Coastal Hazards Atlas of Texas: A Tool for Hurricane Preparedness and Coastal Management – Volume 3
The South Coast

James C. Gibeaut and Thomas A. Tremblay
Development and compilation of Geographic Information System (GIS) database by Thomas A. Tremblay, Senior GIS Analyst

A Report of the Texas Coastal Coordination Council pursuant to National Oceanic and Atmospheric Administration Award No. NA07OZ0134
GLO Contract Number 02-208 R

Bureau of Economic Geology
Scott W. Tinker, Director
John A. and Katherine G. Jackson School of Geosciences
The University of Texas at Austin
Austin, Texas 78713-8924

August 2003
## Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Relative Sea-Level Rise</td>
<td>3</td>
</tr>
<tr>
<td>The Moving Gulf of Mexico Shoreline</td>
<td>5</td>
</tr>
<tr>
<td>Long-Term Change</td>
<td>6</td>
</tr>
<tr>
<td>Short-Term Change</td>
<td>8</td>
</tr>
<tr>
<td>Episodic Shoreline Retreat</td>
<td>10</td>
</tr>
<tr>
<td>The Pattern of Shoreline Change Today and the Effects of Human-Made Structures: Rio Grande to Mansfield Channel</td>
<td>11</td>
</tr>
<tr>
<td>The Moving Bay Shoreline</td>
<td>13</td>
</tr>
<tr>
<td>Tropical Storms and Hurricanes</td>
<td>15</td>
</tr>
<tr>
<td>Storm-Surge Level</td>
<td>17</td>
</tr>
<tr>
<td>Storm Washover Features</td>
<td>19</td>
</tr>
<tr>
<td>References</td>
<td>20</td>
</tr>
<tr>
<td>Appendix: Excerpts from Geographic Information System Documentation Files</td>
<td>22</td>
</tr>
<tr>
<td>Bay Erosion</td>
<td>22</td>
</tr>
<tr>
<td>Environmental Sensitivity Index (ESI) Shoreline</td>
<td>22</td>
</tr>
<tr>
<td>Gulf of Mexico Shoreline Change</td>
<td>23</td>
</tr>
<tr>
<td>Hurricane Surge and Flooding</td>
<td>25</td>
</tr>
<tr>
<td>Computer Model Surge Data</td>
<td>25</td>
</tr>
<tr>
<td>Hurricanes Beulah and Carla</td>
<td>26</td>
</tr>
<tr>
<td>National Wetland Inventory (nwi)</td>
<td>27</td>
</tr>
<tr>
<td>Shorelines</td>
<td>27</td>
</tr>
<tr>
<td>Washover Features</td>
<td>28</td>
</tr>
</tbody>
</table>
Introduction

This report accompanies the CD-ROM and Website of the *Texas Coastal Hazards Atlas – Volume 3, 2003* ([www.beg.utexas.edu/coastal/hazardsIndex.htm](http://www.beg.utexas.edu/coastal/hazardsIndex.htm)) (Figure 1). The atlas is being developed in response to the need for technical information by coastal planners and to increase public awareness of coastal processes. The area covered in Volume 3 is the south coast from Baffin Bay on the north to the Rio Grande River on the south and includes the coastal portions of southern Kleberg County and Kenedy, Willacy, and Cameron Counties (Figure 2). The atlas consists of Geographic Information System (GIS) files in ArcView format. The maps may be viewed and customized on a personal computer using ArcView or ArcExplorer (see link for free download) software. Following is the database structure:

<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. <strong>Cities</strong></td>
</tr>
<tr>
<td>2. <strong>County Boundaries</strong></td>
</tr>
<tr>
<td>3. <strong>Base Imagery</strong> <em>(.ecw)</em> Images are scale dependent.*</td>
</tr>
<tr>
<td>A. Color-Infrared Aerial photo Mosaic (&lt;1:50,000)</td>
</tr>
<tr>
<td>B. SPOT Panchromatic Mosaic (&lt;1:150,000)</td>
</tr>
<tr>
<td>- <strong>N27W0974 SPOT</strong></td>
</tr>
<tr>
<td>- <strong>N27W0973 SPOT</strong></td>
</tr>
<tr>
<td>- <strong>N26W0973 SPOT</strong></td>
</tr>
<tr>
<td>- <strong>N26W0974 SPOT</strong></td>
</tr>
<tr>
<td>- <strong>N26W0971 SPOT</strong></td>
</tr>
<tr>
<td>4. <strong>Environmental Sensitivity Index (ESI) Shoreline</strong></td>
</tr>
<tr>
<td>This is the Environmental Sensitivity Index Shoreline characterization of the Lower Texas Coast.</td>
</tr>
<tr>
<td>5. <strong>Shoreline Change</strong></td>
</tr>
<tr>
<td>A. <strong>Gulf of Mexico</strong></td>
</tr>
<tr>
<td>B. <strong>Baffin Bay</strong></td>
</tr>
<tr>
<td>6. <strong>Hurricane Surge and Flooding</strong></td>
</tr>
<tr>
<td>A. Water Depth - Derived from Computer Model Surge Data</td>
</tr>
<tr>
<td>B. Hurricanes Beulah and Carla Flood Areas</td>
</tr>
<tr>
<td>7. <strong>National Wetland Inventory 1992 (nwi)</strong></td>
</tr>
<tr>
<td>NWI map codes legend</td>
</tr>
</tbody>
</table>
|   The files in this directory are compiled from 1992 US Fish and Wildlife Service National Wetland Inventory data. See the nwi map code file for a schematic diagram of the NWI Wetlands and Deepwater Habitats Classification System.
8. Shorelines

A. Gulf of Mexico
   1. Historic Shorelines
   2. Projected 2055 Shorelines

B. Baffin Bay
   1. Historic Shorelines
   2. Projected 2055 Shorelines

9. Washover Features
   Washover Channels and Interdune Drainages (Polygons)

The following sections describe the hazards mapped along the south Texas coast. The text is intended for the general public, but more technical references are provided for those interested. Hyperlinks are also provided to various Websites. The appendix contains excerpts from documentation files (metadata) found on the CD-ROM or downloaded with the data from the Website. These files provide technical descriptions of the data and the methods used for processing in the Geographic Information System.

