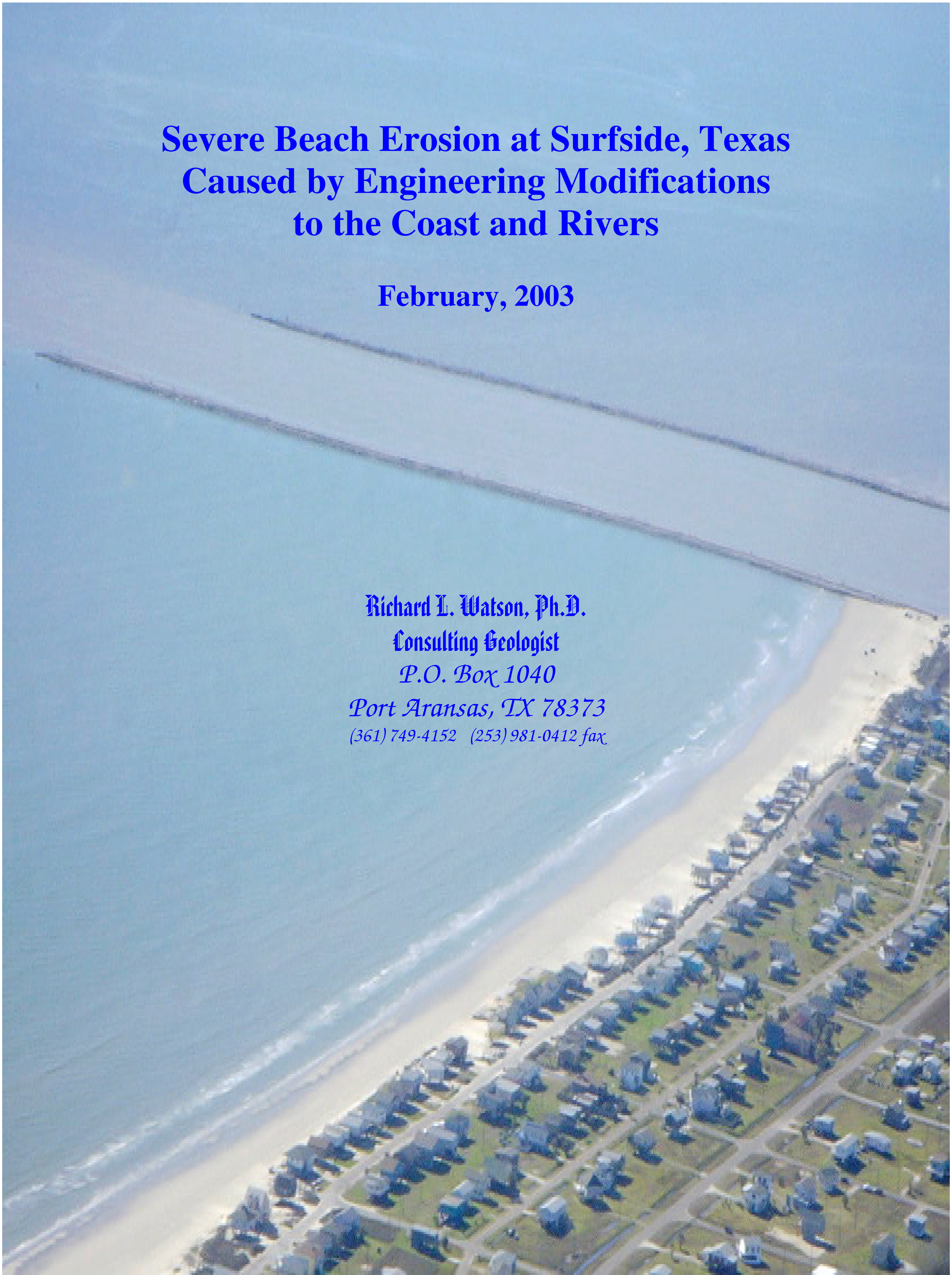

Severe Beach Erosion at Surfside, Texas Caused by Engineering Modifications to the Coast and Rivers

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EXECUTIVE SUMMARY

It is well established that there is a severe and accelerating beach erosion problem at Surfside, Texas. While a small part of the erosion may be due to natural causes, such as decreased sand transport to the coast by rivers and global sea level rise, it is obvious, at this location, most of the erosion is caused by man-made changes to the Brazos River and the Freeport Harbor entrance channel. Diversion of the river 7 miles in the downdrift direction has starved the Surfside and Quintana beaches of river sand. Numerous upstream dams and reservoirs on the Brazos river have drastically reduced the amount of sand the river now carries to the coast.

Construction of long jetties and a deep channel precludes sand transport in either direction across the harbor entrance. In addition, sand moving southwest along the beach at Surfside is carried out along the east jetty and deposited in the channel, where it is forever lost to the Surfside beach, unless it is placed back on the beach by a dredge during beach nourishment accompanying channel maintenance.

The Corps of Engineers and the Bureau of Economic Geology maintain that the lack of an updrift fillet of sand and the recently accelerated erosion at surfside beach may be due to wave amplification by the recently extended east jetty or sand inventory reduction by dredging of the channel. Since the jetty was extended in 1992 and the channel was deepened to 45 feet, the amount of sediment dredged annually from the outer bar channel has nearly doubled.

It has been nearly 75 years since the Brazos river was diverted to the south, and the old Brazos delta has completely eroded away and no longer serves as a nearshore source for sand that waves can bring onshore to nourish the beach. There is, now, little sand offshore, with only a thin veneer of sand over deltaic mud. Likewise, dunes in the Surfside area are very small and store only a small volume of sand which can be transported offshore during storms to flatten the beach profile and reduce wave attack. If any of that sand is washed offshore onto the clay zone, it will not be transported back to the beach.

Finally, extraction of large amounts of ground water for the Freeport industries has caused subsidence of the land surface at Surfside, resulting in at least one foot of relative sea level rise. Extrapolation of the rate of subsidence suggests the total is now two or 2.5 ft. at Surfside, resulting in additional shoreline retreat.

Distant man-made changes in the shoreline have drastically reduced the amount of sand which is available to be transported to the southwest along the coast. About 11 million cu.yd. of sand has been lost inward through Rollover Pass since it was built in 1956 and more than 30 million cu.yd. of sand have been caught and permanently stored east of the jetties at Bolivar Roads. A smaller amount of sand is stored in the fillet at East Beach, Galveston in the wave shadow of the jetties.

The best solution to provide a beach at Surfside (and to stop further erosion) is to nourish the beaches with beach quality sand from nearby sources. The problem is that there may not be adequate nearby sources of sand. It appears that the only beach quality sand being dredged from the channel is near station 0+00 at the end of the jetties. That is most likely sand eroded from Surfside beaches and can be pumped back onto the beach by a pipeline dredge. If that part of the channel is maintained with hopper dredges, it is unlikely the sand can be placed back on the beach. There may also be a sand source in Oyster Creek, which used to flow to the coast, but now terminates in the Intracoastal Waterway. There are no surface sand deposits in the offshore area which are suitable for beach nourishment. In a recent study, Texas A&M Galveston researchers found a buried channel below the Beaumont clay offshore from Surfside (Dellapenna, Allison, and Seitz, 2002). It is likely a sand-filled channel and could possibly be a source of beach sand. However, exploitation of this sand resource would require deep dredging and would leave a deep hole offshore in which beach sand may be lost during storms.

One of the greatest drawbacks of using seawalls and revetments such as at Galveston and at Sargent is they accelerate beach erosion in the downdrift direction. This should not be a concern if these structures are used at Surfside and Quintana because the beaches downdrift of the Freeport jetties are receiving no sand from the updrift beaches at present and the beaches downdrift of the new Brazos delta are being nourished by sand from the delta and the Brazos River. There are few locations where armoring the shoreline would cause less downdrift damage that such structures at Surfside and Quintana.

There is no other location on the coast which is subject to such a complete collection of man-made causes of beach erosion. Of the possible man-induced causes of beach erosion: river diversion, reduced sand output by a nearby river, jetty construction, maintenance of a deep channel, land subsidence due to water or oil extraction, and blockage of updrift sand sources, all are present at Surfside. In addition, Surfside is located on an eroding delta which is composed largely of mud with little in the way of nearshore sand sources.

The severe beach erosion at both Surfside and Quintana is almost entirely due to man-made changes in the Brazos River and the coastline. Only man-made changes in the form of beach nourishment and/or armoring the shoreline with a sea wall or revetment will stop the erosion.

INTRODUCTION

Most of the Texas coast has been undergoing erosion during the past 100 years, with the exception of Central Padre Island, beaches protected by jetties, and the new Brazos River delta. Prior to the development of deep inlets with long jetties, necessary for commercial traffic, and damming the rivers that flowed to the Gulf for flood control and water supply during the 20th century, much of the Texas coast was stable or accreting and beach erosion was not a problem.

Development of navigation inlets with long jetties has compartmentalized the coast and restricted longshore sediment transport along the coast, confining it to cells between major jettied inlets. Huge amounts of sand are trapped and stored in fillets adjacent to the updrift jetties and sometimes adjacent to long downdrift jetties. Sand is also lost inward to flood tidal deltas and jetted offshore by ebb currents to depths where waves cannot return the sand to the beach. Additional sand is lost by dredge material disposal in locations where the sand cannot return to the longshore transport system of the beach. Since the longshore sediment transport of system of the Texas Coast carries sand west and south along the coast to a convergence at Central Padre Island (Watson, 1971), sand moving southwest along the Bolivar Peninsula is now trapped at the east Galveston jetty and can no longer nourish beaches on Galveston Island and Follets Island.

Damming the Sabine River and the Brazos River has also reduced sand supply to the upper Texas coast by trapping sand in the reservoirs, and reducing peak flows which could carry sand sized material to the coast. The lower Texas coast is even more severely starved for sand because the flow in the Rio Grande River has been so reduced by reservoirs for agricultural and municipal use, that the entrance has recently been closed by a bar leaving zero flow into the Gulf. On the lower coast longshore sediment transport is north to the convergence area on Central Padre Island (Watson, 1971).

