Coastal Processes and Beach Erosion: The Saco Bay Shoreline

by
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2005

Introduction

This slideshow provides information on coastal morphology and coastal processes in Maine, with a focus on Saco Bay, home of the longest stretch of sandy shoreline within the state, and Camp Ellis, home of some of the worst erosion in the state.

Contents

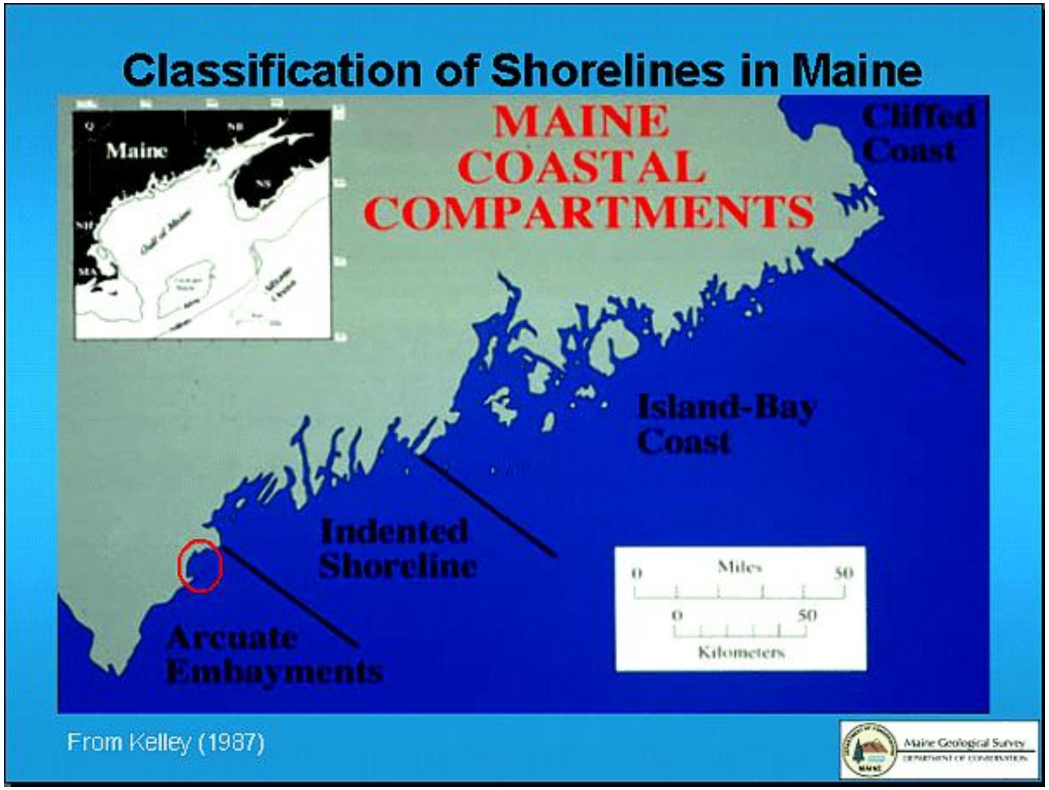
Beach Morphology

Major factors on beach morphology in Maine include sea-level rise, waves, currents, tides, and winds, underlying geology, sediment supply, shoreline stabilization, development pressure, and recreational usage. Sea level at Portland, Maine has risen about 0.6 ft in the last century. Global sea level is forecast to rise about 2 feet in the next 100 years. Beaches transgress, or move landward, in response to sea-level rise. If sea level rises faster than sediment supply can keep up, beaches can disappear. Waves, currents, tides and winds are daily forces that influence the shape of our shorelines on time-scales that humans can plainly see. Underlying geology can influence sediment supply, the pathways along which sediment may move, and where accretion or erosion takes place. Sediment supply is extremely important in determining whether a beach will erode or accrete. Beaches along the Maine coast are supplied with sediment from rivers and the erosion of existing materials in the nearshore. Shoreline stabilization influences how a beach responds to hydrodynamic forces. About 50% of Maine's sandy beaches are stabilized with seawalls. Development pressure along sandy beaches in Maine is very high because it is a prime location to live. Finally, recreational usage is an important factor. One of every 2 Mainers live near the coast, and over 6 million people visit Maine's coastline each year, the majority of these to sandy beaches.

