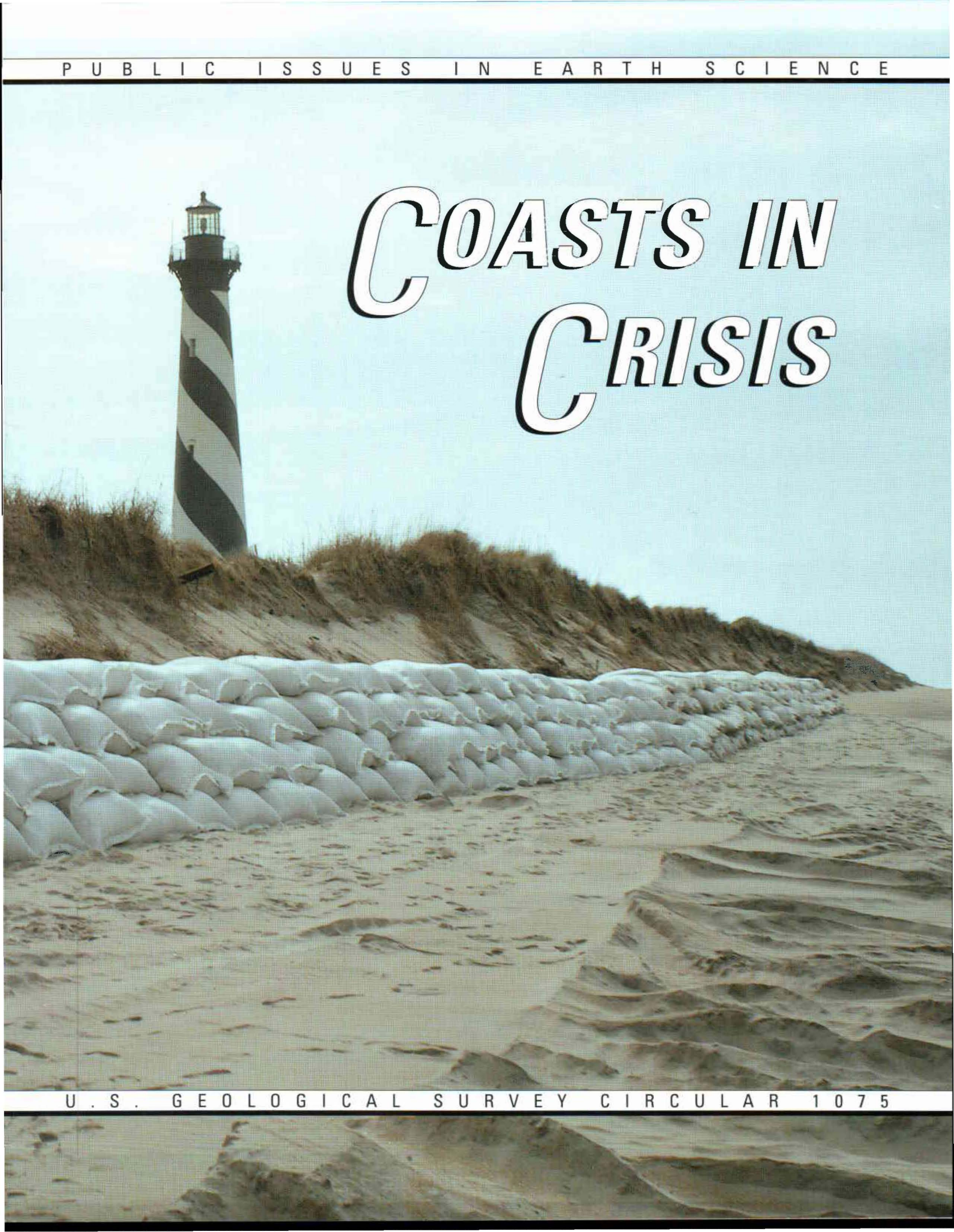
PUBLIC ISSUES IN EARTH SCIENCE

COASTS IN CRISIS



U.S. GEOLOGICAL SURVEY CIRCULAR 1075

Front cover: The Cape Hatteras lighthouse stands behind a seawall of sandbags that temporarily stabilized the eroding shore; wave action destroyed the seawall soon after it was built. The erosion of North Carolina's chain of barrier islands has prompted a National Research Council committee to recommend that this historic lighthouse be relocated.

COASTS IN CRISIS

By
S. Jeffress Williams,
Kurt Dodd, and
Kathleen Krafft Gohn



U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Gordon P. Eaton, Director

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FOREWORD

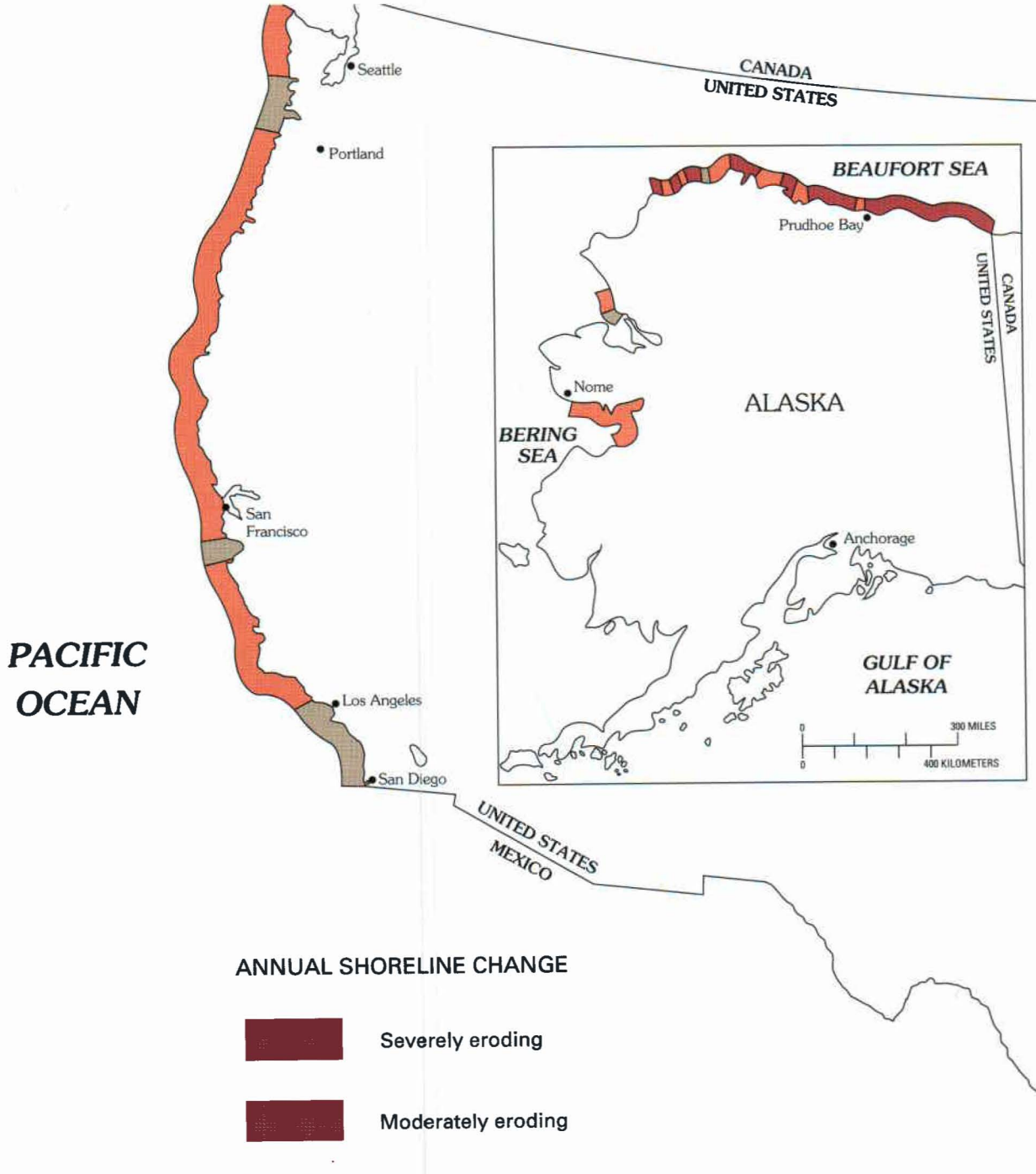
This publication is the first in a planned series, Public Issues in Earth Science, published by the U.S. Geological Survey. Its purpose is to describe the importance of the earth sciences in an issue vital to our society: the deterioration of our ocean and Great Lakes shorelines and wetlands.

The personal effect of this crisis on people living in coastal regions is enormous—homes are destroyed, savings lost. The effect on coastal communities and recreation and fishing industries is devastating—businesses are destroyed, resources and jobs lost. The long-term repercussions on Federal, State, and local agencies and the insurance industry can be huge. According to the 1990 census, the most dramatic population growth over the past decade occurred in the coastal States; continuation of this trend will increase the stress on our coastal environments.

In this book, the authors describe our Nation's varied coastal environments and the natural processes and human actions that are constantly modifying them. Ignorance of these processes exacerbates the tragic collisions between people and nature—such as Hurricane Hugo last year in South Carolina, which left thousands homeless and destroyed billions of dollars of property. We are still learning the lesson that Francis Bacon expounded almost four centuries ago: "Nature to be commanded must be obeyed." To obey and command nature, however, we must improve our scientific understanding of its forces and processes; only then can we address the crisis now facing coastal communities.

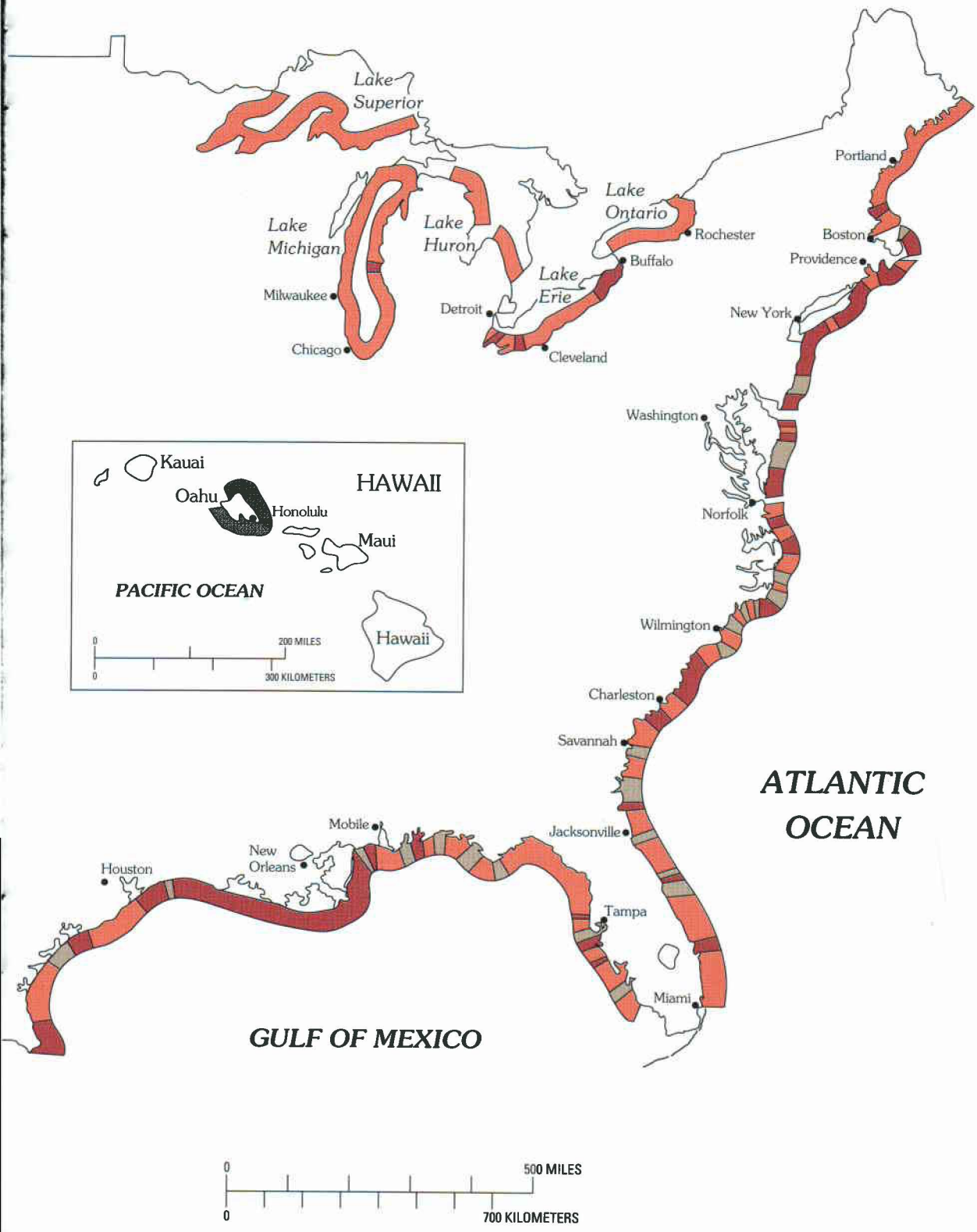
The earth sciences provide information critical to understanding and resolving this crisis. Through cooperative investigations, the earth-science community can contribute to a better understanding of coasts, their dynamic processes, and their responses to human intervention. As the primary Federal earth-science agency, the U.S. Geological Survey is the lead organization in the collection, interpretation, and dissemination of earth-science data and analyses—critical first steps in helping to resolve the crisis facing our coastal environments and communities.