Figure 1. The Texas coast with areas covered by each Coastal Hazards Atlas volume.
Relative Sea-Level Rise

A rise in the surface of the ocean, a lowering of the land surface or both may cause relative sea-level rise. By looking at sediments once deposited along ancient coasts and now buried beneath more recent sediments or submerged on the continental shelf, geologists know that 18,000 years ago, when the last ice age ended, sea level was about
400 ft lower than it is today.\(^{(1)}\) Since that time and on a scale of thousands of years, the addition of water to the oceans by melting continental ice sheets has caused sea level to rise and the shoreline to move landward.

During the last half of the 20\(^{th}\) century along the south Texas coast, the rate of relative sea-level rise has been about 0.133 inches per year (about 7.3 inches in 55 years) as measured by the Port Isabel tide gauge in Port Isabel (Figure 3). This rise is caused by compaction of sediments causing a lowering of the land surface (land subsidence) and by a rise in the global ocean surface caused by melting glaciers and thermal expansion of seawater.\(^{(2)}\) Global sea level is rising between 0.0394 and 0.0945 inches per year, therefore, the south Texas coast has a relatively high rate of relative sea-level rise; this is caused by land subsidence. The rate of rise on Padre Island, however, is about half the rate on Galveston Island where land subsidence is great compared to the south Texas coast. Global warming scenarios predict an increase in the rate of global sea-level rise, but even if that does not happen and relative sea-level rise continues at its present rate there is reason for concern and special planning.

![Figure 3](image)

Figure 3. This plot is from a NOAA CO-OPS Web page and shows data from the Port Isabel tide gauge beginning in 1944. Note that the measurement unit is meters and that the horizontal lines are 0.1 m (3.94 inches) apart. Click on the link to view sea-level plots from other tide gauges in Texas. This plot shows the monthly mean sea level with the average seasonal cycle removed (dashed curve), a 5-month average (solid curve), and the linear trend with its 95% confidence interval which was obtained after accounting for the average seasonal cycle. The average seasonal cycle is removed from the data mathematically to increase detection of the long-term trend.
Long-term sea-level rise as measured over 10’s to 100’s of years is important when considering development of coastal zones and the loss of very gently sloping coastal marshes, mangroves, and flats where a small rise can drown large expanses of these environments. If coastal development or steep upland slopes do not provide the room for low-lying environments to expand landward as the sea rises then important habitat will be lost. Relative sea level was 0.6 ft lower in 1945 then it is today (2003). If beaches have enough sand available to them, they can build up and hold their position against a rising sea. This is generally not the case along the south Texas coast and rising relative sea level is one process causing shoreline retreat over the last 100 years. Furthermore, storms occurring today that are similar in severity to those that occurred 50-years ago have the potential to subject broader areas to flooding. Given the rate of rise along the south coast, residents should be concerned for the stability of structures and environments when their outlook is for a period of about 50 years or more when sea level will be about ½ foot higher than it is today. This amount may be enough to significantly increase the landward penetration of storm surges, increase the rate of shoreline retreat, and drown significant areas of marsh.

**The Moving Gulf of Mexico Shoreline**

The natural character of sandy beaches is to change shape constantly and to move landward (retreat) or seaward (advance). The changes are caused by changes in the forces that move the sand, namely wind, waves, and currents, and by the supply of sand. Short- and long-term changes in the level of the ocean also controls shoreline movement. The setting of the shoreline and the supply of sand determine how the shoreline changes at a particular location. Setting refers to whether a beach is sheltered from waves, is adjacent to a tidal or storm channel, or is next to a jetty or seawall, to state a few examples. Much research has been conducted on the various time and spatial scales of shoreline change. To understand and predict the rate of change, we need to distinguish between long-term, short-term, and episodic changes and to understand their causes. In the following discussion, long-term change refers to changes occurring over a hundred to thousands of
years, short-term change refers to movement occurring over several months to 10’s of years, and episodic change is that which occurs in response to a single storm.

**Long-Term Change**

Geologists have compared several Texas shoreline positions that were mapped over the last 100 years and have found that, overall, the shoreline has continued to shift as it has since about 4,000 years ago when sea level approached its current position following the last ice age. These historical shorelines are available for downloading or viewing on the Website. Along the south Padre Island Gulf of Mexico coast, the shoreline retreated more than 1,000 ft since 1880, but 30 miles north of Mansfield Channel in central Kenedy County the shoreline was stable or advanced a couple hundred feet since 1880. Along Brazos Island, the shoreline advanced up to 500 ft from 1854 to the 1930’s after which it began retreating. The jetties at Brazos Santiago Pass and Mansfield Channel, and the human-caused reductions in the flow of the Rio Grande have altered shoreline change patterns since the 1930’s.

We basically understand that it is the changing of sea level relative to the land and the increase and decrease in sand supply to the coast that causes the shoreline to retreat or advance over a period of 100 years or more. The long-term rise in relative sea level along the south Texas coast has moved the shoreline by simply inundating it and by shifting the action of waves and currents landward. Relative sea-level rise over the last several thousands of years has also limited sand supply to the coast by drowning ancient river valleys and forming the coastal bays, such as Baffin and Corpus Christi Bays. Rivers that used to supply sand to the beaches now dump their sand at the heads of these bays, where it is kept from reaching the open coast.

The Rio Grande is the only river in south Texas that currently reaches the Gulf, but its ability to carry sand to the coast has been greatly diminished from several thousands of years ago. This is because of a decrease in water flow as a result of climate changing to more arid conditions since the end of the last ice age. More recently, the building of the Falcon Dam in 1955 and other dam and water diversion activities since 1955 have greatly diminished the Rio Grande’s capacity for carrying sand to the coast. Today, the mouth of the Rio Grande is at times closed by a sand bar because the river
flow is not even powerful enough to overcome the force of waves moving sand alongshore.