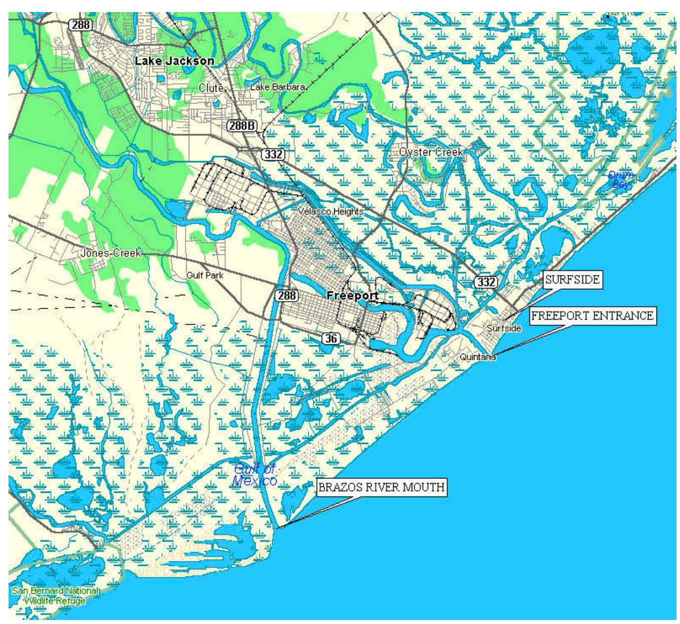

Figure 1. Brazos River to Surfside
(Map by Delorme Topo-USA)

In addition, rising sea level due to both natural and manmade causes further retreat of the beaches along the Texas coast.

The beach at Surfside Texas (Fig. 1), has been suffering accelerating beach erosion in recent years due to all of these factors and some additional significant manmade changes specifically affecting the Surfside area. The Surfside area may be unique in that it is subject to ALL of the manmade and natural causes of beach retreat operating on the Texas coast. These include: diverting the Brazos River to a location 6.5 miles south of its original outlet, lengthening, widening and deepening the Freeport Ship Channel in 1992, and groundwater withdrawal by Freeport industry which has caused several feet of subsidence, and thus relative sea level rise at Surfside, resulting in considerable shoreline retreat. Prior to the diversion of the Brazos River mouth from the location of the Freeport Harbor Entrance to a location 6.5 miles to the south in 1929, Surfside was located on a stable river delta. Now, the delta is building at the new location, and the old delta has eroded away, leaving no sand supply for Surfside or the beaches at Quintana or Bryan Beach. The Freeport Harbor Entrance was widened, and lengthened in 1992, which resulted in doubling the dredge maintenance volume and rapidly increasing erosion of the beach at Surfside.

Figure 2. No fillet on east jetty. (Photo by Richard L. Watson, January 2003)

The longshore sand transport system east of the Freeport Harbor Entrance is so starved for sand that the usual fillet of sand updrift (east) of the jetties is now absent and beaches on both sides of the jettied entrance are rapidly eroding (Fig. 2). Note that there is no sand fillet on the updrift side (down in the photo) of the jetty. The distant bulge in the coast at the top of the photograph is the location of the new Brazos River delta where the river channel was diverted in 1929. The sediment that has formed the new Brazos River delta after the 1929 diversion has made the very visible bulge in the coast. If the river was still flowing into the Gulf at the location of the jetties, the sediment which built the new delta would have protected the beach at Surfside from erosion.

> The coast between San Luis Pass and Brown Cedar Cut…is composed of a central fluvial deltaic headland flanked by sandy barrier peninsulas (Matagorda Peninsula and Follets Island). During part of the Holocene, both the ancestral Brazos and Colorado Rivers reached the Gulf in this area (McGowen and others, 1976), constituting an important local source of new sediment to the Texas barrier-strandplain system. Caney Creek marks the last position of the Colorado River before its natural diversion into Matagorda Bay (Bonnell, 1840; Bouma and Bryant, 1969). Fluvial sand is now supplied only by the Brazos and San Bernard Rivers, …. Human modifications affecting the headland include the 1929 diversion of the Brazos River; the Freeport jetties, which protect the mouth of the old Brazos River and extend about 3,000 feet into the Gulf; and the Freeport Harbor

Channel, dredged to a depth of 36 ft (U.S. Army Corps of Engineers, 1986). The channel and jetties both trap longshore sediment (Paine and Morton, 1989).

COASTAL PROCESSES

The wind in the nearshore Gulf of Mexico generates waves which move toward the shore in the direction the wind is blowing. As the waves approach shallow water, they become steeper and eventually break, forming surf. Once the waves have broken, they become a moving mass of water approaching the shoreline at a slight angle. This generates a current moving parallel with the shoreline within the surf. Whenever a wave breaks, it suspends sand from the bottom into the water. This sand is then carried a short distance along the shoreline until it settles out, only to be re-suspended and carried along by the next breaking wave. This process creates a virtual conveyor belt of sand along the shoreline in the surf zone. It has been called a river of sand and frequently amounts to hundreds of thousands of cubic yards of sand. The diagram from Lockwood Andrews and Newnam (1974) shows a wind rose of the duration of winds for each direction throughout the year for the nearby Bolivar Peninsula. Winds from the southeast and east dominate and produce average wave directions from the east through the south. These waves approach the shore at an angle and result in a net movement of beach material from northeast to southwest (Fig. 3).

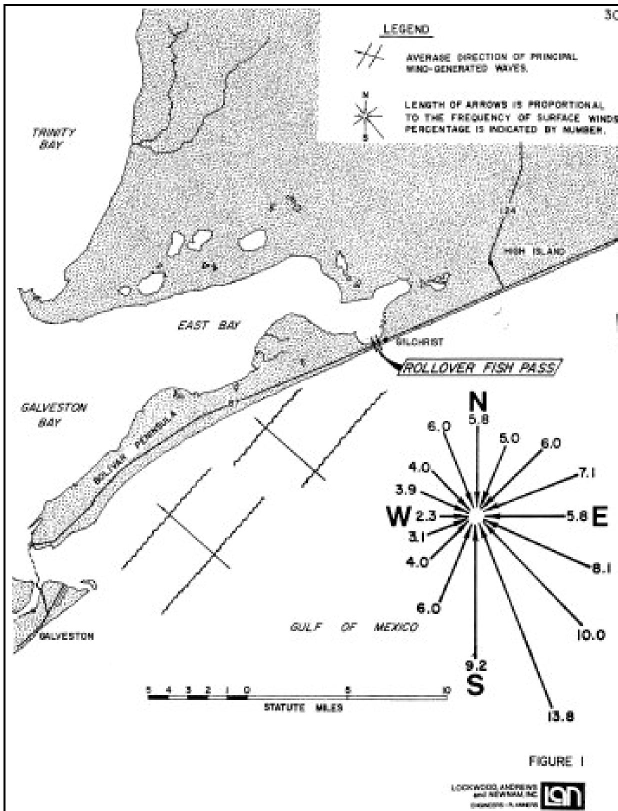

Figure 3. Winds and Waves (From Lockwood, Andrews and Newnam, 1974)

The amount of sediment transported along the shoreline as littoral drift at any location is dependent on the size of the breaking waves, and the angle they meet the shore. If there is sand present on the beach, it will be transported in a downdrift direction. In order for there to be equilibrium and not have a net loss of sand and beach erosion due to the littoral drift sand transport system, it is critical that each section of beach have the same amount of sand supplied to it from the updrift direction as is removed in the downdrift direction. If less is supplied than is removed, then beach erosion will occur. If more is supplied than removed, then beach growth, or accretion, will occur. This causes a large fillet of sand to build up on the updrift side of a jetty or groin. Sand is being brought in from the updrift side, but none can get past the jetty. At the same time, the downdrift side of the jetty or groin usually has a highly eroded beach. Sand is still leaving on the littoral drift conveyor belt, but no sand is coming from the updrift side. It is trapped by the jetty.

Inlets also produce beach erosion by starving the downdrift beaches of sand. Sand flows in through the inlet and is deposited in the bay. The beaches, downdrift of the inlet, are starved by the amount of sand that flows in through the inlet.

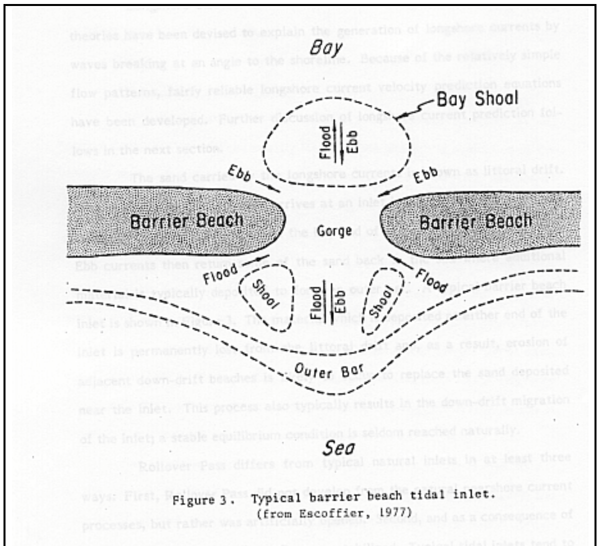

Figure 4. Ebb and Flood deltas (From Bales and Holley, 1984)

In addition to washing sand into the bays and forming a flood tidal delta in the bay, the ebb jet washes material offshore and forms an ebb tidal delta as well (Fig. 4). The sand in the ebb and flood tidal deltas is no longer available for transport down the beaches.

Tropical storms and hurricanes cause both permanent and temporary loss of beach sand. During a storm, the upper beach and dunes are eroded and much of that sand is carried offshore into a nearshore bar system. With the return of calm waves after the storm, that material is carried back up onto the beach over a period of many months and sometimes years. Once the sand is deposited on the beach by waves, the wind will blow it inland to the first vegetation and a dune ridge will form. This is important, because the sand in that dune ridge will be carried Gulfward to the bar system in the next large storm. This cycle repeats with every storm. In some cases, if there is no dune ridge and the barrier island or peninsula is very low, a considerable amount of sand is carried inland and deposited as flats on the bay side of the barrier.

If there is no dune ridge storing sand between storms, and sand is carried inland, or further offshore out of reach of the gentle waves which can carry it back onshore, there is permanent beach erosion. The sand body in the vicinity of Surfside is very thin and is underlain by clay. When storms attack a clay shore, all of the clay is carried permanently away in suspension. It is not deposited just offshore in the bar system to be carried back onshore with the return of gentle waves.

