Geotubes for Temporary Erosion Control and Storm-Surge Protection along the Gulf of Mexico Shoreline of Texas

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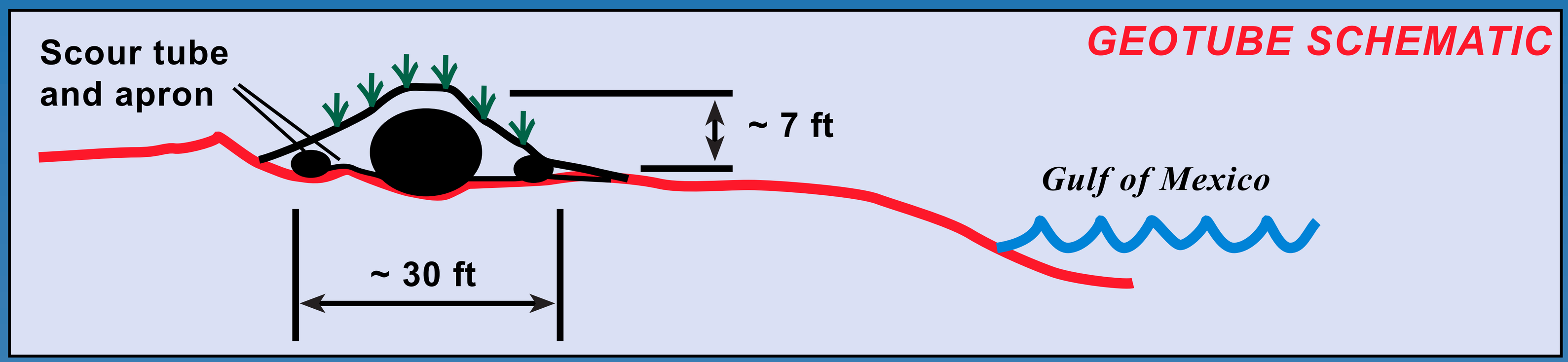
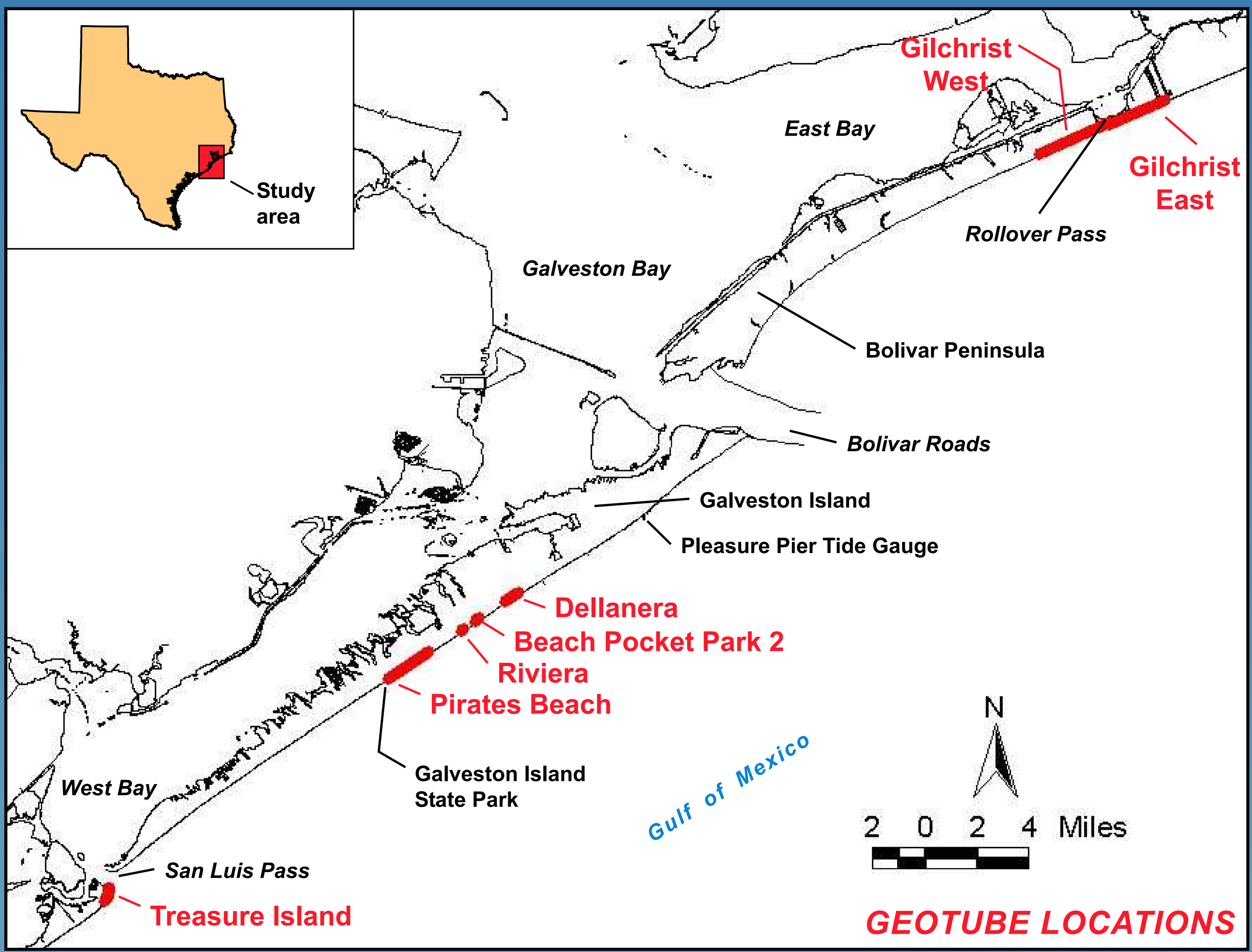
ABSTRACT