These conditions mean that sand available for building beaches and dunes today is mostly derived from sediments originally deposited more than 4,000 years ago in the ancient Rio Grande Delta. The old delta deposits, however, include a lot of muddy sediment that does not form beaches. Furthermore, much of the sand has already been incorporated into Padre and Brazos Islands since 4,000 years ago when sea level approached its current level and waves and currents started to erode the Rio Grande Delta lobe. Now the major source of sand for any given location on the Gulf of Mexico shoreline is that which is eroded from beaches updrift of the location. Thus the natural geological setting of the lower Texas coast has created a shoreline that is low in sand supply and is undergoing long-term relative sea-level rise. For these reasons, the shoreline will continue to retreat in the foreseeable future unless human intervention prevails.

Sand moves along the beach as well as in an onshore-offshore direction. Currents created by waves that approach the beach at an angle cause the sand to move alongshore. Tidal currents paralleling the shore may also be important especially near inlets such as Brazos Santiago Pass, Mansfield Channel, and temporary storm washover channels. The wind creates the waves and the prevailing winds on the southern lower Texas coast are from the southeast. The orientation of the shoreline along south Padre Island is northwesterly as a result of the remnant promontory created by the ancient Rio Grande Delta. Thus most of the time waves approach the shoreline at an angle open to the north causing the average net direction of sand movement to be toward the north along south Padre Island. Along north Padre Island, however, the winds and waves move sand toward the south creating a zone of convergence of beach sand in the vicinity of Big Shell Beach along central Padre Island. Central Padre Island, therefore, is the recipient of sand eroded from beaches to the north and south, and the shoreline has advanced there since the mid 1800’s. The exceptionally high dunes backing Big Shell beach are further evidence for this zone of convergence of sand. Changes in weather patterns, however, can cause temporary reversals in the direction of alongshore sand movement and hence alter shoreline change patterns created by the long-term average conditions.
Short-Term Change

A shoreline that has retreated over the last 100 years may have experienced periods of relative stability or even shoreline advance. Shoreline change that occurs over about 10 years or less and that may be in the opposite direction of the long-term trend is difficult to understand and predict. These short-term shoreline changes can also be quite variable alongshore. One portion of the coast may be experiencing rapid retreat while just a few miles away stable or advancing conditions may prevail. This is often the case along Padre Island where the occasional opening of washover channels causes temporary changes to the alongshore sand budget. It is important, however, for coastal residents and managers to understand that even though a particular beach may have been advancing or stable over the last several years, if it has been retreating for the previous decades, then retreat will eventually resume. An exception to this would be if something fundamental, such as a “permanent” increase in the sand supply, changes in the system.

Short-term shoreline change is caused by changes in the heights and directions of waves arriving at the beach, the frequency of storms, and shifts in the amount of sand immediately offshore of the beach out to 10 to 20 foot water depth. Shifts in offshore sand deposits are caused by waves, currents generated by waves, and tidal currents. Along much of the south Texas coast, this sand is swept up into two or three alongshore bars and in deposits at the mouths of channels such as Brazos Santiago Pass and the entrance of Mansfield Channel (Figure 4). These offshore sand deposits are available to feed the beach and lesson the rate of erosion or reverse it from time to time. The difficulty of tracking this sand is one of the things that makes understanding short-term shoreline change so difficult. Furthermore, waves and currents are responsible for moving and depositing the sand, but the presence of the sand in turn affects the actions of the waves and currents. This is known as a feedback loop in natural systems and can make predicting the outcome of seemingly simple processes extremely difficult.
Large storms redistribute significant volumes of sand which can affect shoreline change rates for several years causing them to be quite different from the long term rates. This was documented along the upper coast after Hurricane Alicia struck the south end of Galveston Island in 1983 and transported much sand offshore and alongshore. This storm altered the patterns of shoreline change for at least 5 years as the sand moved back to the beaches from offshore at some locations but was not available at others. After Alicia,
portions of the shoreline experienced accelerated retreat, changed from being stable to retreating, experienced accelerated advance, or changed from retreating to advancing. Thus large storms not only cause episodic shoreline retreat, but they can also alter shoreline change patterns for years.

**Episodic Shoreline Retreat**

From Brazos Santiago Pass to about 25 mi north of Mansfield Channel there is no major natural source of new sand. The sand that makes up the barrier islands and that extends 1 to 2 mi offshore is all that is available to the beaches and dunes. Most of the time, the beaches are struck by waves that are less than 5 ft high (See buoy #42020 for real-time and historical offshore wave data from the National Data Buoy Center.). The average difference between low and high tide on the open coast is 1.6 ft (See Bob Hall Pier tide gauge for real-time and historical tide data on the open coast; data provided by the Conrad Blucher Institute of Texas A&M Corpus Christi.). This means that between storms the beach and dune elevations and shapes adjust to low energy and, in most locations, low sand supply conditions. Dune heights may reach more than 30 ft, but at many locations they are much lower or nonexistent. Beaches are relatively narrow and gently sloping, and the land behind the beaches and dunes is low in elevation and generally slopes toward the bays. These conditions mean that when a large storm does strike the coast, it has profound effects that last for a long time. In the northern part of the atlas area (northern Kenedy and Kleberg Counties), sand supply is greater than in the south, and dunes are higher and more continuous. These conditions provide a buffer to storm impacts.

Hurricane Carla in 1961 caused significant beach erosion along the entire Texas coast. Even though Carla made landfall 150 miles to the north at Port O’Connor, Gulf beaches adjacent to Mansfield Channel on South Padre Island retreated 100 to 150 ft in just a few days. (11) Undoubtedly, the shoreline advanced for perhaps a year or more following the storm as the beach made an initial recovery, which was the case for Galveston Island beaches following Hurricane Alicia in 1983. (12, 13) By 1975, however, the shoreline was 150 to 400 ft landward of its pre-Carla position, except for a section extending 2 miles south of the Mansfield Channel jetties where sand built up against the
jetty and caused the shoreline to advance up to 1,000 ft. These changes are evident by comparing the 1960 (pre-Carla) and 1975 historical shorelines in the atlas. Hurricane Bret struck the middle part of the study area in August of 1999 and caused about 100 ft of shoreline retreat in the central Padre Island area. This area has a stable or advancing long-term trend of shoreline change, and by 2000 the shoreline had advanced back to its 1995 location.