History of Brazos River Mouth and Freeport Entrance

Table 1 presents the chronology of Federal improvements at the Freeport Harbor Entrance. The first major change affecting erosion of the beach at Surfside was the diversion of the Brazos River to a location 6.5 miles south of the original location at the jetty entrance. The outer bar channel was deepened to 38 feet in 1961 and 47 feet in 1990. In 1992, a major project moved the north jetty 640 feet to the northeast, increasing the distance between the jetties to 1,200 feet. Finally, the jetty channel was deepened to 45 feet in 1992. The north jetty was also extended 500 feet into the Gulf in 1993.

Year	Activity
1908	Repaired jetties constructed by the Brazos River Channel and Dock Company. The jetties were 560 feet apart; the length of the North Jetty was 4,708 feet and the South Jetty 5,018 feet.
1911	Dredged 18- by 150-foot channel from outer end of jetties to railway wharf.
1919	Channel deepened to 22 feet.
1929	Dredging of Diversion Channel to relocate mouth of the Brazos River completed.
1931	Outer Bar and Jetty Channels improved to 25 feet deep and 150 feet wide.
1936	Outer Bar Channel improved to 32 feet deep and 300 feet wide, and Jetty Channel improved to 32 feet deep and 200 feet wide.
1958	Realigned Outer Bar Channel on straight alignment with Jetty Channel.
1961	Outer Bar Channel deepened to 38 feet; Jetty Channel deepened to 36 feet.
1990	Outer Bar Channel improved to 47 feet deep and 400 feet wide.
1991	North Jetty relocated 640 feet to the northeast, increasing the distance between the jetties to 1,200 feet.
1992	Jetty Channel improved to 45 feet deep by 400 feet wide.

Table 1. Chronology of Federal Improvements at Freeport Channel. (From U.S. Army Engineer District, Galveston, Tx., August 1992., p. 18.)

Prior to channel modification (in 1992), the average dredging cycle for the entrance at Freeport was 1.2 years to remove 1.2 million cubic yards of material. Maintenance dredging of the Freeport Outer Bar and Jetty Channels has been performed by hopper dredge and the material placed in an offshore disposal area located southwest of the Outer Bar Channel. An average shoaling rate of 960,000 cubic yards per year was calculated for this channel. …. Historical records showing grain size of the material removed from the channel indicate a very low percentage of sand at all stations from 1957 through 1976, generally less than 20%. Samples taken in December 1976 had sand percentages ranging from 0% to 50% with the exception of one sample showing 71% sand at station 0+00 (the end of the jetties). Samples taken in the channel from 1983 to 1989 between stations -100+000 to 50+000 show the sand content to range from 3% to 52%. **From this data it was concluded that dredged material from the Freeport Outer Bar and Jetty Channels is not considered suitable for placement on beaches.** (U.S. Army Engineer District, Galveston, Tx. August, 1992, p. 19).

The lower 5 miles of the Brazos River is known as the Brazos River Diversion Channel. It was completed in 1929 by the Federal Government in an effort to divert the sediment-laden waters of the Brazos River away from the deep-draft navigation facilities located at Freeport along the lower portion of the river. This was accomplished by damming the river about 7.5 miles upstream of the original mouth and rerouting the river flows through the Brazos River Diversion Channel to discharge into the Gulf of Mexico at a point approximately 6.5 miles southwest of the original mouth. **From the time the Freeport Jetties were constructed in the late 1800's, the areas adjacent to the jetties accumulated material forming a delta into the Gulf on both sides of the jetties. When the river was diverted in 1929 to its present location, the delta near the jetties began to erode, and a delta at the relocated mouth began to form. Since 1949 the new delta has been eroding because of a reduction in sediment loads on the river.** (U.S. Army Engineer District, Galveston, Tx. August, 1992, p. 22).

The aerial photos of Figure 5 **clearly** show the change in the deltas of the Brazos River. The top photo was taken in 1935 and clearly shows the extent of the original delta at the mouth of the Brazos on the right. Note the arcuate bar in deep water extending to nearly the end of the west jetty. Note also the underwater growth of the new Brazos delta on the left as shown by the seaward offset of depth contours offshore of the new mouth of the Brazos.

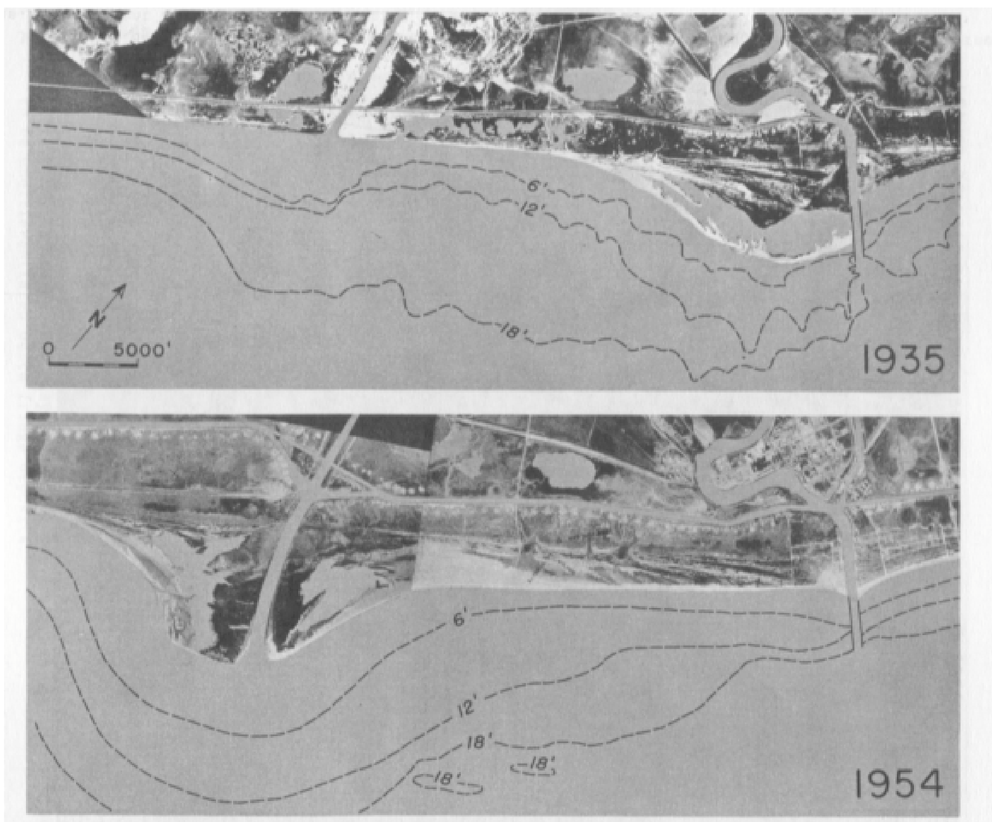

Figure 5. Old and new Brazos deltas in 1935 and 1954. (From Bureau of Economic Geology, The University of Texas at Austin.)

By 1954, most of the old delta at the jetties had eroded away, but there was still a fillet of sand at the base of both jetties and a wide beach at Surfside. The extent of the erosion of the old delta can bee seen by comparing beach ridges on the two photos. The subaerial new delta had grown quite large and the submarine delta even larger as indicated by the contour lines sweeping out to sea**. It is very likely that neither Surfside or Quintana would be having an erosion problem today if the Brazos river was still discharging at its original, natural mouth.** An intermediate photo from 1939 shows that erosion was rapidly destroying the old delta at the jetty entrance while the new delta was forming at the new mouth to the west. Note that the beach at Surfside was still quite wide, but that sand was moving into the jetty channel from both sides (Figure 6).

Figure 6. Brazos River deltas in 1939 from photos at the Galveston District Office of the Army Corps of Engineers.

In 1999, the new Brazos delta still projected far beyond the normal shoreline into the Gulf showing the huge volume of sediment accumulated since the river was diverted in 1929 (Figure 7).

Figure 7. New Brazos River delta in 1999. The river in the foreground is the San Bernard River. The Freeport Harbor Entrance is at the top left of the photo (photo by Richard L. Watson, 1999).

The following graph (Figure 8) was created from dredging data provided by the U. S. Army Engineer District in Galveston. This data is for the outer bar channel from the end of the jetties to the seaward limit of the channel. Note that the average annual dredge maintenance nearly doubled from about 1 million cubic yards per year to 1.9 million cubic yards per year when the channel was deepened, widened and extended in 1992. This long, wide and deep channel is a total barrier to sediment moving along the coast in either direction.

