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BEACH EROSION AND DEPOSITION ON DAUPHIN ISLAND, ALABAMA, U.S.A.



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Beach Erosion and Deposition on Dauphin Island, Alabama, U.S.A.

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ABSTRACT

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Beach erosion and deposition along the Gulf of Mexico beaches of Dauphin Island, Alabama, were evaluated using air photos, beach profiles, visual wave observations, and historical coastal engineering archives. The eastern end of the island has two reaches of shorelines which are receding and a reach of shoreline in between them which is accreting. Shoreline recession was measured during the year of this study at rates up to 15 m/yr. Based on beach profile surveys, the changes observed this year are consistent with the changes that have occurred during the past decade. Averaged over the past decade, maximum recession rates of 6 m/yr were found. The recession/accretion/recession pattern at the eastern end of the island appears to be a response to changes in the position of the Mobile Pass ebb-tidal shoals and related ephemeral islands immediately offshore. Mobile Pass is one of the largest tidal inlets in the country. The shoals and islands (commonly called Sand Island) provide both sand for the Dauphin Island beaches and wave sheltering to those beaches. The shoreline along the remainder of the Dauphin Island beaches to the west appears to have been generally stable during the past decade. Coastal engineering works which have modified the natural coastal processes of the Dauphin Island littoral system include coastal structures at the east end of the island and the removal of sand from the littoral system by dredging.

ADDITIONAL INDEX WORDS: Gulf of Mexico, coastal engineering, beach nourishment, longshore sand transport, dredging, monitoring, erosion, inlets.

INTRODUCTION

Dauphin Island, Alabama, is a 25 km long barrier island on the Gulf of Mexico just to the west of Mobile Bay Pass (Figure 1). The eastern portion of the island is several kilometers wide with a sand dune field with elevations of over 14 m above sea level and an extensive maritime forest (Figure 2). The western portion of the island is only several hundred meters wide, has maximum elevations of less than 3 m above sea level, and no maritime forest.

Dauphin Island was briefly the capital of the Louisiana Territory in the 1700's and since then has been inhabited by descendants of Europeans. Fort Gaines, on the eastern tip of the island, was part of the Civil War naval battle in which Farragut said "damn the torpedoes. . . ." Yet, modern land development on the island only began when the first bridge was built to the island in 1958. The western half of the island is still undeveloped.

Beaches and boating are important present-day concerns at Dauphin Island. However, erosion of the beaches and shoaling of the boat launching areas and channels have been persistent problems. Although shoreline movement is a natural coastal process, it causes significant problems when

it affects man-made structures such as historic Fort Gaines. The winter and spring of 1991 brought storms that caused some of the worst erosion in recent history along several stretches of beach. Erosion along one area threatened the structural integrity of a public fishing pier, bathhouse, and picnic pavilions. Also during 1991, several people drowned while swimming off the beaches of Dauphin Island. The erosion and resulting media attention emphasized that long- and short-term management decisions concerning public facilities should be made within the context of an understanding of the natural coastal processes.

A comprehensive coastal processes study for Dauphin Island has not previously been published. However, a number of reports have included information on the geologic, oceanographic, and engineering aspects of the island's coastal processes. OIVOS (1979) describes the geological framework of this portion of the Gulf coast. Historic shoreline change maps of the area are presented by SAMP *et al.* (1975); U.S. ARMY ENGINEER DISTRICT, MOBILE (1978); and HUMMEL (1990). The response of the island to Hurricane Frederic in 1979 was investigated by SORUM *et al.* (1979), NEMMEDAL *et al.* (1979), and U.S. ARMY ENGINEER DISTRICT, MOBILE (1981). The hurricane overwashed the entire western end of the island. Sand

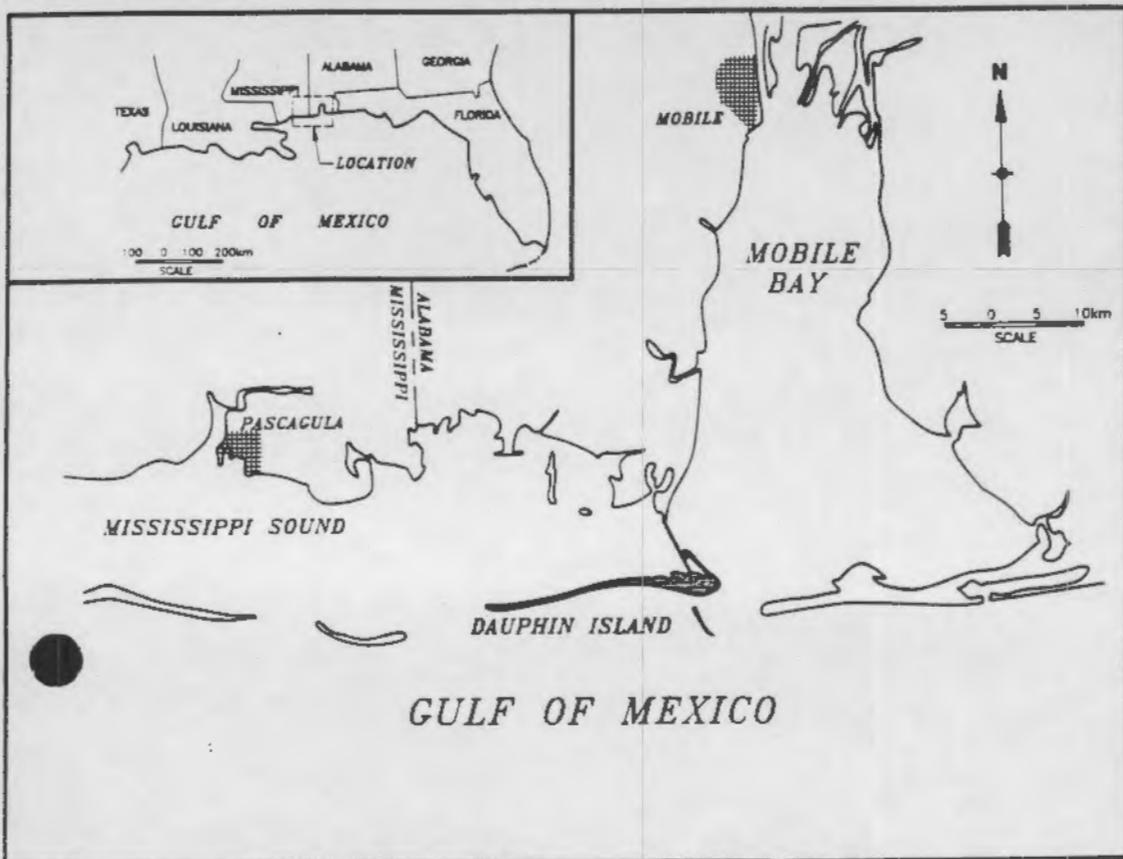


Figure 1. Location map.

overwash fans into Mississippi Sound on the north side of the island were seen on the post-storm air photos. The eastern end of the island experienced high water elevations, but the higher dune elevations prevented overwash.

SCHROEDER and WISEMAN (1985) evaluated tide and wind data from the eastern end of Dauphin Island. They found the mean sea level in 1977-1982 was roughly 0.1 m above the National Geodetic Vertical Datum (NGVD). The winds during 1974-1984 show seasonal patterns with stronger, northerly winds dominant in the winters and milder, southerly winds dominant in the summers. The tides are diurnal with a mean range of 0.37 m (NOAA, 1990).

LAMB (1987) shows that the shoreline position along the easternmost kilometer of Dauphin Island appears to be going through cycles of recession and accretion. Lamb speculates that these

shoreline changes on Dauphin Island are controlled by changes in the ephemeral islands and shoals immediately offshore. These offshore islands have undergone dramatic changes in recorded history. Portions of them have been called Pelican Island and Sand Island. In this present paper, the term Sand Island will be used. Sand Island is on the edge of the ebb-tidal delta of Mobile Pass and is essentially just that portion of the ebb-tidal shoal which emerges above sea level long enough to become vegetated at any point in time.

The 1987 construction of an underwater berm south of Dauphin Island with sand is discussed in HANDS and BRADLEY (1990) and BRADLEY and HANDS (1989). The sand, dredged from the Mobile Ship Channel, was placed on the ebb-tidal delta of Mobile Pass and not dumped in deep water several miles from the ebb-tidal delta at the reg-



Figure 2. Eastern end of Dauphin Island, Alabama (October 11, 1991)

ular disposal location. The berm had moved toward the shallower depths of the Sand Island shoal complex by 1990 (HANDS, 1991). Thus, the berm construction method appears to have successfully kept the dredged sands in the littoral system. However, the berm may be trapping sand in its lee. MCLELLAN and IMSAND (1989) discuss the creation of a much larger mound of dredged material in deep water offshore of the ebb-tidal delta. This mound was created with dredged materials from the deepening of the Mobile Ship Channel including sands from the ebb-tidal delta area and fines from inside Mobile Bay.