It is important for coastal residents to realize that shoreline retreat is not always a continuous and steady process with a little more of the beach eroded each year. Tropical storms and hurricanes along the lower Texas coast can move the shoreline more than 100 ft landward in a day. There is often dramatic recovery for months and years following a storm, but it is often incomplete in an area undergoing long-term retreat, and the shoreline may remain significantly landward of its pre-storm position. In places where the shoreline is relatively stable or advancing, people should still consider the amount of erosion that may occur during a single storm and not build too closely to the shore. Even though shoreline change rates are given as annual rates, they must be considered “average” annual rates for the period over which the historical shorelines were compared. A particular shoreline with a long-term retreat rate of 5 ft per year would be expected to be 300 ft landward in 60 years. A single storm, however, could cause a large amount of this movement. Furthermore, even though a shoreline may be advancing in the long run, it is still subject to episodic retreat during storms.

The Pattern of Shoreline Change Today and the Effects of Human-Made Structures: Rio Grande to Mansfield Channel

The long-term average annual rate of shoreline change for the Gulf shoreline from the Rio Grande to Mansfield channel is calculated by comparing historical shorelines dating back to 1930.Earlier shorelines are not used because of the human-caused changes in the flow of the Rio Grande and the obstruction to alongshore sand movement created by the jetties at Brazos Santiago Pass and Mansfield Channel. These changes have caused a “permanent” change in the sand budget of the beaches and dunes beginning about 1930, and because the intent of calculating the rate of change is to provide an indication of what will likely happen in the future, the pre-1930 shorelines are not used.
Overall, the shoreline from the Rio Grande to Mansfield Channel is retreating at a rate of 2 to 15 ft per year (Figure 5, also see shoreline change layer in Geographic Information System files). Adjacent to the Brazos Santiago and Mansfield Channel jetties, however, the shoreline is stable or advancing. The jetties at Brazos Santiago Pass extend ½ mile offshore and shelter the beach on South Padre Island from waves approaching from the southeast. Wave refraction also tends to bend the waves from the southeast to be more from the east in the area north of the jetties. This process at least reduces alongshore sand transport to the north and may cause movement to the south along the southern 3 miles of South Padre Island. On the south sides of Brazos Santiago Pass and Mansfield Channel, the jetties simply block sand from moving farther to the north. The jetties have caused an impoundment of sand in these locations, but it appears that the shoreline on the north side of Brazos Santiago Pass and on the south side of Mansfield Channel stabilized by the 1970’s. Significant further advance is not expected. Sand continues to pile up against the jetty, however, on the south side of Brazos Santiago Pass.

Shoreline retreat is notably higher near the mouth of the Rio Grande and in a 5-mi area just south of the Cameron-Willacy County line (Figure 5). The reduction in flow of the Rio Grande since the 1950’s has reduced the supply of sand to the coast, and now the shoreline is retreating. The area south of the Cameron-Willacy County line is a particularly low-lying portion of the barrier island where storm surges often washover the entire island transporting beach sand to the Laguna Madre.

From 1937 to 1995, approximately 474 acres of land eroded from the highly developed South Padre Island Gulf coast from Brazos Santiago Pass to 12 miles north where the road is often covered by sand. This erosion was partly offset by 145 acres of accretion created by sand deposited in an area adjacent to the Brazos Santiago north jetty to a point 2.5 mi north of the jetty where the beach becomes erosional. Comparing the projected 2055 shoreline with the 1995 shoreline reveals that an additional 511 acres of land may be lost.
Figure 5. Average annual rate of Gulf of Mexico shoreline change from the Rio Grande to Mansfield Channel.

The Moving Bay Shoreline

Baffin Bay is the only bay with shoreline change data in the study area. The patterns of shoreline change in Texas Bays are complicated because of the various shoreline protection structures, shoreline types, shoreline orientations, and fetches. Fetch refers to the distance across water over which wind can generate waves that erode the shore. Baffin Bay is relatively small compared to other major bays of the Texas coast, therefore, fetch is short and waves are small. Shoreline orientation and the southeast prevailing wind direction controls the relative amount of wave energy approaching Baffin Bay shores and partly explains shoreline change patterns. Relative sea-level rise has had an important effect in causing shoreline retreat in Galveston Bay on the upper coast where land subsidence is significant and much of the shoreline is defined by flat marshes (see volume 1 of the atlas). In Baffin Bay, however, land subsidence is less of a problem, and most of the shoreline consists of relatively steep beaches and bluffs making relative sea-level rise less important in causing shoreline retreat.
Here the shoreline is relatively stable and even advancing along the southeast shore compared to Bays on the upper Texas coast. The average rate of shoreline change was -0.1 ft/yr in the landward direction. Thus Baffin Bay has a stable shoreline change presented in the atlas was determined by comparing shorelines mapped using vertical aerial photographs from 1941, 1956, 1982, and 1995. During this period, 5 percent of the shoreline retreated at a rate of more than 2 ft/yr, 5 percent advanced at a rate of more than 2 ft/yr, and 90 percent of the shoreline length changed by less than 2 ft/yr, which is considered to be stable. The average rate of shoreline change was -0.1 ft/yr in the landward direction. Thus Baffin Bay has a stable shoreline compared to Bays on the upper Texas coast.

Although the change is subtle in Baffin Bay, the pattern of change is interesting (Figure 6). The south coast is on the lee side of the prevailing winds out of the southeast. Here the shoreline is relatively stable and even advancing along the southeast shore.
where wind-blown sand and silt is feeding the shore. Along the northeastern side of the bay a subtidal rocky reef, which is a relict serpulid worm reef, protects the shore. Even though this is a windward shoreline, the reef shelters the beach from waves. The highest rates of retreat are along the northern shores that have southeasterly fetches. However, there are some advancing spits, which get their sand from adjacent eroding beaches.