In September 1998, Tropical Storm Frances caused severe beach and dune erosion along the Gulf of Mexico 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.

The geotubes are intended to serve as temporary storm-surge protection and erosion-control structures. Their effectiveness in protecting against storm surge had not been tested by March 2003. However, in places where geotubes were in the swash zone because of ongoing erosion, they were destroyed or damaged. 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.

The geotubes are significant engineering structures that have changed and are changing the geomorphology and sedimentary environments of the beach/dune system. In most places, they rise abruptly from the backshore and appear more like earthen dikes than wind-formed dunes. The geotubes lack the complex topography of natural dunes and have not allowed the formation of the coppice-mound environment as is present on adjacent beaches. This is because the geotube beaches are not wide enough to supply wind-blown sand to the back beach or to keep the back beach out of the swash zone during moderate wave and water level conditions. Continued maintenance and beach-nourishment projects will be required to mitigate adverse effects on public beaches.





Geotube project lengths as of March 2003.

Geotube project	Location	Completion date	Meters	Feet	Miles
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	3,935	12,910	2.44
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	4,341	14,242	2.70
Dellanera	Galveston Isl., West Beach	June 2000	459	1,506	0.29
Bench Pocket Park 2	Galveston Isl., West Beach	December 1999	120	394	0.07
Riviera	Galveston Isl., West Beach	January 2001	147	482	0.09
Pirates Bench	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

OBJECTIVE

Evaluate the effectiveness of geotubes for mitigating erosion and storm flooding hazards and assess the effects of geotubes on beach and dune environments.

FIELD MONITORING

Beach Profiles:

Repeat beach profile surveys at 16 locations, some within geotube projects and some adjacent to projects.