Maine's Beaches

Maine is unique in that beaches (sand and cobble) only comprise about 2% of the overall shoreline, or about 70 miles. About ½ of these beaches are located from Portland south to Kittery. Most of these beaches are called "pocket beaches" because they are enclosed by headlands, making them closed littoral cells. Maine beaches generally have a limited sand supply due to damming of rivers, and a general lack of sediment-rich rivers along the shoreline. Tides in the state are semi-diurnal (twice daily), and the tidal variation ranges from about 9 feet in the southern portion of the state, up to about 20 feet in the northeastern part of the state. Finally, Maine beaches are also unique in that private property owners, if deeded, can own down to the low water line pursuant to the Colonial Ordinance of 1641-1647, which originated from Massachusetts laws. Most states own the beach up to the high water line. In Maine, the public only has the right in the intertidal zone (from high-water to low-water) for fishing, fowling, and navigation.

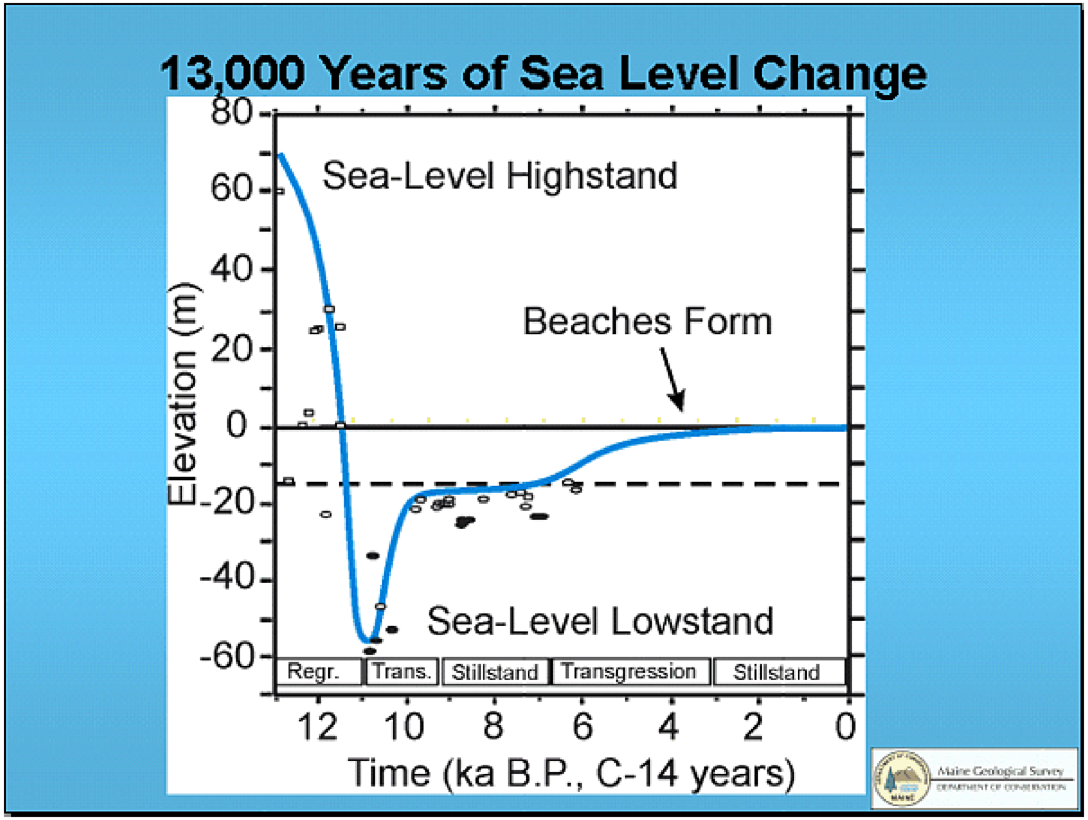
Shoreline Classes



From Kelley (1987)

