Evaluation of coastal response to Hurricane Ike through pre-storm and post-storm aerial photography

By

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ABSTRACT

Hurricane Ike was one of the most damaging hurricanes to strike the United States. The destruction along the upper Texas coast is documented by pre-storm and post-storm aerial photographs taken by the author. The damage on Bolivar Peninsula was severe; two towns were completely destroyed, and all other towns were severely damaged. Other than the seawall protecting the city of Galveston, only parts of the central Texas coast from North Padre Island to Matagorda Peninsula are protected by significant foredune ridges. The meager foredune ridges along the Texas coast from Freeport to the Louisiana border were destroyed, and the barrier islands and peninsulas were overwashed. Many homes were left standing on the beach seaward of the probable recovery vegetation line. They will likely have to be removed under state law and the Texas Open Beaches Act, which gives the public a permanent easement to the beach below the vegetation line. Construction setbacks requiring new structures to be built further back from the vegetation line and the beach should be considered. New rules should prohibit moving sand from the upper beach or dunes. The foredune ridges which serve as a natural dune seawall must be protected and enhanced.

ADDITIONAL KEYWORDS: Bolivar Peninsula, Galveston, Surfside, Caplen, Gilchrist, Follets Island, Rollover Pass, Matagorda, Aransas, Mustang Island, Port Aransas, Crystal Beach, beach erosion.

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It was truly a dark and stormy night when Hurricane Ike roared across Galveston Island, TX. "Hurricane Ike made landfall over the eastern end of Galveston Island just after 2 a.m. on Saturday, 13 September 2008 as a Category 2 hurricane on the Saffir-Simpson scale. The storm then tracked northward across Galveston Bay. Ike was very large as it moved across the Gulf of Mexico and made landfall, with tropical storm force winds (39 mph) extending 275 miles outward. Ike's large wind field contributed to storm surge values well in excess of those normally associated with a category two storm" (National Weather Service (NWS) Houston/Galveston 2008) (Figure 1, Figure 2).

Damage on Galveston Island, the landfall site, was high; but the greatest damage occurred on the Bolivar Peninsula where more than 3,600 homes were totally destroyed (pers. comm., Ray Newby, Texas General Land Office). "Towns on the Bolivar Peninsula were heavily damaged by wind and storm surge, with an estimated 80-90 percent of the homes in the communities of Crystal Beach, Gilchrist and Caplen destroyed. The level of destruction, relative scarcity of water marks, and the damaging high surf component on top of the surge, make it difficult to estimate surge quantitatively. Harris County Flood Control District reported high water marks in the 12- to 16-foot range. NWS survey teams found some indication that water reached the 20-foot level in a few places, due to surge but also possibly due to waves on top of the surge. The tide gauge at Rollover Pass on the eastern part of the peninsula measured a water level departure or storm surge of 11.06 feet and was rising at 05:48 UTC, or 12:48 a.m. CDT, just before the time it stopped reporting at 1 a.m. CDT ... From available data, (sic) would estimate surge of 12-16 feet on the Bolivar Peninsula, and possibly higher in spots… High water marks from HCFCD survey on Galveston Island were generally in the 10-13 foot range, which was consistent with estimates from the NWS survey. Surge values were generally closer to 10 feet over the West End, and in 12 to 13 feet over eastern portions of the island" (NWS Houston/Galveston 2008). The surge reached about 6-8 ft at Surfside Village (Figure 3). The tide records from the Texas Coastal Observation Network gauges show the water levels recorded along the coast. The Galveston, Rollover, and Sabine Pass gauges ceased functioning at about 8 ft, 10 ft, and 11 ft above Mean High Water (MHW) respectively (Figure 4).

The United States Geological Survey (USGS) classifies storm-induced coastal change into categories of increasing severity as follows (USGS 2008):

Beach erosion: Where waves and currents remove sand from the beach system.

Dune erosion: Waves attack the front face of the dunes and reduce the volume, width and elevation of the dunes. This leaves property behind the dunes more vulnerable to future storms.

Overwash: Waves wash over the dunes (or seawalls) and sand is transported inland across the island. This can result in significant damage to coastal property.

Inundation and island breaching: The island is completely submerged by the storm surge. Strong currents during the flood or ebb of the surge may carve channels across the island, breaching it.

