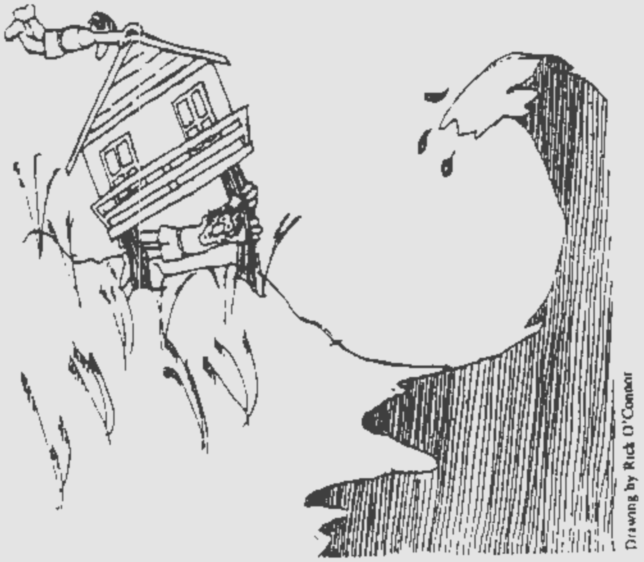
Proceedings from the 1st Annual Coastal Issues Symposium
Topic: Beach Erosion



February 20, 1998

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Keynote Speaker

Orrin Pilkey has published more than 150 technical publications. He is co-editor and sometimes coauthor of the ongoing twenty-one volume, state specific *Living with the Shore* series published by the Duke Press, as well as two 1996 volumes: *The Corps and the Shore* (Island Press) and *Living by the Rules of the Sea* (Duke Press).

Currently he focuses on beach replenishment, the impact of seawalls on beaches, evaluation of the validity of mathematical models of beach behavior, hazard risk mapping on barrier islands, sedimentary processes on shorefaces, mitigation of hurricane property damage on barrier islands, and principles of barrier island evolution in Columbia, South America.

Purpose

The purpose of this symposium was to promote awareness of erosion, find possible causes and discuss solutions.

Alabama's, especially Dauphin Island's, shores are eroding at an alarming rate. Is it due to natural causes or is it brought on by the development of our coastline? Where are our beaches going? Can erosion be stopped? What is the most sensible solution?

In an effort to educate our citizens and leaders about the problems faced with living on a barrier island, we brought together geologists, meteorologists, erosion experts and State and Federal policy enforcement leaders.

The Influence of Atmospheric Conditions on Alabama Beach Erosion

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In general, beaches are migrating (eroding) as sea level slowly rises (Canis et al., 1985). Yet, this migration is not uniform; some beaches may retreat while others may expand. Beach migration is not a steady process over time. Some beaches may erode, then rebuild, then erode further. Others may erode slowly, then more swiftly.

Many factors influence beach erosion: 1) coastal subsidence of the land, 2) changes in beach sand supply, 3) the shape of the beach, 4) the size of the waves. According to Canis et al., 1985, the natural laws of the beach dictate that beaches build when the weather is good; beaches erode when confronted by a big storm.

A study by Douglas and Sanchez (1996) shows that Alabama's Gulf beaches have waxed and waned over the last 25 - 30 years. Their study measured the beach width on 11 separate occasions between 1970 and 1995 at numerous locations along the coast in Baldwin and Mobile counties. This study displays several multi-year periods of general beach growth and of beach retreat.

The author of the present study poses the following question: Since beach migration is influenced, in part, by weather and surf conditions, what significant weather events have occurred in the recent past which may have affected Alabama's beach migration? The author suspects several types of weather events have contributed to changes in Alabama beaches: 1) hurricanes, 2) El Nino events, 3) the "Storm of the Century", and 4) prolonged "non-storm" weather regimes.

Historically, the Alabama coast has been affected by numerous hurricanes either making direct landfall in this area, or passing close enough to produce very rough surf conditions. Between 1715 and 1969, 49 tropical storms or hurricanes passed over or close to the Alabama coast (Ludlam, 1963; Neumann et al., 1981); however, there was a significant lull in area activity between 1927 and 1978 when only three storms threatened. Over the last 20 years, hurricanes have become more common along the Alabama coast (as compared to the previous 50 years). In 1979, powerful Hurricane Frederic made landfall over the west end of Dauphin Island with 130 mph winds and 12-15 foot tides. Six years later, Hurricane Elena raked Dauphin Island and the Ft. Morgan Peninsula with 125 mph winds and tides up to 6 feet. The 1995 season brought Hurricanes Erin and Opal into the Pensacola area, with Opal producing above normal tides and massive surf conditions along the Alabama coast. Most recently, Hurricane Danny moved into Mobile Bay on 19 July 1997 with 85 mph winds and tides up to 6.5 feet; however, Danny's legacy was the prolonged time it remained stalled over Mobile Bay (13 hours) and the resulting torrential rainfall (43" in Mobile Bay with 37" on the east end of Dauphin Island).

El Nino is a massive warming of the waters in the tropical East Pacific Ocean. El Nino alters the jet stream pattern and winter cyclone storm track over North America. As the jet stream relocates southward of it's normal position during strong El Nino events, intense winter cyclones, similar to New England's "Noreasters", develop repeatedly in the Gulf of Mexico. These storms come complete with large expanses of gale-force winds, massive waves, and storm surge tides. Two massive El Nino events have occurred over the last 2 decades in the winters of 1982/83 and 1997/98. Both of these events each were accompanied by three or four winter cyclones of unusual strength.

An exceptional winter cyclone event occurred in March 1993 during a long-running weak El Nino. This storm, known as the "Storm of the Century" along the Gulf and Atlantic coasts was the strongest winter cyclone of record in the Gulf. This intense low pressure system produced 100+ mph winds along the Louisiana and Northwest Florida coasts, a 10 foot storm surge tide along the Florida Gulf coast between Tallahassee and Tampa, and 19 hours of winds gusting in excess of 40 mph at Dauphin Island. Fortunately, the center of this cyclone passed south of the coast, thus the strong winds were generally from the northeast and north and kept tides and surf conditions relatively tame along Alabama's Gulf coast.