Qualitative Geotube Condition Assessment:

A differential GPS was used to locate photographs and points along the geotubes where conditions changed. A line along the seaward edge of the geotubes, as mapped using the lidar survey (see below), was coded in the GIS according to the condition of the tube. 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 (see above photo)

Geotube or ultraviolet radiation shroud damage

None: geotube is neither damaged nor undermined
Yes: some damage
Destroyed: geotube deflated

Vegetation cover

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

Airborne Topographic Lidar Survey:

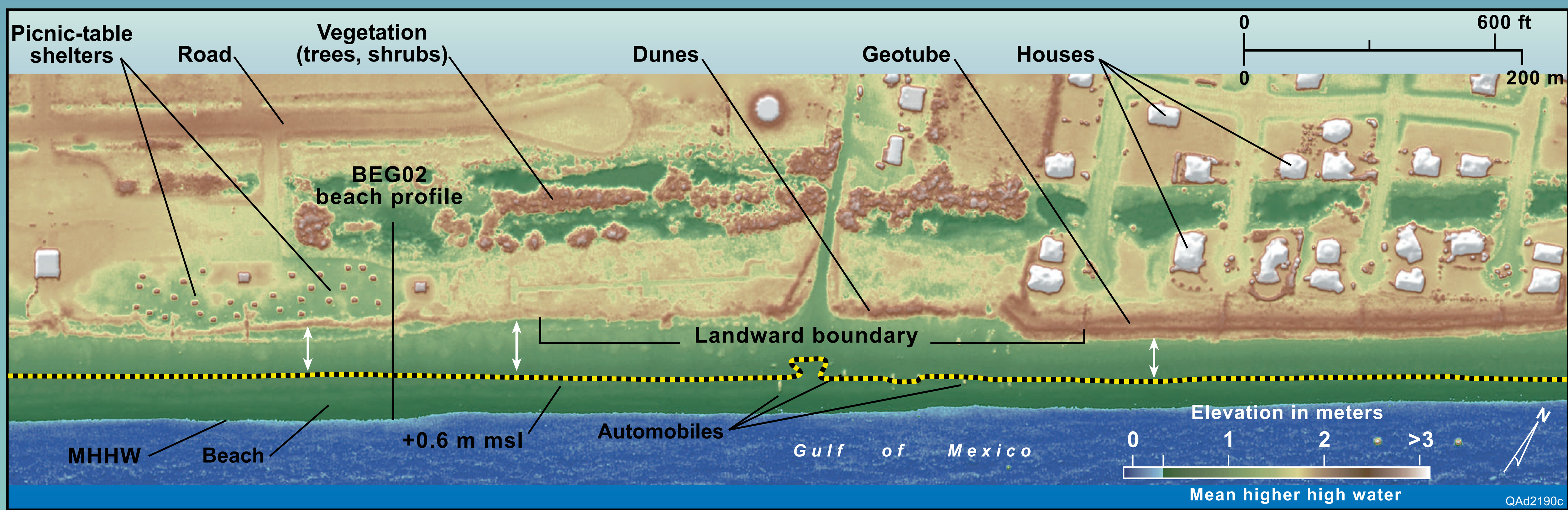
Surveys conducted on July 17, 2001, 6 weeks after Tropical Storm Allison, and on September 18, 2002, one week after Tropical Storm Fay.

Surveys were conducted by The University of Texas at Austin using our Optech 1225 ALTM lidar instrument. One-meter digital elevation models were created, and the vertical datum was adjusted to be relative to local mean sea level.

The seaward edge of the geotubes and foredunes of adjacent beaches were mapped and the +1.97 ft (+0.6 m) contour line was mapped to represent the shoreline corresponding to the typical level of the boundary between wet and dry sand (see image below). Beach width was measured every 16.4 ft (5 m) along shore (see map below).

Process Measurements

Hourly readings from the open-coast tide gauge on Galveston Island (Pleasure Pier) were processed to indicate relative severity of storms.