PRE-STORM AND POST-STORM PHOTOGRAPHS

Towns on Bolivar Peninsula, including Crystal Beach, Caplen, and Gilchrist, were inundated and severely overwashed by Hurricane Ike. Gilchrist, just east of Rollover Pass (inlet), and Caplen, west of Rollover Pass, were located on the right front side of the hurricane at the position of the highest surge, estimated at 12-16

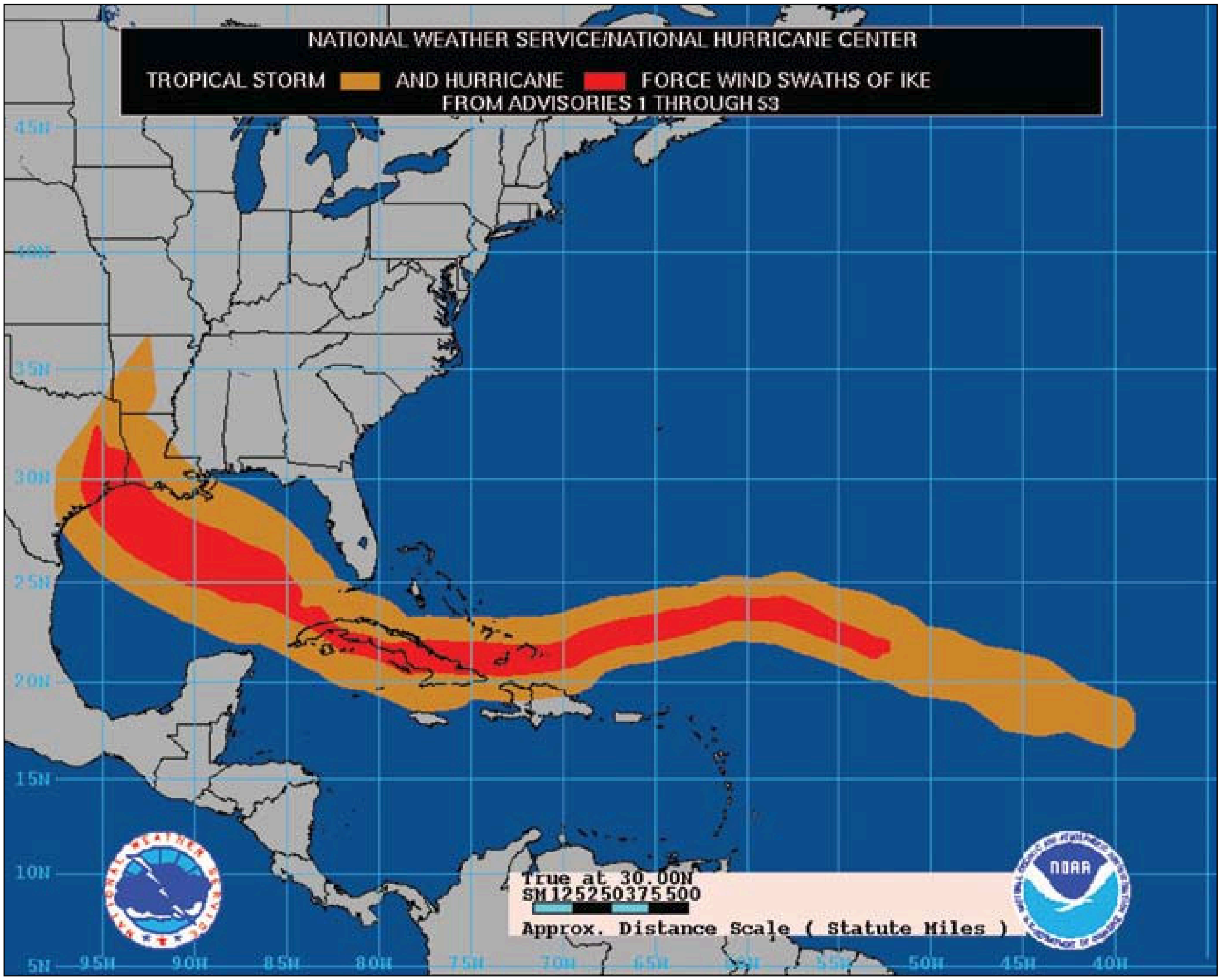

Figure 1. Hurricane Ike track showing landfall at Galveston, TX, and width of hurricane-force winds and tropical storm-force winds.