Finally, "non-storm" weather regimes may play a role in beach erosion. Off-shore weather buoy data and daily weather analyses from 1980-1996 display some multi-month trends in winds over the Alabama coastal waters. Specifically, very few hours of strong onshore winds (>20 knots) were observed during 1985 and 1986. Conversely, an unusually large number of hours with strong onshore winds (> 20 knots) are observed between 1990 and 1993.

Using beach conditions at in the Edith Hammock area on the Ft. Morgan Peninsula as "representative" of beach conditions along the Alabama coast, Table 1 relates certain significant weather events to beach expansion/erosion trends since 1970.

Time Period between Beach Measurements	Beach Width Tendency	Significant Alabama Coast Weather Events
1970 (May) - 1973 (Oct)	Mixed trends	Moderate El Nino (72/73)
1973 (Oct) - 1976 (Oct)	Beach expansion	None known
1976 (Oct) - 1983 (Sep)	Beach erosion	Hurricane Frederic (79) Major El Nino (82/83)
1984 (Jan) - 1986 (Mar)	Beach expansion	Hurricane Elena (85) Extended period of weak onshore winds (85/86)
1986 (Mar) - 1990 (Sep)	Beach erosion	Moderate El Nino (86/87)
1990 (Sep) - 1995 (Sep)	Beach erosion	Extended period of strong on-shore winds (90-93) "Storm of Century" (93) • Hurricane Erin (95) • Hurricane Opal (95)
1995 (Sep) - 1998 (Apr)	?	Hurricane Danny (97) Major El Nino (97/98)

Table 1 Beach erosion/expansion trends and observed weather events along the Alabama Gulf coast (1970-1998). Beach width trends are for the Edith Hammock area on the Ft. Morgan Peninsula (Douglas and Sanchez, 1996) and are taken to be somewhat representative of Alabama beach trends; however, individual locations may show much different trends than those at Edith Hammock.

In summary, a large number of weather events may influence beach migration along the Alabama coast. In addition to the well-known beach over-wash effects from hurricanes, significant beach migration influences may arise from:

1. Unusually strong winter storms over the northern Gulf and coastal zones (many of these are associated with intense El Nino events).
2. Unusually persistent regimes of brisk onshore winds (during non-stormy periods).

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OFFSHORE SAND RESOURCES FOR USE IN DAUPHIN ISLAND AND MORGAN PENINSULA BEACH NOURISHMENT PROJECTS, ALABAMA

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During the past decade, the Geological Survey of Alabama has been working cooperatively with the Minerals Management Service to assess the occurrence and economic potential of hard mineral resources in the Alabama Exclusive Economic Zone for potential use in Dauphin Island and Morgan Peninsula beach nourishment projects. Based on the results of a 1993 shelf-wide sand resource reconnaissance study, a geological investigation was conducted in a 50-square-mile area of the Gulf of Mexico continental shelf south of Dauphin Island to prospect for sand resource deposits suitable for local beach nourishment projects. Subsurface geologic data were provided by analysis of 28 vibracores and four borings. Sea bottom grab samples collected at each vibracore location were used to describe sea floor sediment texture. Evaluation of the geologic framework of the prospect area indicates that sediments there consist of Holocene ebb-tidal delta, shelf sand sheet, and shelf sand ridge deposits overlying an erosional unconformity of late Pleistocene to early Holocene age. Six lithofacies were delineated based on lithology, sediment texture, sedimentary structures, and environment of deposition; of these, the graded-shelly-sand lithofacies was deemed to have highest potential as a source of sand for beach nourishment.

An 11-foot thick, fining-upward shelf sand ridge composed of the graded-shelly-sand lithofacies was studied in detail to describe ridge geometry and granulometry. Vibracores and grab samples permitted the ridge to be modeled with respect to sediment texture, lithofacies patterns, aerial extent and volume of sand, three-dimensional distribution of sediment type, and compatibility for beach nourishment. Geologic data indicate that the portion of the ridge with the highest potential for recoverable sand resources is confined to federal waters some 5 to 7 miles off the southeast coast of Dauphin Island in water depths of 40 to 55 feet.

A typical composite stratigraphic sequence of lithofacies for the sand resource body shows the general trend of muddy shelly sand overlying the pre-Holocene surface which is overlain in turn by graded shelly sand. Around the margins of the sand resource body, graded shelly sand interfingers with sand-silt-clay or muddy sand. Where these muddy sediments are absent, the sand resource body interfingers with the muddy shelly sand. The shelf sand ridge thickens downdip (toward the southwest), and its main axis trends northeast-southwest, approximately perpendicular to shelf bathymetry.

From a decade of shoreline monitoring and aerial photo interpretation, it is estimated that the Gulf of Mexico shoreline of southeastern Dauphin Island could be restored to near the 1955 shoreline position by application of about 2.6 million cubic yards of sand. The shelf sand ridge contains an estimated 15.5 million cubic yards of graded-shelly-sand lithofacies, which is sufficient to nourish these shoreline segments and to provide additional sand for future nourishment projects.

In 1993, the Geological Survey of Alabama conducted a study to characterize selected sand deposits offshore of Morgan Peninsula for beach nourishment. This study showed that sand resources in the Alabama Exclusive Economic Zone south of Morgan Peninsula were confined to a few shelf sand ridges. These sand resources could be used in some beach nourishment scenarios, but additional research was needed to fully characterize them. However, alternative sand resources exist in the transverse bar field of the east Alabama inner continental shelf. The transverse bars lie in state and federal waters and appear as northwest-southeast oriented linear bathymetric highs. The bars were formed by wave activity from sand that was transported by longshore drift.

Hurricane Danny's damage to Morgan Peninsula Gulf of Mexico beaches has necessitated the need to investigate the sand resource potential of the transverse bars and offshore sand deposits for use in Morgan Peninsula beach nourishment projects. Results of this investigation would bring sand resource development efforts for Morgan Peninsula to the same level as on Dauphin Island.

