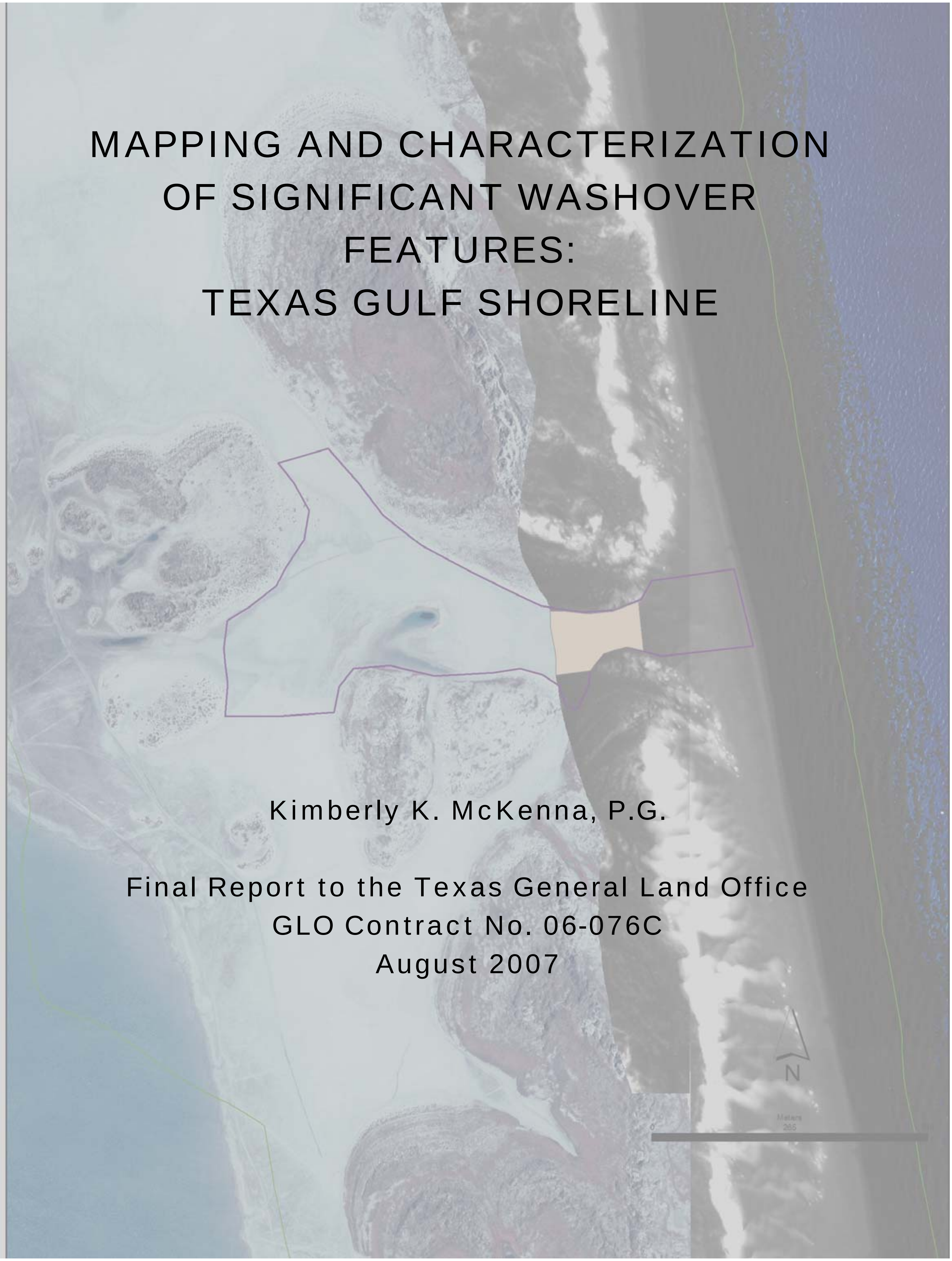


MAPPING AND CHARACTERIZATION OF SIGNIFICANT WASHOVER FEATURES: TEXAS GULF SHORELINE

Kimberly K. McKenna, P.G.

Final Report to the Texas General Land Office
GLO Contract No. 06-076C
August 2007

TASK IV DELIVERABLE
FINAL REPORT TO THE TEXAS GENERAL LAND OFFICE

GLO Contract No. 06-076C, Work Order No. 1348-07-001
August 2007

MAPPING AND CHARACTERIZATION OF SIGNIFICANT WASHOVER FEATURES, TEXAS GULF SHORELINE

Kimberly K. McKenna, P.G.
P.O. Box 9586
Newark, Delaware 19714
k.k.mckenna@comcast.net

EXECUTIVE SUMMARY

Washover areas along the Texas Gulf of Mexico shoreline have low elevations and are vulnerable to flooding during storms. Meteorological data, including information on wind, storm surge and other parameters were compiled for nine significant storms for further evaluation for impacts to five *Priority Areas* along the Texas barrier island shoreline. The areas in order of priority include: A. South Padre Island; B. Follets Island; C. Mustang Island; D. West Galveston Island; and E. East Matagorda Peninsula. Aerial photography was reviewed for each of the *Priority Areas* surrounding the storm time period. A list was compiled that shows the aerial photographic data sets that best represent the storm for a particular *Priority Area*, and (98) 9X9 aerial photographs were chosen for scanning and georeferencing.

This study delineated washover areas for the five *Priority Areas* and summarizes data sources that are available for evaluating overwash processes that impact the Texas Gulf shoreline. These washover areas were digitized from May 2006 aerial photographs and included in a GIS data layer. This washover area data layer was compared to previous washover area locations researched by the BEG and USGS and many of the washover areas identified in this study are found in similar locations as those previously described. However, because this study identified the main indicator as discontinuity (or break) in the foredune, this study found slightly fewer washover areas in general than the previous studies. A reason for the difference in the number found was that the May 2006 aerial photographs contained greater vegetation coverage than those used in the previous works.

LIDAR elevations were used to compare elevations of the identified washover area throats. Though the LIDAR data did not reach entirely across the barrier island, the information was helpful in obtaining high resolution elevations of the throat (from the line of vegetation to the landward limit of the foredune). Many of the throat elevations were below three feet (1 meter) (NAVD88) with the lowest elevations occurring on East Matagorda Peninsula and South Padre Island, and the highest elevations occurring on Follets Island and Mustang Island.

CONTENTS

	Page
Project Overview and Goal	1
Project Tasks	1
Background	3
Hurricanes and Barrier Island Responses	4
Previous Research	6
Data Collection	9
Hurricane Data	9
Aerial Photography	9
Mapping Washover Areas	11
LIDAR	12
Results	15
Priority Areas	16
Aerial Photographs and Storm Data Sets	23
Discussion	26
Conclusions	29
Recommendations	29
Acknowledgements	30
References	30

ILLUSTRATIONS

1. Locations of Priority Areas.	3
2. Tracks of the nine hurricanes evaluated for this study.	6
3. Washover area terminology used in this report.	8
4. Example of *stats_washover* layers the landward limit coinciding with the 2005 LIDAR elevations.	13
5. BEG washover areas compared to those mapped in this study.	15
6. Washover areas on for South Padre Island.	17
7. Washover areas on Follets Island.	18
8A. Washover areas on Mustang Island.	19
8B. LIDAR elevations on Mustang Island.	20
9. Washover areas on Galveston Island.	21
10. LIDAR elevations on Galveston Island	22
11. Washover areas on East Matagorda Peninsula.	24
12. Comparison of low area within the foredunes on South Padre Island defined using aerial photographs and LIDAR-generated elevations.	27
13. Air temperatures and precipitation for May 2006.	28

TABLES

1. Hurricanes that made landfall on the Texas coast between 1940 and 2006. 5
2. Meteorological data for hurricanes included in this study. 10
3. Elevations of the throats of washover areas included in this study. 14
4. Available aerial photography for study of washover areas. 25
5. Climate information for May 2006. 28

APPENDICES

Appendix A. Significant Storm Event Data
B. Photographic Data Sets
C. Listing of Georeferenced Aerial Photographs
D. Metadata Generated Under This Scope of Work
E. Mapped Washover Areas
F. Washover Area Centerline Locations

FINAL REPORT TO THE TEXAS GENERAL LAND OFFICE
GLO Contract No. 06-076C, Work Order No. 1348-07-001
August 2007

MAPPING AND CHARACTERIZATION OF SIGNIFICANT WASHOVER FEATURES, TEXAS GULF SHORELINE

Kimberly K. McKenna, P.G.
P.O. Box 9586
Newark, Delaware 19714
k.k.mckenna@comcast.net

PROJECT OVERVIEW AND GOAL

During a storm surge and/or extreme high tide event, the low-lying barriers of the Texas Gulf of Mexico shoreline are susceptible to overwash (the movement of water and beach sand from the beach face to back barrier environments). The features resulting from this process are known as *washover areas*. Washover areas are common along the Texas Gulf Coast in undeveloped regions as well as in communities with growing populations and structural development. Flooding and overwash can also occur from the bay or lagoon side. This process is known as washout and is dependent upon the amount of precipitation and the direction of storm winds. Current regulations do not deter development in what could potentially be flood hazard zones in low lying washover areas or washouts (Texas Administrative Code 31, §§15.1-15.36). It is for that reason that coastal managers be aware of their locations. The purpose of this study is to compile storm and aerial photographic information that can be used to determine areas of probable overwash during coastal storms. Existing washover areas in specifically chosen *Priority Areas* along the Texas Gulf shoreline are delineated and included in a geographic information system (GIS) database.

PROJECT TASKS

Task 1. Compile aerial photographic and topographic data sets.

This task included the review of the following data sets:

a. available LIDAR (for providing local topography);
b. available digital aerial photography (obtained from GLO, TNRIS, USGS, NOAA, NASA);
c. available printed aerial photography (obtained from GLO, TNRIS, local governments – scanned, saved in digital format, and georeferenced);
d. applicable Texas Coastal Hazards Atlas data (obtained from BEG);
e. washover hazard area gis data set (obtained from GLO); and
f. review existing literature relative to the project.

These data sets were inventoried and characterized by *Priority Area* for usefulness relevant to the study of washover areas. Available aerial photographs were scanned and georeferenced (98 total). For many of the *Priority Areas*, immediate (within 2 weeks) pre- and post-storm aerial photographs were not available, thus an evaluation of changes in washover area size and percent change in vegetative cover was not completed under this investigation.

Task 2. Compile significant storm data.

This task included the compilation of the following data:

a. sustained wind;
b. maximum deepwater wave heights;
c. storm surge elevations;
d. significant wave height, wave direction, wave period peak for storm conditions and tide levels during the storm's duration;
e. Saffir-Simpson category; and
f. point of landfall and distance from the priority location.

These data sets were compiled for Hurricanes Carla (1961), Cindy (1963), Beulah (1967), Celia (1970), Allen (1980), Alicia (1983), Bret (1999), Claudette (2003), and Rita (2005). Unfortunately, not all of the data are available. Detailed meteorological and coastal conditions for each storm are included in Appendix A.

Task 3. Determine the usefulness of the data sets for the purpose of characterizing washover conditions at each priority region.

Using the available information compiled in Tasks 1 and 2, the storm and aerial photographic data sets that best describe storm conditions for each *Priority Area* are found in Table 4. Washover areas were digitized from 2006 digital aerial photographs and georeferenced. Mean elevations of washover area throats were determined from LIDAR.

Task 4. Final report.

The final report presented here includes an analysis of the data obtained in Tasks 1, 2, and 3. Figures showing the digitized and georeferenced locations of washover areas are included for each *Priority Area*. Due to time constraints, changes in washover area morphology and vegetation coverage through time, was not completed under this investigation. However, a centerline was included for all mapped washover areas to represent a baseline feature from which future changes in vegetation coverage may be measured.

BACKGROUND

Five areas (*Priority Areas*) on the Texas Gulf coast were recommended by staff of the Texas General Land Office (GLO) for investigation of the impacts of hurricanes on overwash potential. These *Priority Areas* in priority order are (Figure 1):

A. SOUTH PADRE ISLAND;
B. FOLLETS ISLAND;
C. MUSTANG ISLAND;
D. WEST GALVESTON ISLAND; and
E. EAST MATAGORDA PENINSULA.

All of the *Priority Areas* are barrier beaches and dunes composed of predominantly fine sand; however, shell material and silts are not uncommon and their existence depends upon local antecedent deposits of the barrier and nearshore. Tidal range along much of the Texas Gulf coast is between 1.5 to 2 feet (0.46 to 0.61 m) and the tide is predominantly diurnal. Prevailing wind (and waves) is generally from the southeast, and when combined with local nearshore bathymetry, it generates wave heights of 2 to 6 feet (0.61 to 1.83 m) (McGowen, et al., 1977). However, tides, winds, and waves become elevated during tropical storms and hurricanes, and can impact areas miles away from a storm's landfall. For example, the tide, wind, and waves of Hurricane Allen, a Category 3 storm (Saffir-Simpson scale) that made landfall on August 10, 1980 at the southern tip of South Padre Island, were well above normal. The associated storm surge flooding occurred as far away as Galveston Island where the peak tide height was recorded at 4.5 feet above mean sea level (ft msl; 1.4 m msl) and inundation by overwash was measured up to 200 feet (61 m) landward of the line of vegetation (Morton and Paine, 1985).

Figure 1. Locations of *Priority Areas*.

HURRICANES AND BARRIER ISLAND RESPONSES

Hurricane intensity is rated by the National Oceanic and Atmospheric Administration (NOAA) National Hurricane Center according to wind speed and the Saffir-Simpson Scale (Simpson and Riehl, 1981). Hurricane intensity is a combination of the maximum sustained wind speed, minimum central pressure, and storm surge. Each rating provides an idea of potential damage to coastal areas during storms. Descriptions of potential impacts by category are provided by NOAA (2007).

Several notable hurricanes have made landfall on the Texas coast. Table 1 provides a list of storms that have made landfall within 25 nautical miles (46 km) of the Texas border. These storms have caused significant storm surges and severe beach and dune erosion (Hayes, 1967; Davis 1972; Morton and Paine, 1985). Hurricane Allen's elevated storm surge created numerous overwash channels on Padre Island (Suter, et al., 1982; Gundlach, et al., 1981) and storm surge from Hurricane Carla, in 1961, occurred throughout the Texas coast with bay shorelines experiencing 50% greater surge than along the Gulf (USACE, 1962; Treadwell, M. E., 1962; Simpson and Riehl, 1981; Ho, F. P., 1982; Bureau of Economic Geology, 2001).

For the purpose of this study, the nine hurricanes of interest are: Carla (1961); Cindy (1963); Beulah (1967); Celia (1970); Allen (1980); Alicia (1983); Bret (1999); Claudette (2003); and Rita (2005) (Figure 2). These storms were chosen for the availability of aerial photography with respect to *Priority Area* and the availability of storm meteorological and oceanographic data. Appendix A provides storm data assembled as part of this study. From those records, hurricanes show their variability in parameters such as winds and storm surge, among others. Many of the nine storms affected multiple *Priority Areas*.

Table 1. Hurricanes that made landfall on the Texas coast between 1940 and 2006 (NOAA, 2006). Some storms were classified as a Category 1 hurricane at the time of the advisory by NOAA even though the wind speeds do not reflect the appropriate range (74 mph to 95 mph). Hurricanes in bold were selected for further investigation for impacts to the *Priority Areas*. ND = No data provided.

Year	Month	Day	Name	Wind Speed (mph)	Pressure (mb)	Category
1940	8	8	NOT NAMED	70	972	H1
1941	9	23	NOT NAMED	70	ND	H1
1942	8	21	NOT NAMED	65	ND	H1
1942	8	30	NOT NAMED	95	ND	H2
1943	7	27	NOT NAMED	75	ND	H1
1945	8	27	NOT NAMED	120	966	H4
1947	8	24	NOT NAMED	70	ND	H1
1949	10	4	NOT NAMED	115	ND	H4
1954	6	25	ALICE	70	ND	H1
1957	6	27	AUDREY	125	946	H4
1959	7	25	DEBRA	70	984	H1
1961	**9**	**11**	**CARLA**	**125**	**931**	**H4**
1963	**9**	**17**	**CINDY**	**65**	**997**	**H1**
1967	**9**	**20**	**BEULAH**	**140**	**931**	**H5**
1970	**8**	**3**	**CELIA**	**110**	**945**	**H3**
1971	9	10	FERN	70	988	H1
1980	**8**	**10**	**ALLEN**	**110**	**935**	**H3**
1983	**8**	**18**	**ALICIA**	**100**	**963**	**H3**
1986	6	26	BONNIE	75	995	H1
1989	8	1	CHANTAL	70	984	H1
1989	10	16	JERRY	75	983	H1
1999	**8**	**22**	**BRET**	**100**	**951**	**H4**
2003	**7**	**15**	**CLAUDETTE**	**75**	**982**	**H1**
2005	**9**	**24**	**RITA**	**100**	**935**	**H3**

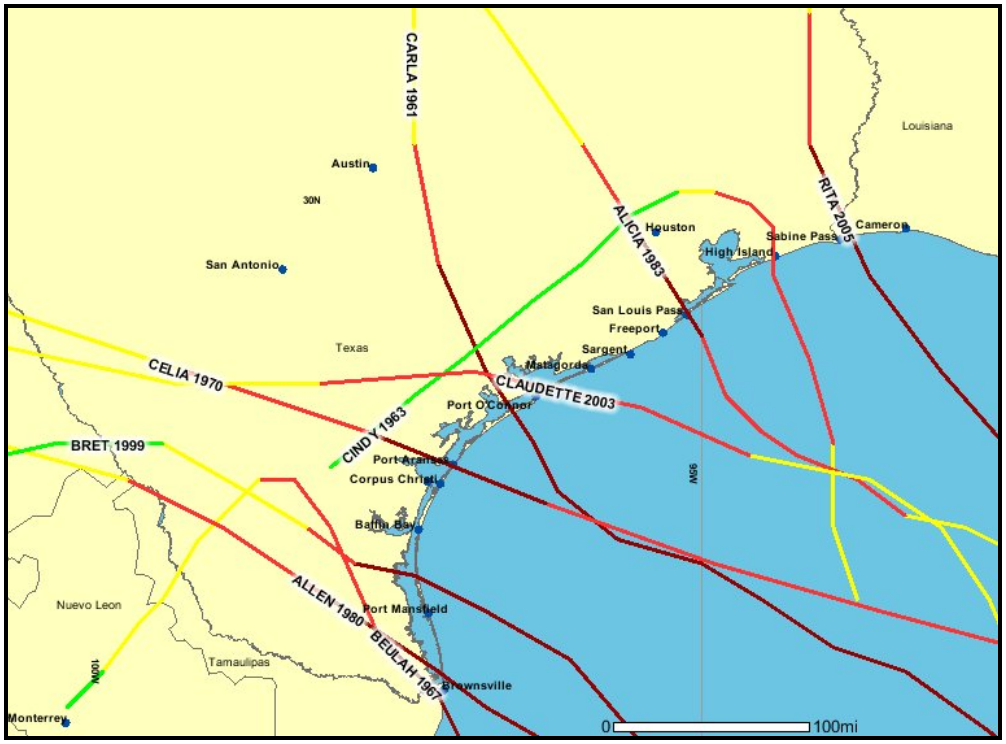


Figure 2. Tracks of the nine hurricanes evaluated for this study. Storm tracks are color coded by Saffir-Simpson scale: maroon = Category 3 to 5; red = Category 1 to 2; yellow = tropical storm; and green = tropical depression (NOAA, 2006).

PREVIOUS RESEARCH

Pioneering research describing hurricane impacts and overwash conditions was conducted for the Texas Gulf coast by Hayes (1967). He studied coastal morphologic response to Hurricanes Carla and Cindy on Mustang Island, describing the erosion of foredunes and alterations to the beach profile as well as depositional elements of the shoreface. Davis (1972) described morphologic changes following Hurricane Fern. Overwash conditions and washover deposits were documented on Galveston Island following Hurricanes Carla, Allen, and Alicia (Morton and Paine, 1985). Follets Island was described as completely submerged during Hurricane Carla (Anderson, 2007). Scott, et al. (1981), Gundlach, et al. (1981), and Giardino, et al. (1984) described the physiographic changes to Padre Island following Hurricanes Beulah and Allen.

Morton and Sallenger (2003) described both depositional and erosional elements associated with washover areas. The processes that create the physiographic changes during large storms are overwash, dune erosion, and channel incision. The features that result can be both depositional and erosional. Depositional elements found on the lagoon side are perched fans (deposited above the normal profile), washover terrace (deposited parallel to shore) and sheetwash lineations (bedforms parallel to the direction of flow). These sediments are carried through the lower elevations or breaks between the dunes by the rushing water. Sand that is not transported landward can be deposited as overwash terraces along the Gulf side of the foredunes. Erosional elements are usually found on the Gulf side of the barrier island and include dune scarps and washover throats caused by channel incision. Erosion of the channels (washout) is generated by receding waters flowing Gulfward. Figures 3A and 3B provide the terminology used to describe the features related washover areas along the Texas Gulf shoreline. Features such as perched fans and sheetwash deposits are not easily discernible using aerial photography in South Padre Island, where these features from various washover episodes can grade into the wind-tidal flats adjacent to the Laguna Madre (Figure 3A). Field studies may be able to determine vertical and aerial boundaries between washover episodes.

In a review of overwash studies, Donnelly et al. (2006) determined that the number and shape of washover areas depend on the elevation of the beach crest, water level, wave height, and duration of a storm combined with backbeach morphology, vegetation, and wind strength and direction. Morton and Sallenger (2003) evaluated flow conditions and sediment volumes that influenced washover deposition along sections of the Texas Gulf shoreline following Hurricane Carla and Hurricane Alicia. They compared patterns of washover penetration by correlating storm intensity, morphological storm impacts and inland sediment transport distances, and determined that morphological responses and washover penetration distances are primarily controlled by water level and the duration of storm surge.

Washover areas have been studied along the Texas Gulf shoreline using remote sensing methods. Light Detection and Ranging (LIDAR) was used by the BEG to measure elevation changes on Matagorda Peninsula and map 45 potential washover channels (Gibeaut et al., 2000). LIDAR is an important tool to use in measuring topographic changes and is available for use in a GIS by the GLO but it does not cover the entire barrier island (GLO, 2007b). Donnelly and Sallenger (2007) have used LIDAR elevations along with lateral spreading angles, infiltration rates, and overwash throat widths in a model to predict subaerial barrier evolution, including the destruction of dunes, lowering of the beach crest, and landward deposition of sediment.

Breaching of the dunes and barrier islands can occur during hurricanes from the seaward and lagoonward directions. From the seaward side, storm surge elevation (including wave setup and runup) and duration, and tidal range are key factors in determining breach susceptibility (Kraus, et al., 2002). Breaching from the lagoon side is influenced by the amount of precipitation that falls during the storm. Texas has a higher breach potential than Atlantic and Pacific beaches because of a smaller tidal range, and barriers and dunes with lower elevations. Models are in development to measure overwash runup and breaching (Donnelly, et al., 2004; Larson, et al., 2004).

Coastal vulnerability and hazards studies have been completed for the Texas coast by the US Geological Survey (USGS) and the BEG (BEG, 2001; Gibeaut et al., 2000; Gibeaut and Tremblay, 2003; Morton and Peterson, 2005; Gibeaut et al., 2006; Morton and Peterson, 2006a; Morton and Peterson, 2006b). The USGS Coastal Classification Map series portrays geomorphic conditions at various locations along the Texas coast during a non-storm period. The data presented in this report complement previous research by investigating the landward extent of overwash and estimating the areas and elevations of washover areas in the *Priority Areas* chosen by the GLO.

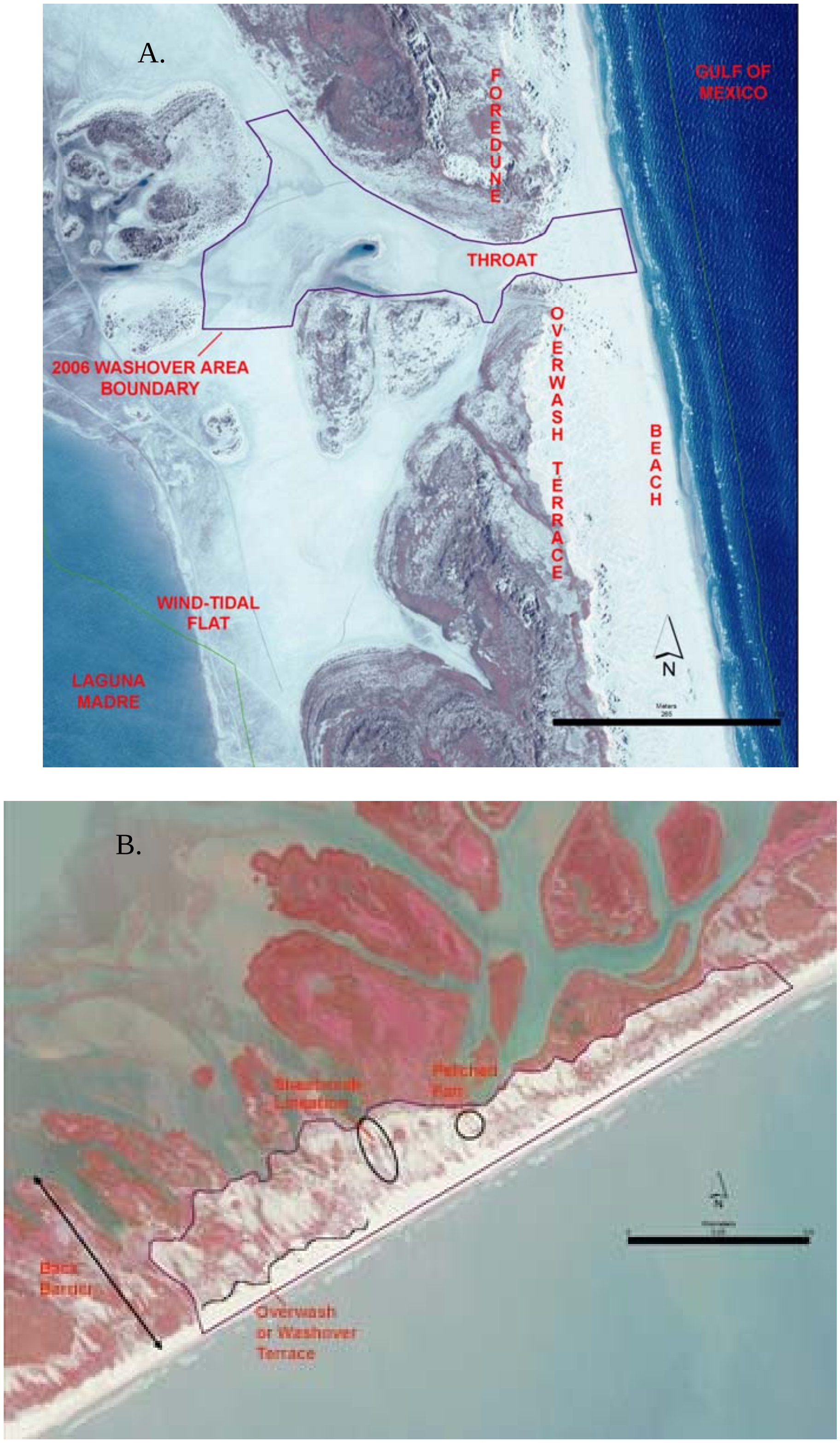


Figure 3. Washover area terminology used in this report. A. An example from South Padre Island. Base photograph from May 2006 courtesy of GLO (2007a.). B. An example from East Matagorda Peninsula. Base photograph from 2004 courtesy of TNRIS (2007).