Dallas L. Peck
Director



Uncolored U.S. shoreline indicates no data are available; data are also lacking for parts of Alaska, as well as Puerto Rico, U.S. Virgin Islands, and the U.S. Pacific Islands, which are not shown on this map.

All 30 coastal States are experiencing erosion along their coastlines. (Modified from Dolan and others,



1985, Coastal erosion and accretion: U.S. Geological Survey National Atlas.)

CONVERSION FACTORS

For readers who wish to convert measurements from the metric system of units to the inch-pound system, the conversion factors are listed below.

Multiply	By	To obtain
	Length	
millimeter	0.039	inch
centimeter	0.394	inch
meter	3.281	foot
kilometer	0.621	mile
	Area	
square kilometer	0.386	square mile
	Volume	
liter	0.264	gallon
cubic meter	1.308	cubic yard

A simple rule of thumb for approximate conversions: 1 inch equals about 25 millimeters, or about 2.5 centimeters; 1 yard equals about 1 meter; 1 quart equals about 1 liter.

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When we think of a coast, most of us envision:

a secluded get-away

(Actually, 50 percent of the U.S. population lives within an hour's drive of a coast.)



with a broad stretch of sand

(In the late 1970's, $64 million was spent replenishing Miami Beach with 13 million cubic meters of sand.)



or perhaps vast marshes and wetlands

(Louisiana is losing as much as 100 square kilometers of wetlands each year, an area the size of the District of Columbia.)



with teeming wildlife and succulent shellfish

(One-third of the Nation's shellfish beds are closed or restricted because of pollution.)

INTRODUCTION

Our coasts are reaching a crisis. Threats to coasts and to coastal communities are growing as development, recreation, and waste disposal activities increase, often in conflict with long-term natural processes. Other threats to our coasts, such as sea-level rise and reduction in sediment supply, result from global warming and the damming of rivers.

The impending crisis of our coasts stems from misconceptions about what coasts are—and from actions based on those misconceptions. Differences between our perceptions and the reality of coasts intensify the conflicts between people and nature. These conflicts will worsen as the coastal population expands and competing uses of the recreational, wildlife, shipping, and mineral resources of coasts increase.

PERCEPTION AND REALITY

We think of land as stable and treat it as a permanent asset. For most land, this premise is reasonable because land generally changes very slowly. Although tectonic and geologic processes, such as continental drift and erosio are always at work, they usually result in very gradual changes that are barely noticeable during a human lifetime.

Coasts, however, are not static; they are dynamic. They quickly change shape and location in response to natural forces and human activities. These forces and activities continually push and pull at coasts—sometimes in the same direction, but often in opposite directions. As a result, the shape of the coastline changes. Sand and other materials are moved onto and off of beaches by currents and waves. Seasonal movement of coastal materials creates broad summer beaches followed by narrow winter beaches in an annual cycle. During major storms, huge waves and storm surges can move large amounts of coastal sediments and can flood vast areas in a matter of hours.

On a larger scale, the coast itself moves as it tries to achieve equilibrium with the forces acting on it. Barrier islands and offshore sand bars move landward and along the coast, driven by longshore currents. Headlands are eroded back, moving the coast inland. Sediment is deposited on river deltas, extending the coast out into the water. Coastlines also move in response to changes in sea level; even if the land remains stationary, a rise in sea level will move the coastline inland.

PRUDHOE BAY, AK

This dock facility at Prudhoe Bay shows the effects of northern Alaska's coastal erosion problem. Strong storm waves and ice action cause the erosion rates in the Beaufort Sea to be among the highest in the United States. Some barrier islands are moving landward as fast as 7 meters per year. These rapid erosion rates endanger causeways and artificial islands built for oil-drilling platforms.



PEOPLE VS. NATURE

Because we treat the coast just like all other land—as a stable platform on which we can safely and easily build—some of our actions directly conflict with the dynamic nature of coasts. Other human activities, such as the increasing release of greenhouse gases, may indirectly affect our coasts through global warming, causing worldwide sea-level rise as glaciers melt. Still other actions, such as the damming of rivers for flood control and water management, may affect the stability of coastlines by restricting the supply of new sediments being carried to the coasts.

Coastal areas across the United States now have population densities five times the Nation's average.

Conflicts between people and nature have always existed along the coasts. The increasing desirability and accessibility of coasts as places to work and live have intensified these conflicts greatly over the past 50 years. The 1990 census shows that 25 of the 30 coastal States have had dramatic population increases since 1980; the largest increases were in Alaska (36 percent), Florida (31 percent), and California (24 percent). Coastal areas across the United States now have population densities five times the Nation's average. Currently, 50 percent of the Nation lives within 75 kilometers of a coast; this number is projected to increase to 75 percent by the year 2010. As the coastal population grows, so does the need for additional facilities for transportation, recreation, potable water, and waste disposal. Pollution is already severe near large coastal urban areas and has hurt recreation activities and the fishing industry.

Wetlands and marshes are now widely recognized as important but fragile parts of the coastal environment. Louisiana, which contains more than 40 percent of the tidal wetlands in the 48 conterminous States, is losing as much as 100 square kilometers of wetlands each year. These marshes are one of the world's most productive ecosystems. Their continued demise seriously affects migratory waterfowl, songbird populations, and fish and shellfish resources, as well as the coastal culture of Louisiana.

In the future, the mineral potential of coastal sand, including its potential for gold and other metals, may result in another competing use of our coastal resources as cheaper onshore mineral supplies are exhausted. Mining coastal sand for heavy minerals and construction materials without a carefully designed plan may further stress the fragile coastal environment.

THE KEY: EARTH-SCIENCE INFORMATION

How should we deal with these competing needs? How can we manage the coastal crisis? The first step is to understand our coasts better, to build a solid foundation of earth-science data on coastal processes and evolution, and to identify what factors are important in quantitatively determining the location and movement of coasts. Only after thorough research and interpretation can the critical scientific results be translated into practical terms and be incorporated into sound coastal management policies.

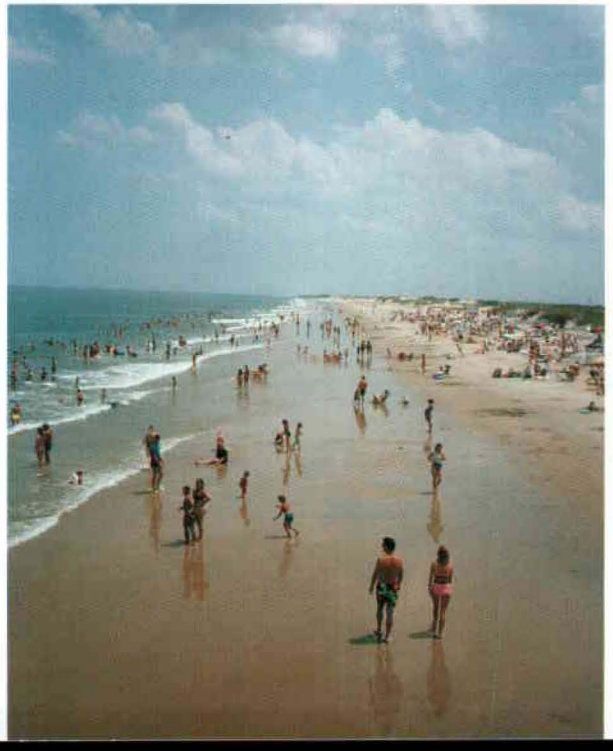
This report briefly explains coasts—the types of coasts, the natural processes that create and modify them, and the human activities that affect them. It gives specific examples of coasts that are dramatically changing as a result of, or in conflict with, human interests and actions. It documents the critical need for a better understanding of our coasts through earth-science investigations and the collection of scientific data—information that is essential to Federal, State, and local agencies as well as to the private sector, homeowners, and other decision-makers who wrestle with the growing crisis on our coasts.

TYPES OF COASTS

Coasts are the dynamic junction of water, air, and land. Winds and waves, tides and currents, migrating sand dunes and mud flats, a variety of plant and animal life—all combine to form our ever-changing coasts. Their dynamic nature results in their great diversity. Most of us envision a coast as a broad stretch of sand with frothy surf breaking along the shore; in fact, many types of coasts are found within the United States, ranging from sandy beaches to rocky shores to coral reefs to coastal wetlands.

ROCKY SHORES

Rocky shores form on high-energy coasts where mountains meet the sea and at the base of sea cliffs. Active tectonic environments, such as in California, produce rocky coasts as a result of mountain-building processes, faulting, and earthquakes. Rocky coasts also form where ice and strong waves have effectively removed fine-grained sediment. In Maine and parts of Alaska, glaciers have scoured most of the sediment cover from the shore. In the arctic, ice gouging and rafting have removed sand-sized particles from some beaches, leaving cobbles and boulders.





The rocky shores of Oregon's Pacific coastline are among the most dramatic in the United States. This rugged coast is geologically young and has not yet been smoothed by erosion.

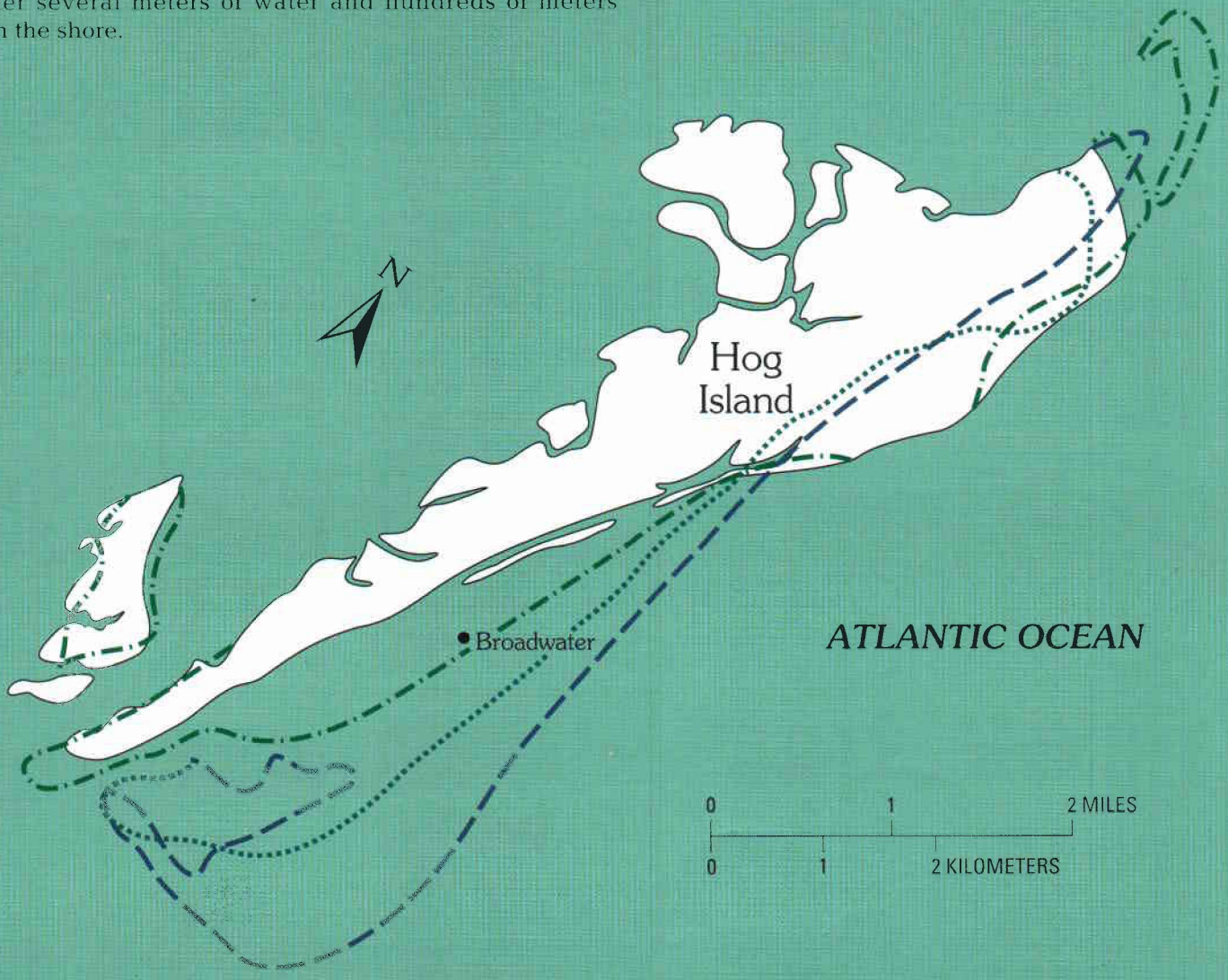
SANDY BEACHES

Sandy beaches can be categorized into three types: mainland, pocket, and barrier beaches. **Mainland beaches** stretch unbroken for many miles along the edges of major land masses. Some are low standing and prone to flooding; others are backed by steep headlands. They receive sediment from nearby rivers and eroding bluffs. Examples of mainland beaches include coasts of the Great Lakes, northern New Jersey, and southern California. **Pocket beaches** form in small bays surrounded by rocky cliffs or headlands. The headlands protect the sandy alcoves from erosion by winter storms and strong currents. Pocket beaches are common in New England and the Pacific Northwest. **Barrier beaches** are found along the Gulf of Mexico, the east coast, and much of Alaska. They are part of complex integrated systems of beaches, dunes, marshes, bays, tidal flats, and inlets. The barrier islands and beaches are constantly migrating, eroding, and building in response to natural processes and human activities.

