of the Gilchrist West project. We do not have the data to determine which factors are the most important in the uncovering of the Gilchrist West geotubes. Continued monitoring is needed to answer this important question.



Figure 16. Pirates Beach geotube at GAL01 profile location (see figure 6 for location). This geotube remained covered and vegetated following Tropical Storm Allison. Note sand fence and lack of coppice mound subenvironment.

From June to November, the length of exposed geotubes decreased because of maintenance activity and relatively fair-weather conditions. The Gilchrist East project was completely recovered by July but 700 ft (213 m) were exposed again in November indicating an ongoing problem even without elevated water and wave conditions (Table 2). Twenty-eight percent of the Gilchrist West project was exposed in November, which represented the majority of exposed geotubes. Based on beach profile data in this report, it is estimated that 4.78 yd³ per 1 linear yard of beach length (4 m³ per 1 m of beach length) is required to cover the seaward face of a geotube. Therefore, it would take about 22,600 yd³ (17,304 m³) of sand to cover the 14,193 ft (4,326 m) of exposed geotubes surveyed in June. A medium-sized dump truck with a 15 yd³ capacity would require 1,500 round trips to deliver this much sand. Most of this sand is needed on the Gilchrist projects. Project designs also call for the geotubes 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).

Effects of geotubes on the beach/dune system

Along Galveston Island and Bolivar Peninsula, beaches in front of the geotubes are narrower than adjacent beaches (Figs. 12 and 13, Table 3). This is primarily because of where the geotubes were installed and not because of shoreline retreat, although shoreline retreat will narrow the geotube beaches even more if there is not adequate beach nourishment. Geotubes were placed 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 line of vegetation and also are the natural geomorphic features that the geotubes emulate. The placement of the geotubes has created landward boundaries to the beaches that are more seaward than the relatively natural boundaries of adjacent beaches. Some geotube segments were routed seaward of