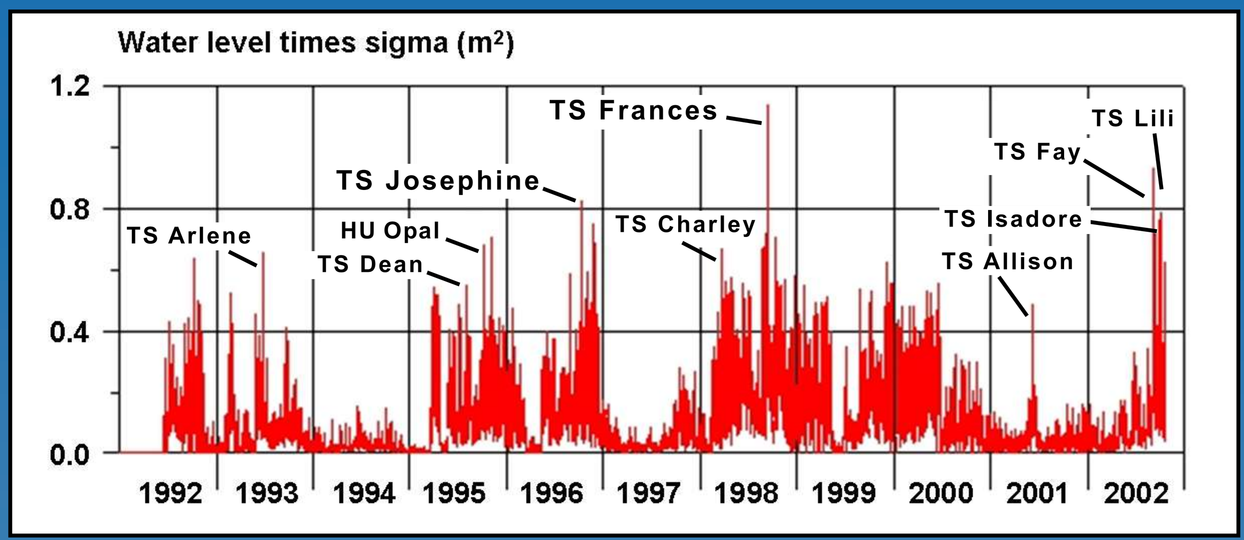
Lidar topographic image of the southwest end of the Pirates Beach geotube project and the northeast end of Galveston Island State Park. Double-ended arrows demonstrate beach width measurement between the 0.6-m level and the landward boundary. These measurements were taken every 16.4 ft (5 m) along shore.

GEOTUBES FUNCTION AND MAINTENANCE

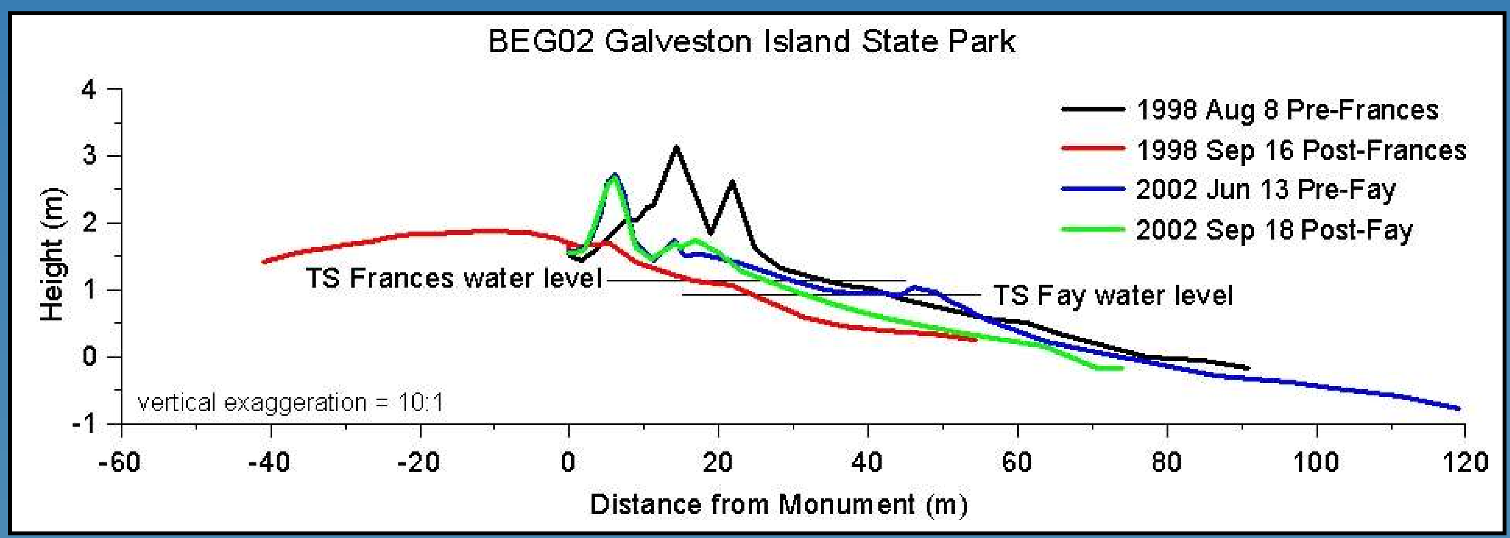
The geotubes are intended to serve as temporary storm-surge protection and erosion-control structures. Their effectiveness in protecting against storm surge is untested and as erosion-control structures is limited. Once the beach erodes to the base of the geotubes, they become undermined and begin to slump seaward. Direct wave attack on the tubes quickly removes the sand cover, damages the ultraviolet radiation shroud, and causes punctures. If beach nourishment does not maintain a beach wide enough to keep the geotubes landward of the swash zone, it is expected that 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.