This paper focuses on the present-day beach erosion processes along the Gulf of Mexico beaches of the eastern, inhabited half of Dauphin Island. A field study was conducted to document the extent and causes of shoreline change. The primary goal of the study was to provide an understanding of the erosion problems that are being experienced today and can be expected in the future. With this information, decision-makers including politicians, managers, and ultimately the citizens of Dauphin Island and Alabama can work with the natural coastal processes of the island or at least be prepared to pay the cost of working against the natural processes if they so decide.

METHODS

Original data were collected for one year, September 1990 to September 1991, to quantify the beach changes during the year and the causes of those changes. This one-year look was enlightening because it appears to have captured some of the important processes that drive the longer term changes. These data were supplemented with available existing data including some historic beach profiles and air photos.

1990-1991 Monitoring Data

Beach changes were measured during the year with air photos along the Gulf of Mexico beaches and with surveyed beach profiles at eight specific locations. The forces causing these changes were measured with visual surf observations. The data collection locations are summarized on Figure 3. Further information obtained during this study included an historical coastal engineering information search, a sand size analysis and a bathymetric survey of an area of sand bars as described below.

Visual Wave Observations

Visual wave observations were made using the low-cost Littoral Environmental Observation (LEO) format (SCHNEIDER, 1981). Breaking wave height, breaking wave angle, wave period, long-shore current speed and direction, type of breaker, width of surf zone, wind speed, and wind direction were estimated daily (or at least 3 times per week) by observers at the three locations shown on Figure 3. The same observer collected the data at two of the sites; site 1, the easternmost site; and site 3, the westernmost site. This observer stayed throughout the whole year. Thus, data at these sites were quantitatively consistent in time and in comparison with each other. The LEO site 2 had three different observers during the year.

Beach Profile Surveying

Elevations were surveyed quarterly along eight shore-normal transects (Figure 3). Each line began at an existing concrete monument that is part of Alabama's construction control line. Complete monument descriptions are given in DOUGLASS and HAUBNER (1992). The profiles were surveyed from the monument, usually in the sand dunes, across the beach to a convenient wading depth, usually over 1 m deep. Elevations were measured with a surveying level and rod. Distances were measured with a surveying tape on the dry beach and estimated by pacing in the water.

Three historical profile surveys were used for comparison with the data collected in 1990-1991. The Mobile District of the Corps of Engineers surveyed the island beaches at 65.6 m (200 ft.) intervals in October 1979 after Hurricane Frederic. These 1979 surveys were done with standard engineering land surveying techniques down to the waterline. Air photo mapping techniques were used to generate an estimate of profile elevations in February 1975. The two sets of profile data, February 1975 and October 1979, were used to quantify the erosion caused by Frederic. The 1975 and 1979 profiles do not correspond precisely with the profiles surveyed in this study. However, since the Corps' survey coverage was so dense, the profiles surveyed in this study were never more than 20 m from a 1975/1979 profile. The data were adjusted in station (horizontal distance) to correspond with the data collected in the present study and plotted as an estimate of the beach width and shape at these locations in the 1970's.

The Geological Survey of Alabama surveyed



Figure 3. Monitoring program data collection locations

three of the profile lines adopted in the present study in 1989 (SMITH and PARKER, 1990). A stadia system was used to measure distance and a horizon method to measure elevation. Elevations were surveyed at major feature locations down to the waterline.

Air Photos

Aerial photographs of the beaches were taken at the beginning and end of this study to document the shoreline changes between the eight surveyed profile lines. The photographs were taken at a low altitude for an original scale of 1:4,800. Standard, mapping-quality air photo equipment, including a camera with 24.6 cm by 24.6 cm (9 in. by 9 in.) negatives, was used. The two flights were September 24, 1990 and September 26, 1991. Quantitative measurement of the beach width changes during the year were scaled off the photos. The nominal scale of the photos, 1:4,800, was checked and assumed accurate. The slight difference in scale between the two sets of photos due to altitude was corrected. Wetline location was measured from the same arbitrary fixed points; e.g., houses, roads, or trees, on both sets of photos. Because of the limitations of results based on only two sets of photos, corrections for scale errors due to tilt and altitude using ground surveys were not performed. Shoreline change values were measured to the nearest 3 m. On the photographs this corresponds to over half of a millimeter. This precision was warranted since the photographs were sharp, original contact prints.

Sand Samples

Sand samples were obtained at the eight beach profiles for size distribution analysis. The samples were obtained in September 1991 at the top of the berm. The sand size distribution of each sample was determined by sieve analysis. Samples were dried and then sieved with a rotap machine. Retained sand was weighed with an electronic scale.

Bathymetric Survey of Sand Bars

A bathymetric survey of sand bars to the west of the north end of Sand Island was made in August 1991. The vertical elevation of the bottom was measured with a calibrated fathometer. A correction was made from mean water depth to MLLW with the aid of a land-based survey crew. Horizontal position was measured by the land-based crew by triangulation. Estimates of accu-

racy are several tenths of a meter in the vertical direction and roughly ten meters in the horizontal direction. The accuracy was sufficient for the purposes of mapping the general shape and location of the sand bars.

Historical Coastal Engineering Data Search

Several coastal engineering structures and dredged channels influence sand movement along Dauphin Island. Part of this present study included a library search to document the history of the coastal engineering projects. The historical files of the library of the Mobile District office of the Corps of Engineers were searched for unpublished design and construction information on the older projects. Unpublished dredging records were searched and summarized.

RESULTS

1990-1991 Monitoring Data

Average monthly wave height, period, and angle at breaking are shown in Figure 4. The daily observations are tabulated in DOUGLAS and HAUBNER (1992). Site 3, the only open Gulf site, clearly had much higher wave heights with longer periods. The other two sites are sheltered by the Sand Island shoals. Site 1 had smaller waves than Site 2 because it was located immediately in the lee of some offshore rubble structures and a sand bar which are discussed below. Most often, waves were approaching from east of south. This trend is fairly constant at the eastern end of the island. The trend reversed for the summer months at Site 3 where the average wave angle to the shoreline was from the west. Thus, the calmer summer months were apparently periods of wave angle reversal on the open Gulf beaches.

The surveyed beach profile data with the available historical data are plotted in Figures 5 to 12. Elevations are referenced to the NGVD.

The Sea Lab Beach profile line (Figure 5) shows significant, recent shoreline recession. From July 1989 to October 1990, the shoreline receded about 20 m. During the year of this study, October 1990 to September 1991, the shoreline receded about another 13 m. The erosion extends from the top of the bluff to the waterline. However, below the waterline, the profile shows little change. There is a flat, planar surface from the base of the bluff out 50 m from the monument.

The Coast Guard Beach profile (Figure 6) also shows significant recent shoreline recession and