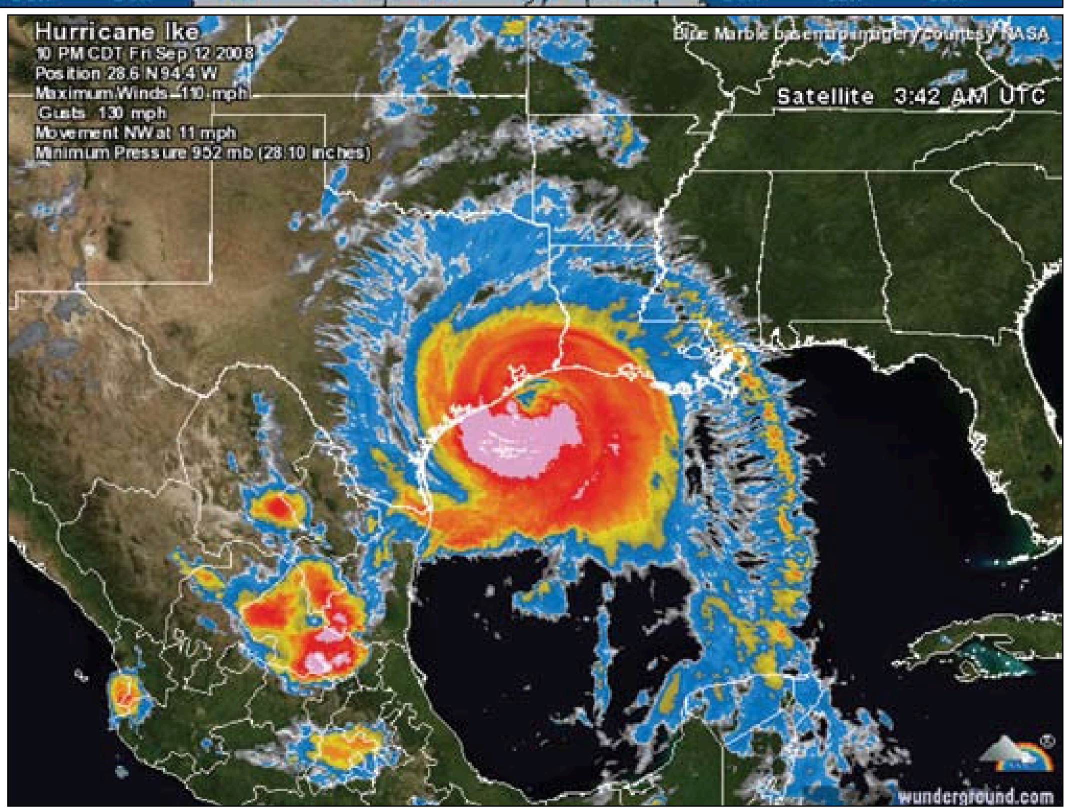

Figure 2. Satellite photo of Hurricane Ike just before landfall at Galveston, TX. Note the large diameter of the storm.

Figure 3. Location map for the upper (north of Freeport) and central Texas coast.

