CHAPTER EIGHTEEN

Hurricane Alicia
Storm Surges And Shore Processes

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Abstract

Hurricane Alicia moved inland over the Texas coast during the night of August 17, 1983 creating waves and surges in the Gulf of Mexico and adjacent bays. Waves eroded beaches and dunes and surges overtopped low-lying areas of barrier islands and inland areas adjacent to the bays behind the barriers. A three-day survey of field evidence of water levels and flow directions was carried out one week after the storm. Physical evidence, such as the elevation of debris lines, water marks in buildings and debris caught on fences was used along with additional data from tide gages operating in the area to estimate the maximum flood levels and flow directions associated with the storm. Before and after aerial photography was used to obtain data on beach recession, retreat of the vegetation line behind the beach and extent of overwash deposits. The evidence gathered shows that the barrier islands were overtopped from front-to- back in some areas and from back-to-front in other areas with quite different results. There was little or no beach erosion to the left of the storm as it came ashore; however, serious beach erosion occurred for 18 miles (29.0 km) to the right of the storm and there was significant erosion for 55 miles (88.5 km) to the right of the storm. Maximum water levels in the Gulf, including the effects of normal tides and storm effects, were 9 to 11 feet (2.74 to 3.35 m) and maximum water levels along the nothern portion of Galveston Bay were 11 to 14 feet (3.35 to 4.27 m).

Introduction

Hurricane Alicia made landfall near the western end of Galveston Island (Figure 1) during the predawn hours of Thursday, August 18, 1983. At landfall, the storm was a little above average in size and intensity with highest winds near 100 miles per hour (44.73 m/second). The area of high winds covered most of Galveston Island and extended eastward along Bolivar Peninsula. High storm water levels and waves overtopped western Galveston Island, Galveston's East Beach and the front of western Bolivar Peninsula. Surges also created high water levels in the bays behind the islands. Waves and surges modified beaches and dunes creating overwash deposits and cutting channels through dunes. This paper presents and discusses field and other evidence of the magnitude and effects of Alicia's waves and water levels.

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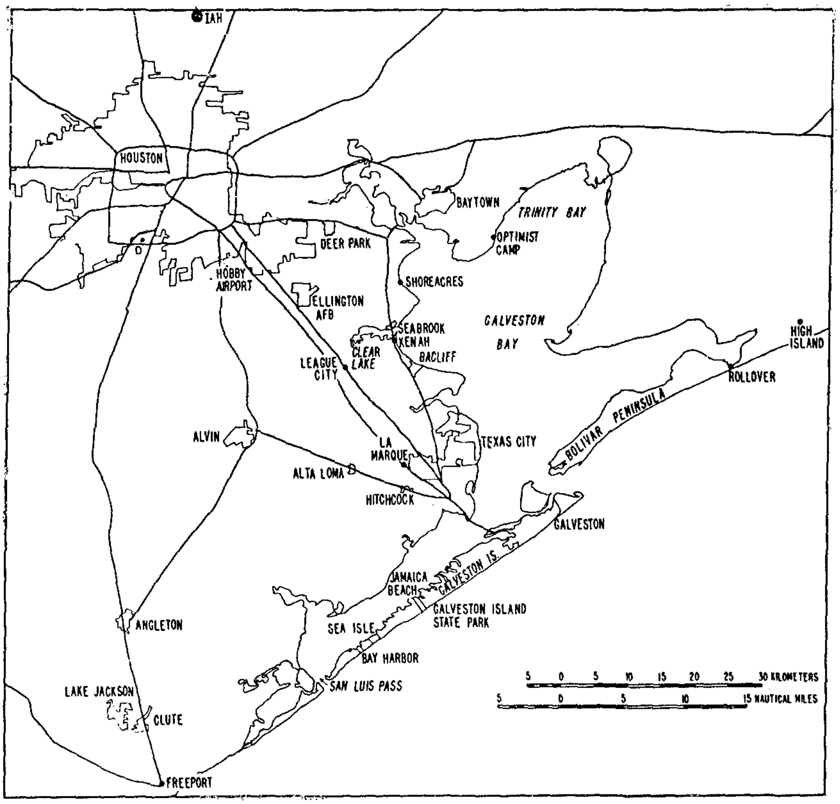

Figure 1. The Houston - Galveston area of Texas

Data Collection

Storm Water Levels

Water level estimates were obtained from field evidence gathered during a field survey on 23, 24 and 25 August (Savage et al. 1984). Field observations included water marks in buildings, debris lines, beach and dune changes, overwash deposits and scour marks. Unless otherwise noted, all elevations refer to the National Geodetic Vertical Datum (NGVD).