**Tropical Storms and Hurricanes**

Because of the overall low-energy, low-sand supply, and gently sloping setting of the lower Texas coast, large storms have a large impact. Not only can dramatic beach erosion and shoreline retreat occur during a tropical cyclone, but also storm surge, high winds, and flooding from torrential rainfall can destroy buildings, roads, and change people’s lives forever. The Saffir-Simpson scale rates hurricanes on a scale of 1 to 5 primarily based on wind speed. A storm’s rating gives an estimate of the potential damage and flooding that may occur. Below is a description of the Saffir-Simpson scale provided by the National Hurricane Center (http://www.nhc.noaa.gov/). The description discusses storm surge, which is a rising of the ocean caused by hurricane winds pushing water toward the coast and by the low atmospheric pressure of the storms allowing ocean level to rise. Storm surge is technically defined as an abnormal rise in sea level accompanying a hurricane or other intense storm, and whose height is the difference between the observed level of the sea surface and the level that would have occurred in the absence of the cyclone. Storm surge is usually estimated by subtracting the normal or astronomic high tide from the observed storm tide.

**The Saffir-Simpson Hurricane Scale**

**Category One Hurricane:**
- Winds 74-95 mph (64-82 kt or 119-153 kph). Storm surge generally 4-5 ft above normal. No real damage to building structures. Damage primarily to unanchored mobile homes, shrubbery, and trees. Some damage to poorly constructed signs. Also, some coastal road flooding and minor pier damage.

**Category Two Hurricane:**
- Winds 96-110 mph (83-95 kt or 154-177 kph). Storm surge generally 6-8 ft above normal. Some roofing material, door, and window damage of buildings. Considerable damage to shrubbery and trees with some trees blown down. Considerable damage to mobile homes,
poorly constructed signs, and piers. Coastal and low-lying escape routes flood 2-4 hours before arrival of the hurricane center. Small craft in unprotected anchorages break moorings.

Category Three Hurricane:

Winds 111-130 mph (96-113 kt or 178-209 kph). Storm surge generally 9-12 ft above normal. Some structural damage to small residences and utility buildings with a minor amount of curtainwall failures. Damage to shrubbery and trees with foliage blown off trees and large tress blown down. Mobile homes and poorly constructed signs are destroyed. Low-lying escape routes are cut by rising water 3-5 hours before arrival of the hurricane center. Flooding near the coast destroys smaller structures with larger structures damaged by battering of floating debris. Terrain continuously lower than 5 ft above mean sea level may be flooded inland 8 mi (13 km) or more. Evacuation of low-lying residences with several blocks of the shoreline may be required.

Category Four Hurricane:

Winds 131-155 mph (114-135 kt or 210-249 kph). Storm surge generally 13-18 ft above normal. More extensive curtainwall failures with some complete roof structure failures on small residences. Shrubs, trees, and all signs are blown down. Complete destruction of mobile homes. Extensive damage to doors and windows. Low-lying escape routes may be cut by rising water 3-5 hours before arrival of the hurricane center. Major damage to lower floors of structures near the shore. Terrain lower than 10 ft above sea level may be flooded requiring massive evacuation of residential areas as far inland as 6 mi (10 km).

Category Five Hurricane:

Winds greater than 155 mph (135 kt or 249 kph). Storm surge generally greater than 18 ft above normal. Complete roof failure on many residences and industrial buildings. Some complete building failures with small utility buildings blown over or away. All shrubs, trees, and signs blown down. Complete destruction of mobile homes. Severe and extensive window and door damage. Low-lying escape routes are cut by rising water 3-5 hours before arrival of the hurricane center. Major damage to lower floors of all structures located less than 15 ft above sea level and within 500 yards of the shoreline. Massive evacuation of residential areas on low ground within 5-10 mi (8-16 km) of the shoreline may be required.

From 1900 to 1996, three category one, four category two, five category three, one category four, and no category five hurricanes struck the south Texas coast (http://www.nhc.noaa.gov/paststate.html). It is very important to realize that characteristics of a particular storm, other than its peak wind speed, will also determine the amount and type of damage that may occur. These characteristics include the storm’s path and speed, the size of the storm, the stage of the tide at the time of maximum storm surge, and the amount of rainfall. Furthermore, the number, location, and types of structures on the coast will, of course, partially determine the amount of property damage. A small hurricane that intersects the coast at a right angle to the shoreline and continues landward may cause much less damage than a hurricane of the same Saffir-Simpson rating that is large, lingers offshore, or travels parallel to the shoreline.
Slow moving tropical storms that do not reach hurricane strength can also cause severe flooding from a combination of moderate storm surge and high rainfall levels. Significant beach erosion may also occur and become a serious problem if structures are close to the shore. Tropical Storm Frances eroded and flooded the upper Texas coast for four days from September 9 to September 13, 1998. Although winds only reached 50 mph, the ocean level was 3 to 5 ft above normal for 36 hours, and waves were 10- to 13-ft high for two and one half days. Because of the long period of time the storm affected the coast, beach erosion and flooding occurred that would normally be associated with at least a strong category 1 hurricane. Furthermore, because of their location close to the shoreline, hundreds of houses were damaged or left on the open beach. The same scenario could also occur along the South Padre Island coast.