DATA COLLECTION

Hurricane Data

Storm data were compiled for nine storms (Table 1) from offshore buoys, local tide gage, WIS hindcast, and NOAA observational reports. These data are presented in Appendix A (*Significant Storm Data*). Storm datasets include information on: a. sustained wind; b. maximum deepwater wave height; c. storm surge elevation; d. significant wave height, wave direction, wave period peak for average and storm conditions, and tide level during the storm's duration; e. Saffir-Simpson category; and e. point of landfall and distance from the *Priority Area*. A list and maps of the closest tide gages and NOAA buoys nearest to the priority locations are also provided in Appendix A. Table 2 summarizes the nine storm datasets that best describe extreme storms for the five *Priority Areas*.

Of the nine storms, the most complete storm data are available for: Hurricanes Allen (1980) and Bret (1999) for South Padre Island and Mustang Island; Hurricanes Alicia (1983) and Rita (2005) for Follets Island and Galveston Island; and Hurricane Claudette (2003) for East Matagorda Peninsula.

Aerial Photography

A task of this project was to review vertical aerial photography available from the Texas Natural Resources Information System (TNRIS) and GLO archives for the purpose of identifying pre- and post-storm data sets that best describe extreme events for each *Priority Area*. Appendix B provides the dates of aerial photographic data sets, where the data sets are housed, if they cover the appropriate *Priority Area*, and if they are available as georeferenced GIS-compatible data layers. Much of the more recent aerial photography (post 1996) is in digital format from TNRIS or the GLO. The indexes providing film roll numbers and locations of the photos can be found at http://www.glo.state.tx.us/coastal/photos/index.html. Some of the digital photos are georeferenced and available from TNRIS at http://www.tnris.state.tx.us/datadownload/download.jsp. Some of the aerial photography was not available in digital format. Individual 9X9-inch black and white frames were scanned using an Epson Expression 1640XL backlit scanner at 600 dots per inch (dpi) and saved in .tif format. The following sets of paper and film aerial photographs were scanned and georeferenced under this investigation. However, they were not used to compare changes in vegetation cover.

Date	Priority Area
8/13/1968 and 7/23/1980	A. South Padre Island
1/8/1962	B. Follets Island
2/23/1999 (already in digital format-georeferenced only)	D. West Galveston Island
8/13/1978; 8/15 -17/1978; and 10/30/1978 2/15/1991	E. E. Matagorda Peninsula

Individual aerial photographs are listed in Appendix C, and the digital georeferenced photographs are provided on an external hard drive. Appendix D includes metadata for georeferenced aerial photographs.

Hurricane	Beulah	**Allen**	**Bret**	Cindy	**Alicia**	**Rita**	Carla	Celia	**Claudette**
Category	5	3	4	1	3	3	4	3	1
Year	1967	1980	1999	1963	1983	2005	1961	1970	2003
Available Data									
Peak Wind (mph)	160 (e)	138	98	74	96	76.3	170	150	89.7
Sustained Wind (mph)	na	55	47	na	na	63	>150	125	71.3
Maximum Deep Wave Height (ft)	na	22.64	27	na	na	20	na	na	18.2
Storm Surge Height (ft)	na	12	8 to 10	na	12	5	18.5	na	3 to 6
Wave Height (ft)	na	22.64	27	na	21.8	15.4	na	na	18.2
Wave Direction	na	NE	SE	na	SE	NW	na	na	E
Peak Wave Period (sec)	na	14.3	11.11	na	12.5	16	na	na	10
Tidal Height (ft)	15	1.55	3.01	3.6	8.87	4.59	1.72	9.2	6.13
Tidal Datum	na	mllw	Mllw	mllw	mllw	mllw	msl	msl	mllw
Tide Gage Number	8778490	8778490	8775870	8771510	8771510	8771510	8775270	8775270	8773701
Buoy Number	na	42002	42020	na	42035, 42019 42010, 42011	42035	na	na	42019
WIS Station Number	na	32	32	na	67	67	na	na	53
Applicable Priority Areas	South Padre Island Mustang Island			Follets Island West Galveston Island			Mustang Island E. Matagorda Peninsula		

(e) - estimated; na - not available; mllw - mean lower low water; msl – mean sea level

Data Sources

NOAA	hurricane tracks	http://maps.csc.noaa.gov/hurricanes/viewer.html
NOAA	tide gage location map	http://tidesonline.nos.noaa.gov/geographic.html
NOAA	tide gage data (historical)	http://tidesandcurrents.noaa.gov/pub.html
NDBC	buoy data	http://www.ndbc.noaa.gov/measdes.shtml
NDBC	buoy location map	http://www.ndbc.noaa.gov/maps/WestGulf.shtml
USACE	WIS stations	http://frf.usace.army.mil/cgi-bin/wis/atl/atl_main.html

Table 2. Meteorological data for hurricanes included in this study. Hurricanes in bold text represent those with the best aerial photographic and meteorological data sets.

Mapping Washover Areas

Washover areas were digitized and georeferenced from the most recent data available. May 2006 aerial photographs and the Environmental Sensitivity Index (ESI) shoreline were used as the base GIS data layers for delineating washovers within the *Priority Areas*. These data are available from the GLO (2007a; 2007b). The ESI shoreline was created by BEG staff from U.S. Fish and Wildlife Service 1992 National Wetland Inventory digital files. It is the shoreline used by the GLO GIS staff for the Texas Gulf coast and does not include aerial photographs in the data layer.

The May 2006 aerial photographs provide the most complete coverage of all five *Priority Areas* in digital form. Using those aerial photographs, washover areas were digitized at a 1:1000 or 1:2000 scale using *ESRI ArcGIS v. 9.2* software. Comparisons were made to the ESI shoreline because it is generally considered to be the most accurate land/water interface for the Texas Gulf coast (GLO, personal communication). It portrays the 1992 average shoreline position.

A “washover areas” GIS layer was completed by the BEG from a review of vegetation coverage in 1992 aerial photography and videography and is available from the GLO (2007c). The BEG washover areas do not consistently align with the 2006 georeferenced aerial photographs at the large scale necessary for this study, and therefore served only as guides for delineating washover areas on the May 2006 photographs. Locations of washover areas identified by the BEG (GLO, 2007c) and USGS (Morton and Peterson, 2005; 2006a; 2006b) studies were compared to the May 2006 photographs (see *Results* section on East Matagorda Peninsula for exception). Washover areas presented in this report were located in many, but not all positions identified by the former studies. Here, using the May 2006 photographs, washover areas were identified from unvegetated former locations and digitized and measured for throat width and landward extent. The landward extent of the washover areas varied by *Priority Area* and site descriptions are provided in the *Results* section that follows. For example, complete overwash is predominantly found in South Padre Island where the foredunes are breached by storm surge and the sediments are carried over or deposited onto the tidal flats or in Laguna Madre. In the upper coast, the landward extent of the washover area is much less than on the lower coast, and rarely extends across the barrier with the exception of the sand flats at San Luis Pass and Mitchell’s Cut (see *Results* section for discussion).

Identifying Washover Areas: Criteria

Washover areas were identified and digitized from May 2006 georeferenced digital aerial photographs. The aerial photographs were taken prior to hurricane season, and it is assumed that the vegetation shown represents normal conditions. Because this study relied on aerial photography, washover area locations were determined from topographic features and by the absence of vegetation. In most areas of the Texas Gulf shoreline, washover areas commonly extend from Gulf to lagoon. However, there are many that are not as extensive. For example, unvegetated areas that adjoin Gulf-side ponds were also mapped as washover areas because there was a break in the foredunes and water landward of the break. The appearance of the ponds increases the potential for channeling floodwater from the Gulf (e.g. West Galveston Island).

Lateral boundaries of the washover areas were determined by the absence of vegetation in breaks within the foredune ridge. The landward terminus of the washover area followed the bare sand/vegetation demarcation and the Gulfward terminus was the boundary between wet and dry sand (shoreline). These unvegetated polygons represent the eroded beach, foredune, and channel and the deposition of a fan as the sediment was transported lagoonward during a storm surge. Sand flat areas adjacent to open inlets are also included as washover areas as these areas are prone to storm-surge flooding and are generally not vegetated.

Throat widths were measured parallel to the shoreline at the narrowest point between the foredunes. Landward extent was measured perpendicular to the shoreline from the shoreline to a landward point bounded by vegetation. Former washover areas identified by the BEG (GLO, 2007c) that were vegetated in the May 2006 aerial photographs were not classified as washover areas under this investigation because it is assumed that vegetated areas are better at trapping sand and include higher elevations.

A georeferenced centerline was added to each washover area polygon. The centerline was located through the center point of the washover area polygon and perpendicular to the shoreline shown in the May 2006 aerial photographs. The purpose of the centerline is to act as a baseline reference for measuring future changes in vegetation coverage. Due to time constraints, time-series changes in vegetation coverage and density were not completed in this investigation.

A list of washover areas identified in this study and their characteristics is provided in Appendix E. The locations of the centerlines (in UTM meters) are supplied in Appendix F.

LIDAR

Light Detection and Ranging (LIDAR) is a remote sensing method that provides location and elevation data for the creation of digital elevation models (DEM) that can show changes in topography. LIDAR data have been used to follow changes in shoreline position more accurately than previous methods (Stockdon, et al., 2002), for studying morphological changes to the Texas Gulf and bay shorelines (Gibeaut, et al., 2000; 2001; 2003a,b,c; 2006; Morton and Peterson, 2005; 2006a; 2006b) and for determining areas at risk for coastal flooding (Webster, et al., 2005). In a study by Gibeaut and others (2003c), topographic relationships of Matagorda Island habitats were quantified using LIDAR data and compared to ground transect elevations. The purpose of the study was to identify whether vegetation had an influence on the vertical accuracy of the digital elevation model. Dune vegetation is generally expected to create an upward elevation bias of about 4 to 8 inches (10 to 20 cm) (Gibeaut, personal communication).

Under this investigation, a one-meter pixel DEM created from LIDAR point data were obtained from the GLO in grid format and organized by USGS quarter quadrangles. Metadata provide information on when the data were collected; horizontal and vertical accuracy, and ancillary information (GLO, 2007d). The DEM covers the entire Texas Gulf shoreline; however, the width of subaerial LIDAR coverage landward of the shoreline on the barrier island is only about 1,312 feet (400 m). In most cases, the LIDAR coverage of the washover areas is incomplete as it does not include the complete foredune and landward elevations, thus it was not used to classify washover areas. Instead, for this study, a smaller area within the washover area (*stats_washover*) was digitized and statistical analyses of the elevations derived for the purpose of providing elevations that may be used in breach models. This smaller area is comprised of elevations of the dry sand area within the washover measured from the line of vegetation to the landward limit of the LIDAR data (Figure 4). The LIDAR elevations were overlain by the *stats_washover* polygons and elevation mean and standard deviation were calculated to provide an idea of the variability of elevations within the washover area (Table 3, Appendix E). Some washover areas (e.g., SPI-11, Figures 3A and 4) include mounds with higher elevations. Those mounds were not included in the washover area and were not subjected to statistical analyses.

The area digitized for the *stats_washover* data layers may not always directly overlay the larger washover area because the 2005 LIDAR show higher elevations such as sandy mounds which might not be vegetated and/or displayed in the 2006 aerial photographs. Descriptive statistics for elevations of washover throats were calculated for the 2005 LIDAR data. Summaries of the results found are presented in Table 3.

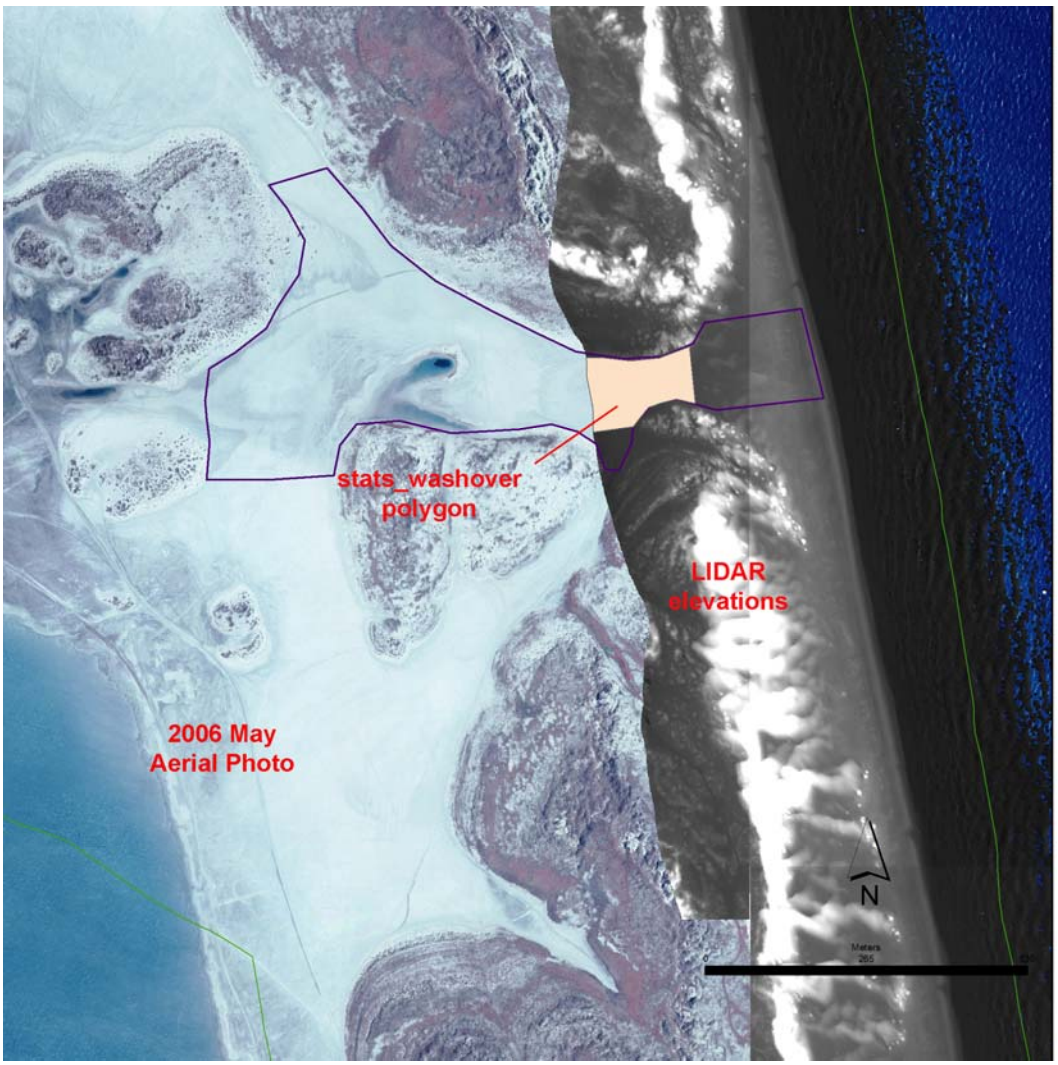


Figure 4. Example of digitized *stats_washover* with the landward limit coinciding with the 2005 LIDAR elevations. The seaward limit was measured at the line of vegetation in the 2006 May aerial photo. Base photograph courtesy of GLO (2007a.).

Table 3. Elevations of washover throats in *Priority Areas*. Mean and standard deviation were calculated from LIDAR data obtained in 2005 reported in meters relative to the North American Vertical Datum of 1988 (NAVD).

Local Washover ID	Washover ID	Mean Land Surface Elevation (NAVD88 m)	Standard Deviation Land Surface Elevation
GI-1	1	0.90	0.18
GI-2	2	0.79	0.22
GI-3	3	none digitized	
FI-1	4	none digitized	
FI-2	5	none digitized	
FI-3	6	1.09	0.38
FI-4	7	1.55	0.68
EMP-1	8	0.89	0.53
EMP-2	9	1.46	0.21
EMP-3	10	1.09	0.39
EMP-4	11	0.67	0.37
EMP-5	12	0.43	0.18
EMP-6	13	0.43	0.23
EMP-7	14	0.31	0.28
MI-1	15	1.45	0.61
MI-2	16	1.08	0.27
SPI-1	17	0.64	0.34
SPI-2	18	1.08	0.51
SPI-3	19	0.56	0.43
SPI-4	20	1.12	0.58
SPI-5	21	0.67	0.29
SPI-6	22	0.73	0.26
SPI-7	23	0.65	0.15
SPI-8	24	0.64	0.20
SPI-9	25	0.54	0.16
SPI-10	26	0.63	0.30
SPI-11	27	0.71	0.33
SPI-12	28	0.75	0.24
SPI-13	29	0.84	0.42
SPI-14	30	1.02	0.49
SPI-15	31	0.62	0.24
SPI-16	32	0.73	0.41
SPI-17	33	0.79	0.53
SPI-18	34	1.29	0.84

RESULTS

Using the May 2006 aerial photographs as a base, washover areas were first identified by breaks in the foredune ridge. When compared to the washover areas delineated by the BEG from 1992 aerial photography and videography (GLO, 2007c), the May 2006 washover areas described in this study were fewer in number, but were found within the same general locations coastwide. An example of the change in vegetation and washover area location is shown in the southern portion of South Padre Island (Figure 5). The majority of the BEG washover areas (in red) have become vegetated. Using the criteria described earlier, vegetated former washover areas were not mapped.

Figure 5. Map of a section of South Padre Island showing the BEG washover areas (red). The washover area data layer digitized in this investigation is outlined in purple. Base photograph from May 2006 courtesy of GLO (2007a.).

Priority Areas

A. South Padre Island Priority Area:

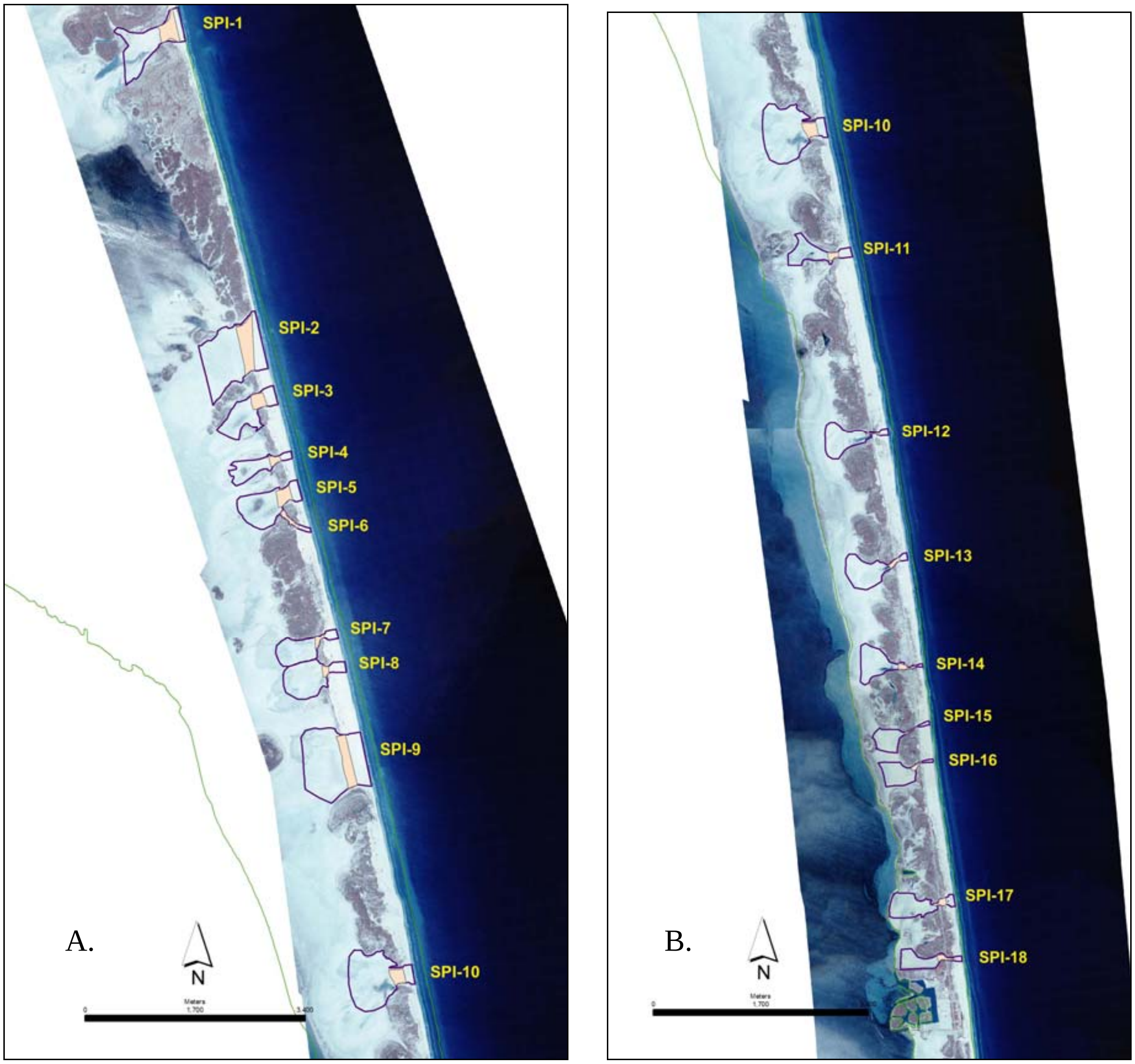
Areas of South Padre Island are sparsely vegetated and washover areas can be difficult to outline from aerial photographs. From the aerial photographs, foredune shapes and vegetation patterns show scars from former washover channels and the surficial depositional features extend from the beach to foredune to wind-tidal flat. Many washover areas are composed of coalesced washover fans that extend into the Laguna Madre. Figure 6 shows the washover areas identified in this investigation.

For the South Padre Island *Priority Area*, a landward limit of 3,281 ft (1,000 m) was set because it is difficult to delineate the boundary between the washover area and wind-tidal flat in aerial photographs and the LIDAR data did not extend far enough landward to show changes in elevation. Vegetation or vegetated coppice mounds were used to mark the boundaries between the foredunes and bare sands of washover areas. Because of the unvegetated nature of the backbarrier on South Padre Island, washover area boundaries were estimated based on changes in the color of the backbarrier from the aerial photographs. Some sand mounds (that could be subject to storm flood waters) were included within the washover areas.

Some washover areas contain multiple channels in addition to the main throat. Delineated boundaries for washover areas did not completely enclose these channels; however, the digitized shape includes perturbations that infer the distributary channels (e.g., SPI-4 and SPI-11). Return-flow channels were also identified as washover areas because they break through the foredunes. In general, return-flow channels are not oriented perpendicular to the shoreline (e.g., SPI-6).

A low, flat area exists near the center of the South Padre Island *Priority Area* at washover areas SPI-7, SPI-8 and SPI-9 (Figure 6a). Washover area SPI-9 has the greatest throat width of those measured for the *Priority Area*. Surrounding foredunes are sparsely vegetated, and washover areas to the north (SPI-7 and SPI-8) coalesce. LIDAR elevations of the measured throats (*stats_washover*, shown in pink polygons) indicate that this region is lower than the other washover areas to the north and south (Table 3) and there is little variation in elevation (+2.8 ft (0.84 m) to +1.25 ft (0.38 m) above the North American Vertical Datum of 1988 (NAVD88)). This area coincides with the narrowing of the island near the Three Islands area along the Gulf Intracoastal Waterway (GIWW). Paine and Morton (1989) found that between 1974 and 1982, the movement of the vegetation line in this portion of South Padre Island had moved landward over 69 ft/year (21 m/yr). Hurricane Allen (1980) may have had a substantial impact on the location of the vegetation line at these washover areas, as they may have coalesced during the storm. Immediate post-storm aerial photographs are not available for this portion of South Padre Island to confirm this possibility.

A small section of South Padre Island was not mapped as a washover area includes the beach paths at Andy Bowie Park (located south of SPI-18) where there are dune blowouts along the foot paths from the parking areas to the beach. These low areas could potentially become washover areas because dunes or stabilizing vegetation are absent, but no evidence of sediment transport from Gulf to lagoon was evident from the May 2006 aerial photographs.



Figures 6. Washover areas identified on South Padre Island. Figure A is located north of B. Base map includes the May 2006 aerial photographs and the Environmental Sensitivity Index (ESI) shoreline (green line) (GLO, 2007a; 2007b). Pink areas represent polygons within the washover area throats where LIDAR elevations were calculated (GLO, 2007d).

B. Follets Island Priority Area:

Figure 7 shows the washover areas in the Follets Island *Priority Area*. The northeastern end of Follets Island is bounded by San Luis Pass, a natural, non-engineered tidal inlet between the Gulf of Mexico and West Bay. A sandy beach and tidal flat span the area from the bay side of the Highway 257/ FM 3005 bridge to the backbarrier adjacent to the Pass (FI-1). Morton and Peterson (2005) concluded that both FI-1 and FI-2 comprise an overwash terrace. However, sandy feature FI-2 extends landward beyond the roadway as does feature FI-3. FI-3 is the former location of “Little Pass” which was filled in the 1950s for construction of the road (GLO, personal communication). While only four washover areas were mapped, the barrier contains many unvegetated dune blowout features that coalesce and could make the area more susceptible to overwash. In addition, vehicular beach access roads also pose a threat for overwash near washover area FI-4 on the bayside of Bluewater Highway 257. Elevations were not calculated for washover areas FI-1 and FI-2 because they are considered sand flats adjacent to San Luis Pass, yet they are still subjected to flooding from storm surge, so were highlighted as washover areas.