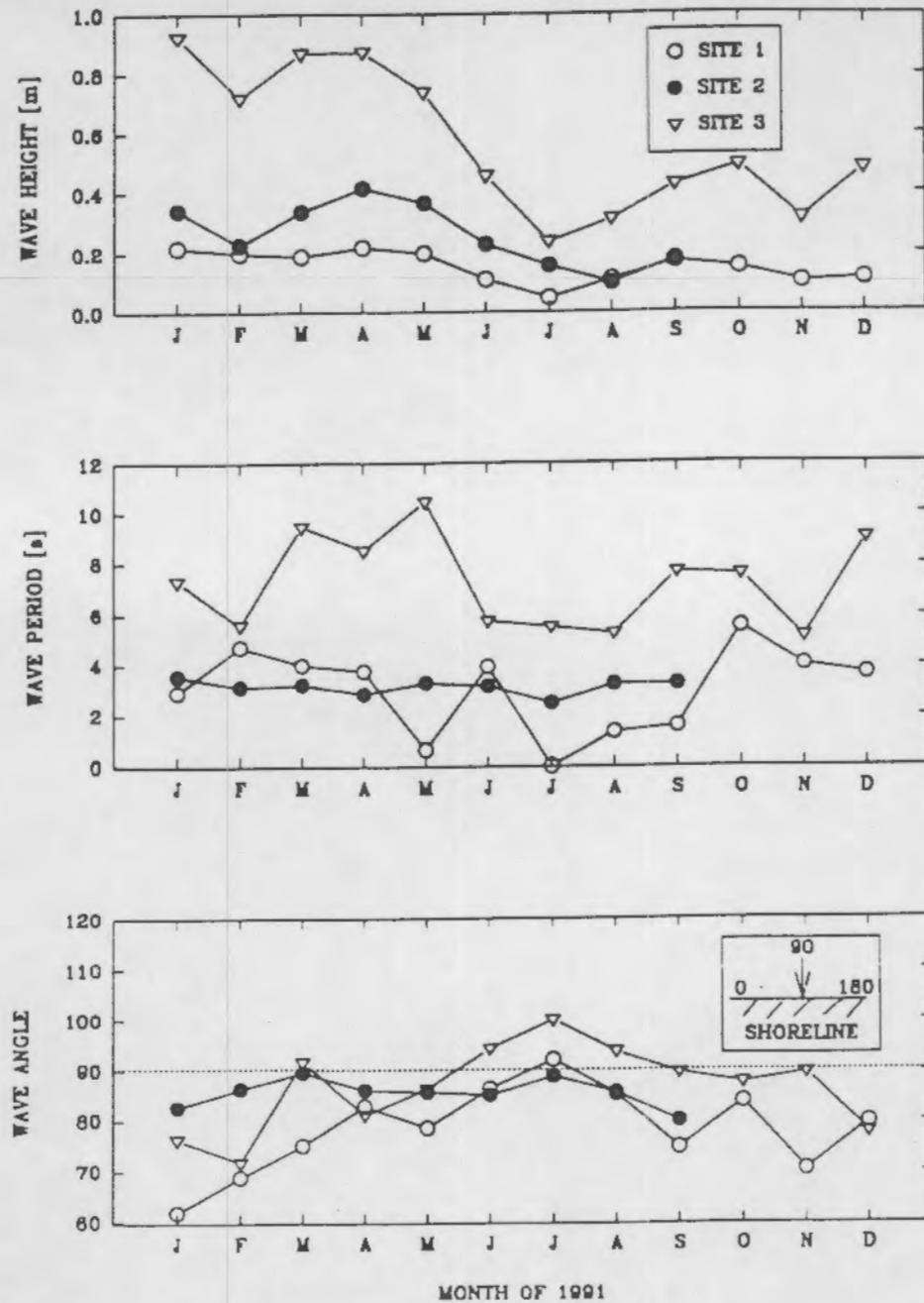


Figure 4. Average monthly wave height, period and angle from visual observations for 1991.

erosion. The bluff receded 6.3 m/yr since 1975. During the year of this study, the bluff crest receded 7 m. The bluff recession rate was not constant through this study year. The greatest bluff

recession, 3.6 m, occurred from April to June 1991. This time period coincides with several strong storms with seas from the east. Unlike the Sea Lab Beach Profile, this beach profile has experi-

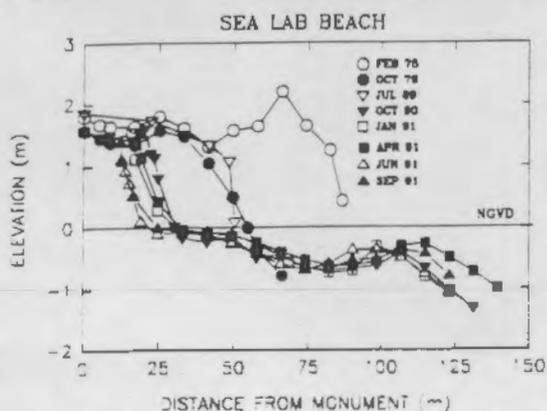


Figure 5. Sea Lab beach profiles.

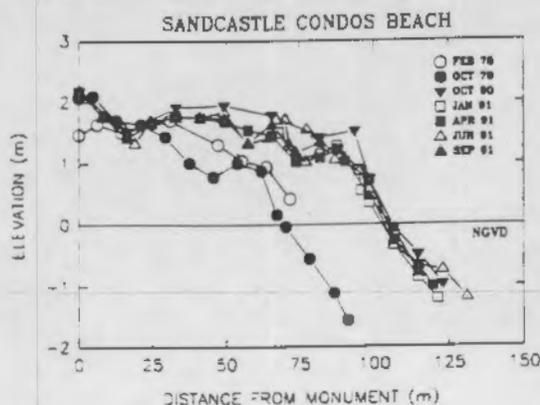


Figure 7. Sandcastle Condos beach profiles.

enced elevation losses along the entire measured profile.

The Sandcastle Condos Beach (Figure 7) has experienced substantial accretion and deposition since 1979. The shoreline has accreted over 30 m. The entire profile has gained sand with a maximum vertical deposition of 3 m. This build-up of sand has caused the formation of a low dune field at an elevation between +1 and -2 m NGVD.

The shoreline at the Park and Beach Board beach receded about 13 m during the year of this study (Figure 8). The recession rate was similar for the previous year. The entire beach profile is vertically eroding. A portion of the profile has eroded 2 m while going from dry foredunes to

submerged bottom. The erosion has exposed previously sand-covered tree stumps in the surf zone.

The Ponchatrain Street beach profile (Figure 9) shows little trend over the past decade yet the shoreline accreted 10 m during the year of this study. Most of the deposition occurred during the spring and summer from April 1991 to September 1991. A nearshore sand bar was present in June. Between June and September, the shoreline accreted while the offshore portion of the profile eroded. These changes are discussed below in terms of the onshore welding of sand bars which originated near the tip of Sand Island.

The three westernmost beach profiles, 2417 Bienville Rd., St. Denis Rd., and West End Beach,

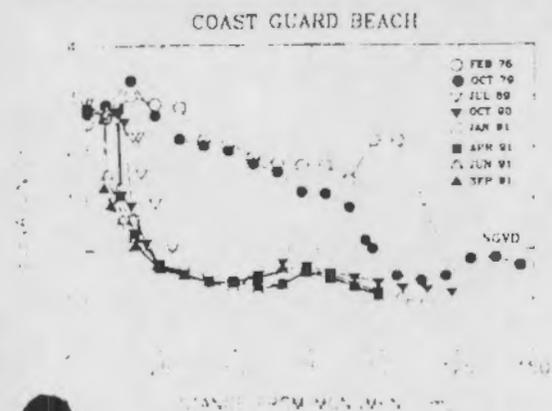


Figure 6. Coast Guard beach profiles.

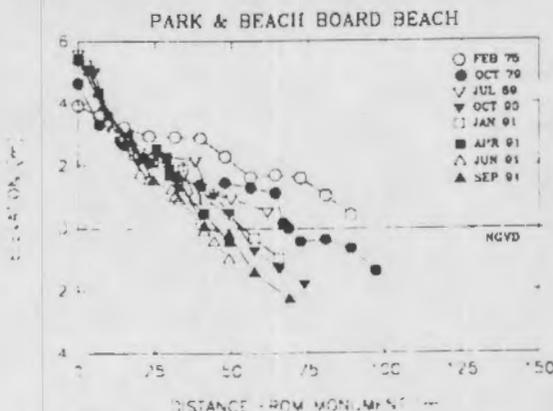


Figure 8. Park & Beach Board beach profiles.

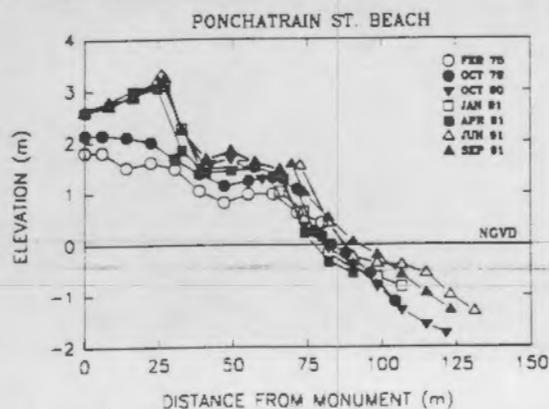


Figure 9. Ponchatrain St. beach profiles.

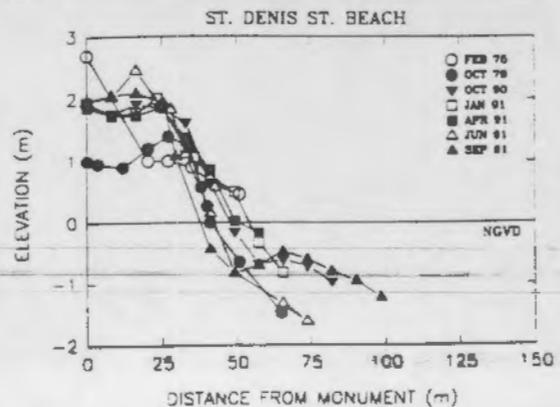


Figure 11. St. Denis St. beach profiles.

(Figures 10–12) show relatively little change over the past decade. During the year of this study, two of them show shoreline recession but sand deposition in a nearshore sand bar.

Shoreline changes during the year based on the analysis of the air photos are shown and summarized on Figure 13. For discussion purposes, a total of four reaches of beach are considered. There are alternating reaches of recession/accretion/recession along the eastern 6 km of the island.

A bathymetric survey of an offshore sand bar is shown in Figure 14. A large, distinct sand bar begins at the northwestern end of Sand Island and extends westward roughly parallel to the Dauphin Island shoreline for about 1 km where

its alignment turns northward towards Dauphin Island. Just north of the sand bar the water depth increases to almost 5 m deep. The bar has an average depth of about 3 m (relative to NGVD). At its western end, where it is probably migrating toward shore, the bar becomes as shallow as 1.5 m deep. The bar is apparently a fairly consistent feature because during the pre-trip planning for the bathymetric survey, the boat operator, who is also a local commercial fisherman, correctly sketched the location and shape of the bar from his memory.

