FINAL REPORT

Coastal Hazards Atlas of Texas: A Tool for Hurricane Preparedness and Coastal Management – Volume 1
The Southeast Coast

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Introduction

This report accompanies the CD-ROM of the *Texas Coastal Hazards Atlas – Volume 1, 2000.* 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 1 (fig. 1) is the southeast coast from the Brazos River on the west to Sabine Lake on the east. The atlas consists of Geographic Information System files in ArcView format. The maps may be viewed and customized on a personal computer using ArcView or ArcExplorer software. Following is the database structure:

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Note: All data are in UTM projection Zone 15, NAD83

Subsequent volumes of the atlas will extend coverage to the entire Texas coast. The following sections describe the hazards mapped along the southeast Texas coast. The text is intended for the general public, but more technical references are provided for those interested. The appendix contains copies of documentation files found on the CD-

ROM. These files provide technical descriptions of the data and how the data were processed in the Geographic Information System.

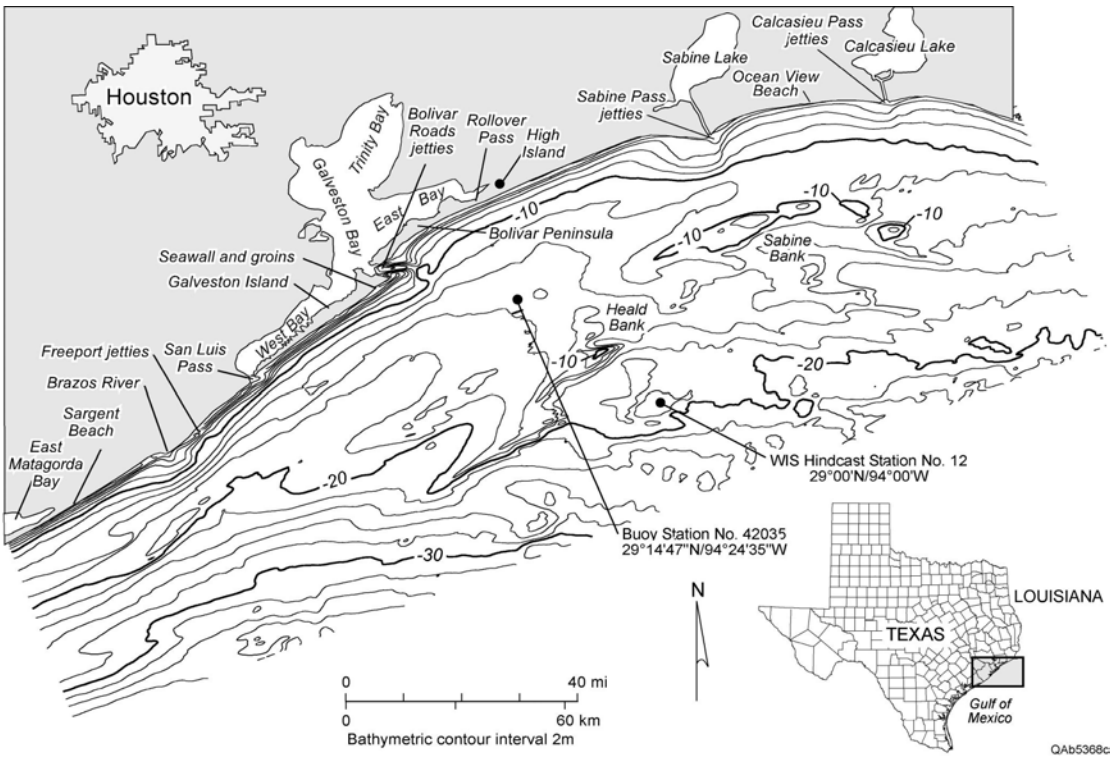

Figure 1. The upper Texas coast.

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 several 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 20th century along the upper Texas coast, the rate of relative sea-level rise has been 0.022 ft/yr (about 1 foot in 46 years) as measured by the Pier 21 tide gauge on Galveston Island (fig. 2). This rise is caused by compaction of sediments causing a lowering of the land surface (see the subsidence section) and by a raising in the global ocean surface caused by melting glaciers and thermal expansion of seawater. The upper Texas coast has a relatively high rate of relative sea-level rise compared to other Gulf of Mexico locations because of the high rate of land subsidence. 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.

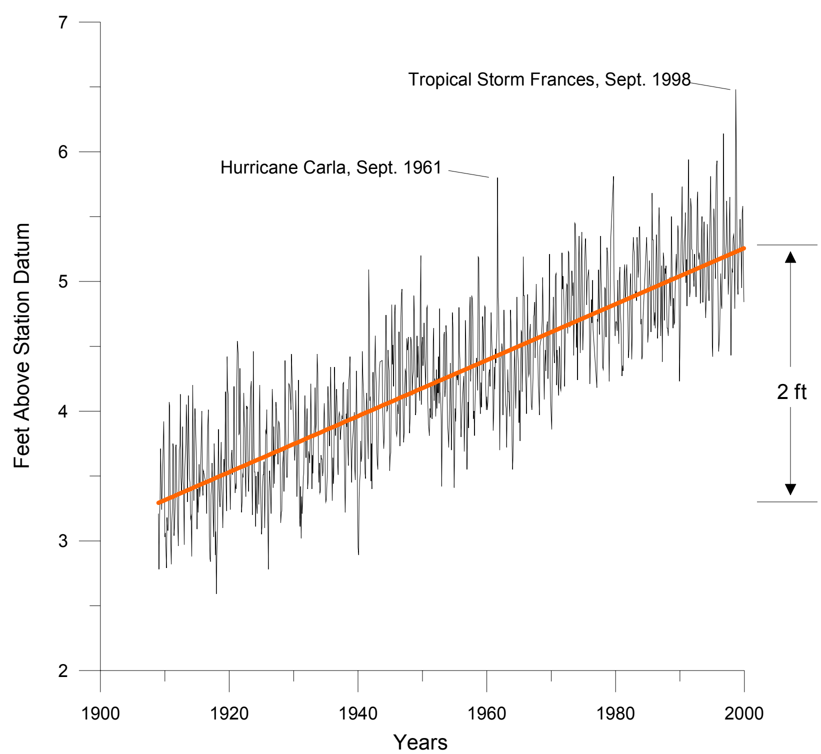

Figure 2. Monthly average sea level since 1909 as measured by the Pier 21 tide gauge in Galveston Bay. Straight line is a linear regression through all the data points.

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 where a small rise can drown large expanses of marsh. [(5)] If coastal development does not provide the room for marshes to expand landward as the sea rises then important habitat will be lost. Relative sea level was 2 ft lower in 1909 then it is today. 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 upper 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 in the earlier part of the century have the potential to subject broader areas to flooding. Given the rate of rise along the upper coast, residents should be concerned for the stability of structures and environments when their outlook is for a period of about 25 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. Long-term change occurs over hundreds to thousands of years, short-term change refers to movement occurring over several seasons to a few tens 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 retreat as it has since the end of the last ice age 18,000 years ago. [(2)] Along most of the upper Texas coast, long-term shoreline retreat is occurring at an average rate of between 3 and 15 ft per year (See Gulf of Mexico erosion layer in Geographic Information System, GIS, data files). There are areas, however, that are retreating much more rapidly and areas where the shoreline is stable or has advanced during the last century.

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 upper 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 Galveston Bay. 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 natural geologic setting has not left much sand offshore to resupply eroding beaches either. The sand turns to mud less than 2 mi offshore Galveston Island and less than 1 mile offshore Bolivar Peninsula, and it is only a thin layer of sand over mud. [(3)] There are other sand deposits farther offshore, but sea-level rise has placed them too far from shore and in too deep of water for waves or currents to move them to the beach. Thus the natural geological setting of the upper 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.

Short-Term Change

Shoreline change that occurs over a few tens of 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. A shoreline that has retreated over the last 100 years may have experienced periods of shoreline advance, and this was the case from 1930 to 1956 when most of West Beach along Galveston Island advanced at a rate of 1 to 6 ft per year.(2) 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, has changed 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 upper Texas coast, this sand is swept up into two or three alongshore bars and in deposits at the mouths of channels such as San Luis Pass and the Freeport Channel. These offshore sand deposits are available to feed the beach and lesson the rate of erosion or reverse it. 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.

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 along West Beach and Follets Island for at least 5 years as the sand moved back to the beaches from offshore at some locations but was not available at others. [6] 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.

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 along the beach. Tidal currents paralleling the shore may also be important especially near passes such as San Luis Pass. Because the wind creates the waves and the prevailing wind direction on the upper Texas coast is easterly, most of the time waves approach the shoreline at an angle open to the southwest. Thus, the average net direction of sand movement is toward the southwest. There are places where tidal currents and wave refraction cause movement to the northeast over relatively short stretches of beach, such as along East Beach South of the Bolivar Roads jetties and south of the Sabine Pass jetties, but overall the movement is to the southwest. Changes in weather patterns can cause temporary reversals in the direction of alongshore sand movement and hence alter shoreline change patterns.

Episodic Shoreline Retreat

The upper Texas coast has no major source of new sand. The sand that makes up the islands and peninsulas and that extends 1 to 2 mi offshore is all that is available to the beaches. Most of the time, the beaches are struck by waves that are less than 4 ft high. [7] The average difference between low and high tide is less than 3 ft. [8] The average wave height, tide range, and amount of sand in the system are small compared with the world's beaches. This means that between storms the beach and dune elevations and shapes adjust to low energy and, in most locations, low sand supply conditions. Maximum natural dune heights are only about 8 ft above sea level, but at many locations they are much lower or nonexistent. Beaches are relatively narrow and gently sloping, and the land behind the beach 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.

Hurricane Carla in 1961 caused significant beach erosion along the entire upper Texas coast. Carla caused the vegetation line to retreat an average of 164 ft along West Beach on Galveston Island. [9] The vegetation line along most of the beach advanced after Carla, but by 1979 only an area between Jamaica Beach and Bay Harbor attained or exceeded the pre-Carla vegetation-line position. Hurricane Alicia in 1983 caused 78 ft of vegetation line retreat. [9] Alicia, as did Carla, completely flattened the dunes along West Beach. After Alicia, detailed studies showed that it took 4 to 5 years for the elevations, widths, and shapes of the beaches to recover and the dunes to reform. [10] However, there was a net loss of sand attributable to the storm; only about 55 percent of the eroded sand returned to the beaches and dunes. If a storm strikes the coast before the beaches have recovered from a previous storm, then we would expect to see even more erosion and damage than we otherwise would.

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 upper 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 usually incomplete, and the shoreline remains significantly landward of its prestorm position. 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 would be expected to be 300 ft landward in 60 years. A single storm, however, could cause a large amount of this movement.

The Pattern of Shoreline Change Today and the Effects of Human-Made Structures

Overall, the shoreline from High Island to the Brazos River is retreating at a rate of 2 to 10 ft per year (fig. 3, also see erosion layer in Geographic Information System files). From 1956 to 1996, approximately 6.9 mi^2 of land eroded; this erosion was partly offset by 0.42 mi^2 of accretion. Comparing the projected 2056 shoreline with the 1996 shoreline reveals that an additional 8.2 mi^2 of land may be lost, which may be offset by 1.0 mi^2 gained.

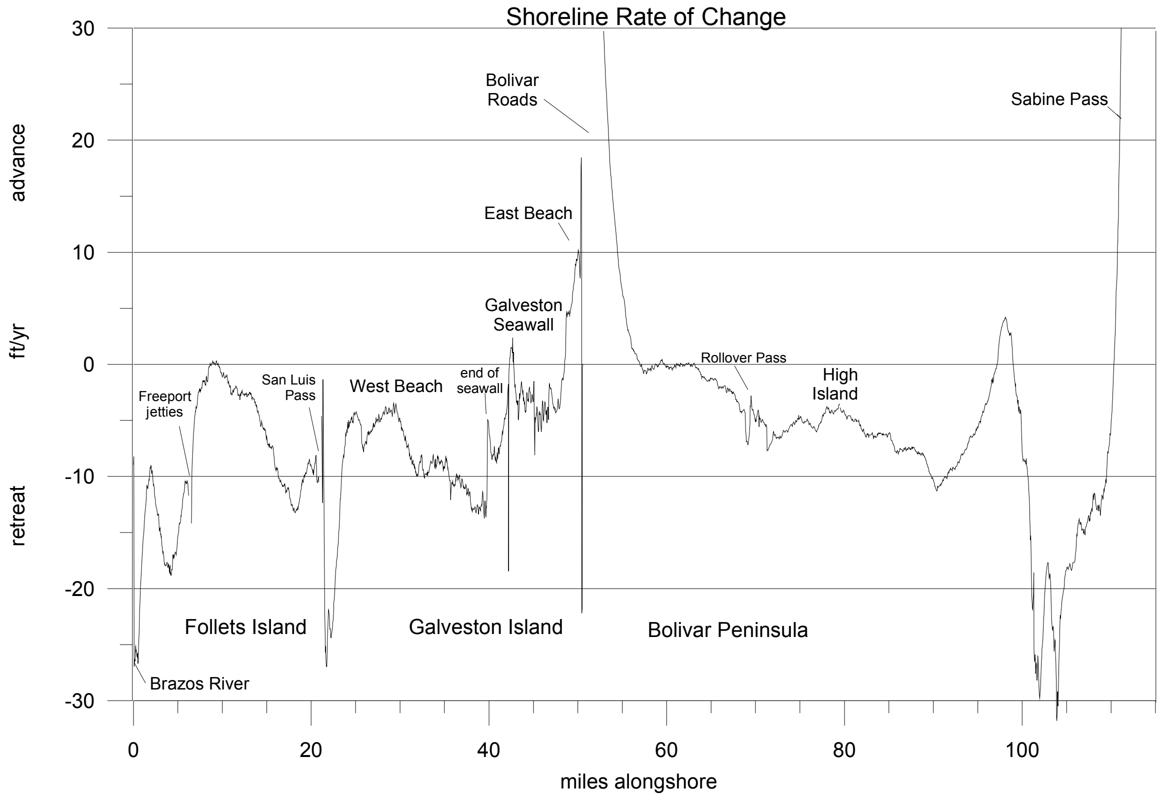

Figure 3. Rate of Gulf of Mexico shoreline change from the Brazos River to Sabine Pass

There are areas of notable exception to the overall erosion rates. These areas are related to San Luis Pass, which is a natural tidal inlet, and to coastal structures. As mentioned above, the supply of sand is very limited along the upper Texas coast. In fact, the major source of sand for a particular beach is that which is eroded from beaches elsewhere. Because the net direction of alongshore sand movement is to the southwest, the supply for any given beach generally lies to the northeast. Any feature that prevents the beach from eroding or traps sand that came from beaches farther to the northeast, will cause enhanced erosion to the southwest. The upper Texas coast has natural and unnatural features that have reduced the sand supply to beaches to the southwest.