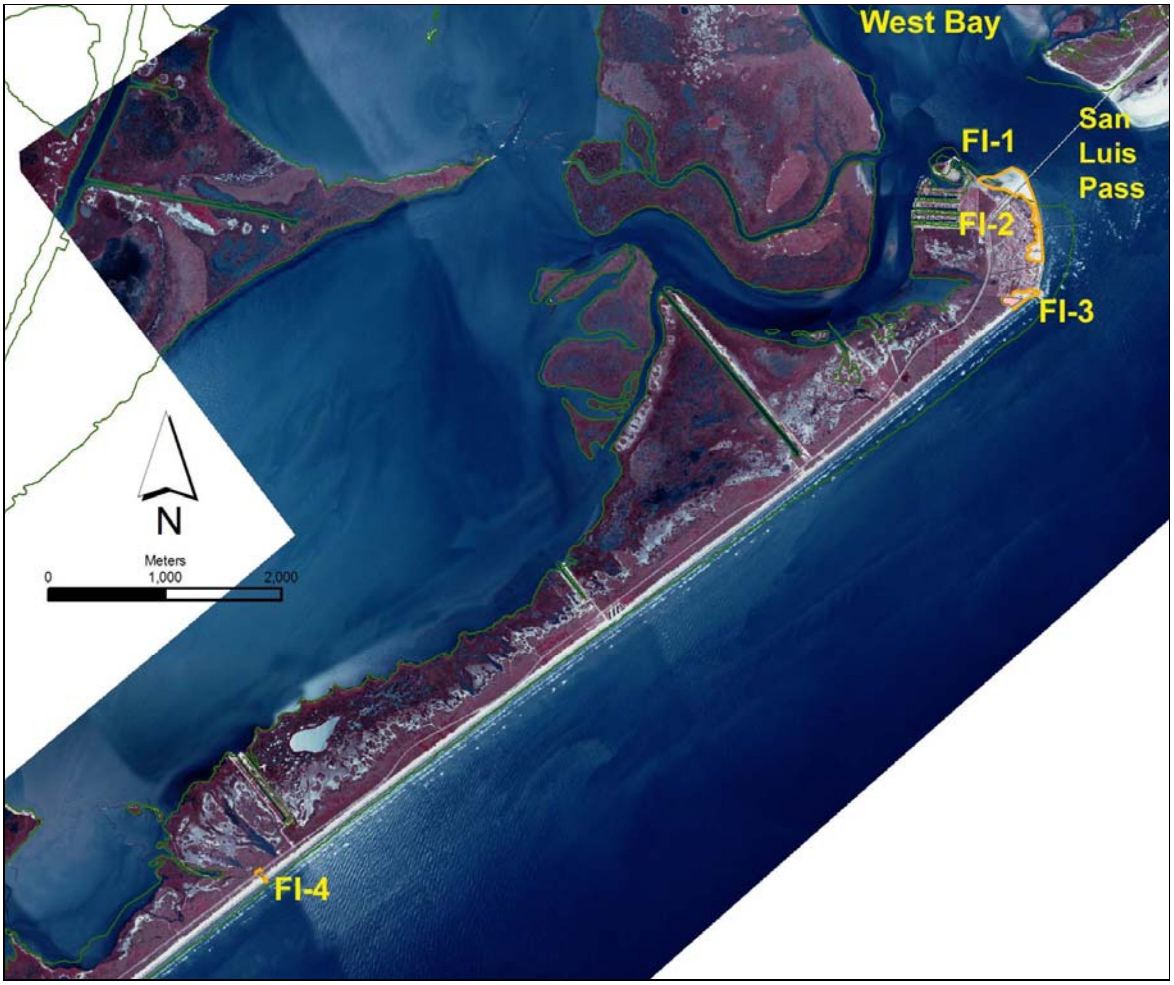


Figure 7. Washover areas identified on Follets Island. Base map includes the May 2006 aerial photographs and the ESI shoreline (GLO, 2007a; 2007b).

C. Mustang Island Priority Area:

Figures 8A and 8B show the locations of washover areas on Mustang Island. The washover areas are restricted to former tidal channels at Corpus Christi Pass and Newport Pass and were the only two washover areas delineated for the Mustang Island Priority Area. The features' landward limit is at Texas Highway 361, where roadway engineered structures are assumed to direct flood waters into Laguna Madre. Hurricanes Carla (1961) and Allen (1980) created channels from the Gulf to the bay at these locations (BEG, 2006). Fish Pass is not considered as a washover area because the former man-made pass has greater vegetation coverage than MI-1 and MI-2. In addition, elevations calculated from LIDAR are greater in Fish Pass than in MI-1 and MI-2 (Figure 8B). Packery Channel (south of

MI-2 and not shown in photo) was also not mapped as a washover area because it is presently an open channel with engineered structures.

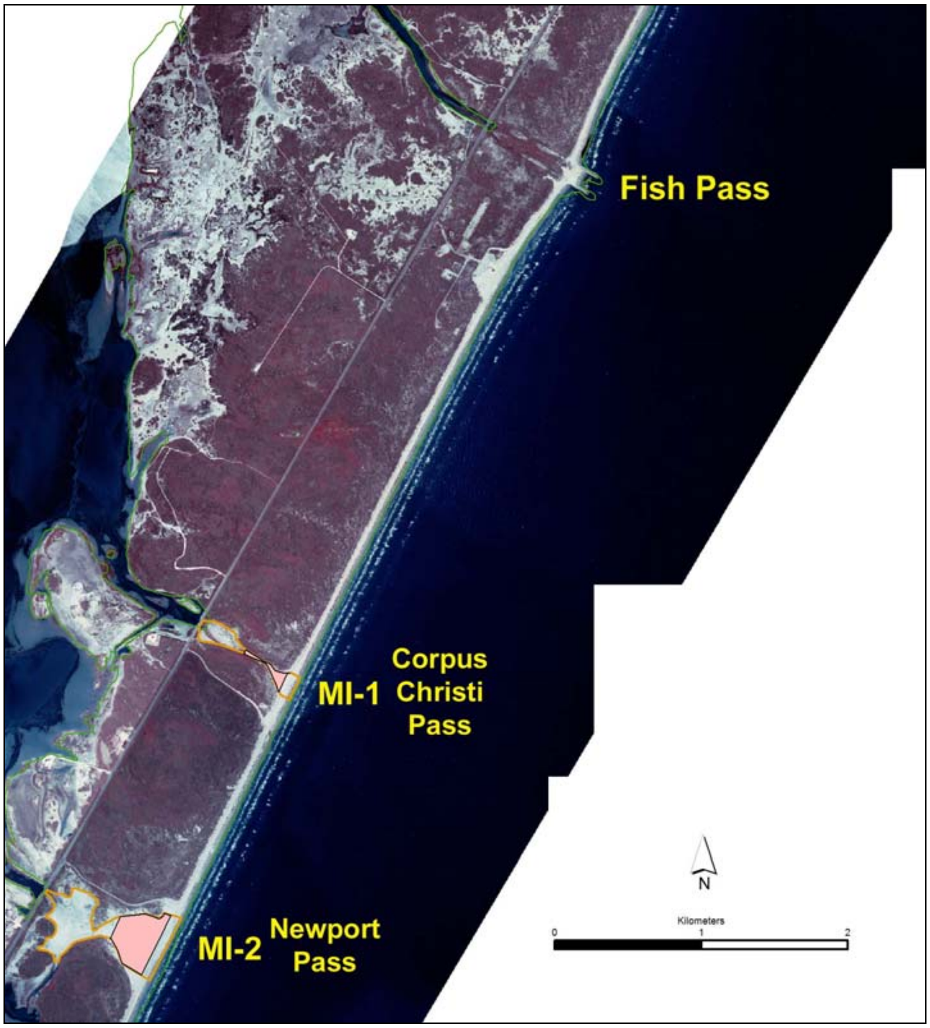


Figure 8A. Washover areas on Mustang Island. Base map includes the May 2006 aerial photographs and the ESI shoreline (GLO, 2007a; 2007b). Pink areas represent polygons within the washover area throats where LIDAR elevations were calculated (GLO, 2007d).

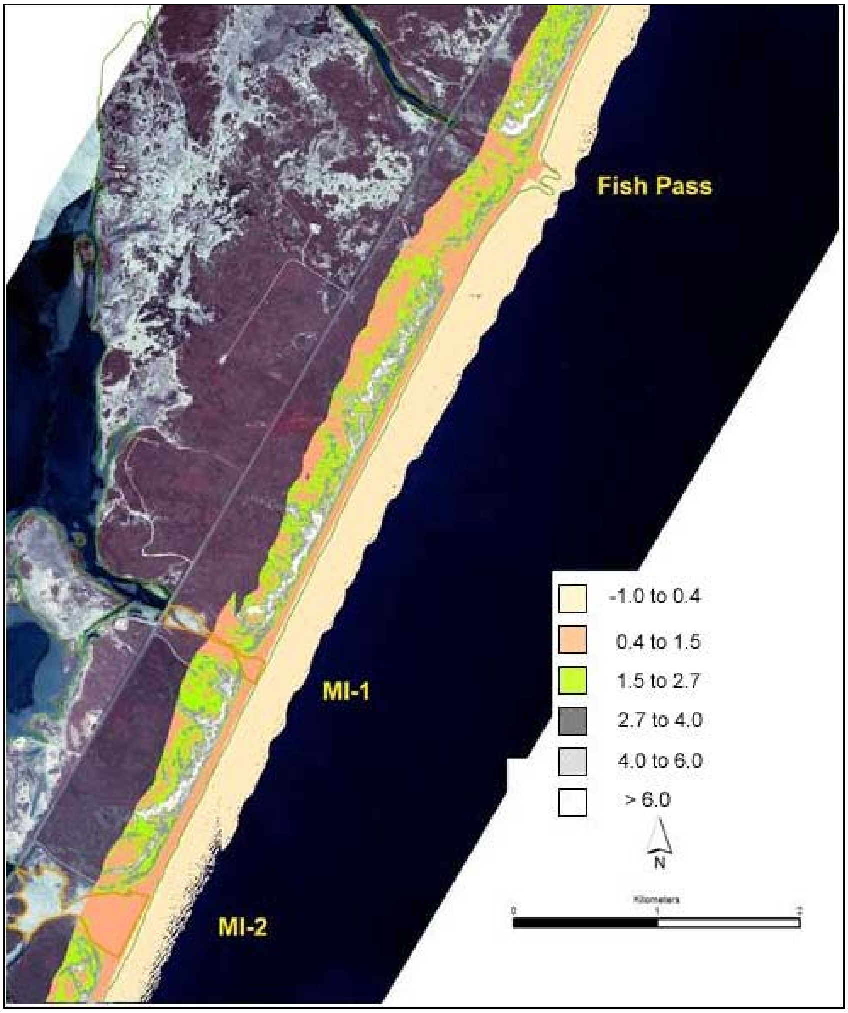
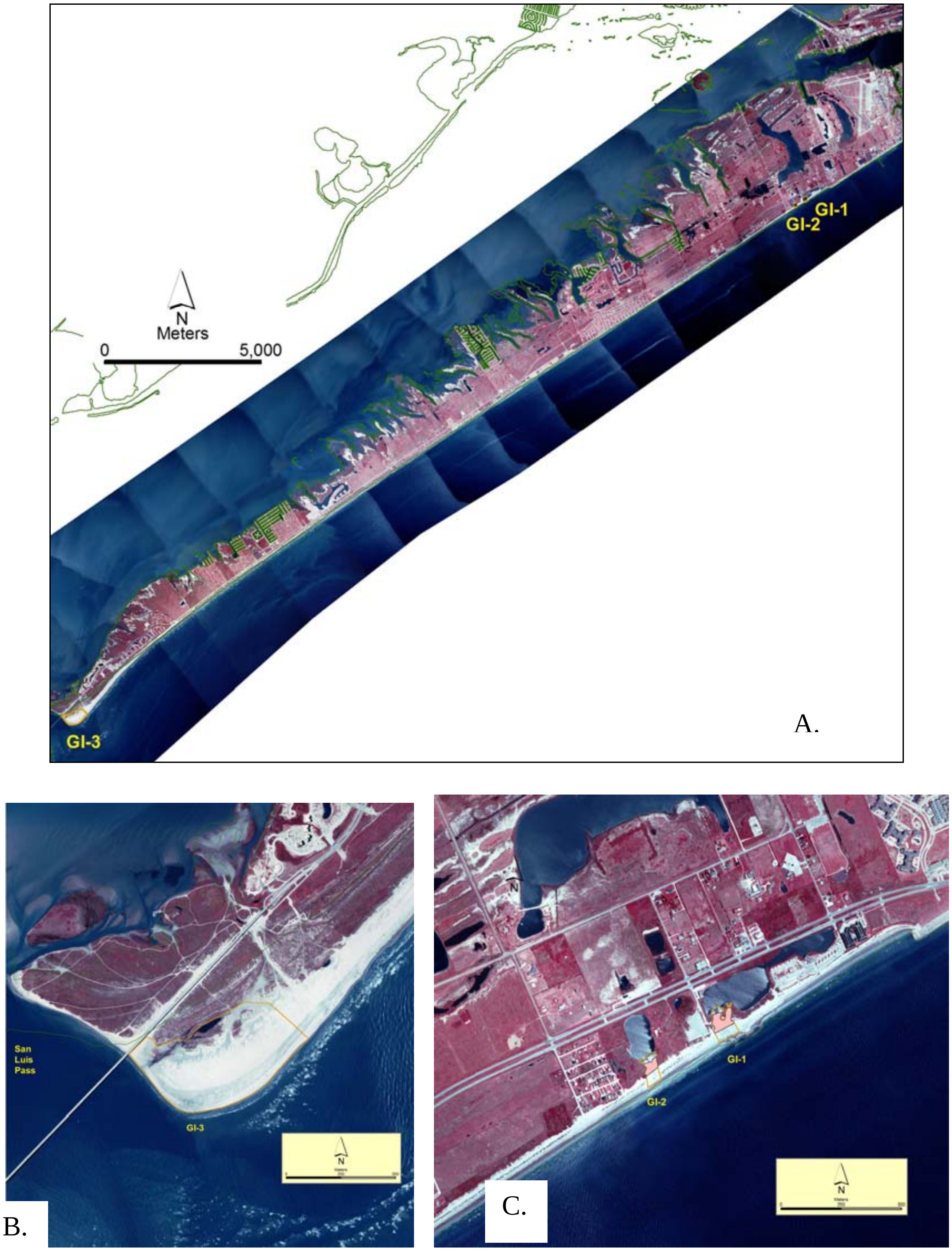


Figure 8B. LIDAR elevations in meters (NAVD 88). Fish Pass elevations are greater than those in MI-1 and MI-2 (GLO, 2007d).

D. West Galveston Island Priority Area:

Figure 9 shows the location of the West Galveston Island *Priority Area* and the washover areas delineated in this study. Geohazard maps based on research by the BEG show washover pathways from Hurricane Carla (1961) concentrated mostly in the western portion of the island (Gibeaut, et al., 2006). The westernmost end of Galveston Island is narrow and lacks the former beach ridge (dated approximately 2,600 years before present) found to the east that may serve as protection from complete barrier island breaching (Anderson, 2007). The washover pathways generated by Hurricane Carla are now vegetated and are not considered as washover areas under this investigation. However, two washover areas (GI-1 and GI-2) were identified. These areas were previously not identified as washover pathways by Gibeaut et al., 2006 because they lie in the eastern portion of the barrier seaward of the former beach ridge. However, GI-1 and GI-2 lie within the overwash terrace noted by the USGS (Morton and Peterson, 2005). Though they do not extend across the barrier island, there is evidence from the aerial photos that sediment has been deposited in the ponds landward of them.



Figures 9. A. Regional view of *Priority Area*. B. and C. are insert maps. Washover areas on Galveston Island. Base map includes the May 2006 aerial photographs and the ESI shoreline (GLO, 2007a; 2007b). Pink areas represent polygons within the washover area throats where LIDAR elevations were calculated (GLO, 2007d).

These washover areas are identified from breaks in the foredunes and LIDAR data correlate with the washover area digitized from the aerial photographs (Figure 10). A washover area/sand flat at the westernmost end of the island adjacent to San Luis Pass is identified (GI-3); however, it does not extend to a nearby washover pathway identified by Gibeaut, et al. (2006) because the May 2006 aerial photographs show that the area is more vegetated than in the photographs used by the BEG or USGS. Statistical elevations were not calculated for washover area GI-3 because it is considered sand flats adjacent to San Luis Pass, yet it is still subjected to flooding from storm surge and should be highlighted as a washover area.

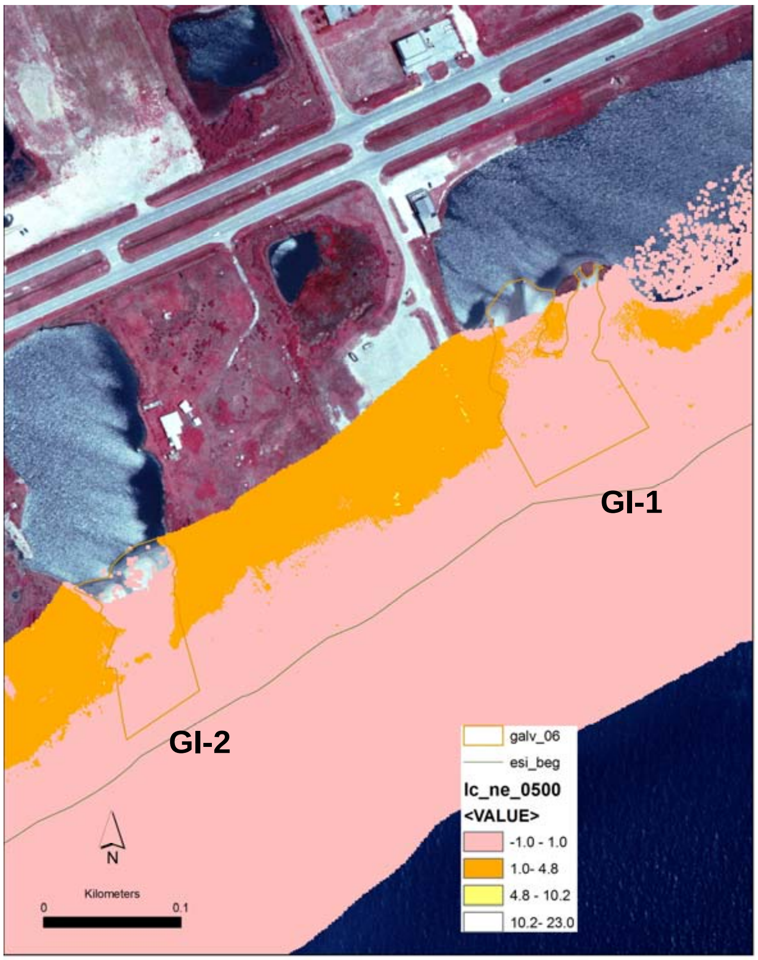


Figure 10. LIDAR elevations in meters (NAVD 88) correlate with unvegetated washover areas (yellow-lined polygon) identified from aerial photography.

E. East Matagorda Peninsula Priority Area:

Figure 11 shows the locations of the washover areas on East Matagorda Peninsula. May 2006 georeferenced aerial photographs were missing for about 9.9 miles (16 km) of shoreline, so orthophotographs from the 2004 Dressing Point, Brown Cedar Cut and Sargent quadrangles were used for this analysis (TNRIS, 2007).

The flame-shaped features on the landward side of the peninsula are relict deposits from former storms which also generated washover channels (Morton and McGowan, 1980). These features resemble the radiating distributary channels and adjacent mounds formed in a washover fan on St. Joseph Island 75 miles (122 km) to the south as described by Andrews (1970). A dune system is established along the peninsula's Gulf of Mexico shoreline and becomes continuous closer to the jetties at the Colorado River. In the easternmost portion of the peninsula, there are many breaks in the dunes and much of the peninsula is covered by an overwash [washover] terrace (elongate deposit oriented parallel to shore). Washover area, EMP-4, is of particular interest in that it resembles an extensive overwash terrace. It has the widest throat width of all the washover areas in this study. The area shows numerous sand deposits in the backbarrier and various splays of sand along the Gulf shoreline. The boundaries for this washover area were difficult to delineate and need to be field verified.

Though the relict overwashes are apparent, the washover areas delineated in this study follow the breaks in the foredunes as indicators of present-day washover areas. Axes of washover areas are commonly oblique to the shoreline, which is a different pattern than observed in other *Priority Areas*. Ponding commonly occurs on the landward terminus of washover deposits as well as closer to the Gulf of Mexico, possibly due to changes in the underlying sediments and infiltration of precipitation.

<u>Aerial Photographs and Storm Data Sets</u>

Table 2 and Appendix B provide information for storms and available aerial photographs. The storms with the best meteorological data are Hurricanes Allen (1980), Alicia (1983), Bret (1999), Claudette (2003), and Rita (2005). All of these storms are know to have caused coastal flooding. The best pre- and post-storm aerial photographic dataset for all *Priority Areas* is for Hurricane Rita (2005). The pre-storm survey occurred less than one month prior to the storm and the post-storm survey occurred about eight months after the storm. Hurricane Rita made landfall east of Sabine Pass but induced high tides and beach erosion along the South Padre Island shoreline more than 350 miles (563 km) to the south (NOAA, 2005a). Aerial photographs for Galveston Island are also available one day following Hurricane Rita (NOAA, 2005b). Hurricane Rita meteorological data is also well documented for all *Priority Areas*. Table 4 provides the list of storms and available aerial photographs that are available to show changes in washover areas for each *Priority Area*. Some of the aerial photographs have been georeferenced (highlighted in yellow and blue) while those not highlighted still require georeferencing. Due to time constraints, these data sets were not evaluated for changes in washover shape or vegetation coverage. Other data sets that can be used to compare washover features are discussed below.

In the South Padre Island *Priority Area*, the best storm/aerial data sets exist for Hurricane Allen (1980). Photographs are available less than three weeks before the storm, and two years after the storm. Other aerial photographic data sets that may be useful for Hurricane Bret (1999) were taken about three years before and one year after the storm. Hurricane Beulah (1967) information is incomplete.

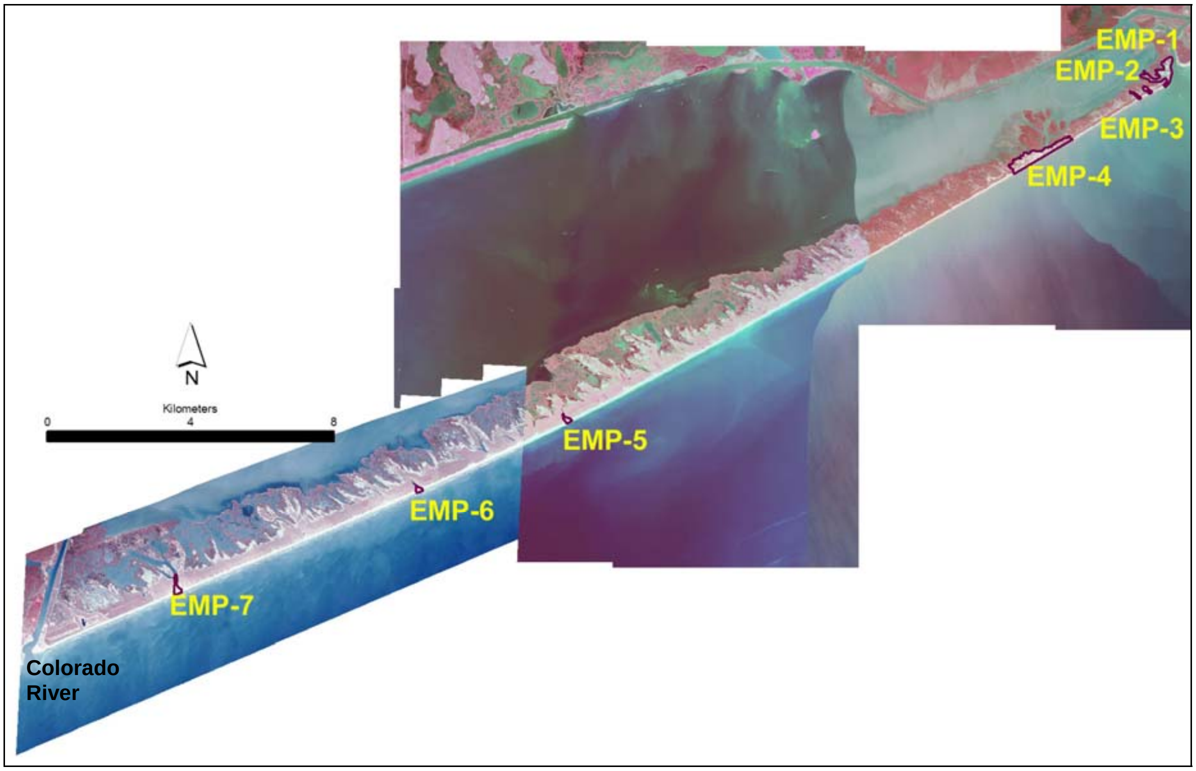


Figure 11. Washover areas on East Matagorda Peninsula. Base map includes the May 2006 aerial photographs and the ESI shoreline (GLO, 2007a; 2007b). Pink areas represent polygons within the washover area throats where LIDAR elevations were calculated (GLO, 2007d).

In the Follets Island *Priority Area*, good storm/aerial data sets are for Hurricane Alicia (1983) where the pre-storm photographs were taken about a year prior to the storm and the post-storm surveys occur from three to six months after the storm. Another good data set is for Hurricane Claudette (2003) where the pre-storm aerial survey was conducted four months prior and the post-storm survey was conducted within two weeks after the storm. And, aerial photography was taken for the area within six months following Hurricane Bret (1999).

In the Mustang Island *Priority Area*, good storm/aerial data sets are from Hurricane Allen (1980). Aerial photographs of the washover areas were taken eight days following the storm. Hurricane Alicia (1983) aerial photographs are available and were taken about a year and a half prior to the storm and about two weeks following the storm. Data for Hurricane Bret (1999) may be helpful but were taken nearly two years following the storm.

In the W. Galveston Island *Priority Area*, good storm/aerial data sets are for Hurricane Claudette (2003) where the pre-storm aerial survey was conducted four months prior and the post-storm survey conducted within two weeks after the storm. Some aerial photographs of the area following Hurricane Alicia (1983) are found in published studies (Savage, et al, 1984; Morton and Paine, 1985) but are not spatially continuous and, at this time, are not available. The available post-storm aerial photographs were taken nearly three years following the storm. Another good data set of aerial photography was taken for the area within six months following Hurricane Bret (1999).