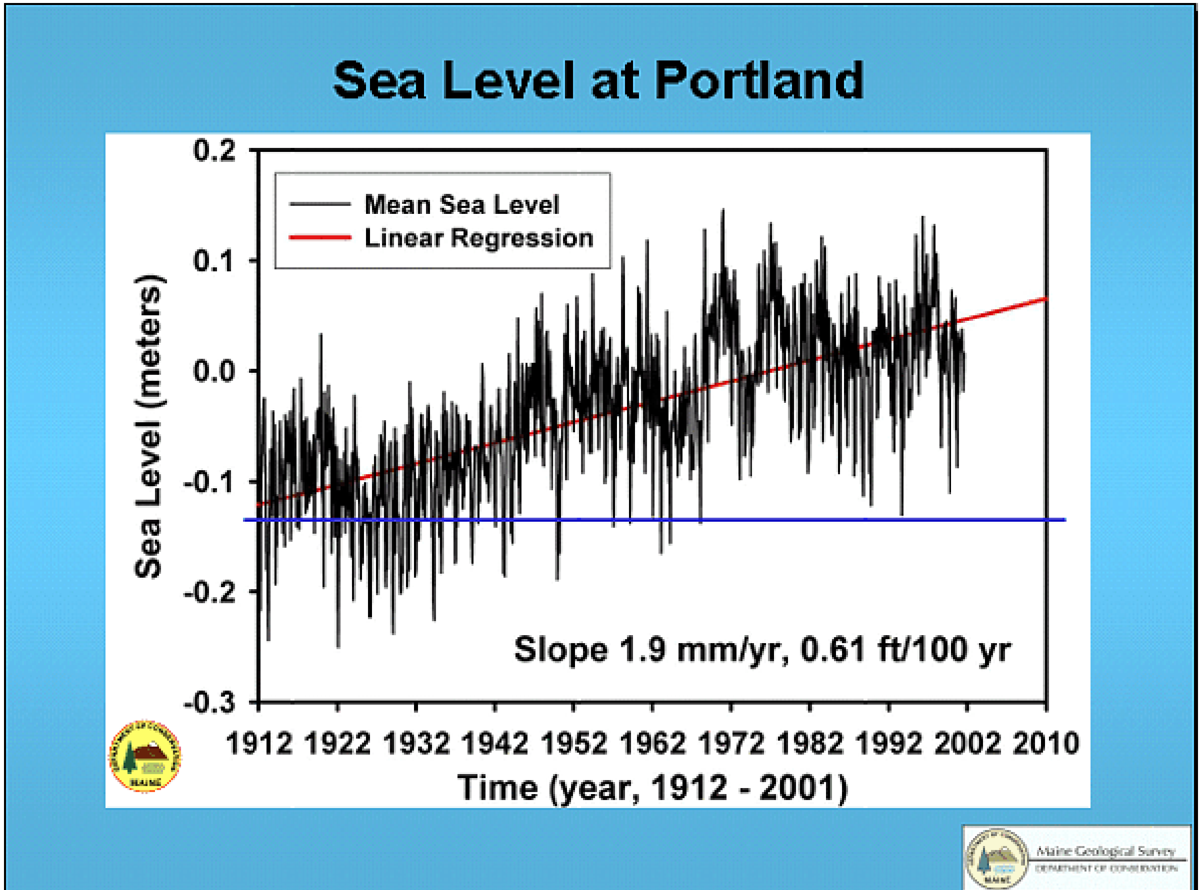
Maine's shoreline can be classified into 4 different regions based on geomorphology (after Kelley, 1987). The shoreline is heavily influenced by past glaciations. From northeast to southwest, these are: cliffed coast; island-bay coast; indented shoreline; and arcuate embayments. It is within the arcuate embayments that the majority of Maine's sandy beaches occur. Saco Bay, home of Maine's longest contiguous sandy beach, is circled in red.

Sea-level Change



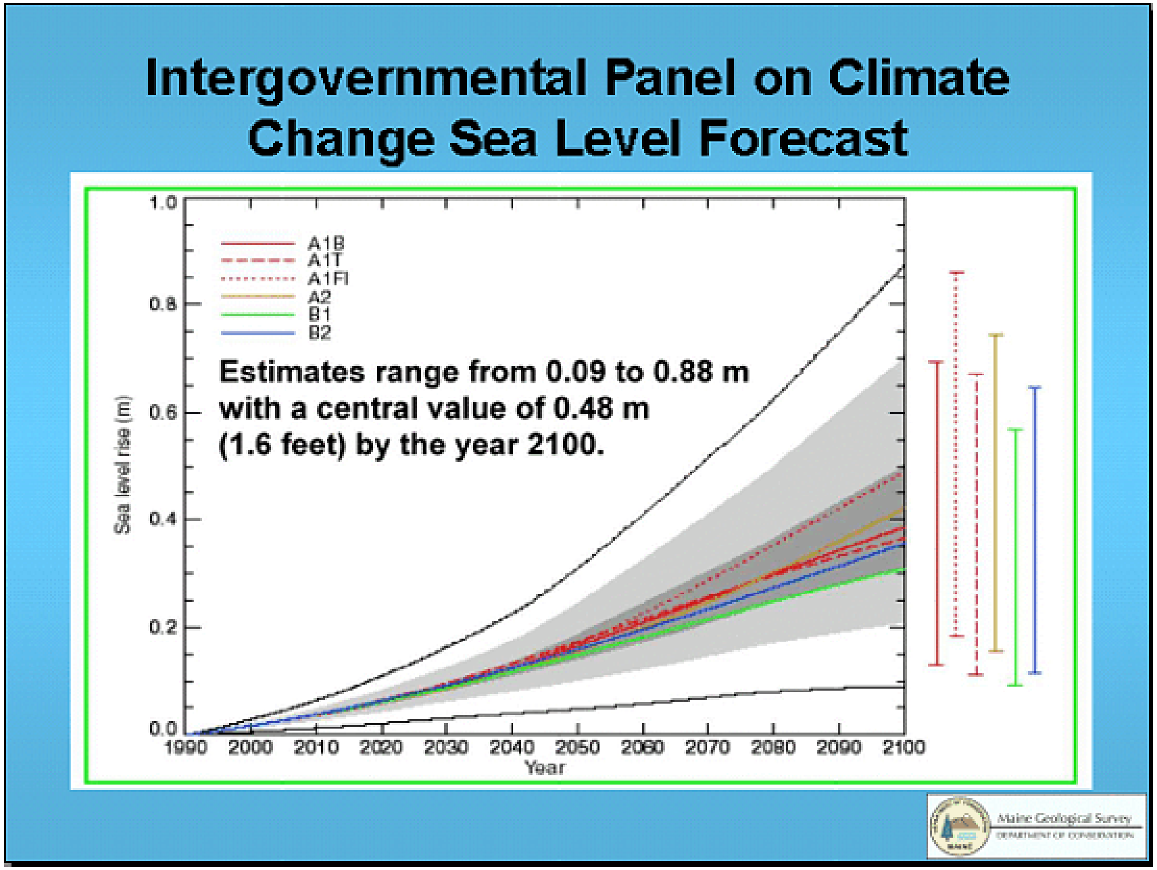
This graph shows the fall and rise in the ocean over the last 13,000 years. Sea level was at its highest (+70 m) about 13,000 years ago, and at its lowest about 11,000 years ago. In the last 3,000 years sea level has been relatively stable (a stillstand), which is during the time that the majority of today's beaches formed.