Sandbridge, Virginia, is a popular beach resort south of Virginia Beach. Erosion rates at Sandbridge are among the highest in Virginia.

HOG ISLAND, VA

In the late 1800's, at least five lavish hunting and fishing clubs were established on Virginia's barrier islands; one of the largest was in the town of Broadwater, on Hog Island. The town, located in a pine forest near the middle of the island, at its height had a population of about 300 and contained 50 houses, a lighthouse, a school, and a church and cemetery. Erosion destroyed the lighthouse before 1930, and in 1933 a hurricane inundated all of Hog Island, destroying much of the town and killing the protective pine forest. By the early 1940's, all inhabitants had left the island. The former site of the town is now under several meters of water and hundreds of meters from the shore.



(Modified from Rice, Niedoroda, and Pratt, The coastal processes and geology: Virginia barrier islands, vol. 1 (Ecosystem description), part B, of Virginia Coast Reserve Study conducted by the Nature Conservancy.)



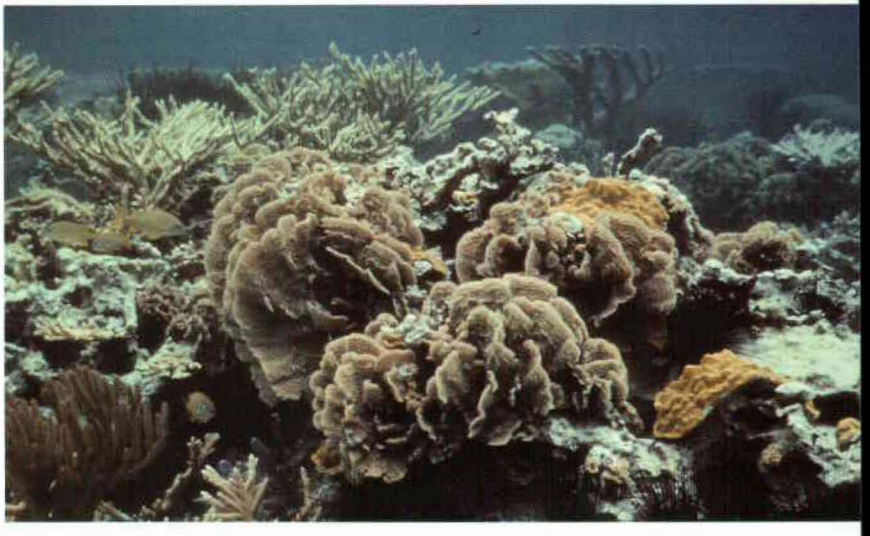
COASTAL WETLANDS

Coastal wetlands include swamps and tidal flats, coastal marshes, and bayous. They form in sheltered coastal environments often in conjunction with river deltas, barrier islands, and estuaries. They are rich in wildlife resources and provide nesting grounds and important stopovers for waterfowl and migratory birds as well as spawning areas and valuable habitats for commercial and recreational fish.

Most of the Nation's coastal wetlands are in Louisiana, along the Mississippi River and its active and ancient deltas, and in Alaska, at the mouths of the Yukon and Kuskokwim Rivers. The Great Lakes and the southeastern seaboard are fringed by other important wetlands, such as Florida's Everglades. Coastal wetlands can be dominated by salt water, as along the gulf coast of Louisiana, or they can contain a complex and changing mixture of salt and fresh water, like the estuaries of the Chesapeake, Galveston, and San Francisco Bays.

CORAL REEFS

Coral reefs abound along the southern coast of Florida and around the Hawaiian Islands, Puerto Rico, the Virgin Islands, and the Pacific Islands. In the shallow waters off tropical isles, living coral organisms build reefs that provide important wildlife habitats and protect coasts from waves and storms. Healthy coral reefs are also an important source of carbonate sediment for tropical beaches. Raised coral platforms no longer inhabited by living coral provide coastal materials and form islands such as the Florida Keys.



Above: In this Louisiana wetland, salt-water intrusion has killed the cypress trees.
Right: A coral reef is a living community, which can easily be damaged by pollution or hurricanes.

COASTAL CHANGE

Diverse and complex natural processes continually change coasts physically, chemically, and biologically, at scales that range from microscopic (grains of sand) to global (changes in sea level). Regional and local characteristics of coasts control the differing interactions and relative importance of these natural processes. Human activity adds yet another dimension to coastal change by modifying and disturbing, both directly and indirectly, the coastal environments and the natural processes of change. Earth-science research on coastal dynamics can quantify these changes and improve our ability to predict coastal responses to human actions.

MONTAUK LIGHTHOUSE, NY

George Washington, as a young engineer, selected the site for the lighthouse at Montauk, at the eastern end of Long Island. He surveyed the land, estimated the erosion rates of the sandy bluffs, and chose a location 60 meters back from the cliff edge that he estimated would be safe from erosion for at least 200 years. His calculations were remarkably accurate. Between 1868 and 1972, the cliff retreated 21 meters, just short of the 30 meters per century that Washington had calculated. A seawall that now protects the lighthouse may prolong its existence beyond George Washington's expectation.



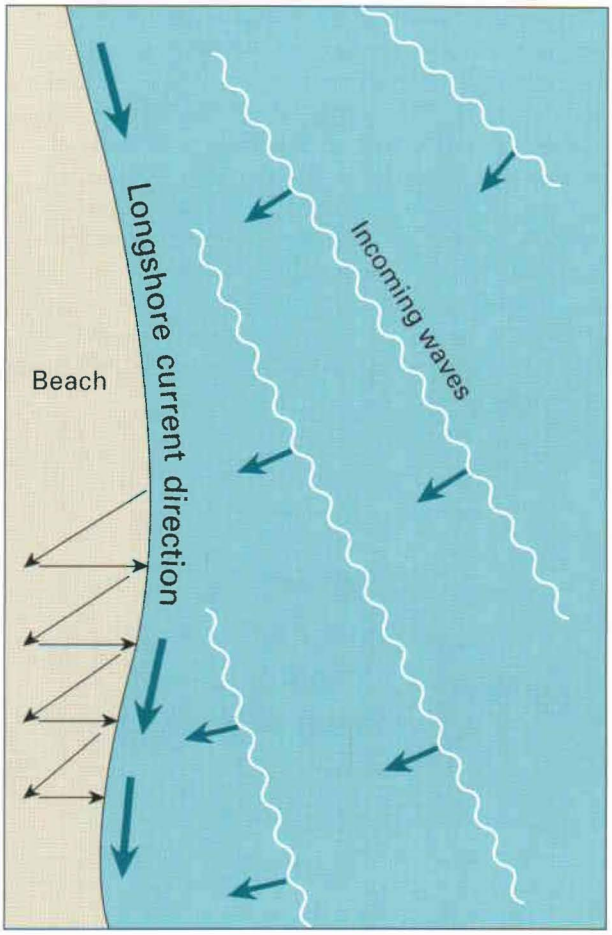
NATURAL PROCESSES

Coastal lands and sediments are constantly in motion. Breaking waves move sand along the coast, eroding sand in one area and depositing it on an adjacent beach. Tidal cycles bring sand onto the beach and carry it back into the surf. Rivers carry sediment to the coast and build deltas into the open water. Storms cause deep erosion in one area and leave thick overwash deposits in another. Plants retain sediment in wetlands and impede movement of coastal dunes. Natural processes that change the water level also affect coastal dynamics. Taken individually, each natural process of coastal transport is complex; taken collectively, they create an extraordinarily intricate system that attempts to achieve a dynamic balance.

WAVES, TIDES, AND WEATHER

Winds create waves that ripple across the surface of lakes and seas until they break on the shallowing bottom and crash into the shore. In many areas, prevailing winds produce waves that consistently approach the coast at oblique angles. Even the slightest angle between the land and the waves will create currents that transport sediment along the shore. These longshore currents are a primary agent of coastal movement; they are a major cause of sand migration along barrier and mainland beaches.

Tides ebb and flood in response to the gravitational attraction of the moon and sun; exceptional high and low tides occur each month when the sun and moon are aligned. Tides help determine where the waves break—low on the beach at low tide, high on the beach at high tide—and, therefore, where sand is deposited and removed.



Sand is transported alongshore by currents formed when waves strike the beach at an angle. Sand is also carried along the shore in a zigzag pattern by waves rushing onto the beach and back to the ocean.

Rip tides, or undertow, occur along most beaches and can move significant amounts of sand offshore.

Storm systems along coasts contain high winds, create large waves, and cause storm surges that raise water levels as much as 7 meters above normal. Although storms are sporadic, they are the primary cause of beach erosion along many coasts. Storms carry sand seaward, forming offshore bars; much of this sand migrates landward during calm weather. Some areas are more storm prone than others. Storms often are concentrated in specific seasons; along the eastern seaboard, for example, hurricanes occur in the late summer and early fall, and storms are especially frequent during the winter months. These seasonal trends result in a general difference between the winter "eroding" beach and the summer "building" beach that is most common along parts of the west coast.

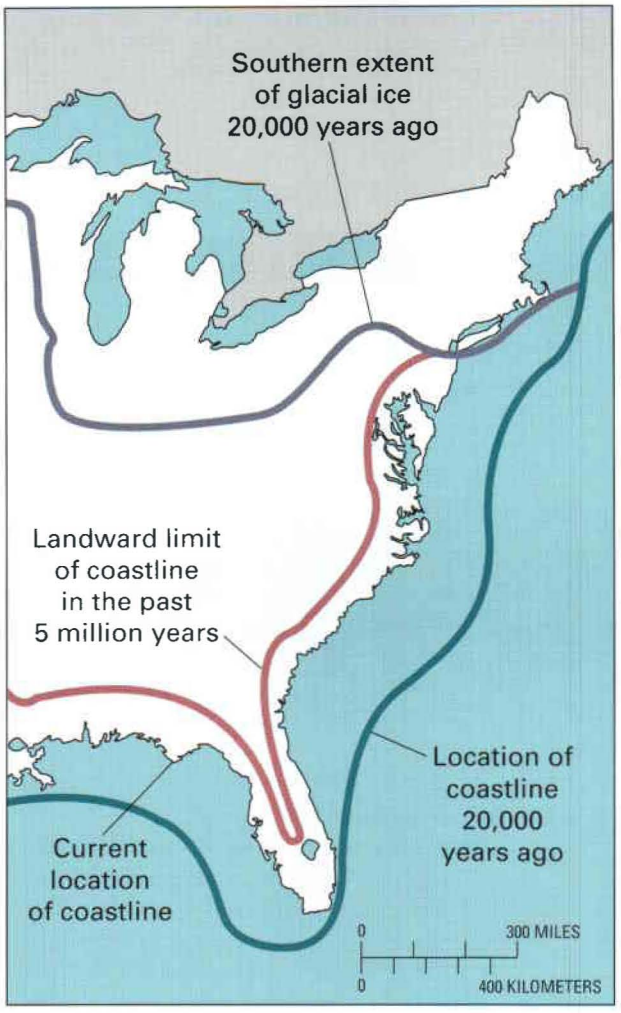
GALVESTON, TX

The city of Galveston, Texas, on a low-lying barrier island in the Gulf of Mexico, is the site of the worst natural disaster ever to strike the United States. In September 1900, a hurricane with wind speeds estimated as high as 160 kilometers an hour raised a 6-meter storm surge that covered the entire island with 3–5 meters of water. At least 6,000 people were killed, more than 3,500 houses were destroyed, and a third of the city was leveled by the wind, waves, and wreckage. A wall of debris—streetcar tracks, lengths of railroad track, sections of wrecked houses—built up about six streets inland from the beach and parallel to it, saving much of the business district from total destruction.