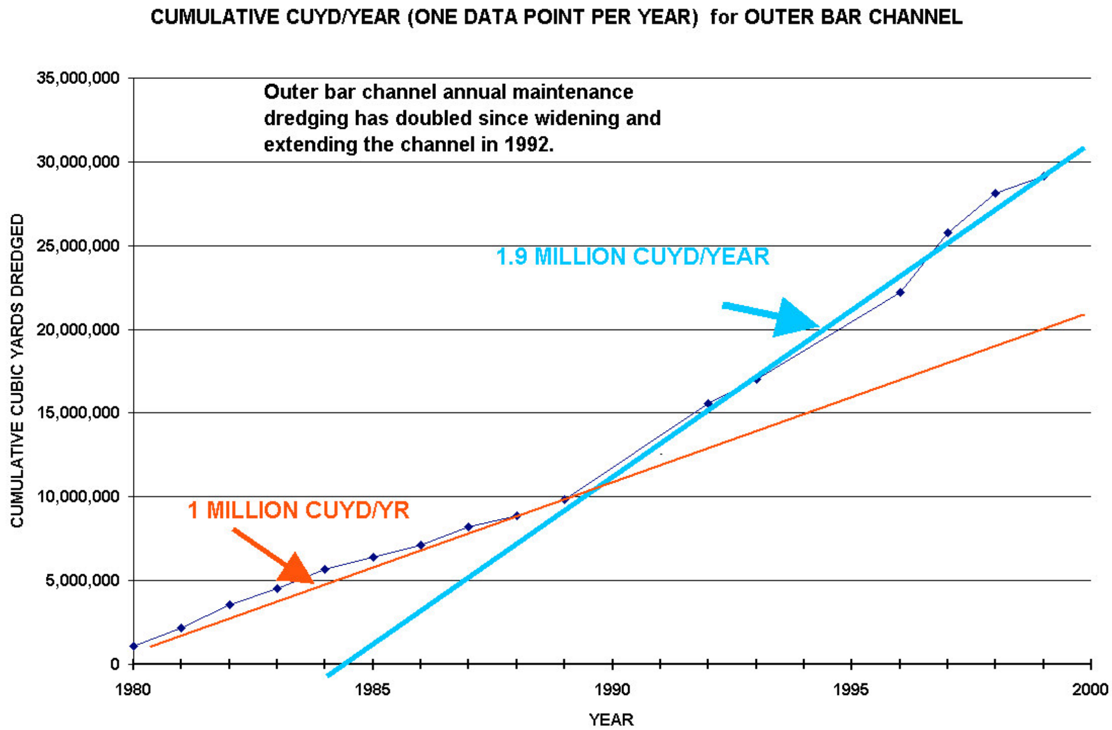

Figure 8. Freeport Outer Bar Channel Maintenance Dredging

Any sand from the Surfside beaches swept to the southwest by the longshore sediment transport system and carried seaward when it intercepts the east jetty will sweep around the end of the jetty and be permanently lost to the Surfside beaches into the channel. The Corps determined that the highest concentration of sand in its dredged material was from station 0+00 which is at the end of the east jetty (U.S. Army Engineer District, Galveston, Texas. August 1992, p. 19).. This is likely sand eroded from the Surfside beach. The Corps concludes that of all of the jettied inlets on the Texas coast, only two have such a high ratio of clay-silt to sand that the material is unsuitable for beach nourishment. They are the Sabine Neches and Freeport. So, while sand from the beaches is being lost into the channel at the jetty mouth, it is mixed with too much clay and silt to be usable for the beaches except at the end of the jetties near station 0+00.

UPSTREAM CHANGES IN BRAZOS RIVER

The Brazos River is one of only three major rivers carrying beach grade sand directly to the Gulf beaches in recent time. The other two are the Rio Grande River and the Sabine River. For a short time from about 1926 to 1992, the Colorado River also flowed directly to the Gulf beaches, but it was diverted into East Matagorda Bay in 1992. The discharge of water by all of these rivers has been significantly reduced by construction of upstream reservoirs for water supply and flood control. A side effect has been very significant reduction of beach grade sand delivered to the Gulf Beaches of Texas. This shortage of sand supply by the major rivers of Texas is a major factor in the present erosion of Texas beaches.

> Major dam and reservoir development within the Brazos River Basin is correlative with a significant decrease in the suspended sediment load of the river and with increased coastal erosion rates near the delta (Figure 9). A hydrologic analysis of the river discharge, by use of cumulative frequency curves, shows that discharge control by dam regulation has reduced the frequency of high discharges, thus smoothing out the river hydrograph and reducing the amount of sediment the river is able to carry and deliver to the coastal zone. In addition, the reservoirs are presently trapping about 76% of all sand produced within the basin. An analysis of bed load samples taken downstream of the dams indicates that the sand sizes necessary for beach nourishment are not being transported through the lower reaches of the river. **The amount of sand denied to the coastal zone through the loss of the river's transporting ability and reservoir entrapment has been determined, and is shown to be enough to account for the entire increase in the coastal erosion rates in the study area since at least 1937** (Mathewson and Minter, 1976, p. ii).

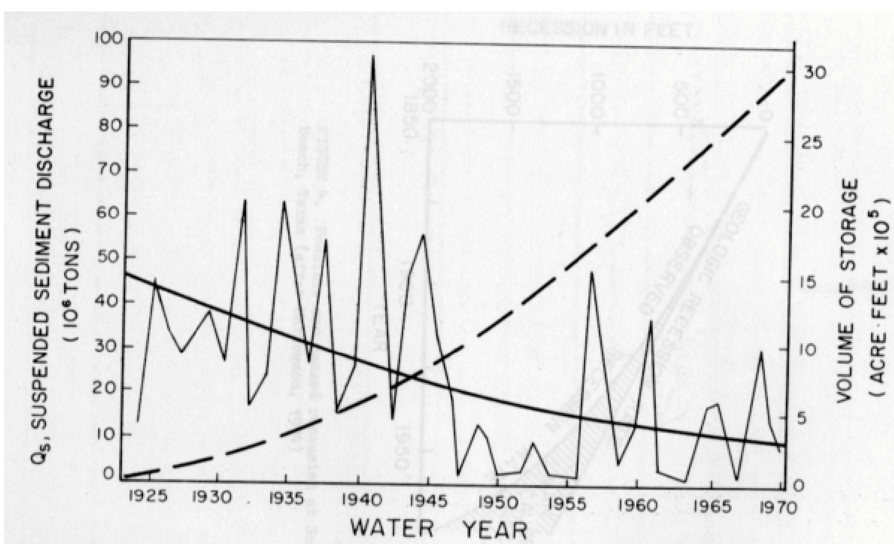

Figure 9. Historical suspended sediment discharge at Richmond. Heavy solid line is least squares fit. Dashed line is the approximate cumulative storage value of major reservoirs upstream of Richmond through time. (Mathewson and Minter, 1976, p. 5).

> …After 1948, the new Brazos delta began to be eroded. By 1952, the old delta (at the location of the Freeport Harbor Entrance) had approximated its 1852 shoreline and was

> no longer supplying sediment to the new delta. Because the new delta was eroding and coastal erosion rates continued to increase, the sand loss must have resulted from a decreased sand supply from the Brazos River…..The history of major water resource development within the Brazos River Basin began with the completion of Mineral wells Reservoir on Rock Creek in 1920. Twenty-eight additional reservoirs with storage capacity in excess of 5,000 acre-feet were completed by 1972….. Regulation of flow for flood control of the Brazos River began with the completion of Possum Kingdom Reservoir in 1941 (Mathewson and Minter, 1976, p14).

The peak discharge flow of the Brazos river decreased 52% at Waco, 46% at Bryan and 30% at Richmond due to construction of reservoirs by 1942 (Mathewson & Minter, 1976, p. 37).

> Seelig and Sorensen (1973) have used Welborn's chart to estimate the historic annual bed load and sand discharge at Richmond. …. Their data indicate an average annual reduction of 35% in the bed load discharge at Richmond since 1941 (Mathewson and Minter, 1976, p40).

In addition to reduction of bed load sand discharge due to reduced maximum river flows, large amounts of sand are trapped and permanently stored in the reservoir basins. Mathewson and Minter, p. 60, estimate that 1.9 million cubic yards of sand is trapped annually in Possum Kingdom Reservoir, 540,000 cu.yd. in Whitney-Granbury Reservoirs, 200,000 cubic feet in Waco, 350,000 cu.yd. at Belton, 70,000 cu.yd. at Somerville, and 1.1 million total for the remaining 23 major reservoirs. This amounts to a total of 4.1 million cu.yd. of sand trapped every year in the reservoirs of the Brazos River. Mathewson and Minter estimate that an additional 1.3 million cu.yd. of sand is trapped in the 714 smaller reservoirs and an estimated 125,000 farm ponds. Construction of the flood control and water supply reservoirs on the Brazos River has reduced the sand available that could be transported to the beach by over 5 million cubic yards per year. For the period 1930-70, Mathewson and Minter (p. 72) estimate that 1,616 million cubic feet of sand have been denied access to the coast. That amounts to a loss of 60 million cu. yd. for the entire time period, or an average loss of 1.5 million cu.yd. per year .

> The increase in the rate of beach erosion along the Texas coastline supplied by sediments from the Brazos River can be related to increased water resource development within the Brazos River Basin. The major changes to the river system brought about by reservoir construction are a change in the hydrology of the river and a reduction in the amount of sand available to be delivered to the coastal zone.
>
> **The frequency of occurrence of high discharges and a reduction in the peak flood discharges at gauging stations below the Whitney Dam have greatly reduced the Brazos River's ability to transport large quantities of sand downstream. Control of river discharge by dams is less effective at greater distances downstream, and as a result, much of the sand is left in the upstream portion of the channel. Even though the river farther downstream has the potential of carrying a larger sand load, the sand is not available to be transported.**
>
> Of the 195.4 million cubic feet (7.2 million cubic yards) produced annually within ghe Brazos River Basin, approximately 76% is trapped within the reservoirs and other smaller ponds within the basin. Although all of the sand trapped would not reach the coast were it allowed to naturally pass through the system, the reduction in the amount of sand available for transport has obvious implications. Calculations of the amount of sand

> denied access to the coast since major water resource development was initiated shows that it is sufficient to account for the entire increase in coastal erosion since at least 1937 (Mathewson and Minter, 1976, p78).. {Note RLW, this applies to erosion from the new Brazos delta through the Sargent area.}

In a study of the effects of changes in the Brazos River on erosion at Sargent Beach, Seelig and Sorenson (1973) estimated that the amount of sand carried to the coast after construction of upstream reservoirs was reduced by two-thirds.

EROSION AT SURFSIDE

One of the first comprehensive studies of beach erosion in the shoreline segment that includes Surfside was completed by Morton and Pieper in 1975. They found the 1852 shoreline in the Surfside-Quintana vicinity was nearly straight. Construction of jetties at the mouth of the Brazos helped to trap sediment and by 1881, the river had formed an arcuate delta into the Gulf. **"The delta continued to prograde seaward until 1929 when the diversion channel was constructed" (Morton & Pieper, 1975, p. 18). They found the 1930 shoreline was the most seaward advance of the old Brazos delta.** It built seaward at an average rate of 27 feet per year (Figure 10).