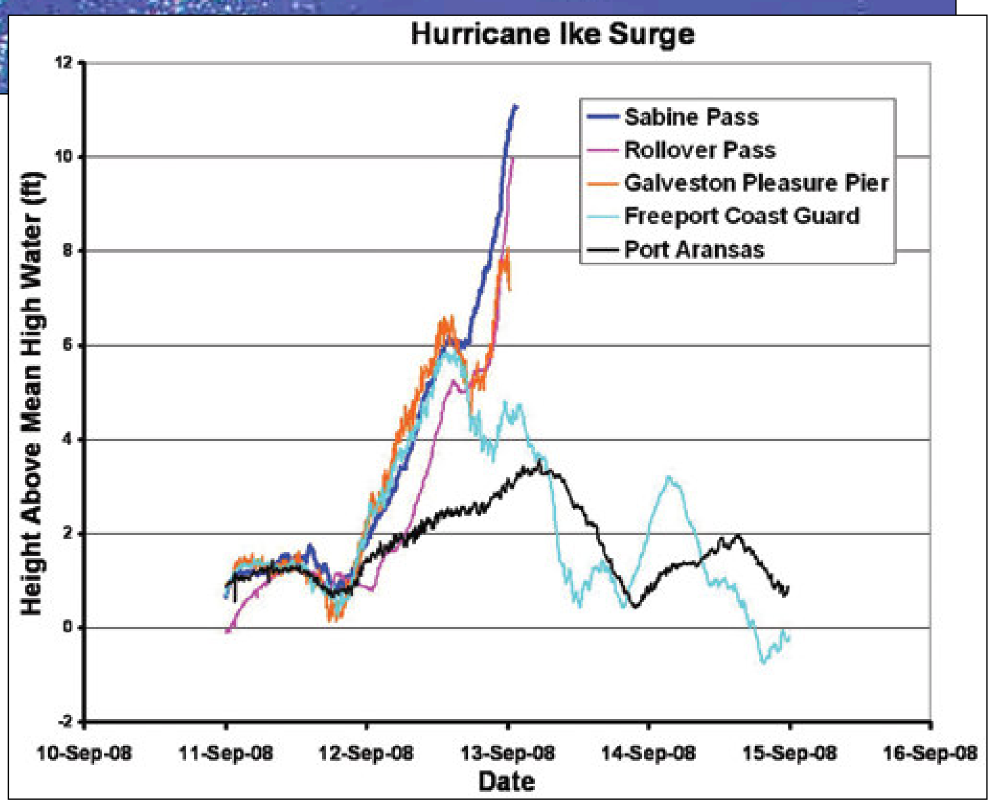

Figure 4 Hurricane Ike surge. (Data obtained from the Texas Coastal Ocean Observation Network, Division of Nearshore Research, Conrad Blucher Institute for Surveying and Science, Texas A&M University-Corpus Christi.)

ft and, probably, the strongest onshore winds. Figures 5 and 6 show Rollover Pass with the town of Gilchrist on the left and Caplen on the right before and after Ike. The inundation and overwash destruction was nearly complete, with only a few homes partially remaining. Only one house remains seaward of the road, and it was severely damaged (Figure 7). Remnants of geotextile tubes can be seen along the beach in the post-storm photographs. They gave no protection against Ike.

Crystal Beach, a much larger town than Gilchrist or Caplen, was severely overwashed with most of the homes in the first nine or 10 rows of homes destroyed (Figures 8 and 9). Like Gilchrist and Caplen, Crystal Beach had little in the way of dune protection.

Galveston has new high-rise buildings and homes being built on vegetated flats behind the low dune line and seaward of the seawall on the east end of the island (Figure 10). Ike had little respect for the low dunes and washed up to, and under, the new buildings (Figure 11.) However, overwash was not nearly as severe as on the Bolivar Peninsula.

Most of the city of Galveston has been protected from overwash by a substantial, long, and high seawall. It was constructed in response to the extreme damage by the 1900 hurricane that nearly completely destroyed the then-important port city. In addition, much of the land behind the seawall was raised with dredged material. The seawall protected the city behind it from frontal overwash by Ike, but much of the protected area was flooded from behind, causing severe damage, though much less than by the full force of frontal overwash. On an overflight only two days after Ike, we were surprised to see the streets were clear and there seemed to be little damage, except for debris along only two blocks of the seawall (Figure 12). This debris is all that remains of the famous Balinese Room, a night club which was built out in the Gulf on pilings seaward of the seawall.

On Galveston Island, west of the area protected by the seawall, there was beach and dune erosion, and damage to houses along the beach (Figures 13 and 14). Two days after storm passage, some of these houses were still standing in the edge of the water. Several of the houses on the right of Figure 13 were destroyed. There was little dune protection along Galveston Island west of the seawall. If Hurricane Ike had made landfall to the southwest of Galveston Island, the island would have been on the right front, dangerous semicircle of the storm, and damage on west Galveston Island would likely have been as severe as the damage to the much smaller towns on the Bolivar Peninsula.

Follets Island, just southwest of Galveston Island, is a narrow barrier island. The only road running along its length approaches the beach in several locations, and it is unprotected by any significant dune ridges or man-made structures. Ike breached the road in many locations and left homes on the beach, with some standing in the remains of hurricane outwash channels (Figures 15 and 16).