Watermarks in closed buildings are good indicators of maximum water levels that do not include the effects of wave action. However, during the field survey, watermarks were difficult to distinguish, probably because the flood waters contained little or no sediment. No water marks were observed on the outside of buildings, and water marks inside buildings were composed of bits of vegetation, including seeds. Debris lines, usually composed of loose vegetation, were common and were usually a clear, though not precise, indicator of maximum water level. Where their height spanned the flood level range, fences were also a good indicator of maximum water level because bits of floating vegetation were caught by the individual fence strands. Thus the line between bare and "clothsline" strands clearly indicated the maximum water level. Estimates of water levels from water marks, debris lines and fences were made by visually estimating the distance of the evidence above the ground level. The elevation of the ground level was obtained from the 7.5 minute series of topographic quadrangle sheets (quad sheets) published by the U. S. Geological Survey (USGS). Maximum water level estimates are probably accurate to plus or minus 1.5 feet (0.46 m). Water level estimates were also obtained from operating tide gages. NOAA maintains two gages in the immediate Galveston area and other gages at Freeport and Sabine Pass, however the Sabine Pass gage did not operate during Alicia's landfall. Other gages, operated by companies, The Corps of Engineers, and Civil Defense Offices were operating in the area affected by the storm (U. S. Army Corps of Engineers, Galveston District, 1984).

Shore Processes

Estimates of horizontal beach, dune and vegetation line changes were obtained from aerial photographs taken before and after the storm by NOAA. The "before" set (nominal scale 1 to 40,000) was taken on October 15, 1982 and November 5, 1982. The "after" set (nominal scale 1 to 30,000) was taken on August 24, 1983, seven days after storm passage. Ground measurements between points visible on the aerial photographs were made from Geological Survey (GS) quadrangle sheets and used to establish scales for individual photographs. Data was scaled from the photographs along selected lines, usually along streets perpendicular to the beach, using a scale divided into 600 parts/foot (1962 parts/m). Though individual measurements were estimated to a tenth of the smallest division, ground distance errors as large a plus or minus 30 feet (9.14 m) are possible. Measurements were made from the cross street nearest the beach to the feature of interest. Horizontal features measured were the high water line, the vegetation line just behind the beach and the scarp line where a scarp existed.

Storm Water Levels and Flow Patterns

Maximum water levels along the Gulf side of Galveston Island varied from 9 to possibly 11 feet (2.74 to 3.35) above NGVD. The NOAA tide gage on Pleasure Pier recorded a maximum water level of 9.0 feet (2.74 m) at 1:24 a. m. Central Standard Time (CST), August 18th (Figure 2). Since the peak of the storm surge occurred at high tide, which should have been at el. 1.7 feet (0.52 m), the storm surge portion of the high water level was about 7.3 feet (2.23 m). Observations along the front of Galveston Island during the field survey showed considerable overtopping of East Beach (a 3.5-mile (5.6 km) beach fronting the Galveston seawall just west of Galveston Inlet)