Hurricane	South Padre Island (Cameron Co)	Follets Island (Brazoria Co)	Mustang Island (Nueces Co)	W. Galveston Island (Galveston Co)	E. Matagorda Peninsula (Matagorda Co)
Hurricane Allen (8/10/1980)					
pre-storm	7/23/80 GLO roll no. 173		10/31/1979 GLO http://www.glo.state.tx.us/coastal/photos/nueces1979/index-east.html		8/1978 & 10/30/1978 TNRIS photo archives
post-storm	4/12/82 GLO roll no. 201		4/12/1982 GLO roll no. 201 8/18/1980 GLO roll no. 175 Willacy shoreline and a few frames of Mustang Is		10/21/1981 TNRIS photo archives
Hurricane Alicia (8/18/1983)					
pre-storm		Jun-Sep 1982 GLO http://www.glo.state.tx.us/coastal/photos/1982jun-sept/1.html	4/12/1982 GLO roll no. 201		
post-storm		11/17/1983 & 2/29/1984 GLO photo archives	8/22/1983 TNRIS photo archives		
Hurricane Bret (8/22/1999)					
pre-storm	1996 TNRIS http://www.tnris.state.tx.us/datadownload/	1996 TNRIS http://www.tnris.state.tx.us/datadownload/	1996 TNRIS http://www.tnris.state.tx.us/datadownload/	2/1999 GLO http://www.glo.state.tx.us/coastal/photos/galveston990223/galvis.html	1996 TNRIS http://www.tnris.state.tx.us/datadownload/
post-storm	9/3/2000 GLO http://www.glo.state.tx.us/coastal/photos/glo9-3-00/index-vertical.html	2/8/2000 GLO http://www.glo.state.tx.us/coastal/photos/mercator000208/brazoria.html	1/8/2002 GLO http://www.glo.state.tx.us/coastal/photos/glo01-08-02/index.html	2/8/2000 GLO http://www.glo.state.tx.us/coastal/photos/mercator000208/galvis.html	11/30/2001 GLO http://www.glo.state.tx.us/coastal/photos/matagorda11-30-01/upper.html
Hurricane Claudette (7/15/2003)					
pre-storm		3/2003 GLO http://www.glo.state.tx.us/coastal/photos/mar2003/index.html		3/2003 GLO http://www.glo.state.tx.us/coastal/photos/mar2003/index.html	11/30/2001 GLO http://www.glo.state.tx.us/coastal/photos/matagorda11-30-01/upper.html
post-storm		7/27/03 GLO http://www.glo.state.tx.us/coastal/photos/claudette/aerials07-27-03/index-vertical.html		7/27/03 GLO http://www.glo.state.tx.us/coastal/photos/claudette/aerials07-27-03/index-vertical.html	8/17-21/2005 GLO http://www.glo.state.tx.us/coastal/photos/2005aug/uppercoast/matagorda-brazos.html
Hurricane Rita (9/24/2005)					
pre-storm	8/17-21/2005 GLO http://www.glo.state.tx.us/coastal/photos/2005aug/lowercoast/spi-northoftown.html	8/17-21/2005 GLO http://www.glo.state.tx.us/coastal/photos/2005aug/uppercoast/folletsisland.html	8/17-21/2005 GLO http://www.glo.state.tx.us/coastal/photos/2005aug/lowercoast/corpuschristi-padreisland.html	8/17-21/2005 GLO http://www.glo.state.tx.us/coastal/photos/2005aug/uppercoast/galvestonisland.html	8/17-21/2005 GLO http://www.glo.state.tx.us/coastal/photos/2005aug/lowercoast/matagordapeninsula.html
post-storm	5/2006 GLO http://www.glo.state.tx.us/coastal/photos/2006may/01/lowercoast.html	5/2006 GLO http://www.glo.state.tx.us/coastal/photos/2006may/01/uppercoast.html	5/2006 GLO http://www.glo.state.tx.us/coastal/photos/2006may/01/lowercoast.html	5/2006 GLO http://www.glo.state.tx.us/coastal/photos/2006may/01/uppercoast.html	5/2006 GLO http://www.glo.state.tx.us/coastal/photos/2006may/01/lowercoast.html

data sets georeferenced under this work order (yellow)
other available georeferenced data sets (cyan)

Table 4. Available aerial photography for study of washover areas.

In the E. Matagorda Peninsula *Priority Area*, reliable storm/aerial data sets are for Hurricane Allen (1980) and Hurricane Claudette (2003) where the pre-storm photographs were taken about two years prior to each storm and the post-storm surveys taken about two years following the storms.

DISCUSSION

Washover areas varied in shape, size, and extent within and between *Priority Areas*. The topography and presence of vegetation lagoonward of the foredunes influences whether sediment is dispersed in lobate fans or confined to channels. For example, nearly all of the washover areas identified for the South Padre Island (an area with no to minimal backbarrier vegetation) were more numerous, fan-shaped, and extended over 3,000 ft (1,000 m) lagoonward. Whereas, the washover areas for the other *Priority Areas* (where vegetation coverage was greater) were less in number, limited by infrastructure, adjacent to natural passes, or flame-shaped. Throat widths were not consistent for any *Priority Area* and ranged from 23 ft to 6,053 ft (7 m to 1,845 m) (Appendix E). In addition to surge level at the time of the event, antecedent geology, depositional facies, and nearshore bathymetry may also contribute to the formation and style of washover areas but were not investigated under this scope of work.

Climate affects whether vegetation grows and eventually traps blowing sand. Along the upper coast, the vegetation was used to determine the boundaries of a washover area deposit. In more arid South Padre Island, the *Priority Area* with the most washover areas, no clear demarcations between the washover sand and wind-tidal sediment were evident from the aerial photographs. Most of the washover areas lagoonward of the foredunes were mapped using changes in sediment color.

In this investigation, washover areas were identified where there was an obvious discontinuity in the foredunes and an adjacent clearly identified washover throat. More subtle features such as overwash terraces and dune blowouts, which could potentially develop into washover areas, were not considered. This conservative approach is preferred because this review is based upon aerial photographic interpretation of vegetation and topographic landforms. Field verification was not included in the scope of the study.

The use of LIDAR-generated altitudes (elevations) was useful for this study as it helped to confirm the locations of the digitized washover areas. Unfortunately, the LIDAR did not extend far enough landward to capture the entire backbarrier elevations. This would have aided in determining elevations of the landward extent of the washover areas. Another benefit in combining the LIDAR with aerial photographs is that areas other than washover areas that have lower elevations that may be prone to flooding during storms can be identified. For example, in the South Padre Island *Priority Area*, a potential weak spot in the dunes occurs between SPI-6 and SPI-7 (Figure 12A, red circle). Scars of possible former washover channels are evident in May 2006 aerial photographs but the area is now mostly vegetated. The LIDAR data suggest that this area is lower in elevation than surrounding foredunes (Figure 12B, darker color within red circle). This area was identified by the BEG to be a washover area (GLO, 2007c). However, field verification is necessary to determine if there is currently a break in the foredune.

LIDAR data were also useful for determining elevations of throats in the washover areas. In general, these areas are less than 3.3 ft (1 m) above NAVD88 (Table 3). The washover areas with the lowest throat elevations occur on East Matagorda Peninsula (EMP-5, EMP-6, and EMP-7). The highest washover throat elevations are found at Follets Island (FI-4) and at Mustang Island (MI-1), but the standard deviation is also greater at these locations indicating a wider range of elevations within the throat (e.g., unvegetated coppice mound).

The primary data gap identified for fully characterizing washover morphology is elevation of the backbarrier. Though low-resolution elevations could be derived from existing topographic maps, high-resolution elevations derived from LIDAR provide much greater detail.

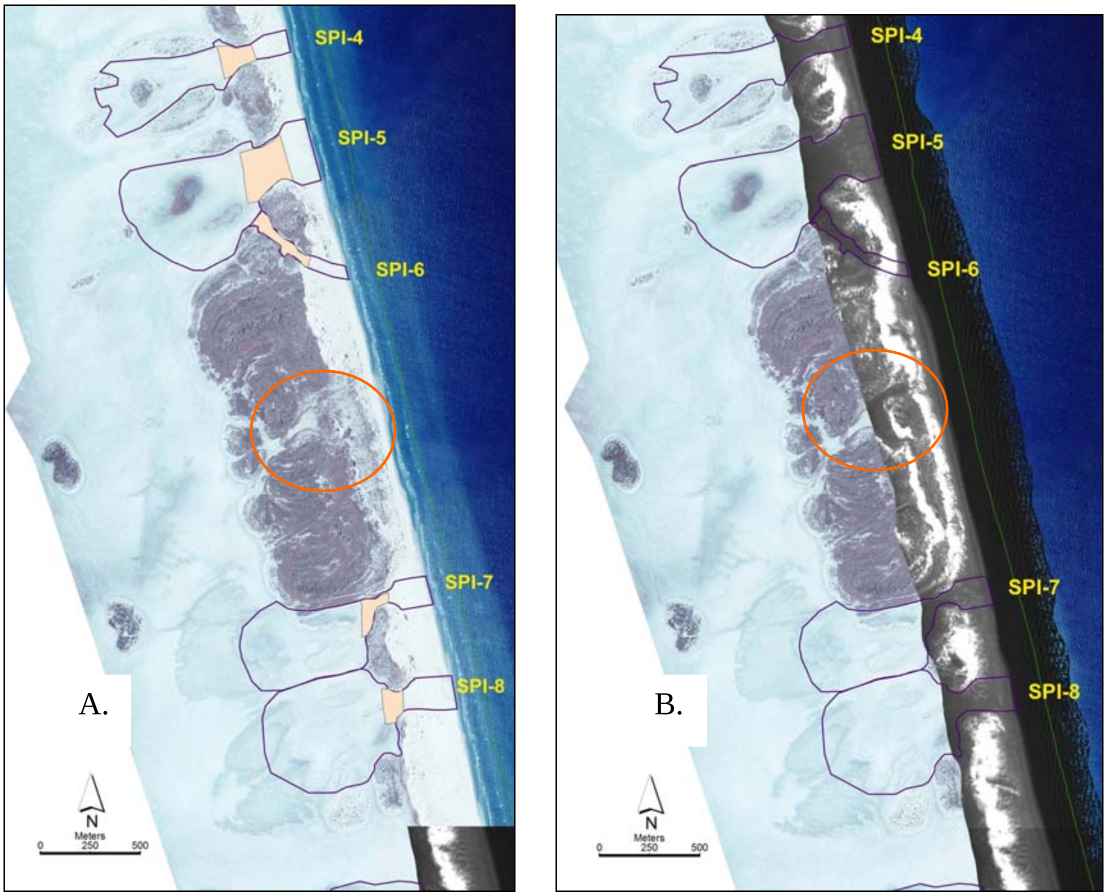


Figure 12. Low area (red circle) within foredunes on South Padre Island. May 2006 aerial photographs, washover areas and identification numbers are shown in both (A) and (B) (GLO, 2007a). (A) Pink areas represent throats within washover areas where descriptive statistics were calculated. (B) Grey-scale areas along the shoreline are the LIDAR-derived digital elevation model. Darker areas represent low elevations (e.g., beachface) and white areas represent higher elevations (e.g., dunes).

Local meteorological conditions may have influenced the relative number of washover areas in the *Priority Areas*. In most areas of the Texas coast, the weather was wetter and warmer than average when the aerial photographs were taken (May 2006; Figure 13; Table 5). Brownsville, Corpus Christi, and Victoria experienced a wetter than average month (Texas Climatic Bulletin, 2006). This may have led to vegetation growth not identified in the surveys by the BEG and USGS (Morton and Peterson, 2005; Gibeaut et al., 2006; Morton and Peterson, 2006a; Morton and Peterson, 2006b).

Table 5. Climatic summary for May 2006 (extracted from Texas Climatic Bulletin, 2006).

	Temperature (deg F)		Precipitation		
Station	**Mean**	**Departure From Normal**	**Number of Days**	**Total (inches)**	**% of Average**
Brownsville	81.8	2.5	6	3.46	140
Corpus Christi	80.8	3.3	6	4.43	127
Galveston	78.5	2	3	3.24	88
Houston	76.7	1	7	8.78	170
Port Arthur	75.4	0	6	5.01	86
Victoria	77.9	1	5	8.99	176

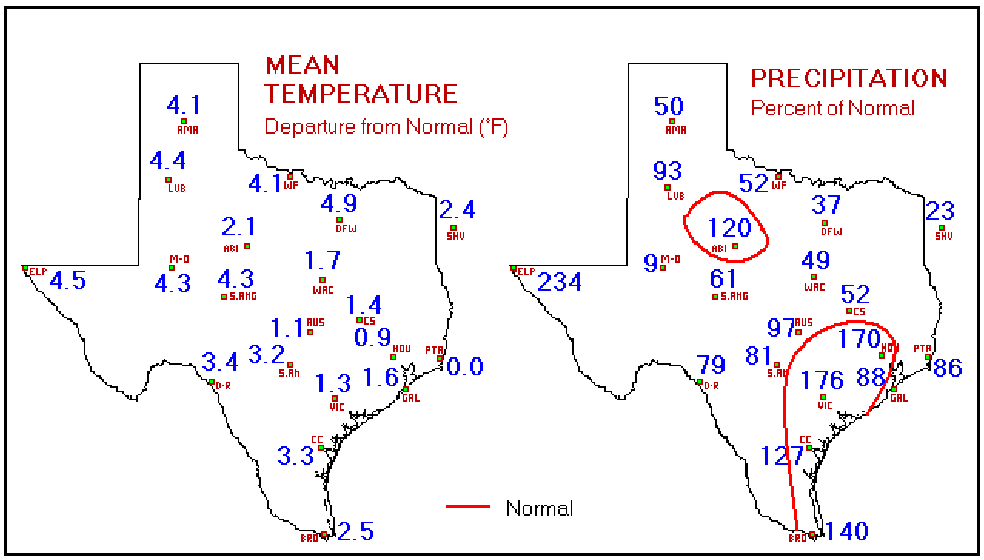


Figure 13. Temperatures and precipitation values from May 2006; the time period when the baseline aerial photographs were taken (Office of the Texas State Climatologist, 2006).

The last hurricane to strike the Texas coast prior to acquisition of the May 2006 photographs was Hurricane Rita on September 24, 2005. This storm made landfall east of the Texas/Louisiana border, but affected the entire Texas Gulf shoreline. Dunes on South Padre Island were breached by the storm waves and areas north of the Town of South Padre Island city limits were flooded two days prior to landfall (NOAA, 2005a; 2005b). It is probable that all of the 18 washover areas identified for the South Padre Island *Priority Area* were flooded. Texas Coastal Bend areas (e.g., Mustang Island) reported flooding of beach access roads, but little beach erosion (NOAA, 2005c). Pre-storm LIDAR is available for Follets Island and Galveston Island. Post-storm LIDAR data are available for Follets Island, Galveston Island, and South Padre Island (GLO, 2007a). Measurements of Hurricane Rita's storm surge and high-water mark elevations are available for the upper Texas coast and may be useful for breach modeling (McGee, et al. 2005; URS Corporation, 2006).

CONCLUSIONS

This report provides hurricane meteorological information and identifies the location and general characteristics of washover areas within five *Priority Areas* along the Texas Gulf shoreline.

- GIS layers were created for washover areas identified on May 2006 aerial photography.
- Washover areas were identified by lateral breaks in vegetation coverage within the foredune ridge and adjacent clearly identified washover channels (throats).
- Sand flats adjacent to active non-engineered inlets or passes are identified as washover areas.
- LIDAR data (2005) provided elevations of washover area throats.
- Washover area occurrence and size is varied among the *Priority Areas*; controlled by topography, the presence of vegetation, and storm surge level.
- Fewer washover areas were identified in this study than those identified by the BEG (GLO, 2007c). Differences in vegetation coverage on the baseline aerial photography may contribute to this.
- Using the criteria established in this investigation, not all historical washover areas were mapped. For example, many washover channels opened during Hurricane Carla on Galveston Island are now vegetated and therefore were not identified as washover areas under May 2006 conditions.
- The use of LIDAR digital elevation models and aerial photography should be combined to determine washover area characteristics.
- Lowest washover area throat elevations were found on sections of East Matagorda Peninsula and South Padre Island. Statistical analyses showed that these areas are very flat with little elevation changes (Table 3).
- Highest washover area throat elevations were found on sections of Mustang Island and Follets Island, but those have greater variability in elevations within the throat (Table 3).
- Meteorological data were compiled for nine hurricanes ranging in strength from Saffir-Simpson Category 1 to 5 (Appendix A).
- Good meteorological information and the best timing of pre- and post-storm aerial photographs for all *Priority Areas* is available for Hurricane Rita (2005, Category 3). Hurricane Bret (1999, Category 4) information is also good; however, pre-storm aerial photographs were taken about three years prior to storm landfall.
- Other aerial photograph and meteorological data sets are available for future use and study of impacts to washover areas on Follets Island and Galveston Island following Hurricane Claudette (2003, Category 1); and for Mustang Island following Hurricane Allen (1980, Category 3) (Appendices A and B; Table 4).
- Unfortunately, appropriate aerial photography and meteorological data are either not available or limited for the larger recorded storms (Hurricane Beulah [1967, Category 5]; and Hurricane Carla [1961, Category 4]) or the other storms (Hurricane Celia [1970, Category 3] and Hurricane Cindy [1963, Category 1]).

RECOMMENDATIONS

- LIDAR elevations are necessary for identifying and classifying washover areas and the digital elevation model should cover the entire barrier island within the *Priority Areas.*

- Washover areas identified in this study should be field verified to identify the landward limit of the washover deposit noting type (sheetwash, perched fan, etc), approximate thickness of the deposit and location on aerial photographs.

- Storm data and aerial photography (Table 4) should be evaluated to determine if there is a threshold storm (one which affected all of the *Priority Areas*).

- Appropriate aerial photographic documentation is not available for all storms at all *Priority Areas*. Future breach / washover area analyses should focus on the storm and aerial photographic data sets identified for Hurricanes Rita (2005) and Bret (1999) as those data sets appropriately cover the beaches and washover areas within the *Priority Areas*.

- Digital aerial photographs of the *Priority Areas* should be completed at two-year intervals for monitoring the impacts of future storms.

ACKNOWLEDGEMENTS

This study was prepared for the Texas General Land Office under contract no. 06-076C. The assistance and knowledge of the Texas coast and GIS by David Parmer (GLO project manager), Scot Friedman (GLO GIS Team Leader), and Dr. Daniel Gao (GLO GIS Analyst) is greatly appreciated. Aerial photographs were scanned by Laura Whitener (GLO intern). I thank R. A. Davis, Jr. and N. C. Kraus as well as staff from the GLO Coastal Resources Program for their review and constructive comments of an earlier draft version of the report.

REFERENCES

Anderson, J.B., 2007. The Formation and Future of the Upper Texas Coast: A Geologist Answers Questions about Sand, Storms, and Living by the Sea. Gulf Coast Studies, 11. Texas A&M University Press, College Station, 163 pp.

Andrews, P.B., 1970. Facies and genesis of a hurricane-washover fan, St. Joseph Island, Central Texas Coast. Report of Investigations 67, University of Texas at Austin Bureau of Economic Geology, Austin, TX, 147 pp.

Bureau of Economic Geology, 2001. Coastal Studies Group, The Texas Coastal Hazards Atlas, Vol. 2, http://www.beg.utexas.edu/coastal/hazard_atlas2.htm.

Bureau of Economic Geology, 2006. Coastal Studies Group, Mustang Island Field Guide, http://images.google.com/imgres?imgurl=http://coastal.beg.utexas.edu/thscmp/images/mustangisland/corpuschristipass.jpg&imgrefurl=http://coastal.beg.utexas.edu/thscmp/fg_mustang_2.htm&h=428&w=640&sz=69&hl=en&start=1&tbnid=e7oHa6ucc46lwM:&tbnh=92&tbnw=137&prev=/images%3Fq%3D%2BTexas%2B1852%2Bpass%26gbv%3D2%26hl%3Den.

Davis, R.A., 1972. Beach changes on the central Texas coast associated with Hurricane Fern, September, 1971. Contributions in Marine Science, 16: 89-98.

Donnelly, C., Kraus, N.C. and Larson, M., 2004. Coastal Overwash, Part 1: Overview of Processes. Regional Sediment Management Demonstration Program Technical Note, ERDC/RSM-TN-14, U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi, 36 pp.

Donnelly, C., Kraus, N.C. and Larson, M., 2006. State of knowledge on measurement and modeling of coastal overwash. Journal of Coastal Research, 22(4): 965-991.

Donnelly, C. and Sallenger, A.H., Jr., 2007. Characterisation and modelling of washover fans. in: N.C. Kraus and J.D. Rosati (Editors), Coastal Sediments '07. Proceedings of the Sixth International Symposium on Coastal Engineering and Science of Coastal Sediment Processes. American Society of Civil Engineers, New Orleans, 2061-2073.

Giardino, J.R., Isett, P.E. and Fish, E.B., 1984. Impact of Hurricane Allen on the morphology of Padre Island, Texas. Environ Geol Water Sci, 6(1): 39-43.

Gibeaut, J. C., Tremblay, T. A., and White, W. A., 2000, Coastal hazards atlas of Texas: a tool for hurricane preparedness and coastal management-volume 1, the southeast coast. The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the Texas Coastal Coordination Council, pursuant to National Oceanic and Atmospheric Administration Award No. NA770Z0202, 69 pp.

Gibeaut, J. C., White, W. A., Hepner, T., Gutierrez, R., Tremblay, T. A., Smyth, R., Andrews, J., 2000. Texas Shoreline Change Project: Gulf of Mexico Shoreline Change from the Brazos River to Pass Cavallo. Report to the Texas Coastal Coordination Council pursuant to National Oceanic and Atmospheric Administration Award No. NA870Z0251, University of Texas at Austin, Bureau of Economic Geology, 34 pp.

Gibeaut, J.C., Hepner, T., Waldinger, R.L., Andrews, J.R., Gutiérrez, R., Tremblay, T.A., and Smyth, R.C., 2001. Changes in Gulf shoreline position, Mustang and North Padre Islands, Texas. The University of Texas at Austin, Bureau of Economic Geology, Final report prepared for the Texas Coastal Coordination Council pursuant to National Oceanic and Atmospheric Administration, under Award No. NA97OZ0179 and GLO Contract No. 00-002R, 28 pp.

Gibeaut, J. C., Crawford, M. M., Gutierrez, R., Hepner, T. L., Nuenschwander, A., White, W. A., Smyth, R. C., Andrews, J. R., and Tremblay, T. A., 2003a. Characterization of the Beach Zone via Airborne Lidar and Hyperspectral Remotely Sensed Data. The University of Texas at Austin, Bureau of Economic Geology, http://www.beg.utexas.edu/environqlty/remote_sensing/lidar_hyperspectral.htm.

Gibeaut, J. C., and Tremblay, T. A., 2003b. Texas coastal hazards atlas-volume 3: ArcView geographic information systems files. The University of Texas at Austin, Bureau of Economic Geology, final report of the Texas Coastal Coordination Council pursuant to National Oceanic and Atmospheric Administration Award No. NA07OZ0134, CD-ROM.

Gibeaut, J.C., White, W.A., Smyth, R.C., Andrews, J.R., Tremblay, T.A., Gutierrez, R., Hepner, T.L, and Neuenschwander, Amy, 2003c, Topographic variation of barrier island subenvironments and associated habitats, in Coastal Sediments '03: Crossing disciplinary boundaries: Proceedings, Fifth International Symposium on Coastal Engineering and Science of Coastal Sediment Processes, Clearwater Beach, Florida, May 18-23, 10 p., CD-ROM.

Gibeaut, J. C., Tremblay, T.A., Waldinger, R., Collins, E.W., Smyth, R.C., White, W.A., Hepner, T.L., Andrews, J.A., and Gutierrez, R. 2006. Galveston Island Geohazard Maps. The University of Texas at Austin, Bureau of Economic Geology, http://coastal.beg.utexas.edu/website/galvestonhazards/viewer.htm.

Gundlach, E.R., Domeracki, D.D., Thebeau, L.C., and Muthig, M., 1981. The Effects of Hurricane Allen (11 August 1980) on Padre Island National Seashore. RPI/R/81/8/19-28, RPI, Inc., Columbia, SC, 60 pp.

Hayes, M.O., 1967. Hurricanes as Geological Agents: Case Studies of Hurricanes Carla, 1961, and Cindy, 1963. No. 61, Bureau of Economic Geology, University of Texas at Austin, Austin, Texas, 55 pp.

Kraus, N.C., Militello, A. and Todoroff, G., 2002. Barrier breaching processes and barrier spit breach, Stone Lagoon, California. Shore and Beach, 70(4): 21-28.

Larson, M., Wise, R.A., and Kraus, N.C., 2004. Coastal Overwash, Part 2: Upgrade to SBEACH. Coastal and Hydraulics Engineering Technical Note, Regional Sediment Management Demonstration Program Technical Note, ERDC/RSM-TN-15, US Army Engineer Research and Development Center, Vicksburg, MS, 43 pp.

McGee, B.D., Goree, B.B., Tollett, R.W., Woodward, B.K., and Kress, W.H., 2005. Hurricane Rita Surge Data, Southwestern Louisiana and Southeastern Texas, September to November 2005, U.S. Geological Survey Data Series 220, http://pubs.usgs.gov/ds/2006/220/index.htm#fig1.

Morton, R.A., 2002. Factors controlling storm impacts on coastal barriers and beaches - a preliminary basis for near real-time forecasting. Journal of Coastal Research, 18(3): 486-501.

Morton, R.A. and Paine, J.G., 1985. Beach and Vegetation-Line Changes at Galveston Island, Texas: Erosion, Deposition, and Recovery from Hurricane Alicia. Geological Circular 85-5, University of Texas at Austin, Bureau of Economic Geology, Austin, Texas, 39 pp.

Morton, R.A. and Peterson, R.L., 2005. Southeast Texas Coastal Classification Maps - Sabine Pass to the Colorado River. Coastal Classification Atlas, USGS Open File Report 2005-1370. http://coastal.er.usgs.gov/coastal-classification/.

Morton, R.A. and Peterson, R.L., 2006a. Central Texas Coastal Classification Maps - Aransas Pass to Mansfield Channel. Coastal Classification Atlas, USGS Open File Report 2006-1096. http://coastal.er.usgs.gov/coastal-classification/.

Morton, R.A. and Peterson, R.L., 2006b. South Texas Coastal Classification Maps - Mansfield Channel to the Rio Grande. Coastal Classification Atlas, USGS Open File Report 2006-1133. http://coastal.er.usgs.gov/coastal-classification/.

Morton, R.A. and McGowen, J.H., 1980. Modern Depositional Environments of the Texas Coast. Guidebook No. 20, Bureau of Economic Geology, University of Texas at Austin, Austin, Texas, 167 pp.

Morton, R.A. and Sallenger, A.H., Jr., 2003. Morphological impacts of extreme storms on sandy beaches and barriers. Journal of Coastal Research, 19(3): 560-573.

National Oceanic and Atmospheric Administration 2005a. National Weather Service, Preliminary Storm Report Hurricane Rita, Brownsville, TX. http://www.weather.gov/rita/PSHBRO.txt.

National Oceanic and Atmospheric Administration 2005b. National Geodetic Survey, Hurricane Rita Images. http://ngs.woc.noaa.gov/rita/.

National Oceanic and Atmospheric Administration 2005c. National Weather Service, Preliminary Storm Report Hurricane Rita, Corpus Christi, TX. http://www.srh.noaa.gov/lch/rita/rita_pshCRP.php.

National Oceanic and Atmospheric Administration, 2006. Coastal Services Center, Historical Hurricane Tracks. http://maps.csc.noaa.gov/hurricanes/viewer.html.

National Oceanic and Atmospheric Administration, 2007. National Hurricane Center, Saffir-Simpson Hurricane Scale. http://www.nhc.noaa.gov/aboutsshs.shtml.

Office of the Texas State Climatologist, 2006. Texas Climatic Bulletin, vol. 19, no. 5, May 2006. http://www.met.tamu.edu/met/osc/tx/MayBull06.htm.

Savage, R.P., Baker, J., Kareem, A. and Manning, B.R., 1984. Hurricane Alicia: Galveston and Houston, Texas, August 17-18, 1983, National Research Council, 168 pp. http://www.csc.noaa.gov/hes/docs/postStorm/H_ALICIA_GALVESTON_HOUSTON.pdf.

Scott, A.J., Hoover, R.A. and McGowen, J.H., 1981. Effects of Hurricane "Beulah", 1967 on Texas coastal lagoons and barriers. In: S.P. Leatherman (Editor), Overwash Processes. Benchmark Papers in Geology. Hutchinson Ross Publishing Company, Stroudsburg, PA, pp. 215-224.