Sea-level Change at Portland



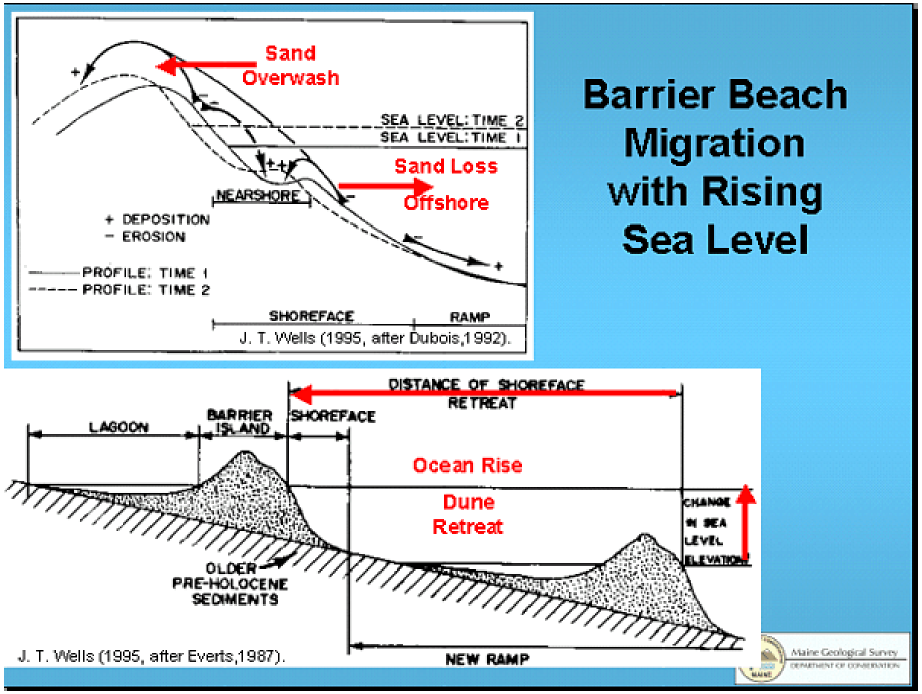
This graph shows sea level changes at the Portland tide gauge. Sea level has risen about 0.6 feet over the past 100 years.

Sea-level Forecast



The Intergovernmental Panel on Climate Change (IPCC) used several different models to predict sea level rise in the next 100 years. The central value of these predictions is about 1.6 feet by the year 2100.