The jetties and dredged channels at Freeport Channel, Bolivar Roads, and Sabine Pass serve to keep shipping lanes open, but they have also trapped much sand and have enhanced shoreline retreat away from them to the southwest. Jetty construction and dredging activities began at these channels in the late 1800's and were completed by 1910. The Freeport and Sabine jetties extend about 1/2 mile seaward of the natural shoreline trend to depths of 12 ft. The Bolivar Roads jetties extend 4.5 mi into the Gulf of Mexico to 26 ft depth. [(11)] In addition to these large structures, dredging in 1955 created the small, 200-foot wide Rollover Pass on Bolivar Peninsula. [(12)]

The Bolivar Roads and Sabine Pass jetties impound sand against them and cause stable or advancing shorelines in their immediate vicinity, but much of this sand could have been available to beaches to the southwest where erosion has been increased. The Brazos River used to flow through Freeport channel before it was diverted to the southwest in 1929. [(11)] This caused a reduction in sand supply in the Freeport area, hence the shorelines on both sides of those jetties are still adjusting to this reduction and eroding. It does appear, however, that the Freeport jetties are enhancing erosion for several miles to the southwest. Some of the sand moving along the beach at Rollover Pass is diverted into the channel and trapped in the bay, and some is trapped on the beach east of the pass by the short jetty. It appears that erosion is enhanced for about 2 mi to the southwest of Rollover Pass. San Luis Pass has no jetties and has not been dredged, hence this pass is not a permanent trap for beach sand, but the tidal currents that flow through the pass create a large, shallow sand deposit that extends about 1.5 mi offshore and 3 mi alongshore. Large swings in shoreline position occur adjacent to this pass because of the shifting of the offshore sand, the strong tidal currents, and the effect the sand deposit has on the waves.

Construction of the Galveston Island seawall and groin field began in 1902 and was completed to its current length of 10 mi in 1963. [(13)] In the 1930's, 13 500-foot-long groins were constructed in front of the seawall. The seawall and groin field on the east end of Galveston Island have affected shoreline change by preventing erosion at the seawall and reducing the supply of sand for beaches to the southwest of the seawall

(West Beach). Enhanced erosion rates occur for about 4 mi down to the Bermuda Beach subdivision.

The jetties and Galveston seawall have had a significant effect on the long-term shoreline change rates along the upper Texas coast. The jetties have compartmentalized the coast causing dramatic shoreline advance or reduced shoreline retreat rates adjacent to them, but starving beaches to the southwest of them. The Galveston seawall has protected the City of Galveston from storm surge and has held the shoreline in place, but in doing so , it has cutoff a major supply of sand. Because these structures will stay in place for the foreseeable future, we must consider them when predicting the likely future rate of shoreline change. [14] For this reason, when comparing the positions of historical shorelines to determine how the shoreline will change in the future, only shorelines since the 1950's are considered. It is thought that by the 1950's shoreline change patterns had adjusted to the presence of the structures.

The Moving Bay Shoreline

The patterns of shoreline change in the Galveston Bay system, which includes Trinity, Galveston, West, and East 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. Waves generated in West Bay are smaller than waves in Galveston Bay because of the shorter fetch in West Bay. Shoreline orientation also controls the size of waves approaching the shore because of the prevailing wind directions that generate the waves. Unlike the continuous sandy coast of the Gulf of Mexico shoreline, the Galveston Bay shoreline is made up of a combination of steep clay bluffs, very gently sloping barren tidal flats and marshes, sand and shell beaches, and dredge material taken from shipping channels. Each of these shoreline types responds in different ways to the forces that cause shoreline change, namely waves, relative sea level change, and sediment supply. A patchwork of various shoreline protection measures also exists. These measures, which began to be constructed in the 1930's, include vertical walls and piles of rock or concrete and have varying effects on shoreline change.

Bay shoreline change that is presented in the atlas was determined by comparing shorelines mapped in the early 1850's with those mapped using 1982 vertical aerial photographs. [15] During this period, 78 percent of the shorelines retreated, and the average landward movement was 2.2 ft per year. Approximately 12.5 mi^2 of land was lost. The average rate of shoreline retreat increased from 1.8 to 2.4 ft per year after 1930. [15] Since the 1950's, increased rates of land subsidence have caused some shorelines to retreat dramatically. The pumping of underground water, as described in the subsidence section, enhanced the subsidence.

Tropical Storms and Hurricanes

Because of the overall low-energy, low-sand supply, and gently sloping setting of the upper 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/aboutsshs.html; Brian Maher and Jack Beven). 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.

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 destructon 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, seven category one, three category two, three category three, four category four, and no category five hurricanes struck the upper Texas coast. 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 but 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 (fig. 4). 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 level 1 hurricane.

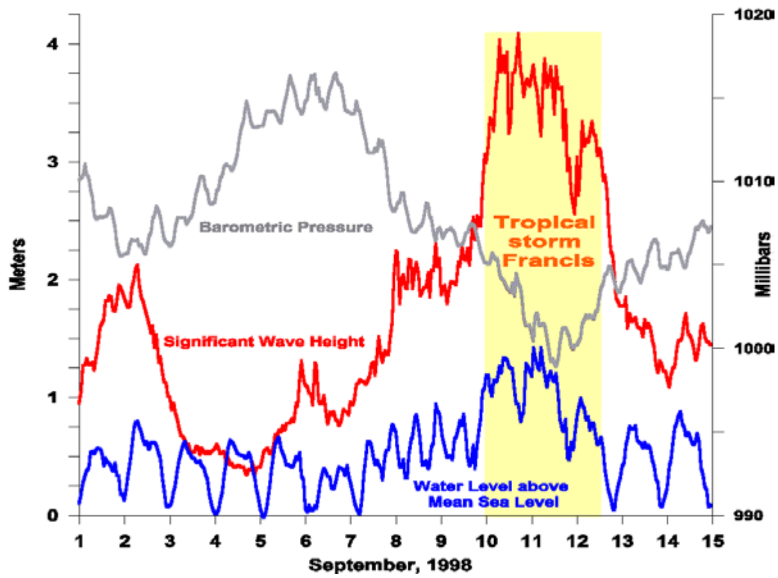

Figure 4. Plots of barometric pressure, wave height, and ocean level during Tropical Storm Frances.

Furthermore, because of their location close to the shoreline, hundreds of houses were damaged or left on the open beach.

Storm-Surge Penetration

The atlas contains data layers that show the limits of storm-surge penetration 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 penetration 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 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 line of storm-surge penetration is drawn as the boundary between dry and wet cells (Preceding description is from a written communication of Chris Blakely, The Research Division, Texas A&M University). The atlas contains layers for each hurricane category. The atlas also contains a layer that shows the actual limit of storm-surge penetration by Hurricane Carla in 1961. [(16)]

Storm Washover Features

The storm surges and waves associated with Hurricane Carla and later Hurricane Alicia in 1983 caused breaches to occur in the beaches and dunes. 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. 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.

Subsidence

Problems

Land-surface subsidence poses problems and hazards for both natural and human resources in Texas coastal areas. Low-lying land along the Gulf and around bays and estuaries is subject to intermittent flooding, and even small drops in elevation due to subsidence can lead to permanent flooding and loss of land and wetlands. Thousands of acres of vegetated wetlands have been submerged by subsidence and replaced by open water in the Galveston Bay System (fig. 5).(17) Near the head of Galveston Bay, a residential community was condemned and converted into a nature preserve and wetland area because of persistent flooding as a result of subsidence (fig. 6). In addition, lowering of the land surface by subsidence can lead to more extensive erosion and flooding during hurricanes, tropical storms, and stream runoff.

Location

Subsidence of varying degrees has occurred along the entire Texas coast, but the most significant subsidence is in the Houston-Galveston area where a large subsidence "bowl" with as much as 10 ft of subsidence near its center has formed (fig. 7; also see subsidence layer in Geographic Information System, GIS, data files). In this area, the amount of land undergoing at least one foot of subsidence, including the area around Texas City, has grown from about 140 mi^2 in the 1940's to more than 3,600 mi^2 in the 1980's (fig. 8). Average maximum rates of subsidence at the center of the "bowl" were as high as 0.4 ft/yr for the period 1964 to 1973.(18)

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Figure 5. Effects of subsidence on natural resources such as marshes and swamps in the Clear Lake area. Vegetation has been submerged and replaced by open water.

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Figure 6. Effects of subsidence on a residential area in Baytown at the head of Galveston Bay. The area was so impacted by subsidence and associated flooding during hurricanes that the houses were ultimately abandoned and the area converted into marshes and aquatic habitats.

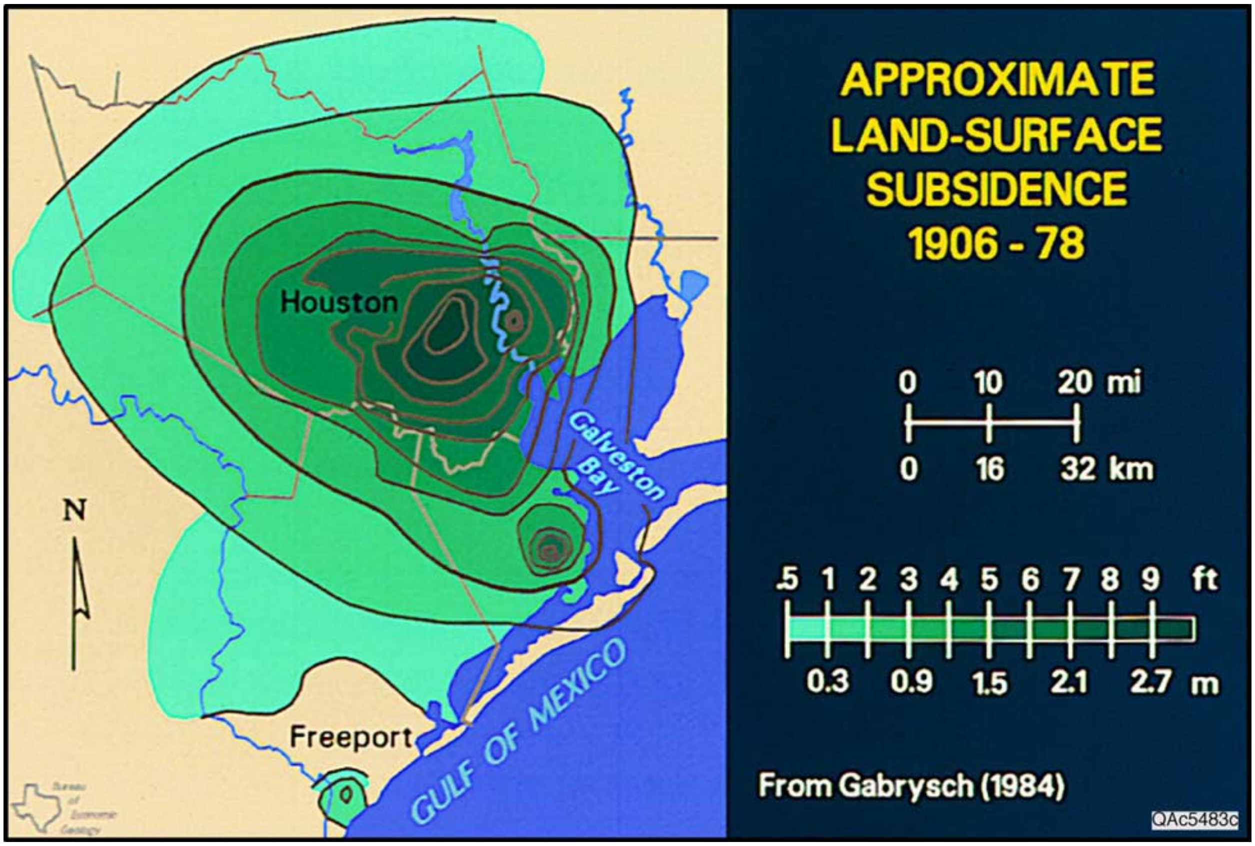

Figure 7. Land surface subsidence in the Houston-Galveston area from 1906-1978.[26] This is a period during which much of the subsidence took place in the eastern part of the subsidence bowl. Since the late 1970's, reductions in rates of ground-water withdrawal in that area have greatly reduced rates of subsidence.[19]