Surfside Village, located just northeast of the Freeport Entrance Channel, experienced severe beach erosion for many years. Even before Hurricane Ike, there were houses standing on the beach (Figure 17). Just weeks before Ike came ashore, the Texas General Land Office (TGLO) completed a low granite revetment landward of the homes shown in Figure 18 and along the very edge of Beach Drive, the road along the beach. Even though Ike removed nearly all of the remaining homes on the beach, the revetment protected Beach Drive from serious damage and probably helped protect the homes on the landward side of the road (Figure 18).

TEXAS OPEN BEACHES ACT AND HOME RECONSTRUCTION

Texas state law controls which structures can be rebuilt after a storm and which must be removed. The legal boundary between the private upland property and the state submerged lands is the Mean High Water (MHW) line, or the Mean Higher High Water (MHHW) line in some cases. The MHW line is defined as the average daily high water level for a period of 18.6 years as determined by water level recorders. So, if a storm moves the MHW line inland across all or a portion of private property, it becomes state-owned submerged land. In addition, the Open Beaches Act, which provides permanent public access to Texas beaches for all Texans, creates a public easement from the Mean Low Water (MLW) line up to the natural vegetation line. No permanent structures can be built or rebuilt seaward of the vegetation line, and any existing structures must be removed if the vegetation line moves landward (TGLO 2008b).

Hurricane Ike moved both the MHW line and the vegetation line landward. A great many homes and destroyed homes are now seaward of the vegetation line. Because the vegetation line may, in time, move seaward again, these structures do not have to be immediately removed. The TGLO surveyed a line which approximates the normal vegetation line at 4.5 ft NAVD88 (which is about 4.0 ft above Mean Sea Level (MSL) at Galveston) and has published the following temporary regulations.

"Property owners whose houses are completely or partially landward of the 4.5-foot elevation line may apply to the local government for a Beachfront Construction Certificate/Dune Protection Permit (Coastal Construction Permit in Galveston County) to fill the lots occupied by the houses to pre-Ike conditions up to the line. Generally, dunes may be restored up to 20 feet seaward of the 4.5-foot elevation line (Figure 8 and Figure 13). Property owners whose houses are completely seaward of the 4.5-foot line cannot fill lots to pre-Ike conditions, but may stabilize a house with sand or sand mixed with clay under Emergency Rule 15.20 (31 Texas Administrative Code § 15.20). The area of stabilization may extend no farther than five feet from the perimeter of the house. Repairs to make the house habitable may be permitted (TGLO 2008c)."

This regulatory guidance allows owners to make temporary repairs, but they may still be required to remove their structures in the future. The 4.5 ft. MSL "vegetation line" is plotted on high resolution, pre-storm and post-storm aerial photographs so that property owners can see how their property is affected (TGLO 2008d).

SUFFERING FROM MANMADE EROSION

Long-term mapping by the Bureau of Economic Geology of the University of Texas at Austin and the TGLO shows that the entire Texas Gulf coast is eroding, with the exception of a few areas protected by long navigation jetties, a few deltaic headlands, and a longshore drift convergence zone on Central Padre Island (Watson 1971; TGLO 2008a; Morton 1975, 1977, 1979; Gibeaut et. al. 1999). Seaward growth of multiple dune ridges on Galveston Island and other barrier islands and peninsulas shows that the shoreline was advancing in the recent past. However, long jetties constructed at Sabine Pass, Bolivar Roads (at Galveston), Aransas Pass (at Port Aransas), and other locations have permanently trapped and stored large volumes of beach sand on beaches directly updrift of the jetties and in the wave shadow of long down-drift jetties (Morton *et al.* 1983; Watson 1999, 2003). The east jetty at Galveston is holding about 30 million cu yd of sand. These jetty fillets have starved downdrift beaches of the amount of sand in storage.

Construction of reservoirs on the major rivers flowing to the Gulf has severely reduced new sand supply to Gulf beaches. Reservoirs on the Brazos River have reduced the sediment supply to only one-fourth of pre-reservoir conditions (Mathewson and Minter 1976; Seelig and Sorenson 1973). The Rio Grande River flow is frequently zero, and the river now supplies little sand. The Colorado River was diverted into East Matagorda Bay in 1992, and it no longer provides sand to the Gulf beaches.