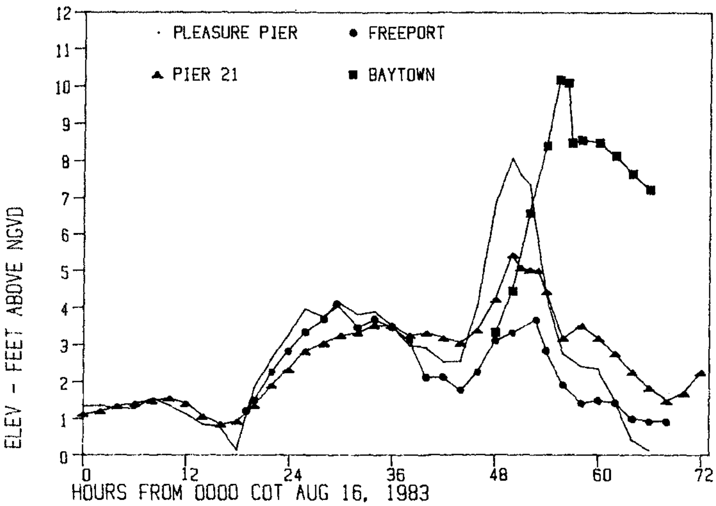

Figure 2. Tide hydrographs from gages at Baytown, Pleasure Pier, Pier 21, and Freeport during Hurricane Alicia. The reference level for the Baytown gage is mean sea level.

and the western portion of Galveston Island all the way to San Luis Pass. Maximum water levels along the back of Galveston Island varied from 6 feet (1.82 m) to as much as 9 feet (2.74 m). The NOAA tide gage on Pier 21 in Galveston Channel (behind Galveston) recorded a maximum water level of 5.8 feet (1.77m) at 2:12 a. m. CST on August 18th (Figure 2). Observations along the back of Galveston Island indicated that the maximum water level was generally not more than 1 to 2 feet (0.31 to 0.62 m) above the land level - estimated at 5 to 7 feet (1.52 to 2.13 m) from quadrangle sheets. Maximum water levels along the back of the island increased from about 6 feet (1.82 m) at the eastern end of the island to about 9 feet (2.74 m) 3 miles (4.8 km) east of San Luis Pass. To the west, water level elevations exceeded 10 feet (3.05 m) in the bays behind Follets Island.

Along the front of East Beach, the beach was overtopped by 2 to 4 feet (0.62 to 1.24 m) of water which then flowed landward toward the seawall. When the overtopping water reached the seawall, it turned eastward and ran over the shoreward part of the north jetty into Galveston Inlet. The higher dunes on the front of East Beach were not overtopped, but were partially eroded while acting as headlands that created accelerated flow and scour channels in low areas between dunes (Figure 3). Observations along the front of Galveston Island west of the seawall showed that the front of the island had been overtopped by a foot (0.31 m) or more of water along most of the island length. Two areas not overtopped, a half-mile (0.8 km)

Figure 3. View toward Gulf showing channel cut by overtopping Gulf water on East Beach. Note vegetation along back of beach, showing cut did not extend through beach, and beginning of outwash fan that forms the landward end of the cut.

section about one-half mile (0.8 km) east of Galveston Island State Park and a two and one-half mile (4.0 km) section eastward from Sea Isle (Figure 1), had dunes higher then 10 feet (3.05 m) in elevation. In other areas, debris lines on fences and against embankments and dunes along the highway indicated maximum Gulf water elevations of 8 to 11 feet (2.44 to 3.35 m), including the effects of wave action. Evidence of water flow across the body of the island from the bay toward the Gulf began about 3 miles (4.8 km) east of San Luis Pass. Otherwise, all evidence pointed to water flow from the Gulf toward the bay.

Follets Island is immediately west of Galveston Island across San Luis Pass. Only the eastern eight and one-half miles (13.7 km) of this island were covered by the ground survey. In this area, flow evidence was remarkably consistent - water flowed only from the bays toward the Gulf. Maximum water elevations in the bays were about 10 feet (3.05 m) or more. Maximum water level evidence consisted of debris lines on the bay side of the dunes at distances of 1.5, 2.0, 4.5, 7.5 and 8.5 miles (2.4, 3.2, 7.3, 12.1 and 13.7 km) from the eastern end of the island and a stranded houseboat between the highway and the dunes fronting the Gulf at the 4.5 mile (7.3 km) point. Evidence for flow direction was the location of debris lines on the bay side of the dunes, the location of the grounded houseboat and the characteristics of several cuts through the dunes and body of the island between the highway and the Gulf (Figures 4-6).

Figure 4. Aerial view of cut formed by Gulfward flowing water on Follets Island.

These cuts started at the beach and ended seaward of or at the highway; however, one cut extended completely through the highway and other cuts ended in the highway pavement (Figures 4 & 6).