Tropical Storms (TS) Allison and Fay struck the coast in June 2001 and September 2002, respectively. These storms, however, were not significant with regard to storm surge or beach erosion. Hence, damage to houses behind the geotubes would not have been expected, even without the geotubes present. Allison and Fay did, however, remove much of the sand from the faces of the geotubes, and it is likely 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 mostly in places where the geotubes were installed seaward of houses that were probably on the public easement before geotube installation.

On the basis of beach profile data, it is estimated that 5 yd^3 per linear yard of beach length is required to cover the seaward face of a geotube. Therefore, it would take about 23,655 yd^3 of sand to cover the exposed geotubes surveyed in June 2001 following TS Allison and 50,820 yd^3 after TS Fay in September 2002. 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. Keeping even a 25% vegetation cover, however, has proven difficult (see table below).



Hourly time-series plot of mean water level multiplied by the standard deviation (sigma) of 180, 1-second readings of water level at the open-coast Pleasure Pier tide gauge on Galveston Island. High sigma values correspond to high waves arriving at the gauge; high values in this plot thus indicate times of simultaneous high water level and high waves. TS Frances occurred before the geotube projects were installed and is the only storm that washed over foredunes. Subsequent storms have not tested the storm-surge protection function of the geotubes.



Beach profiles at a location without geotube installed. TS Frances caused complete erosion and washover of the foredune and was the impetus for geotube installation on adjacent beaches. Erosion by subsequent storms has been moderate at this relatively natural setting.

Exposed geotube on July 19, 2001 in the Treasure Island project. This section was destroyed four months later in November, 2001 during slightly elevated (1 ft.) water level and wave conditions. Note exposed scour apron and damaged UV shroud.

Exposed and sparsely vegetated geotubes.

	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**

	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**

Puncture in Gilchrist West geotube on November 15, 2001.

Pirates Beach geotube on November 15, 2001. Geotube at this location was routed seaward of the house, creating 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.