The results of the sand size analyses are summarized in Table 1. The median diameters ranged from 0.28 mm to 0.43 mm. Using the Wentworth

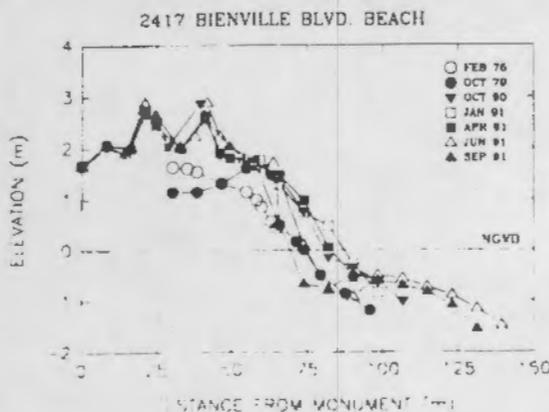


Figure 10. 2417 W Bienville Rd. beach profiles.

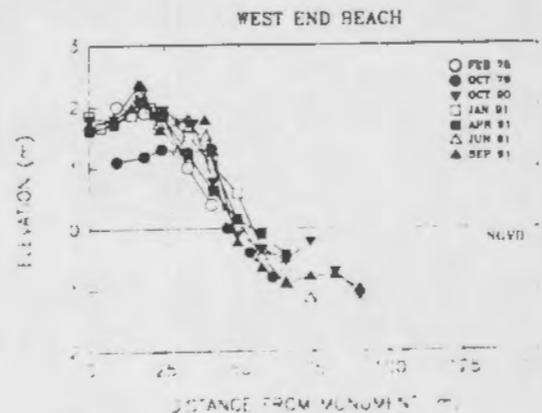


Figure 12. West End beach profiles.

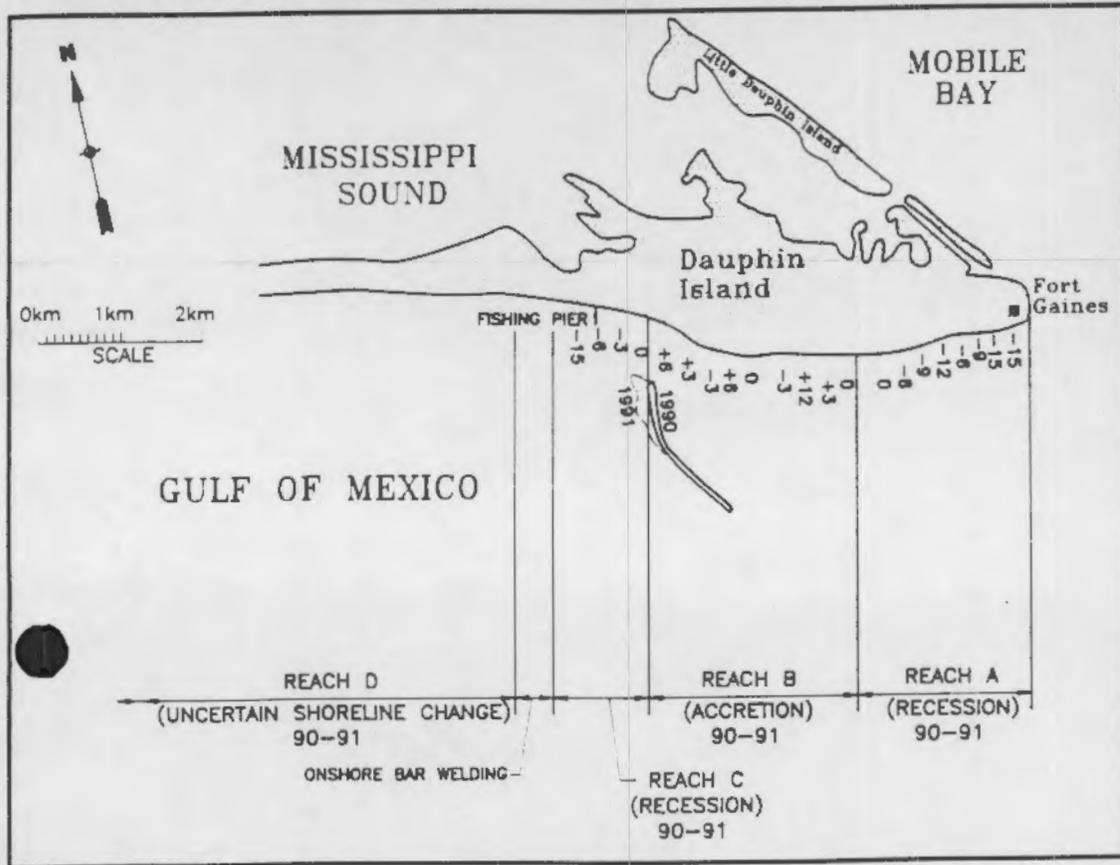


Figure 13. Dauphin Island shoreline changes from Sept. 1990 to Sept. 1991.

phi scale units, the median diameters ranged from 1.84 ϕ to 1.22 ϕ . This size of sand is classified as medium size sand according to the Wentworth Classification and as fine-to-medium size sand according to the Unified Soils Classification. Each

sample had a small range of sand sizes in the distribution. Inman's standard deviation in ϕ units is shown in Table 1. Since all values are less than 0.5, the samples are well sorted. The entire sand size distributions are plotted in Douglass and

Table 1. Sand size analysis summary

	d_{10} (mm)	d_{50} (mm)	d_{90} (mm)	F_{10}	F_{50}	F_{90}	s.d.
Sea Lab	0.28	0.34	0.21	1.84	1.56	2.25	0.35
Coast Guard	0.31	0.37	0.24	1.69	1.43	2.06	0.31
Sandcastle Condos	0.28	0.31	0.21	1.84	1.60	2.25	0.33
Park & Beach Board	0.28	0.35	0.21	1.84	1.51	2.25	0.37
Ponchatrain St.	0.44	0.44	0.26	1.56	1.18	1.94	0.38
2417 Buenville Blvd	0.43	0.55	0.32	1.22	0.86	1.64	0.39
St. ... St.	0.35	0.47	0.26	1.51	1.09	1.34	0.43
W ... rd	0.47	0.46	0.28	1.43	1.12	1.84	0.36
Eastern Average	0.29	0.35	0.22	1.80	1.53	2.20	0.34
Western Average	0.37	0.48	0.28	1.43	1.06	1.84	0.39

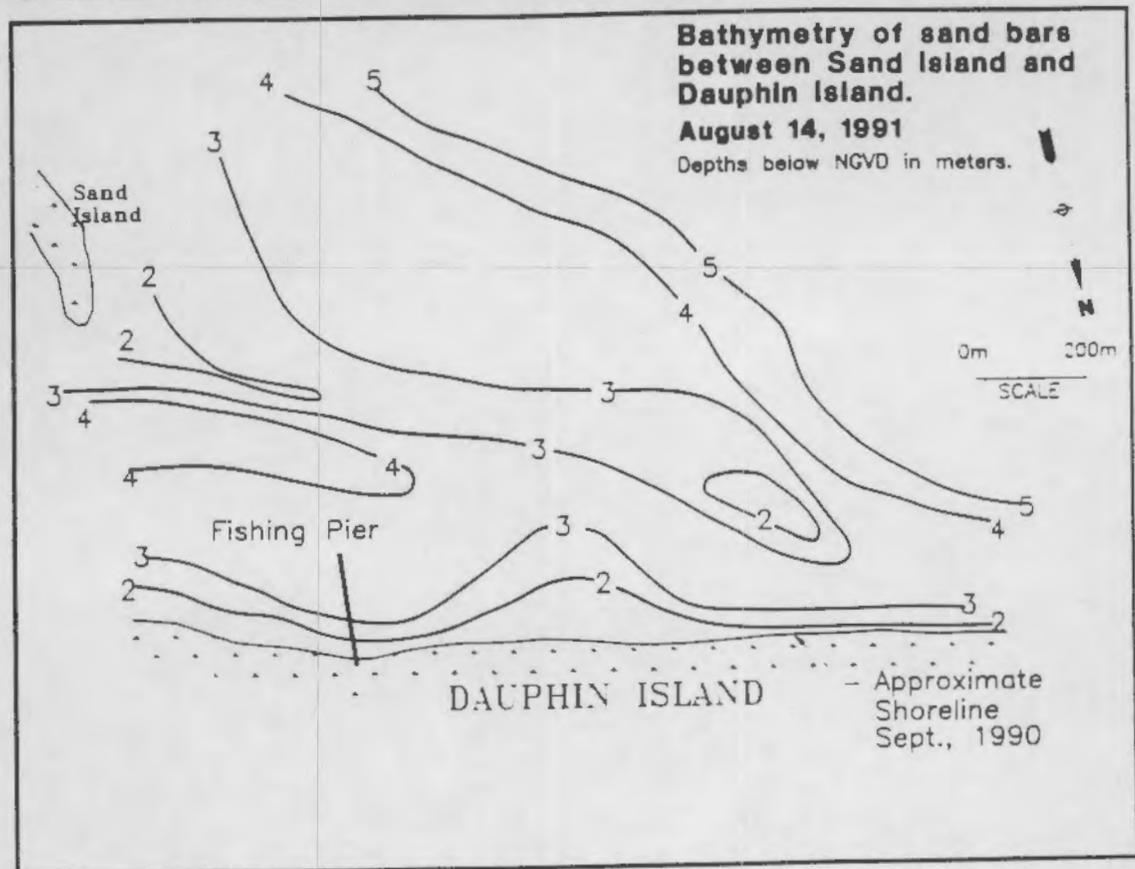


Figure 14. Bathymetry of sand bars between Sand Island and Dauphin Island (Aug. 14, 1991).