> 1930-37 to 1956-57. The most dominant shoreline change during this period resulted from construction of the diversion channel and rerouting of the Brazos River west of the original mouth. The old delta entered an erosional cycle, and new delta construction was initiated at the mouth of the new channel. ….The shoreline between points 1 and eleven continued to erode…. Minor accretion occurred between points 11 and 15 (the location of Surfside) due to the entrapment of sediment by the east jetty. The shoreline remained relatively unchanged at point 11, but accretion increased to 125 feet near the east jetty at point 14. Rates of accretion for this segment of the shoreline were greater between 1856 and 1930.
>
> Diversion of the Brazos River prevented fluvial transport of sediment through the old channel, thus the shoreline from the west jetty to point 19 underwent erosion that varied from 4,700 feet at point 17 to 1350 feet at point 18. By 1956, the offshore bars outlining the seaward limits of the old delta had been destroyed.
>
> The new Brazos delta extends from point 19 to point 25. Extreme accretion along this segment of the shoreline ranged from 725 ft. or 27.4 feet per year at point 25 to 6,800 or 256.6 feet per year at point 23. …. Seelig and Sorenson (1973b) state that the new delta attained its most seaward position by 1948 (p. 22) (Morton & Pieper, 1975, p. 22).
>
> 1956-57 to 1965. … . The shoreline east of the Freeport jetties was erosional at all points except points 1, 9, and 12, where accretion was exhibited and at points 6 and 11 where the shoreline remained relatively stationary. … With the exception of minor accretion at point 20, erosion west of the jetties ranged from 100 feet at point 19 to 825 feet at point 23 (p. 22).
>
> 1965 to 1974. ….From point 2 to point 22, the shoreline was erosional with rates varying from moderate to extreme {note RLW: this includes the Surfside beaches}. The area of extreme erosion was on the old delta west of the jetties (points 16-20). Erosion along this segment ranged from 75 feet to 600 feet and averaged about 207 feet or 23.1 feet per year (p. 23). Rates of erosion increased along this segment of the coast between 1965 and 1974.
>
> The new Brazos delta continued to build seaward and westward (point 23-26). By 1974, the new delta had accreted a maximum distance of 6,000 ft at point 24. (Morton & Pieper, 1975, p. 23).
>
> Net rates of erosion and accretion are relatively high along the this segment of the Texas coast. Net rates of erosion on Follets Island decrease from 10.9 feet per year at San Luis Pass to 2.0 feet per year at point 12 where shoreline changes were influenced by the Freeport Jetties. The average net rate of erosion was 6.3 feet per year. Net rates of

accretion recorded from points 13 to 25 ranged from 2.7 feet per year immediately east of the jetties at point 13 to 49.6 feet per year on the new Brazos delta at point 23. The average net rate of accretion was 10 feet per year (Morton & Pieper, 1975, p. 25).

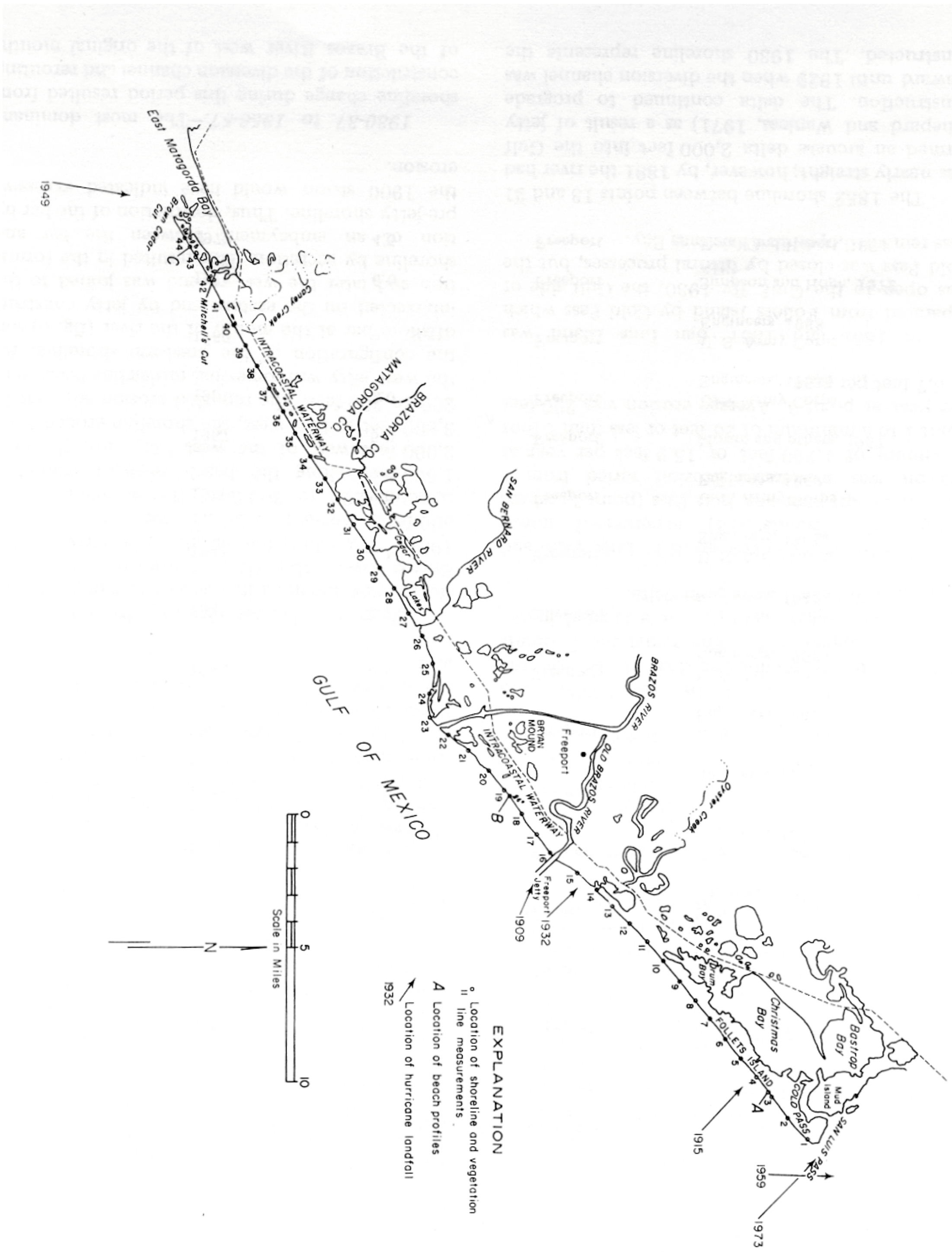

Figure 10. Location map of points of measurement, beach profiles and hurricane landfall (Morton and Pieper, 1975, p. 20)

Between 1974 and 1982, the shoreline was relatively stable for much of Follets Island between San Luis Pass and the Freeport jetties, while erosion between the jetties and the new Brazos River mouth was severe (Figure 11).

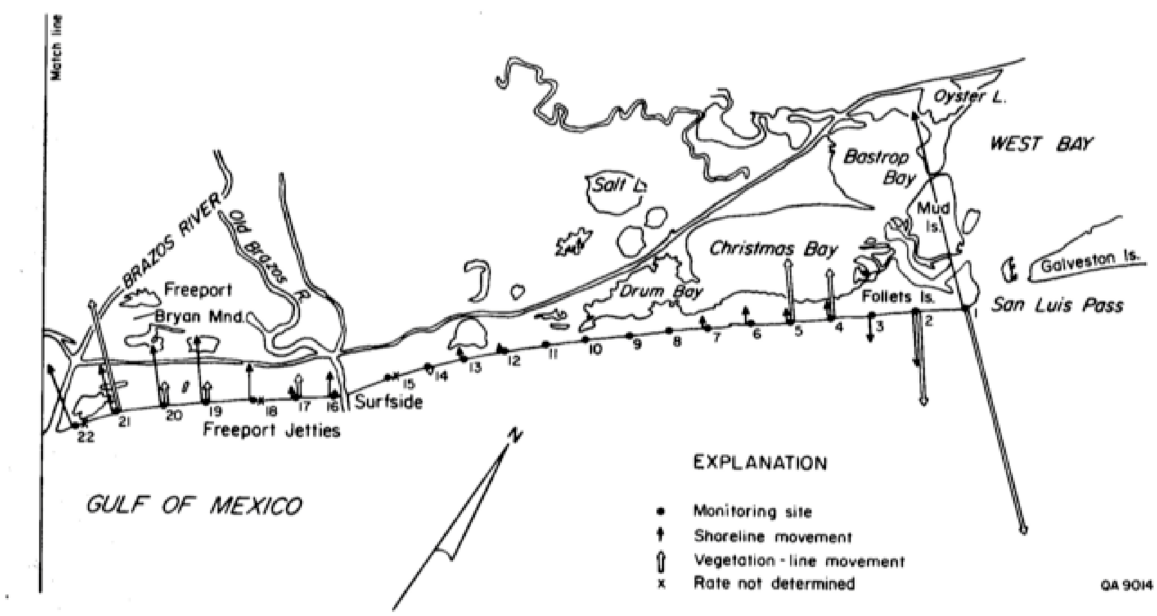

Figure 11. Shoreline and vegetation-line changes between San Luis Pass and Brown Cedar Cut, 1974-1982 (From Paine and Morton, 1989, p. 21).

Shorelines along the headland were relatively stable northeast of the Freeport jetties (stations 11 to 15) between 1974 and 1982. Three of the five monitoring sites along this segment showed no detectable shoreline change, and the other two recorded minimal rates of retreat (1.6 to 3.4 ft/yr.). In contrast, most of the shoreline between the Freeport jetties (old Brazos River) and the new Brazos River retreated at relatively high rates (3.1 to 19.5 ft/yr at stations 16 to 24 between 1974 and 1982) (Paine and Morton, 1989) (Figure 12).

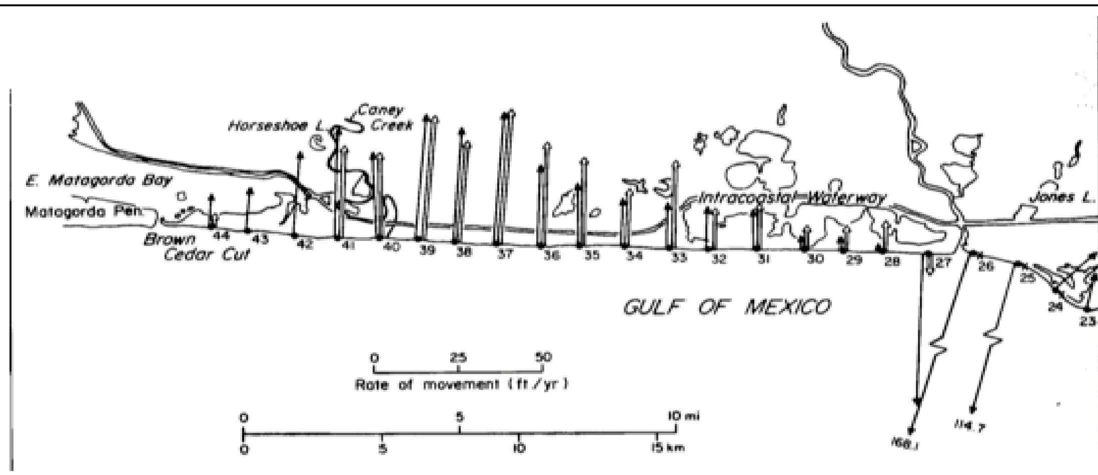

Figure 12. Shoreline and vegetation-line changes between San Luis Pass and Brown Cedar Cut, 1974-1982 (From Paine and Morton, 1989, p. 20).