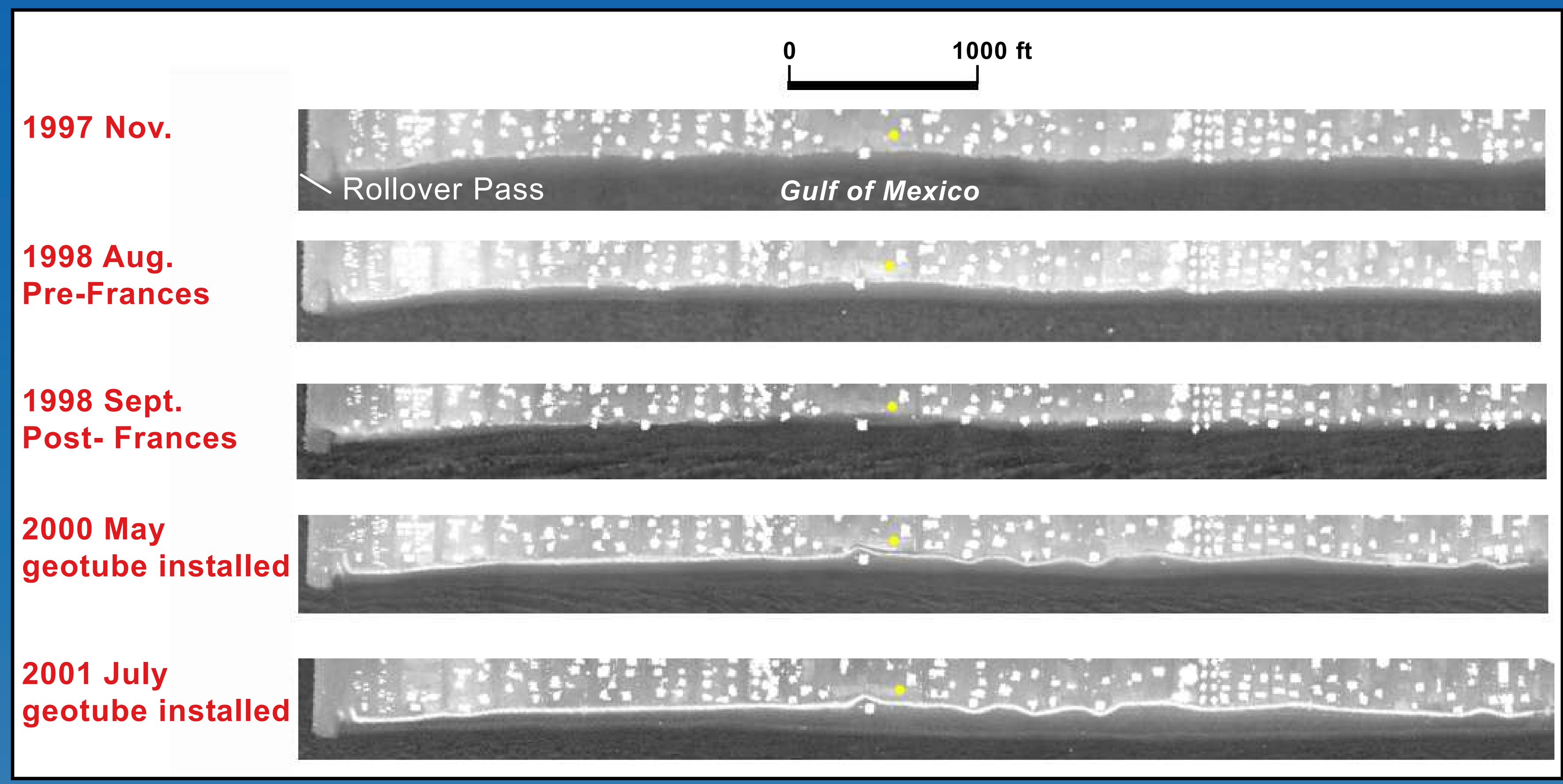
EFFECTS ON BEACH/DUNE ENVIRONMENT

The geotubes 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. 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. The beaches in front of the geotubes are significantly narrower than they would be if the geotubes and houses seaward of the natural line of vegetation were not there (see table below); thus the public's use of the beach may be diminished.