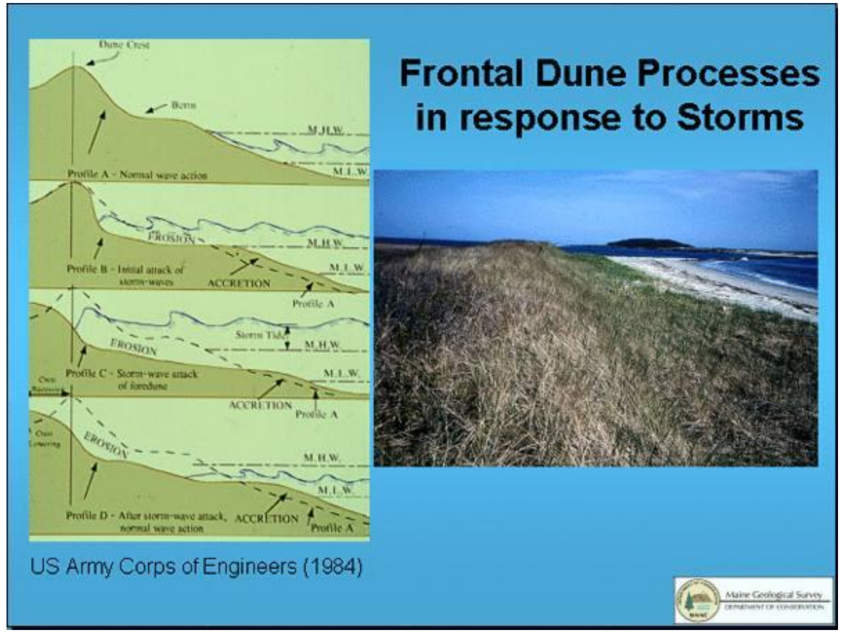
Barrier Beach Migration



From J. T. Wells, 1995 after Everts, 1987 and Dubois, 1992

Beaches typically migrate landward in response to sea-level rise. As sea level rises, waves can attack the upper part of the beach profile, pushing sand over the dune in a process called overwash. At the same time, sand is pulled offshore (upper figure). The lower figure shows how the barrier beach migrates landward, rolling landward over itself. The initial beach migrates landward over its own marsh into its second position. This is why you can find peat deposits, tree stumps, and oyster shells in the surf zone. Think of the beach as a tread on a tank rolling over itself in a landward direction.

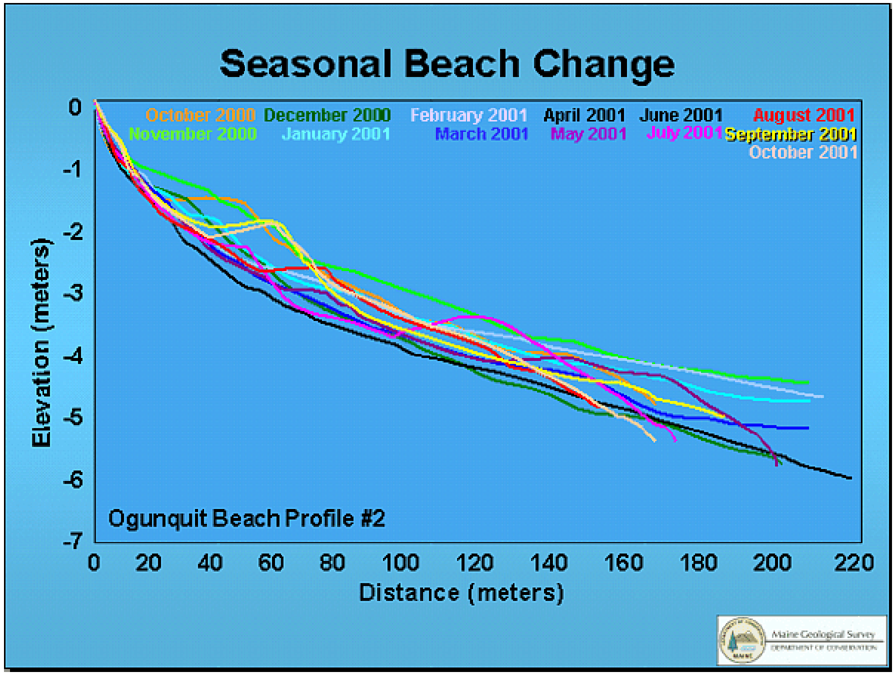
Response to Storms



U. S. Army Corps of Engineers, 1984

On the left is a diagram showing how a beach and dune system responds to a storm. The top image is of the beach during normal conditions. The 2nd image shows a storm occurring with an increase in water level and waves attacking the dune. The 3rd image shows the natural response of the beach system - sand is eroded from the berm and dune and transported offshore and deposited into an offshore bar. The formation of this bar is the beach's natural response to protect itself - the bar causes waves to break farther offshore, at the bar, and redistribute sand landward, slowly building the beach back up (4th image). The picture on the right shows the frontal dune ridge in Cape Elizabeth. About half of the ridge was eroded and subsequently rebuilt with American beach grass and sand.