An investigation of changes in bathymetry and sediment distribution from 1732-1997 in a portion of the Alabama nearshore Gulf of Mexico shows that the depth and length of the ebb-flood tidal channel of Mobile Bay were the primary factors in determining nearshore sediment transport pathways. The bathymetric and sediment budget (bathymetric differencing) maps, produced from historic hydrographic surveys and nautical charts, and historic illustrations and documents, chronicle a cycle of geographical and bathymetric change spanning the past 294-year history of a study area that includes the ebb-tidal delta of Mobile Bay, Main Pass, southeastern shoreline of Dauphin Island, and nearshore Gulf of Mexico continental shelf. The interplay between coastal geography, bathymetry, ebb-flood tidal channel dredging, scouring, and filling, punctuated by hurricanes and tropical storms, dictated nearshore sediment transport pathways, Gulf of Mexico wave orientation, patterns of shoreline erosion and accretion, and tidal current velocity.

In general, when the ebb-flood tidal channel of Mobile Bay was deep and extended from Morgan Peninsula to the southern apex of the ebb-tidal delta of Mobile Bay, the channel acted as a barrier to sediment transport from the Morgan Peninsula Gulf of Mexico shoreline across Main Pass to Dauphin Island Gulf of Mexico shoreline. In this case, the dominant nearshore sediment transport pathway was from Morgan Peninsula southward, along the eastern margin of the ebb-tidal delta of Mobile Bay, around the southern apex of the delta, and northwestward, along the western margin of the delta (and Pelican and Sand Islands) to Dauphin Island. When the ebb-flood tidal channel was relatively shallow, and short or discontinuous, nearshore sediment transport was from Morgan Peninsula westward, through Pelican Bay, to Dauphin Island. Most of the time over the past 265 years, both nearshore sediment transport pathways had been operational, but always one pathway was dominant over the other. During times when the nearshore sediment transport pathway from Morgan Peninsula was essentially west to Dauphin Island, most of the southeastern shoreline of Dauphin Island was in a state of accretion. Sediment starvation, brought about by the nearshore sediment transport pathway following the margin of the ebb-tidal delta of Mobile Bay, resulted in a state of erosion for most of the southeastern Dauphin Island shoreline. When both pathways were active, even though the ebb-tidal delta of Mobile Bay pathway was dominant, there may have been enough sediment in transport along the direct, westward route, to keep the southeastern Dauphin Island shoreline stable or accretionary.

Sediment obtained from the Morgan Peninsula littoral drift system and tidal current erosion of channel margins was used by the study area hydrographic system to infill the ebb-flood tidal channel of Mobile Bay. Hurricanes, and dredging of the Mobile Bay entrance channel over the past 74 years, was responsible for deepening and lengthening the ebb-flood tidal channel.

Dauphin Island's Beach Erosion

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Researchers in the Department of Civil Engineering and Marine Sciences at the University of South Alabama have studied beach erosion on Dauphin Island for years. These studies have found that the island's shoreline has been extremely dynamic throughout recorded history in response to both natural forces and man's engineering.

The shoreline position on Dauphin Island is sensitive to the elevations of the shoals and islands immediately offshore (Sand/Pelican/Dixie Bar). These islands and shoals are part of the ebb-tidal shoal of Mobile Pass, one of the world's largest tidal inlets. The shoal feeds sand to west end and shelters the east end of Dauphin Island.

Man's engineering has significantly influenced the present day location of the shoreline of Dauphin Island. The seawall at Fort Gaines has stopped the western migration of the east end of the island for the past century. Without that seawall, the fort and sea lab property probably would have been destroyed by erosion. The seawall has successfully protected the upland property but not the beaches. The beach in front of the seawall has been lost due to the interaction between the natural forces and the engineering.

The largest, present-day erosion problem on the island, from the Coast Guard beaches to the Audubon Place beaches, is also due to the interaction between the natural forces and an engineering project. The erosion is being indirectly exacerbated by the removal of sand from the littoral system for the Mobile Ship Channel. During the past 25 years, over 16 million cubic yards of sand has been dredged from the portion of the channel that passes through the ebb-tidal shoal and disposed of offshore. This has probably permanently lowered the elevation of the shoals around the Lighthouse and exposed the eroding beaches to more wave energy from the southeast. About 400,000 cubic yards of sand has eroded from the beaches and shifted to the next mile of beaches to the west in response to the waves since 1984. The most landward erosion of these beaches is the portion most attributable to the removal of sand for the ship channel. A few, very small beachfills at the eastern end of these beaches in the 1990's have reduced the seriousness of the erosion problem. Properly engineered beachfills can save both the upland property and the beach.

The future of Dauphin Island's beaches is inexorably linked to both mother nature and coastal engineering. Sand dredged for navigation has to be kept in and returned to the littoral system for the long-term health of the island's beaches. Beaches will continue to be damaged by seawalls built on receding shorelines. Future engineering decisions should try to work with the natural processes of the littoral system as much as possible and be based on an improved understanding of the effects of the engineering on the beaches.

MAINTENANCE DREDGING OF THE MOBILE BAY CHANNELS

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The main ship channel portion of the Mobile Harbor project as shown on Figure 1 can be divided into three segments based on physical nature of the material and disposal locations. Dredging of segment A which is located in the Mobile River involves a mixture of sands and fine grain materials ('muds') which are typically placed in upland areas west of the channel. Segment B represents the majority of the bay channel with sediments dredged being predominately fine-grained in nature. This material is transported to the ocean disposal site located south of Dauphin Island (see Figure 2, location I). Segment C, which is the southernmost terminus of the existing channel, consists primarily of sandy material, although from time to time this area contains significant quantities of fine-grained material, which is also transported to the ocean disposal site for placement.