HACHNER (1992). There are two different populations of sand on the Dauphin Island beachface. The median diameter is smaller at the eastern end of the island, 0.29 mm, than at the western end, 0.37 mm. One of the western samples, 2417 Bienville Rd., had a much larger sand size than the other three. This may be an isolated pocket of larger sand. A more comprehensive sampling regime in the longshore and cross-shore directions would be required to identify more trends in sand size distribution along the beaches.

Coastal Engineering History

Coastal engineering of the beaches and waterways of Dauphin Island probably began over three centuries ago. However, coastal processes are presently being affected by engineering projects completed within the last century. These coastal engineering projects (Figure 15) include rubble-

mound coastal structures around the east end of the island; a 1980 beachfill project which affected shoreline position at the east end during the 1980's; dredging of Dauphin Island's waterway system; and dredging of the Mobile Ship Channel.

Coastal Structures

The coastal structures on Dauphin Island are concentrated at the eastern end of the island. Diggins and seawall at the eastern tip of the island were built around the turn of the century to protect Fort Gaines from erosion. An 1894 map of shoreline positions (not shown) shows that the shoreline east of the fort had progressively receded about 70 m during the previous forty years. An old concrete wharf was located about 100 m north-east of the fort. This location is now over 50 m from shore and under about 4 m of water. A groin field was built in 1894, rebuilt with a seawall in



Figure 17. Coastal engineering around Dauphin Island.

1897 and rebuilt again in 1908. The seawall was extended to the southwest and another groin field was added to the southwest in 1909. No records were located concerning any subsequent repair and maintenance of these coastal structures. Figure 16 is an oblique photograph of the eastern end of the island showing the coastal structures. Note that the 1909 groins were flanked in 1991; i.e., the shoreline had receded past the landward end of the rocks and the rocks were completely surrounded by water.

1980 Beachfill

Hurricane Frederic caused shoaling in the Fort Gaines Channel. In February 1980, 140,000 m³ of sand were dredged from the channel and placed on a beach east of the fort. Although this beachfill was not monitored, available air photos (not shown) show the disappearance of the fill during

the next few years. Much of the sand moved around to the southwest over the next several years and filled the 1909 groin field. However, this sand left the groin field in the next few years. In September 1984, the two westernmost groins were flanked. In September 1985, three of the groins were flanked. By October 1986, eight of the 1909 groins were flanked.

1991 Beachfill

A 2,000 m³ beachfill was placed on the beach around the fishing pier in June 1991. The beachfill was monitored as part of this study with profiles, sand samples, and oblique photographs. The fill material was taken from Mississippi Sound on the north side of Dauphin Island as part of a natural gas well development project. It was donated at no cost to the Park and Beach Board, the local beach authority responsible for the beaches around

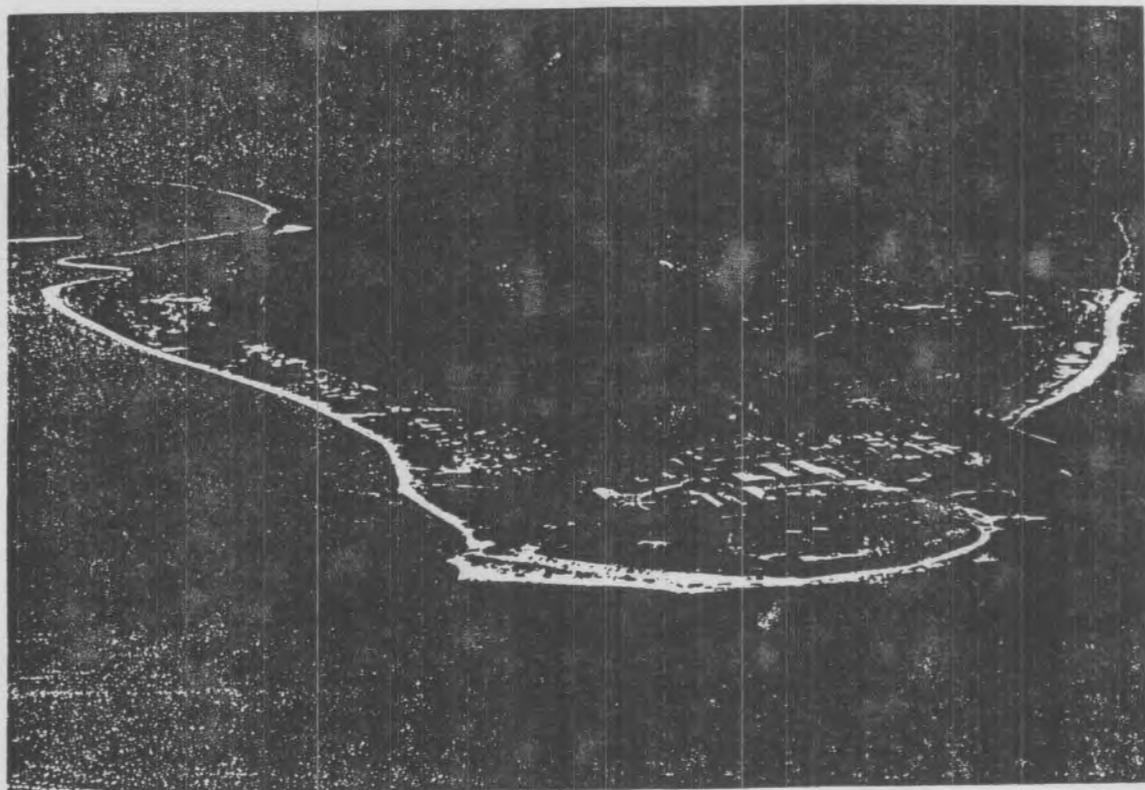


Figure 16. East end of Dauphin Island, Alabama looking west—August 1992).

the fishing pier. The fill material was mechanically placed above the waterline to replicate a dune which had eroded within the past year.

The fill material had a median diameter of 0.38 mm, slightly coarser than the native beach material. The fill had 8% silts and 5% shells by weight. The color of the fill was initially much darker than the native material. Within two months after placement, however, the visible top layer of the fill had bleached to nearly the shade of the native sand. For the first few weeks after the fill, it was very difficult for people to walk on the fill because the bearing capacity of the saturated material could not support a human. The shells present in the fill armored the top surface of the fill within a few weeks of the completion of the fill. Apparently, the upper layer of the fill was changed by heavy rainfall which washed away the silt and sand, leaving a lag of shells on the surface. It was very difficult to walk on the fill without shoes or sit on the fill after this shell

lagging occurred. In summary, people could not use the fill for the first few weeks because it was too soft and could not use it after that because of the oyster shells. The fill progressively eroded from the Gulf side in the form of bluff erosion as high waters allowed waves to reach the toe of the bluff. The fill was almost completely washed away within nine months after construction. This very small beachfill had no significant effect on the overall coastal processes of the island but did provide some level of protection to the threatened structures for several months.

Dauphin Island's Waterways

In the late 1950's, a waterway system was constructed around the eastern end of the island. Fort Gaines Channel (Figure 15) was dredged through the northeastern shore of Dauphin Island. Prior to the dredging of this channel, the shoreline of Dauphin Island was continuous from the port to the northeast about 2 km to Pass Drury. An 000-

km² anchorage basin, Bill Goat Hole, was dredged behind the new channel. Fort Gaines Channel and Billy Goat Hole were dredged 2.3 m (7 ft.) deep. Government Cut channel was dredged in the estuary behind the barrier beach to connect Billy Goat Hole with Dauphin Island Bay. Dredged material was used to build a sand dune on the barrier beach immediately to the northeast of the channel. Pass Drury, the natural pass from Dauphin Island Bay to Mobile Bay, was closed off with dredged material. Fort Gaines Channel was stabilized with a rubble-mound jetty on the north side and a rubble-mound revetment on the south side against Dauphin Island during construction around 1959.