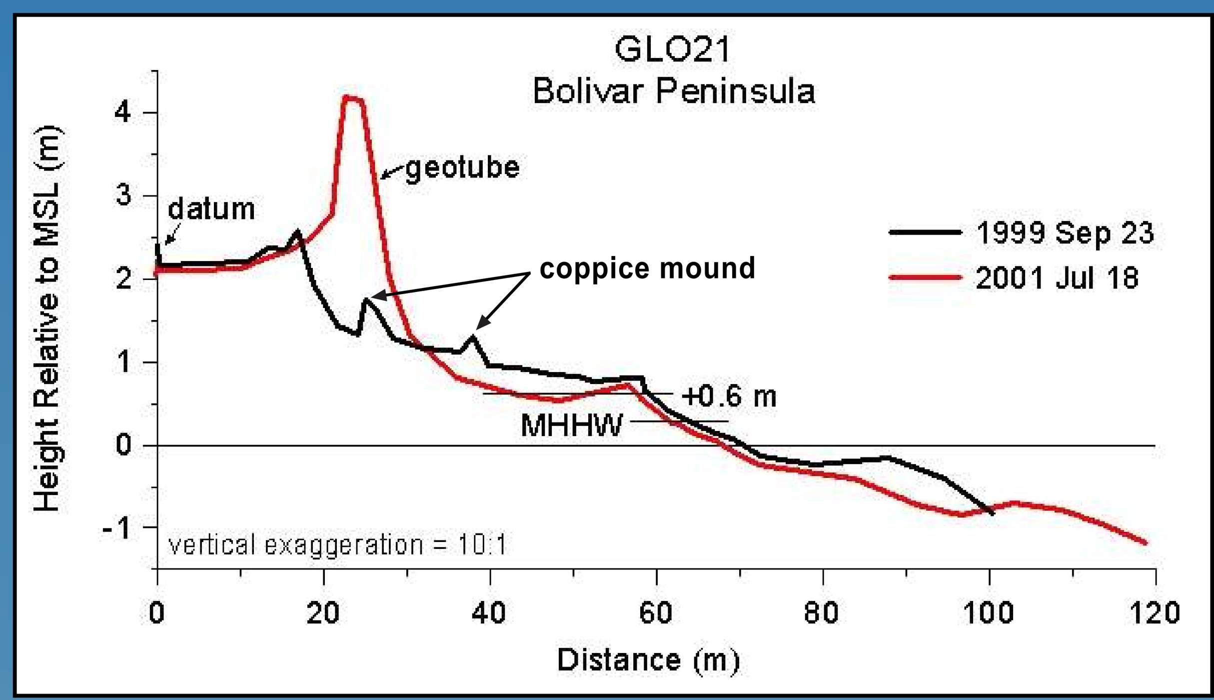
Coppice mounds at GLO06 profile location in Galveston Island State Park on September 18, 2002. This subenvironment of wind-blown sand and sparse vegetation was eroded but survived Tropical Storm Fay.

Pirates Beach geotube at GAL02 profile location on September 18, 2002. This geotube was uncovered following Tropical Storm Fay. Note lack of coppice-mound subenvironment when compared with the GLO06 profile location.

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.



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 the overall geomorphic impact of the project and how the geotube was routed around some houses.



Beach profiles at a location in the Gilchrist West project area before and after geotube installation. Note coppice-mound subenvironment before geotube installation and the unnatural morphology of the geotube.

Comparisons of beach width in front of and adjacent to geotubes July 17, 2001.

	Minimum width (ft)		Average width (ft)		
Project	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

CONCLUSIONS

1. Geotubes will fail when exposed to direct wave attack, making them useful for only short-term erosion control. 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.

2. Keeping the geotubes repaired, covered with sand, and vegetated requires a significant effort. Moderate tropical and winter storms can erode the sand cover, exposing the seaward face of the geotubes. Approximately 5 yd^3 per linear yard of beach length is required to recover the geotubes. Keeping them vegetated has, for the most part, not been possible.

3. Beaches in front of the geotubes are narrower than adjacent beaches. This is because the geotubes were installed farther seaward than the natural landward boundaries represented by the line of vegetation, foredunes, or bluffs and because the beaches have eroded in front of them.

4. 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 ft (0.30 m) above mean higher high water. Outflows from street-drainage pipes erode channels perpendicular to the beach that at times hinder passage along the beach.

5. The geotubes along the upper Texas Gulf coast have altered the natural geomorphology and sedimentology 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. 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, nor does it exist in front of the geotubes because the beaches are not wide enough to provide dry sand for wind transport or to prevent waves or salt spray from inundating the back beach.

6. 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.

7. 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 maintain the geotubes and to mitigate adverse effects on public beaches.

For more information see the Geotubes Monitoring Web Site at www.beg.utexas.edu/coastal/geotube.htm.

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