Simpson, R.H. and Riehl, H., 1981. The Hurricane and Its Impact. Louisiana State University Press, Baton Rouge, 398 pp.

Stockdon, H.F., Sallenger, A.H., List, J.H. and Holman, R.A., 2002. Estimation of shoreline position and change using airborne topographic Lidar data. Journal of Coastal Research, 18(3): 502-513.

Suter, J.R., Nummedal, D., Maynard, A.K. and Kemp, P., 1982. A process-response model for hurricane washovers. In: B.L. Edge (Editor), Eighteenth coastal engineering conference, Cape

Town, South Africa, Nov. 14-19, 1982. Proceedings of the Eighteenth Coastal Engineering Conference. Am. Soc. Civ. Eng., New York, NY, United States (USA), pp. 1459-1478.

Texas Administrative Code, 2007. Rules for Management of the Beach/Dune System, http://info.sos.state.tx.us/pls/pub/readtac$ext.ViewTAC?tac_view=5&ti=31&pt=1&ch=15&sch=A&rl=Y.

Texas General Land Office, 2007a. 2006 Aerial Photographs. http://www.glo.state.tx.us/coastal/photos/2006may/index.html.

Texas General Land Office, 2007b. Environmental Sensitivity Index Shoreline. http://www.glo.state.tx.us/gisdata/metadata/esi_beg.htm.

Texas General Land Office, 2007c. BEG Washover Polygons. http://www.glo.state.tx.us/gisdata/gisdata.html.

Texas General Land Office, 2007d. LIDAR data. http://www.glo.state.tx.us/coastal/photos/index.html.

Texas Natural Resources Information System, 2007. Data Search and Download. http://www.tnris.state.tx.us/datadownload/county.jsp?Name=Matagorda.

Webster, T., Christian, M., Sangster, C. and Kingston, D., 2005. High-resolution elevation and image data within the Bay of Fundy coastal zone, Nova Scotia, Canada. In: D. Bartlett and J. Smith (Editors), GIS for Coastal Zone Management. CRC Press, Boca Raton, pp. 195-218.

URS Corporation, 2006. Hurricane Rita Rapid Response Texas Coastal and Riverine High Water Mark Collection, Federal Emergency Management Agency Hazard Mitigation Technical Assistance Program Contract No. EMW-2000-C0-0247, 60 pp.

Appendix A
Report: Significant Storm Event Data

SIGNIFICANT STORM DATA

Kimberly K. McKenna, P.G.
P.O. Box 9586, Newark, DE 19714
k.k.mckenna@comcast.net

Summary

The purpose of this report is to identify strong storms that made landfall on the Texas coast and compile storm data that best represents overwash conditions. These data may be used in models that estimate potential overwash and dune breaching settings on barrier islands. Though tropical storms can cause overwash, only hurricanes ranging from Category 1 through 5 and from those, only the hurricanes that affected Gulf coastal *Priority Areas* identified by the General Land Office (GLO) staff are included in this report (GLO, 2007). The hurricanes that were chosen were observed, or are assumed to have caused erosion and created washovers on the Texas barrier islands. All chosen hurricanes occurred after 1940 when vertical aerial photography became more common and could be available through the Texas Natural Resources Information System (TNRIS) aerial photo archives.

Introduction

Winds and lower barometric pressure brought on by hurricanes can cause the water level in the Gulf of Mexico to rise above barrier elevations resulting in beach and dune erosion and breaches by overwash. To study overwash processes, information on the primary controlling factors that may have caused them should be compiled including: storm data, barrier geomorphology, geology, and human alterations to the landscape such as infrastructure, buildings, and access ways. Barrier islands and spits can also be breached from the lagoon or bay side by precipitation brought by hurricanes; however, a review of this process was not included in this scope of work.

This deliverable supplies information on storms that likely caused overwash. Along the Texas coast, remnants of washover areas (channels and deposits) are the direct result of previous strong storms. This *Task 2* document includes information from nine named storms that made landfall on the Texas coast as hurricanes. Priority areas for researching the impacts of hurricanes on overwash potential were chosen by staff of the GLO and include in priority order (Figure 1):

A. SOUTH PADRE ISLAND;
B. FOLLETS' ISLAND;
C. MUSTANG ISLAND;
D. WEST GALVESTON ISLAND;
E. EAST MATAGORDA PENINSULA.

Figure 1. Locations of Priority Areas.

Figure 2 shows the paths of the 24 recorded hurricanes (Saffir-Simpson Categories 1 through 5, from 1940 to 2006 [Simpson and Riehl, 1981; NOAA, 2007a]) that made landfall on the Texas coast. Table 1 provides the dates and conditions at landfall for the hurricanes in Figure 2.

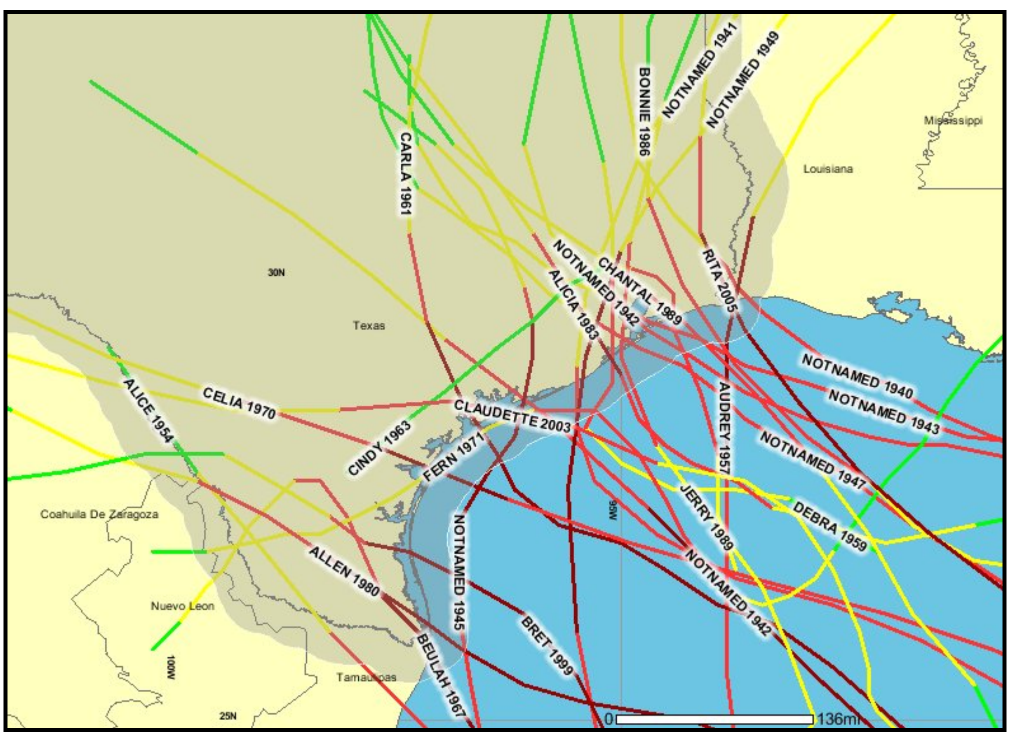


Figure 2. Paths of hurricanes passing within 25 nautical miles of the Texas coast from 1940 to 2006 (NOAA, 2007a).

Year	Month	Day	Name	Wind Speed (mph)	Pressure (mb)	Category
1940	8	8	NOT NAMED	70	972	H1
1941	9	23	NOT NAMED	70	ND	H1
1942	8	21	NOT NAMED	65	ND	H1
1942	8	30	NOT NAMED	95	ND	H2
1943	7	27	NOT NAMED	75	ND	H1
1945	8	27	NOT NAMED	120	966	H4
1947	8	24	NOT NAMED	70	ND	H1
1949	10	4	NOT NAMED	115	ND	H4
1954	6	25	ALICE	70	ND	H1
1957	6	27	AUDREY	125	946	H4
1959	7	25	DEBRA	70	984	H1
1961	9	11	CARLA	125	931	H4
1963	9	17	CINDY	65	997	H1
1967	9	20	BEULAH	140	931	H5
1970	8	3	CELIA	110	945	H3
1971	9	10	FERN	70	988	H1
1980	8	10	ALLEN	110	935	H3
1983	8	18	ALICIA	100	963	H3
1986	6	26	BONNIE	75	995	H1
1989	8	1	CHANTAL	70	984	H1
1989	10	16	JERRY	75	983	H1
1999	8	22	BRET	100	951	H4
2003	7	15	CLAUDETTE	75	982	H1
2005	9	24	RITA	100	935	H3

Table 1. Hurricanes that made landfall on the Texas coast between 1940 and 2006 (NOAA, 2007a).

Data Collected

Storms in Table 1 were evaluated to determine the location of landfall with respect to the Priority Areas and the availability of aerial photography and storm data. Nine hurricanes were identified in the broad geographical areas (Lower Coast, Upper Coast, and Coastal Bend) for the more detailed evaluation presented in this report (Figure 3):

A. Lower Coast hurricane landfalls – Priority Areas: South Padre Island and Mustang Island

Beulah (1967)
Allen (1980)
Bret (1999)

B. Upper Coast hurricane landfalls – Priority Areas: West Galveston Island and Follets' Island

Cindy (1963)
Alicia (1983)
Rita (2005)

C. Coastal Bend hurricane landfalls – Priority areas: Mustang Island and East Matagorda Peninsula

Carla (1961)
Celia (1970)
Claudette (2003)

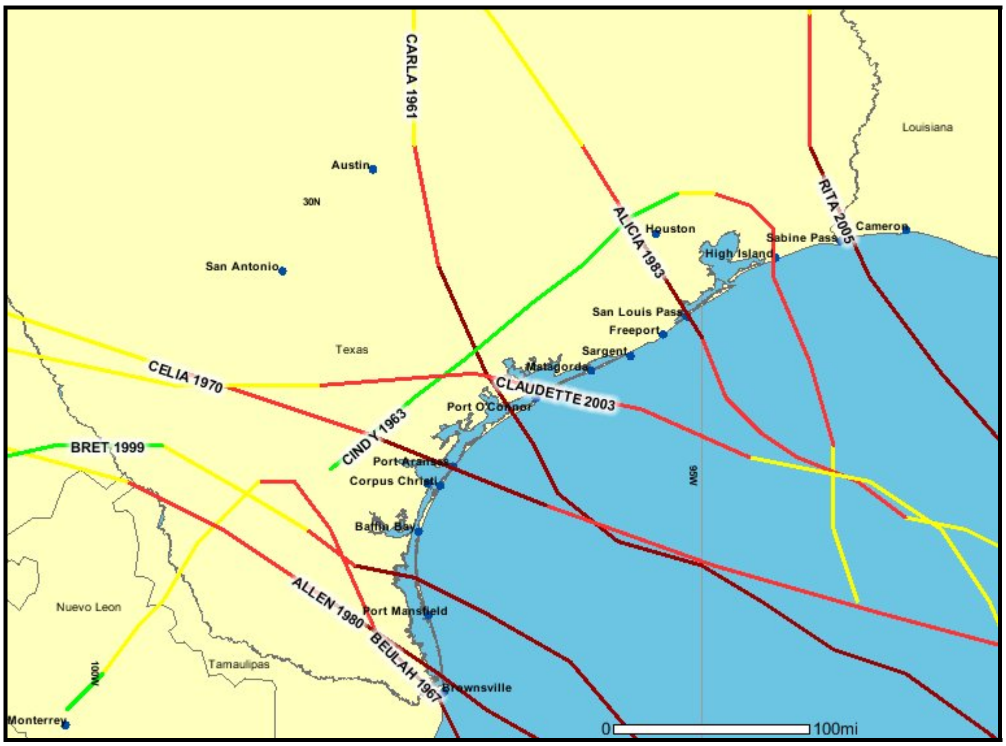


Figure 3. Tracks of the nine hurricanes evaluated in this report (NOAA, 2007a).

For some hurricanes, wind speed, pressure, and location track are available as data layers for geographic information systems (GIS) and may be useful in determining the duration of strong winds (NOAA, 2007a).

Hurricane parameters were compiled to enable the proposed interpretation of the impacts to *Priority Area* barriers. The storm characteristics compiled are: point of landfall; distance and location from landfall to the *Priority Area*; Saffir-Simpson hurricane intensity category at landfall; winds; deepwater wave height; storm surge elevation; and wave and tide information. These characteristics were identified as critical parameters in determining the morphological responses and washover penetration on coastal barriers (Suter et al., 1982; Morton and Sallenger, 2003;

Donnelly and Sallenger, 2007). In addition to these characteristics, a *Notes* section is included for each of the hurricanes. These sections contain excerpts or direct quotes about the state of the coast during the storm by National Oceanic and Atmospheric Administration (NOAA) observers or other researchers.

Figure 4 shows the locations of active tide gauges along the Texas coast. Historical water levels (tides) are available from the NOAA/ National Ocean Service (NOS) for all of the major storms included in this report.

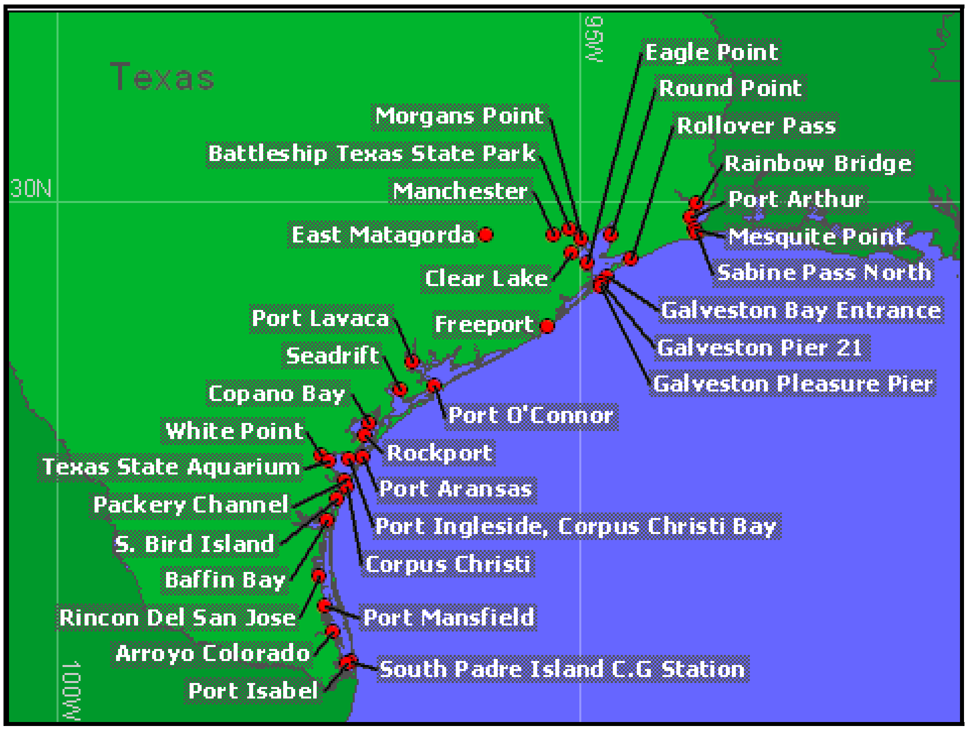


Figure 4. Tide gauges from NOAA/NOS (NOS, 2007b).

Figure 5 shows the locations of buoys included in the NOAA National Data Buoy Center (NDBC) database. The NDBC stations collect valuable data regarding wind speed, peak gusts, wind direction, and significant wave heights. This information can be useful as input variables into coastal flood models. Historical data sets for NDBC buoys are available from NOAA (NOAA, 2007c). Definitions of acronyms are provided in Appendix A.

Periods of record vary by buoy. The oldest date of service for buoys along the Texas coast is 1973 (station 42002); however, other buoy stations began collection in 1990. In addition to the buoys, the NDBC also maintains the U.S. Coast Guard Coastal-Marine Automated Network (C-MAN) stations. These stations were established in the early 1980s and record meteorological data such as barometric pressure, wind direction, speed and gust, and air temperature and some are able to measure water level and waves, among others.

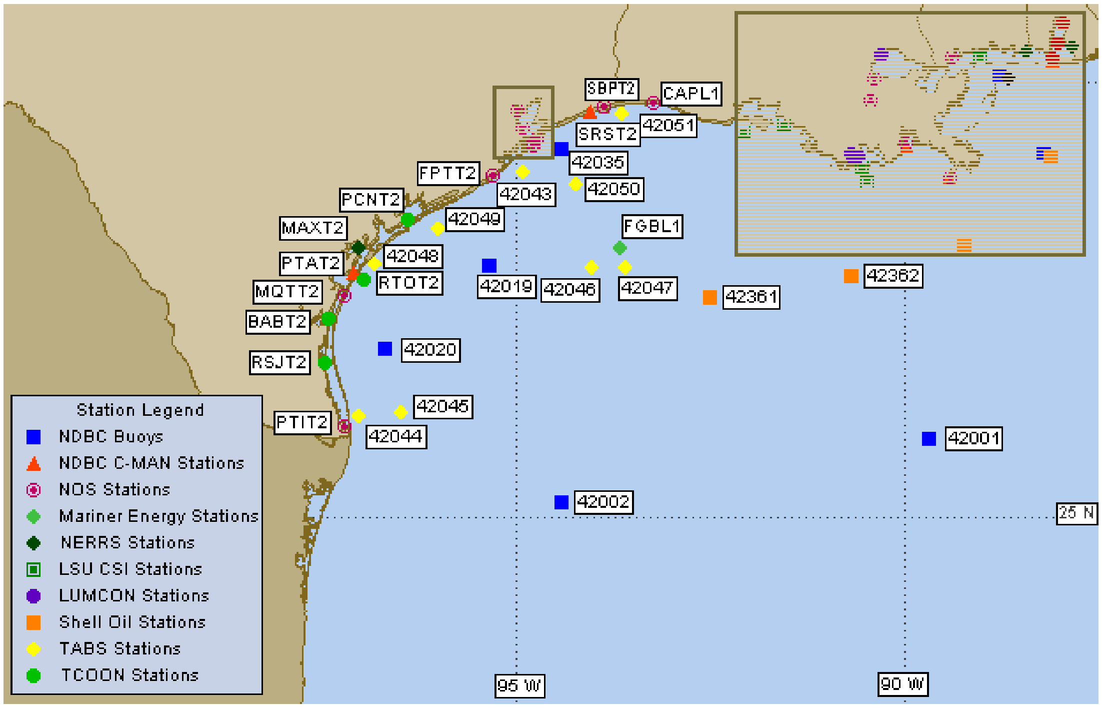
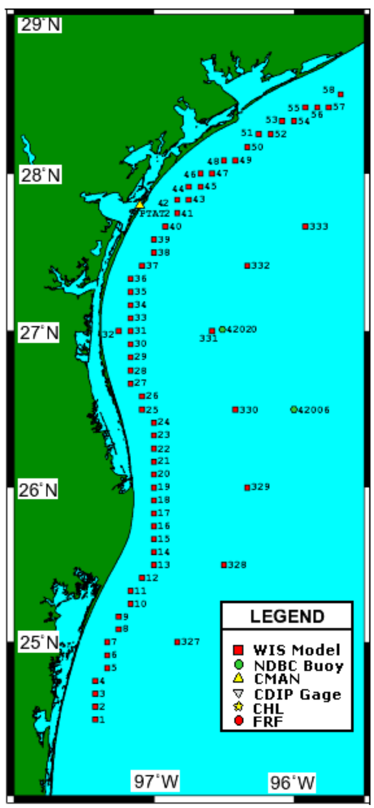
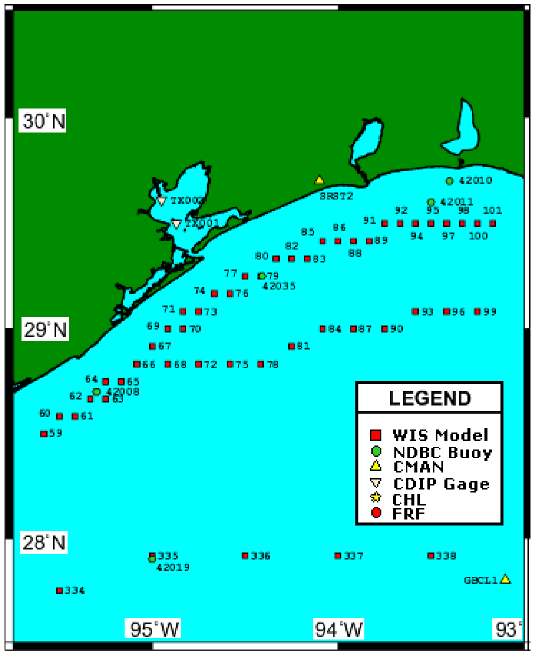


Figure 5. Locations of Texas and western Gulf of Mexico buoys (NOAA 2007c).



6A. Lower Coast



6B. Upper Coast

Figure 6A and 6B. Locations of USACE WIS hindcast stations offshore Texas (USACE, 2007).

Where buoy data were not available, NOAA tide gauge and/or hindcast wave data from the U.S. Army Corps of Engineers (USACE) wave information studies (WIS) of the Gulf of Mexico was used (USACE, 2007) (Figure 6A and 6B). Hindcast WIS data are theoretically-calculated nearshore wave elevations which are compared to actual buoy data. Definitions of acronyms used in WIS data are provided in Appendix A.

The following section provides event data for the nine hurricanes chosen for review. The data are given in geographic region in general order by Priority Area. Appendix B provides a list of available storm data for each Priority Area.

LOWER COAST
Priority Areas – A. South Padre Island and C. Mustang Island

Hurricane Beulah, 1967

A. Point and Time of Landfall: Near mouth of Rio Grande, 7 am, September 20, 1967 (Figure 7)

B. Landfall with Respect to Priority Area: Within 3 miles of the southern boundary of the **South Padre Island** Priority Area and approximately 115 miles south of the center of **Mustang Island** Priority Area.

C. Saffir-Simpson Category at Landfall: 5

D. Wind:

Peak: estimated at 160 mph in Gulf of Mexico, (see *Notes* below); measured at 136 mph from S.S. SHIRLEY LYKES docked at Port Brownsville (US Army, 1968).
Sustained: 72 mph ESE measured at Corpus Christi (US Army, 1968)

Figure 7. Track of Hurricane Beulah and Priority Areas A and C (NOAA, 2007a).

E. Maximum Deepwater Wave Height: Unknown

F. Storm Surge Elevation (observed WL – harmonic predicted WL): Unknown; however, the still high water mark elevation of 9.4 ft msl at Nueces County Park No. 1 on Padre Island (US Army, 1968).

G. Waves:

Significant Height: Unknown
Significant Direction: Unknown
Period (peak): Unknown

H. Tide Level: 6.0 ft msl highest observed tide on September 20, 1967 (Port Aransas H. Caldwell Pier station ID 8775270) (U.S. Weather Bureau, 1967).

I. Notes:

No WIS data were available for this review. Beulah preceded data collection which began in 1980 for all stations offshore of the Texas coast (USACE, 2007). No NDBC meteorological data were available prior to 1973 (buoy 42002 was not available prior to 1973 and 42020 was not available prior to 1990).

The Port Mansfield tide gage was established in 1962 and is located between the South Padre Island and Mustang Island *Priority Areas*. Data collected at this gage are primary water level, air temperature, and water temperature; however, no tidal data were recorded for the September 18 to 23, 1967 time period that includes Hurricane Beulah landfall. (http://tidesandcurrents.noaa.gov/station_info.shtml?stn=8778490%20Port%20Mansfield,%20TX). Due to the lack of historical time-series data, storm information was extracted from the NOAA hurricane history description (NOAA, 2007d) that follows:

"At landfall winds near the center were about 136 miles an hour, and the central pressure, which had been as low as 27.26 inches (937 mb), was 28.07 inches, or 951 mb at Brownsville, which gave the storm a tide producing potential of about 15 feet. The highest winds and tides were expended against the coast about 20 miles north of Port Isabel. As the storm center moved over land southwest of Corpus Christi, generally higher winds occurred in inland areas of the Coastal Bend than in coastal areas. Gale winds began at Corpus Christi International Airport at 10:30 AM on Sept. 20 and continued until 2 AM on Sept. 21; a duration of 15.5 hours, and hurricane winds occurred in gusts between 5:57 PM and 8:40 PM on the 20th.

Flooding from salt water along the bays was added to by the very heavy rainfall and runoff from the rainfall over land. The water level in the bays was slow to fall because of the copious runoff from the rains inland, even though Corpus Christi Pass and two other new channels were opened between the bays and the Gulf by the storm. At one time the water level in the bays was about two feet higher than that in the Gulf, and the outflow through channels was very heavy.

Most of the damage from Beulah was from the floods following the storm's extremely heavy rains. Rainfall attributable to the storm ranged 10 to 20 inches over a widespread area of southern Texas, and amounts ranged up to nearly 30 inches. Adding also to the flooding potential of these rains, was the near saturation of the ground over wide areas resulting from earlier rains in August and September" (NOAA, 2007d).

Table 2 provides wind direction and speed, water levels, rainfall, and barometric pressure readings for some stations within the Lower Coast during Hurricane Beulah as documented by the National Weather Service. The highest water levels were measured near Aransas Pass at 7+ ft above msl. The speeds shown in Table 2 differ from those recorded by the National Weather Service, Southern Region Headquarters which found the greatest wind to be estimated at 160 mph (NOAA, 2007e).
J: Usefulness of Data:

The dataset for this storm is incomplete. Some data from Table 2 may be useful parameters for models estimating breaching conditions; however the majority of event data are unavailable.

Station	Highest Wind (MPH)				Lowest Pressure		Highest Tide, Ft. MSL	Rainfall (in)
	Dir.	Speed	Gust	Time, CDT 9/20/67	Pressure (in)	Time, CDT 9/20/67		
Corpus Christi Intl Airport	ESE	72	86	8:40 PM	29.25	6:05 PM		14.43
Corpus Christi Navy	ESE	67	69	1:10 PM	29.26	6:00 PM	5.1	
Aransas Pass	SE		84	8:20 PM	29.44	6-8 PM	7+	14.73
Rockport	ESE	58	81	11:30 PM	29.52	7:00 PM	6.4	12.30
Port Aransas							6.73	

Table 2. Rainfall, pressure, and water level data for Hurricane Beulah (from http://www.srh.noaa.gov/crp/docs/research/hurrhistory/Beulah/beulah.html).

Hurricane Allen, 1980

A. Point and Time of Landfall: Southern tip of South Padre Island, northeast of Brownsville around midnight on August 10, 1980 (Figure 8)

B. Landfall with Respect to Priority Area: At the southern boundary of the **South Padre Island** Priority Area and approximately 110 miles south of the center of **Mustang Island**.