In 1981 Mason studied 5 Texas inlets for the Army Corps of Engineers. He found dam construction on the Brazos River in the 1940's reduced river flows and significantly reduced sediment transport to the coast. He noted this caused recession of the new Brazos delta.

> The major change in the bathymetry offshore of Freeport entrance between 1946 and 1966 was a general deepening of the entire area (Seelig and Sorenson, 1973). ….
>
> Within the survey limits on the east side of the entrance, a loss of 3.3 million cubic yards occurred between 1966 and 1975, mostly in a zone centered about 4,000 feet east of the jetties (Figure 13). Some material accumulated in a localized area between this erosion zone and the jetties, and about 4,000 feet offshore. These zones of deposition and erosion were formed primarily between 1970 and 1975. Within the scour zone, the 12 and 20 foot contours moved inshore. This erosion may have contributed to the current increased shoreline recession rates east of the jetties by allowing larger waves to reach the foreshore, particularly at the apex of the zone where recent MSL retreat rates have been about 33 feet per year. However, subsidence is also a possible contributing factor.

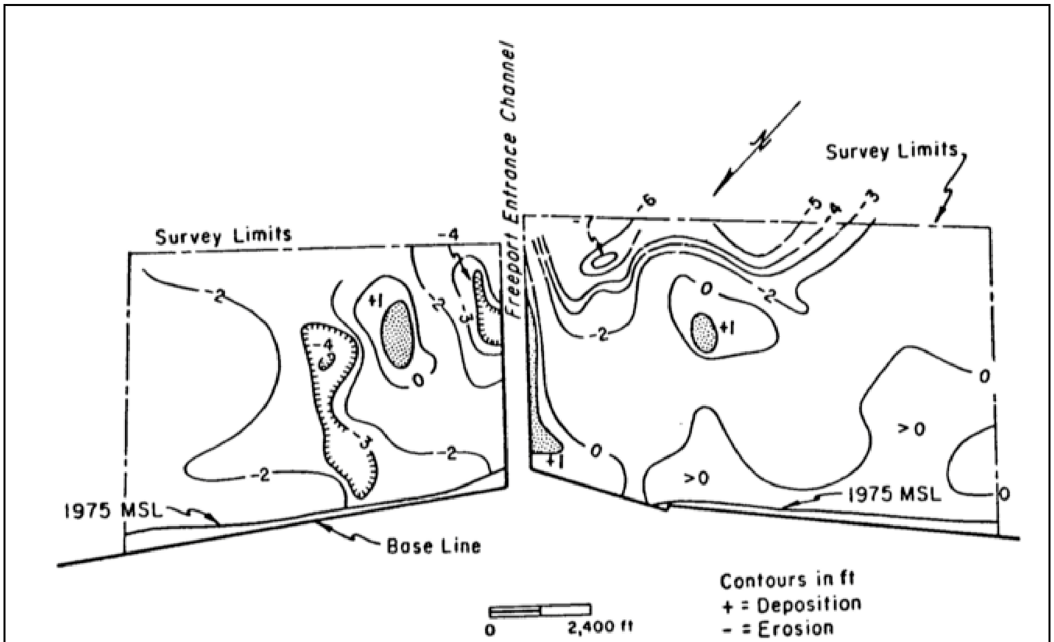

Figure 13. Depth Changes, Freeport Harbor, Texas, 1966-75 (C. Mason, 1981, p. 22).

> On the west side of the entrance, an accretion zone occurred between 1966 and 1975 in the same relative position with respect to the jetties as on the east side: 4,000 feet offshore and 4,000 feet west of the jetties. However, a net erosion of 2.1 million cubic yards occurred between 1966 and 1975. Along the offshore limits of the control area, extensive erosion occurred between 1966 and 1970, with some accretion immediately adjacent to the west jetty (Mason, 1981).

In 1996, Morton again surveyed beach profiles along the upper Texas coast. Table 4 shows the transects 8 through 15, which include the beach at Surfside and the beach just west of the west jetty accreted between 1974 and 1996 (see Figure 10 for locations) (Morton, 1997).

Transect	Net change (ft)	Average rate (ft/yr)	Transect	Net change (ft)	Average rate (ft/yr)
1	–892	–40.7	12	+79	+3.8
2	–66	–3.0	13	+16	+0.9
3	+292	+13.3	14	+4	+0.4
4	+69	+3.1	15	+27	+1.5
5	–39	–1.8	16	–27	–1.2
6	–56	–2.6	17	–25	–1.0
7	–34	–1.6	18	–112	–5.0
8	+57	+2.6	19	–302	–13.6
9	+86	+3.9	20	–289	–13.0
10	+81	+3.7	21	–243	–10.9
11	+30	+1.4	22	+78	+3.8

Table 2. Net shoreline changes from San Luis Pass to the Brazos River, 1974-1996. Locations of transects are shown in Figure 10. Plus sign indicates shoreline advance; minus sign indicates shoreline retreat. (From Morton, 1997, p. 17).

Note that the area immediately east of the jetty at Surfside was accreting with rates of 0.4 to 3.9 ft/yr. of accretion (transects 8-15), while the area west of the jetties from Quintana to Bryan Beach was eroding rapidly, with the exception of transect 22, the transect nearest the Brazos River mouth.

> From central Follets Island to Surfside (transects 8-15), the beach is moderately wide, and the berm-crest is the shoreline erosion feature. Along this beach segment the shoreline advanced slightly or was relatively stable between 1974 and 1996 … despite lowering of the beach 1 to 1.5 feet and inland transport of sand by Hurricane Gilbert in 1988. Slight net advancement of the beach at transect 15 … is related to dredged material placed on the beach in conjunction with relocation of the jetties and widening of the ship channel at the entrance to Freeport Harbor. This undesigned beach replenishment project was conducted by the Corps of Engineers in October, 1991 (Morton, 1997, p. 21).

The most recent erosion estimates for the shoreline at Surfside are shown in Figure 14. This shows rates from 2 ft/yr. at the north end of Surfside Beach increasing to rates of 9 to 14 ft/yr. near the northeast jetty. Only a few years earlier the rates of erosion along this shoreline segment were much slower, or even nearly stable, in the time period between 1974 and 1982. Between 1974 and 1996, the shoreline was showing accretion at Surfside. This latest data also shows very rapid erosion west of the jetties. Something has changed to produce the rapid erosion.

> **In general the erosion of Surfside Beach is the result of the sand-starved environment similar to the entire Gulf of Mexico infrastructure. However, the targeted project area of the Pedestrian Beach , a one mile strip north of the Freeport jetties, represents a recognized anomaly experiencing accelerated erosion, in an area**

that should be experiencing accretion due to littoral drift toward the jetty. The Corps of Engineers and the University of Texas Bureau of Economic Geology have both commented on this anomaly and possible causative factors have included: increased scouring due to wave amplification by the jetty structure … sand inventory reduction from dredging and the displacement of the Brazos River mouth, subsidence (>2 feet documented) from historical industrial ground water pumping and sand loss due to the porosity of the jetty and/or inability to migrate across the cut (25 ft. depth at jetty mouth). {Note, RLW, this should be 45 ft. depth}

The result is erosion at approximately two to three times the average coastal rate for this area that also has the highest population density for the community of Surfside and is one of the most popular tourist venues (Project Goal Summary Surfside Beach, 9/29/99, General Land Office website, http://www.glo.state.tx.us/coastal/erosion/projects/pdf/cycle01/SurfsidePGS.pdf)

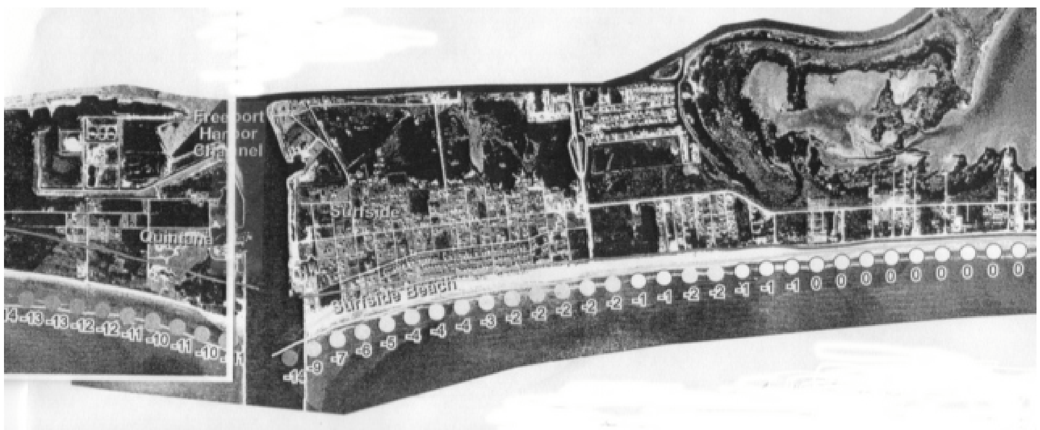

Figure 14. Average annual rates of shoreline change (feet/year). (From Gibeaut, Morton and Angle, 1999).

Two photographs from the Surfriders club show the massive erosion at Surfside Beach.

Figure 15. Two photos from Surfside show the dome building and the wide beach in 1969 and the dome in 2000 with no beach shortly before it was demolished. This location is a short distance east of the jetties. (Photos from Surfriders website)

Many other houses have been lost due to erosion and another row of houses are facing loss at this time. The following photos taken in January, 2003 show another row of houses facing loss, if the beach is not replaced (Figure 16).

Figure 16. Aerial Photos taken on January 4, 2003 showing houses at Surfside Beach facing imminent loss due to erosion. The photos proceed to the east from the jetty (photography by Richard L. Watson, 2003).