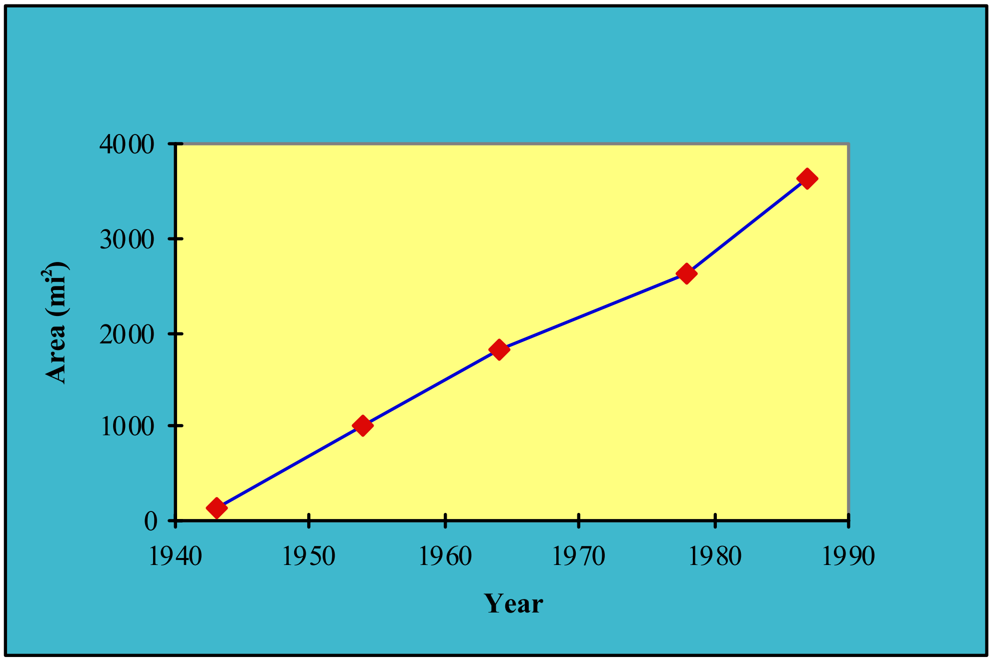

Figure 8. Growth of the Houston-Galveston area subsidence "bowl" from 1943 to 1987. Defined by cumulative area in which subsidence is more than one foot.[16,19]

Causes

There are many causes of subsidence including regional downwarping or tilting of the earth's crust due to loading, which is significant over a geologic time frame along the Texas coast but not over an historic time frame.[20] Within an historic time frame, the cause of subsidence in the Houston-Galveston area is primarily due to ground-water withdrawal and secondarily oil and gas production that began in the early part of this century. In the Houston-Galveston area, ground water is produced from sand aquifers as deep as 3,000 ft. Subsidence occurs as water levels are lowered in the aquifers and interbedded clay begins to lose water and compact.[18] The reduction in water or artesian pressure reduces the support for overlying sedimentary strata and the land surface begins to sink or subside. Most of the compaction is permanent because of the inelastic nature of the clay. However, if ground-water pumpage is stopped or reduced so that the aquifer water levels are maintained or raised, clays are no longer exposed to drying, and subsidence rates are greatly reduced.[19] On the eastern side of the subsidence bowl in the Houston-Galveston region, rates of subsidence have decreased dramatically in some areas due to curtailment of ground-water pumpage (fig. 9).[19] To the west, however, rates of pumpage have remained high, as have rates of subsidence (fig. 9; also see GIS layers).[21]

Subsidence is also associated with oil and gas production in some areas. Good examples are the Goose Creek Field near the head of Galveston Bay, and the Saxet oil and gas field near Corpus Christi.[22,23,24] In these fields, there has been a close correspondence between rates of hydrocarbon production and rates of subsidence. Subsidence associated with oil and gas fields depends on many factors such as reservoir size, depth, thickness, consolidation, volume and rate of production, and fault associations. But in general, subsidence occurs as production of oil, gas, and associated water reduces pore pressures in the producing zone, which leads to an increase in effective load from the weight of overlying strata and compaction of compressible beds.[25] The compaction of beds at depth can result in subsidence at the land surface.

Measuring Subsidence

Methods of measuring subsidence include conventional leveling, extensometers, tide gauges, and more recently, Global Positioning Systems (GPS). Conventional leveling is the most frequently used method, and involves comparing the elevations of benchmarks through time using precise leveling techniques. Borehole extensometers (fig. 10) have been used at specific locations to determine small changes in elevations; extensometers can provide very precise, continuous records with information on the compacting interval, but they are costly to install and have small areal application (see extensometer layer in GIS data files).[26] Subsidence can be determined by comparing tide gauge records from two different stations, but this method is less precise than leveling and extensometers. Today, many benchmarks are releveled using satellites or GPS, which provide very precise measurements.

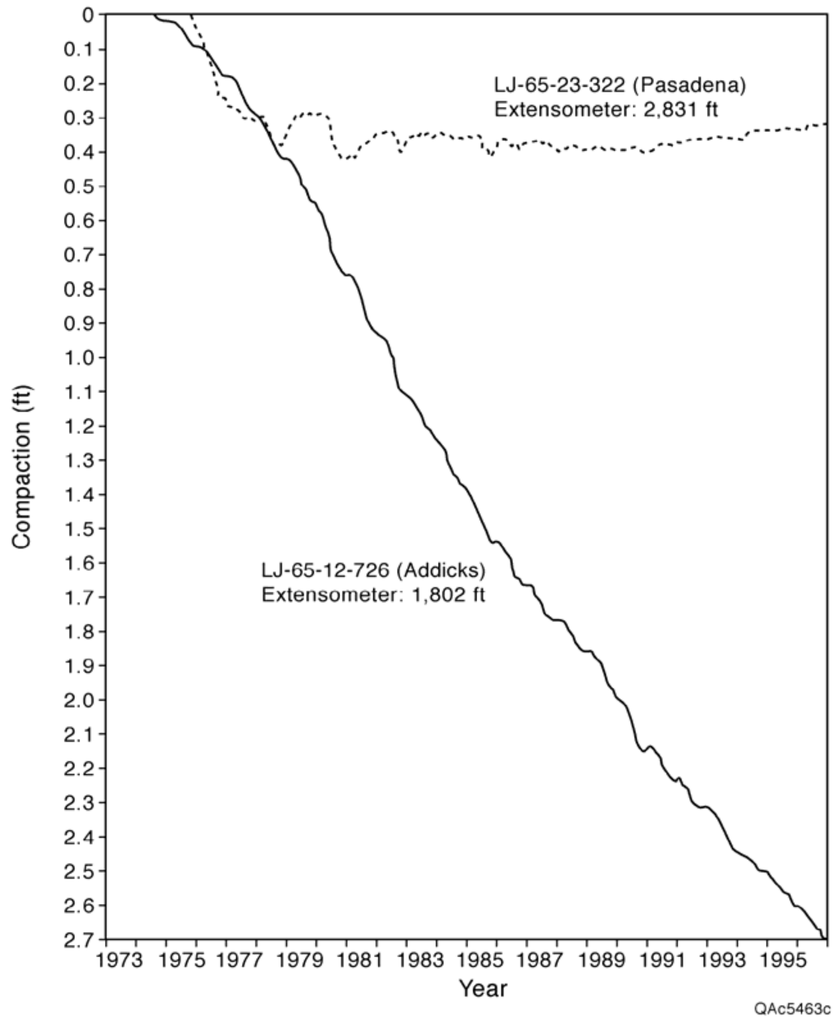

Figure 9. Cumulative compaction as measured by extensometers located at Pasadena and Addicks. [21] Pasadena is located on the eastern side of the subsidence bowl, and Addicks is on the western side. Note that cumulative compaction at Pasadena was high in the mid-1970's, but since that time has leveled off and even had some reversals, whereas at Addicks, rates of compaction remained high from the 1970's to the 1990's.

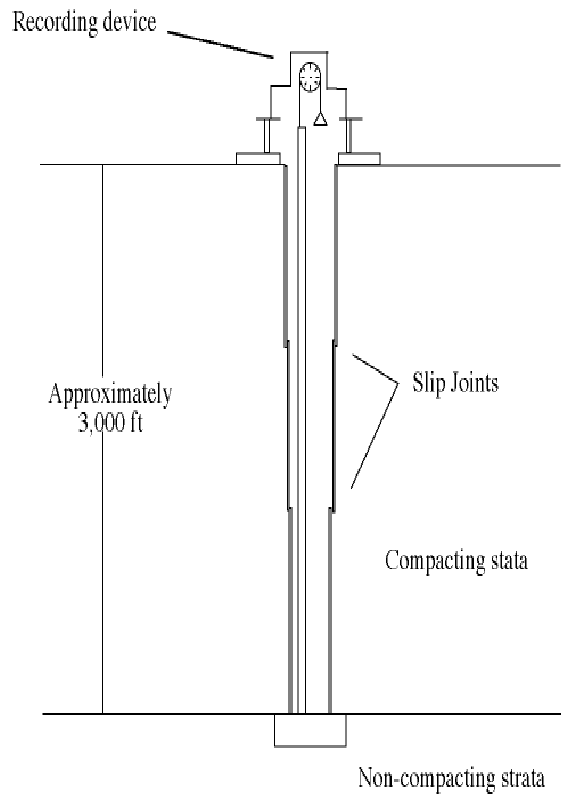

Figure 10. Illustration of a typical borehole extensometer. The inner rigid pipe maintains its position with respect to the outer segmented pipe and surface installation, which become lower as subsurface strata compact. The amount of compaction or shortening is measured by the wire tape rolling over the drum.[27]

Faulting

Problems

Geologically, active surface faults along the Texas coast are fractures in the earth's crust along which movement has occurred within the past few thousand years. Generally, the earth's surface moves downward or subsides at a faster rate on one side (downthrown side) of the fault than on the other side (Figs. 11 and 12). This produces a fault scarp or sharp change in elevation at the surface along the trace of the fault. Unlike faults along the West Coast where stress builds and then is released producing earthquakes, earthquakes are extremely rare on the Texas Gulf Coast. Nevertheless, active faults are significant geologic hazards because their movement at the surface breaks and bows structures such as highways, railroads, foundations of residential and commercial developments, pipelines, air field runways, football stadiums, and other features. Millions of dollars of damage are caused annually by faults.[28] Natural resources such as wetlands are also affected by faulting. As the land surface moves downward along a fault that intersects a wetland, more frequent and eventually permanent inundation can lead to replacement of marsh vegetation by open water (fig. 11).

Locations and Characteristics

The major zone of surface faulting along the Texas coast is in the Houston-Galveston area where at least 160 faults with a cumulative length of more than 250 linear mi have been reported.[28] Forty faults, together measuring about 93 mi have been identified and mapped in marsh areas along the upper coast (fig. 13, and GIS fault layer).[29] The lengths of individual fault traces range from less than 0.5 mi to more than 8 mi. The measurable vertical displacement of faults at the surface varies from 0 to 12 ft,[30] but the heights of most fault scarps are from less than 1 to 3 ft.[31] Rates of fault movement commonly range between 0.2 and 0.8 in/yr but many exceed 1.6 in/yr.[28, 30, 32, 33] Movement along surface faults apparently occurs episodically.[30]

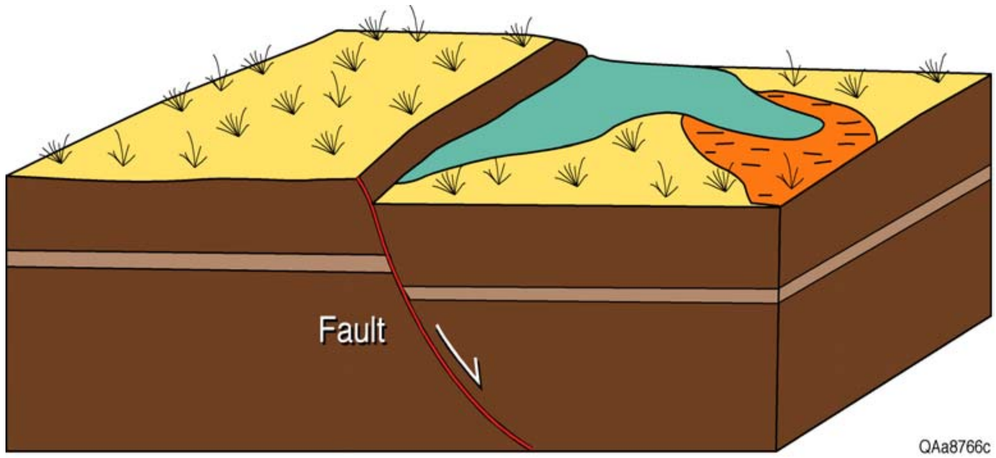

Figure 11. Diagram illustrating changes in wetlands along an active surface fault. There is generally an increase in low marshes and ponded water on the side of the fault that is moving downward.[17]

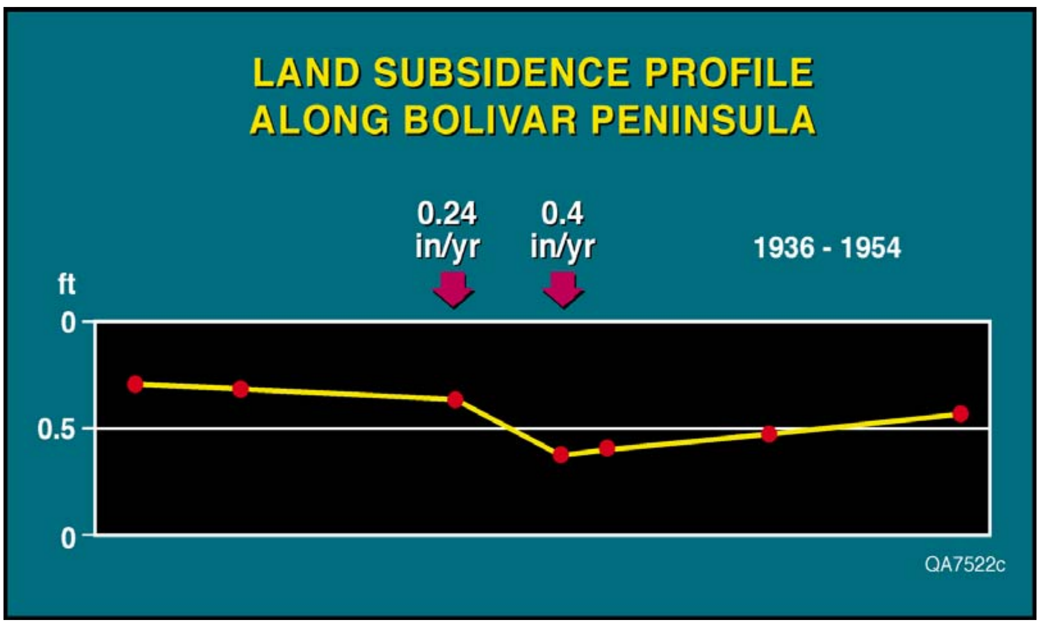

Figure 12. Profile constructed from benchmark releveling surveys that cross a fault along a highway on Bolivar Peninsula.[28] The increase in subsidence of 0.24 in/yr to 0.4 in/yr shows that the downthrown side of the fault is subsiding at a faster rate than the upthrown side for the period of the surveys, 1936-1954. Fault activation and subsidence at this site appear to be associated with hydrocarbon production.