Bolivar Peninsula lies eastward across Galveston Inlet from Galveston Island. Only the first 11 miles 17.7 km) of the Peninsula were surveyed during the ground survey. The 3 miles (4.8 km) of the island immediately east of Galveston Inlet is low with maximum elevations of 6 feet (1.83 m) or less. East of this point, a relic dune ridge rises near the middle (front-to-back) of the island and extends eastward to Caplen (1.5 miles (2.4 km) west of Rollover Pass - Figure 1) where the dune ridge joins the dunes behind the beach. Maximum elevations of the dune ridge vary from 9 to 11 feet (2.74 to 3.35 m). Debris lines on fences, scour adjacent to the highway and the way the grasses were bent showed that the first 5 miles (8.1 km) of the road along the Peninsula had been overtopped by water flowing from the Gulf toward the sound. Evidence of overtopping ended abruptly where the road rose from the lower elevation to cross and run behind the relic dune ridge. Thus, water levels in the Gulf along the western part of Bolivar Peninsula were higher than 6 feet (1.83 m), but lower than 10 feet (3.05 m).

Figure 5. Gulfward view of Follets Island cut showing erosion of dunes behind beach. Highway pavement is in foreground.

Figure 6. Landward end of a Follets Island cut showing undercutting of road pavement.

Study of the aerial photographs of Bolivar Peninsula taken after the storm showed that the front of the western 17 miles (27.4 km) of the Peninsula had been overtopped by the Gulf storm surge. Though water flowed accross the western 3 miles (4.8 km) of the Peninsula, the relic dune ridge running from the center (front-to-back) of the Peninsula at the 3-mile (4.8 km) point to the beach at Caplen caused the overtopping water to pond between the Gulf frontal dunes and the relic dune ridge. When the water level in the Gulf dropped, the ponded water flowed back into the Gulf through a series of low points (at least 4) in the frontal dunes creating cuts accross the beach and through the frontal dunes similar to those on Follets Island (Figure 4). However, the cuts were different in that they were triangular - wide at the beach and narrow inland - presumably because the cutting flow rates dimenished as the level of the ponded water level dropped.

Only two mainland areas adjacent to Galveston Bay were covered by the ground survey - Seabrook and the Texas City hurricane flood protection dike, both on the western side of the Bay. The debris line on the Texas City dike was low on the front of the dike indicating maximum water levels there of about 5 feet (1.52 m). At Seabrook, along Todville Road, scour in the yards of houses and damage to structures showed water levels had been at least 3 feet (0.93 m) above the ground level. In the Baytown area, tide gage records (Figure 2) and debris line measurements showed maximum water levels of 10 to 11 feet (3.05 to 3.35 m).

Shore Processes

A total of about 70 miles (112.7 km) of coastline are covered by the aerial photograph measurements; about 55 miles (88.6 km) to the east (right) of the storm and about 15 miles (24.2 km) to the west (left) of the storm. No measurements were made in front of the Galveston seawall or just east of Galveston Inlet. Results of the measurements are presented in Table 1 and Figures 7-9 where the inland direction is positive. Change in the high water line and vegetation line is shown in columns 2 and 3 of Table 1 for the distances in column 1. Columns 4 and 5 contain data only where a beach or dune scarp existed after the storm. The change in high water line (column 2) is a rough measure of beach retreat during the storm. The measure is rough because the data (aerial photographs) were taken about a year apart and some of the change may have occurred before the storm. In addition, the measurement technique could result in errors of 50 feet or more in the change figures. The meaning of the change in the vegetation line (column 3) varies with conditions after the storm at the measurement point. In overwash areas the change in the vegetation line measures the magnitude of both erosion and overwash. Where there was beach and dune erosion that ended in a scarp, the change in the vegetation line is a measure of the beach and dune recession (column 4). In some areas overwash deposits extended inland from scarps. In these cases, the horizontal magnitude of both the beach and dune erosion and the overwash deposits (column 5) were defined.

TABLE 1. Changes in Beach and Nearshore Features From High Island Westward to Freeport Inlet.