The construction of Rollover Pass in the late 1950s has caused an annual loss of more than 200,000 cu yd of beach sand into Rollover Bay and the adjacent Gulf Intracoastal Waterway (GIWW) (Bales and Holley 1984, 1985, 1989; Watson 1999). Erosion on the Bolivar Peninsula in the vicinity of Caplen and Gilchrist would likely have been much less if 10-14 million cu yd of beach sand had not been lost through Rollover Pass and into the bay and GIWW since the pass was opened. Bayward sand transport is one of the main causes of severe ongoing beach erosion at Gilchrist and Caplen adjacent to Rollover Pass and has left the upper portion of the Bolivar Peninsula with few remaining sand resources (Watson 1999). This has left the upper Bolivar Peninsula poor in sand, with only a thin veneer of sand overlying outcropping marsh deposits (Watson 1999 and personal observations by the author, February 2009).

In 1928, the mouth of the Brazos River was moved from the Freeport Entrance Channel at Surfside 7 miles to the west. Relocation of the river mouth removed its sediment supply at Surfside and caused erosion of the old delta and the beaches at Surfside (Watson 2003).

The lack of new sand supply to the coast coupled with storage losses at jetties and huge losses through inlets such as Rollover Pass have made much of the coast much more vulnerable to damage from strong storms such as Ike. Beach, dune, and shore face sand lost due to erosion in past storms has not been replaced, and the shoreline retreat has been permanent. Before Ike, most of the Texas coast (with the exception of the Texas coast from central Padre Island to Matagorda Island) no longer had a foredune ridge system adequate to prevent severe frontal overwash during strong storms. After Ike, the coast from Surfside to the Louisiana border no longer has any dune protection at all (personal observation by the author, 2009).

STRONG, CONTINUOUS FOREDUNE RIDGES CAN PREVENT FRONTAL OVERWASH

The central Texas coast, including North Padre Island, Mustang Island, San Jose Island, and Matagorda Island have relatively wide, high, and continuous foredune ridges which provide overwash protection. These long, continuous, and sometimes multiple parallel dune ridges serve as a natural seawall and prevent overwash. Personal observations by the author for 40 years, both on the ground and over 900 hours of observation from the air indicate that these strong dune lines have not been breached in many decades and perhaps more than 100 years. There are no recent breaks except at the ends of these barrier islands. All of the relict washover fans behind these islands are subsiding and have not been active for a very long time. The feeder channels for those washover fans are long closed well inland of the dune ridges. During storms, the faces of these dune ridges are eroded by storm waves, and that sand flattens the beach profile and slows further wave attack. Except in the location of semi-permanent hurricane washover channels at the ends of these islands, these barrier islands have not been overwashed in a long time. Even Hurricane Carla in 1961 did not breach the dune lines on these barrier islands protected by very strong dune ridges. However, the beaches along these barrier islands are now erosional, and the beaches are narrowing. Beach narrowing will lead to more frequent storm attack on the protective foredune ridges and reduced probability of the dune ridge healing and rebuilding in the seaward direction during the time between major storms.

Port Aransas was far from storm landfall and located on the left side of the storm with offshore winds and a surge of less than 4 ft. During Ike, the wide beaches at Port Aransas, 175 miles southwest of Ike's landfall, provided some protection to the dunes, and the dunes suffered only minor erosion. Later on, the same storm deposited a berm on the upper beach next to the dunes and partly on the sand beach road. A few miles further south, the much narrower beach allowed direct attack on the dunes with much more dune erosion (personal observation by the author, September 2008). After Hurricane Rita (which made landfall north of Sabine Pass, TX, in September 2005) deposited a similar storm berm on Port Aransas beaches, the city convened a beach committee to study the problem. The TGLO hired an expert to study the problem of sand and seaweed management on Port Aransas beaches, and to work with the beach committee to establish best management practices. The expert final report recommends building a new dune ridge seaward of the foredunes and recommends against moving sand in a seaward direction (McKenna 2006).