To protect the city from further disastrous hurricanes, Galveston and the U.S. Army Corps of Engineers raised the land surface by more than 3 meters and built a massive seawall along the entire Gulf side of the city, at a cost of $3.5 million—a vast sum in 1900. Later additions have extended the wall along the coast more than 16 kilometers. Where no groins hold the sand, the beach has disappeared; beyond the western end of the wall, the beach has eroded back about 50 meters. In 1961 Hurricane Carla struck the Texas coast, flooding more than 1.5 million acres of land and causing considerable damage in the parts of Galveston not protected by the seawall.

Deadliest U.S. natural disasters

1900	Galveston, Texas	Hurricane and flood	More than 6,000 dead; 3,600 houses destroyed.
1889	Johnstown, Pennsylvania	Dam collapse and flood	More than 2,200 dead.
1871	Peshtigo, Wisconsin	Fire	More than 1,200 dead; 2 billion trees burned.
1906	San Francisco, California	Earthquake and fire	More than 700 dead or missing; more than 10 square kilometers of the city razed.
1925	Missouri-Illinois-Indiana	Tornado	695 dead.



Sea level has risen dramatically since the end of the last ice age, about 20,000 years ago.

WATER-LEVEL CHANGES

In addition to the daily cycles of tides, many other forces lead to significant changes in water level. Predominantly closed bodies of water such as lakes experience dramatic water-level changes in response to precipitation, spring snowmelt, and evaporation. A prolonged period of wet weather in Utah in the early 1980's, for example, raised the Great Salt Lake's water level to record highs, flooding parts of Salt Lake City.

Other local changes in water level occur when the land either rises or falls relative to the water. Along tectonically active coasts, such as the coast of earthquake-prone southern California, land may rise as much as 4 centimeters per century. In recently abandoned deltas, such as near the mouth of the Mississippi River, compaction of newly deposited sediment results in extensive land subsidence (as much as 1 meter per century). The Earth's crust in parts of Alaska and the Great Lakes area, which was pressed down by the weight of the massive ice sheets that blanketed the north during the last great ice age, is now rising due to the retreat of the glaciers. In southeastern Hudson's Bay, Canada, this crustal rebound is raising vast areas of land at rates as high as 4 meters per century; rates along Lake Superior's north shore reach 60 centimeters per century.

Sea level has been rising continuously over the last 20,000 years.

Global changes in sea level result from tectonic processes, such as the down- or upwarping of the ocean basins, or from changes in the total volume of water in the oceans. During the last great ice age, which began 36,000 years ago, huge amounts of ocean water were transformed into glaciers, resulting in a 100-meter drop in the global sea level. We are still emerging from that ice age, and sea level has been rising continuously over the last 20,000 years; during the past century, the rate of sea level rise has averaged 10–15 centimeters per century worldwide.

The slope of a coast is critical to determining how water-level changes will affect it. Steeply sloping coasts experience small shifts in their coastlines as the water level changes; however, because wave action along steep coasts is concentrated within a narrow zone, small water-level increases can result in significant erosion of

bluffs or dunes. On a gently sloping coast, like the U.S. east coast or around the Gulf of Mexico, small changes in water level cause the coastline to shift dramatically; however, the gentle slope absorbs and dissipates the waves' energy along a broad front.

COASTAL VEGETATION

Rooted plants flourish along the shores of bays, estuaries, deltas, and other coastal environments that are protected from the full fury of pounding waves. Plants stabilize dunes through root networks. They build and maintain marshes by catching and retaining in their roots the fine sediment carried by the water. Their natural decay cycle further enriches coastal soils and sediment with decomposing plant matter. Differences in weather regimes, tidal depth, and water salinity determine which plant populations will thrive in a given coastal environment.

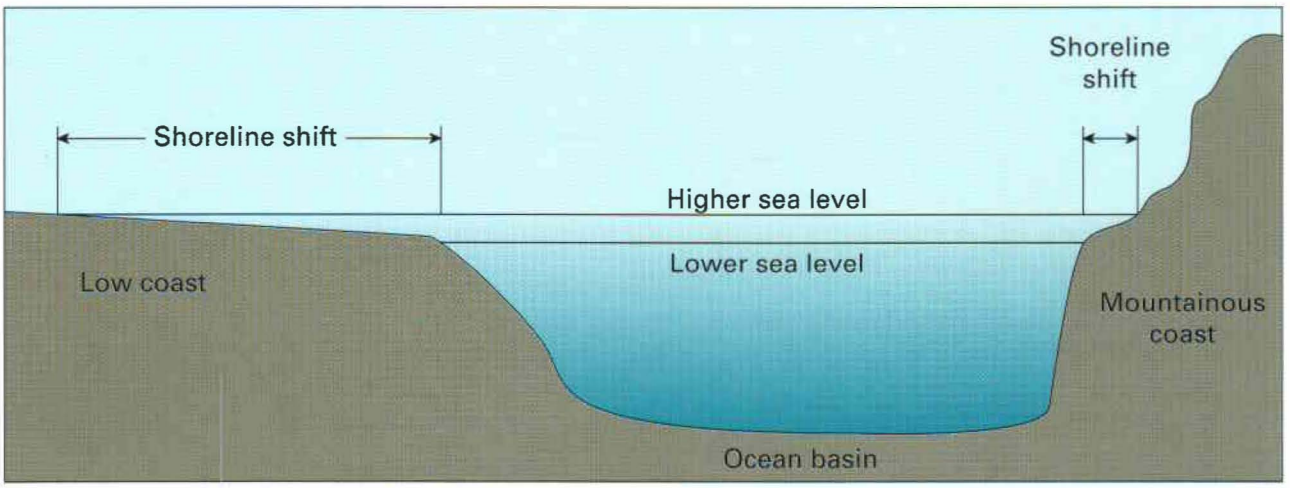
A large variety of plant species occurs in coastal areas where tides are extreme, since some plants require total submergence, some tolerate cyclical submergence and aeration, and others flourish in environments that remain dry except at the highest tides. Diversity of species is greatest where water salinity is low. Those few plant species that live in the most saline water have developed ways to control the internal osmotic pressure of their cells.



Freshwater marshes, like this one on Lake Michigan's coast, are subject to a wide range of water levels.

Gradual changes in weather patterns, salinity, tidal action, and sea level allow normal plant succession to occur in protected coastal environments. Abrupt changes in these conditions often result in widespread destruction of plant communities and the loss of sediment being held by their roots. For example, erosion of barrier islands can lead to saltwater intrusion and increased wave action, which kills plants and destroys the wetlands behind the islands.

Small vertical changes in water level shift coastlines dramatically on gently sloping coasts but cause only minor shifts on steep coasts.



LOCAL CONDITIONS

While the same dynamic processes cause continuous change on every coast, coasts do not all respond in the same way. Interactions among the different processes and the degree to which a particular process controls change depend upon local factors. They include the coast's proximity to sediment-laden rivers and tectonic activity, the topography and composition of the land, the prevailing wind and weather patterns, and the configuration of the coastline and nearshore geometry. Earth-science research is showing that these local conditions determine not only the changes to the coast but also the type of coast produced.

MAINLAND BEACHES (Southern California)

The mainland beaches of southern California border an active tectonic region of fault-bounded crustal blocks with high elevations. Ancient shoreline terraces hundreds of meters above present sea level are evidence of rapid and extensive crustal uplift along the coast. The narrow offshore continental shelf is cut by numerous submarine canyons and bordered by deep ocean basins. The weather is temperate year round, but winter storms often dramatically reshape the coast.

The major sediment sources for the beaches of southern California are eroding headlands and adjacent beaches and, to some degree, sediment from local rivers in flood. The major agent of sediment transport along the coast is longshore drift, which moves the sand southward. Submarine canyons in some areas are so close to the shore that they intercept the longshore drift and funnel beach sand seaward into very deep water. The beaches are relatively steep, resulting in a narrow wave zone between high and low tide. This narrow zone receives the brunt of the waves' pounding, and movement of beach sediment (erosion and deposition) is concentrated within this zone.

BARRIER BEACHES (Southeastern United States)

The southeastern coast, rimmed by a series of barrier islands and spits, separates the mainland coastal plain from a wide, gently sloping offshore continental shelf. This generally tectonically stable region has a storm and hurricane season during the late summer to winter months; high-wind events such as Hurricane Hugo, which came ashore near Charleston, South Carolina, in 1989, are not uncommon. Most rivers cutting through the low-lying coastal plain flow slowly to the sea and deposit their sand-sized sediment in bays and estuaries before reaching the coast.

Instability of the bluffs behind mainland coasts, such as this one in California, is a major environmental concern.





Storm overwash and other processes have deposited sand in complex patterns along this South Carolina barrier spit.

The river's suspended load of finer particles settles out in the sounds and bays that are protected by barrier islands and spits.

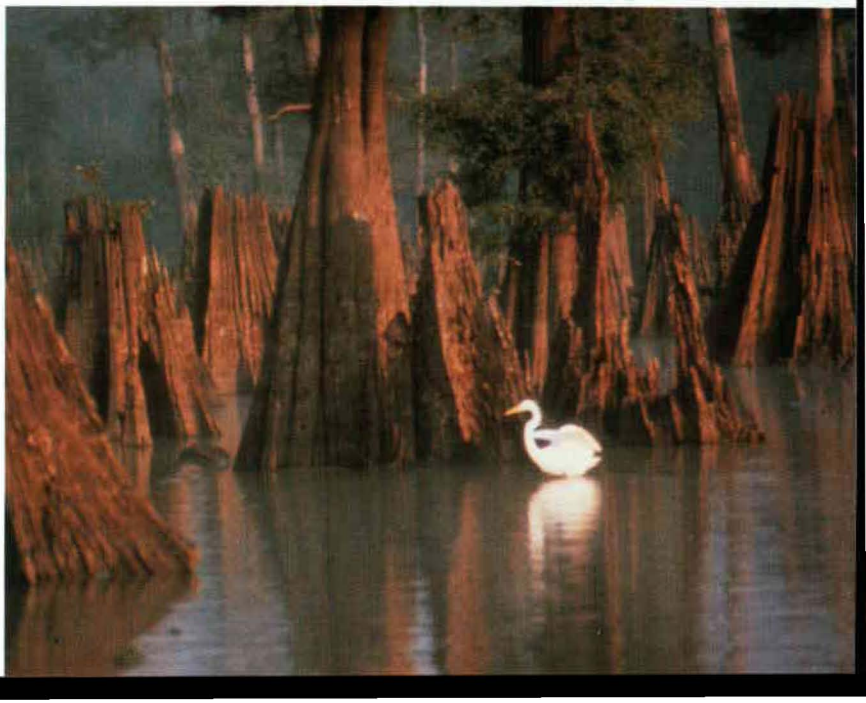
The major source of new sediment to the barrier beaches of the Southeastern United States is erosion of the adjacent headlands and beaches, whose sand generally migrates south as a result of longshore transport. Sand transported landward from the continental shelf also may contribute to the coast and nearshore sand budget. The gentle slope of the southeastern beaches results in widely separated high- and low-tide zones, and wave energy is absorbed along this broad surface.

WETLANDS
(Coastal Louisiana)

The gulf coast of Louisiana includes a broad expanse of wetlands sheltered from the wave action of hurricanes and winter storms by low-lying barrier islands. Both the wetlands and their protecting islands have formed as a direct result of the shifting of the Mississippi River delta lobes during the past 7,000 years. The deltaic processes that control the movement of water and sediment have resulted in a system of complex drainage patterns, natural ridges and levees, and offshore barrier beaches—all of which restrict the advance and encroachment of salt water.

Plant life is vital to building and maintaining wetlands. The coastal Louisiana wetlands are biologically zoned on the basis of the salinity of the water and the fluctuations in water depth, with different plant populations living in different areas. The dependence of these wetlands on the Mississippi River and its distributaries as a direct source of sediment and fresh water leaves them vulnerable to changes in the river system. Their dependence on barrier islands for protection against waves leaves them vulnerable when the barrier islands are eroded.