Location	Distance From Storm Center-Miles	Change in Water Line (feet)	Change in Vegetation Line (feet)	Erosion of Vegetation Line (feet)	Overwash (feet)
High Island	55.5	-38	18	---	---
	53.5	-92	24	---	---
	52.6	23	26	26	0
		32	193	---	---
	49.4	49	250	---	---
	48.4	-9	146	---	---
Rollover Pass	48.2				
	47.7	-21	208	---	---
Caplen	46.7				
	46.4	118	208	---	---
	45.0	-22	136	55	81
	43.6	-62	86	---	---
	42.0	101	116	---	---
Crystal Beach	39.1	62	67	16	51
	37.1	21	31	15	16
Flake	35.3				
	34.8	-18	92	62	30
Galveston Seawall extends from 18.9 miles to 28.5 miles					
	17.9	13	238	134	104
	16.9	102	171	161	10
	15.9	91	210	75	135
	14.7	128	156	80	76
	13.1	151	177	152	25
State Park	12.3				
Jamaica Beach	11.4	166	233	65	16
	11.1	127	194	107	87
	10.0	144	164	---	---
	8.7	108	61	61	0
	8.3	108	70	70	0
	7.5	48	114	73	41
	6.5	145	145	---	---
Sea Isle	6.1				
	5.7	77	138	---	---
	5.1	172	1,058	---	---
	4.6	182	245	91	154
Bay Harbor	4.4				
	4.3	168	310	79	231
	2.9	166	141	89	52
	2.2	195	170	88	82
	1.6	110	146	28	118
San Luis Pass	0.0				
	2.1	-30	45	---	---
	3.5	-58	8	---	---
	5.5	-58	-21	---	---
	7.5	-51	---	---	---
	9.1	9	---	---	---
	11.2	-6	-11	---	---
	12.5	78	16	---	---
	13.4	-35	-4	---	---
Surfside Beach	13.9	-33	55	---	---
	14.5	-3	28	---	---
Freeport Inlet	14.7				

A striking aspect of the high water line changes is the abrupt change where the center of the storm crossed the coast. Recession prevailed to the right of the storm and accretion to the left of the storm. The demarcation at the center of the storm is a strong indication that the large, erosive waves generated by the onshore winds to the right of the storm during the nearshore storm surge were closely confined to the area of the strong onshore winds. A second, somewhat unexpected result, is the advance of the high water line immediately to the left of the storm. Two phenomena could account for this. First, flattening of the beach profile by the storm could shift the high water shoreline seaward even though there had been volumetric erosion of the beach and dunes. Second, from Figure 4 it is apparent that considerable beach accretion (50 feet (15.24 m) or more) occurred after the storm, but before the photograph was taken. Since the Figure 4 photograph was taken on August 26 and the aerial photographs were taken on August 24, it is likely that the accretion is included in the beach change measurements. If so, similar accretion is probably included in the high water line change measurements to the right of the storm. Thus, the column 2 figures probably underestimate the beach recession by as much as 50 feet (15.24 m).

The largest recession rates occurred just to the right of the storm center and measured recession of 100 feet (30.5 m) or more extended up to 17 miles (27.4 km) to the right of the storm center where the Galveston seawall starts. There was little or no beach in front of the seawall either before or after the storm and no measurements were made there. While recession of more than 100 feet (30.48 m) was measured on Bolivar Peninsula, not many points changed that much. Recession appeared to be tapering off at High Island, 55 miles (88.6 km) to the right of the center of the storm.

Changes in the vegetation line generally followed the pattern of high water line changes. Changes in the vegetation line were larger because the vegetation line can be changed by both erosion (the vegetation is carried away) and overwash (the vegetation is buried). The largest change in the vegetation line (over 1000 feet (304.8 m)) was measured at Terramar Beach. From both the ground survey and the photographs, it was obvious that most of this change was caused by overwash which buried the vegetation under up to three feet of sand. On western Galveston Island, the vegetation line receded over 100 feet (30.48 m) at all points where measurements were made except for two adjacent points between Jamaica Beach and Sea Isle. The ground survey showed that this area was one of the limited areas not overtopped by the storm surge on western Galveston Island. Vegetation line retreat was over 200 feet (60.96 m) at three of the measurement points on Bolivar Peninsula and over 100 feet (30.48) at three others, but tapered off in the vicinity of High Island, 55 miles (88.6 km) to the right of the center of the storm.