The initial improvement of Mobile Harbor was authorized in 1826; and between that date and 1857, a 10-foot channel was dredged in Mobile Bay up to the City of Mobile. Between 1870 and 1876, the depth was increased to 13 feet. In 1880, a project was adopted to provide a channel 17 feet deep and 200 feet wide. It was modified in 1888 to provide a depth of 23 feet and a width of 290 feet. The project was again modified in 1899 to provide for a channel 23 feet deep and 100 feet wide from the mouth of the Mobile River to the mouth of Chickasaw Creek. In 1910, the project was improved to provide a width of 200 feet in Mobile Bay, all to a depth of 27 feet. In 1917, authorization was given for an increase in dimensions to 33 feet by 450 feet across the Bar (entrance into Mobile Bay – segment C), and a 30-foot by 300-foot channel in the Bay and River. Between 1931 and 1949, the Harbor was improved to a 36- by 450-foot Bay Channel, a 32- by 500- to 775-Foot River Channel, a 25- by 250-foot Chickasaw Creek Channel, and smaller channels and turning basins included in the existing project. In 1954, Congress authorized improvements to the project resulting in a 40-foot navigation depth. The Water Resources Development Act (WRDA) of 1986 authorized improvements to the project which when constructed would provide for a channel 55-foot by 550 to 650-foot within the Bay to the vicinity of Little Sand Island at the mouth of the Mobile River and a 57- by 700-foot channel across the bar at the mouth of the Bay. Phase I of the project which was constructed between 1987 and 1990 provides for a navigation depth of 45 feet.

Referring to Figure 1, there is a stretch of the channel between the southern end of segment B and the northern end of segment C which is rarely dredged. This is due to the fact that natural depths in this portion of the Bay are greater than those required for navigation. This natural deepening of the throat of the bay is due in large part to the quantities of freshwater which exit the bay and the low tidal range experienced in the northern Gulf of Mexico. These factors are also responsible for the existence of the massive ebb tidal delta located south of the mouth of the bay.

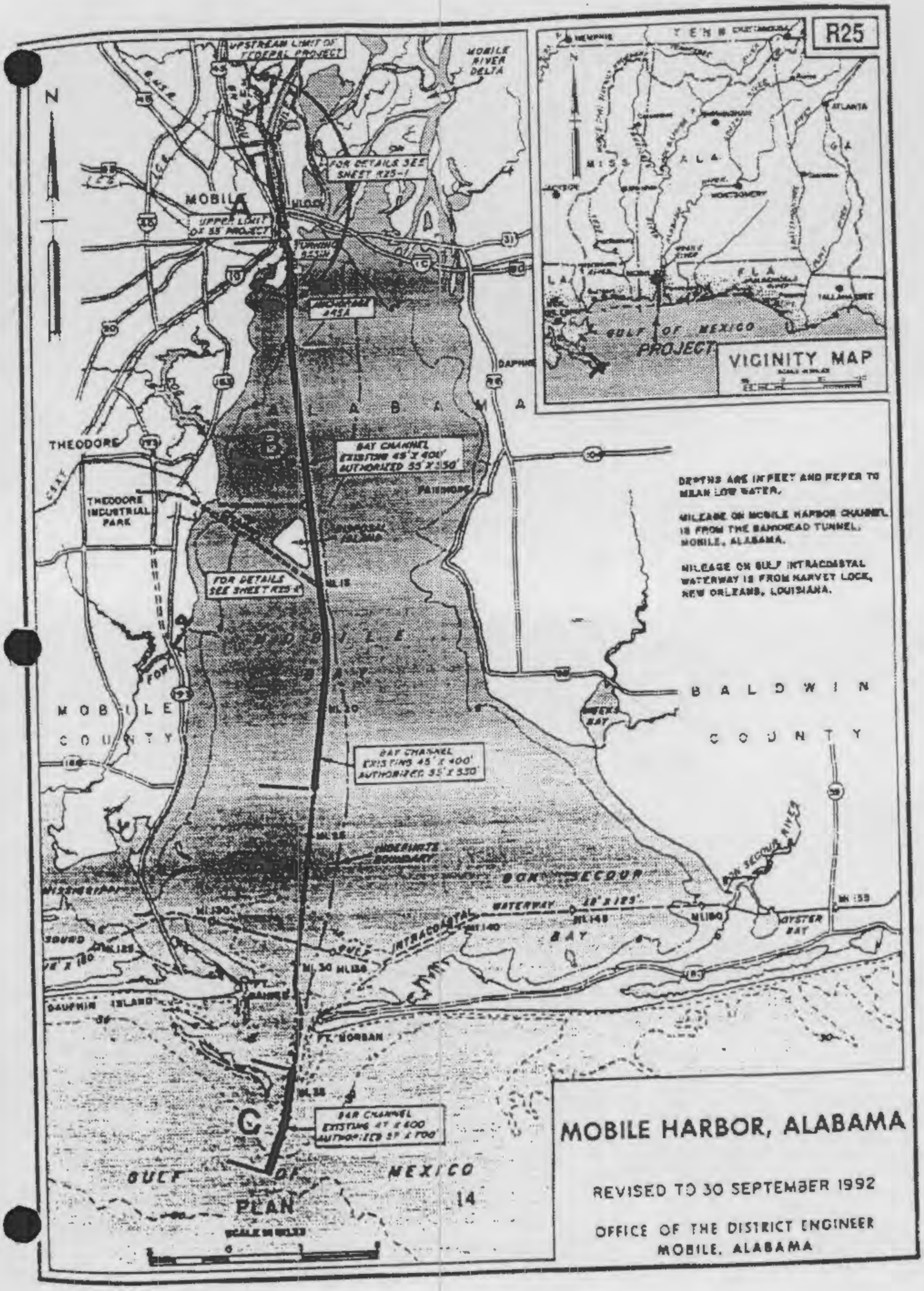
In response to WRDA '86, all materials dredged from the main ship channel are transported to the ocean disposal site south of Dauphin Island for placement. This includes the average annual quantity removed from the bar channel of approximately 170,000 – 250,000 cubic yards of predominately sandy material. In an effort to beneficially utilize dredged materials from the channels within Mobile Bay, the Mobile District has placed approximately 331,000 cubic yards of material on the east end of Dauphin Island. This quantity includes approximately 184,000 cubic yards dredged during the construction of the ferry channel following Hurricane Frederic in 1980.