CAUSES OF SEVERE BEACH EROSION AT SURFSIDE

Most of the Texas Gulf coast beaches are undergoing erosion. Some of the fastest rates of erosion are on deltaic headlands such as the Colorado River - San Bernard River - Brazos River headland. This includes Surfside Beach on the eastern margin of the headland. Natural erosion may be due to reduced sand supply on the nearshore shelf that can be transported to the beaches by wave action, naturally reduced sand supply from the major rivers which reach the Gulf Beaches due to reduced rainfall in the past several thousand years, and slowly rising sea level. However, these natural causes of beach erosion are dwarfed by man-made changes in the rivers and the longshore sediment transport system along much of the coast. "On the Texas coast nearly half of the total beach sand supplied by updrift erosion, presently a major sediment source, has been trapped by jetties at harbor entrances. This impoundment of sand at impermeable barriers together with reduced sediment influx from damming of rivers suggest that anthropogenic augmentation of natural shoreline erosion will likely increase from local to regional effects" (Morton, 1979, p 1101).

At Surfside, man-made changes are causing extremely high rates of erosion. "The strongest indictments against human-induced shoreline changes are the unpredictable but rapid local responses attendant with engineering modifications. For example, maximum sustained rates of accretion (+75 m/yr.) and erosion (-55m/yr) documented for the Texas coast were associated with jetty construction and subsequent channel diversion at the mouth of the Brazos River (Morton and Pieper, 1975)" (Morton, 1979, p. 1108).

> Nearly 36 million cubic meters of sand and mud were deposited near the jetties between 1855-57 and 1937. Maximum net deposition, however, was probably greater because erosion was coincident with river diversion eight years prior to the hydrographic survey. For the same reason, net erosion of 42 million cubic meters between 1937 and 1974 … may underestimate total erosion since river diversion. Net bathymetric changes between 1855-57 and 1974 are erosional with nearly equal volumes from updrift and downdrift erosion. ... Total net losses amount to about 5.35 million cubic meters. The latest trend, however, is erosional and recent rates of shoreline erosion, have been extremely high, especially east of the jetties (Morton, 1977a, p. 280.)

After the jetties were constructed in the 1890s, the shoreline built seaward as much as 6,000 feet in a 40-year span. But in 1929 the Brazos River mouth was diverted westward about 6 miles where it now empties into the Gulf. The reason this story is important to the home dweller in this area is that diverting the river cut off an important supply of beach sand and caused very rapid erosion at Surfside and Quintana on the order of 10 to 15 feet per year (Morton, et al., 1983, p. 71) Fig. 17 .

Figure 17. Beach house eroding at Surfside in the early 1980s. (From Morton, et al., 1983, p. 76)

Both global sea-level rise and local relative sea-level rise due to natural sediment compaction and man-made subsidence from withdrawal of ground water have caused some of the shoreline retreat at Surfside.

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. 18). This rise is caused by compaction of sediments causing a lowering of the sand surface …. and by a raising of the global ocean surface caused by melting glaciers and thermal expansion of sea water. 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 (Gibeaut, White, and Tremblay, 2000, p. 4).

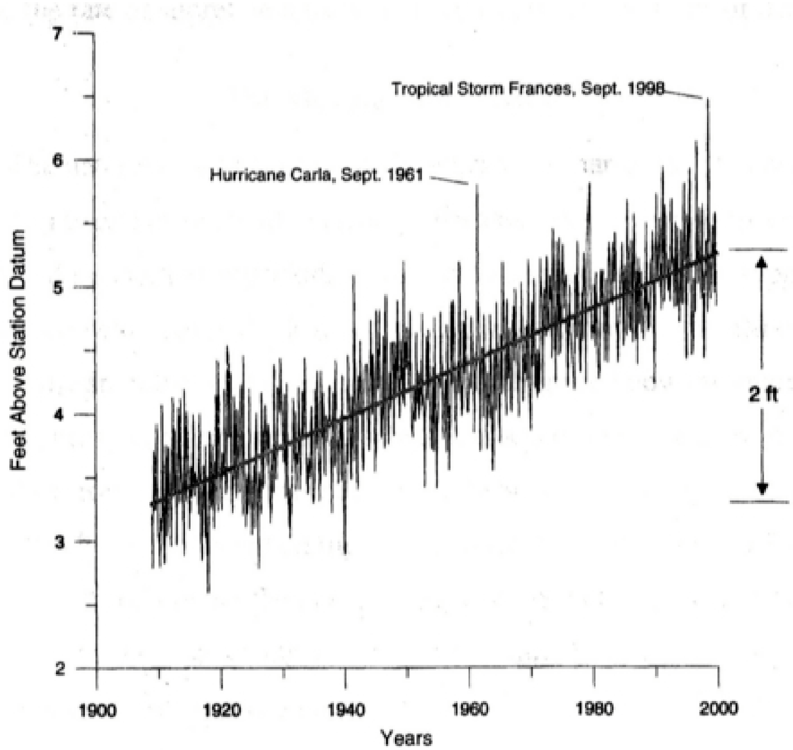

Figure 18. Monthly average sea level since 1909 as measured by Pier 21 tide gauge in Galveston. Straight line is a linear regression through all the data points (From Gibeaut, White, and Tremblay, 2000, p. 4).

In the past, there was sufficient sand available for the beaches to build up and keep pace with rising sea levels; however, this is no longer true for most of the Texas beaches. This situation is particularly critical in areas such as Surfside and the Brazos-Colorado deltaic headland in general, where the beaches and peninsulas are only a thin veneer of sand over mud and the offshore bottom is mostly mud.

In the Houston, Texas City and Freeport areas there has been significant land subsidence due to subsurface extraction of groundwater and/or petroleum by deep wells. Figure 19 shows subsidence of about 2 ft. in the Freeport area and about 1 ft. at surfside. Ground water extraction has continued. It is likely that there has been more subsidence at Surfside since 1978, the latest data presented on this map. Rising sea-levels due to global sea-level rise or local land subsidence do not cause beach erosion, but the rise in sea level results in a shift of the shoreline in the landward direction which has the same net effect on the shoreline.

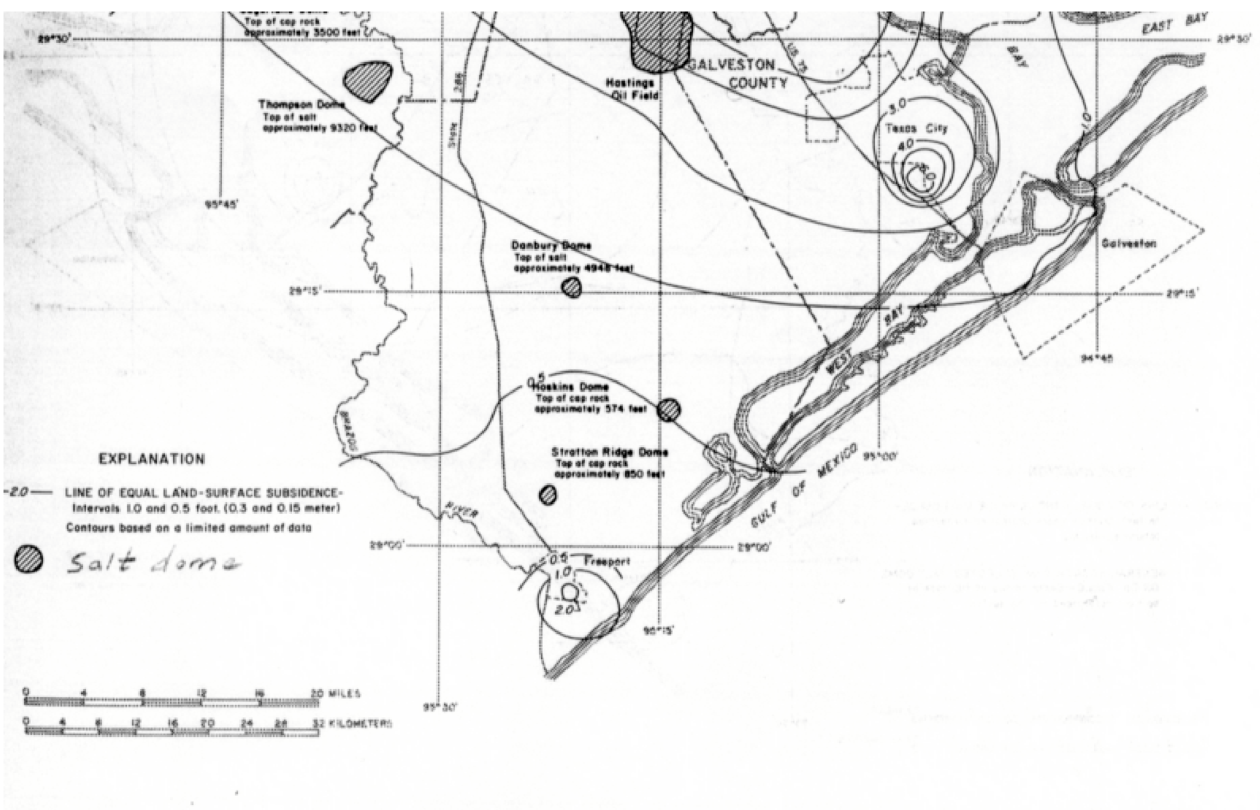

Figure 19. Approximate land-surface subsidence, 1906-78. (From Gabrysch, 1982, p.19)

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. 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 (Gibeaut, White, and Tremblay, 2000, p. 21).

Swanson and Thurlow (1973) used tide gauge data from Florida to Texas to estimate rates of relative sea-level rise that were due to land subsidence. For Freeport, they estimated from 1955 to 1971 the rate of subsidence at Freeport was 1.12 cm/yr. (Swanson and Thurlow, 1973, p. 2668). This would be equal to 0.44 in/yr. This rate would mean that the subsidence from 1960 to 2003 would be a total of about 1.5 feet of relative sea-level rise due to subsidence. This alone can account for considerable shoreline retreat on a gently sloping shoreline.

Gibeaut and White (1999) summarize the effects of man-made structures on shoreline retreat on the upper Texas Coast.