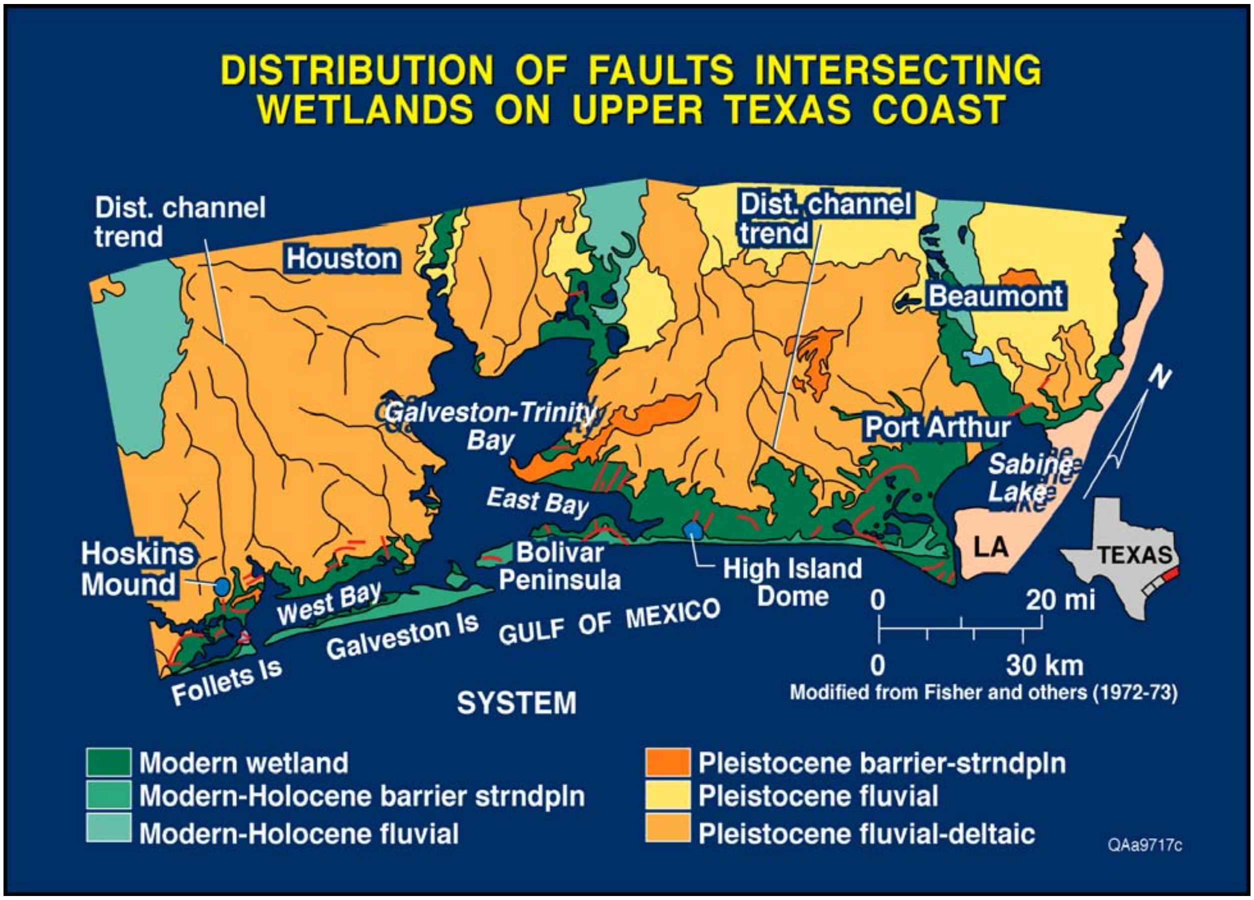

Figure 13. Surface faults, shown in red, that intersect marshes between Follets Island and the Louisiana border. The faults were mapped from sequential aerial photographs. Only about 25 percent of the faults were visible on photographs taken in the 1930's, but the remaining 75 percent could be seen on later photographs indicating that they have become active since the 1930's.[28]

Causes

Surface faults correlate with, and appear to be natural extensions of subsurface faults in many areas.[28,29,32,34,35] Although movement of the earth's surface along some faults is related to natural processes, there is evidence that most of the surface faulting in the Houston metropolitan area and the upper Texas coast has taken place during the last few decades, and is largely due to the withdrawal of water, oil, and gas, which has reinitiated and accelerated fault activity.[28,29,30,35] Most of the faults in the Houston-Galveston area occur within the subsidence bowl caused by ground-water withdrawal, but at some locations there is a close association between the faults and oil and gas production.[23,24,29]

Locating and Mapping Active Faults

Analysis of aerial photographs is a common method used to detect possibly active faults. Photographs showing linear and curvilinear features across which there are changes in colors and tones provide evidence that a fault may be present (fig. 14). These tonal variations across a fault may be caused by a combination of factors such as changes in vegetation, soil moisture, soil types, standing water, and elevation. Analysis of sequential photographs can provide evidence that a linear feature is an active fault. Many faults are not visible on historical photographs but are visible on more recent photographs, which indicates that they have become active recently. Other lines of evidence of fault activity are (1) reoccurring breaks and repairs in pavements, buildings, and other structures, (2) abrupt changes in elevations as shown on topographic maps, and (3) sharp changes in the rates of subsidence along benchmark releveling profiles (fig. 12).

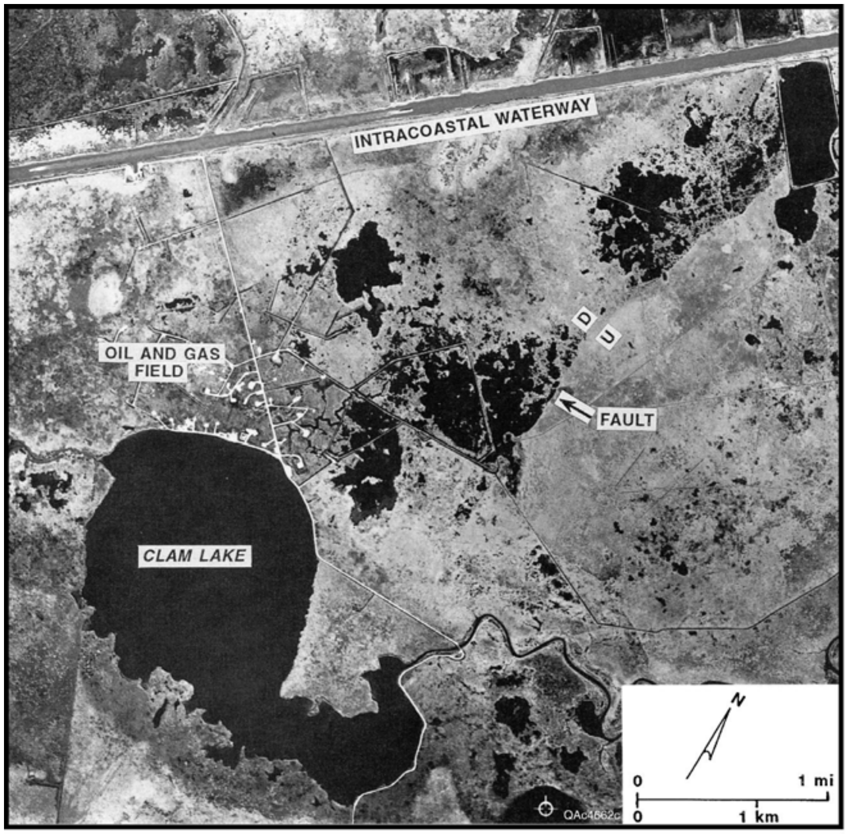

Figure 14. Example of fault trace on a photograph taken in 1989 in the Clam Lake area between Sabine Lake and Galveston Bay. Topographically low marshes and open water (black areas) are more abundant on the side of the fault that is moving downward (labeled D). This fault is not visible on aerial photographs taken in the 1950's, but it is on photographs taken in the 1960's or later indicating that movement along the fault has occurred since the 1950's.[17]

Summary of Subsidence and Faulting

Subsidence and faulting are substantial hazards along the Texas coast. Of particular concern, is the Houston-Galveston region where as much as 10 ft of subsidence has occurred. The area affected by at least one foot of subsidence has grown 25 times larger since the 1940's, to more than 3,600 mi^2. The principal cause of subsidence in this area is withdrawal of ground water, and secondarily oil and gas. The Houston-Galveston area is also the region most affected by surface faulting, with at least 160 faults having a cumulative length of more than 250 mi. The active faults have caused millions of dollars of damage annually to structures such as highways, airport runways, and building foundations. As many as 40 faults have affected biologically productive marsh resources along the upper Texas coast. Subsidence along active faults submerges marsh vegetation converting it to open water. Thousands of acres of marsh habitat have been impacted by this process.

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Appendix: Geographic Information System Documentation Files

Following are excerpts of the text of the documentation files found on the CD-ROM. The documentation contains technical information related to the data and to the processing of the data in the Geographic Information System.

I. Bay Erosion

Abstract:
Changes in shoreline position occuring for more than a century provide estimates of the relative stability of shorelines and, along the Texas coast,allow comparisons of shoreline changes before and after human modifications became significant. Despite the widespread use of shoreline protection measures, about 78 percent of the shorelines within the Galveston Bay system retreated between the early 1850's and 1982. During this period, bay shorelines moved an average of 2.2 ft/yr landward, causing the loss of about 12.5 square miles of land. (Above is taken from Paine and Morton, 1986.)
Purpose:
Field observations and regional mapping suggest that most of the shorelines are unstable and are moving landward at rates from a few feet to a few tens of feet per year. In some bays, biologically productive wetlands and other areas of State-owned natural resources are diminishing. The substantial cumulative land loss translates directly to significant economic losses, both to the State and to private landowners. As shorelines change, public and private investments may be jeopardized and property damaged or destroyed. Taken together, the public and private losses are of significant magnitude to warrant investigation of shoreline movement. (Above is taken from Paine and Morton, 1986.)

Limitations_of_Data:
The erosion points were digitized at 1:24000 scale. It is important to note that interpretation or analysis using this data at scales larger than 1:24000 could result in a loss of accuracy. Reference should be made at 1:24000 scale or smaller.
Entity_and_Attribute_Overview:
-STATION
Measuring point location; bay name followed by point number
ex: T23 T= Trinity Bay
23= 23rd point location in Trinity Bay
E = East Bay
T = Trinity Bay
G = Galveston Bay
W = West Bay
-COMB_DIST_FT
Combined net gain/loss distance in feet, measured to the nearest 25ft. Combined distance from the earliest measured date (1850, 1851, or 1852) to the latest measure date (1974 or 1982). An asterick indicates distances with inaccurate rates of change (see RATE_FT-YR_C).
-RATE_FT-YR
Total combined distance divided by number of years from 1850's to 1982. Value of -9999000 indicates an inaccuracy in rate calculation (see RATE_FT-YR_C).
-RATE_FT-YR_C
A letter that describes the type of error encountered in calculating the COMB_DIST_FT and the RATE_FT-YR items. The inaccuracies are denoted as follows:
D = Shoreline retreated due to DREDGING or excavation

I = Shoreline change an artifact of INTERPRETATIONAL differences between
aerial photographs and 1850's topographic charts
L = Shoreline advanced due to commercial development, LANDFILL
S = Shoreline advanced due to dredged SPOIL deposition

Procedures_Used:
Initial mapping preformed by Jeffrey Paine and Robert Morton (Paine and Morton, 1986) utilized near-vertical aerial photographs and topographic surveys to determine changes in shoreline position. USGS topographic maps (7.5 minute) were used. Topographic charts and aerial photographs were either reduced or enlarged to the scale of the USGS topographic sheets. Shorelines were mapped directly on sequential aerial photographs and optically transferred onto a common base map. Transferral of the shorelines to the base map allowed direct comparison and quantification of changes in shoreline position with time.