In addition, the District participated in the Underwater Berms National Demonstration Program between 1987 and 1992. In 1987, approximately 456,000 cubic yards of maintenance material was dredged from segment C and placed in a 'feeder berm' (location II on Figure 2) utilizing a shallow draft split-hull hopper dredge. This area was monitored to determine whether placement in such a location, 16 – 24 feet depth, would allow for the sandy material to become incorporated in the littoral drift system of the barrier islands. Results of monitoring performed by the US Army Waterways Experiment Station (WES) indicated a slow movement of the structure northward onto the Mobile ebb tidal delta as well as a movement to the west in the direction of the predominant littoral drift.

A 'stable berm' was also constructed within the ocean disposal site (location I on Figure 2) during the construction of improvements to the Mobile Ship Channel between 1987 and 1990. Approximately 16,000,000 cubic yards of material varying from fat clay to sandy material was placed in a structure with a bottom footprint of 1 mile by 3 miles in water depths averaging 45 feet. The resultant structure was approximately 20 feet high above the bottom. This structure was monitored to determine: 1) whether it would remain stable through time, 2) whether the structure would provide a reduction in the energy transmitted by long-period waves resulting from storms in the Gulf of Mexico, and 3) whether the structure would provide fishery benefits through increased habitat complexity. A joint monitoring effort was designed by the Mobile District, WES and the National Marine Fisheries Service to answer these questions. In summary the answers to the questions in all cases was yes.

Additional efforts to provide for beneficial uses of the material dredged from the main ship channel were begun in 1995 with the proposed designation of the Sand Island Beneficial Use Area (location III on Figure 2). The characteristics of this area are similar to those of the 'feeder berm' site and therefore material placed within this area should augment the littoral drift system of Sand – Pelican Islands as well as western Dauphin Island. Although the designation had not been completed, the Alabama Department of

Environmental Management permitted the one time use of a portion of the site in 1997. This allowed for the placement of sandy material which had shoaled in the vicinity of the northernmost end of segment C during Hurricane Danny to be placed in a beneficial manner. Approximately 54,400 cubic yards of material was determined suitable for placement in this area. Additional studies of the Sand Island Beneficial Use Area concerning historic resources have been conducted. Upon certification by ADEM, this area will be available for the placement of suitable material dredged from the channel. Additional research on what constitutes suitability from a physical grain size standpoint will be conducted as part of the Corps of Engineers Dredging Operations Environmental Research Program in 1998.



DEPTHS ARE IN FEET AND REFER TO MEAN LOW WATER.

MILEAGE ON MOBILE HARBOR CHANNEL IS FROM THE BANKHEAD TUNNEL, MOBILE, ALABAMA.

MILEAGE ON GULF INTRACOASTAL WATERWAY IS FROM HARVEY LOCK, NEW ORLEANS, LOUISIANA.

MOBILE HARBOR, ALABAMA

REVISED TO 30 SEPTEMBER 1992

OFFICE OF THE DISTRICT ENGINEER
MOBILE, ALABAMA

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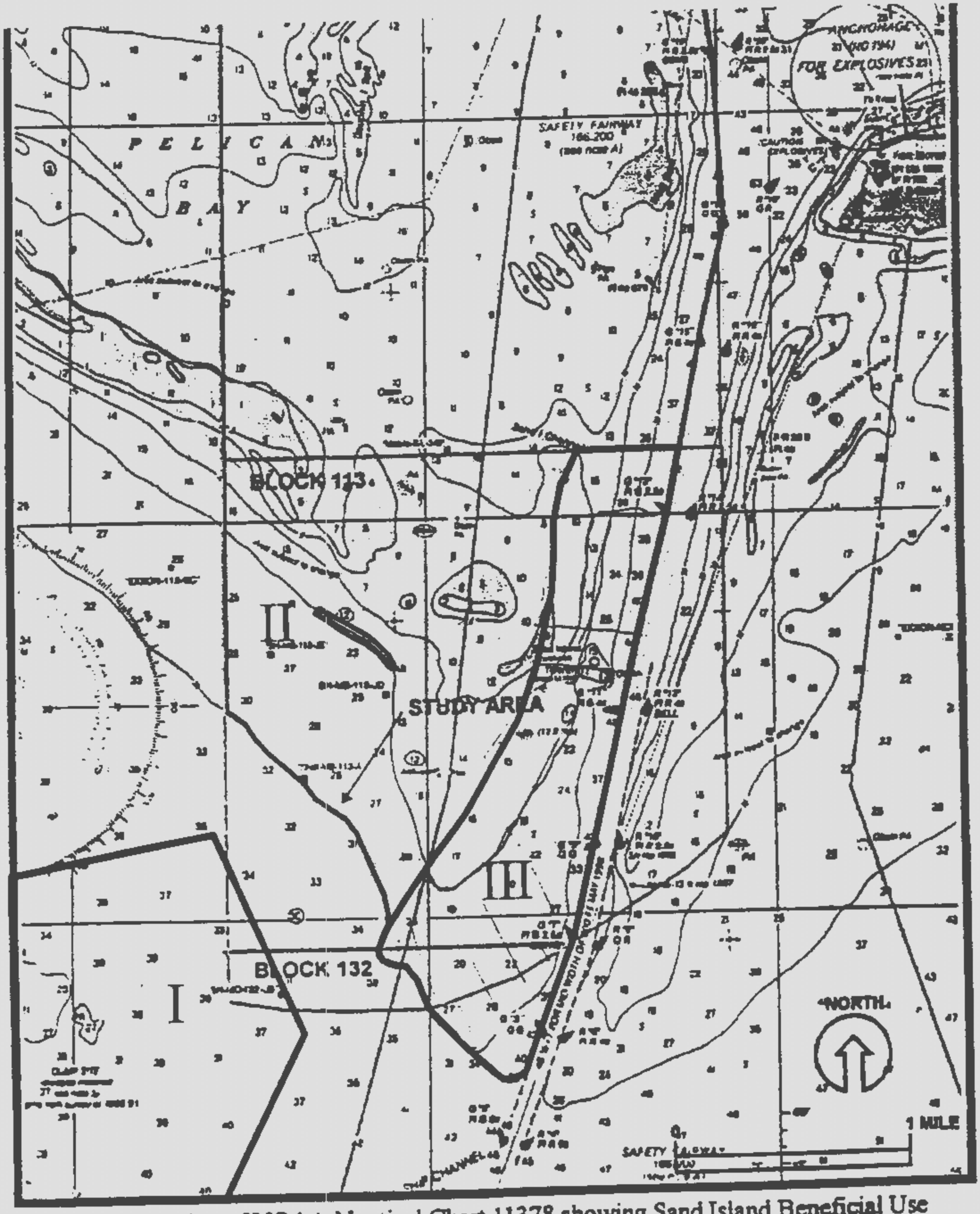

