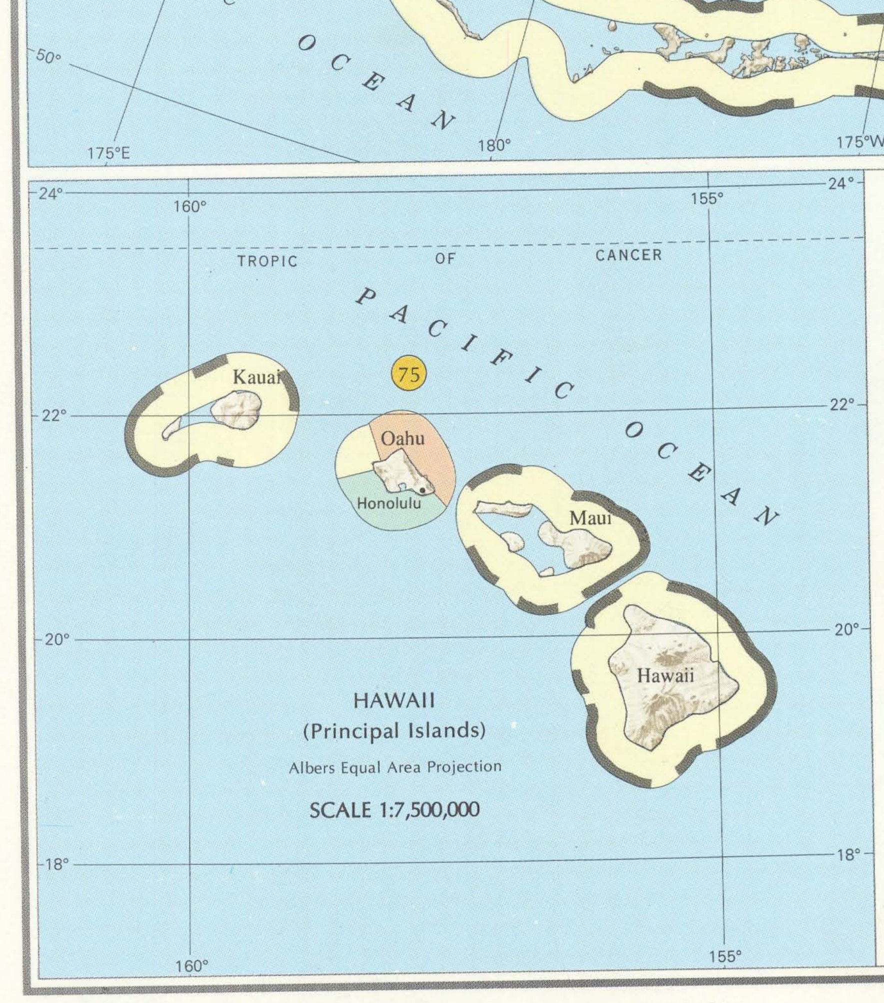

ANNUAL SHORELINE CHANGE

EROSION / ACCRETION

5 meters or more

3.0–4.9 meters

1.0–2.9 meters

Less than 1 meter

No data

PERIOD OF RECORD (YEARS)

More than 100 · 50–100 · Less than 50

TYPE OF RECORD (WHEN CITED IN SOURCE MATERIAL)

Aerial Photography

Maps and Charts

Maps, charts, and aerial photography

78 Numerals indicate most recent record year when cited in source material

Symbols without numerals: no record year cited; symbols without color: type of record not cited

AREAS OF EPISODIC CLIFF RETREAT

Rocky headlands with pocket beaches

Narrow beaches backed by cliffs

NATIONAL ATLAS OF THE UNITED STATES OF AMERICA
DEPARTMENT OF THE INTERIOR, U.S. GEOLOGICAL SURVEY
RESTON, VIRGINIA 22092

COASTAL EROSION AND ACCRETION

By Robert Dolan, University of Virginia, and Suzette Kimball, Coastal Engineering Research Center, Waterways Experiment Station, U.S. Army Corps of Engineers

Long-term changes in shoreline positions are a product of four factors: (1) the stability of sea level; (2) the power of the coastal processes impinging on the shoreline; (3) the type of landforms adjacent to a coastal area; and (4) the type and volume of sediment supplied to the shore. In addition, man may play an important role by altering natural processes through navigation works and construction of dams on streams and rivers that supply sediment to the coast.