Digitizing the erosion points, or stations was manually done in ArcView. Digital raster graphs (DRG's) of 7.5 mintue U.S. Geological Survey maps were used as a base and the points were estimated and entered as shapefiles.The shapefiles were converted to ArcInfo coverages and projected to UTM. The individual coverages were then appended into a single seamless set. Attributes were added to the seamless coverage in ArcView. The individual coverages and the seamless dataset were both quality checked in house.

Revisions:
This dataset is version 1.0 and has no predecessor.

Reviews_Applied_to_Data:
In house review covered in 'Procedure' above.

Related_Spatial_and_Tabular_Data_Sets:
None

References_Cited:
Paine J. G. and Morton, R. A., 1986, Historical Shoreline Changes in Trinity,
Galveston, West, and East Bays, Texas Gulf Coast: Geological Circular 86-3, Bureau of Economic Geology, The University of Texas at Austin, 58 p.
Notes:

Currentness_Reference:
This reference document was update 4-21-99.

Maintenance_and_Update_Frequency:
None planned

Access_Constraints:
None

Data_Set_Credit:
Bureau of Economic Geology
Jeffrey G. Paine
Robert A. Morton
Tom Tremblay

Sarah Dale

Completeness_Report:
Complete

Horizontal_Positional_Accuracy_Report:
90 percent of well defined point features fall within 40 ft of their true
position.

Vertical_Positional_Accuracy_Report:
N/A

Cloud_Cover:
N/A

II. Cities

cities.shp
The cities.shp file was generated from cities.e00.gz
downloaded from TNRIS at www.tnris.state.tx.us.
Datum information was not included with the .e00 file.
Also, a few of the polygons were not coded (i.e.
Jamaica Beach on Galveston Island).

urban.shp
The urban.shp file was generated from urbanareas.e00.gz
downloaded from TNRIS at www.tnris.state.tx.us.
Again, datum information was not included in the .e00 file.
Also, polygons do not have attribute information.

III. County Boundaries

No accompanying documentation.

IV. Digital Orthophoto Mosaics (doqq)

The digital orthophoto quarter quadrangles are produced under the Texas Orthophoto Program. The photos are color infra-red and were acquired in January and February 1995.

The following steps were taken to generate
the digital orthophoto quarter quandrangle (DOQQ) mosaics located on this CD.

1. First, the 24-bit, 1 meter resolution
DOQQs (Digital Orthophoto Quarter Quadrangles)
were aquired in tiff format (with accompanying
.tfw file).

2. These image files were then imported into ERMapper5.5 and resampled to 2.5 meter resolution.

3. The 2.5m resolution files were then 'mosaicked' into 22 separate sections (as listed in the directories 'north' and 'south.')

4. These 22 ERMapper .ers files were then exported back to 24-bit tiff format (each with its own .tfw file).

5. Finally, the twenty-two tiff images were opened in PaintshopPro4.0 and saved as the 7-bit (128 color) images. These are the images located in the directories 'north' and 'south.'

For more information on DOQQs visit:
http://www.txdoqq.com
http://www.eisyscorp.com/html/doppa.html
http://www.tnris.state.tx.us/DigitalData/doqs.htm

V. Environmental Sensitivity Index (ESI) Shoreline

Abstract:
Environmental Sensitivity Index (ESI) mapping of the Texas coastline was conducted in the Galveston Bay system and north to the Louisiana border (Morton and White, 1995). ESI classification of the shoreline was interpreted from aerial videography and transferred to paper USGS 7.5' quadrangle maps. Aerial photography and National Wetlands Inventory (NWI) data provided supplementary information where aerial videography was lacking. Information from the 7.5' quads was digitized and coded as to the ESI classification.

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

Limitations_of_Data:
The original mapping was conducted at 1:24,000 scale. Therefore, this dataset should not be used for mapping at scales larger than 1:24,000.

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

Procedures_Used:
See abstract.

Revisions:

Reviews_Applied_to_Data:

Related_Spatial_and_Tabular_Data_Sets:

References_Cited:
Morton, R .A., and White, W. A., 1995, Shoreline types of the upper Texas coast:Sabine-Galveston-Freeport-Sargent areas: The University of Texas at Austin, Bureau of Economic Geology, final report prepared for the Texas Natural Resources Inventory Program, Texas General Land Office, Texas Natural Resource Conservation Commission, and Texas Parks and Wildlife Department under GLO contract no. 94-177R and Minerals Management Service Gulfwide Information Systems at Louisiana State University, CMI-30660-19901, 42 p.

VI. Faulting

The Faulting directory contains geologic faults from three publications:
beg_faults-   William White and Robert Morton. "Wetland Losses Related to Fault Movement and Hydrocarbon Production, Southeastern Texas Coast". 1997.

egat_faults-   L.F. Brown, Robert A. Morton, Joseph H. McGowen, Charles W. Kreitler, and W.L. Fisher. "Natural Hazards of the Texas Coastal Zone." University of Texas Bureau of Economic Geology, 1974.

usgs_faults-   E.R. Verbeek and U.S. Clanton, 1978, Map Showing Surface Faults in the Southeastern Houston Metropolitan Area, Texas., USGS open file report no. 78-797.

BEG Faults
faults: Fault lines

faults_symb: upthrown/downthrown symbology

Metadata:

Identification_Information:
Citation:
Citation_Information:
Originator: William White and Robert Morton
Publication_Date: Fall 1997
Publication_Time:
Title: Wetland Losses Related to Fault Movement and Hydrocarbon Production, Southeast Texas Edition: 1.0
Geospatial_Data_Presentation_Form:
Series_Name:
Issue_Identification:
Publication_Information:
Publication_Place: Royal Palm Beach, FL
Publisher: The Coastal Education and Research
Other_Citation_Details: Journal of Coastal Research
Online_Linkage:

Description:
Abstract:
Time series analysis of surface fault activity and nearby hydrocarbon production from the southeastern Texas coast show a high correlation among volume of produced fluids, timing of fault activation, rates of subsidence, and rates of wetland loss. Greater subsidence on the downthrown sides of faults contributes to more frequent flooding reflected in changes to plant communities or progressive transform-ation of emergent vegetation to open water. Since the 1930's and 1950's, about 5,000 hectares of marsh habitat has been lost as a result of subsidence associated with faulting. Seventy-five percent of the faults visible on recent aerial photographs are not visible on photographs taken in the 1930's, indicating relatively recent fault movement. (The above is taken from White and Morton, 1997.)

Purpose:
Direct wetland losses caused by excavation of drilling sites, construction of canals, and installation of pipelines are easily observed and have been documented as a primary environmental impact (Turner and Cahoon, 1988).Less obvious but equally destructive are wetland losses associated with subsidence and faulting induced by oil and gas production. There is evidence that many faults have become active during the past few decades as a result of the withdrawl of water, oil and gas (Van Siclen, 1967; Gustavson and Kreitler, 1976; Verbeek and Clanton, 1981). In this study,40 faults that intersect coastal wetlands on the upper Texas gulf coast were identified, mapped, and examined using aerial photographs. Primary objectives were to document the locations and lengths of surface faults intersecting coastal wetlands, to determine historical activity of the faults, and to examine the relationship between fault movement, underground fluid production, and wetland changes. (The above is taken from White and Morton, 1997.)

Supplemental_Information:

Procedures_Used:

In the initial mapping, preformed by William White and Robert Morton, faults were identified primarily on photographs taken in 1979, from which the fault traces were optically transferred to USGS 7.5 minute topographic base maps. Faults crossing wetlands are traceable on aerial photographs due to slightly lower elevations on the faults' downthrown side creating contrasting moisture regimes and vegetation communities that highlight the fault traces.

The USGS quad sheets with the transferred fault traces were digitized in ArcInfo on a per quad basis. The coverages were projected into UTM and then appended into a single coverage (faults_up). Attribute information was added in ArcEdit. The final data set was quality checked in house for accuracy and completeness.

Revisions:

This dataset is version 1.0 and has no predecessor.

Reviews_Applied_to_Data:

In house review covered in 'Purpose' above.

Related_Spatial_and_Tabular_Data_Sets:

None

Other_References_Cited:

White, W. A. and Morton, R. A., 1997, Wetland losses related to fault movement and hydrocarbon production, southeastern Texas coast: Journal of Coastal Research, v. 13, no. 4, p. 1305-1320.

Turner, R. E. and Cahoon, R. R., (eds.), 1988, Causes of wetland loss in the coastal central Gulf of Mexico, Volume II: Technical Narrative. New Orleans, Louisiana: U.S. Department of the Interior, Minerals Management Service, OCS Study/MMS 87-0120, 400 p.

Van Siclen, D., 1967, The Houston fault problem: Proceedings of the American Institute of Professional Geologists, 3rd Annual Meeting, Texas Section, Dallas, p. 9-31.

Gustavson, T. C. and Kreitler, C. W., 1976, Geothermal resources of the Texas Gulf Coast - Environmental concerns arising from the production and disposal of geothermal waters: Austin Texas: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 76-7, 35 p.

Verbeek, E. R. and Clanton, U. S., 1981, Historically active faults in the Houston metropolitan area, Texas, In: Etter, E. M., (ed.), Houston Area Environmental Geology: Surface Faulting, Ground Subsidence, Hazard Liability, Houston, Texas: Houston Geological Society, p. 28-68.

Notes:

Time_Period_of_Content:

Time_Period_Information:

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   Currentness_Reference:
    This reference document was updated on 2-26-98.

  Status:
    Progress:  Complete
    Maintenance_and_Update_Frequency:
     None planned.

  Spatial_Domain:
    Bounding_Coordinates:
      West_Bounding_Coordinate: -95.75654802
      East_Bounding_Coordinate: -93.819143
      North_Bounding_Coordinate: 30.06479514
      South_Bounding_Coordinate: 28.74316151
  Keywords:
    Theme:
      Theme_Keyword_Thesaurus:  None
      Theme_Keyword:  faulting, coastal erosion, coastal wetlands, land
subsidence
    Place:
      Place_Keyword_Thesaurus:  None
      Place_Keyword:  Sabine Lake to Matagorda Bay, Upper Texas Gulf
Coast
    Stratum:
      Stratum_Keyword_Thesaurus:  None
      Stratum_Keyword: None
    Temporal:
      Temporal_Keyword_Thesaurus:  None
      Temporal_Keyword: None
  Access_Constraints:
   None

  Use_Constraints:
   The faults were digitized at 1:24000 scale.  It is important to note
that interpretation or analysis using this data at scales larger than
24000 could result in the loss of accuracy.  Reference should be made
at 24000 scale or smaller.

  Point_of_Contact:
   Contact_Information:
    Contact_Person_Primary:
      Contact_Person: Tom Tremblay
      Contact_Organization: Bureau of Economic Geology
    Contact_Position: GIS Coordinator
    Contact_Address:
      Address_Type: mailing address
      Address: 10100 Burnet Road, Building 130
      City: Austin
      State_or_Province: Texas
      Postal_Code: 78758
      Country: USA
    Contact_Voice_Telephone: 512-471-1534
    Contact_Electronic_Mail_Address: trembalyt@begv.beg.utexas.edu
    Hours_of_Service: 8:00 - 4:00