These channels and basins have been dredged eleven times since 1964 with about 450,000 m³ of material being removed. The majority of this material was placed on the beaches of the barrier island immediately to the northeast of Government Cut. This barrier island was naturally part of Dauphin Island and is presently (since Pass Drury is closed) part of Little Dauphin Island. Pass Drury reopened in its historical location in 1961 during Hurricane Frederic as the storm surge in Dauphin Island Bay forced its way back out through the artificially closed inlet into Mobile Bay. Dredged material has been placed back in Pass Drury to close it off again.

Mobile Ship Channel

The southern end of the Mobile Ship Channel crosses the ebb-tidal delta system of Mobile Pass. The channel has been maintained at progressively deeper depths since at least 1910. Navigation charts from around the turn of the century clearly show a navigation channel. The channel depths have increased from 8.8 m (27 ft.) in 1910, to 11.8 m (36 ft.) in 1936, to 13.8 m (42 ft.) in 1974 and 16.1 m (49 ft.) in 1989. The width of the channel is presently 183 m (600 ft.) in the southern section across the ebb-tidal shoal bar.

Table 2 is a summary of dredging records for the outer bar area of the ebb-tidal shoal of Mobile Pass since 1974. The volumes are from the channel south of the throat of the Pass between Ft. Morgan Peninsula and Dauphin Island. Dredging records prior to 1974 were not available. Almost 12,000,000 m³ of sediment were removed from the Pass between 1974 and 1989. Thus, the average removal has been about 750,000 m³ yr during this period. The large volume shown as being

Table 2. Dredging of Mobile Pass.

Year	Volume (m ³)
1974	270,000
1975	750,000
1976	1,040,000
1977	970,000
1979	540,000
1980	150,000
1981	470,000
1983	240,000
1984	430,000
1985	1,060,000
1987	500,000
1989	5,170,000

dredged in 1989 was for the deepening of the Ship Channel to 16.1 m (49 ft.). Excluding this volume from the calculation still gives an annual rate of removal of over 450,000 m³. Almost all of this sediment has been removed from the littoral system of coastal Alabama to deepwater disposal sites. The sediments dredged in 1987 were fine sands with a significant proportion of finer material, silts or clays (HANDS and BRADLEY, 1990). In the dredge hoppers, sediments had a median diameter of 0.17 mm with 10% fines and a sorting standard deviation of 0.57 Φ . Immediately after disposal, the bottom sediments had a median diameter of 0.22 mm with no fines and a sorting standard deviation of 0.44. Sediment sizes from the other dredging episodes are not known.

In 1987, 350,000 m³ of sand dredged from the Mobile Ship Channel were placed on the edge of the ebb-tidal delta south of the Sand Island shoals (Figure 15) as a continuous underwater mound or berm roughly 2 m high and over 1.5 km long (HANDS and BRADLEY, 1990). By 1988, the berm's upper surface had been planed off by wave activity. By 1990, a portion of the berm had migrated northward about 100 m (HANDS, 1991).

DISCUSSION

Mobile Pass is one of the largest tidal inlets in the country and influences the beaches of Dauphin Island several ways. Mobile Pass is a tidally dominated inlet (HUNYAN *et al.*, 1979) in a microtidal environment (DUNCAN, 1965). The pass has one of the largest tidal prisms, 10¹² m³, and one of the largest cross-sectional inlet areas in the country (DUNCAN, 1976). It has the largest volume of sand stored in its ebb-tidal delta in the country (WATSON and ADAMS, 1976). The freshwater in-

flow into the upper end of the bay, the fourth largest freshwater drainage volume in the nation, contributes to the ebb dominance of the inlet. Since Mobile Pass fits into the empirical relationships of JARRETT (1976) and WALTON and ADAMS (1976), albeit as an extreme point, the pass's geometry is apparently controlled by the same general tidal inlet processes found elsewhere. The ebb-tidal delta system includes all of the shoals around the Pass and can be roughly defined by the 10 m depth contour on Figure 15. It includes the shoals on the eastern side of the Mobile ship channel, Dixie Bar Shoals. At previous times, Dixie Bar Shoal also was emergent. The lighthouse was built on a large island, part of the Sand Island complex, which has since eroded completely away. These shoals have been formed over the centuries by the tidal currents through Mobile Pass and the longshore transport of sand along the Alabama coast. Sand Island is part of these shoals. Apparently, because there is so much sand in the ebb-tidal delta system, portions of the outer edge of the delta emerge from the water long enough for Sand Island to form. Another factor, in addition to the large volume of sand present, which may be contributing to this rather unique phenomenon of commonly emergent distal shoals at Mobile Pass, is the relatively mild wave climate. The only other inlets in the country which have a similar size tidal prism and shoal volume are the Columbia River entrance and the Golden Gate entrance to San Francisco Bay. Both of these inlets are exposed to a much more energetic wave climate.

The ebb-tidal shoals provide both sand for the Dauphin Island beaches and wave sheltering to those beaches. Mobile Pass appears to bypass sand as an extreme and modified form of FITZGERALD'S (1988) stable inlet processes model whereby sand is moved onshore on the downdrift side of an inlet with a relatively stable inlet throat position. Mobile Pass has been modified by the maintenance dredging of the throat. It is extreme because there is so much sand in the ebb-tidal delta that the swash bars which form in the distal end of the ebb channel (near the lighthouse) emerge from the water and form Sand Island. Wave induced sand transport along the periphery of the ebb-tidal delta (BOYD and GARDNER, 1959) is probably the dominant process moving sand toward Dauphin Island. As discussed below, there is some evidence that episodic breaching of Sand Island and the relocation of Pelican Pass has occurred and may occur again in the next few decades.

Sand Transport Paths

Sand Island has a dramatic influence on the wave climate on the eastern 6 km of Dauphin Island. This end of the island is sheltered from the larger open Gulf waves. The sheltering affects the wave height, period and angle (Figure 4). The two populations of median sand size (Table 1) are probably due to the sheltering effect of the Sand Island shoal complex. The four easternmost sites with the smaller grain sizes have experienced a much milder wave climate due to the presence of the shoals. On the more energetic beaches to the west, the finer grain material probably gets winnowed out of the beach sands.

Longshore sand transport rates were estimated from the visually observed breaker height and angle using the empirical relationship of the U.S. ARMY (1984). The longshore component of wave energy flux was calculated for each individual wave observation and the resulting transport rate estimated. The average annual net sand transport rates and directions are shown on Figure 17. At all three sites, net sand transport for the year was to the west. The estimated rates are 20,000; 30,000; and 200,000 m³/yr to the west at Sites 1, 2, and 3, respectively. At Site 3, the rate of westerly net transport of sand was an order of magnitude greater than at the other two sites. The actual numerical longshore sand transport rate estimates should not be considered very precise because of the inherent imprecision in the methodology. However, Figure 17 probably represents the qualitative and relative sand transport along Dauphin Island for the year.

There was proportionally less eastward, or reversal, transport at the sites in the lee of the Sand Island shoals. The ratio of net transport to gross transport was about 95% at Site 1 and 60% at Site 3. For example at Site 3, eastward transport was about 60,000 m³/yr, westward transport was 260,000 m³/yr and thus, gross transport, westward plus eastward, was about 320,000 m³/yr.

The eastern end of Dauphin Island is actually inside the Mobile Pass inlet and the beaches are bypassed by direct updrift littoral drift and affected by backpassing or reversal toward the inlet. Along the eastern beaches, sand moves west when Gulf waves are coming from the east across the Dixie Bar area of the ebb-tidal shoals. But when the waves come from the west, these beaches are more completely sheltered by Sand Island. Therefore, with the present configuration of Sand Is-