**Storm-Surge Level**

The atlas contains data layers that show the depth of water caused by storm-surge as calculated by a computer model. The National Hurricane Center runs the storm surge model called SLOSH (Sea, Lake, and Overland Surges from Hurricanes). In the model are large amounts of data pertaining to storm size, speed of forward movement, storm path, maximum wind speed, bathymetry, topography, and other parameters, for each of 5 grids along the Texas coast. The model calculates the maximum surge level for each of many possible storm scenarios of a given Saffir-Simpson category. For example, a category 1 hurricane may be modeled with each of many movement tracks, movement speeds, and points of impact. Each of these 'runs' generates output indicating a surge height for each grid cell. For a given storm category, speed, and land fall direction, the runs may be combined into a MEOW (Maximum Envelope of Water) which takes the highest surge value from any run for each grid cell. All the MEOW’s for a particular category are then combined to yield a Maximum of MEOW’s (MOM) data set. A MOM map, therefore, shows the worst-case surge scenario, which is produced by the composite of many runs of a particular storm category (Figure 7). No single real storm is expected to actually produce these conditions. The storm surge water depth in the atlas is calculated by subtracting the height of the land from the storm surge level. Data for each
hurricane category are included. The atlas also contains a layer that shows the actual area of storm-surge and rainfall flooding caused by Hurricane Carla in 1961 and Beulah in 1967. (15)

Storm Surge for Category Five Hurricane

Figure 7. Computer-generated storm-surge flood map showing water depths expected for a category five hurricane. Map is created from a composite of results of a computer model run for a variety of category five hurricane scenarios. No single hurricane is expected to cause this distribution of flooding. Water depths over the water bodies, such as the Laguna Madre and Gulf of Mexico, are actually depths from the top of the storm surge to mean sea level. See text for further explanation. Map is created using GIS files available on the atlas CD-ROM and Website.
**Figure 7** is a map showing water depth calculated by subtracting the land elevation from the MOM for a category five hurricane scenario. Over the bays and Gulf the water depth represented is only the additional depth added by the storm surge. It is important to note that additional flooding would be caused by rainfall and river flow. According to the map, storm surge from the Gulf has the potential to reach as far inland as Brownsville and completely inundate South Padre Island and Port Isabel. Urban areas around the western shoreline of Laguna Madre and Baffin Bay could also be flooded.

**Storm Washover Features**

The storm surges and waves associated with Hurricane Carla and more recently Hurricane Bret created temporary breaches in the beaches and dunes (**Figure 8**). The flow of seawater was concentrated in these breaches and formed channels. In some areas, discrete breaches and channels did not occur, but broad areas were inundated with landward flowing water. These breaches and areas are called storm washover features, and they are included in a layer in the atlas (**Figure 9**). The importance of recognizing these features lies in the fact that the same areas tend to be washed over during subsequent storms, and therefore, they should be avoided. If the storm is severe enough and close enough, however, a broad expanse of shoreline may be completely inundated (**Figure 7**).

![Figure 8](image.jpg)

**Figure 8.** Hurricane washover channels on Padre Island, Texas, 2.5 miles north of Port Mansfield Channel. Hurricane Bret formed these channels when it struck on August 22, 1999. More than a dozen other former washover channels were re-activated by Bret. The photographs in this mosaic were taken on August 30, 1999.
Figure 9. Storm washover channels and areas on South Padre Island just north of the developed area. Map created from GIS files available on the atlas CD-ROM and Website.

References


Appendix: Excerpts from Geographic Information System Documentation Files

Following are excerpts of the text of the documentation files found on the CD-ROM and Website. These excerpts provide information on what the data represent. The complete metadata documentation contains further technical information related to the data and to the processing in the Geographic Information System.

Bay Erosion

Abstract:
Rates of Gulf of Mexico shoreline change are calculated on the basis of a linear regression of past shoreline positions. A computer program called the Shoreline Shape and Projection Program (SSAPP), developed by the Bureau of Economic Geology of The University of Texas at Austin, was used to calculate the rate of shoreline change every 82 ft (25 m) alongshore. SSAPP automatically draws a segmented baseline that follows the mean position of historical shorelines. Transects that intersect the shorelines are constructed perpendicular to this baseline. Distances between the shoreline positions along each transect are determined, and a linear regression model is used to calculate the average annual rate of shoreline change.

The following historical shorelines were used in the analysis: 1941, 1956, 1982, and 1995

Purpose:
State and Federal agencies with coastal management responsibilities currently rely on average rates of shoreline movement and projected future shoreline positions for regulatory purposes. As a result of this dependency on scientific data, regional studies of shoreline movement are now regarded as important sources of information for formulating coastal management policies and long range planning. These coastal investigations now serve as a primary technical basis for decisions made by coastal planners and managers of natural resources located near the shore.

Procedures used for shoreline mapping:
Mapped shorelines spanning from 1941 to 1982 were created by digitizing a line interpreted from a series of georectified historic aerial photographs. The 1995 shoreline was directly interpreted and digitized on color infra red digital orthophoto quarter quadrangles.

The Gulf erosion points were imported into ArcView as a text file conversion. The original points and attribute information being SSAPP output. Projection and datum information was checked to affirm correct placement of points along the shore. In-house quality checking was completed.

Environmental Sensitivity Index (ESI) Shoreline

Abstract:
Environmental Sensitivity Index mapping of the south Texas coastline was conducted for 18 USGS 7.5’ quads including the Baffin Bay and Laguna Madre systems. ESI classification of the shoreline was interpreted from low-altitude color video, digital orthophotoquads,
The ESI ranking was transferred to paper plots of the Texas shoreline and captured into the GIS. The shoreline was provided by the Texas General Land Office. Aerial photography and NWI data provided supplementary information where aerial videography was lacking.

Purpose:
ESI mapping is conducted principally for oil spill response applications.

References:

Entity and Attribute Overview:
The .aat contains the ESI code for each portion of the shoreline. The ESI code is defined as a character item 10 characters in width.