On sandy coasts, each wave and any variation in sea level alters, to some degree, the shoreline. Beach sands are transported offshore, onshore, and in the direction of prevailing along-the-shore currents. Beaches constantly adjust elevation and shape to accomodate different tide, wave, and current conditions. On rocky coasts, erosion may be slower than on sandy coasts, but the effect of the continuous action of waves on the shoreline causes the coast to erode. Periods of erosion and accretion are superimposed on a longer trend of world-wide rising sea level. This long-term rise submerges the coast, causes shoreline recession, and forces the beach landward.

SHORELINE PROCESSES

Sea Level

Sea level elevation has oscillated several times during the past half-million years (Bloom and others, 1974; Evans, 1979; Cronin and others, 1981). During the cooler glacial periods, water was withdrawn from the seas, stored on land as glacial ice, and the shorelines of the oceans receded seaward across the continental shelves. When the ice melted during warmer interglacial periods, the ocean basins refilled and coastlines moved back across the continental shelves. This process involved great quantities of seawater, enough to move the shoreline across about 150 km of mid-Atlantic continental shelf.

When the last period of glaciation came to an end about 15,000 years ago, sea level was approximately 120 m lower than it is today. The shorelines of the Atlantic and Gulf Coasts were 60 to 150 km seaward of their present positions. West Coast glacial shorelines were considerably closer to the present shoreline because the Pacific Coast continental shelf is very narrow. As glacial conditions gradually changed to interglacial conditions, the sea rose (Curray, 1965; Emery and Millman, 1970), reaching within a few meters of the present level about 4,000 years ago. Sea level has risen more slowly during the past 2,000 years, causing continued recession of shorelines and the enlargement of bays and sounds. Over the last 100 years the rise in sea level has totaled about 15 cm (fig. 1).

Storms, Waves, and Tides

Hurricanes and winter storms are the principal agents of change on the coast. Storms generate high waves and surges, which in turn erode the rocks and sediment exposed along the coast. Storm surges are caused by strong onshore winds blowing water to heights above the normal levels near the coast. The higher mean water levels, in turn, permit larger more powerful waves to reach the coast.

Much of the coastal erosion, property damage, and loss of life along the Atlantic Coast is caused by winter storms called "northeasters." The great Ash Wednesday storm of March 7, 1962, produced waves over 10 m high, which resulted in serious erosion and caused millions of dollars of property damage along the mid-Atlantic Coast (fig. 2) (Cooperman and Rosendal, 1963; Podufaly, 1962; Stewart, 1962; Bretschneider, 1964; Wood, 1976). Similar winter storm damage has occurred along the West Coast. In January 1983, a series of winter storms caused millions of dollars of damage along the coast of California.

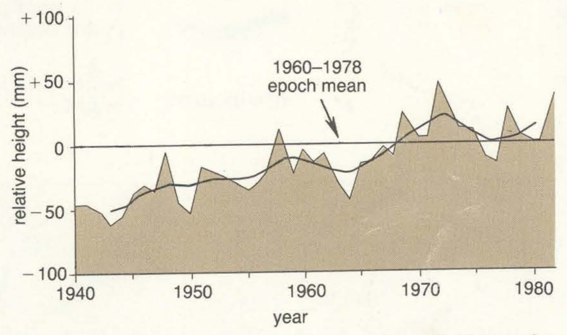

Figure 1. Average annual sea level rise and smoothed curve for United States coastlines (excluding Alaska and Hawaii) from tidal gauge records (Update from Hicks, *et al,* 1983)

Figure 2. Storm damage on Fire Island, N.Y. 1962 (UPI)

Tides, storm waves and surge, and long-term sea level fluctuations cause variations in water level along the coast. Tidal action alone has little effect on sediment transport, but when storm surge and high waves are superimposed, the elevation and depression of the water level becomes a significant agent in sediment movement.