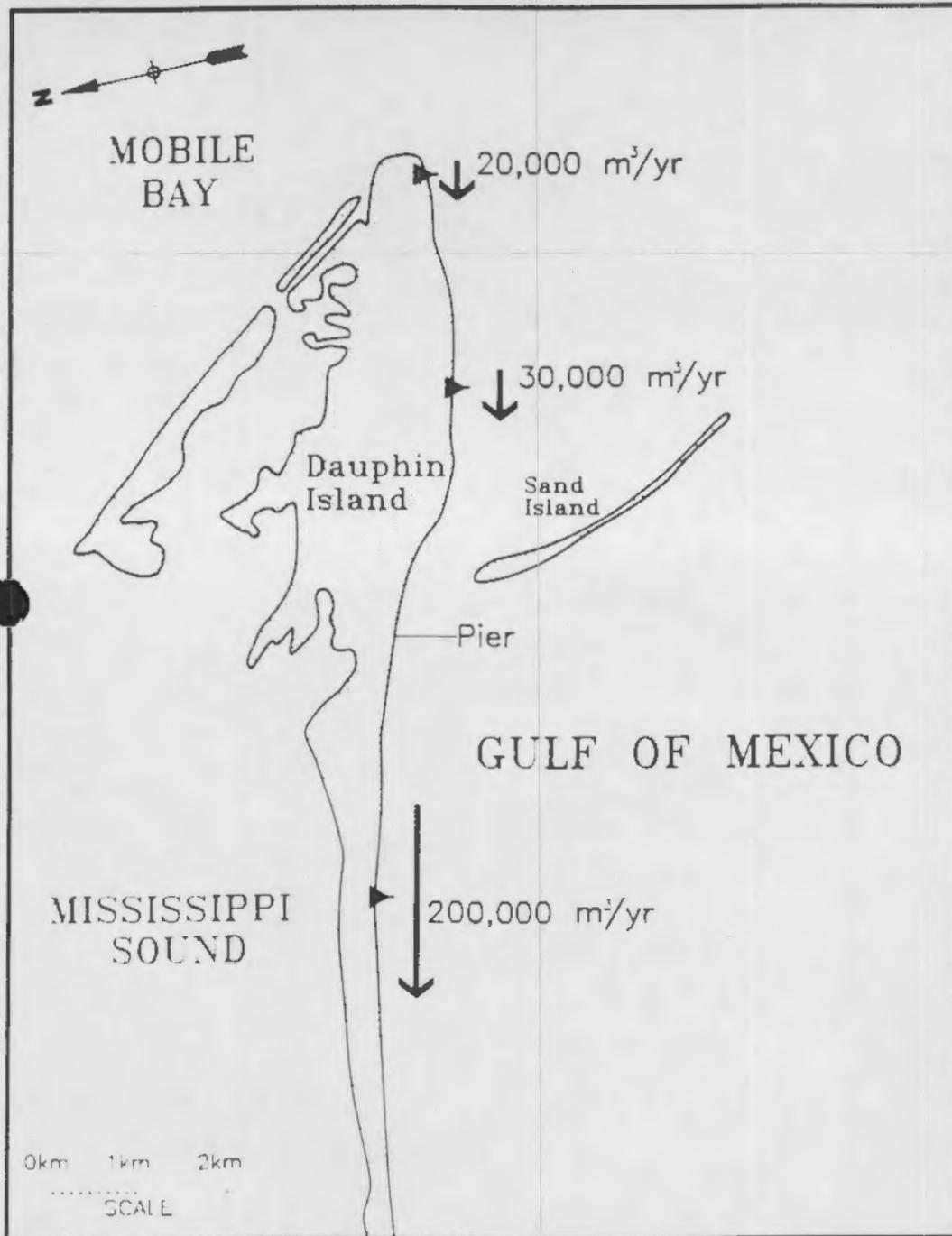


Figure 17. Longshore sand transport estimates from video wave data (1991).



Figure 18. Summary of sand transport paths in the vicinity of Dauphin Island.

land, significant amounts of sand can only move one-way, westward, along the eastern beaches. Changes in the ebb-shoals have probably contributed to the recession and accretion pattern at the east end of the island. Sand has moved from the eastern eroding end to the accreting reach as discussed below. The probable sand transport paths are summarized schematically on Figure 18.

Beach Changes

The beach changes, including both erosion and deposition, presently occurring on Dauphin Island can be explained by the sand transport paths related to the dynamics of Mobile Pass. The following discussion refers to shoreline reaches indicated on Figure 18.

Reach A: Shoreline Recession at East End

During the year of this study, the easternmost 2 km of the island, Reach A, experienced shoreline recession of an average of 10 m with maximums of about 15 m. Two surveyed profiles, Sea Lab Beach and Coast Guard Beach, fall within this reach (Figures 5 and 6).

The alignment of the Sea Lab Beach profile line passed midway between the third and fourth westernmost groins. The probable explanation for the absence of vertical erosion farther out on the profile is the presence of the groin field. The flanked groin field still traps some sand immediately between the piles of rock in a sand bar. The sand bar and the rocks are providing wave sheltering to the beaches. At the Coast Guard Beach profile, which is about 200 m west of the flanked groin field, the vertical erosion extended out across the entire measured profile.

The erosion along Reach A is due to littoral sand starvation. The probable cause of this starvation is a change in relative longshore sand transport rates due to changes in wave climate caused by the northwestward migration of Sand Island and the loss of elevation of the Dixie Bu Shoals during the past few decades. The different sand-feeding has probably increased the westward sand transport along this reach while decreasing the eastward transport along Reach A.

Reach B: Shoreline Accretion

Reach B (Figure 1) extends over a stretch of about 1.5 km roughly 100 m east of the historic pier. Within Reach B the general trend is the shoreline

accretion. Two accretionary geomorphologic features, bulges in the shoreline platform, dominate the reach. They are shown in an oblique photograph in Figure 19 (also on Figures 2 and 16). The accreting Sandcastle Condos Beach profile (Figure 7) is on the eastern bulge. Inspection of available historical air photos shows that the bulges have been gaining sand and widening for the past decade. The bulges are geomorphological evidence of the recent dominance of westward transport over eastward transport on these beaches. Both bulges migrated westward during the year of this study. The eastern bulge grew about 25 m to the west. In this growth area, the beaches gained 70 m of width as measured along the north-south line. The tip of the western bulge also grew about 25 m to the west. The sand that formed the growth of each bulge has apparently come from the beaches immediately to the east of each bulge. The sand eroded from Reach A, including the Coast Guard Beach area, has moved to the eastern bulge.

The bulges appear to be instabilities in the shoreline in the sense that they have continued to grow during the past decade. Such bulges are not common on open ocean coasts where wave driven littoral drift tends to diffuse or smooth the coastline. They are probably due to the sheltering of the wave climate by Sand Island.

Immediately to the west of each of the two bulges there are short stretches of shoreline recession. These areas are apparently being starved by the growth of the bulges immediately to their east. Within the overall coastal processes picture, these recession areas are minor ramifications of the two bulges. However, the recession area between the two bulges is not so minor to the managers of the local golf course because it threatens one tee. Some form of shore protection structure has been used for at least the past decade to protect the tee. Remnant pilings and cross bracing are visible. During the year of these photographs, an improved bulkhead or seawall was constructed on the beach. Although the previous shore protection structures have failed, they have provided some limited sand protection.

The western end of reach B has experienced shoreline accretion along about 100 m of shoreline. The sand in this accretionary stretch probably has two sources, the beaches to its immediate east and west. This stretch of beach is being sheltered by the northern end of Sand Island about 100 m away with the accretion of 100 m to the west



Figure 10. Accretionary shoreline bays (looking east) August 1992.

transport from another set of daily wave observations at the fishing pier during the summer of 1991 indicated significantly less westerly transport and a greater net easterly transport than was

found at any of the other wave observation sites discussed above. Waves from the west probably transport sand along the beach face into this area from the beaches around the fishing pier.

Reach C: Shoreline Recession Near Fishing Pier

Reach C (Figure 13) is the 1 km recessionary shoreline around the fishing pier. The shoreline recession during the year varied from 3 m on the east side of the pier to almost 17 m. The Park and Beach Board Beach profile (Figure 8), which has eroded up to 2 m vertically, is 228 m west of the fishing pier. This erosion is probably being caused by the northerly migration of Sand Island. The marginal tidal channel, Pelican Passage, is being diverted farther north into Dauphin Island than at any time in the past century. In 1850, Sand Island was as far north but at a location about 1 km east of its present location (U.S. ARMY ENGINEER DISTRICT, MOBILE, 1978). The westerly migration of Sand Island may have been due to a westerly migration of this portion of the ebb-tidal delta. The beach around the fishing pier will probably continue to experience high rates of recession and erosion for the next few years. The erosion will probably continue until the position of Sand Island and Pelican Passage changes dramatically. The most likely scenario for the change is a relocation of Pelican Passage through a new, more southerly, breach in Sand Island. There is no clear evidence that such a breach occurred in the 1850's or 1860's, but it is probable. If this breach and relocation of Pelican Passage occurs, a very large volume of sand presently in Sand Island will be driven onto the beaches of Dauphin Island in the vicinity of the fishing pier.

Welding of Sand Bars from Sand Island onto Dauphin Island

There is evidence that sand is presently moving to the beaches of Dauphin Island from Sand Island via an underwater shoal system to the west of Reach C. As sand is driven by waves into Pelican Passage from Sand Island, the daily ebb-tidal currents move the sand westward. As the tidal currents outflow into the Gulf, the sand forms into bars which are driven onto Dauphin Island by waves. This scenario is supported by two pieces of evidence: the presence of the sand bar (Figure 14) and indications of onshore bar welding seen in the Poinsettiam Street beach profile located in this area (Figure 9). Some of the sand driven by waves from Sand Island into Pelican Passage is probably moved eastward during flood tidal currents. Local fishermen report the existence of a sand bar east of the northern tip of Sand Island.