  Data_Set_Credit:
   Bureau of Economic Geology
```

William White
Robert Morton
Tom Tremblay
Sarah Dale

Security_Information:
Security_Classification_System: None
Security_Classification: Unclassified
Security_Handling_Description: None
Native_Data_Set_Environment: SunOS, 5.5.1, sun4m UNIX, ARC/INFO version 7.1.1
Cross_Reference:
Citation_Information:
Originator: William White and Robert Morton
Publication_Date: Fall 1997
Publication_Time:
Title: Wetland Losses Related to Fault Movement and Hydrocarbon Production, Southeast T
Edition: 1.0
Geospatial_Data_Presentation_Form:
Series_Information:
Series_Name:
Issue_Identification:
Publication_Information:
Publication_Place: Royal Palm Beach, FL
Publisher: The Coastal Education and Rese
Other_Citation_Details:
Online_Linkage:

Data_Quality_Information:
Attribute_Accuracy:
Attribute_Accuracy_Report: See Entity_Attribute_Information
Quantitative_Attribute_Accuracy_Assessment:
Attribute_Accuracy_Value: See Explanation
Attribute_Accuracy_Explanation:
Attribute accuracy is described, where present, with each attribute defined in the Entity and Attribute Section.
Logical_Consistency_Report: Chain-node topology present.
Completeness_Report:
Complete

Positional_Accuracy:
Horizontal_Positional_Accuracy:
Horizontal_Positional_Accuracy_Report:
90 percent of well defined features fall within 40 feet of their true position.

Quantitative_Horizontal_Positional_Accuracy_Assessment:
Horizontal_Positional_Accuracy_Value: 40 ft
Horizontal_Positional_Accuracy_Explanation: Resolution as reported
Vertical_Positional_Accuracy:
Vertical_Positional_Accuracy_Report:

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  Lineage: See also Supplemental_Information:
   Source_Information:
    Source_Citation:
     Citation_Information:
      Originator:
      Publication_Date:
      Title:
    Source_Scale_Denominator: 24000
    Type_Of_Source_Media:
    Source_Time_Period_of_Content:
      Time_Period_Information:
       Single_Date/Time:
        Calendar_Date:
      Source_Currentness_Reference:
    Source_Citation_Abbreviation:
    Source_Contribution:
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  Horizontal_Coordinate_System_Definition:
    Planar:
      Grid_Coordinate_System:
        Grid_Coordinate_System_Name:
        Universal_Transverse_Mercator
          UTM_Zone_Number: 15
      Planar_Coordinate_Information:
        Planar_Coordinate_Encoding_Method: coordinate pair
        Coordinate_Representation:
          Abscissa_Resolution: 1.0
          Ordinate_Resolution: 1.0
        Planar_Distance_Units: METERS
    Geodetic_Model:
      Horizontal_Datum_Name: North American Datum of 1983
      Ellipsoid_Name:  GRS1980
      Semi-major_Axis: 6378206.4
      Denominator_of_Flattening_Ratio: 294.98

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  Detailed_Description:
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      Entity_Type_Label:  FAULTS_UP.PAT
      Entity_Type_Definition:  points indicating upthrown and
downthrown side of faults
      Entity_Type_Definition_Source:  USGS quad sheets prepared by
William White
    Attribute:
      Attribute_Label:  -
      Attribute_Definition:  points indicating upthrown and downthrown
side of faults
      Attribute_Definition_Source:  USGS quad sheets prepared by
William White
      Attribute_Domain_Values:
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          Enumerated_Domain_Value:  -
          Enumerated_Domain_Value_Definition:
          Enumerated_Domain_Value_Definition_Source:
    Attribute:
      Attribute_Label:  AREA
      Attribute_Definition:  Degenerate area of point
```

```
      Attribute_Definition_Source:  Assigned
      Attribute_Domain_Values:
        Enumerated_Domain:
          Enumerated_Domain_Value:  0
          Enumerated_Domain_Value_Definition:
          Enumerated_Domain_Value_Definition_Source:
    Attribute:
      Attribute_Label:  PERIMETER
      Attribute_Definition:  Degenerate perimeter of point
      Attribute_Definition_Source:  Assigned
      Attribute_Domain_Values:
        Enumerated_Domain:
          Enumerated_Domain_Value:  0
          Enumerated_Domain_Value_Definition:
          Enumerated_Domain_Value_Definition_Source:
    Attribute:
      Attribute_Label:  FAULTS_UP#
      Attribute_Definition:  Internal feature number
      Attribute_Definition_Source:  Computed
      Attribute_Domain_Values:
        Enumerated_Domain:
          Enumerated_Domain_Value:  Sequential unique positive integer
          Enumerated_Domain_Value_Definition:
          Enumerated_Domain_Value_Definition_Source:
    Attribute:
      Attribute_Label:  FAULTS_UP-ID
      Attribute_Definition:  User-assigned feature number
      Attribute_Definition_Source:  User-defined
      Attribute_Domain_Values:
        Enumerated_Domain:
          Enumerated_Domain_Value:  Integer
          Enumerated_Domain_Value_Definition:
          Enumerated_Domain_Value_Definition_Source:
    Attribute:
      Attribute_Label:  CODE
      Attribute_Definition:  integer referring to upthrown or
downthrown side of fault
      Attribute_Definition_Source:  USGS quad sheets prepared by
William White
      Attribute_Domain_Values:
        Enumerated_Domain:
          Enumerated_Domain_Value:  1 or 2
          Enumerated_Domain_Value_Definition:
          Enumerated_Domain_Value_Definition_Source:
    Entity_Type:
      Entity_Type_Label:  FAULTS_UP.AAT
      Entity_Type_Definition:  fault line coding and upthrown direction
      Entity_Type_Definition_Source:  USGS quad sheets prepared by
William White
    Attribute:
      Attribute_Label:  -
      Attribute_Definition:  fault line coding and upthrown direction
      Attribute_Definition_Source:  USGS quad sheets prepared by
William White
      Attribute_Domain_Values:
        Enumerated_Domain:
          Enumerated_Domain_Value:  -
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      Enumerated_Domain_Value_Definition:
      Enumerated_Domain_Value_Definition_Source:
Attribute:
  Attribute_Label:  FNODE#
  Attribute_Definition:  Internal number of from-node
  Attribute_Definition_Source:  Computed
  Attribute_Domain_Values:
    Enumerated_Domain:
      Enumerated_Domain_Value:  Sequential unique positive integer
      Enumerated_Domain_Value_Definition:
      Enumerated_Domain_Value_Definition_Source:
Attribute:
  Attribute_Label:  TNODE#
  Attribute_Definition:  Internal number of to-node
  Attribute_Definition_Source:  Computed
  Attribute_Domain_Values:
    Enumerated_Domain:
      Enumerated_Domain_Value:  Sequential unique positive integer
      Enumerated_Domain_Value_Definition:
      Enumerated_Domain_Value_Definition_Source:
Attribute:
  Attribute_Label:  LPOLY#
  Attribute_Definition:  Internal number of poly to left of arc
  Attribute_Definition_Source:  Computed
  Attribute_Domain_Values:
    Enumerated_Domain:
      Enumerated_Domain_Value:  Sequential unique positive integer
      Enumerated_Domain_Value_Definition:
      Enumerated_Domain_Value_Definition_Source:
Attribute:
  Attribute_Label:  RPOLY#
  Attribute_Definition:  Internal number of poly to right of arc
  Attribute_Definition_Source:  Computed
  Attribute_Domain_Values:
    Enumerated_Domain:
      Enumerated_Domain_Value:  Sequential unique positive integer
      Enumerated_Domain_Value_Definition:
      Enumerated_Domain_Value_Definition_Source:
Attribute:
  Attribute_Label:  LENGTH
  Attribute_Definition:  Length of arc in coverage units
  Attribute_Definition_Source:  Computed
  Attribute_Domain_Values:
    Enumerated_Domain:
      Enumerated_Domain_Value:  Positive real numbers
      Enumerated_Domain_Value_Definition:
      Enumerated_Domain_Value_Definition_Source:
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  Attribute_Definition:  Internal feature number
  Attribute_Definition_Source:  Computed
  Attribute_Domain_Values:
    Enumerated_Domain:
      Enumerated_Domain_Value:  Sequential unique positive integer
      Enumerated_Domain_Value_Definition:
      Enumerated_Domain_Value_Definition_Source:
Attribute:
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      Attribute_Definition:  User-assigned feature number
      Attribute_Definition_Source:  User-defined
      Attribute_Domain_Values:
        Enumerated_Domain:
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          Enumerated_Domain_Value_Definition:
          Enumerated_Domain_Value_Definition_Source:
    Attribute:
      Attribute_Label:  CODE
      Attribute_Definition:  fault line code for solid or dashed
(approximate) line
      Attribute_Definition_Source:  USGS quads sheets prepared by
William White
      Attribute_Domain_Values:
        Enumerated_Domain:
          Enumerated_Domain_Value:  1 or 2
          Enumerated_Domain_Value_Definition:
          Enumerated_Domain_Value_Definition_Source:
    Attribute:
      Attribute_Label:  DIRECTION
      Attribute_Definition:  fault upthrown direction
      Attribute_Definition_Source:  USGS quad sheets prepared by
William White
      Attribute_Domain_Values:
        Enumerated_Domain:
          Enumerated_Domain_Value:  character NE, NW, SE, SW
          Enumerated_Domain_Value_Definition:
          Enumerated_Domain_Value_Definition_Source:
  Overview_Description:
    Entity_and_Attribute_Overview:
     For the .pat:
     -CODE
     An integer value, either a 1 or 2 indicating whether the point is
a U or
     D symbol as follows:
     1 = U, Upthrown side
     2 = D, Downthrown side
     For the .aat:
     -CODE
     An integer value, either a 1 or 2 indicating the type of fault
trace as
     follows:
     1 = solid or certain fault trace
     2 = dashed or inferred fault trace
     -DIRECTION
     A character value; NW, NE, SW, SE, depicting the direction of the
     upthrown side of the fault trace.


    Entity_and_Attribute_Detail_Citation: Not Available

 Distribution_Information:
 Metadata_Reference_Information:
  Metadata_Date: 19980226
  Metadata_Contact:
   Contact_Information:
```

Contact_Person_Primary:
Contact_Person: Tom Tremblay
Contact_Organization: Bureau of Economic Geology
Contact_Position: GIS Coordinator
Contact_Address:
Address_Type: mailing address
Address: 10100 Burnet Road, Building 130
City: Austin
State_or_Province: Texas
Postal_Code: 78758
Country: USA
Contact_Voice_Telephone: 512-471-1534
Contact_Electronic_Mail_Address: trembalyt@begv.beg.utexas.edu
Hours_of_Service: 8:00 - 4:00

Metadata_Standard_Name: FGDC Content Standards for Digital Geospatial Metadata
Metadata_Standard_Version: 19940608
Metadata_Time_Convention: Local Time
Metadata_Security_Information:
Metadata_Security_Classification_System: None
Metadata_Security_Classification: Unclassified
Metadata_Security_Handling_Description: None

EGAT Faults

Metadata:

Identification_Information:
Citation:
Citation_Information:
Originator: L.F. Brown, Jr., Robert A. Morton, Joseph H. McGowen, C.W. Kreitler, W.L. Fisher
Publication_Date: 1974
Publication_Time:
Title: Natural Hazards of the Texas Coastal Zone Edition: 1.0
Geospatial_Data_Presentation_Form:
Series_Name:
Issue_Identification:
Publication_Information:
Publication_Place: University of Texas
Publisher: Bureau of Economic Geology
Other_Citation_Details:
Online_Linkage:

Description:

Abstract:

The faults in this dataset were captured from a published copy of the 1:250,000 scale Galveston-Houston Area natural hazards map in the "Natural Hazards of the Texas Coastal Zone" (1974) atlas. Active surface faults, depicted as solid lines, are coded number 1.Inferred faults, depicted as dashed lines, are coded number 2. Fault displacement is not noted on the original map. For further general information concerning faulting along the Texas coast see the accompanying text.

Purpose:
These data characterize and locate the position and extent of surface faults in the Galveston-Houston area of the Texas Coastal Zone.

Supplemental_Information:

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

Revisions:
This dataset is version 1.0 and has no predecessor.

Reviews_Applied_to_Data:
In house review covered in 'Procedure' above.

Related_Spatial_and_Tabular_Data_Sets:
None

Other_References_Cited:
L.F. Brown, Robert A. Morton, Joseph H. McGowen, Charles W. Kreitler, and W.L. Fisher. "Natural Hazards of the Texas Coastal Zone." University of Texas Bureau of Economic Geology, 1974.

Notes:

Time_Period_of_Content:
Time_Period_Information:
Calendar_Date: Unknown
Currentness_Reference:
This reference document was updated on 1-19-99

Status:
Progress:
Maintenance_and_Update_Frequency:
None planned

Spatial_Domain:
Bounding_Coordinates:
West_Bounding_Coordinate: -95.90416763
East_Bounding_Coordinate: -93.6804997
North_Bounding_Coordinate: 30.37462368
South_Bounding_Coordinate: 28.81413191
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Theme:
Theme_Keyword_Thesaurus: None
Theme_Keyword: faulting, coastal erosion, coastal wetlands, land subsidence,
hurricane flooding

Place:
Place_Keyword_Thesaurus: None

Place_Keyword: Upper Texas Gulf Coast, Sabine Lake to Matagorda Bay
Stratum:
Stratum_Keyword_Thesaurus: None
Stratum_Keyword: None
Temporal:
Temporal_Keyword_Thesaurus: None
Temporal_Keyword: None
Access_Constraints:
(Describe any restrictions or legal pre-requisites for accessing the dataset. Enter n/a if no restrictions apply.)

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.