The Moon has its greatest influence on ocean tides when it is closest to the Earth (perigee). When lunar perigee coincides with the alignment of the Earth, Moon, and Sun, higher than normal tides, called perigean spring tides, are generated. Approximately one hundred of the most severe coastal storms between 1635 and 1976, including the Ash Wednesday storm of 1962, occurred during perigean spring tides (Wood, 1976).

Geology and Erosion

The beaches and barrier islands that rim the United States coastline are, for the most part, composed of quartz sand—a very resistant mineral that is abundant in nature. Some of the West Coast beaches consist primarily of dark sands that weather from the volcanic rocks (basalt) common to that area. The sources for these beach and barrier island materials include the continental shelf, glacial outwash, cliff and bluff erosion, and sediment transported to the coast by rivers and streams.

The rate of shoreline erosion depends on the intensity of the waves striking the coast and associated nearshore processes, and the local geology, including the sediment making up the beach or barrier island, the topography, and rock structure. Soft sedimentary rocks and unconsolidated deposits are usually associated with rapid shoreline erosion; resistant crystalline rocks erode slowly. The mid-Atlantic and Gulf shorelines are backed by broad coastal plains of unconsolidated sedimentary deposits containing materials that are easily eroded and transported. Consequently, these coasts are eroded rapidly. A transition from unconsolidated deposits and soft sedimentary rocks to coastal exposures of resistant crystalline rocks occurs north of Long Island. The Maine coast is particularly noted for cliffs and bays within the recently glaciated, slowly eroding crystalline rocks. Similarly, spectacular cliffs and coastlines occur along the West Coast in areas of recent tectonic activity. Along much of the West Coast, however, the shoreline is backed by cliffs of soft sedimentary materials which erode rapidly during storms.

DETERMINATION OF SHORELINE CHANGE

Scientists have long recognized beaches and shorelines as elements of a highly dynamic geologic system. The information needed for good planning and intelligent development within the coastal zone includes knowledge of the current position of the shoreline, its rate of change through time, and the geologic processes involved. This information can be obtained from ground surveys, maps and charts, and aerial photographs (Dolan and others, 1980).

Table 1: Rate of change for states and regions

A. Oceanic Coastlines

Region	Mean, m/yr*	Standard Deviation*	Total Range*	N†
Atlantic Coast	–0.8	3.2	25.5/24.6	510
Maine	–0.4	0.6	1.9/–0.5	16
New Hampshire	–0.5	—	–0.5/–0.5	4
Massachusetts	–0.9	1.9	4.5/–4.5	48
Rhode Island	–0.5	0.1	–0.3/–0.7	17
New York	0.1	3.2	18.8/–2.2	42
New Jersey	–1.0	5.4	25.5/–15.0	39
Delaware	0.1	2.4	5.0/–2.3	7
Maryland	–1.5	3.0	1.3/–8.8	9
Virginia	–4.2	5.5	0.9/–24.6	34
North Carolina	–0.6	2.1	9.4/–6.0	101
South Carolina	–2.0	3.8	5.9/–17.7	57
Georgia	0.7	2.8	5.0/–4.0	31
Florida	–0.1	1.2	5.0/–2.9	105
Gulf of Mexico	–1.8	2.7	8.8/–15.3	358
Florida	–0.4	1.6	8.8/–4.5	118
Alabama	–1.1	0.6	0.8/–3.1	16
Mississippi	–0.6	2.0	0.6/–6.4	12
Louisiana	–4.2	3.3	3.4/–15.3	106
Texas	–1.2	1.4	0.8/–5.0	106
Pacific Coast	–0.0	1.5	10.0/–5.0	305
California	–0.1	1.3	10.0/–4.2	164
Oregon	–0.1	1.4	5.0/–5.0	86
Washington	–0.5	2.2	5.0/–3.9	46
Alaska	–2.4	2.0	2.9/–6.0	69

*Negative values indicate erosion: the positive values indicate accretion.

†Total number of 3-min grid cells over which the statistics are calculated.