Reach D: Uncertain/Stable Shoreline

The shoreline change trends for the western portion of the inhabited island, Reach D (Figure 13), are generally stable. The surveyed profiles show stability over the past decade. The profile changes seen during the year of this study are explained by changes in the beach bar system. Offshore bars clearly visible on the 1991 photos (not shown) are not visible on the 1990 photos. The bars are attached to the beach every 30 m to 200 m and the result is a rhythmic topography of the nearshore. This rhythmic topography is probably due to a large storm that hit the Alabama coast several weeks before the September 16, 1991, flight. The beach may have never fully recovered from the severe winter and spring storms of earlier in 1991. The rhythmic topography resulted in shoreline change data that depended on the specific location. For those locations behind a bar, there was an apparent loss of up to 12 m of dry beach width between the two flights. However, for those locations on the horn or mini-headland where the bar was welding onto shore, there was no apparent shoreline change during the year. Inspection of the air photos and surveyor notes shows that two of the three profiles located along Reach D were in the cusp of a rhythmic bar formation and the third, West End Beach, was on a horn.

Coastal Engineering

Coastal Structures

Considering the functional purpose of the coastal structures designed and built in 1908, they have been a success. Fort Gaines has been protected from shoreline recession. Without this protection, it is highly probable that the shoreline of the eastern end of Dauphin Island would have continued to migrate westward through the fort and the property to its west. The 1909 groin field to the south of the fort has not been a functional success to date. It has not maintained the shoreline in its 1909 location. The groin field was flanked during Hurricane Frederic and by more gradual recession in the 1980's. At present, eight of the nine groins are flanked.

From a structural standpoint, the engineering design of the seawall and groins can be considered a success. The structures have survived with relatively little or no maintenance for the past eighty years. These eighty years included several major hurricanes. At the present time, however, the seawall is showing signs of structural failure. The fill

material behind the rocks has been pulled out by wave action. Backfill has been needed in recent years to protect the road behind the seawall.

Waterway System

Fort Gaines Channel and the jetties and revetment on both sides have separated the northwest corner of Dauphin Island into two littoral systems. Previously, sand was free to move back and forth across this area. The sand being removed from the channel comes off the adjacent beaches. Probably most of the sand comes from Dauphin Island. By continually moving the dredged sand to the northwest onto the new Little Dauphin Island, the channel maintenance dredging operations have essentially functioned as a one-way valve draining sand from Dauphin Island but not returning any.

Mobile Ship Channel

Dredging of the Mobile Ship Channel is the largest coastal engineering feat in the vicinity of Dauphin Island. The dredging has probably impacted the beaches of Dauphin Island several ways. Almost all of the sediment dredged from the outer bar has been permanently removed from the littoral system of the Alabama coast. The littoral system of Dauphin Island and Sand Island has probably not received any littoral drift from east of Mobile Pass in fifty years. Also, the wave climate on Dauphin Island and the hydraulics of the tidal currents through Mobile Pass have probably been changed by the dredging and the effects of the dredging on the Sand Island shoals.

The magnitude of the sediment removal since 1974 can be envisioned two ways. This volume, roughly 12,000,000 m³, could build a 300 m wide beach along the inhabited portion of Dauphin Island. Also, 12,000,000 m³ is roughly 100 times the above-sea-level volume of Sand Island. 12,000,000 m³ represents about 1/2% of the total volume of sediment in the ebb-tidal shoals. WALTON and ADAMS (1976) estimated the total volume of the shoals at the mouth of Mobile Bay to be 900,000,000 m³. In terms of the total volume removed this century, perhaps 40,000,000 m³, the volume of removal is roughly 5%.

A second way to envision the magnitude of the sediment removal since 1974 is in terms of the natural littoral drift rate along this coastline. A rough estimate of the gross transport rate along this coast is 100,000 to 300,000 m³/yr of sand

(WALTON 1976; U.S. ARMY ENGINEER DISTRICT, MOBILE, 1955). The average net transport rate, westward transport minus eastward transport, is probably on the order of 100,000 m³/yr to the west. Thus, the dredging is removing sediment at a much greater rate than the net littoral drift rate along this coast.

In essence, because of the dredging practices, Mobile Pass has probably functioned as a sink for sand moving along the coast this century. Assuming that all of the sediment dredged from the outer bar came from the littoral system, the "efficiency" of the sink has been much greater than 100% relative to the flowrate of sand along the coast. The dredging rates on the ebb-tidal delta could be higher than the littoral drift rates for several reasons. Sand which enters the channel from both sides, east or west, gets dredged and removed to deep water. Thus, the dredge operations should be expected to remove at least the gross littoral drift rate. Also, the long, linear shoals on the edges of the channel allow sand to be driven into the channel along several miles. In particular, Dixie Bar Shoals parallel the eastern side of the channel for about 4 km. During periods of waves from the east, sand is probably driven into this entire length of channel. Thus, the dredging to maintain navigation depths should be expected to remove more than the gross transport rate along the Alabama beaches. The dredged volumes (Table 2) indicate that this is happening. Based on the historic dredging rates and assuming that the deeper, longer channel will require more maintenance, future dredging can be expected to exceed an average of 500,000 m³/yr. Most of the material dredged from the channel probably comes from the littoral system. Some fraction of the material is fines from Mobile Bay and its river system that settle in the channel. The maintenance dredging in 1987 included 10% fines but was mostly sand with a smaller median diameter and a wider gradation than the Dauphin Island beach sands. With the fines and fine sands removed, the dredged material has size characteristics similar to the beach sands.

Dredging of the outer bar of Mobile Pass has also probably indirectly affected the beaches of Dauphin Island by changing the wave climate. The erosion along the eastern 2 km of Dauphin Island, Reach A, may be a response to increased southeasterly wave exposure caused by the lowering of the shoals around the lighthouse area. Long term sediment starvation due to the dredg-

ing removals could be expected to effect this area first.

The tidal hydraulics of Mobile Pass have also been affected by the presence of the Ship Channel. The Main Pass is more efficient at allowing water to move out and in Mobile Bay because of the ship channel. Natural maximum depths across the outer bar of Mobile Pass are about 6 to 7 m. Dredging of the ship channel forces these depths to around 16 m. A comprehensive study that conclusively correlates the changes in the shoals and the erosional-depositional patterns on Dauphin Island with the dredging history and storm and wave climate record was beyond the scope of this study. However, such a study is warranted to fully determine the environmental impacts of the dredging.

Management Suggestions

Suggestions for the management of Dauphin Island's beaches based on the findings of this study were made. The philosophy underlying these suggestions is that management and development decisions should be made either:

- 1) to work with the coastal processes, or
- 2) with an understanding of the costs of working against the coastal processes.

Successful management strategies are not based on technical information alone. They are based on value judgements made by the policy-makers and the decision-makers. The technical information provided by this study is only one input to the decision-making process. Thus, the technical input can be used to come to different management conclusions. The following management strategies are based on a blend of the technical input and author's perceptions of what is most important to Dauphin Island at this time.

Suggestions were made to fully determine the environmental impacts of historic and future dredging on the littoral system including the beaches of Dauphin Island. The ultimate goal should be to understand the changes in the shoals and man's impacts on the shoals and beaches. One obvious management alternative is to replace the natural sand bypassing interrupted by the dredging by placing all dredged sands in the littoral system. The 1987 sand berm construction showed that this was technically feasible for the Mobile Ship Channel. It may also be instituted for environmental and economic impact reasons. Suggestions were made to reevaluate the location of some

public recreation facilities (including bathhouses and swimming beaches) on Dauphin Island based on erosion and site suitability considerations. Suggestions were made concerning the future maintenance of coastal engineering projects around the east end to protect Fort Gaines and to minimize the erosion problems. Essentially, most of the suggestions were focused towards treating the littoral sand as a valuable resource.

CONCLUSIONS

Some of the Gulf of Mexico beaches along the eastern 6 km of Dauphin Island are eroding and some are gaining sand. Two reaches of shoreline are receding and the reach of shoreline in between them is accreting. This pattern has been developing over the past decade. Maximum rates of shoreline recession approached 15 m/yr when averaged over a single year and 6 m/yr when averaged over the past decade. The fluctuations in shoreline position on the eastern end of Dauphin Island are controlled by the presence of Mobile Pass, one of the largest tidal inlets in the country, and its ebb-tidal shoals. The shoals, including the portions which are ephemerally emergent islands, are a source of sand for the Dauphin Island beaches and also provide wave sheltering to those beaches. The remainder of Dauphin Island's beach shorelines, to the west of the ebb-tidal delta, move from year-to-year but have been relatively stable over the past decade.

The shoreline changes on the eastern end of Dauphin Island have been effected by coastal engineering activities. Without man's intervention over the past century, including seawalls, groins, beachfills and dredging, the shoreline position today would be different. Future decisions about coastal engineering and management alternatives will be made with an improved understanding of the coastal processes of the island.

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