Seasonal Beach Change



This chart shows the evolution of a beach profile over the course of a year, illustrating the processes discussed on Slide 9. Land is to the left and ocean to the right. The beach profile is conducted from a dune crest out to the low water line. The chart begins in October 2000, when the beach has a well-developed berm. This builds up in November. From December through April the beach flattens and loses sand offshore in response to a series of winter storms. In May 2001, the beach begins to recover. There was no profile in June, but in July, the sand has moved farther landward up the profile. By October 2001, the berm has reformed, but slightly lower and seaward of its position in 2000.

Dune Scarp Formation

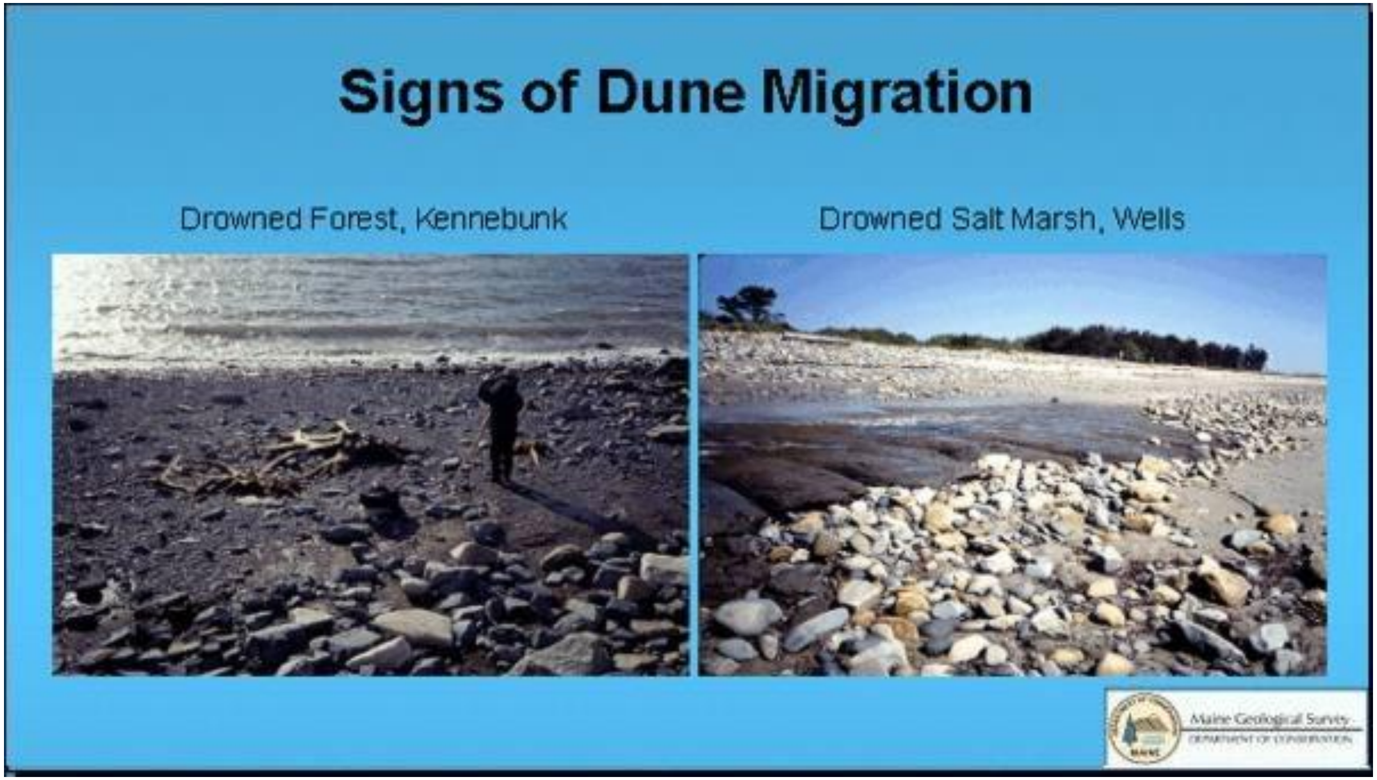
A four-day northeaster in December 1992 resulted in a coastal storm surge (left) of less than 2 feet yet it produced an erosional cut in the dunes at Seawall Beach, Phippsburg. Northeasters commonly produce frontal dune erosion and scarp formation (right). Note the person in the picture on the right for scale. Dune scarps from major storms can take years to return to the pre-storm condition.

Frontal Dune Overwash

Photo by S. M. Dickson, 1991

Examples of frontal dune overwash resulting from the Halloween 1991 "Perfect" Storm. The frontal dune ridge is built primarily from wave action. In storms, waves deposit sand on the crest of the dune ridge. Most frontal dune ridges are built by the process of overwash to the elevation of active wave run-up and sand transport in a 100-year storm. Lesser storms add sand to low dune areas where wind and foot traffic have lowered the ground elevation. American beach grass grows through the new sand and helps hold it in place. MGS File Photos of Pine Point in Scarborough (left) and Ferry Beach State Park, Saco (right).