B. Bays and Lakes

Region	Mean, m/yr*	Standard Deviation*	Total Range*	N†
Delaware Bay				
New Jersey	–1.9	1.3	0.3/–3.0	13
Delaware	–1.3	2.1	5.0/–3.0	12
Chesapeake Bay	–0.7	0.7	1.5/–4.2	136
Western shore	–0.7	0.5	1.5/–1.9	67
Maryland	–0.7	0.3	–0.1/–1.3	35
Virginia	–0.8	0.7	1.5/–1.9	32
Eastern shore	–0.7	0.8	0.1/–4.2	69
Maryland	–0.8	0.9	–0.3/–4.2	47
Virginia	–0.5	0.4	0.1/–1.2	22
Great Lakes	–0.7	0.5	0.6/–2.7	327
Lake Erie	–0.7	0.6	–0.2/–2.4	98
Ohio	–0.6	0.6	–0.2/–2.2	68
Pennsylvania	–0.3	0.1	–0.2/–0.4	14
New York	–1.4	0.6	–0.5/–2.4	20
Lake Ontario	–0.5	0.2	–0.2/–1.2	58
Lake Huron	–0.4	0.3	–0.3/–1.3	28
Lake Michigan	–0.6	0.8	0.6/–9.9	184
Western shore	–0.6	0.4	0.6/–1.5	62
Eastern shore	–0.7	0.9	0.3/–9.9	122
Wisconsin	–0.7	0.3	–0.3/–1.5	46
Illinois	–0.2	0.4	0.6/–0.9	16
Indiana	–0.4	0.5	–0.3/–0.9	12
Michigan	–0.7	0.9	–0.3/–9.9	110
Lake Superior	–1.3	0.7	0.3/–2.7	35
Minnesota	–0.8	0.4	–0.3/–1.5	16
Wisconsin	–1.8	0.6	–0.9/–2.7	19

*Negative values indicate erosion: the positive values indicate accretion.

†Total number of 3-min grid cells over which the statistics are calculated.

Ground surveys provide shoreline data of the highest detail. Such surveys are time consuming and costly, however, and have thus been made in only a few coastal areas. Except for a few scattered sites, accurate historical records that could be used for comparison of coastline position are lacking for most of the U.S. coastline. Maps and charts are available for numerous coastal locations and frequently extend back to the mid-1800's. While charts are useful, some are of questionable accuracy and are frequently restricted to areas immediately adjacent to major shipping lanes and port facilities. Maps and charts best serve as supplemental information in determining trends in shoreline change.

Aerial photographs taken with mapping cameras are available for most coastal locations in the United States. The earliest of these photographs date from the 1930's, and images for subsequent decades are generally available. Aerial photographs have many advantages over the other types of information in coastal mapping. In a matter of hours hundreds of miles of coast can be photographed, making available an "instantaneous" record, unlike a ground survey that might take months to complete. Photographs include a measure of detail over extended areas unavailable with any other information base, and they are permanent and easily duplicated.

Data Collection

The data for this map of coastal erosion and accretion were obtained from the best of the existing information sets contributed by coastal engineers and planners nationwide. Preference was given to data that spanned considerable time and area and that were already available in graphic form. Once the broad reaches were covered, more detailed, site-level information was used.

District and division offices of the U.S. Army Corps of Engineers were contacted for information. Through their involvement with the National Shoreline Study of 1972, the Corps held lists of coastal scientists and engineers who could provide shoreline erosion data. Requests for data were also made to State offices with responsibility for coastal affairs, Sea Grant offices, and university faculty.

A considerable amount of historical information was available for the mid-Atlantic, southeast, Gulf of Mexico, and Great Lakes regions. In contrast, the Pacific, Alaskan, and northeast coasts have not been surveyed as extensively or quantitatively. These areas lack information because either shoreline change is not perceived as a continuous day-to-day threat by the coastal communities, or, in the case of Alaska, the population densities are so low that continuous shoreline monitoring is not a high priority.

When two or more information sets were available for a given coastal area, the time span and currency of information were considered. More recent studies were selected over older ones because they are generally made with knowledge of preceding work, and therefore reflect the earlier information. Where a choice of length of the historical record appeared, long-term data were favored over short-term for two reasons: (1) the effects of catastrophic events are less prominent in the long-term data sets; and, (2) many data sets were found that were based on late 19th Century surveys, making these studies similar in terms of the initial baseline.