An egret picks its way among cypress knees in a Louisiana wetland.



CHICAGO, IL

Chicago's extensive waterfront along Lake Michigan includes many engineering structures built 50 to 80 years ago to protect the city from storm waves and flooding. A period of high lake level in the mid-1980's exacerbated the deterioration of many of these aging seawalls, revetments, and other structures. The U.S. Geological Survey (USGS), in cooperation with the Illinois State Geological Survey, used sidescan sonar instruments to determine the causes and extent of the deterioration. This knowledge contributed potential savings of tens of millions of dollars to the structural repair of Chicago's waterfront by distinguishing areas that were still structurally sound from those needing repairs. Other USGS studies in progress provide data on the specific erosional processes at work, vital knowledge for those attempting to mitigate the damages. Water levels have dropped slightly since the record highs of a few years ago, but continuing studies have shown that those highs are part of the natural cycles of lake-level fluctuations in the Great Lakes.



LAKE SHORES
(Lake Erie)

Lake Erie is the shallowest of five large interconnected bodies of fresh water, known collectively as the Great Lakes, that form part of our political border with Canada. The basins of the Great Lakes were carved by continental glaciers during the last great ice age and filled with melt waters as the glaciers retreated northward.

Wave and tide action are generally limited in lakes because they are relatively small bodies of water. However, due to Lake Erie's size and oblong shape, communities at the ends of the lake, like Buffalo and Toledo, suffer from dangerous storm surges. These storm surges can quickly raise the local lake level by more than a meter. Though they may last only a few hours, surges can do considerable damage, primarily from flooding.

Much of Lake Erie and its beaches and cliffs are frozen during winter, inhibiting the formation of storm waves and reducing erosion. However, during ice formation in early winter and during the spring thaw, ice processes can accelerate erosion. The spring rains, snowmelt, and low evaporation rates cause Lake Erie's average water level in June to be more than 30 centimeters above the typical January level. Several years of above-normal precipitation, as in the mid-1980's, can cause Lake Erie's water level to rise significantly above its long-term average, increasing the likelihood of flooding and erosion.

Left: Parts of Chicago's protective seawall are 80 years old and badly deteriorated.
Above right: The heavily engineered Chicago shoreline is vulnerable to damage from Lake Michigan.
Right: The once-wide beach at Cape May, New Jersey, has been stripped of its sand by longshore currents; the sand that would normally have replenished the beach is trapped updrift by jetties at Cape May inlet.



HUMAN INTERVENTION

Human activities add another layer of complexity to the natural processes of coastal lands and materials. These activities may have direct or indirect effects on our changing coasts. They may affect sources of new sediment to the coast and the movement of sediment within the coastal environment; they may promote changes in sea level, both local and global.

People's activities are often conducted without an adequate understanding of coastal geology and processes. As a result, they can lead to unforeseen degradation of coasts. Even human actions intended to save or improve the coast may inadvertently increase erosion. Cooperative scientific investigations are starting to provide the crucial information needed to minimize the unintended effects of human disturbances along coasts.



PRESQUE ISLE, PA



About six million people per year visit the State Park at Presque Isle, near Erie, Pennsylvania. The park is a sandspit, nearly 10 kilometers long, that has built out from the Lake Erie shore. The narrow neck connecting it with the mainland is eroding as fast as 2.5 meters per year. Large harbor jetties built in the 1800's along the Lake Erie coast in Ohio may have trapped much of the sediment that is carried eastward by longshore currents. The U.S. Army Corps of Engineers has spent millions of dollars over the past century to stabilize the area, but the problems continue. In the mid-1970's, an attempt was made to replenish the beach on Presque Isle; unfortunately, the dark sand chosen as fill contained too much calcium carbonate, which cemented the sand particles to form an escarpment as much as 1 meter high. Below the sand scarp, the natural beach sand continues to erode. Recently, the Corps of Engineers has begun a project to construct a series of 58 segmented breakwaters at a cost of $30 million to protect Presque Isle.



SEDIMENT STARVATION

For some coastal regions, such as the Pacific coast, a large part of their sediment budget is supplied by rivers. Dams built for flood control and water catchment along the rivers leading to these coasts inhibit the transport of large-grained sediments. Lacking new material, the sediment-starved coasts erode and migrate inland. Damming of tributary rivers to the Mississippi River over the past 60 years has also reduced the movement of sediment. Studies by the USGS in recent years demonstrate that the amount of sediment carried by the Mississippi has been cut in half, aggravating the deterioration of Louisiana's wetlands.

An important source of sediment to Louisiana's deltaic wetlands was periodic flooding of the Mississippi River, which deposited new material on the flood plain. Massive levees built along the riverbanks now contain these floods and eliminate the supply of sediment to the wetlands. As a result, the natural compaction and subsidence of the delta are no longer balanced by the deposition of new sediment, and the relative local sea level is rising as much as 1 centimeter per year. Sediment-laden water, retained by levees along the Mississippi River, deposits its load into deep water at the mouth of the delta, where most of the sediment is lost to the coastal environment. To counteract the effects of damming and channelization, the U.S. Army Corps of Engineers is building structures to divert fresh water from the Mississippi River to adjacent wetlands.

Attempts to counter sediment starvation along severely eroding coasts have included the artificial replenishment of beach material by placing sand directly onto the beach. Beach nourishment is not a permanent solution and is expensive, but in some regions it can be cost effective. The lack of clean sand suitable for fill often limits beach nourishment programs, but offshore surveys can locate sand bodies for dredging and transport to the beach. A few

Above left: Erosion threatens the highway along the neck that connects Presque Isle to the Pennsylvania shore. Below left: Darker sand used for beach replenishment at Presque Isle forms a 1-meter-high scarp.

beach replenishment programs have had long-term positive effects; the Miami Beach replenishment done in the late 1970's at a cost of $64 million has already survived more than a decade. Typically, these nourishment projects are not as effective; along the east coast, half of the replenished beaches lasted 2 years or less.

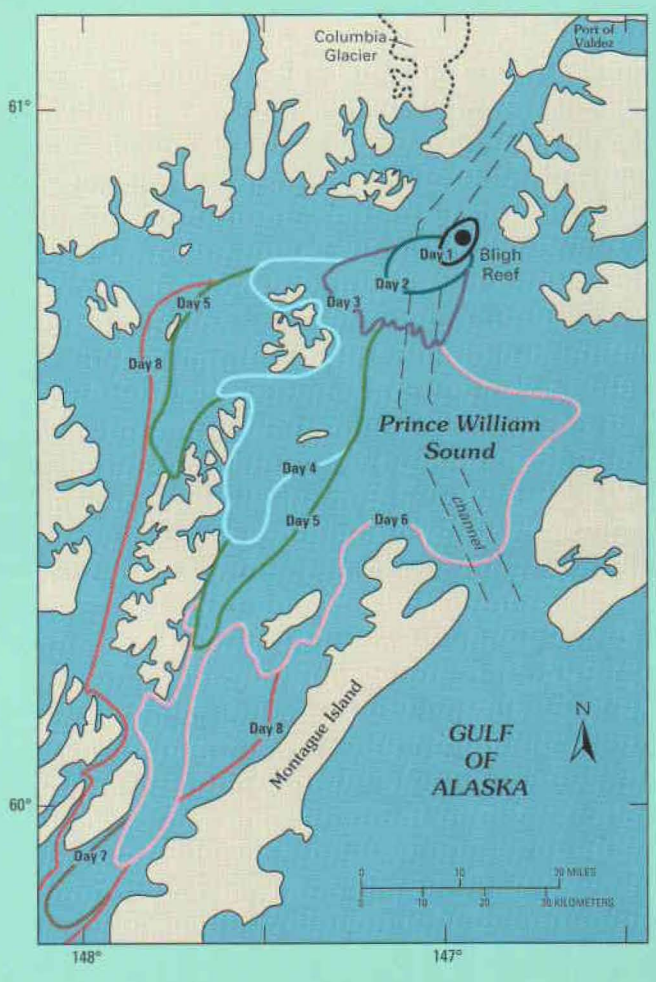
POLLUTION

As the number of active landfills dwindles and coastal populations grow, offshore waste dumping and coastal pollution increase. This additional dumping increases the possibility of improper waste disposal polluting the coastal environment. Living coral reefs are particularly vulnerable to pollution, but other coastal environments suffer as well. Medical waste, including used hypodermic needles, was washed onto the New Jersey and New York beaches during the summer of 1988, resulting in an economic disaster for the recreation industries in the region. Fishing industries have also been severely damaged by coastal pollution; more than one-third of our Nation's shellfish beds are closed or restricted as a result of contamination.

SEDIMENT TRAPPING

The natural movement of sand is at best a nuisance for owners of beachfront property. When this movement results in a net loss of sand from the beach, the natural process may be considered by owners as a serious threat. To prevent beach loss, groins are often constructed out into the water. These solid structures impede the littoral drift of sand caused by longshore currents. The beach then expands on the updrift side of the groin; however, the downdrift side of the groin loses sand because of continuing longshore movement. Small groins may have little effect on sediment movement along the entire beach. Larger groins or jetties, such as the ones at the southern end of Ocean City, Maryland, and at Cape May, New Jersey, can lead to impressive retention of beach materials on the updrift side, but these gains must be balanced against the coastal degradation on the downdrift side. Sediment carried out past the jetty may be deposited as shoals offshore in deeper water

PRINCE WILLIAM SOUND, AK



On March 24, 1989, an oil tanker struck Bligh Reef in Prince William Sound, Alaska, releasing more than 200 million liters of oil. The map above outlines the oil-spill front as it expanded from 1 to 8 days after the spill; it was compiled from aerial observations by the National Oceanic and Atmospheric Administration, Exxon, the U.S. Coast Guard, and the Alaska Department of Environmental Conservation. Bottom sediments studied by the USGS more than 7 weeks after the spill contained no clear evidence of oil pollution; possible traces of contamination were found near the south end of the Sound, but the presence of oil could not be confirmed. Much of the oil was carried onshore by surface currents and deposited along the beaches. Long-term monitoring is needed to assess the effect of the spill on the marine environment. *(Modified from Carlson, P.R., and Reimnitz, Erk, 1990, Characterization of sample sites along the oil spill trajectory in Prince William Sound and the Gulf of Alaska: U.S. Geological Survey Open-File Report 90–39–A, 24 p.)*



At Manasquan, New Jersey, a groin has trapped sand on the updrift side, but the downdrift beach is starved of sand.



A series of groins at Norfolk, Virginia, interrupts the natural transport of sand by longshore currents.

and removed from the active coastal sediment budget, further increasing downdrift erosion.

Seawalls constructed to protect property along retreating beaches often exacerbate beach erosion. They confine the wave energy and intensify the erosion by concentrating the sediment transport processes in an increasingly narrow zone. Eventually, the beach disappears, leaving the seawall directly exposed to the full force of the waves. For example, a massive seawall built to protect a highway and beach houses along the northern New Jersey coast has resulted in the complete disappearance of the beach itself.

COASTAL DEGRADATION

Human actions that lead to the destruction of dune grasses and the disturbance of coastal landforms promote increased erosion and movement of beach materials. Off-road vehicles and foot traffic on sand dunes compact sand, destroying plant roots and animal burrows. Other wildlife habitats, such as nesting and feeding areas for shorebirds, are disturbed by human activity; young birds are especially vulnerable to these disruptions.

The downdrift side of the groin loses sand because of continuing longshore movement.



Fragile wetlands are easily damaged by salt water that invades canals dredged for navigation and oil exploration.

Sand dunes help absorb the pounding of high waves and reduce overwash flooding during storms; bulldozing dunes to improve views of the sea destroys this natural protection. Dredging navigation channels and tidal inlets and discharging the material in deep water also remove sediment from the coastal system and interfere with longshore transport. Canals cut in wetlands for navigation, pipelines, and drainage provide channels for salt-water invasion during storms and high tides; the increased salinity often kills marsh plants, leading to accelerated land loss and deterioration of wetlands.

WATER-LEVEL CHANGES

Human activities can cause local and possibly global changes in sea level. Pumping of ground water, salt brines, and petroleum resources from coastal environments has led to significant subsidence in many regions; the Texas coast around Galveston Bay has experienced a particularly alarming rise in its relative sea level. The increasing release of greenhouse gases, such as carbon dioxide and methane from automobile and industrial exhaust, may promote global warming, the melting of massive ice sheets in Greenland and Antarctica, and consequently the raising of sea level worldwide.



Vehicle tracks cut across the sand dune, destroying plants and leaving it vulnerable to erosion.