Figures 7-9 present the Table 1 data as averages over 5-mile (8.1 km) intervals along the coast. The number of measurements used in 5-mile (8.1 km) intervals varies from none along the seawall, accross Galveston Inlet and the western portion of Bolivar Peninsula to as many as 7 along part of western Galveston Island.

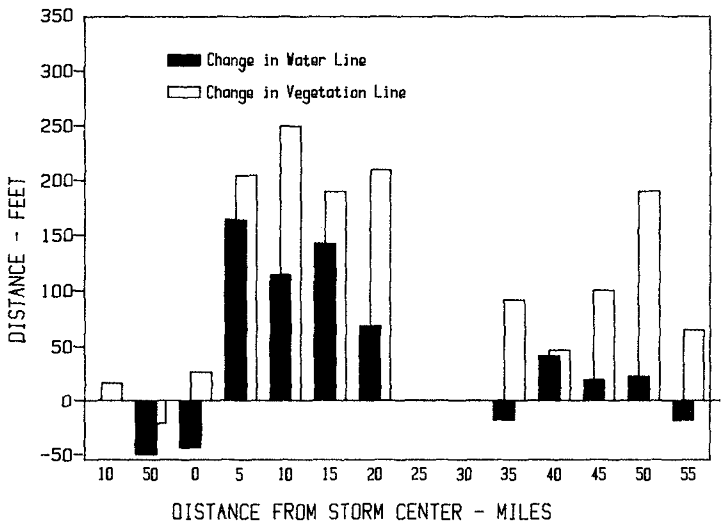

Figure 7. Change in high water line compared to the change in the vegetation line.

Beach and dune erosion and the width of overwash deposits could be measured separately where a scarp existed. A scarp was common along western Galveston Island, uncommon along Bolivar Peninsula and non-existent in the measurements made to the right of the storm center. Where measured separately (Figure 8), beach and dune recession on western Galveston Island averaged 90 feet (27.43 m) with a maximum of 160 feet (48.76 m). Overwash deposit widths on western Galveston Island that could be measured separately (Figure 9) averaged 87 feet (26.52 m) with a maximum of 154 feet (46.92 m).

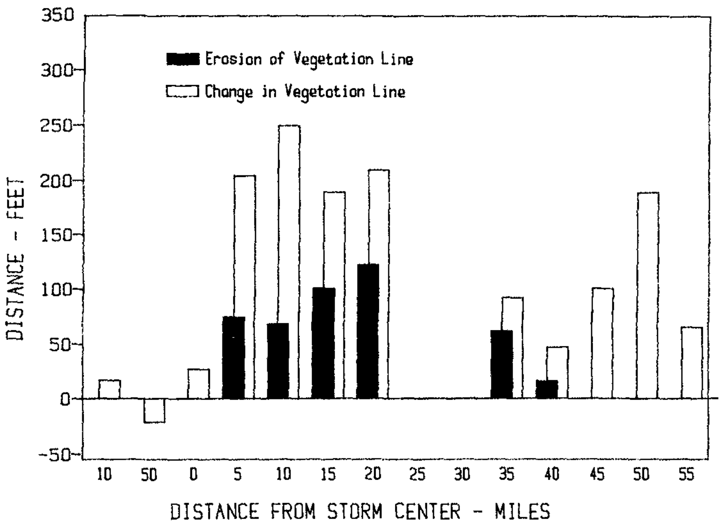

Figure 8. Erosion of vegetation line as shown by erosion scarps compared to the total change in the vegetation line.

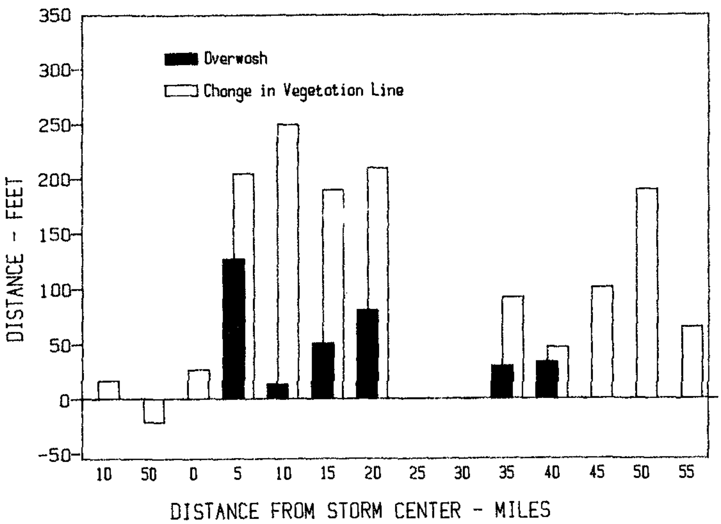

Figure 9. Width of overwash fans landward of erosion scarps compared to the magnitude of the change in the vegetation line.