> **Overall, the shoreline from High Island to the Brazos River is retreating at a rate of 2 to 10 feet per year….. 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 the 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 the 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 (Gibeaut and White, 1999, p. 9,10).**

The area enclosed in red in Figure 20 clearly shows the huge amount of sediment trapped and permanently stored by the east jetty of Bolivar Roads since the jetty was built in 1876. Morton, *et al.* 1983 noted: "The most recent shoreline accretion on the Peninsula's western tip can be attributed to sediment supplied by beach erosion and trapped by the north jetty at Bolivar Roads. Over 28 million cubic yards of sand have been added to the beach and along the jetties by coastal processes since jetty construction in 1876." "This huge accumulation of beach materials that was carried west along the shore of Bolivar Peninsula and accumulated north of the jetty at the Galveston Entrance Channel is shown in Figure 20. This amounts to about 260,000 cuyd/yr and may be a good estimate of the net longshore sediment transport to the southwest along Bolivar Peninsula" (Watson, 1999). This huge amount of sand is forever denied to the beaches further downdrift along the coast on Galveston Island and Follets Island, including the beach at Surfside. The jetties at Bolivar Roads are so long they provide a wave shadow on the west side of the pass which protects the beaches from waves coming from the northeast. This has caused another large accumulation of sand trapped at East Beach in Galveston which further starves downdrift beaches to the southwest.

Figure 20. Sediment accumulation northeast of the Bolivar Roads east jetty. Photo by Richard L. Watson, 1999)

Dredging data from the U.S. Army Corps of Engineers (Bales and Holley, 1985, 1989) indicates 240,000 to 290,000 cu.yd. of beach materials are transported through Rollover Pass and deposited in the Gulf Intracoastal Waterway. This means that almost 10 million cu.yd. of sediment has been lost from the beaches through Rollover Pass since it was built in 1956 (Watson, 1999).

> **The Brazos River used to flow through Freeport Channel before it was diverted to the southwest in 1929. 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. …
>
> Construction of the Galveston island seawall and groin field began in 1902 and was completed to its current length in 1963. In the 1930's thirteen 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 four miles 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 retreat rates adjacent to them, but starving beaches to the southwest of them** (Gibeaut and White, 1999, p. 10,11).

The bathymetric diagram showing depth contours off the upper Texas coast clearly shows deltaic accumulation of sediment offshore of the present mouth of the Brazos River and the absence of any such accumulation at the Freeport jetties, the location of the Brazos River prior to its diversion in 1929 (Figure 21). Even though the amount of sand carried to the coast by the Brazos has been significantly reduced due to upstream dam and reservoir construction, the post 1929 mouth of the Brazos River is still maintaining both a subaerial and submarine delta. If the river had not been diverted, that sediment would be dumping into the Gulf at the Freeport jetties and the present severe shoreline retreat and beach erosion either would not be occurring or would be occurring at a much slower rate. The large sand accumulation adjacent to each of the Bolivar Roads jetties is also apparent.

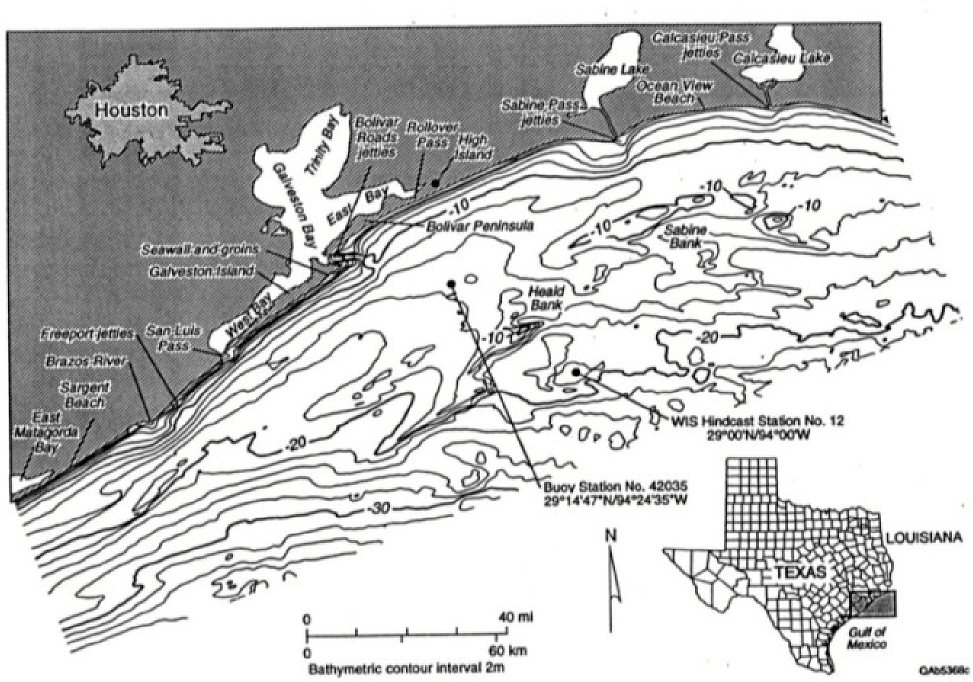

Figure 21. Upper Texas Coast (From Gibeaut and White, 1999, p. 3)

CONCLUSIONS

It is well established that there is a severe and accelerating beach erosion problem at Surfside, Texas. While a small part of the erosion may be due to natural causes, such as decreased sand transport to the coast by rivers and global sea level rise, it is obvious that at this location, most of the erosion is caused by man-made changes to the Brazos River and the Freeport Harbor entrance channel. Diversion of the river 7 miles in the downdrift direction has starved the Surfside and Quintana beaches of river sand. Numerous upstream dams and reservoirs on the Brazos river have drastically reduced the amount of sand the river now carries to the coast.

Construction of long jetties and a deep channel precludes sand transport in either direction across the harbor entrance. In addition, sand moving southwest along the beach at Surfside is carried out along the east jetty and deposited in the channel, where it is forever lost to the Surfside beach, unless it is placed back on the beach by a dredge during beach nourishment.

The Corps of Engineers and the Bureau of Economic Geology maintain that the lack of an updrift fillet of sand and the recently accelerated erosion at surfside beach may be due to wave amplification by the recently extended east jetty or sand inventory reduction by dredging of the channel. Since the jetty was extended in 1992 and the channel was deepened to 45 feet, the amount of sediment dredged annually from the outer bar channel has nearly doubled.

It has been nearly 75 years since the Brazos river was diverted to the south, and the old Brazos delta has completely eroded away and no longer serves as a nearshore source for sand that waves can bring onshore to nourish the beach. There is, now, little sand offshore, with only a thin veneer of sand over deltaic mud. Likewise, dunes in the Surfside area are very small and store only a small volume of sand which can be transported offshore during storms to flatten the beach profile and reduce wave attack. If any of that sand is washed offshore onto the clay zone, it will not be transported back to the beach.

Finally, extraction of large amounts of ground water for the Freeport industries has caused subsidence of the land surface at Surfside, resulting in at least one foot of relative sea level rise. Extrapolation of the rate of subsidence suggests the total is now two or 2.5 ft. at Surfside, resulting in additional shoreline retreat.

Distant man-made changes in the shoreline have drastically reduced the amount of sand which is available to be transported to the southwest along the coast. About 11 million cu.yd. of sand has been lost inward through Rollover Pass since it was built in 1956 and more than 30 million cu.yd. of sand have been caught and permanently stored east of the jetties at Bolivar Roads. A smaller amount of sand is stored in the fillet at East Beach, Galveston in the wave shadow of the jetties.

In the middle part of the 20th century, hard structures such as groins and seawalls along with beach nourishment were the primary methods used to slow or stop beach erosion. Since groins and jetties starve downdrift beaches and merely pass the erosion problem to downdrift beaches, they have fallen into disfavor. Seawalls accelerate erosion of the beach in front of them, rather than protect it, while they protect the landward property as long as they last. However, unless they are truly massive such as the Galveston seawall, they usually fail in severe storms. By the end of the 20th century, it has become the practice to just allow beaches to erode or to use beach nourishment with beach quality sand, when it is economically feasible to do so.

The best solution to provide a beach at Surfside (and to stop further erosion) is to nourish the beaches with beach quality sand from nearby sources. The problem is that there may not be adequate nearby sources of sand. It appears that the only beach quality sand being dredged from the channel is near station 0+00 at the end of the jetties. That is most likely sand eroded from Surfside beaches and can be pumped back onto the beach by a pipeline dredge. If that part of the channel is maintained with hopper dredges, it is unlikely the sand can be placed back on the beach. There may also be a sand source in Oyster Creek, which used to flow to the coast, but now terminates in the Intracoastal Waterway. There are no surface sand deposits in the offshore area which are suitable for beach nourishment. In a recent study, Texas A&M Galveston researchers found a buried channel below the Beaumont clay offshore from Surfside (Dellapenna, Allison, and Seitz, 2002). It is likely a sand-filled channel and could possibly be a source of beach sand. However, exploitation of this sand resource would require deep dredging and would leave a deep hole offshore in which beach sand may be lost during storms.

Sources of beach quality sand to nourish the beaches at Surfside are limited, and even if exploited, will not be sufficient to serve long into the future. Even though there is reluctance to armoring the shoreline with seawalls or revetments, such structures may be the only long term solution to erosion and shoreline retreat at Surfside and at Quintana. Such structures will mean there will be no usable pedestrian beach in front of them in the future, but they can stabilize the shoreline and prevent further erosion for a long time. This was done in the Sargent area to protect the Intracoastal Waterway and the remaining houses seaward of the waterway.

One of the greatest drawbacks of using seawalls and revetments such as at Galveston and at Sargent is they accelerate beach erosion in the downdrift direction. This should not be a concern if these structures are used at Surfside and Quintana because the beaches downdrift of the Freeport jetties are receiving no sand from the updrift beaches at present and the beaches downdrift of the new Brazos delta are being nourished by sand from the delta and the Brazos River. There are few locations where armoring the shoreline would cause less downdrift damage that such structures at Surfside and Quintana.

There is no other location on the coast which is subject to such a complete collection of man-made causes of beach erosion. Of the possible man-induced causes of beach erosion: river diversion, reduced sand output by a nearby river, jetty construction, maintenance of a deep channel, land subsidence due to water or oil extraction, and blockage of updrift sand sources, all are present at Surfside. In addition, Surfside is located on an eroding delta which is composed largely of mud with little in the way of nearshore sand sources.

5 The severe beach erosion at both Surfside and Quintana is almost entirely due to man-made changes in the Brazos River and the coastline. Only man-made changes in the form of beach nourishment and/or armoring the shoreline with a sea wall or revetment will stop the erosion.

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