COASTAL CONFLICTS

Conflicts between human activities and natural systems exist wherever the two come together in the coastal environment; indeed, some clashes are inevitable. However, increasing demands on our coastal environments as a result of the competition between human goals and natural processes have led to dramatic examples of these conflicts. Among the most striking examples are Ocean City, Maryland; Hurricane Hugo's effects on Puerto Rico and South Carolina; Isles Dernieres, Louisiana; and Boston Harbor, Massachusetts.

OCEAN CITY— An Urbanized Barrier Island

Ocean City, Maryland, has been a popular beach resort for more than a century. During the 1920's, several large hotels and a boardwalk were built to accommodate visitors. Development was slow but steady until the early 1950's, when a dramatic boom in construction began that lasted almost 30 years. Early concerns about the coastal environment were raised in the late 1970's and led to Federal and State laws to limit dredging and filling of wetlands.

The resort is built on the southern end of Fenwick Island, one of the chain of barrier islands stretching from New York to Florida. Ocean City Inlet, which connects the quiet backwater bay with the Atlantic Ocean at the southern end of the island, was opened during the great hurricane of 1933, by storm-surge overwash from the bay side. To maintain the inlet as a navigation channel, two stone jetties were constructed by the U.S. Army Corps of Engineers shortly after the storm. The jetties have stabilized the inlet, but they have drastically altered the sand-transport processes near the inlet. The net longshore drift at Ocean City is southerly; it has produced a wide beach at Ocean City north of the jetty, but Assateague Island, south of the inlet, has been starved of sediment. The result is a westerly offset of more than 500 meters in the once-straight barrier island.



Oblique view of the highly developed barrier beach at Ocean City. The dunes that once protected the island have been removed to improve the view, and the tall apartment buildings are so close to the water's edge that the beach is shadowed by midafternoon. Many of these buildings were damaged by flooding immediately after their construction. Beach replenishment along Fenwick Island in 1988 and 1990 by the State of Maryland and the U.S. Army Corps of Engineers is designed to provide some temporary protection to the buildings and to increase the recreational value of the beach.

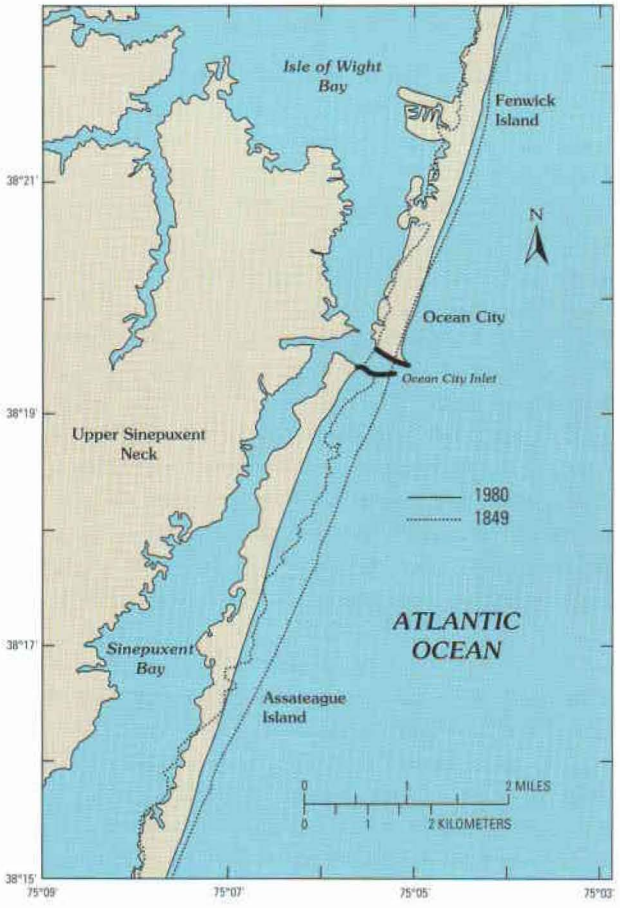
The most damaging storm to hit Ocean City within historic times was the Five-High or Ash Wednesday northeaster of early March 1962. It caused severe erosion and flooding along much of the middle Atlantic Coast. For 2 days, over five high-tide cycles, all of Fenwick Island except the highest dune areas was repeatedly washed over by storm waves superimposed on the 2-meter-high storm surge. Property damage to Ocean City alone was estimated at $7.5 million. Given the dense development of the island over the last 20 years, damage from a similar storm would today be hundreds of millions of dollars.



Above: The dashed line on this 1978 photograph marks the approximate limit of the storm surge during the Five-High storm of March 1962. Most of the large buildings within the storm-surge zone were constructed during the 1970's; capital expenditures for these buildings and the large number of mobile-home parks that are also within the surge zone were more than $100 million. Their value today is several billion dollars. (From Dolan and others, 1980.)



Oblique view of Ocean City Inlet (about 1980) showing the 500-meter offset between Fenwick Island (north) and Assateague Island (south) due to sediment starvation as a result of construction of the jetties in the 1930's.



Right: Shoreline changes in the Fenwick Island-Assateague Island region between 1849 and 1980 show the dramatic effects of the two large jetties at Ocean City Inlet on the natural sediment-transport processes along the coast.



Hurricane Hugo caused at least $2.5 billion in damages to Puerto Rico.

HURRICANE HUGO— Storm Devastation

Hurricane Hugo struck Puerto Rico in mid-September 1989, packing wind speeds of more than 250 kilometers per hour at the height of the storm. The 0.6-meter storm surge, combined with the rising tide and the 3- to 5-meter storm waves, inflicted serious damage to the island and its economy; total monetary damage was $2.5 billion, and eight people died during the hurricane and its aftermath. The position of the shoreline remained generally constant, but much sand was removed from the beach and deposited behind the dunes, outside of the coastal environment. Coral colonies were choked by sediment, and many were destroyed. A large offshore sand deposit (about 90,000,000 cubic meters) was leveled by storm waves and dispersed over the ocean floor.

Hugo hit the U.S. mainland just north of Charleston, South Carolina, bringing sustained winds of 215 kilometers per hour and a maximum storm surge of more than 6 meters. The barrier islands along the South Carolina coast are generally less than 3 meters above sea level, and many showed evidence of having been completely inundated by the storm surge. In many places, beaches were severely eroded and dunes were leveled. Much of the sand removed from the beach was overwashed landward or carried offshore. A total of 29 people in South Carolina died, and total damages were $5.9 billion.

The damage Hugo caused along South Carolina's barrier islands and shore communities clearly shows the importance of good construction and the natural protection provided by a wide, high beach and sand dunes. Folly Beach, south of Charleston, was on the weaker (south) side of the hurricane, but its beaches were already severely narrowed by long-term erosion; homeowners had dumped boulders and concrete rubble on the beach to form a protecting revetment. The revetment proved useless during Hugo. The storm surge (over 3.5 meters at Folly Beach) overtopped the structure, caused major damage to beachfront houses, and totally swept away a popular seafood restaurant. Isle of Palms and Sullivans Island, north of Charleston, suffered substantial damage, but the effects were somewhat lessened by a wide beach and dunes. Houses that survived were built to withstand high winds and flooding, in contrast to homes built to lower standards that were totally destroyed.





Damage by Hugo to South Carolina's Isle of Palms and Sullivans Island underscores the need for knowledge of beach and storm processes in order to protect lives and property.

ISLES DERNIERES— Eroding Barrier Islands

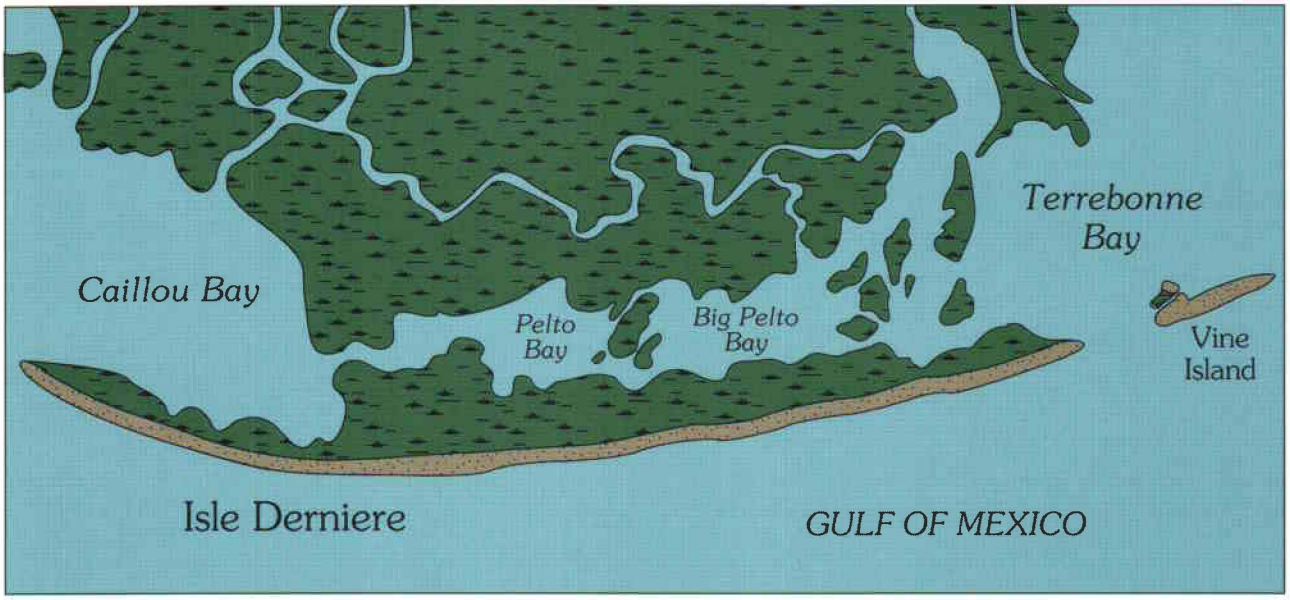
The Isles Dernieres barrier chain stretches for 32 kilometers along the coast of Louisiana, about 100 kilometers west of the mouth of the Mississippi River and 120 kilometers southwest of New Orleans. Coastal studies conducted since 1985 by the USGS and the Louisiana Geological Survey indicate that the Isles Dernieres are eroding as fast as 20 meters per year. These high erosion rates, caused by both natural forces and human actions, have produced one of the most rapidly deteriorating shorelines in the world.

Geologic investigations during the last 40 years have shown that the low-lying plain and coastal barrier islands of southern Louisiana consist of fine sand and mud deposited by the Mississippi River in four successive delta complexes over the past 7,000 years. Each time the river channel moved to a new position, the combination of natural subsidence and reduction in sediment supply caused erosion and deterioration of the abandoned delta. The Isles Dernieres mark the end of a delta that reached its maximum size about 500 years ago.

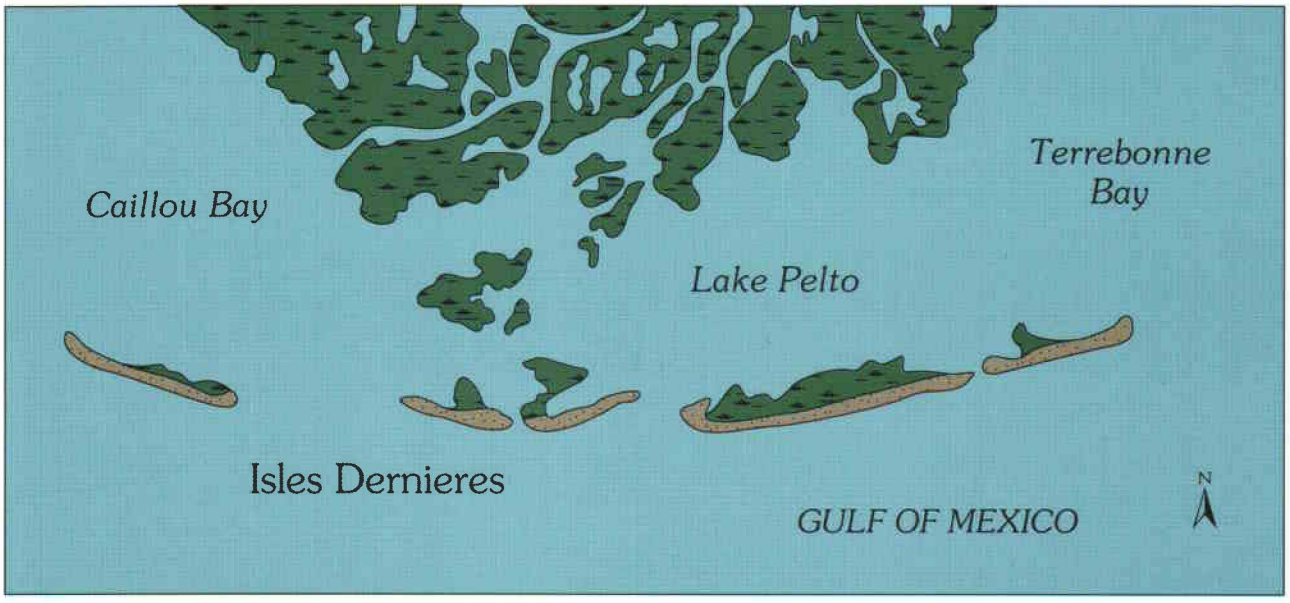
By the mid-1800's, the Isles Dernieres were a single wide barrier island supporting mature forests and a thriving resort community. A devastating hurricane struck the island in 1856, destroying the resort and killing hundreds of people. Over the past 130 years, natural processes of storm erosion and a rise of more than a meter in relative sea level have dramatically reshaped the Isles Dernieres. The once-continuous island has been cut by wide tidal inlets into five smaller islands, which have shrunk rapidly in recent years. They are now so close to sea level that they are overwashed during storms and high tides six to eight times a year. Extrapolation of the historic data shows that if these erosion rates continue the Isles Dernieres will be submerged by approximately the year 2020. Although the disappearance of these islands will not have an immediately noticeable impact, as would the destruction of a developed barrier like Ocean City, Maryland, it will expose the wetlands and estuaries of southern Louisiana to greater wave and current action and may hasten the loss of these vital resources.