C. Saffir-Simpson Category at Landfall: Category 3

D. Wind:
Peak: 138 mph at Port Mansfield (see *Notes* below)
Sustained: 55 mph at Corpus Christi Airport (see *Notes* below)

E. Maximum Deepwater Wave Height: 22.64 ft (NDBC buoy 42002- see Figure 5 for location)

F. Storm Surge Elevation: 12 ft at Port Mansfield; 7 and 9 ft in the Coastal Bend (see *Notes* below)

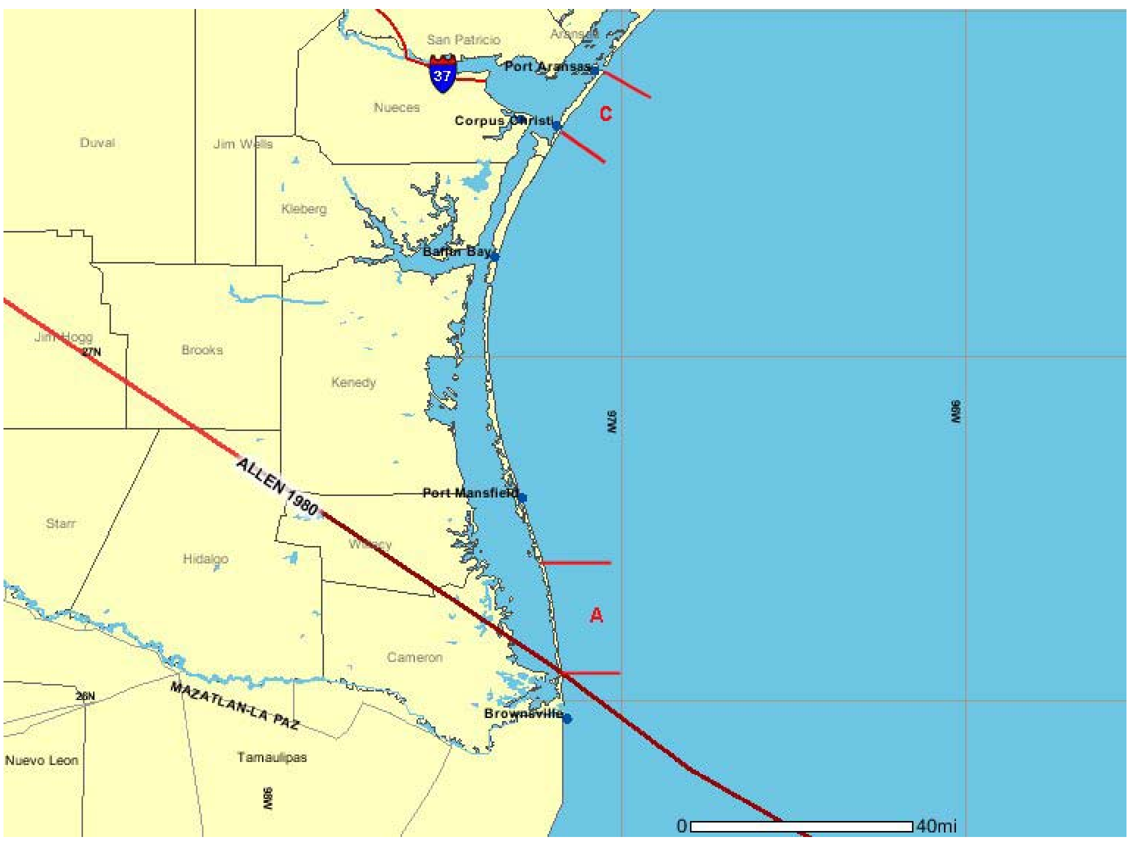


Figure 8. Track of Hurricane Allen at landfall and Priority Areas A and C (NOAA, 2007a).

G. Waves: NDBC buoy 42002, August 8, 1980, (NOAA, 2007c)
Significant Height: (WVHT) 22.64 ft
Significant Direction: (MWD) not available; (WD) 78º (from NE)
Period (peak): (DPD) 14.30 sec.

H. Tide Level: 1.55 ft mllw highest predicted tide on August 10, 1980 (Corpus Christi Bob Hall Pier, station ID 8775870) (NOAA, 2007b).

I. Notes:

The meteorological data from buoy 42002 were not available during the August 9 to 27, 1980 time period, so data from August 8, 1980 were used to provide wave heights and direction. The Corpus Christi tide gage No. 8775870 at Bob Hall Pier on the Gulf of Mexico was used to provide historic water levels for August 10, the date of landfall. However, higher tide levels were reported August 8 (NOAA, 2007b). Hurricane surge information was extracted from the NOAA hurricane history description (NOAA, 2007d):

"Daily rainfall records were set for Corpus Christi on the 9th and 10th (6.34 inches and 6.93 inches, respectively), which led to a new rainfall record for the month of August (14.39 inches). Daily rainfall records were also set on August 10 in Victoria (2.51 inches) and Laredo (3.92 inches). Flooding was a great problem. Ten to fifteen inch rains produced widespread flooding, the most critical being in the Kingsville area.

The highest wind gust reported was from Port Mansfield, registering 138 mph. At the Corpus Christi Airport, the highest sustained wind was 55 mph and the highest wind gust 92 mph, both occurring on August 10. Peak wind gusts at Port Aransas and Aransas Pass were between 105 and 110 mph.

Storm surges reached 12 feet at Port Mansfield, and between 7 and 9 feet in the Coastal Bend. The Naval Air Station in Corpus Christi estimated a surge of 9 feet. Padre Island was cut through in 68 places, and dunes previously on the island were leveled. Most buildings on South Padre Island were destroyed except the Champion Club, its oldest building. Purdy's pier was destroyed. Also, 90 percent of the structures at Port Mansfield had major damage, while North Beach had 75 percent of its structures suffer major damage. In Corpus Christi, most of the damage was done to signs, trees, fences, shingles off roofs, and broken windows. Many boats in the downtown marina suffered major damage, and many were sunk tied at the docks. Finally, wind damage was also reported in the communities of Norias and Rachal, especially just before and after the eye of Allen passed."

J. Usefulness of Data:

There are probably sufficient data available to support models estimating breaching conditions.

Hurricane Bret, 1999

A. Point and Time of Landfall: Central Kenedy County, 20 miles north of Port Mansfield (60 miles south of Corpus Christi), about 5:45 pm, August 22, 1999 (Figure 9).

B. Landfall with Respect to Priority Area: Thirty-four miles north of the northern boundary of the **South Padre Island** Priority Area and approximately 57 miles south of the center of **Mustang Island**.

C. Saffir-Simpson Category at Landfall: Category 4

Figure 8. Hurricane Bret at landfall and Priority Areas A and C (NOAA, 2007a).

D. Wind: reported from Port Aransas C-MAN station (http://www.nhc.noaa.gov/1999bret.html)
Peak: 98 mph (gusts)
Sustained: 47 mph (max)

E. Maximum Deepwater Wave Height: 27 ft (NDBC buoy 42002- see Figure 5 for location) (NOAA, 2007c)

F. Storm Surge Elevation (observed WL – harmonic predicted WL): Theoretical from SLOSH model estimated 8 to 10 feet along Central and North Padre Island (from http://www.nhc.noaa.gov/1999bret.html).

G. Waves: NDBC buoy 42020, August 22, 1999 (NOAA, 2007c)
Significant Height: (WVHT) 26.9 ft
Significant Direction: (MWD) 148º (from SE)
Period (peak): (DPD) 11.11 sec.

H. Tide Level: 3.01 ft mllw highest observed tide on August 22, 1999 (Corpus Christi Bob Hall Pier, station ID 8775870) (NOAA, 2007b). The surge water level was measured at 2.85 ft mllw obtained from the Texas Coastal Ocean Observation Network (TCOON, 2007)

I. Notes:

Some storm information for this report was extracted from the NOAA hurricane history description (NOAA, 2007d):

"By Saturday evening (August 21) Bret quickly intensified to a major hurricane (category 3 or greater), reaching category 4 strength by 7:00 p.m. Saturday. In just 18 hours, the central surface pressure in the storm dropped from 980 millibars (mb) to 952 mb. Maximum sustained winds increased from 90 to 135 mph around the center. At 10:00 p.m. Saturday evening, the NHC extended hurricane warnings to Port O'Connor, Texas 80 miles northeast of Corpus Christi. Now, the center of Bret was located about 250 miles southeast of Corpus Christi. Sunday morning (August 22) Bret lingered 115 miles southeast of Corpus Christi with maximum sustained winds of 140 mph. The lowest estimated central pressure was 944 mb, (27.88 inches). Late Sunday morning, Bret finally slowed and churned slowly west-northwest, focusing its eventual landfall between Brownsville and Corpus Christi. In two days, reports in excess of 15 inches fell over central Kenedy County. Elsewhere around the Coastal Bend, 6 to 10 inch rainfall amounts were reported. Flash flooding became a concern, as extremely heavy rains within Bret's squalls persisted over the same areas. Several major roadways around Corpus Christi were closed due to high water.

An interesting meteorological phenomenon associated with Hurricane Bret, was the unusually small diameter of hurricane force winds that extended out from the center of this powerful storm. Even as Bret rapidly intensified to a major hurricane, the hurricane force winds (winds sustained of 75 mph or greater) extended out only 30 to 40 miles in all directions from the center. For major hurricanes (winds greater than 115 mph), the typical outward extent of hurricane force winds is 60 to 80 miles from the center, and sometimes more. This factor is normally dependent on the total size of the hurricane and its strength. The total size of the Bret was 250 to 300 miles in diameter, similar to the size of Hurricane Andrew that slammed into south Florida in 1992. Because of the very small diameter of hurricane force winds, only Kenedy County experienced a surge of Gulf water where Bret made landfall.

Buoy 42020 at 45 miles southeast of Baffin Bay, recorded swells (waves) up to 27 feet. The center or "eye" of Hurricane Bret passed within 40 miles southwest of the buoy, producing sustained winds of 68 mph gusting to 85 mph from the southeast. Channel Cuts…where the center of Bret crossed Padre Island National Seashore, east of Kenedy County, as many as 12 new channel cuts were revealed by areal photography and visible satellite images. The largest cut was so wide, it was mistaken for Mansfield Pass. One cut was measured 150 feet wide and 5 to 10 feet deep. "

Greatest rainfall totals from August 21 to 24 were recorded at Exxon Gas Plant (Kleberg) at 16.00 inches and at Port Aransas at 14.5 inches. The highest wind (Direction/Speed) and gusts (G) were recorded at Port Aransas (PTAT2) at NE/48 G61 mph. Maximum storm tides occurred at Bob Hall Pier at 2.6 feet above mean sea level (msl) and at Port Aransas at 1.8 feet msl (NOAA, 2007d).

J: Usefulness of Data:

There are probably sufficient data available to support models estimating breaching conditions.

UPPER COAST
Priority Areas – B. Follets Island, D. West Galveston Island, and E. East Matagorda Peninsula

Hurricane Cindy, 1963

A. Point of Landfall: Near High Island, September 17, 1963 (Figure 9).

B. Landfall with Respect to Priority Area: 60 miles NE of the center of the **Follets Island** Priority Area, 44 miles NE of the center of the **W. Galveston Island** Priority Area, and 106 miles NE from the center of the **E. Matagorda Peninsula Priority Area.**

C. Saffir-Simpson Category at Landfall: Category 1

Figure 9. Track of Hurricane Cindy and Priority Areas B., D., and E. (NOAA, 2007a).

D. Wind:

Peak: 74 mph at Galveston (see *Notes* below)
Sustained: not available

E. Maximum Deepwater Wave Height: not available

F. Storm Surge Elevation (observed WL – harmonic predicted WL): not available

G. Waves:
Significant Height: not available
Significant Direction: not available
Period (peak): not available

H. Tide Level: 2.18 ft mllw highest predicted tide on September 17, 1963 (Galveston Pleasure Pier, station ID 8771510) (NOAA, 2007b)

I. Notes:

There are no historical buoy data available for Hurricane Cindy. Information supplied by NOAA include winds (mph): Galveston at 74, Sabine estimated at 75, High Island 60-69, Houston Yacht Club at 64 and pressure (inches): High Island at 29.45 and Houston at 29.73 (http://www.srh.noaa.gov/hgx/hurricanes/1960s.htm). Tide gauge information was available from the Galveston Pleasure Pier station no 8771510 (NOAA, 2007b).

No WIS data were available for this review. H. Cindy preceded data collection which began in 1980 for all stations offshore of the Texas coast (USACE, 2007).

J. Usefulness of Data:

Event data for this storm is incomplete and not sufficient to support models estimating breaching conditions.

Hurricane Alicia, 1983

A. Point and Time of Landfall: San Luis Pass, early morning, August 18, 1983 (Figure 10).

B. Landfall with Respect to Priority Area: At the NE boundary of the **Follets Island** Priority Area, at the SW boundary of the **W. Galveston Island** Priority Area, and 55 miles NE from the center of the **E. Matagorda Peninsula** Priority Area.

C. Saffir-Simpson Category at Landfall: Category 3

D. Wind: Alvin, Texas Weather Station
Peak: 127 mph (see *Notes* below)
Sustained: 96 mph

E. Maximum Deepwater Wave Height: not available

F. Storm Surge Elevation (observed WL – harmonic predicted WL): 12 ft at Seabrook (see *Notes* below) and 12.7 ft above msl measured at San Luis Pass (Morton and Paine, 1985)

Figure 10. Track of Hurricane Alicia and Priority Areas B., D., and E. (NOAA, 2007a).

G. Waves: from WIS station 67, August 18, 1983 (USACE, 2007)
Significant Height: (Hmo) 21.8 ft
Significant Direction: (wv) 115º, from the SE
Period (peak): (DTp) 12.5 sec

H. Tide Level: 2.27 ft mllw predicted tide on August 18, 1983 (Galveston Pleasure Pier, station ID 8771510) (NOAA, 2007b)

I. Notes:

The meteorological data from buoys 42035, 42019, 42010, 42011, 42008 were not available during the August 16 to 18, 1983 time period. The Galveston Pleasure Pier tide gauge No. 8771510 on the Gulf of Mexico was used to provide water levels for August 18, 1983 (NOAA, 2007b). Some storm statistics for this report were extracted from the USACE and National Weather Service hurricane history descriptions that follow:

"Wind waves from the storm began to affect the beaches of the Gulf shore long before the early winds of the storm reached shore. During the two-day period that the Gulf water level was rising, the beaches were continually responding to unusual waves and water levels. The waves, fresh from their generation areas in the nearby storm, were short and steep. Moving ashore on the high water level, they eroded the beaches and dunes behind the beaches, cutting further into the dunes as time passed and water levels rose. Along most of western Galveston Island and some of western Bolivar Peninsula, Gulf water levels eventually rose so high that waves began to overtop low areas in the dunes, usually at street ends. Water carrying sand then began to flow across the highway behind the beach and down the back of the island into the bays. As the Gulf water levels increased further and the dunes behind the beach continued to erode, water overtopped most of western Galveston Island, flowing across the highway and the island. Water depths on the island were from 1 to 3 ft, and overwash fans of sand up to 3 ft deep were created extending inland from the beach. As water levels in the Gulf rapidly receded after the peak of the storm surge, the water in the bays behind Follets Island flowed Gulfward through low places in the dunes, cutting more than 30 channels across the dunes and beach seaward of the highway. In several places these cuts reached the highway and began to undercut the pavement."
http://chps.sam.usace.army.mil/USHESDATA/Assessments/alicia/introduction.htm

"The highest winds recorded on land were 96 mph sustained, and gusts were up to 127 mph. The lowest barometric pressure recorded on land was 28.55 in at the Alvin weather service office. Rainfall amounts exceeded 5 inches in most places, and the east side of Houston received almost 11 inches. The highest storm surge was a 12 ft reading at Seabrook on Galveston Bay. On the gulf side of Galveston Island, tides were 7.5 ft, and on the bay they were 8 ft"
http://www.srh.noaa.gov/hgx/hurricanes/1980s.htm#Alicia1983

J. Usefulness of Data:

Event data for this storm is incomplete and not sufficient to support models estimating breaching conditions.

Hurricane Rita, 2005

A. Point and Time of Landfall: Louisiana Chenier Plain, around 2:30 am CDT, September 24, 2005 (Figure 11).

B. Landfall with Respect to Priority Area: 100 miles NE from the center of the **Follets Island** Priority Area, approximately 90 miles NE from the center of the **W. Galveston Island** Priority Area, and 150 miles NE from the center of **E. Matagorda Peninsula** Priority Area.

C. Saffir-Simpson Category at Landfall: Category 3

D. Wind: NDBC buoy 42035 (NOAA, 2007c) (see *Notes* below)
Peak: 76.3 mph
Sustained: 63 mph (120 mph http://www.ncdc.noaa.gov/oa/climate/research/2005/rita.html)

E. Maximum Deepwater Wave Height: 20 ft at NDBC buoy 42035 (NOAA, 2007c)

F. Storm Surge Elevation (observed WL – harmonic predicted WL): 5 ft at Sabine Pass (http://www.nhc.noaa.gov/pdf/TCR-AL182005_Rita.pdf)

Figure 11. Track of Hurricane Rita and Priority Areas B., D., and E (NOAA, 2007a).

G. Waves: NDBC buoy 42035 (NOAA, 2007c)
Significant Height: (WVHT) 15.4 ft
Significant Direction: (MWD) 324º (from NW)
Period (peak): (DOMPD) 16 sec

H. Tide Level: 9.82 ft mllw observed tide on August 24, 2005 (Sabine Pass, station ID 8770570) (NOAA, 2007b)

I. Notes:

Meteorological data was provided by NDBC buoy 42035, located offshore Bolivar Peninsula, for September 24, 2005 (NOAA, 2007c). Hindcast data is not available (1980 to 1999). LIDAR survey analyses are available from the US Geological Survey, Coastal and Marine Geology Program (Morton and Peterson, 2005).

J: Usefulness of Data:

There are probably sufficient data available to support models estimating breaching conditions.

COASTAL BEND
Priority Areas – C. Mustang Island and E. East Matagorda Peninsula

Hurricane Carla, 1961

A. Point and Time of Landfall: Between Port O'Connor and Port Lavaca, around noon CST, September 11, 1961 (Figure 13).

B. Landfall with Respect to Priority Area: Approximately 43 miles NE from the northeast boundary of the **Mustang Island** Priority Area and about 45 miles SW from the southwest boundary of the **E. Matagorda Peninsula** Priority Area.

C. Saffir-Simpson Category at Landfall: Category 4

D. Wind: (see *Notes* below)
Peak: 170 mph at Port Lavaca (NOAA, 2007d); 94 mph N.N.E. at Victoria and 112 S.E. at Galveston (US Army Engineer District, 1962)
Sustained: over 150 mph

E. Maximum Deepwater Wave Height: not available

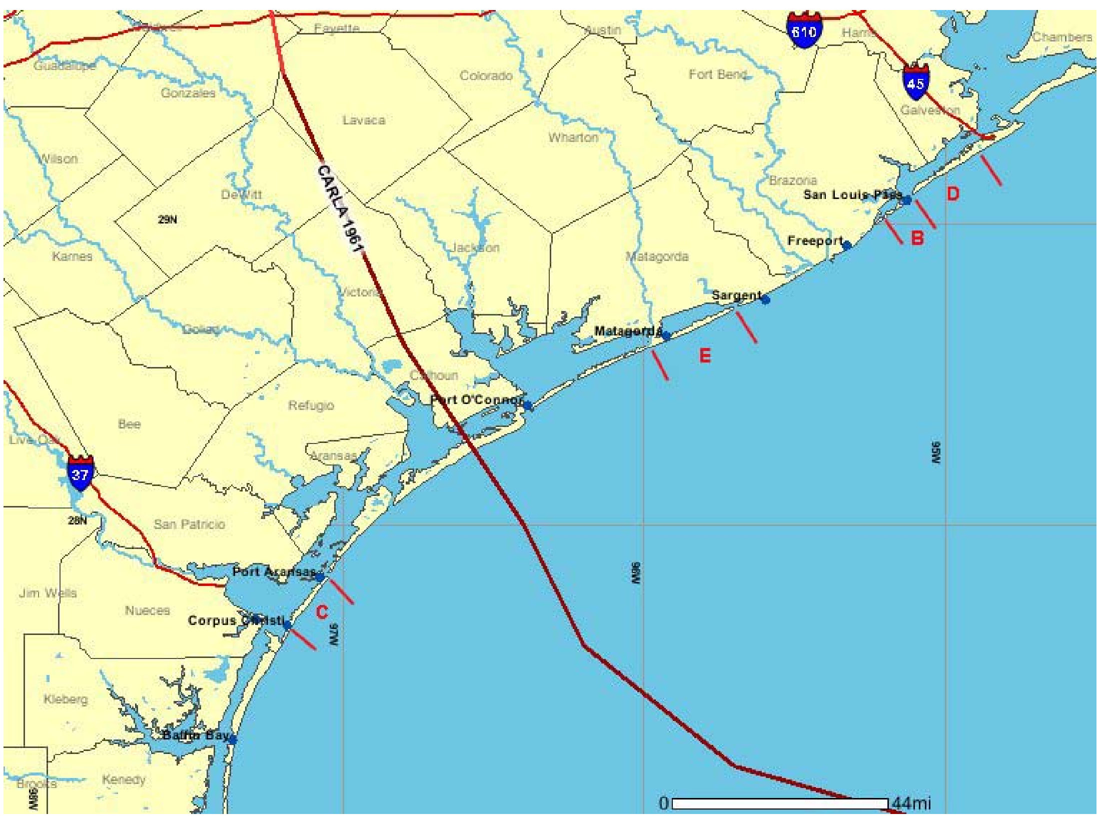


Figure 13. Track of Hurricane Carla and Priority Areas C. and E. (NOAA, 2007a).

F. Storm Surge Elevation (observed WL – harmonic predicted WL): 18.5 ft at Port Lavaca (see *Notes* below)

G. Waves:

Significant Height: not available
Significant Direction: not available
Period (peak): not available

H. Tide Level: 1.72 ft mllw highest predicted tide on September 11, 1961 (Port Aransas H. Caldwell Pier station ID 8775270) (NOAA, 2007b). The highest observed tide gage water levels were recorded on September 11, 1961:

i. Saluria Bayou Coast Guard Station near Port O'Connor at 12.3 feet msl (US Army Engineer District, 1962); ii. Galveston Pleasure Pier (station ID 8771510) at 9.1 ft NGVD29 (Ho and Miller, 1982); and iii. Port Aransas H. Caldwell Pier station ID 8775270 at 9.0 ft NGVD29 (Ho and Miller, 1982).

I. Notes:

There is no historical buoy data is available for Hurricane Carla, nor were WIS data available for this review. H. Carla preceded data collection which began in 1980 for all stations offshore of the Texas coast (USACE, 2007). NOAA observations follow:

"Hurricane Carla made landfall between Port O'Connor and Port Lavaca on the day of September 11, 1961. In the open waters of the Gulf, a minimum central pressure of 931mb, or 27.50 inches along with maximum sustained wind speeds over 150 mph, made Carla a category 5 hurricane on the Saffir-Simpson scale of hurricane intensity. When the "eye" or center of Hurricane Carla made landfall early in the morning of the 11th, the intensity had dropped off but the storm was still packing winds of 120 mph in areas from Port O'Connor up the coast to Galveston. The "eye" of the storm came within 65 miles to the east of Corpus Christi.

Hurricane warnings were issued along the entire Texas coast on the 9th prompting immediate evacuation of all islands just offshore and low coastal areas. The wind, not the rain, became the major weather factor for the Coastal Bend area. Preliminary wind reports from locations hit hardest by Carla indicated sustained wind speeds of 115 mph in Matagorda…110 mph in Victoria…and 88 mph in Galveston. Peak wind gusts were estimated at 150 mph in Victoria and 170 mph at Port Lavaca. Average wind gusts of 80 to 90 mph were reported across Corpus Christi, with a peak wind of 81 mph recorded at the tower of the Weather Bureau Office, before failure of the instrument.

Rainfall amounts were heaviest from Port Lavaca up the coast to Galveston and within 50 miles inland, ranging from 10 to 16 inches in some spots. Galveston Airport recorded 16.49" of rain in a four-day period. Closer to home, at the airport in Corpus Christi, a relatively light 1.22" fell, but downtown Corpus had 5.15". Victoria recorded a notable 6.25" of rain.

With the intense wind, storm surge became a major problem. In some areas from Port Aransas to Sabine Pass, tides were 10 feet above normal…the highest levels since the storm of 1919. One report out of Port Lavaca had a tide level 18.5 feet above normal. The above normal tides produced extensive beach and inland damage to houses and businesses." (NOAA, 2007d)

In addition to the NOAA observations, other researchers evaluated the impacts of H. Carla on Mustang Island and E. Matagorda Peninsula. Observations included numerous washover channel formation and near destruction of the foredune ridge on Mustang Island (Hayes, 1967). Hayes also noted turbidite deposits located seaward of the barrier islands that formed from washout of the flood waters from the lagoons. Hurricane washover deposits were found to cover 18.4 million square meters (22 million square yards) along a 200 km (124.28-mile) stretch of shoreline (Morton and Sallenger, 2003).

J. Usefulness of Data:

Event data for this storm is incomplete and not sufficient to support models estimating breaching conditions.

Hurricane Celia, 1970

A. Point and Time of Landfall: Near Aransas Pass, afternoon, August 3, 1970

B. Landfall with Respect to Priority Area: Within the northeast boundary of the **Mustang Island** Priority Area and approximately 85 miles SW from the southwest boundary of the **E. Matagorda Peninsula** Priority Area.

C. Saffir-Simpson Category at Landfall: Category 3

D. Wind: (see *Notes* below)
Peak: (gusts) 150 mph from the NE
Sustained: 125 mph

E. Maximum Deepwater Wave Height: not available

F. Storm Surge Elevation (observed WL – harmonic predicted WL): not available

Figure 14. Track of Hurricane Celia and Priority Areas C. and E. (NOAA, 2007a).

G. Waves:

Significant Height: not available
Significant Direction: not available
Period (peak): not available

H. Tide Level: High water level at 9.2 ft msl (see *Notes* below, Figure 15)

I. Notes:

There is no historical buoy data is available for Hurricane Celia, nor were WIS data available for this review. H. Celia preceded data collection which began in 1980 for all stations offshore of the Texas coast (USACE, 2007). NOAA observations follow:

"Celia continued to move on a northwesterly track as further intensification occurred. At 5 p.m. on the 1st, Celia was upgraded to a hurricane; by midnight, she was packing 100 mph winds near the center. A hurricane warning was issued at 11 a.m., CDT, Sunday (8/2), for the Texas Gulf Coast from Palacios to Port Arthur, and evacuations were begun. The hurricane warnings were extended to the Corpus Christi area at 5 a.m., CDT, Monday. Late Monday morning, when Celia was only 95 miles east of Corpus Christi, an Air Force reconnaissance plane reported the maximum sustained wind at 115 mph near the center.

Celia's extreme winds caused the greatest destruction. At the cooperative weather station at Aransas Pass the highest sustained wind speed was 130 mph. The anemometer blew down after measuring wind gusts of 150 mph from the northeast. According to Robert L. Herndon, Cooperative Weather Observer, winds were much stronger on the back side of the storm. Aransas Pass was in the north quadrant of the hurricane's eye for 30 to 40 minutes. The maximum sustained wind at the Weather Bureau Office at Corpus Christi International Airport was 125 mph with a gust of 161 mph occurring at 5:28 p.m., CDT. A peak gust of 138 mph was observed at the Reynolds Metal Plant near Gregory.