In areas where detailed information was not available for periods of over 100 years, the length of the measurement base became the criterion for inclusion. Since the development of mapping-quality aerial photography in the 1930's, the determination of shoreline changes over large reaches of coast has become possible. The period of record is generally 50 years; and as studies are current, the effects of recent engineering structures are usually included.

The most reliable shoreline change data are, of course, obtained by careful survey in the field; however, the number of sites having a long history of field surveys is limited. Therefore, the next most reliable source of shoreline change data, aerial photographs, represents the major type of information used in determining the rates of shoreline change depicted on this map. Old maps and charts are also valuable data sources. For a detailed discussion of the reliability of maps, charts, and aerial photographs in mapping shoreline change, we recommend reading Dolan and others (1980).

Table 2: Rate of change for coastal landform types

Region	Mean, m/yr*	Standard Deviation*	Total Range*	N†
Mud flats				
Fla.	–0.3	0.9	1.5/–1.5	9
La.-Texas	–2.1	2.2	3.4/–8.1	84
All Gulf	–1.9	2.2	3.4/–8.1	93
Rock shorelines				
Atlantic	1.0	1.2	1.9/–4.5	36
Pacific	–0.5	—	–0.5/–0.5	7
Pocket beaches				
Atlantic	–0.5	—	–0.5/–0.5	9
Pacific	–0.2	1.1	5.0/–1.1	144
Sand beaches				
Maine-Mass.	–0.7	0.5	–0.5/–2.5	17
Mass.-N.J.	–1.3	1.3	2.0/–4.5	22
Atlantic	–1.0	1.0	2.0/–4.5	39
Gulf	–0.4	1.6	8.8/–4.5	121
Pacific	–0.3	1.0	0.7/–4.2	19
Sand beaches with rock headland	–0.3	1.9	10.0/–5.0	134
Deltas	–2.5	3.5	8.8/–15.3	155
Barrier Islands				
La-Texas	–0.8	1.2	0.8/–3.5	76
Fla-La.	–0.5	1.7	8.8/–4.5	82
Gulf	–0.6	1.5	8.8/–4.3	158
Maine-N.Y.	–0.3	2.6	4.5/–1.5	12
N.Y.-N.C.	–1.5	4.5	25.5/–24.6	159
N.C.-Fla.	–0.4	2.6	9.4/–17.7	256
Atlantic	–0.8	3.4	25.5/–24.6	421

*Negative values indicate erosion: the positive values indicate accretion.

†Total number of 3-min grid cells over which the statistics are calculated.

The rate of shoreline change, length of record, and final year of data are indicated on the map. At a scale of 1:7,500,000, 7.5 km ground distance is 1 mm map distance. A mapping unit distance of about 75 km (1 cm map distance) is the most visually balanced and allows adequate space for all symbols. To show the maximum amount of information, however, all data sets were processed to conform with a minimum mapping unit of 2 mm, or 15 km ground distance. Where barrier islands are present, islands shorter than the minimum mapping unit are depicted as a single unit. Errors involved in obtaining average rates of change from limited numbers of sites are diminished by the use of the rate classes. The broad classes bracket the true rate for a given reach in an acceptable graphic form.

STATISTICAL SUMMARY OF THE STATE OF THE NATION'S SHORELINES

The shoreline change map data base was used to determine statistical summaries of rate of change data for each coastal State and for reaches with similar geology and shoreline geomorphology (Tables 1 and 2). Along the Atlantic Coast, the average erosion rate is 0.8 m/yr. The Virginia barrier islands, Maryland, and New Jersey have the most pronounced erosion rates, up to 4.2 m/yr. Georgia, New York, and Delaware have, in the aggregate, only slightly eroding, stable, or accreting coasts. The shoreline of Delaware Bay is receding at higher rates than the Atlantic Coast, while erosion rates along the Chesapeake Bay are about the same as the open ocean coasts. Overall, the Atlantic Coast is receding, with 79 percent of the shoreline showing some measure of erosion (May and others, 1983).