The Isles Dernieres have one of the most rapidly eroding shorelines in the world; they are overwashed by storms and high tides half a dozen times a year.





1853



1978

0 5 MILES
0 5 KILOMETERS

In the past 150 years, rapid erosion of the protecting barrier islands has exposed Louisiana's valuable wetlands and estuaries to increased storm waves and currents. (Modified from Penland and others, 1989.)

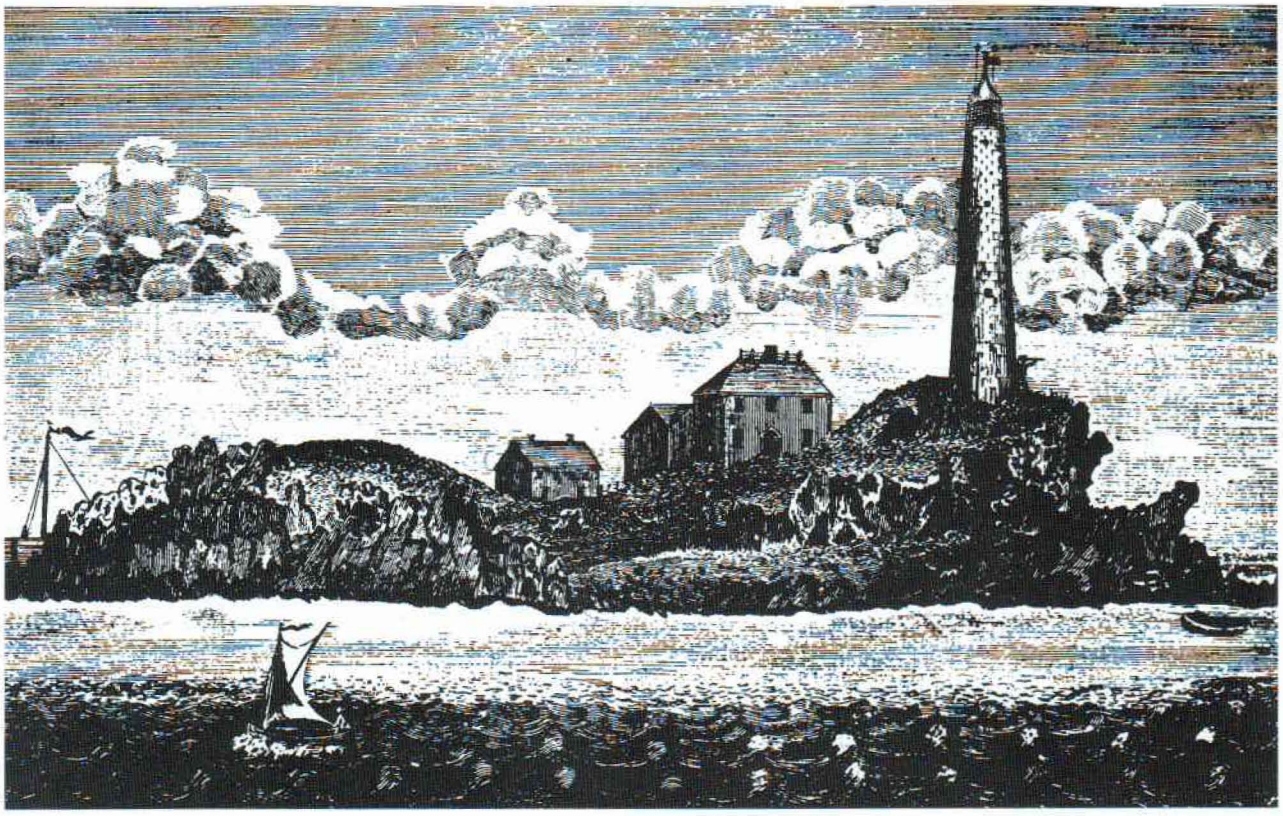


The protecting islands that enclose Boston Harbor also block ocean currents, which would otherwise help disperse urban pollution.

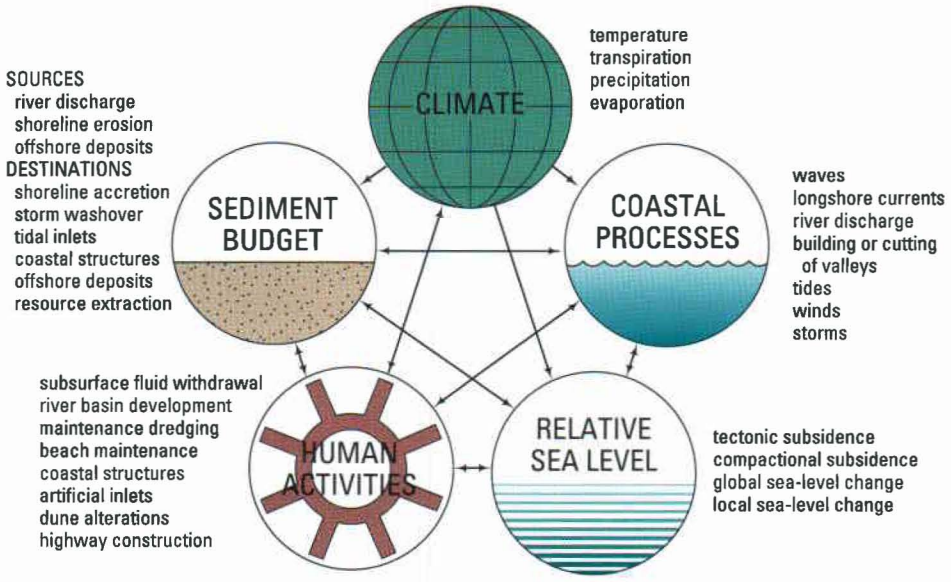
BOSTON HARBOR— Centuries of Pollution

Boston, one of the oldest and largest metropolitan centers in the United States, covers about 1,500 square kilometers and includes more than 75 separate cities and towns. One of the earliest metropolitan boards to unite these separate entities was the Metropolitan Sewerage Board, established in 1889 to deal with the growing pollution of Boston's rivers by raw sewage. A century later, Boston Harbor and the surrounding beaches are still plagued by pollution. In addition to the continued sewage problem, heavy metals (chromium, copper, lead, and zinc, for example) also contaminate the sediments in the harbor, as well as the fish and shellfish that are a major source of revenue. These contaminated sediments may continue to be sources of toxins long after the primary pollution sources are reduced or eliminated.

A $6 billion cleanup plan, to be completed by the year 2000, includes elimination of ocean discharge of sewage sludge, upgrades of sewage treatment, and construction of a new ocean outfall for the treated effluent about 13 kilometers seaward of the harbor mouth. As part of the effort and in cooperation with the Massachusetts Water Resources Authority, the USGS has established a long-term current and sediment-transport monitoring station in Massachusetts Bay to provide information vital to the design of the proposed ocean outfall. Additional USGS studies, coordinated with other Federal and State agencies through the Massachusetts Bay Management Committee, are mapping the sediment composition on the bay floor, determining the levels of various contaminants in the sediments, and estimating rates of sediment accumulation and mixing. Data and interpretations gained though these studies are helping to determine the fate and effects of pollutants and will assist coastal managers to develop efficient cleanup procedures and mitigation measures.



Boston has been an important harbor for centuries; this engraving shows its lighthouse in 1789. (From the Massachusetts Magazine, 1789).



Factors affecting coastal environments are interwoven in an intricate web. (Modified from Pilkey and others, 1989, Coastal land loss; 28th International Geological Congress Short Course: Washington, D.C., American Geophysical Union, 73 p.)

CONCLUSIONS— Earth-Science Challenges and Opportunities

Coasts, as boundaries between land and water, are characterized by the geologic nature of the land, which is unstable and often fragile, and the dynamic power of wind and sea. As a result, coastal environments are constantly changing as they seek to achieve and maintain equilibrium among the many opposing natural forces. The vibrant beauty of shore areas is attracting a growing population of homeowners and vacationers; however, the ever-changing character of coasts makes them hazardous for people and, in the long term, for buildings and structures. The risks associated with living along a coast are comparable to those experienced by people living on a river flood plain, near an earthquake fault, or close to a volcano—all carry the possibility of eventual catastrophe. Because coastal regions have wide public appeal as places to live, population growth continues to accelerate along our Nation's coastline. This population explosion superimposed on the dynamic forces acting on coasts is leading to a coastal crisis marked by the following concerns:

* Coastal erosion at widely varying rates affects all 30 coastal States and all of the U.S. Island Territories.

* During the past 200 years, more than half of our valuable wetlands have been lost due to a combination of natural processes and human intervention.

* Pollution of coastal areas has forced the closing of one-third of the Nation's shellfish beds, has restricted beach use, and has permanently contaminated ground water in some communities.

* In many coastal urban areas, hard-mineral resources such as sand and gravel for construction and beach nourishment are no longer available onshore. Offshore deposits may provide an alternative but pose environmental and economic dilemmas.

The crisis in the coastal zone is worldwide but is especially alarming in the United States, where an expanding and more affluent popula-

tion combined with a variety of government subsidies over the past 50 years have enabled widespread and often unwise development to take place. If present demographic trends of population growth and expanded development continue, and if sea-level rise brought on by potential climate changes also occurs, stress on our coastal environments will increase substantially.

Intelligent stewardship of our coastal resources requires balancing human needs and expectations with coastal realities. Earth-science information that is based on sound scientific research on our coasts, the way they change, and the factors influencing their development is critical in any attempt to lessen the conflicts and ease the tensions brought on by competing human goals and natural processes.

Ignorance and continued disregard of the geologic processes that constantly reshape our coasts are tragically intensifying the collisions between people and nature. Despite historical precedents, catastrophes like Hurricane Hugo catch us unaware and unprepared. As powerful as Hugo was, it will be surpassed by bigger storms in the future; population growth and increased development along the coasts suggest that these future storms may cause even more damage and loss of life. Hugo is providing a regional incentive to increase our understanding of coastal environments and processes, and it is forcing an examination of laws and insurance regulations that govern societal actions within coastal zones.

RESEARCH QUESTIONS ON COASTAL PROCESSES

How do the prevailing winds, waves, tides, and seasonal weather patterns affect coastal environments?

What are the sediment sources, sediment volumes, and rates of sediment movement into, out of, and within coastal areas?

What biologic communities inhabit specific coasts? How do they affect (and how are they affected by) sediment movement?

What short-term and long-term factors and processes control the movement of sediment and changes to the coastal sediment budget?

RESEARCH QUESTIONS ON SHORT-TERM COASTAL EVENTS

How often do major storms strike specific sections of the coastline?

What are the geologic effects of these storms—extent of flooding, height of storm surge, sediment mixing in estuaries and bays?

What are the effects on coastal sediments—erosion, deposition, changes in the sediment budget?

Can these movements of water and sediment be quantitatively predicted for storms of specific strength and duration?

Which effects of storms are permanent and which are temporary?

Coordinated multidisciplinary efforts are needed to improve our understanding of how coasts form and evolve. A clear understanding of how coastal environments have formed and what natural changes they have undergone in the recent geologic past can be critical in predicting with confidence their future. Many different scientific disciplines must be involved. Many different scientific groups can provide critical expertise in specific fields of research. Cooperation among Federal, State, and local agencies will ensure that this scientific expertise is applied in site-specific studies to solve the individual problems that make up the coastal crisis. Concerted efforts focused on under-

standing our coasts require efficient coordination to get maximum return from the limited resources available.