The highest tides generated by Hurricane Celia were 9.2 feet above MSL and 9.0 feet above MSL, at Port Aransas Beach and Port Aransas Jetty, respectively. These occurred about 2:40 p.m., CDT, on the 3rd. The lowest station pressure recorded on land was 28.03 inches (949 mb), at 4:45 p.m., CDT, at Aransas Pass. The station elevation is 18 feet above mean sea level." (http://www.srh.noaa.gov/crp/docs/research/hurrhistory/Celia/report.html)

The highest tide levels were recorded at Port Aransas Beach (9.2 ft msl), Port Aransas Jetty (9.0 ft msl), and Mustang Island (7.9 ft msl) (http://www.nhc.noaa.gov/archive/storm_wallets/atlantic/atl1970-prelim/celia/prelim11.gif).

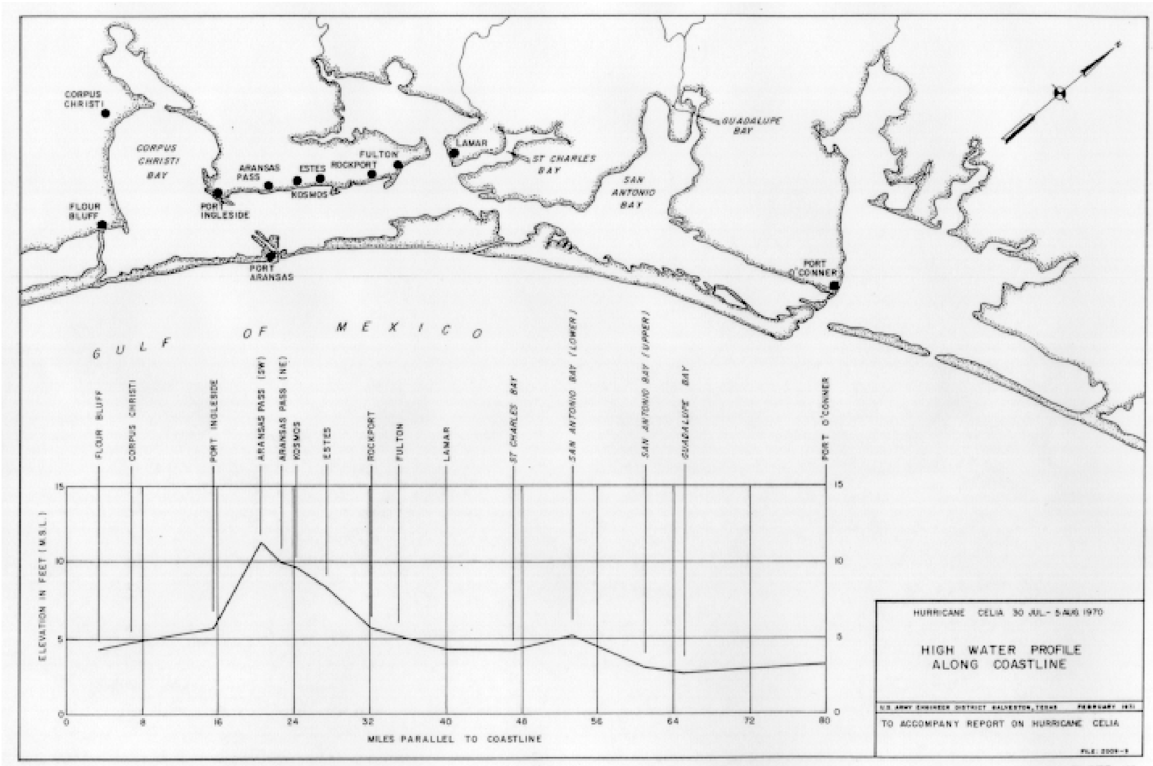


Figure 15. Hurricane Celia's highest water levels were recorded at Aransas Pass (http://www.srh.noaa.gov/crp/docs/research/hurrhistory/Celia/celia-13.jpg).

J. Usefulness of Data:

Event data for this storm is incomplete and not sufficient to support models estimating breaching conditions.

Hurricane Claudette, 2003

A. Point and Time of Landfall: Near Port O'Connor in the late morning of July 15, 2003 (Figure 16)

B. Landfall with Respect to Priority Area: 60 miles NE from the northeast boundary of the **Mustang Island** Priority Area and approximately 27 miles SW from the southwest boundary of the **E. Matagorda Peninsula** Priority Area.

C. Saffir-Simpson Category at Landfall: Category 1

D. Wind: Port O'Connor Texas Coastal Ocean Observation Network (TCOON) station (see *Notes* below)
Peak: 89.7 mph (gusts)
Sustained: 71.3 mph

E. Maximum Deepwater Wave Height: 18.2 ft (NOAA, 2007c)

F. Storm Surge Elevation (observed WL – harmonic predicted WL): 3 to 6 ft above normal tide levels at eye (see *Notes* below)

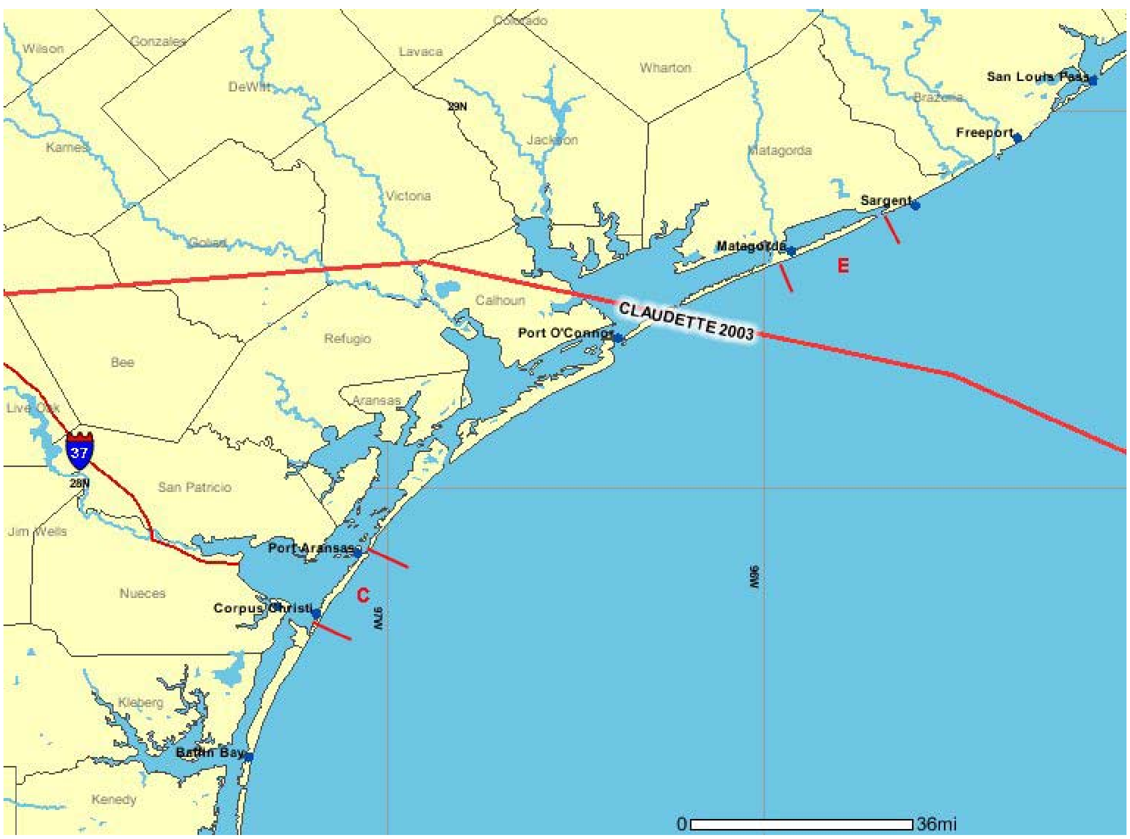


Figure 16. Track of Hurricane Claudette and Priority Areas C. and E. (NOAA, 2007a).

G. Waves: NDBC buoy 42019, (NOAA, 2007c)
Significant Height: (WVHT) 18.2 ft
Significant Direction: (MWD) 87º (near due E)
Period (peak): (DPD) 10 sec.

H. Tide Level: 6.13 ft mllw at Port O'Connor (from http://www.nhc.noaa.gov/2003claudette.shtml)

I. Notes:

Meteorological data was provided by NDBC buoy 42019 for July 15, 2003 (NOAA, 2007c). Hindcast data was not used because NDBC buoy data was available. NOAA observations include:

"Aircraft and surface data indicate hurricane conditions occurred over portions of the middle Texas coast. The maximum sustained winds reported by an official observing site was a 10-min average of 65 kt at the Remote Automated Weather Stations (RAWS) site on Matagorda Island, Texas. The Texas Coastal Ocean Observation Network (TCOON) station at Port O'Connor reported a 6-min average sustained wind 62 kt with a gust to 78 kt in the western eyewall. Victoria, Texas, reported 54-kt sustained winds with a gust to 72 kt, although that data is incomplete due to a power failure. The 84-kt and 83-kt unofficial observations suggest the possibility that Claudette strengthened to a Category 2 hurricane as it was making landfall. This was not supported by the aircraft data, which suggest maximum sustained winds of 75-80 kt as the eye crossed the coast. Data from the NWS WSR-88D Doppler radars indicated winds of 95-105 kt between 5,000-10,000 ft in the northwest eyewall after Claudette made landfall. It is uncertain how to convert these winds to sustained surface winds over land. However, reduction factors derived from GPS dropsonde data over water suggest 85-90 kt sustained surface winds. A further reduction for land friction would reduce the radar winds to at or below the 75-80 kt range suggested by the aircraft data.

Storm-surge flooding of 3-6 ft above normal tide levels occurred near where the eye of Claudette made landfall. Storm tides (storm surge plus astronomical tide) of 6-9 ft were measured in the Galveston-Freeport area. Tides were 1-2 ft above normal as far north as the southwestern Louisiana coast and as far south as the Baffin Bay, Texas area.

Claudette moved quickly westward after landfall, which limited rainfall totals. The highest storm-total rainfall was 6.5 in four miles south-southeast of Tilden, Texas), and there are other reports of 3-6 in amounts along the storm track. NWS WSR-88D radar data estimates that as much as 8 in may have fallen in some areas. These rains caused minor flooding in southern Texas and some flash flooding in southwestern Texas."
(http://www.nhc.noaa.gov/2003claudette.shtml)

I: Usefulness of Data:

There are probably sufficient data available to support models estimating breaching conditions.

REFERENCES

Donnelly, C. and Sallenger, A.H., 2007. Characterisation and modelling of washover fans. In: N.C. Kraus and J.D. Rosati (Editors), Coastal Sediments '07. Proceedings of the Sixth International Symposium on Coastal Engineering and Science of Coastal Sediment Processes. American Society of Civil Engineers, New Orleans, pp. 2061-2073.

General Land Office, 2007. General Work Order No. 1348-07-001.

Hayes, M.O., 1967. Hurricanes as Geological Agents: Case Studies of Hurricanes Carla, 1961, and Cindy, 1963. No. 61, Bureau of Economic Geology, University of Texas at Austin, Austin, Texas, pp. 55.

Ho, F.P. and Miller, J.F., 1982. Pertinent Meteorological and Hurricane Tide Data for Hurricane Carla. NOAA Technical Report NWS 32, US Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, Silver Spring, Maryland, pp. 111.

Morton, R.A. and Paine, J.G., 1985. Beach and Vegetation-Line Changes at Galveston Island, Texas: Erosion, Deposition, and Recovery from Hurricane Alicia. Geological Circular 85-5, University of Texas at Austin, Bureau of Economic Geology, Austin, Texas, pp. 39.

Morton, R.A. and Peterson, R.L., 2005. Southeast Texas Coastal Classification Maps - Sabine Pass to the Colorado River. Coastal Classification Atlas, USGS Open File Report 2005-1370. http://coastal.er.usgs.gov/coastal-classification/.

Morton, R.A. and Sallenger, A.H., 2003. Morphological impacts of extreme storms on sandy beaches and barriers. Journal of Coastal Research, 19(3): 560-573.

National Oceanic and Atmospheric Administration, 2007a, http://maps.csc.noaa.gov/hurricanes/viewer.html.

National Oceanic and Atmospheric Administration /National Ocean Service, 2007b, http://tidesonline.nos.noaa.gov/geographic.html.

National Oceanic and Atmospheric Administration /National Data Buoy Center, 2007c, http://www.ndbc.noaa.gov/measdes.shtml.

National Oceanic and Atmospheric Administration/National Weather Service Forecast Office, 2007d, http://www.srh.noaa.gov/crp/docs/research/hurrhistory/.

National Oceanic and Atmospheric Administration/National Weather Service Southern Region Headquarters, 2007e, http://www.srh.noaa.gov/bro/haw2007.htm#history.

Simpson, R.H. and Riehl, H., 1981. The hurricane and its impact: Baton Rouge, Louisiana State University Press, 398 p.

Suter, J.R., Nummedal, D., Maynard, A.K. and Kemp, P., 1982. A process-response model for hurricane washovers. In: B.L. Edge (Editor), Eighteenth coastal engineering conference, Cape Town, South Africa, Nov. 14-19, 1982. Proceedings of the Eighteenth Coastal Engineering Conference. Am. Soc. Civ. Eng., New York, NY, United States (USA), pp. 1459-1478.

Texas Coastal Ocean Observation Network (TCOON), Division of Nearshore Research, Conrad Blucher Institute for Surveying and Science, Texas A&M University-Corpus Christi, 2007, http://lighthouse.tamucc.edu/pq.

U.S. Army Corps of Engineers, 2007, http://frf.usace.army.mil/cgi-bin/wis/atl/atl_main.html.

U.S. Army Engineer District, 1962, Report on Hurricane Carla 9-12 September 1961. R-4-62, U.S. Army Engineer District, Galveston, Texas, pp. 29 plus appendices.

U.S. Army Engineer District, 1968, Report on Hurricane Beulah 8-21 September 1967. U.S. Army Engineer District, Galveston, Galveston, Texas, pp. 26 plus appendices.

U.S. Geological Survey, Coastal and Marine Geology Program, 2007, http://coastal.er.usgs.gov/hurricanes/rita/discussion.html.

U.S. Weather Bureau, 1967. Hurricane Beulah, September 7-22, 1967; Preliminary Report with Advisories and Bulletins Issued. U.S. Department of Commerce Environmental Science Services Administration, Silver Spring, Maryland, pp. 74.

Definitions of Acronyms Used in Data Sets

STANDARD METEOROLOGICAL DATA DEFINITIONS FOR NDBC DATA (NOAA, 2007C)

WDIR Wind direction (the direction the wind is coming from in degrees clockwise from true N) during the same period used for WSPD.

WSPD Wind speed (m/s) averaged over an eight-minute period for buoys and a two-minute period for land stations. Reported Hourly.

GST Peak 5 or 8 second gust speed (m/s) measured during the eight-minute or two-minute period. The 5 or 8 second period can be determined by payload.

WVHT Significant wave height (meters) is calculated as the average of the highest one-third of all of the wave heights during the 20-minute sampling period.

DPD Dominant wave period (seconds) is the period with the maximum wave energy.

APD Average wave period (seconds) of all waves during the 20-minute period.

MWD Mean wave direction corresponding to energy of the dominant period (DPD). The units are degrees from true North just like wind direction.

PRES Sea level pressure (hPa). For C-MAN sites and Great Lakes buoys, the recorded pressure is reduced to sea level using the method described in NWS Technical Procedures Bulletin 291 (11/14/80).

ATMP Air temperature (Celsius).

WTMP Sea surface temperature (Celsius).

DEWP Dewpoint temperature taken at the same height as the air temperature measurement.

VIS Station visibility (statute miles). Note that buoy stations are limited to reports from 0 to 1.9 miles.

PTDY Pressure Tendency is the direction (plus or minus) and the amount of pressure change (hPa) for a three hour period ending at the time of observation.

TIDE The water level in feet above or below Mean Lower Low Water (MLLW)

WIS DATA DEFINITIONS

ID Station number

YEAR Year using 4 digits

MM Month number (January is 1, October is 10)

DD Day of the month

HH Hour of day (GMT)

LONG Longitude of station (- indicates West Longitude) in degrees

LAT Latitude of station in degrees North

DPTH Depth of station in meters

Hmo Significant wave height in meters (includes high frequency parametric tail energy)

DTp Peak spectral wave period in seconds using discrete frequencies in calculation

Atp Peak spectral wave period in seconds using a parabolic fit in calculation

tmean Mean wave period in seconds calculated using the inverse first moment

wdvmn Overall vector mean wave direction in degrees using Meteorological (MET) convention

wv Vector mean wave direction at spectral peak frequency in degrees in MET convention

wsp Wind speed in meters per second

wdir Wind direction in MET convention

Appendix B
Photographic Data Sets

Hurricanes of Interest and Corresponding Aerial Photo Data Sets

	South Padre Island (Cameron Co)	Follets Island (Brazoria Co)	Mustang Island (Nueces Co)	West Galveston Island (Galveston Co)	East Matagorda Peninsula (Matagorda Co)
coastwide 1953-54 from GLO	http://www.glo.state.tx.us/coastal/photos/coastwide1954/index.html	http://www.glo.state.tx.us/coastal/photos/coastwide1954/index.html	http://www.glo.state.tx.us/coastal/photos/coastwide1954/index.html	http://www.glo.state.tx.us/coastal/photos/coastwide1954/index.html	http://www.glo.state.tx.us/coastal/photos/coastwide1954/index.html
H. Carla (9/11/1961)	not avail / no Cameron Co 1960s photos, use 1954	order from TNRIS 12/11/58	order from TNRIS 1-2/61	order from TNRIS 4/5/58	order from TNRIS 12/11/58
	order from TNRIS 1/62	from TNRIS photo archives 1/8/62	order from TNRIS 8-9/68	order from TNRIS 11/23/61	order from TNRIS 10/28/65
H. Cindy (9/17/1963)	order from TNRIS 1/62	order from TNRIS 11/23/61	order from TNRIS 1-2/61	order from TNRIS 1/8/62	order from TNRIS 12/11/58
	order from TNRIS 8/64	order from TNRIS 10/30/65	order from TNRIS 8-9/68	order from TNRIS 2/22/64	order from TNRIS 10/28/65
H. Beulah (9/20/1967)	order from TNRIS 8/64	order from TNRIS 10/30/65	order from TNRIS 1-2/61	order from TNRIS 2/22/64	order from TNRIS 10/28/65
	from TNRIS photo archives 8/13/68	order from TNRIS 9/28/67	order from TNRIS 8-9/68	order from TNRIS 11/28/68	order from TNRIS 1/26/75
H. Celia (8/3/1970)	from TNRIS photo archives 8/13/68	order from TNRIS 9/28/67	order from TNRIS 2-3/69	order from TNRIS 5/6/70	order from TNRIS 10/28/65
	order from GLO 6/17/74	June-Sep 1974 http://www.glo.state.tx.us/coastal/photos/1974jun-sept/index.html	order from TNRIS 2-6/74 or use 10/31/79 http://www.glo.state.tx.us/coastal/photos/nueces1979/index-east.html	June-Sep 1974 http://www.glo.state.tx.us/coastal/photos/1974jun-sept/index.html	TNRIS 1/26/75 did not include Peninsula
H. Allen (8/10/1980)	GLO roll no. 173 7/23/80	June-Sep 1974 http://www.glo.state.tx.us/coastal/photos/1974jun-sept/index.html	10/31/79 http://www.glo.state.tx.us/coastal/photos/nueces1979/index-east.html	3/14/78 http://www.glo.state.tx.us/coastal/photos/galveston1978/overview.html	from TNRIS photo archives 8/78 and 10/30/78
	GLO roll no. 175; 8/18/80; Willacy Gulf shoreline and few frames of Mustang Is	June-Sep 1982 http://www.glo.state.tx.us/coastal/photos/1982jun-sept/1.html	GLO roll no. 201; 4/12/82	June-Sep 1982 http://www.glo.state.tx.us/coastal/photos/1982jun-sept/1.html	order from TNRIS 10/21/81
H. Alicia (8/18/1983)	GLO roll no. 201; 4/12/82	June-Sep 1982 http://www.glo.state.tx.us/coastal/photos/1982jun-sept/1.html	GLO roll no. 201; 4/12/82	June-Sep 1982 http://www.glo.state.tx.us/coastal/photos/1982jun-sept/1.html	GLO roll no. 201; 4/12/82
	order from GLO 4/12/87	order from GLO 11/17/83 & 2/29/84	order from TNRIS 8/22/83	1/8/87 http://www.glo.state.tx.us/coastal/photos/galveston1987/overview.html	from TNRIS photo archives 2/15/91
H. Bret (8/22/1999)	1996 georef. photos avail from TNRIS http://www.tnris.state.tx.us/datadownload/	1996 georef. photos avail from TNRIS http://www.tnris.state.tx.us/datadownload/	1996 georef. photos avail from TNRIS http://www.tnris.state.tx.us/datadownload/	2/99 http://www.glo.state.tx.us/coastal/photos/galveston990223/galvis.html	1996 georef. photos avail from TNRIS http://www.tnris.state.tx.us/datadownload/
	9/3/00 http://www.glo.state.tx.us/coastal/photos/glo9-3-00/index-vertical.html	2/8/00 http://www.glo.state.tx.us/coastal/photos/mercator000208/brazoria.html	1/8/02 http://www.glo.state.tx.us/coastal/photos/glo01-08-02/index.html	2/8/00 http://www.glo.state.tx.us/coastal/photos/mercator000208/galvis.html	11/30/01 http://www.glo.state.tx.us/coastal/photos/matagorda11-30-01/upper.html

	South Padre Island (Cameron Co)	Follets Island (Brazoria Co)	Mustang Island (Nueces Co)	West Galveston Island (Galveston Co)	East Matagorda Peninsula (Matagorda Co)
H. Claudette (7/15/2003)	9/3/00 http://www.glo.state.tx.us/coastal/photos/glo9-3-00/index-vertical.html	3/03 http://www.glo.state.tx.us/coastal/photos/mar2003/index.html	1/8/02 http://www.glo.state.tx.us/coastal/photos/glo01-08-02/index.html	3/03 http://www.glo.state.tx.us/coastal/photos/mar2003/index.html	11/30/01 http://www.glo.state.tx.us/coastal/photos/matagorda11-30-01/upper.html
	2004 georef. photos avail from TNRIS http://www.tnris.state.tx.us/datadownload/	7/27/03 http://www.glo.state.tx.us/coastal/photos/claudette/aerials07-27-03/index-vertical.html	8/17-21/05 http://www.glo.state.tx.us/coastal/photos/2005aug/lowercoast/corpuschristi-padreisland.html	7/27/03 http://www.glo.state.tx.us/coastal/photos/claudette/aerials07-27-03/index-vertical.html	8/17-21/05 http://www.glo.state.tx.us/coastal/photos/2005aug/uppercoast/matagorda-brazos.html & http://www.glo.state.tx.us/coastal/photos/2005aug/lowercoast/matagordapeninsula.html
H. Rita (9/242005)	8/17-21/05 http://www.glo.state.tx.us/coastal/photos/2005aug/lowercoast/spi-northoftown.html	8/17-21/05 http://www.glo.state.tx.us/coastal/photos/2005aug/uppercoast/folletsisland.html	8/17-21/05 http://www.glo.state.tx.us/coastal/photos/2005aug/lowercoast/corpuschristi-padreisland.html	8/17-21/05 http://www.glo.state.tx.us/coastal/photos/2005aug/uppercoast/galvestonisland.html	8/17-21/05 http://www.glo.state.tx.us/coastal/photos/2005aug/uppercoast/matagorda-brazos.html & http://www.glo.state.tx.us/coastal/photos/2005aug/lowercoast/matagordapeninsula.html
	5/06 http://www.glo.state.tx.us/coastal/photos/2006may/01/lowercoast.html	5/06 http://www.glo.state.tx.us/coastal/photos/2006may/01/uppercoast.html	5/06 http://www.glo.state.tx.us/coastal/photos/2006may/01/lowercoast.html	5/06 http://www.glo.state.tx.us/coastal/photos/2006may/01/uppercoast.html	5/06 http://www.glo.state.tx.us/coastal/photos/2006may/01/lowercoast.html

(yellow)	georeferenced data sets under this work order
(cyan)	available georeferenced data sets for future comparison

Appendix C
Listing of Georeferenced Aerial Photographs

Upper and Lower Gulf Coast Aerial Photographs (98 total)				
Location	*Name*	*Type*	*Projection*	*Data Frame*
aerials-tx\data\aerials\Galveston_utm15\1999_02_23	506_05.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Galveston_utm15\1999_02_23	506_06.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Galveston_utm15\1999_02_23	506_07.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Galveston_utm15\1999_02_23	506_08.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Galveston_utm15\1999_02_23	506_09.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Galveston_utm15\1999_02_23	506_10.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Galveston_utm15\1999_02_23	506_11.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Galveston_utm15\1999_02_23	506_12.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Galveston_utm15\1999_02_23	506_13.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Galveston_utm15\1999_02_23	506_14.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Galveston_utm15\1999_02_23	506_15.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Galveston_utm15\1999_02_23	506_16.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Galveston_utm15\1999_02_23	506_17.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Galveston_utm15\1999_02_23	506_18.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Galveston_utm15\1999_02_23	506_19.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Galveston_utm15\1999_02_23	506_20.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Galveston_utm15\1999_02_23	506_21.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Galveston_utm15\1999_02_23	506_22.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Galveston_utm15\1999_02_23	506_23.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Galveston_utm15\1999_02_23	506_24.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Galveston_utm15\1999_02_23	506_25.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Galveston_utm15\1999_02_23	506_26.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Galveston_utm15\1999_02_23	506_27.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Galveston_utm15\1999_02_23	506_28.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Galveston_utm15\1999_02_23	506_29.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Galveston_utm15\1999_02_23	506_30.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Galveston_utm15\1999_02_23	506_31.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Galveston_utm15\1999_02_23	506_32.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Galveston_utm15\1999_02_23	506_33.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Galveston_utm15\1999_02_23	506_34.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Galveston_utm15\1999_02_23	506_35.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Galveston_utm15\1999_02_23	506_36.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Follets_Is_utm15\1962_01_08	3_089.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83