Figure 2. Section of NOAA Nautical Chart 11378 showing Sand Island Beneficial Use Area and oil and gas lease block designations.

Coastal Erosion

by Orrin H. Pilkey

Most of the World's shorelines are retreating. An erosion crisis is at hand because development in the endangered zone is increasing, and halting shoreline erosion can be very costly in economic and environmental terms. The shoreline erosion problem is "solved" by (1) hard shoreline stabilization, for example, seawalls; (2) soft shoreline stabilization, for example, beach replenishment; and (3) building relocation. Because of concern for preservation of recreational beaches, the use of hard stabilization, that is, seawalls, is sometimes being restricted.

Introduction

Coastal erosion is a major problem for developed shoreline everywhere in the world. Where sufficient capital exists, as in Japan, massive structures are built and maintained to hold back the forces of the sea. Where poverty is the norm, as in much of Africa, buildings tumble into the sea routinely, or they are moved back step by step, apace with shoreline retreat.

In the United States, the coastal erosion problem annually becomes more critical as large numbers of wealthy, influential people crowd against a retreating shoreline. In the Mississippi Delta, salt marsh is disappearing at an alarming rate owing to a combination of erosion, drowning, and the impact of man on the marsh. Here endangered buildings are not the problem, but the land loss is.

The coastal erosion crisis is man made, in a sense, because if no one lived next to the shore, there would be no problem. Furthermore, man is immeasurably compounding the problem by actually increasing rates of erosion in a number of ways. But, examination of the world's barrier-island shorelines indicates that fundamental and purely natural global changes are also afoot. Many barrier islands are regressive in nature, indicating a seaward accretion of the island over the last 3,000 to 4,000 yr. Most regressive barrier islands (for examples, Galveston Island, Texas, and Bogue Banks, North Carolina), however, are now eroding on both the ocean and lagoon sides. Clearly within the last few millennia a profound change has taken place, and shoreline retreat has replaced shoreline growth.

The role of man in coastal retreat range from global to local. Production of excess carbon dioxide is leading to greenhouse-effect sea-level rise and accelerated erosion. Construction of dams reduces the supply of sand to the beaches and leads to accelerated erosion. The armoring of the shoreline to present erosion often leads to more erosion rather than less. And increasingly there is widespread concern that efforts to save manmade structures along shorefronts lead to the destruction of recreation beaches that were often the reason the buildings were built to begin with.

United States erosion data have been summarized recently by Dolan and others, 1985. A broad discussion of the U.S. problem along with methodology, political implications, and costs for mitigation is furnished by the National Research Council

(1990).

Bird (1985) in a global review of coastal changes, emphasizes the need to consider the different types of coasts separately in study of the rates and mechanics of erosion. Bird's review highlights the fact that the coastal erosion problem is truly global in its scope.

Shoreline erosion is best termed shoreline retreat. This is because the beach, the most visible and valuable part of most shorelines is not really eroding; it is simply changing its position in space. This fact can be expressed as a shoreline truth that is critical for he understanding of the shorelines by both the public and the scientific community. This truth is: shoreline erosion does no damage to the recreational beach.

This truth is partially illustrated by the Morris Island Lighthouse seaward of Morris Island, South Carolina. During World War II the lighthouse was on land beside a large U.S. Coast Guard Station adjacent to a broad sandy beach. Now the broad sand beach is 400 m east of its World-War II position, still a broad beach.

A second truth is that there is no shoreline erosion problem until a man-made structure is threatened. On a log-strewn beach on St. Catherine's Island, Georgia, no erosion problems have been reported. Clearly the shoreline here is retreating at a rapid rate. But this is a shoreline with no shorefront development, so no one is complaining or asking for government aid. However, on a log-strewn beach on a tropical rain-forest-covered barrier island on the Pacific coast of Columbia, South America, an erosion problem does exist and has been documented because a building is in imminent danger of loss from shoreline erosion.

Causes of shoreline erosion

Beaches can be viewed as systems in dynamic equilibrium. The equilibrium involves 4 factors: (1) the level of the sea, (2) wave and tidal energy, (3) beach sediment supply, and (4) position in space. Each of these factors is to some degree dependent on the others, and a change in one factor must result in adjustments by the others.

Sea Level Rise

The sea level is rising at a rate of about 30 cm per century along U.S. coastal plain coasts and at varying rates along other coasts. The highest relative sea level rise rate in the U.S. may be found in parts of the sinking Mississippi delta, where the rate of rise may exceed 1.2m per century. Locally, rapid sea level rises may also be due to man-induced subsidence, for example, Galveston, Texas, and Long Beach, California.

For two sealwalls protecting Timbalier Island, Louisiana, a dark colored wall (rock revetment) has gone to sea and the light colored one will soon meet the same fate. This sequence of events reflects the very rapid rise in sea level here in the Mississippi Delta and is a harbinger of the future for other U.S. shorelines.