As important as increasing our basic scientific understanding of the earth-science processes affecting coasts is, it is equally important to make this information available to coastal-zone planners, managers, and engineers in forms that they understand and can use. These groups must have adequate, accurate information on coastal processes in order to make decisions, assess risks, and solve problems in an efficient and cost-effective manner.

Some engineering practices and human activities that are incompatible with natural processes and that cause long-term harm to

RESEARCH QUESTIONS ON LONG-TERM CHANGES IN WATER LEVELS

Can paleoclimate studies help us to predict future global climate change?

How has global sea level changed throughout geologic and historic times? What factors have determined these changes?

For specific sections of the coast, are changes in relative water level significant on a local or regional scale?

What effects will future changes in water level, global and local, have on coasts and development in the coastal zone?

What is the current rate of worldwide sea-level change? Can we predict future changes with confidence?

Are lake-level changes cyclic, and can we predict their magnitudes, frequency, and duration?

RESEARCH QUESTIONS ON HUMAN INVOLVEMENT ALONG COASTS

What are the qualities and quantities of construction materials (sand, gravel, and shell), metals (gold, titanium, and so on), and potable water resources?

What effects do groins, jetties, breakwaters, seawalls, revetments, levees, and other engineering structures have on coastal processes?

Can mitigation techniques, such as the mechanical transport of sediment trapped by jetties at tidal inlets, be designed to reduce downdrift erosion caused by engineering structures?

How are buildings, roads, bridges, pipelines, and other infrastructure affected by coastal processes?

What long-term effects does the damming of rivers have on the sediment budget of coastal areas?

What effects does the withdrawal of underground fluids and minerals have on sediment compaction and local subsidence?

How are contaminated sediments and pollutants dispersed in the coastal zone? What is their ultimate disposition in the coastal environment?

How are ground-water resources affected by dredging of navigation channels, mining of minerals, and waste disposal in the coastal zone?



The aftermath of a storm in the South Pacific.

the coast can be modified to lessen their effect. In other cases, erosion mitigation techniques that closely replicate natural processes, such as beach nourishment, sand dune creation, and shoreline restoration, can be used to provide temporary protection. In extreme circumstances, abandonment and relocation of communities might be the best alternative.

Dealing effectively with the present coastal crisis and resolving future conflicts along our coasts will require a combination of solutions that must be based on long-term societal needs and on sound scientific and technical knowledge, rather than emotional responses to short-term desires. Results of scientific investigations must be clearly communicated to coastal planners, engineers, and managers—and, most important, to political decision-makers and the public. Only when these diverse groups understand the range of choices, and the costs (social, financial, and environmental) and risks associated with each choice, can prudent and enlightened decisions be made.

Research and field investigations by the U.S. Geological Survey and other groups over the past few decades have enhanced our understanding of the processes affecting the coasts, but many uncertainties remain. The earth-science community—the USGS and other Federal and State agencies, departments of academic institutions, and private research organizations—is beginning to address many complex and fascinating scientific aspects of coastal evolution. Through focused and concerted efforts, earth scientists will be able to provide decisionmakers and the public with the information and interpretations they need in order to plan wisely for the future of our coasts.

FURTHER READING

COASTAL WETLANDS

Chabreck, R.A., 1988, Coastal marshes; ecology and wildlife management: Minneapolis, Minn., University of Minnesota Press, 138 p.

Part of a series on wildlife habitats; this volume describes the coastal marshes of the United States with particular emphasis on the northern Gulf of Mexico coastline. Environmental influences, plant and animal communities, and the reasons for alteration and loss of marshes are clearly explained for the nontechnical reader; sections on marsh management and the future of marshes give the author's suggestions for minimizing damage to this ecologically valuable environment.

Crisis on Louisiana's coast...America's loss, published by U.S. Army Corps of Engineers, New Orleans District, in cooperation with the State of Louisiana, 12 p.

Explains the economic and ecological importance of Louisiana's wetlands, the causes of their loss, and the steps being taken by the State and six Federal agencies to address this critical problem, in an easy-to-read style.

BARRIER ISLANDS

Dolan, Robert, Lins, Harry, and Stewart, John, 1980, Geographical analysis of Fenwick Island, Maryland, a middle Atlantic coast barrier island: U.S. Geological Survey Professional Paper 1177–A, 24 p.

Dolan, Robert, and Lins, Harry, 1986, The Outer Banks of North Carolina: U.S. Geological Survey Professional Paper 1177–B, 47 p.

Highly urbanized Fenwick Island and the less developed islands of North Carolina are analyzed to demonstrate the processes and hazards associated with coastal barrier islands. The intended audience includes land-use planners, managers, and developers.

Leatherman, S.P., 1988, Barrier island handbook: College Park, Md., University of Maryland Coastal Publications Series, 92 p.

A thorough, nontechnical explanation of barrier island environments, their evolution, and the impact of recreation and construction on them.

SEA-LEVEL CHANGE AND COASTAL EROSION

Committee on Coastal Erosion Zone Management, 1990, Managing coastal erosion: Washington, D.C., National Academy Press, 182 p.

This report was commissioned by the Federal Emergency Management Agency's Federal Insurance Administration to provide options for implementation of a coastal erosion zone management program; it also explores some of the major questions about developing a national policy on coastal erosion.

Committee on Engineering Implications of Changes in Relative Mean Sea Level, 1987, Responding to changes in sea level — Engineering implications: Washington, D.C., National Academy Press, 148 p.

The first half of this book examines the history and estimated future (over the next century) of sea level, including the effects of sea-level rise on the coastal zone; the second half gives general and specific engineering responses to sea-level rise. The committee concludes that, in most areas, acceleration in the rate of mean sea-level rise is likely enough that it will affect planning and design of coastal facilities. It recommends increases in the funding of research on coastal processes, to provide adequate scientific knowledge to support decisions about protecting or abandoning coastal facilities as sea level rises.

Committee on Options for Preserving Cape Hatteras Lighthouse, 1988, Saving Cape Hatteras lighthouse from the sea — Options and policy implications: Washington, D.C., National Academy Press, 135 p.

The Cape Hatteras lighthouse, the tallest brick lighthouse in the United States, is a symbol of the erosion problem on the southern Atlantic Coast. This report, commissioned by the National Park Service, documents the options the Park Service has to preserve the lighthouse and recommends that it be relocated rather than protected in place. The choices discussed also apply to many other National Parks, where historic buildings are subject to destruction by erosion.

Penland, Shea, Ramsey, K.E., McBride, R.A., Moslow, T.F., and Westphal, K.A., 1989, Relative sea level rise and subsidence in Louisiana and the Gulf of Mexico: Baton Rouge, La., Louisiana Geological Survey Coastal Geology Technical Report No. 3, 65 p.

Documents the rates of land loss in Louisiana and the northern Gulf of Mexico through the combined action of subsidence due to compaction and sea-level rise. Highest rates were found for the Mississippi River Delta plain; the authors extrapolate a relative sea-level rise of 1.5–2 meters over the next century.

BEACH AND WAVE MECHANICS

Bascom, Willard, 1980, Waves and beaches; the dynamics of the ocean surface (revised and updated): Garden City, N.Y., Anchor Press/Doubleday, 366 p.

A highly readable book that describes the theory of wave action and the considerable effects that waves can have on beaches, ships, and other engineered structures.

King, C.A.M., 1972, Beaches and coasts (2d ed.): New York, St. Martin's Press, 570 p.

Examines different types of beaches and coasts and the wave and wind processes that shape them. Many of the examples are from Great Britain.

SHORE DEVELOPMENT

Culliton, T.J., Warren, M.A., Goodspeed, T.R., Remer, D.G., Blackwell, C.M., and McDonough, J.J., III, 1990, 50 years of population change along the Nation's coasts, 1960–2010: Rockville, Md., National Oceanic and Atmospheric Administration Coastal Trends Series, 2d report, 41 p.

Provides information on current and future population trends along the Nation's coastlines, which are grouped into five major regions: Northeast, Southeast, Great Lakes, Gulf of Mexico, and Pacific. Size, distribution, and density projections are given for regions, States, and counties.

Kaufman, Wallace, and Pilkey, O.H., Jr., 1983, The beaches are moving; the drowning of America's shoreline (with a new epilogue): Durham, N.C., Duke University Press, 336 p.

Originally published in 1979 and reprinted with a new epilogue in 1983 to accompany the series "Living with the Shore" (see below). The authors hold strong views against building structures near the coastline; this nontechnical book explains the natural coastal processes that form and change beaches and describes some of the problems that arise when we attempt to control these natural processes.

Morrison, H.R., and Lee, C.E., 1981, America's Atlantic Isles: Washington, D.C., National Geographic Society, 200 p.

Beautiful photographs and readable text describe the wide variety of islands found along the U.S. Atlantic shoreline from Maine to Florida, as well as the range of wildlife and human communities that inhabit this region.

Pilkey, O.H., and Neal, W.J., series editors, Living with the shore: Durham, N.C., Duke University Press.

This series currently contains 14 volumes, each of which examines the shoreline of an individual State (Florida has two volumes, for East and West Florida). The books are intended for a nontechnical audience; they review the geologic history, the history of development, the coastal processes affecting the shoreline, human intervention on the shore, government programs affecting coastal real estate, and safeguards to take when buying or building to prepare for storms and hurricanes. The books also contain a detailed analysis of the entire shoreline with recommendations of where and where not to buy shore property.

Yasso, W.E., and Hartman, E.M., Jr., 1976, Beach forms and coastal processes: MESA New York Bight Atlas Monograph 11, 50 p.

Presents findings on natural and manmade beaches, dunes, shoreline structures, beach growth and erosion, and storm effects along the New York Bight, the part of the Atlantic coastline from Long Island to New Jersey. This paper is one of a series of technical monographs providing decision makers with information on the complex coastal processes of the Bight and the human impact on these processes. The series was a cooperative effort between the National Oceanic and Atmospheric Administration and the New York State Sea Grant Institute.

Federal Agencies With Regulatory or Research Responsibilities for Our Coasts

Federal Emergency Management Agency (independent Federal organization) administers the National Flood Insurance Program (NFIP), which provides Federally subsidized insurance protection in many coastal and flood-prone areas of the United States. Making NFIP self-supporting and eliminating Federal subsidies are major goals.

National Oceanic and Atmospheric Administration (U.S. Department of Commerce) conducts studies of wetlands and coastal habitats that support marine resources; prepares nautical charts and geodetic surveys of coastal areas; monitors storm activities; operates an environmental satellite system; administers a grants program for marine research.

National Park Service (U.S. Department of the Interior) administers an extensive system of public lands, including lakeshores and seashores, set aside for the protection of natural environments, the preservation of historic properties, and the education and enjoyment of our citizens.

National Science Foundation (independent Federal organization) supports fundamental, long-term coastal research in the earth sciences and in engineering fields. This support is made through grants, contracts, and agreements awarded to universities and other research groups.

U.S. Army Corps of Engineers (U.S. Department of Defense) conducts applied research and development for design, construction, operation, and maintenance activities related to harbors, navigational waterways, and coastal protection. The Corps also administers laws for protecting navigable waters and related coastal resources such as wetlands.

U.S. Coast Guard (U.S. Department of Transportation) is responsible for enforcing laws related to the protection of marine environments; provides a national response center that investigates oil and chemical spills, initiates penalty actions, and monitors and coordinates cleanups.

U.S. Environmental Protection Agency (independent Federal agency) funds and conducts contaminant studies and related coastal research; regulates the discharge of coastal pollutants and the disposal of dredged sediments.

U.S. Fish and Wildlife Service (U.S. Department of the Interior) manages extensive coastal lands as wildlife preserves; conducts research on coastal wetlands, fish and wildlife populations, and changes in habitat.

U.S. Geological Survey (U.S. Department of the Interior) conducts research on the geologic framework of coasts and on sediment-transport processes; collects and analyzes hydrologic data; makes topographic, geologic, and hydrologic maps of coastal areas; investigates ancient and modern coastal environments.

U.S. Minerals Management Service (U.S. Department of the Interior) studies the potential impact of offshore activities, including the placement and construction of petroleum pipelines, on coastal wetlands and resources; funds research through State geoscience agencies for identifying mineral resources in the coastal zone.

U.S. Soil Conservation Service (U.S. Department of Agriculture) carries out detailed soil surveys for coastal and wetland regions; identifies superior plant varieties for erosion control in coastal zones.