Dune Migration



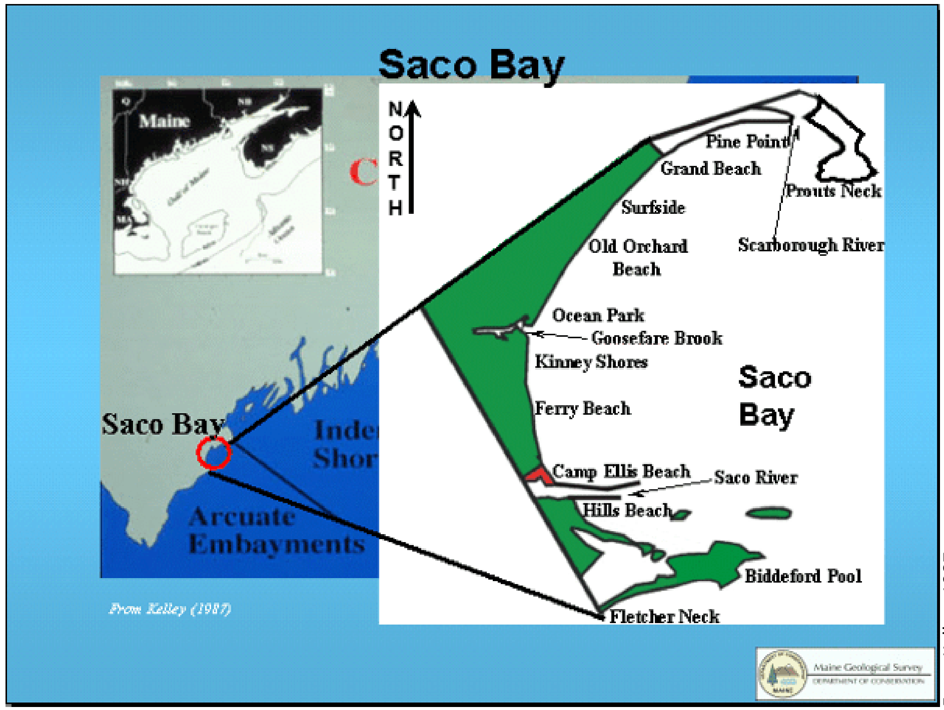
Evidence of sea-level rise and beach and dune transgression (retreat). Tree stumps (in situ) on a beach in Kennebunk were drowned by the rising sea (left). Salt marsh peat from the back barrier marsh is exposed on Laudholm Beach in Wells (right). In both locations, the barrier beach and dunes have migrated inland over forest and marsh environments due to sea-level rise of about 6 feet in the last 3,000 years.

Seawalls

Seawalls result in wave reflection that causes enhanced beach scour in front of the wall. When a wave hits a wall, wave reflection leads to dramatic spray in an upward direction due to the energy of the wave hitting a solid structure. The energy transmitted upwards (right image) is also transmitted down, into the beach. Over time the beach will lower and expose more of the wall. Continued erosion in front of the wall leads to a narrower beach and the need to reinforce or enlarge the wall to increase its resistance to wave action.