Standardized ESI Rankings for Texas
ESI No.    Shoreline Type
1       Exposed walls and other structures made of concrete, wood, or metal
2A      Scarps and steep slopes in clay
2B      Wave-cut clay platform
3A      Fine-grained sand beaches
3B      Scarps and steep slopes in sand
4       Coarse-grained sand beaches
5       Mixed sand and gravel(shell) beaches
6A      Gravel (shell) beaches
6B      Exposed riprap structures
7       Exposed tidal flats
8A      Sheltered solid man-made structures, such as bulkheads and docks
8B      Sheltered riprap structures
8C      Sheltered scarps
9       Sheltered tidal flats
10A     Salt- and brackish-water marshes
10B     Fresh-water marshes (herbaceous vegetation)
10C     Fresh-water swamps (woody vegetation)
10D     Mangroves

Gulf of Mexico Shoreline Change

Abstract:
Rates of Gulf of Mexico shoreline change are calculated on the basis of a linear regression of past shoreline positions. A computer program called the Shoreline Shape and Projection Program (SSAPP), developed by the Bureau of Economic Geology of The University of Texas at Austin, was used to calculate the rate of shoreline change every 164 ft (50 m) alongshore. SSAPP automatically draws a segmented baseline that follows the mean position of historical shorelines. Transects that intersect the shorelines are constructed perpendicular to this baseline. Distances between the shoreline positions along each transect are
determined, and a linear regression model is used to calculate the average annual rate of shoreline change. The following historical shorelines were used in the analysis: From Brazos Santiago Pass to approximately 6.5 km north of the pass: 1934, 1937, 1960, 1974, 1991, 1995 All other areas: 1930's, 1960's, 1970's, 1995.

Purpose:
State and Federal agencies with coastal management responsibilities currently rely on average rates of shoreline movement and projected future shoreline positions for regulatory purposes. As a result of this dependency on scientific data, regional studies of shoreline movement are now regarded as important sources of information for formulating coastal management policies and long range planning. These coastal investigations now serve as a primary technical basis for decisions made by coastal planners and managers of natural resources located near the shore.

Attributes:

- TRAN
  Transect number output from SSAPP. For each shoreline segment, numbers start with the most negative number on the north end and increase to the south.

- LR_M_YR
  Calculated erosion rate using the linear regression method, in meters/yr.

- LR_FT_YR
  Calculated erosion rate using the linear regression method, in feet/yr.

EASTING_UTM
Longitudinal coordinate of shoreline change point in UTM, from GPS.

NORTHING_UTM
Latitudinal coordinate of shoreline change point in UTM, from GPS.

S1 through S10
Actual years of shorelines used in the rate of change calculation.

Procedures used:
Mapped shorelines spanning from 1934 to 1991 were optically transferred to topographic bases having common map scales. Shoreline positions were interpreted from vertical aerial photographs and transferred to U.S. Geological Survey 7.5' maps. The 1995 shoreline was directly interpreted and digitized on color infra red digital orthophoto quarter quadrangles. In-house review covered in 'Purpose' The Gulf erosion points were imported into ArcView as a text file conversion. The original points and attribute information being SSAPP output. Projection and datum information was checked to affirm correct placement of points along the shore. In-house quality checking was completed.
Hurricane Surge and Flooding

The atlas contains hurricane related information derived from two separate sources. The computer surge data are calculated through computer modeling and depict the worst case scenario for various force level hurricanes. The flood data were mapped in the Natural Hazards of the Texas Coastal Zone (1974) and depict the landward extent of salt water flooding and areas of potential fresh water flooding as a result of hurricanes Beulah and Carla. Carla struck the Texas coast at Port O'Connor on September 11, 1961 and was characterized by extensive storm-surge flooding and shoreline erosion along the upper Texas coast. Beulah crossed the south Texas coast in September 1967 and was characterized by large amounts of rainfall resulting in freshwater flooding.

Computer Model Surge Data

Abstract:
The data in this layer depict the predicted water depth (ft.) associated with the storm surge of various strength hurricanes. Water depth is calculated by subtracting ground elevation at a particular location from the predicted storm surge height at that location. Surge height is measured in feet above mean sea level. The computer surge data are calculated through computer modeling and depict the worst case scenario for various force level hurricanes (source: Wilson Shaffer at NOAA). The National Hurricane Center runs a storm surge model called SLOSH (Sea, Lake, and Overland Surges from Hurricanes). Incorporated into the model are large amounts of data pertaining to storm size, forward movement speed, track, maximum windspeeds, bathymetry, topography, etc., for each of 5 grids along the Texas coast. The model calculates maximum surge penetration for each of many possible storm scenarios. For example, a category 1 hurricane may be modeled with each of many movement tracks, movement speeds, and points of impact. Each of these 'runs' generates output indicating a surge height for each grid cell. For any given storm category, all of the associated runs may be combined into a MEOW (Maximum Envelope of Water) which takes the highest surge value from any run for each grid cell. The MEOW therefore shows the worst-case surge scenario, which is produced by the composite of many runs. No one real storm is expected to actually produce these conditions. The surge inundation limits displayed on the maps in this atlas reflect a further compositing of the MEOWs into Maximums of the Maximums (MOM)s. The MOMs represent the maximum surge expected to occur at any given location, regardless of the storm track or direction of the hurricane. The only variable is the intensity of the hurricane represented by category strength (1-5). Ground elevation is derived from the US Geologic Survey's National Elevation Dataset (NED). Elevation measurements reported in meters are converted to feet for water depth calculation.

Purpose:
This dataset is intended to provide information for planners, engineers, and anyone else interested in the potential hazards associated with hurricane flooding along the South Texas coast.
Procedures used:
NED dems were contoured to create a polygon feature layer containing a 1 meter contour interval. SLOSH model output in polygon format was merged with the ground elevation dataset to produce a layer depicting elevation contours intersected with a water elevation grid. Ground elevation in meters was converted to feet and subtracted from the water height. This produced a thematic layer that contained polygons with water depth values.

Use constraints:
The data are suited for general application only. Spatial precision of storm surge data varies according to location. Generation points for this dataset are Corpus Christi and Port Isabel, Texas. Data precision decreases away from these locations.

Accuracy is dependent upon the accuracy of the reported storm surge data and the ground elevation data. The ground elevation data should conform to USGS standards. NOAA states that SLOSH model results are generally accurate within plus or minus 20 percent.

The accuracy of this dataset is limited by the spatial resolution of the storm surge data. Storm surge data are stored as a varying cell size grid which radiates outward from a generation source. In this case the sources are Corpus Christ and Port Isabel, Texas.

Attributes:
Attributes include values in feet for land elevation and surge height and water depth for each of 5 hurricane categories.