Upper and Lower Gulf Coast Aerial Photographs (98 total)				
Location	*Name*	*Type*	*Projection*	*Data Frame*
aerials-tx\data\aerials\Follets_Is_utm15\1962_01_08	3_091.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Follets_Is_utm15\1962_01_08	3_093.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Follets_Is_utm15\1962_01_08	3_094.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Follets_Is_utm15\1962_01_08	3_105.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Matagorda_utm15\1991_02_15	1_04_028.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Matagorda_utm15\1991_02_15	1_04_030.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Matagorda_utm15\1991_02_15	1_07_057.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Matagorda_utm15\1991_02_15	1_07_059.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Matagorda_utm15\1991_02_15	1_08_095.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Matagorda_utm15\1991_02_15	1_09_099.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Matagorda_utm15\1991_02_15	1_10_159.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Matagorda_utm15\1991_02_15	1_11_162.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Matagorda_utm15\1991_02_15	1_12_224.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Matagorda_utm15\1978_10_30	1_12_234.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Matagorda_utm15\1978_10_30	1_11_175.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Matagorda_utm15\1978_10_30	1_10_173.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Matagorda_utm15\1978_10_30	1_09_111.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Matagorda_utm15\1978_10_30	1_08_110.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Matagorda_utm15\1978_10_30	1_07_070.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Matagorda_utm15\1978_10_30	1_07_069.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Matagorda_utm15\1978_08_16	1_06_056.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Matagorda_utm15\1978_08_15	1_06_055.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Matagorda_utm15\1978_08_13	1_06_054.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Matagorda_utm15\1978_08_16	1_04_024.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Matagorda_utm15\1978_08_17	1_03_014.tif	Raster Dataset	NAD_1983_UTM_Zone_15N	Upper Coast UTM 15 NAD 83
aerials-tx\data\aerials\Padre_isl_utm14\2000_09_03	9-3-00southpadre-01-03.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\2000_09_03	9-3-00southpadre-01.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\2000_09_03	9-3-00southpadre-02.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\2000_09_03	9-3-00southpadre-03.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83

Upper and Lower Gulf Coast Aerial Photographs (98 total)				
Location	*Name*	*Type*	*Projection*	*Data Frame*
aerials-tx\data\aerials\Padre_isl_utm14\2000_09_03	9-3-00southpadre-04.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\2000_09_03	9-3-00southpadre-05.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\2000_09_03	9-3-00southpadre-06.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\2000_09_03	9-3-00southpadre-07.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\2000_09_03	9-3-00southpadre-08.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\2000_09_03	9-3-00southpadre-09.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\2000_09_03	9-3-00southpadre-1112.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\2000_09_03	9-3-00southpadre-1113.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\2000_09_03	9-3-00southpadre-1114.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\2000_09_03	9-3-00southpadre-1115.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\2000_09_03	9-3-00southpadre-1116.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\2000_09_03	9-3-00southpadre-1117.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\2000_09_03	9-3-00southpadre-1118.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\2000_09_03	9-3-00southpadre-1119.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\2000_09_03	9-3-00southpadre-1120.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\2000_09_03	9-3-00southpadre-1121.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\2000_09_03	9-3-00southpadre-1122.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\1980_07_23	17301001.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\1980_07_23	17301003.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\1980_07_23	17301005.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\1980_07_23	17301007.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\1980_07_23	17301009.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\1980_07_23	17301011.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\1980_07_23	17301013.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\1980_07_23	17301015.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\1980_07_23	17301017.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\1980_07_23	17301019.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\1980_07_23	17301021.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\1980_07_23	17301023.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\1980_07_23	17301025.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\1968_08_13	1_1_04.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\1968_08_13	1_1_06.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\1968_08_13	1_1_08.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\1968_08_13	1_1_10.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\1968_08_13	1_1_12.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83
aerials-tx\data\aerials\Padre_isl_utm14\1968_08_13	1_1_14.tif	Raster Dataset	NAD_1983_UTM_Zone_14N	Lower Coast UTM 14 NAD83

Appendix D
Metadata Generated Under This Scope of Work

Metadata for **2006 washover area polygons** delineated for this study:

Identification_Information:
  Citation:
    Citation_Information:
      Originator: Diamond Coastal & Environmental, LLC, Newark, DE
      Publication_Date: 20071205
      Title: Washover areas in Priority Areas, Texas coast
      Geospatial_Data_Presentation_Form: vector digital data
      Other_Citation_Details: Five shapefiles: e_matpen_06, follets_06, galv_06, mustang_06, spi_06
      Online_Linkage: \\MOTION1\F$\Working\TX_TomWork\200712\MetadataWork\e_matpen_06.shp
  Description:
    Abstract: Washover areas on Texas Gulf of Mexico Shoreline in TX GLO Priority Areas (South Padre Island, Mustang Island, East Matagorda Peninsula, Follets Island, Galveston Island) as interpreted from aerial photographs taken in May 2006.
    Purpose: These data were collected for the purpose of understanding shoreline change in specific areas (Priority Areas) of the Texas Gulf of Mexico coast.
  Time_Period_of_Content:
    Time_Period_Information:
      Single_Date/Time:
        Calendar_Date: 200605
    Currentness_Reference: 200605
  Status:
    Progress: Complete
    Maintenance_and_Update_Frequency: None planned, as needed
  Spatial_Domain:
    Bounding_Coordinates:
      West_Bounding_Coordinate: -95.944631
      East_Bounding_Coordinate: -95.655370
      North_Bounding_Coordinate: 28.753178
      South_Bounding_Coordinate: 28.611125
  Keywords:
    Theme:
      Theme_Keyword_Thesaurus: none
      Theme_Keyword: shoreline
      Theme_Keyword: coast
      Theme_Keyword: beach
      Theme_Keyword: barrier
      Theme_Keyword: dune
      Theme_Keyword: storm
      Theme_Keyword: topography
      Theme_Keyword: geomorphology
    Place:
      Place_Keyword_Thesaurus: none
      Place_Keyword: Gulf of Mexico
      Place_Keyword: Texas
      Place_Keyword: South Padre Island
      Place_Keyword: Mustang Island
      Place_Keyword: East Matagorda Peninsula
      Place_Keyword: Follets Island

Place_Keyword: Galveston Island
Temporal:
Temporal_Keyword_Thesaurus: none
Temporal_Keyword: 2006
Temporal_Keyword: May
Access_Constraints: none
Use_Constraints: These data were collected for the purpose of understanding shoreline change in specific areas (Priority Areas) of the Texas Gulf of Mexico coast. Any conclusions drawn from analysis of this information are not the responsibility of Diamond Coastal & Environmental, LLC.
Point_of_Contact:
Contact_Information:
Contact_Organization_Primary:
Contact_Organization: Diamond Coastal & Environmental, LLC
Contact_Person: Kimberly K. McKenna, P.G.
Contact_Address:
Address_Type: mailing address
Address: PO Box 9586
City: Newark
State_or_Province: Delaware
Postal_Code: 19714
Country: United States
Contact_Electronic_Mail_Address: k.k.mckenna@comcast.net
Hours_of_Service: 0800 -1700 EST
Data_Set_Credit: Kimberly K. McKenna, Diamond Coastal & Environmental, LLC.
Security_Information:
Security_Classification: Unclassified
Native_Data_Set_Environment: Microsoft Windows XP Version 5.1 (Build 2600) Service Pack 2; ESRI ArcCatalog 9.2.4.1420
Data_Quality_Information:
Logical_Consistency_Report: not applicable
Positional_Accuracy:
Horizontal_Positional_Accuracy:
Horizontal_Positional_Accuracy_Report: Data estimated to have a horizontal accuracy of 30 m from digitizing from aerial photographs (0.3-m pixels) at 1:5000 scale.
Vertical_Positional_Accuracy:
Lineage:
Source_Information:
Source_Citation:
Citation_Information:
Originator: P2ES
Title: Georeferenced color infrared digital images for Texas coast (UTM NAD 83, Zone 15 (upper coast), Zone 14 (lower coast), units: meters; 1.0 ft/pixel)
Type_of_Source_Media: digital file
Source_Time_Period_of_Content:
Time_Period_Information:
Single_Date/Time:
Calendar_Date: 200605
Source_Currentness_Reference: ground condition
Source_Citation_Abbreviation: aerial photograph
Source_Contribution: Base for interpreting and digitizing washover areas

Process_Step:
Process_Description: Polygons digitized on-screen from georeferenced digital aerial photographs at scales from 1:2000 to 1:5000
Source_Used_Citation_Abbreviation: aerial photograph
Process_Date: 20071001-20071130
Source_Produced_Citation_Abbreviation: digital vector data
Process_Contact:
Contact_Information:
Contact_Organization_Primary:
Contact_Organization: Diamond Coastal & Environmental, LLC, Newark, DE
Contact_Person: Kimberly K. McKenna
Contact_Address:
Address_Type: mailing address
Address: PO Box 9586
City: Newark
State_or_Province: Delaware
Postal_Code: 19714
Country: United States
Spatial_Data_Organization_Information:
Direct_Spatial_Reference_Method: Vector
Point_and_Vector_Object_Information:
SDTS_Terms_Description:
SDTS_Point_and_Vector_Object_Type: G-polygon
Point_and_Vector_Object_Count: 7
Raster_Object_Information:
Spatial_Reference_Information:
Horizontal_Coordinate_System_Definition:
Planar:
Grid_Coordinate_System:
Grid_Coordinate_System_Name: Universal Transverse Mercator
Universal_Transverse_Mercator:
UTM_Zone_Number: 15
Transverse_Mercator:
Scale_Factor_at_Central_Meridian: 0.999600
Longitude_of_Central_Meridian: -93.000000
Latitude_of_Projection_Origin: 0.000000
False_Easting: 500000.000000
False_Northing: 0.000000
Planar_Coordinate_Information:
Planar_Coordinate_Encoding_Method: coordinate pair
Coordinate_Representation:
Abscissa_Resolution: 30
Ordinate_Resolution: 30
Planar_Distance_Units: meters
Geodetic_Model:
Horizontal_Datum_Name: North American Datum of 1983
Ellipsoid_Name: Geodetic Reference System 80
Semi-major_Axis: 6378137.000000
Denominator_of_Flattening_Ratio: 298.257222
Vertical_Coordinate_System_Definition:

Altitude_System_Definition:
Entity_and_Attribute_Information:
Detailed_Description:
Entity_Type:
Entity_Type_Label: e_matpen_06
Entity_Type_Definition: washover areas
Attribute:
Attribute_Label: FID
Attribute_Definition: Internal feature number.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain: Sequential unique whole numbers that are automatically generated.
Attribute:
Attribute_Label: Shape
Attribute_Definition: Feature geometry.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain: Coordinates defining the features.
Attribute:
Attribute_Label: wash_gisid
Attribute_Definition: unique washover id for set of priority areas
Attribute:
Attribute_Label: local_id
Attribute_Definition: id specific to each priority area
Overview_Description:
Entity_and_Attribute_Detail_Citation: Diamond Coastal & Environmental, Newark, DE, 2007
Distribution_Information:
Distributor:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Kimberly K. McKenna
Contact_Organization: Diamond Coastal & Environmental, LLC
Contact_Address:
Address_Type: mailing address
Address: PO Box 9586
City: Newark
State_or_Province: Delaware
Postal_Code: 19714
Country: United States
Contact_Voice_Telephone:
Contact_Facsimile_Telephone:
Contact_Electronic_Mail_Address: k.k.mckenna@comcast.net
Hours_of_Service: 0800-1700 Monday-Friday
Contact_Instructions:
Resource_Description: Downloadable Data
Distribution_Liability: These data were collected for the purpose of understanding shoreline change in specific areas (Priority Areas) of the Texas Gulf of Mexico coast. Any conclusions drawn from analysis of this information are not the responsibility of Diamond Coastal & Environmental, LLC.
Standard_Order_Process:
Digital_Form:

Digital_Transfer_Information:
Transfer_Size: 0.005
Metadata_Reference_Information:
Metadata_Date: 20071205
Metadata_Review_Date: 20071206
Metadata_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Kimberly K. McKenna
Contact_Organization: Diamond Coastal & Environmental, LLC
Contact_Address:
Address_Type: mailing address
Address: PO Box 9586
City: Newark
State_or_Province: Delaware
Postal_Code: 19714
Country: United States
Contact_Voice_Telephone:
Contact_Facsimile_Telephone:
Metadata_Standard_Name: FGDC Content Standards for Digital Geospatial Metadata
Metadata_Standard_Version: FGDC-STD-001-1998
Metadata_Time_Convention: universal time
Metadata_Extensions:
Online_Linkage: http://www.esri.com/metadata/esriprof80.html

Metadata for **2006 washover area centerlines** delineated for this study:

Identification_Information:
  Citation:
    Citation_Information:
      Originator: Diamond Coastal & Environmental, LLC, Newark, DE
      Publication_Date: 20071205
      Title: Washover areas in Priority Areas, Texas coast
      Geospatial_Data_Presentation_Form: vector digital data
      Other_Citation_Details: Five shapefiles: e_matpen_06, follets_06, galv_06, mustang_06, spi_06
      Online_Linkage: \\MOTION1\F$\Working\TX_TomWork\200712\MetadataWork\e_matpen_06.shp
  Description:
    Abstract: Centerlines of washover areas on Texas Gulf of Mexico shoreline in TX GLO Priority Areas (South Padre Island, Mustang Island, East Matagorda Peninsula, Follets Island, Galveston Island) as interpreted from aerial photographs taken in May 2006.
    Purpose: These data were collected for the purpose of understanding shoreline change in specific areas (Priority Areas) of the Texas Gulf of Mexico coast.
  Time_Period_of_Content:
    Time_Period_Information:
      Single_Date/Time:
        Calendar_Date: 200605
    Currentness_Reference: 200605
  Status:
    Progress: Complete
    Maintenance_and_Update_Frequency: None planned, as needed
  Spatial_Domain:
    Bounding_Coordinates:
      West_Bounding_Coordinate: -95.944631
      East_Bounding_Coordinate: -95.655370
      North_Bounding_Coordinate: 28.753178
      South_Bounding_Coordinate: 28.611125
  Keywords:
    Theme:
      Theme_Keyword_Thesaurus: none
      Theme_Keyword: shoreline
      Theme_Keyword: coast
      Theme_Keyword: beach
      Theme_Keyword: barrier
      Theme_Keyword: dune
      Theme_Keyword: storm
      Theme_Keyword: topography
      Theme_Keyword: geomorphology
    Place:
      Place_Keyword_Thesaurus: none
      Place_Keyword: Gulf of Mexico
      Place_Keyword: Texas
      Place_Keyword: South Padre Island
      Place_Keyword: Mustang Island
      Place_Keyword: East Matagorda Peninsula
      Place_Keyword: Follets Island

Place_Keyword: Galveston Island
Temporal:
Temporal_Keyword_Thesaurus: none
Temporal_Keyword: 2006
Temporal_Keyword: May
Access_Constraints: none
Use_Constraints: These data were collected for the purpose of understanding shoreline change in specific areas (Priority Areas) of the Texas Gulf of Mexico coast. Any conclusions drawn from analysis of this information are not the responsibility of Diamond Coastal & Environmental, LLC.
Point_of_Contact:
Contact_Information:
Contact_Organization_Primary:
Contact_Organization: Diamond Coastal & Environmental, LLC
Contact_Person: Kimberly K. McKenna, P.G.
Contact_Address:
Address_Type: mailing address
Address: PO Box 9586
City: Newark
State_or_Province: Delaware
Postal_Code: 19714
Country: United States
Contact_Electronic_Mail_Address: k.k.mckenna@comcast.net
Hours_of_Service: 0800 -1700 EST
Data_Set_Credit: Kimberly K. McKenna, Diamond Coastal & Environmental, LLC.
Security_Information:
Security_Classification: Unclassified
Native_Data_Set_Environment: Microsoft Windows XP Version 5.1 (Build 2600) Service Pack 2; ESRI ArcCatalog 9.2.4.1420
Data_Quality_Information:
Logical_Consistency_Report: not applicable
Positional_Accuracy:
Horizontal_Positional_Accuracy:
Horizontal_Positional_Accuracy_Report: Data estimated to have a horizontal accuracy of 30 m from digitizing from aerial photographs (0.3-m pixels) at 1:5000 scale.
Vertical_Positional_Accuracy:
Lineage:
Source_Information:
Source_Citation:
Citation_Information:
Originator: P2ES
Title: Georeferenced color infrared digital images for Texas coast (UTM NAD 83, Zone 15 (upper coast), Zone 14 (lower coast), units: meters; 1.0 ft/pixel)
Type_of_Source_Media: digital file
Source_Time_Period_of_Content:
Time_Period_Information:
Single_Date/Time:
Calendar_Date: 200605
Source_Currentness_Reference: ground condition
Source_Citation_Abbreviation: aerial photograph
Source_Contribution: Base for interpreting and digitizing washover areas

Process_Step:
Process_Description: Polygons digitized on-screen from georeferenced digital aerial photographs at scales from 1:2000 to 1:5000
Source_Used_Citation_Abbreviation: aerial photograph
Process_Date: 20071001-20071130
Source_Produced_Citation_Abbreviation: digital vector data
Process_Contact:
Contact_Information:
Contact_Organization_Primary:
Contact_Organization: Diamond Coastal & Environmental, LLC, Newark, DE
Contact_Person: Kimberly K. McKenna
Contact_Address:
Address_Type: mailing address
Address: PO Box 9586
City: Newark
State_or_Province: Delaware
Postal_Code: 19714
Country: United States
Spatial_Data_Organization_Information:
Direct_Spatial_Reference_Method: Vector
Point_and_Vector_Object_Information:
SDTS_Terms_Description:
SDTS_Point_and_Vector_Object_Type: G-polygon
Point_and_Vector_Object_Count: 7
Raster_Object_Information:
Spatial_Reference_Information:
Horizontal_Coordinate_System_Definition:
Planar:
Grid_Coordinate_System:
Grid_Coordinate_System_Name: Universal Transverse Mercator
Universal_Transverse_Mercator:
UTM_Zone_Number: 15
Transverse_Mercator:
Scale_Factor_at_Central_Meridian: 0.999600
Longitude_of_Central_Meridian: -93.000000
Latitude_of_Projection_Origin: 0.000000
False_Easting: 500000.000000
False_Northing: 0.000000
Planar_Coordinate_Information:
Planar_Coordinate_Encoding_Method: coordinate pair
Coordinate_Representation:
Abscissa_Resolution: 30
Ordinate_Resolution: 30
Planar_Distance_Units: meters
Geodetic_Model:
Horizontal_Datum_Name: North American Datum of 1983
Ellipsoid_Name: Geodetic Reference System 80
Semi-major_Axis: 6378137.000000
Denominator_of_Flattening_Ratio: 298.257222
Vertical_Coordinate_System_Definition:

Altitude_System_Definition:
Entity_and_Attribute_Information:
Detailed_Description:
Entity_Type:
Entity_Type_Label: e_matpen_06
Entity_Type_Definition: washover areas
Attribute:
Attribute_Label: FID
Attribute_Definition: Internal feature number.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain: Sequential unique whole numbers that are automatically generated.
Attribute:
Attribute_Label: Shape
Attribute_Definition: Feature geometry.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain: Coordinates defining the features.
Attribute:
Attribute_Label: wash_gisid
Attribute_Definition: unique washover id for set of priority areas
Attribute:
Attribute_Label: local_id
Attribute_Definition: id specific to each priority area
Overview_Description:
Entity_and_Attribute_Detail_Citation: Diamond Coastal & Environmental, Newark, DE, 2007
Distribution_Information:
Distributor:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Kimberly K. McKenna
Contact_Organization: Diamond Coastal & Environmental, LLC
Contact_Address:
Address_Type: mailing address
Address: PO Box 9586
City: Newark
State_or_Province: Delaware
Postal_Code: 19714
Country: United States
Contact_Voice_Telephone:
Contact_Facsimile_Telephone:
Contact_Electronic_Mail_Address: k.k.mckenna@comcast.net
Hours_of_Service: 0800-1700 Monday-Friday
Contact_Instructions:
Resource_Description: Downloadable Data
Distribution_Liability: These data were collected for the purpose of understanding shoreline change in specific areas (Priority Areas) of the Texas Gulf of Mexico coast. Any conclusions drawn from analysis of this information are not the responsibility of Diamond Coastal & Environmental, LLC.
Standard_Order_Process:
Digital_Form:

Digital_Transfer_Information:
Transfer_Size: 0.005
Metadata_Reference_Information:
Metadata_Date: 20071205
Metadata_Review_Date: 20071206
Metadata_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Kimberly K. McKenna
Contact_Organization: Diamond Coastal & Environmental, LLC
Contact_Address:
Address_Type: mailing address
Address: PO Box 9586
City: Newark
State_or_Province: Delaware
Postal_Code: 19714
Country: United States
Contact_Voice_Telephone:
Contact_Facsimile_Telephone:
Metadata_Standard_Name: FGDC Content Standards for Digital Geospatial Metadata
Metadata_Standard_Version: FGDC-STD-001-1998
Metadata_Time_Convention: universal time
Metadata_Extensions:
Online_Linkage: http://www.esri.com/metadata/esriprof80.html

Appendix E
Mapped Washover Areas (from May 2006 aerial photographs)

Washover Area ID.	Unique ID in GIS Layer	Washover Area Landward Extent (m)	Throat Width (m)	Throat Land Surface Elevation	Standard Deviation	Notes
						***Washover areas are labeled north to south for each Priority Area*
South Padre Island Cameron Co. (UTM 14)						
SPI-1	17	>1000	260	0.64	0.34	See Results section for discussion on landward extent.
SPI-2	18	>1000	750	1.08	0.51	northern South Padre Island
SPI-3	19	>1000	212	0.56	0.43	northern South Padre Island
SPI-4	20	>1000	82	1.12	0.58	northern South Padre Island; includes mound within washover area
SPI-5	21	>1000	192	0.67	0.29	northern South Padre Island
SPI-6	22	210	34	0.73	0.26	probable return flow channel, landward extent measured perpendicular to shoreline and from shoreline to break in foredune
SPI-7	23	>1000	40	0.65	0.15	coalesce with SPI-8
SPI-8	24	>1000	108	0.64	0.20	coalesce with SPI-7; mound separates coalesce with SPI-9
SPI-9	25	>1000	790	0.54	0.16	possible large sheetwash feature
SPI-10	26	>1000	205	0.63	0.30	south-central South Padre Island
SPI-11	27	>1000	74	0.71	0.33	contains splay flow channel, located approx. 1900 m north of the end of Park Rd 100
SPI-12	28	>1000	5	0.75	0.24	throat width may have been wider in the past, but coppice mounds now exist east of Park Rd 100
SPI-13	29	>1000	49	0.84	0.42	throat width may have been wider in the past, but coppice mounds now exist west of Park Rd 100
SPI-14	30	>1000	20	1.02	0.49	throat width may have been wider in the past, but coppice mounds now exist east of Park Rd 100 and vegetation cover has increased west of Park Rd 100
SPI-15	31	>1000	12	0.62	0.24	coalesce with SPI-16; throat width may have been wider in the past, but coppice mounds now exist east of Park Rd 100 and vegetation cover has increased west of Park Rd 100
SPI-16	32	>1000	8	0.73	0.41	coalesce with SPI-15; throat width may have been wider in the past, but vegetation cover has increased west of Park Rd 100
SPI-17	33	>1000	21	0.79	0.53	throat width may have been wider in the past, but vegetation cover has increased west of Park Rd 100; human impacts maintain the width of the washover seaward of Park Rd 100
SPI-18	34	>1000	20	1.29	0.84	throat width may have been wider in the past, but vegetation cover has increased west of Park Rd 100; human impacts maintain the width of the washover seaward of Park Rd 100
Follets Island Brazoria Co. (UTM 15)						
FI-1	4	170	414	none digitized		located on west bank of San Luis Pass (under bridge) / also considered as a overwash terrace and sand flat
FI-2	5	138	165	none digitized		located on west bank of San Luis Pass / overwash terrace
FI-3	6	137	270	1.09	0.38	on Gulf side of Treasure Island subdivision / overwash terrace
FI-4	7	119	20	1.55	0.68	beach access w/ sand splay landward of Hwy 257

Washover Area ID.	Unique ID in GIS Layer	Washover Area Landward Extent (m)	Throat Width (m)	Throat Land Surface Elevation Mean (m)	Standard Deviation	Notes
Mustang Island Nueces Co. (UTM 14)						
MI-1	15	777	10	1.45	0.61	Corpus Christi Pass- meas to seaward side of roadway
MI-2	16	912	38	1.08	0.27	Newport Pass- meas to seaward side of roadway
West Galveston Island Galveston Co. (UTM 15)						
GI-1	1	143	73	0.90	0.18	just northeast to Beach Pocket Park 1
GI-2	2	117	59	0.79	0.22	just southwest to Beach Pocket Park 1
GI-3	3	433	657	none digitized		located adjacent to San Luis Pass and GOM / also considered as an overwash terrace or sand flat
East Matagorda Peninsula Matagorda Co. (UTM 15)						
EMP-1	8	772	76 (throat of channel); 853 (along Mitchell's Cut)	0.89	0.53	located on west bank of Mitchell's Cut; part of the inlet hazard area; overwash terrace, sheetwash and sand flat
EMP-2	9	249	30	1.46	0.21	eastern portion of peninsula
EMP-3	10	348	45	1.09	0.39	selected main channel only, could extend fan eastward, but should be field verified; landward extent measured from shoreline was not perpendicular length
EMP-4	11	356	1,845	0.67	0.37	represents a coalesced overwash terrace; complete breach of foredunes; meas. at 1:10,000
EMP-5	12	296	158	0.43	0.18	foredune/backdune delineations are not clear
EMP-6	13	197	165	0.43	0.23	foredune/backdune delineations are not clear
EMP-7	14	540	202	0.31	0.28	foredune/backdune delineations are not clear; trails surround edges of feature

Appendix F
Washover Areas Centerline Locations

Washover Area Centerline Locations

Priority Area / Washover Area ID.	UTM Easting (m)	UTM Northing (m)	UTM Easting (m)	UTM Northing (m)
	Line Seaward Point		Line Lagoonward Point	
South Padre Island Cameron Co. (UTM 14)				
SPI-1	677048	2922152	676781	2922086
SPI-2	678227	2917232	678021	2917231
SPI-3	678403	2916429	678193	2916381
SPI-4	678642	2915503	678476	2915462
SPI-5	678804	2914979	678592	2914894
SPI-6	678920	2914447	678662	2914611
SPI-7	679318	2912750	679183	2912690
SPI-8	679392	2912229	679288	2912227
SPI-9	679739	2910834	679603	2910806
SPI-10	680560	2907488	680351	2907451
SPI-11	680902	2905490	680732	2905469
SPI-12	681545	2902670	681332	2902659
SPI-13	681863	2900692	681707	2900562
SPI-14	682110	2898968	682028	2898943
SPI-15	682147	2898019	681958	2897910
SPI-16	682215	2897470	682055	2897374
SPI-17	682606	2895223	682411	2895206
SPI-18	682717	2894342	682471	2894345
Follets Island Brazoria Co. (UTM 15)				
FI-1	none digitized			
FI-2	none digitized			
FI-3	293092	3217607	292946	3217630
FI-4	286597	3212671	286579	3212697
Mustang Island Nueces Co. (UTM 14)				
MI-1	678898	3059274	678774	3059418
MI-2	678026	3057467	677752	3057596
West Galveston Island Galveston Co. (UTM 15)				
GI-1	317593	3235854	317613	3235939
GI-2	317293	3235674	317289	3235715
GI-3	none digitized			
East Matagorda Peninsula Matagorda Co. (UTM 15)				
EMP-1	240317	3183109	239925	3183122
EMP-2	239738	3182545	239589	3182710
EMP-3	239444	3182389	239191	3182576
EMP-4	236728	3180813	236672	3180910
EMP-5	223448	3173367	223313	3173541
EMP-6	219274	3171422	219224	3171518
EMP-7	212528	3168569	212469	3168927