It is obvious that the relative sea-level rise is made up of both tectonic and eustatic components, and the literature discussing the relative importance of each is voluminous (for example, Devoy, 1987).

The literature (see review in Carter, 1988) is also voluminous on the subject of projected sea-level rise owing to the expected melting of the West Antarctic Ice Sheet caused by the greenhouse effect. The nature and complexity of the models used to predict greenhouse-effect sea-level changes (Barth and Titus, 1984) are beyond the scope of this paper. Predicted eustatic sea-level rise by the year 2100 ranges from 0.5 to 2m above the present sea level.

From the geologic hazard standpoint, the most important research question is predicting the effect of sea-level rise on shoreline-retreat rates. The problem is a complex one (Pilkey and Davis, 1987) and standard engineering models such as the Bruun rule are too rigid and are based on too many narrow assumptions to have wide application.

If the sea level rises 10m in the next year, the shoreline would be at the 10m contour interval. But if the level of the sea rises 2m in the next 200 years the problem of shoreline location and retreat rate becomes much more complex. Endangered coastal communities need accurate predictions of shoreline position on a decades timeframe; a more difficult task.

There is a strong possibility that, if the higher prediction scenarios of sea-level rise due to the greenhouse effect come to be, our society will not be worrying about shorefront-recreation communities on the East and Gulf coasts. Instead, concern and funding will focus on the fate of Galveston, Texas; Miami, Florida; Charleston, South Carolina; Manhattan, New York; and other major cities.

Sand Supply

Each shoreline reach has a unique combination of sand sources. The major sources include rivers, eroding bluffs and cliffs, and the continental shelf. Locally, longshore transport of material from an adjacent shoreline segment may be important. The continental shelf contribution, via the landward pushing action of fair-weather waves, is the most difficult to determine. In most analyses, the continental shelf contribution is assumed to be the amount that cannot be accounted for from other sources.

The contribution to the erosion problem by the activities of man has been increasing dramatically in recent decades. Damming of rivers is cutting off a major source of beach sand in California. Seawalling of coasts, a very extensive process on European shores (Walker, H.J., 1988) has cut off the supply of sand normally contributed to the beaches by eroding bluffs. The myriad groins, seawalls, breakwaters, and jetties that line developed shorelines everywhere divert offshore, slowdown, trap, and otherwise reduce the regional beach sediment supply and hence increase erosion rates.

A spectacular example of the negative role of jetties on beach sand supply is afforded by the northern end of Assateague Island, Maryland. The jetties were constructed shortly after the inlet opened during the 1933 hurricane. Since that time, the loss of sand accumulating in front of Ocean City to the north has caused the shoreline to retreat and the island to migrate completely landward of the 1933 surf zone. Prior to 1933, there were no shoreline offset; the two islands were one and the same.

The prognosis is for an accelerating decrease in sediment supply to most of the developed beaches of the world.

Wave Energy

Storms cause the most visible and obvious shoreline retreat, but often storm-caused erosion is substantially "repaired" by poststorm on-shore transportation of sediment. Different shorelines are adjusted to different wave climates. New England shorelines are subjected to frequent northeastern storms on an annual basis. The erosion rate of Florida's Gulf of Mexico beaches, on the other hand, is most affected by hurricanes spaced decades apart.

The most intriguing questions about the impact of waves and wave climate on future shoreline retreat involve an anticipated change in storm climate owing to the greenhouse effect. Both frequency and intensity of Atlantic hurricanes are predicted to increase. This will impact Gulf of Mexico-shoreline retreat rates more than those on the U.S. East Coast, where northeastern storms tend to be the more important shoreline erosion event.

Solutions to the erosion problem

The basic problem with responding to the shoreline erosion crisis is that two conflicting societal priorities come into play which cannot be simultaneously fulfilled. One priority is the preservation of shoreline property. In the U.S. such property is highly valued, and as a result it tends to be owned by influential individuals who are active in defense of their property. The second priority is preservation of the recreational beach. The beach is utilized and valued by numbers of people much larger than the numbers of property owners. But swimmers, surfers, fishermen, and beach walkers tend to be less vocal and less active in defense of beach preservation. If one beach is damaged in the process of saving houses, there is always another beach down the road.

The problem is illustrated by the lonely and underworked life-guard on Myrtle Beach, South Carolina. There is only a very narrow, almost nonexistent beach left in front of a seawall. The seawall, designed to protect buildings behind it, has been directly or indirectly responsible for the narrowing of the recreational beach. Was the price of beach loss worth protecting these buildings? Which is more important: buildings or beaches?

There are three main ways that our society can "solve" the beach erosion problem: (1) hard stabilization, (2) soft stabilization, and (3) relocation. Hard stabilization is any method of holding the shoreline in place using "hard" fixed objects. Soft stabilization is the emplacement of additional beach sand as a means of holding the shoreline in place. Relocation is the moving of threatened structures back as the shoreline retreats.

Hard stabilization

Hard stabilization structures can be divided into two types, those that block wave energy and those that trap sand. Seawalls, energy absorbing shore-parallel structures built on the subaerial beach, are the most common type of hard structure used worldwide. Shore-perpendicular groins and shore-parallel offshore breakwaters are designed to increase beach width by trapping sand.

Advantage:

1. Most dependable way to save property adjacent to the beach.

Disadvantages:

1. Degradation of the recreational beach,
2. Costly,
3. Ugly, and
4. Makes beach access difficult.

Seawalls and related structures are said to degrade the beach for the following reasons (Pilkey and Wright, 1988):

Seawall placement seaward of the high tide line. - On the day of seawall completion part or all of the recreational beach is missing. Seawall placement was responsible for much of the beach loss in Miami Beach prior to the 1980 beach replenishment project. The Sandbridge, Virginia, seawall, which was built in 19989, is a more recent example of beach degradation by this means.