Point_of_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Tom Tremblay
Contact_Organization: Bureau of Economic Geology
Contact_Position: GIS Coordinator
Contact_Address:
Address_Type: mailing address
Address: 10100 Burnet Road, Building 130
City: Austin
State_or_Province: Texas
Postal_Code: 78758
Country: USA
Contact_Voice_Telephone: 512-471-1534
Contact_Electronic_Mail_Address: tremblayt@begv.beg.utexas.edu
Hours_of_Service: 8:00 - 5:00

Data_Set_Credit:
Bureau of Economic Geology
Thomas Tremblay
Greg Jeffers

Security_Information:
Security_Classification_System: None
Security_Classification: Unclassified
Security_Handling_Description: None
Native_Data_Set_Environment: SunOS, 5.5.1, sun4m UNIX, ARC/INFO version 7.1.1
Cross_Reference:
Citation_Information:
Originator: L.F. Brown, Robert A. Morton, Joseph H. McGowen, Charles W. Kreitler,
and W.L. Fisher
Publication_Date: 1974
Publication_Time:
Title: Natural Hazards of the Texas Gulf Coast
Edition: 1.0

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    Geospatial_Data_Presentation_Form:
    Series_Information:
      Series_Name:
      Issue_Identification:
    Publication_Information:
      Publication_Place: Austin, Texas
      Publisher: Bureau of Economic Geology
    Other_Citation_Details:
    Online_Linkage:

Data_Quality_Information:
 Attribute_Accuracy:
    Attribute_Accuracy_Report:  See Entity_Attribute_Information
    Quantitative_Attribute_Accuracy_Assessment:
      Attribute_Accuracy_Value:  See Explanation
      Attribute_Accuracy_Explanation:
        Attribute accuracy is described, where present, with each
        attribute defined in the Entity and Attribute Section.
 Logical_Consistency_Report:  Line topology present.
 Completeness_Report:
  Complete


 Positional_Accuracy:
    Horizontal_Positional_Accuracy:
      Horizontal_Positional_Accuracy_Report:
       Unknown

    Vertical_Positional_Accuracy:
      Vertical_Positional_Accuracy_Report:
       N/A

 Lineage: See also Supplemental_Information:
  Source_Information:
    Source_Citation:
     Citation_Information:
      Originator:
      Publication_Date:
      Title:
    Source_Scale_Denominator: 250000
    Type_Of_Source_Media:
    Source_Time_Period_of_Content:
      Time_Period_Information:
       Single_Date/Time:
        Calendar_Date:
      Source_Currentness_Reference:
    Source_Citation_Abbreviation:
    Source_Contribution:

Spatial_Data_Organization_Information:
 Direct_Spatial_Reference_Method:  Vector
 Point_and_Vector_Object_Information:
    SDTS_Terms_Description:
      SDTS_Point_and_Vector_Object_Type:  Point
      Point_and_Vector_Object_Count:  446
      SDTS_Point_and_Vector_Object_Type:  String
      Point_and_Vector_Object_Count:  886
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      SDTS_Point_and_Vector_Object_Type:  GT-polygon composed of chains
      Point_and_Vector_Object_Count:  447

Spatial_Reference_Information:
 Horizontal_Coordinate_System_Definition:
   Planar:
      Grid_Coordinate_System:
        Grid_Coordinate_System_Name:
        Universal_Transverse_Mercator
          UTM_Zone_Number: 15
      Planar_Coordinate_Information:
        Planar_Coordinate_Encoding_Method: coordinate pair
        Coordinate_Representation:
          Abscissa_Resolution: 1.0
          Ordinate_Resolution: 1.0
        Planar_Distance_Units: METERS
   Geodetic_Model:
      Horizontal_Datum_Name: North American Datum of 1983
      Ellipsoid_Name:  GRS1980
      Semi-major_Axis: 6378206.4
      Denominator_of_Flattening_Ratio: 294.98

Entity_and_Attribute_Information:
 Detailed_Description:
   Entity_Type:
      Entity_Type_Label:  FLOODUTM.AAT
      Entity_Type_Definition:  Attribute table of ATLASFLT.
      Entity_Type_Definition_Source:  ARC/INFO

   Attribute:
      Attribute_Label:  CODE
      Attribute_Definition:  An integer value
      Attribute_Definition_Source:
      Attribute_Domain_Values:
        Enumerated_Domain:
          Enumerated_Domain_Value:  1,2
          Enumerated_Domain_Value_Definition:

 Overview_Description:
   Entity_and_Attribute_Overview:
      for atlasflt.aat:
     -code
      An integer value for line type
      1 = normal
      2 = inferred
   Entity_and_Attribute_Detail_Citation: Not Available

Distribution_Information:
Metadata_Reference_Information:
 Metadata_Date: 19990119
 Metadata_Contact:
  Contact_Information:
   Contact_Person_Primary:
      Contact_Person: Tom Tremblay
      Contact_Organization: Bureau of Economic Geology
   Contact_Position: GIS Coordinator
   Contact_Address:
```

Address_Type: mailing address
Address: 10100 Burnet Road, Building 130
City: Austin
State_or_Province: Texas
Postal_Code: 78758
Country: USA
Contact_Voice_Telephone: 512-471-1534
Hours_of_Service: 8:00 - 5:00

Metadata_Standard_Name: FGDC Content Standards for Digital Geospatial Metadata
Metadata_Standard_Version: 19940608
Metadata_Time_Convention: Local Time
Metadata_Security_Information:
Metadata_Security_Classification_System: None
Metadata_Security_Classification: Unclassified
Metadata_Security_Handling_Description: None

USGS Faults

Abstract:
This dataset was captured through tablet digitization of the "Map Showing Surface Faults in the Southeastern Houston Metropolitan Area, Texas.", 1978, by E.R. Verbeek and U.S. Clanton. The map depicts surface faults transferred to a USGS 1:24,000 scale base. Faults are classified as to the type of fault-normal, concealed, or inferred; and the origin of the fault- active, probable, or possible. Digitized line work was coded and transformed to a polyconic projection. The final dataset was projected to UTM zone 15.

Purpose:
This dataset forms part of the faulting layer of the Digital Hazards Atlas of the Texas Coast. The original mapping is the most detailed fault mapping known for the Houston area. Knowledge of fault location, extent, and characteristics are useful for land use planning.

Limitations_of_Data:
It is not recommended to use these data for applications requiring a map accuracy greater than 1:24,000 scale.

Entity_and_Attribute_Overview:
Line features are coded as to the type of fault and the origin of the fault. Fault types include normal (1), concealed (2), and inferred (3). Fault origin refers to the relative evidence of faulting- active (1), probable (2), and possible (3).

Procedures_Used:
See abstract.

Revisions:
N/A

Reviews_Applied_to_Data:
(Spatial data ready to be documented and placed in a library must go through some in-house review. A review includes inspection of the LOG

file for completeness and conformance to the steps described in this narrative, verification of table and column/item identities and definitions, validity of the reference datasets and citations, and review of any additional quality assurance measures performed on the dataset.)

Related_Spatial_and_Tabular_Data_Sets:
N/A

References_Cited:
E.R. Verbeek and U.S. Clanton, 1978, Map Showing Surface Faults in the Southeastern Houston Metropolitan Area, Texas., USGS open file report no. 78-797.

Notes:
N/A

VII. Gulf of Mexico Shoreline Erosion (gomerosion)

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:

Sabine Pass to High Island:

From High Island to 4.5 miles (7.25 km) northeast of High Island: 1882, 1930, 1955, 1974, 1990, 1996

From 4.5 miles (7.25 km) northeast of High Island to 4 miles (6.45 km) southwest of Sabine Pass: 1882/83, 1930, 1955/56/57, 1974, 1996

From 4 miles (6.45 km) southwest of Sabine Pass to Sabine Pass: 1883, 1930, 1955, 1996

Bolivar Peninsula

East of High Island: 1882, 1930, 1956/57, 1974, 1990, 1996

From 0.62 miles (1 km) west to 1.9 miles (3 km) northeast of Rollover Pass: 1930, 1956/57, 1965, 1974, 1990, 1996

Everywhere else on Bolivar Peninsula: 1882, 1930, 1956/57, 1965, 1974, 1990, 1996

Galveston Island

East Beach: 1956, 1970, 1990, 1996

In front of the Galveston Seawall: 1956, 1965, 1990

West Beach: 1956, 1965, 1974, 1990, 1996

San Luis Pass to the Brazos River

San Luis Pass to Freeport Harbor Channel: 1930, 1956, 1965, 1974, 1990, 1996

Freeport Harbor Channel to Brazos River: 1956, 1965, 1974, 1990, 1996

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 mangement 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:

Entity_and_Attribute_Overview:

-TRAN

Transect number output from SSAPP. For each shoreline segment, numbers start with the most negative number on the west end and increase to the east.

-BL_LENGTH

Length of baseline segment used in analysis, output from SSAPP.

-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.

-TIME_SPAN

Time span of years used by SSAPP to calculate rate.

-EASTING_UTM

Longitudinal coordinate of erosion point in UTM, from GPS.

-NORTHING_UTM

Latitudinal coordinate of erosion point in UTM, from GPS.

-S1 through S10

Actual years of shorelines used in the rate of change calculation.

Procedures_Used:

The 1996 shoreline was surveyed using differential GPS mounted on a four-wheel vehicle. Horizontal postions were collected at a 1sec sampling rate (approximately 15ft to 10ft spacing). The raw GPS data were converted to State Plane, Nad27. The converted files of shoreline segments were merged, creating a continuous coverage.

Mapped shorelines spanning from 1850 to 1990 were optically transfered to topographic bases having common map scales.Shorelines from the 1880's and 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.

The Gulf erosion points were imported into ArcInfo 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.

Revisions:

This dataset is version 1.0 and has no predecessor.

Reviews_Applied_to_Data:

In-house review covered in 'Purpose' above

Related_Spatial_and_Tabular_Data_Sets:

None

References_Cited:

Notes:

Currentness_Reference:

This reference document was updated on 3-2-2000.

Maintenance_and_Update_Frequency:

None Planned

Access_Constraints:

None

Data_Set_Credit:
Edward Angle
Erika Boghici
Sarah Dale
James Gibeaut
Robert Morton
Tom Tremblay

Completeness_Report:

Complete

Horizontal_Positional_Accuracy_Report:

90 percent of well defined points fall within 40 feet of their true position

Vertical_Positional_Accuracy_Report:

N/A

VIII. Hurricane Surge and Flooding

This directory 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

All surge files are in UTM

frptlev: Freeport levee

galvsea: Galveston seawall

surge.txt   README file from A&M, data contact info and original projection info

max1.shp: max surge polygon for each level hurricane (1-5)

max2net.shp net increase in surge area from previous level (2-5)

txcitylev: Texas City levee

portarthur_levee: Port Arthur Levee

13 January 1998

To whom it may concern:

The following is a brief description of the procedure which was used to generate lines of maximum surge penetration.

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.

In order to produce the lines of maximum penetration, the MEOW grid overlays were analyzed visually over paper basemaps, and a line for maximum penetration was drawn at the boundary between the dry and wet cells. This line was adjusted as necessary to account for topographic variations within each grid cell. Where surge penetration reached the inland edge of the grid, the line was extended further inland using various topographic projection methods.

The lines were then digitized from paper onto new layers in digital county basemaps. The lines conform to the following projection and coordinate system:

TEXAS STATEWIDE MAPPING SYSTEM (NAD 27)

Projection:	Lambert Conformal Conic
Spheroid:	Clarke 1866
Datum:	North American 1927
Longitude of Origin:	100 degrees west (-100)
Latitude of Origin:	31 degrees 10 minutes north
Standard Parallel # 1:	27 degrees 25 minutes north lat.
Standard Parallel # 2:	34 degrees 55 minutes north lat.
False Easting:	3,000,000 feet
False Northing:	3,000,000 feet
Unit of Measure:	feet (international)

Please feel free to contact me if this is unclear or you have any additional questions.

Best,

Chris Blakely
The Research Division

Texas A&M University
(409)845-2946
blakely@tamu.edu

Hurricanes Beulah and Carla

Metadata:

Identification_Information:
Citation:
Citation_Information:
Originator: L.F. Brown, Jr., Robert A. Morton, Joseph H. McGowen, C.W. Kreitler, W.L. Fisher
Publication_Date: 1974
Publication_Time:
Title: Natural Hazards of the Texas Coastal Zone
Edition: 1.0
Geospatial_Data_Presentation_Form:
Series_Name:
Issue_Identification:
Publication_Information:
Publication_Place: University of Texas
Publisher: Bureau of Economic Geology
Other_Citation_Details:
Online_Linkage:

Description:
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 flodding 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.

Supplemental_Information:

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

Revisions:
This dataset is version 1.0 and has no predecessor.

Reviews_Applied_to_Data:
In house review covered in 'Procedure' above.

Related_Spatial_and_Tabular_Data_Sets:
None

Other_References_Cited:
L.F. Brown, Robert A. Morton, Joseph H. McGowen, Charles W. Kreitler, and W.L. Fisher. "Natural Hazards of the Texas Coastal Zone." University of Texas Bureau of Economic Geology, 1974.

Notes:

Time_Period_of_Content:
Time_Period_Information:
Calendar_Date: Unknown
Currentness_Reference:
This reference document was updated on 1-19-99

Status:
Progress:
Maintenance_and_Update_Frequency:
None planned

Spatial_Domain:
Bounding_Coordinates:
West_Bounding_Coordinate: -95.90416763
East_Bounding_Coordinate: -93.6804997
North_Bounding_Coordinate: 30.37462368
South_Bounding_Coordinate: 28.81413191
Keywords:
Theme:
Theme_Keyword_Thesaurus: None
Theme_Keyword: faulting, coastal erosion, coastal wetlands, land subsidence, hurricane flooding

Place:
Place_Keyword_Thesaurus: None
Place_Keyword: Upper Texas Gulf Coast, Sabine Lake to Matagorda Bay

```
    Stratum:
      Stratum_Keyword_Thesaurus:  None
      Stratum_Keyword: None
    Temporal:
      Temporal_Keyword_Thesaurus:  None
      Temporal_Keyword: None
  Access_Constraints:
   (Describe any restrictions or legal pre-requisites for accessing the
dataset. Enter n/a if no restrictions apply.)


  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.