On the Texas coast, only two natural processes supply sand to the foredunes. One is the long-term southeast wind blowing sand from the dry upper beach, and the other is storm berms that are formed from small or distant storms. As part of beach-maintenance operations, it would be better to deposit sand removed from the upper beach in front of the dunes, within, or landward of the foredune ridge to build the natural dune seawall stronger (McKenna 2006; Watson 2008). Previous large hurricanes (Carla, 1961) have eroded our foredune ridge back as much as 200 ft (Hayes 1967).

Despite the rapidly expanding development of barrier islands, it is critical for sand that is naturally transported toward the dunes (which will build the dune stronger) be allowed to remain on the upper beach or be placed within the dune system. Sand should not be mined from the upper beach and deposited on the lower beach or in the surf. A high, wide, and continuous foredune system acting as a sacrificial seawall can prevent or mitigate severe damage by overwash. Even though a strong dune system may be severely eroded by a hurricane, it can often buy enough time for the storm to subside before overwash occurs. The

Figure 5. Rollover Pass, with the towns of Gilchrist on the left and Caplen on the right before Hurricane Ike. Photograph taken by the author, 16 June 2006.

Figure 6. Rollover Pass, Gilcrest, and Caplen 15 September 2008, two days after Hurricane Ike. The towns are completely destroyed. Photograph by the author.

Figure 7. Only one house in Gilchrist in the upper center of the photograph remains standing post-Ike. Photograph by the author, taken 28 October 2008.

Figure 8. Crystal Beach, from Google Earth before Hurricane Ike. The Texas General Land Office (TGLO) 4.5 ft line is the estimated new vegetation line. Structures seaward of that line cannot be rebuilt.

Figure 9. Crystal Beach after Hurricane Ike. Many blocks of homes have been completely destroyed. Photograph by the author taken 28 October 2008.

Figure 10. East Beach Galveston January 2007. Photograph by the author.

Figure 11. East Beach Galveston 15 September 2008. Hurricane Ike destroyed the small dunes and the vegetation seaward of the condominiums. Photograph by the author.

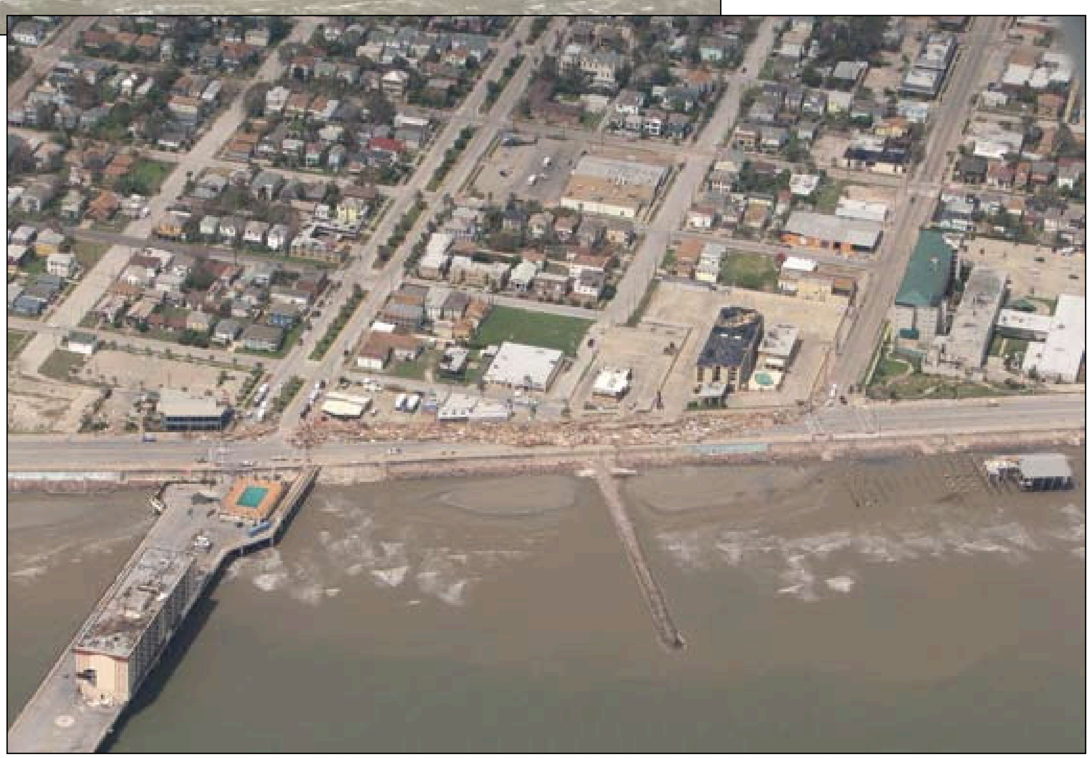

Figure 12. Remains of the Balinese Room (center of photograph) on top of the seawall. Note that the streets are clear and most of the structures behind the seawall are relatively undamaged. Photograph by the author, taken two days after Ike on 15 September 2008.