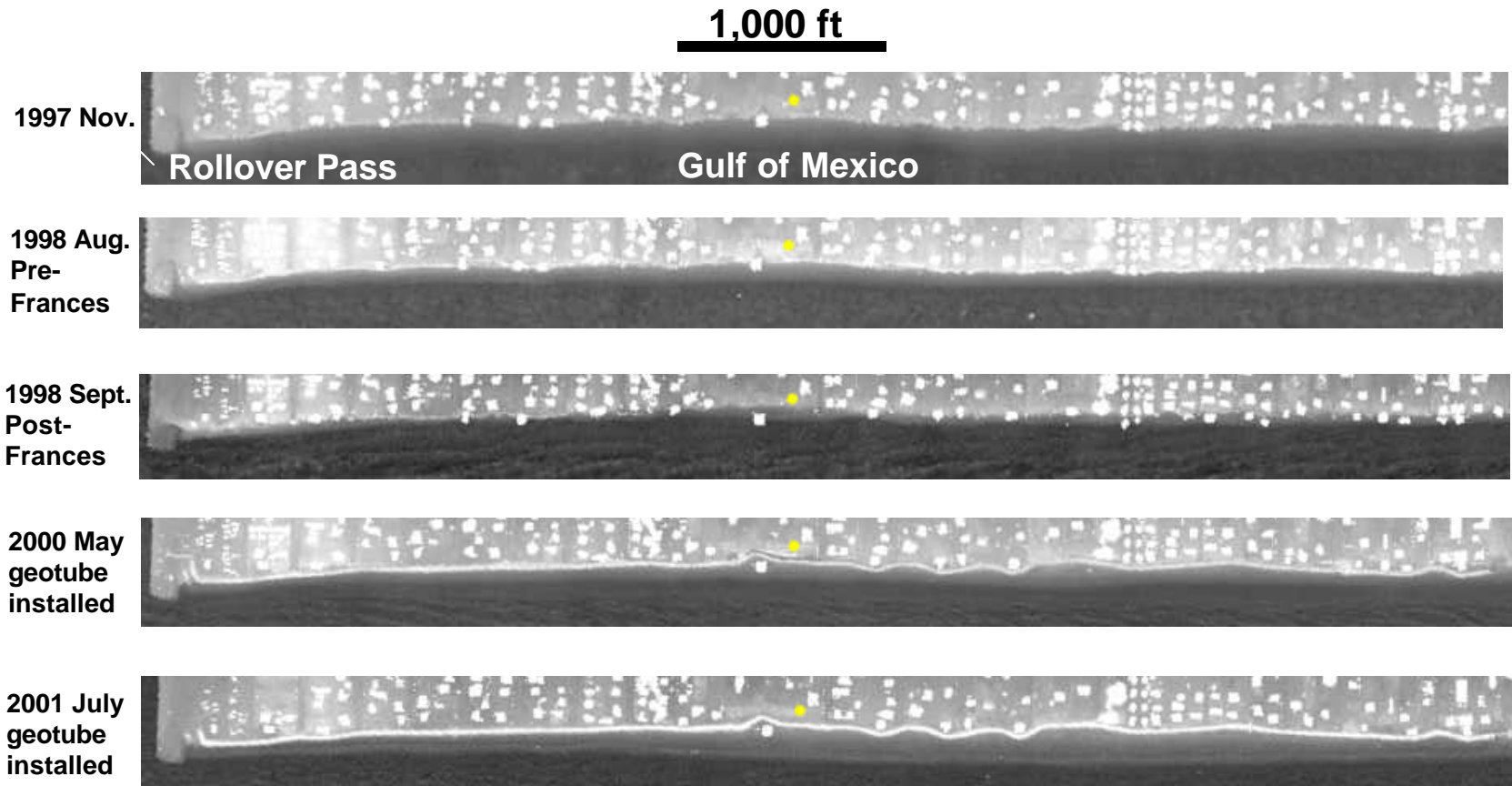


Figure 17. Lidar topographic images of Gilchrist East project. Dark areas are low elevation, lighter higher elevation. Geotube was present during the 2000 and 2001 surveys. Note how geotube was routed seaward of some houses and the overall geomorphic impact of the project.

individual houses or groups of houses (Fig. 17, 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. 18). Furthermore, outflow from the drainage pipes along the Pirates Beach project erode channels perpendicular to the shoreline that at times hinder passage (Fig. 19). These drainage pipes, which concentrate flow through the geotubes, are required to prevent flooding from rainfall landward of the geotube.



Figure 18. Pirates Beach geotube on November 15, 2001. Geotube at this location was routed seaward of the house causing a particularly narrow beach and difficulty in maintaining a sand cover on the geotube. Water level was about 2.0 ft (0.61 m) above mean sea level.



Figure 19. Pirates Beach geotube project on June 14, 2001 after Tropical Storm Allison. Rainfall runoff from Allison flowed through the black street drainage pipe beneath the geotube on the right and eroded this channel in the beach.

With regard to geomorphology, geotubes 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. 20). This is the case even where the geotubes are covered with vegetated sand. The geotubes 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 geotubes also lack the complex topography that natural dunes possess and in most places appear more like earthen dikes than wind-formed dunes (Fig. 17 and Plates 1, 2, and 3). 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. 20). 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 geotubes even where driving is not permitted, such as along the Pirates Beach project. Beaches to the northeast and 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 geotube project, however, the coppice mound subenvironment does not exist or is poorly developed (Figure 16). This is because the geotube 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.



Figure 20. Coppice mounds at BEG02 profile location in Galveston Island State Park on June 14, 2001 (see figure 6 for location). This subenvironment of wind-blown sand and sparse vegetation was eroded but survived Tropical Storm Allison.

At this time there is no indication that the geotubes have increased the rate of retreat of adjacent beaches, and it is not likely they will have a significant impact in the future. Sand supply to adjacent beaches would be reduced and erosion increased if beaches in front of the geotubes completely eroded and the geotubes were able to prevent further erosion of the sand behind them. If the beaches in front of the geotubes are maintained by nourishment, however, then the nourishment sand will supply adjacent beaches as it is eroded. If the geotube beaches are not maintained, the geotubes 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.

Conclusions

1. The storm protection function of the geotubes has not been tested.
2. The geotubes 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 geotube fabric along the Gilchrist West project. To prevent failure it is critical to keep the geotubes covered with sand, to maintain a beach in front of them, and to repair holes in the fabric as soon as possible.
3. 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 geotubes cannot stop the movement.
4. 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 geotube and contributes by far the greatest length of exposed geotubes along the upper coast. Further monitoring and analyses are required to determine the cause of this.
5. In contrast to the Gilchrist projects, the Pirates Beach project on Galveston Island has maintained a vegetated sand cover over 90% of the project. Continued monitoring is required to determine the cause of this.
6. In June, after Tropical Storm Allison, 44% of the lengths of geotubes 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. Most of the exposed geotubes are along the Gilchrist West project.
7. Keeping at least a 25% vegetation cover along the Gilchrist East and West projects has not been possible.
8. Keeping the geotubes repaired, sand covered, and vegetated requires a significant effort.
9. Beaches in front of the geotubes are narrower than adjacent beaches. This is primarily because the geotubes were installed farther seaward than the natural landward boundaries represented by the line of vegetation, foredunes, or bluffs.
10. Some geotube segments were routed conspicuously 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.

11. 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.
12. Geotubes alter the natural geomorphology of the beach/dune system and have hindered the formation of coppice mounds.
13. The geotubes have not enhanced erosion rates on adjacent beaches. If the beaches in front of the geotubes are not nourished with sand from outside the littoral system, then there may be a small enhancement of erosion of adjacent beaches until the geotubes are destroyed by wave action.

Appendix A: Beach Profile Positions

Geotube 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.