Conclusions

Coastal Surges

1. Storm water levels in the Gulf of Mexico reached a maximum level of 9 to 10 feet (2.74 to 3.35 m) in the area from the west jetty of the Galveston entrance westward to and just past Bay Harbor on western Galveston Island, a distance of about 25 miles (40.3 km). Maximum water levels decreased slowly with distance both eastward and westward of this central area.

2. Maximum water levels in East and West Bays just behind Bolivar Peninsula and Galveston Island were generally 6 to 7 feet (1.83 to 2.13 m). However, in the Bays behind Follets Island, water levels increased reaching elevations of from 8 to 10 feet (2.44 to 3.05 m).

3. Maximum water levels around the west side of Galveston and Trinity Bays reached elevations ranging from around 8 feet (2.44 m) near Texas City and Baycliff to between 10 and 11 feet (3.05 to 3.35 m) in the Baytown area.

4. With the exception of the 9.5-mile (15.3 km) section protected by the Galveston seawall, almost all of Galveston Island was overtopped by a foot or more of water from the Gulf of Mexico. East Beach, in front of the Galveston Seawall, was overtopped by 3 to 6 feet (0.91 to 1.83 m) of water.

5. Follets Island was overtopped by the high water level in the bays behind the island from San Luis Pass to within 4 miles (6.4 km) of the Freeport entrance channel. This overtopping from bays-to-Gulf cut more than 30 distinctive channels starting at the beach, through the frontal dunes, toward, to, and in some cases into, the highway running behind the beach.

6. The western 3 miles (4.8 km) of Bolivar Peninsula was overtopped by water from the Gulf of Mexico. East of that point the front of the Peninsula was overtopped, with water ponding between the foredunes behind the beach and a relic dune ridge inland on the island. When the Gulf surge retreated, the ponded water ran back into the Gulf, cutting at least four large, triangular channels through the frontal dunes and beach.

Shore Processes

1. A striking aspect of the shore processes during the storm was the strong demarcation between high-water line recession to the right of where the center of the storm crossed the coastline, and high water line advance just to the left of the storm center.

2. Retreat of the high-water line on western Galveston Island, measured from before and after aerial photographs, ranged from about

15 feet (4.57 m) near the seawall to almost 200 feet (60.96 m) near San Luis Pass. Along most of the beach from Jamaica Beach westward, retreat was more than 100 feet (30.48 m). At Terramar Beach and westward, high-water line recession was 170 feet (51.82 m) or more.

3. The vegetation line retreated more than 1,000 feet (304.8 m) at Terramar Beach, with an average retreat of 200 ft or more on western Galveston Island.

4. On Follets Island, the mean high-water line advanced an average of about 30 feet (9.14 m). Vegetation line retreat was small, usually less than 25 feet (7.62 m).

5. There was serious retreat of the high-water line (100 feet (30.48 m) or more) for the first 17 miles (27.4 km) to the right of the storm and significant retreat (20 feet (6.10 m) or more) for at least 55 miles (88.6 km).

6. Changes in the vegetation line generally followed the pattern of changes in the high-water line, but vegetation line changes were larger because they were a result of both erosion and overwash.

7. There was a marked difference in the frequency and appearance of scour cuts made in areas where water flowed from Gulf to bay as opposed to areas where water flowed from bay to Gulf. Where water flowed form Gulf to bay, there were few scour cuts and the cuts that were found were short and shallow, starting behind the beach and ending in an outwash deposition fan. Where water flowed from bay to Gulf, cuts were frequent and deep and it appears that if flow had continued long enough, scour would have cut completely through the island.

Acknowledgements

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