  Point_of_Contact:
   Contact_Information:
    Contact_Person_Primary:
      Contact_Person: Tom Tremblay
      Contact_Organization: Bureau of Economic Geology
    Contact_Position: GIS Coordinator
    Contact_Address:
      Address_Type: mailing address
      Address: 10100 Burnet Road, Building 130
      City: Austin
      State_or_Province: Texas
      Postal_Code: 78758
      Country: USA
    Contact_Voice_Telephone: 512-471-1534
    Contact_Electronic_Mail_Address: trembalyt@begv.beg.utexas.edu
    Hours_of_Service: 8:00 - 5:00

  Data_Set_Credit:
   Bureau of Economic Geology
   Thomas Tremblay
   Greg Jeffers

  Security_Information:
    Security_Classification_System: None
    Security_Classification:  Unclassified
    Security_Handling_Description: None
  Native_Data_Set_Environment: SunOS, 5.5.1, sun4m UNIX, ARC/INFO
version 7.1.1
  Cross_Reference:
   Citation_Information:
    Originator: L.F. Brown, Robert A. Morton, Joseph H. McGowen,
Charles W. Kreitler, and W.L. Fisher
    Publication_Date: 1974
    Publication_Time:
    Title: Natural Hazards of the Texas Gulf Coast
    Edition: 1.0
    Geospatial_Data_Presentation_Form:
    Series_Information:
      Series_Name:
      Issue_Identification:
```

```
   Publication_Information:
     Publication_Place: Austin, Texas
     Publisher: Bureau of Economic Geology
   Other_Citation_Details:
   Online_Linkage:

Data_Quality_Information:
 Attribute_Accuracy:
   Attribute_Accuracy_Report:  See Entity_Attribute_Information
   Quantitative_Attribute_Accuracy_Assessment:
     Attribute_Accuracy_Value:  See Explanation
     Attribute_Accuracy_Explanation:
       Attribute accuracy is described, where present, with each
       attribute defined in the Entity and Attribute Section.
 Logical_Consistency_Report:  Polygon topology present.
 Completeness_Report:
  Complete


 Positional_Accuracy:
   Horizontal_Positional_Accuracy:
     Horizontal_Positional_Accuracy_Report:
      Unknown

   Vertical_Positional_Accuracy:
     Vertical_Positional_Accuracy_Report:
      N/A

 Spatial_Data_Organization_Information:
 Direct_Spatial_Reference_Method:  Vector
 Point_and_Vector_Object_Information:
   SDTS_Terms_Description:
     SDTS_Point_and_Vector_Object_Type:  Point
     Point_and_Vector_Object_Count:  446
     SDTS_Point_and_Vector_Object_Type:  String
     Point_and_Vector_Object_Count:  886
     SDTS_Point_and_Vector_Object_Type:  GT-polygon composed of chains
     Point_and_Vector_Object_Count:  447

Spatial_Reference_Information:
 Horizontal_Coordinate_System_Definition:
   Planar:
     Grid_Coordinate_System:
       Grid_Coordinate_System_Name:
       Universal_Transverse_Mercator
         UTM_Zone_Number: 15
     Planar_Coordinate_Information:
       Planar_Coordinate_Encoding_Method: coordinate pair
       Coordinate_Representation:
         Abscissa_Resolution: 1.0
         Ordinate_Resolution: 1.0
       Planar_Distance_Units: METERS
   Geodetic_Model:
     Horizontal_Datum_Name: North American Datum of 1983
     Ellipsoid_Name:  GRS1980
     Semi-major_Axis: 6378206.4
     Denominator_of_Flattening_Ratio: 294.98
```

```
 Entity_and_Attribute_Information:
  Detailed_Description:
    Entity_Type:
      Entity_Type_Label:  FLOODUTM.PAT
      Entity_Type_Definition:  Attribute table of FLOODUTM.
      Entity_Type_Definition_Source:  ARC/INFO
    Attribute:
      Attribute_Label:  -
      Attribute_Definition:  Attribute table of FLOODUTM.
      Attribute_Definition_Source:  ARC/INFO
      Attribute_Domain_Values:
        Enumerated_Domain:
          Enumerated_Domain_Value:  -
          Enumerated_Domain_Value_Definition:
          Enumerated_Domain_Value_Definition_Source:
    Attribute:
      Attribute_Label:  AREA
      Attribute_Definition:  Area of poly/region in square coverage
units
      Attribute_Definition_Source:  Computed
      Attribute_Domain_Values:
        Enumerated_Domain:
          Enumerated_Domain_Value:  Positive real numbers
          Enumerated_Domain_Value_Definition:
          Enumerated_Domain_Value_Definition_Source:
    Attribute:
      Attribute_Label:  PERIMETER
      Attribute_Definition:  Perimeter of poly/region in coverage units
      Attribute_Definition_Source:  Computed
      Attribute_Domain_Values:
        Enumerated_Domain:
          Enumerated_Domain_Value:  Positive real numbers
          Enumerated_Domain_Value_Definition:
          Enumerated_Domain_Value_Definition_Source:
    Attribute:
      Attribute_Label:  FLOODUTM#
      Attribute_Definition:  Internal feature number
      Attribute_Definition_Source:  Computed
      Attribute_Domain_Values:
        Enumerated_Domain:
          Enumerated_Domain_Value:  Sequential unique positive integer
          Enumerated_Domain_Value_Definition:
          Enumerated_Domain_Value_Definition_Source:
    Attribute:
      Attribute_Label:  FLOODUTM-ID
      Attribute_Definition:  User-assigned feature number
      Attribute_Definition_Source:  User-defined
      Attribute_Domain_Values:
        Enumerated_Domain:
          Enumerated_Domain_Value:  Integer
          Enumerated_Domain_Value_Definition:
          Enumerated_Domain_Value_Definition_Source:
    Attribute:
      Attribute_Label:  SYMBOL
      Attribute_Definition:  An integer value
      Attribute_Definition_Source:
```

```
      Attribute_Domain_Values:
        Enumerated_Domain:
          Enumerated_Domain_Value:  1,2,3, or 9
          Enumerated_Domain_Value_Definition:
          Enumerated_Domain_Value_Definition_Source:
    Attribute:
      Attribute_Label:  TYPE
      Attribute_Definition:  character description of flooding
      Attribute_Definition_Source:
      Attribute_Domain_Values:
        Enumerated_Domain:
          Enumerated_Domain_Value:
          Enumerated_Domain_Value_Definition:
          Enumerated_Domain_Value_Definition_Source:
  Overview_Description:
    Entity_and_Attribute_Overview:
      for floodutm.pat:
     -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'
    Entity_and_Attribute_Detail_Citation: Not Available

 Distribution_Information:
 Metadata_Reference_Information:
  Metadata_Date: 19990119
  Metadata_Contact:
   Contact_Information:
    Contact_Person_Primary:
      Contact_Person: Tom Tremblay
      Contact_Organization: Bureau of Economic Geology
    Contact_Position: GIS Coordinator
    Contact_Address:
      Address_Type: mailing address
      Address: 10100 Burnet Road, Building 130
      City: Austin
      State_or_Province: Texas
      Postal_Code: 78758
      Country: USA
    Contact_Voice_Telephone: 512-471-1534
    Hours_of_Service: 8:00 - 5:00

  Metadata_Standard_Name: FGDC Content Standards for Digital Geospatial
Metadata
  Metadata_Standard_Version:  19940608
  Metadata_Time_Convention:  Local Time
  Metadata_Security_Information:
    Metadata_Security_Classification_System:  None
    Metadata_Security_Classification:  Unclassified
```

Metadata_Security_Handling_Description: None

IX. 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. The classification system is available on the CD-ROM.

X. Shorelines

"year":   historic shorelines, single coverage by year
"year"_projected: shore2056: projected shorlines, single coverage by year.

shore9656: area bounded by the 1996 and 1956 shoreline, single coverage polygon.

shoreline_doc: documentation file

Abstract:
The mapping of historical shorelines is an important step in understanding the rate of past shoreline change 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 mangement 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, 2) errors introduced while digitizing the shoreline positions, and 3) inaccuracies in the recorded 1996 GPS shoreline position.

Entity_and_Attribute_Overview:
There are no user defined attributes for the shoreline data.
Procedures_Used:
Historical shorelines-
The 1996 shoreline was surveyed using GPS mounted on a four-wheel vehicle. Horizontal postions were collected at a 1 second sampling rate (approximately 15ft to 10ft spacing). The raw GPS data were converted

to UTM zone 15, NAD83. The converted files of shoreline segments were merged, creating a continuous coverage.

Mapped shorelines spanning from 1850 to 1990 were optically transfered to topographic bases having common map scales. Shorelines from the 1800's and 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 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 2006, 2026, and 2056 shorelines by multiplying the rate of change by 10, 30, and 60 years to yield distances and then plotting those distances from the measured 1996 shoreline along each transect. The Bureau of Economic Geology, using a differential Global Positioning System technique, acquired the 1996 shoreline position. The shorelines are not projected along the Galveston Seawall because the seawall stops the landward movement of the shoreline, nor is it expected that the beach will advance in front of it. The projected shorelines were imported into ArcInfo 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.
Revisions:
This dataset is version 1.0 and has no predecessor.
Reviews_Applied_to_Data:
In-house review.

Related_Spatial_and_Tabular_Data_Sets:
None
References_Cited:

Notes:

Currentness_Reference:
This reference document was updated on 4-23-99.

Maintenance_and_Update_Frequency:
None planned
Access_Constraints:
None
Data_Set_Credit:
Edward Angle
Erika Boghici

Sarah Dale
James Gibeaut
Robert Morton
Tom Tremblay

Completeness_Report:
Complete
Horizontal_Positional_Accuracy_Report:
90 percent of well defined points fall within 40 feet of their true position
Vertical_Positional_Accuracy_Report:
N/A
Cloud_Cover:
N/A

XI. Subsidence

contour06: Approximate land-surface subsidence 1906-1987

contour83: Approximate land-surface subsidence 1983-1987

extensometer: Extensometer measurement sites

"addicks".tif: Image files of extensometer graphs (compaction versus year).
Tif image may be hot-linked to data collection site in extensometer measurement site theme. View window must be resized to obtain optimum visibility.

contour06_doc: documentation file

Contours

Abstract:
See reference document, Gabrysch and Coplin, 1990.

Purpose:
See reference document, Gabrysch and Coplin, 1990.

Limitations_of_Data:
The subsidence contours were digitized from maps at a scale of 1" = 15 miles. Users should not incorporate this data into larger-scale models or datasets.

Entity_and_Attribute_Overview:
CODE
Integer value for line type:
1 = solid contour
2 = dashed (approximate) contour
VALUE
Integer value for contour interval
Range: in feet from 1 to 10
Procedures_Used:

The contour lines were digitized from an enlarged copy of Figure 13 from the reference document Gabrysch and Coplin, 1990. The digitzation was done in ArcInfo. Attributes were assigned in ArcEdit. The coverage was projected to UTM, zone 15, nad83. Quality check was preformed in-house.

Revisions:
This dataset is version 1.0 and has no predecessor.

Reviews_Applied_to_Data:
In house review covered in 'Procedure' above.

Related_Spatial_and_Tabular_Data_Sets:
None

References_Cited:
R.K. Gabrysch and L.S. Coplin, 1990, Land-Surface Subsidence Resulting from
Ground-Water Withdrawls in the Houston-Galveston Region, Texas,Through 1987: U.S. Geological Survey, Report of Investigations no. 90-01,53 p.

Notes:
This documentation also applies to the coverage 'contour83utm'. All categories apply except the figure reference is Figure 17 in Gabrysch and Coplin, 1990.

Currentness_Reference:
This reference document was updated 4-23-99.

Maintenance_and_Update_Frequency:
None planned

Access_Constraints:
None

Data_Set_Credit:
R.K. Gabrysch
L.S. Coplin
Thomas Tremblay
Sarah Dale

Completeness_Report:
Complete

Horizontal_Positional_Accuracy_Report:
Unknown

Vertical_Positional_Accuracy_Report:
N/A

Cloud_Cover:
N/A

Extensometer Data

Abstract:
See reference document Kasmarek, Coplin, and Santos, 1990.

Purpose:
See reference document Kasmarek, Coplin, and Santos, 1990.

Limitations_of_Data:
The extensometer point coverage was digitized from a 1:100000 scale map.Users should be wary of incorporating this data into larger-scale models or datasets.

Entity_and_Attribute_Overview:
NAME
      The name of the extensometer site
IMAGE
      The path to the linked graph showing measured compaction over time
Procedures_Used:
The extensometer points were digitized into ArcInfo and attributed in ArcEdit. The coverage was projected to UTM, zone 15, nad83. In-house quality checked. The linked graphs were also digitized in ArcInfo and checked in-house.

Revisions:
This dataset is version 1.0 and has no predecessor.

Reviews_Applied_to_Data:
In-house review covered in 'Procedure' above

Related_Spatial_and_Tabular_Data_Sets:
None

References_Cited:
Mark C. Kasmarek, L.S. Coplin, and Horacio X. Santos, 1997, Water-level Altitudes 1997, Water-level Changes 1977-1997 and 1996-97, and Compaction 1973-96 in the Chicot and Evangeline Aquifers, Houston-Galveston Region, Texas: U.S. Geological Survey Open-File Report 97-181.

Notes:
This document applies to the graph files as well.

Currentness_Reference:
This reference document was last updated on 4-23-99.

Maintenance_and_Update_Frequency:
None planned

Access_Constraints:
None

Data_Set_Credit:
Mark C. Kasmarek
L.S. Coplin
Horacio X. Santos
Tom Tremblay
Sarah Dale

Completeness_Report:
Complete

Horizontal_Positional_Accuracy_Report:
Unknown
Vertical_Positional_Accuracy_Report:
N/A

Cloud_Cover:
N/A

XII. Washover Features

This directory contains shapefiles representing storm washover features of the Texas coast. 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 agencies standard Texas shoreline dataset. The relative position between shoreline and washover features may change due to coastal modification.

Entity_and_Attribute_Overview:
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.

Revisions:
1. Original coverage provided to the Texas General

Land Office by the Bureau of Economic Geology.
2. Washover features adapted to GLO shoreline.
3. GLO washover coverage acquired by the BEG and edited.

Reviews_Applied_to_Data:
Check plots of the original data, with feature labels, were plotted to scale and quality checked by Bill White. The GLO version of the dataset was acquired and checked against the original by Tom Tremblay. Data were compared to DOQ data by James Gibeaut.