States bordering the Gulf of Mexico have the most rapid average erosion rates (1.8 m/yr). Within the Gulf region, the coast of Louisiana is by far the most dynamic (4.2 m/yr erosion). Like the Atlantic Coast, the Gulf region can be described as eroding, but the percentage of receding shoreline is less, 63 percent.

The Great Lakes shorelines are eroding at an average rate of 0.7 m/yr. The Pacific Coast, including Alaska, has the lowest erosion rates (0.005 m/yr), as well as the lowest overall percentage of eroding areas, less than 30 percent of the shoreline. This is understandable given the amount of resistant rock exposed along the Pacific and Alaska Coasts.

When the national erosion rates are grouped on a basis of shorezone geology, the resulting patterns are for the most part predictable. Coasts with fine-grained sediments, deltas and mudflats that offer the least resistance to wave action, have the highest mean erosion rates (2.0 m/yr). Most sandy beaches and barrier islands are eroding at slightly lower rates (0.8 m/yr). The rock shorelines and glacial areas of the Atlantic Coast show rates of accretion of as much as 1.0 m/yr. Along the West Coast and Alaska the coastal rock-types vary over relatively short distances, so average erosion rates are less meaningful. In general, areas of resistant rock are not eroding, whereas areas of softer sedimentary rocks are eroding.

REFERENCES

Bloom, A.L., W.S. Broecker, J.M.A. Chappell, R.K. Matthews, K.J. Mesolella, 1974, Quaternary sea level fluctuations on a tectonic coast: New $^{230}Th/^{234}U$ dates from the Huon Peninsula, New Guinea: Quaternary Research, 4:185–205.

Bretschneider, C. L., 1964, The Ash Wednesday East Coast storm, March 5–8, 1962—a hindcast, causes, and effects: Nat. Eng. Science Co., SN–134–4.

Cooperman, A. I., and H. E. Rosendal, 1963, Mean five-day pressure pattern of the Great Atlantic Coast storm, March, 1962: Monthly Weather Review, p. 337–344.

Cronin, T. M., B. J. Szabo, T. A. Ager, J. E. Hazel, and J. P. Owens, 1981, Quaternary climates and sea levels of the U.S. Atlantic coastal plain: Science 211:233–239.

Curray, J. R., 1965, Late Quaternary history, continental shelves of the United States, in H.E. Wright, Jr., and D. G. Frey, eds., The Quaternary of the United States: p. 723–735.

Dolan, R., B. Hayden, and S. May, 1980, The reliability of shoreline change measurements from aerial photographs: Shore and Beach, 48(4):22–29.

Emery, K. O., and J. D. Milliman, 1970, Quaternary sediments of the Atlantic continental shelf of the United States: Quaternaria, 12:3–18.

Evans, 1979, Quaternary transgressions and regressions: J. Geol. Soc. London, 136:125–132.

Hicks, S. D., and J. E. Crosby, 1975, An average long period, sea-level series for the United States: NOAA/NOS Technical Memorandum NOS 15, Rockville, Md., 6 p.

Hicks, S. D., H. A. Debaugh, Jr., and L. E. Hickman, Jr., 1983, Sea level variations for the U.S. 1855–1980: NOAA/NOS, Rockville Md., 170 p.

May, S. K., R. Dolan, and B. Hayden, 1983, Erosion of U.S. shorelines: EOS, 64:521–523.

Podufaly, E. T., 1962, Operation five-high: Shore and Beach 3(2):9–18.

Stewart, J. W., 1962, The great Atlantic Coast tides of 5–8 March 1962: Weatherwise, 15:117–120.

Wood, F. J., 1976, The strategic role of perigean spring tides in nautical history and North American coastal flooding, 1635–1976: Washington, D.C., U.S. Department of Commerce, NOAA, 538 p.

Suzette Kimball is currently affiliated with the Virginia Institute of Marine Science, College of William and Mary.

INTERIOR—GEOLOGICAL SURVEY, RESTON, VIRGINIA—1988

FOR SALE BY U.S. GEOLOGICAL SURVEY
DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
55135-AG-NA-07M-00