Hurricanes Beulah and Carla

Abstract:
Storm-surge flooding and aftermath-rainfall flooding and ponding are the most destructive aspects of hurricanes. Storm-surge tides of 10 feet above mean sea level have occurred repeatedly this century; high-storm-tide levels up to 22 feet have been recorded in restricted, shallow bays. The physical character of the Texas Coast-barrier islands, lagoons, bays, headlands, peninsulas, and narrow funnel-shaped bays contributes significantly to the degree of tidal flooding that will occur under various storm conditions. Heavy rainfall that accompanies and follows hurricane passage causes streams on the coastal plain to flood extensively; low, depressed areas are also flooded by ponded waters. Frontal-related storms produce extensive flooding on the coastal plain.

Data on areas of flooding by Hurricanes Carla or Beulah, provided by the U.S. Army Corps of Engineers, are used to delineate flood-prone areas. Areas of Beulah rainfall flooding and ponding provide a historical record of potential fresh-water flooding along the southwestern Texas Coast. Geologic/geomorphic interpretation of floodplains defines flood-prone areas along the northeastern coastal plain. Approximately 3,164 square miles were flooded by Hurricanes Carla and/or Beulah, and 2,187 square miles of the southwestern Coastal Zone were flooded by Beulah rainfall. At Least 2,073 square miles along the north-eastern coastal plain are flood prone.
Purpose:
Mitigation of hurricane destruction includes an array of engineering structures (dikes, seawalls) to prevent flood-surge damage. Natural defenses such as well-vegetated barrier islands and dense marshes and grassflats also provide protection from extensive erosion and damage from storm surges. Protection from hurricanes may, in some cases, be best accomplished by land-use planning. Flood-prone areas may be best suited for activities that will preclude extensive damage and loss of life.

Reference:

Procedures used:
The coverage was digitized from the reference document. The digitization was done in ArcInfo. Attributes were assigned in ArcEdit. The coverage was projected to UTM, zone 15, nad83. Quality check was performed in-house.

Use constraints:
The coverage was digitized at 1:250000 scale. It is important to note that interpretation or analysis using this data at scales larger than 250000 could result in the loss of accuracy. Reference should be made at 250000 scale or smaller.

Attributes:
-symbol
An integer value for polygon type
1 = saltwater flooding by Beulah or Carla
2 = potential freshwater flooding by hurricane rainfall
3 = freshwater flooding by beulah
9 = N/A - area not affected by hurricane flooding
-type
character description of flooding
'saltwater flooding by Beulah or Carla'
'potential freshwater flooding by hurricane rainfall'
'freshwater flooding by beulah'
'N/A'

National Wetland Inventory (nwi)

Each of the NWI files (located within their respective county (i.e. galvesco) and 7.5 minute quadrangle (i.e. christp) directory) was downloaded from the Fish and Wildlife Service's NWI site at www.nwi.fws.gov in January, 1999.

Shorelines

Abstract:
The mapping of historical shorelines is an important step in understanding the rate of past shoreline changes and how the shoreline may retreat landward or advance seaward in the future.
Purpose:
State and Federal agencies with coastal management responsibilities currently rely on average rates of shoreline movement and projected future shoreline positions for regulatory purposes. As a result of this dependency on scientific data, regional studies of shoreline movement are now regarded as important sources of information for formulating coastal management policies and long range planning. These coastal investigations now serve as a primary technical basis for decisions made by coastal planners and managers of natural resources located near the shore.

Limitations of Data:
Potential sources of error that influence the final projected position of the shoreline include: 1) errors in the original mapping and registry of shoreline positions, and 2) errors introduced while digitizing the shoreline positions.

Procedures used:
Historical shorelines-
The 1995 shoreline was directly interpreted and digitized on color infra red digital orthophoto quarter quadrangles.

Mapped shorelines spanning from 1850 to 1990 were optically transfered to topographic bases having common map scales. Shorelines from the 1800's and before 1930 were transferred from paper maps to U.S. Geological Survey 7.5' maps. Shoreline positions from after 1930 to 1990 were interpreted from vertical aerial photographs and transferred to U.S. Geological Survey 7.5' maps.

Projected shorelines-
Rates of Gulf of Mexico shoreline change are calculated on the basis of a linear regression of past shoreline positions. A computer program called the Shoreline Shape and Projection Program (SSAPP), developed by the Bureau of Economic Geology of The University of Texas at Austin, was used to calculate the rate of shoreline change at least every 164 ft (50 m) alongshore. SSAPP automatically draws a segmented baseline that follows the mean position of historical shorelines. Transects that intersect the shorelines are constructed perpendicular to this baseline. Distances between the shoreline positions along each transect are determined, and a linear regression model is used to calculate the average annual rate of shoreline change.

SSAPP projected the position of the 2005, 2025, and 2055 shorelines by multiplying the rate of change by 10, 30, and 60 years to yield distances and then plotting those distances from the measured 1995 shoreline along each transect.

Washover Features

Storm washover features include washover channels, interdune drainages, and washover areas. Channels and drainages are represented as polygon features (washpol) while washover areas are represented as linear shoreline features (washarc).
Abstract:
Storm washover features of the Texas coast. Features include washover channels, interdune drainages, and washover areas. Channels and drainages are represented as polygon features while washover areas are represented as linear shoreline features.

Purpose:
The dataset was created as part of the Texas Natural Resource Inventory (NRI) and is intended for oil spill response and identification of coastal hazards.

Limitations of Data:
The data were captured at 1:24,000 scale. Original washover mapping was modified by the Texas General Land Office to conform with that agency's standard Texas shoreline dataset. The relative position between shoreline and washover features may change due to coastal modification.

Attributes:
Washover-id in the .PAT is coded as to the type of washover feature. Washover channels are coded 2 and interdune drainages are coded 3. Washover.AAT contains the item ID (4 5 B). Shorelines which delimit washover areas are coded as ID 99. All other arcs are coded 9999.

Procedures used:
Washover features were interpreted from 1992 aerial videography supplemented with early 1990s aerial photography and zoom transferred to USGS 7.5' quadrangles by Bill White. The quads were then digitized, coded as to washover feature type, and transformed and projected by Tom Tremblay.