Passive beach loss. - If a wall is placed on a shoreline that is retreating (which, of course, is usually the case), whatever is causing the retreat will continue to do so, and the beach will narrow up against the wall. Since most shorelines are eroding, seawalls will degrade most beaches through passive means. This is a long-term process (decades).

Active Beach loss.- This beach front degradation caused by the direct impact of the wall on nearshore oceanographic processes. There is no disagreement about the fact that seawalls, where they extend into the surf zone, adversely affect the lateral transport of sand. More controversial is the question of how the wall actually affects the beach in front.

Kraus (1988) reviews the literature on seawall/beach interaction and concludes that walled and unwalled beaches exhibit similar beach changes. Kraus' review is mainly concerned with events (storm response). It is difficult to extrapolate the decades long phenomenon of beach degradation in front of walls from the observation of single storm events.

There is little doubt among coastal geologist that seawalls are responsible for beach degradation. Apparently doubts remain in the coastal engineering community as indicated by the following statement from the U.S. National Academy of Engineering (National Research Council, 1990). "Properly engineered seawalls and revetments can protect the land behind them without causing adverse effects to the fronting beaches." This statement, is a surprising one since, judging from the engineering literature, there is no apparent disagreement over the validity of the passive role of seawalls in beach degradation (for example, Pilkey and Wright, 1988; Tait and Griggs, 1990). The statement is a good illustration of the depth of philosophical disagreement that exists between engineers and scientists over the long-term impact of seawalls.

A crude seawall protecting the foundations of some small buildings on a recreational beach along the south shore of Puerto Rico represents the basis of growing public concern over beach degradation (whatever the mechanism) by hard stabilization. Here, in Puerto Rico, an important recreational beach has been strongly degraded in order to save a few low-cost buildings.

Of course all buildings protected from shoreline erosion are not small and low cost. Needless to say the public dilemma over the question of which should be preserved, buildings or beach, deepens considerably when 20-story beachfront condominiums are involved.

Beaches may have different values to our society in different locations, which can result in a different view of hard stabilization. In Seattle, Washington, bordering Puget Sound, there are a number of examples of narrow to nonexistent beaches fronting seawalls. Public indignation over these seems minimal, perhaps because the beaches are not heavily used for swimming because of cold water temperatures.

Beach Replenishment

Advantages:

1. "Improves" the beach and
2. Protects buildings while in place.

Disadvantages:

1. Costly and
2. Temporary.

Beach replenishment is the emplacement of "new" sand to rebuild beaches that have retreated close to seawalls or to buildings. Sand is usually pumped to the beach from inlets, tidal delta shoals, or the continental shelf. In some cases, sand is trucked in from inland quarries.

The life span of replenished beaches is highly variable. Miami Beach, a 16km-long, $60-million, artificial beach, is largely in place after 10 years. On the other hand, a 1982, $5-million beach in Ocean City disappeared in a little more than 2 months.

There are strong regional differences in beach life span along the U.S. East Coast barrier island shoreline (Pilkey 1988). East Coast Florida beaches south of Cape Canaveral typically last 7 years; north of Cape Canaveral, 5 years; Georgia through Delaware, 2-4 years; and New Jersey, less than 2 years. The minimum cost of a replenished beach capable of reducing the impact of a hurricane ranges from $1 million up to $10 million per mile. The replenishment alternative is a very costly one (Pilkey and Clayton, 1987). It could cost $2 billion per decade to replenish the entire New Jersey developed shoreline and perhaps $200 million per decade for the South Carolina developed shore.

Mathematical models used to predict beach behavior have routinely failed. This is because of a lack of understanding of the principles of nearshore oceanography, especially as far as storm processes are concerned. One cannot model what is not understood. There is also a tendency to accept storms as accidents, which greatly weakens applications of the models.

There is even a great difference of opinion as to the life span of a beach once it is emplaced. This is because: (1) Replenished beaches disappear at varying rates along their lengths making it possible to choose different locations from which to interpret life spans, and (2) frequently, it is assumed that sand removed from the subaerial beach is residing just offshore, still having a favorable dampening impact on storm waves. The offshore fate of replenished sand has yet to be studied. From the community standpoint, however, an underwater beach has little credibility.

Clearly, the beach replenishment alternative to erosion mitigation is not for developing countries. The cost is just too great. In addition, if sea-level rise continues and accelerates, the price of holding the shoreline in place and preventing loss of property along sandy low-lying shorelines will likely become unacceptable even to more wealthy nations.

Relocation

Advantages:

1. Preserves the beach,
2. Saves shoreline stabilization costs, and
3. Preserves buildings,

Disadvantages:

1. Politically difficult,
2. Could be financially costly, and
3. Loss of land.

Relocation is the general term for any shoreline erosion response that does not involve shoreline stabilization. This could mean relocation of buildings, demolishing of buildings, or simply letting them fall in.

Prior to World War II and the advent of the bulldozer, the latter two approaches were generally taken on rapidly eroding shorelines and still are in developing countries. Occasionally, beachfront buildings were moved back along the U.S. East Coast as long as the mid 1800's. In Nags Head, North Carolina, the 120-yr-old Outlaw family cottage has been moved back five times, and now it is once again close to the surf zone. In 1888, the Brighton Hotel on Coney Island in New York City was moved back 600m with the aid of five steam locomotives. The move was made because of shoreline erosion.

The future

Coastal erosion promises to be an increasingly visible geologic hazard as sea level rises and the rush of development to the shore continues worldwide. Response to the problem will vary dramatically. Japan and Holland intend to suffer no land loss. In fact, Holland continues to increase its land area at the expense of the area of the sea floor. Four U.S. states (New Jersey, North Carolina, South Carolina, and Maine) have now opted for the retreat option and have declared future hard stabilization illegal.

Considering the change in public perception of the value of beaches and the building-versus-beaches controversy, it is very likely that future erosion strategies will tilt in favor of responses that will allow preservation of beaches. What society needs now from the scientific and engineering community is an accurate basis for developing long-term coastal erosion strategies. Most important, is the means of predicting the impact of sea-level rise on shoreline retreat.

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