Hurricane Ike overwash damage to the upper Texas coast from Surfside to Louisiana would have been greatly reduced if that part of the coast had a natural dune system as strong as the dunes of the central Texas coast. Unfortunately the upper and lower Texas coasts had only low, narrow, and often discontinuous dune systems, sometimes enhanced with geo-textile tubes.

The state of Texas has clear dune protection rules. Nueces County controls beaches and dunes on North Padre Island and part of Mustang Island, by agreement with the TGLO. The county recently increased the construction setback to 350 ft landward from the vegetation line for new construction. This wise rule will delay storm attack on new structures on the eroding barrier island shoreline. Unfortunately, most of the coast has much narrower construction setbacks, and structures are permitted near the beach and vegetation line. Wider construction setbacks are needed on the coast, as evidenced by damage caused by Hurricane Ike, especially where the islands are low and narrow and have no significant dune protection.

CONCLUSIONS

Pre-storm and post-storm aerial photography shows the extreme destruction to the upper Texas coast by Hurricane Ike. The greatest damage was on the Bolivar Peninsula where two towns were destroyed by frontal overwash and inundation and other towns were severely damaged. Much of the city of Galveston was spared overwash by the presence of a high and sturdy seawall. Even so, much of the city was flooded from the bay, and damage was severe. West Galveston Island was partially overwashed and flooded with beachfront homes destroyed or damaged. Had the storm made landfall to the southwest of Galveston, rather than across Galveston, the island would have been on the dangerous semicircle of the storm and suffered much greater damage. Follets Island and Surfside Village were partially overwashed. The only access highway was cut in many places, and many homes were destroyed or left standing on the beach or in hurricane outwash channels. Further southwest along the coast, damage to structures was minimal and consists mostly of beach and dune erosion, as well as destruction of minor structures on the beach.

Most of the central Texas Coast, from North Padre Island to Matagorda Peninsula, is protected by high, wide, and continuous dunes. Had Hurricane Ike concentrated its energy there, the damage (while severe) would likely have consisted mostly of surge flooding from the back rather than frontal overwash and total destruction, as occurred on the Bolivar Peninsula. However, local governments have decided to remove sand deposited on the upper beach by Hurricane Ike and transport it to the lower beach and the edge of the water. That sand was enroute to the foredune ridges where it would further strengthen the strong dune system and provide even better future protection from hurricane overwash. After seeing Ike's damage on the Bolivar Peninsula, it is obvious that having the highest and widest natural dune system is the best possible protection from future storms where man-made seawalls are not present.

It would be wise for coastal communities to follow Nueces County's example and create construction set-back lines that are further inland from the beach and vegetation line. The Texas Gulf Coast is an eroding shore, and future storms are likely to cause further damage.

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Figure 13. West Galveston before Ike, from Google Earth. The TGLO 4.5 ft line is the estimated new vegetation line.

Figure 14. West Galveston Island two days after Ike. Some homes have been destroyed and others are still standing in the water. Photograph by the author taken 15 September 2008.

Figure 15. The only road running the length of Follets Island was cut here and in many other locations. Most channels across the beach were probably excavated by outwash of the surge flood. Photograph by the author, taken 15 September 2008.

Figure 16. Follets Island homes standing on the beach and in hurricane outwash channels. Photograph by the author, taken 15 September 2008.

Figure 17. Long-term erosion and shoreline recession have left many homes on the beach at Surfside Village even before Hurricane Ike. Another row of homes seaward of these was lost in recent years. Photograph by the author, taken 26 April 2007.

Figure 18. Surfside Village after Hurricane Ike. Most of the homes that were on the beach were destroyed. Photograph by the author, taken 28 October 2008.