Saco Bay

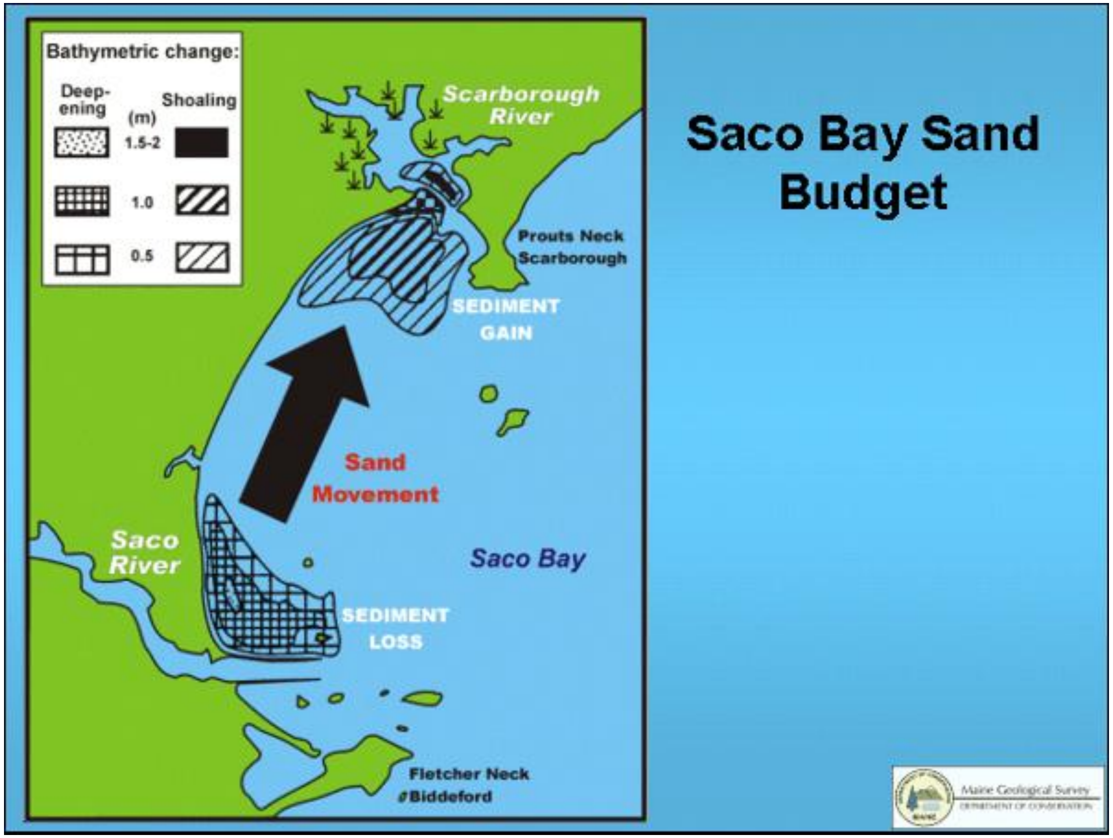
We will now take a closer look at Saco Bay, home to Maine's longest contiguous sandy beaches and the town of Camp Ellis, which has some of the highest (and most dramatic) erosion in all of Maine.



From Kelley, 1987

Saco Bay is an arcuate embayment along the southwestern Maine coast. It is bound by two headlands, Fletcher Neck/Biddeford Pool in the south and Prouts Neck in the north. There are three tidal rivers that empty into the Bay: the Saco River in the south, the Goosefare Brook in the middle, and the Scarborough River in the north. A major source of sand to the bay is the Saco River. The major communities on the bay are also shown. Camp Ellis is shown in red.

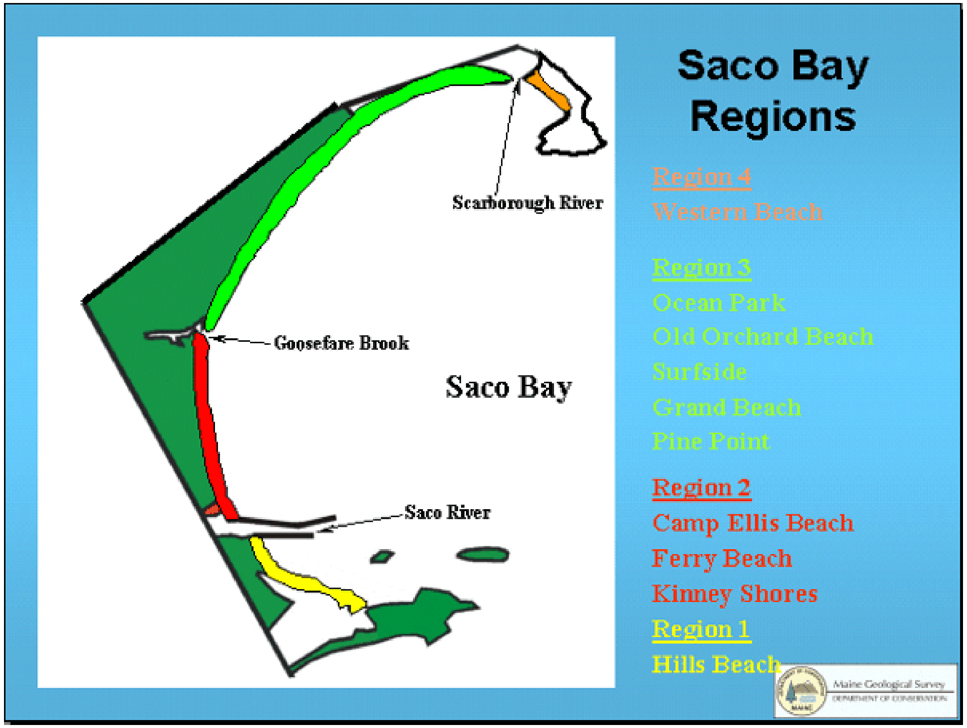
Saco Bay Sand Budget



From Kelley and others, 1995

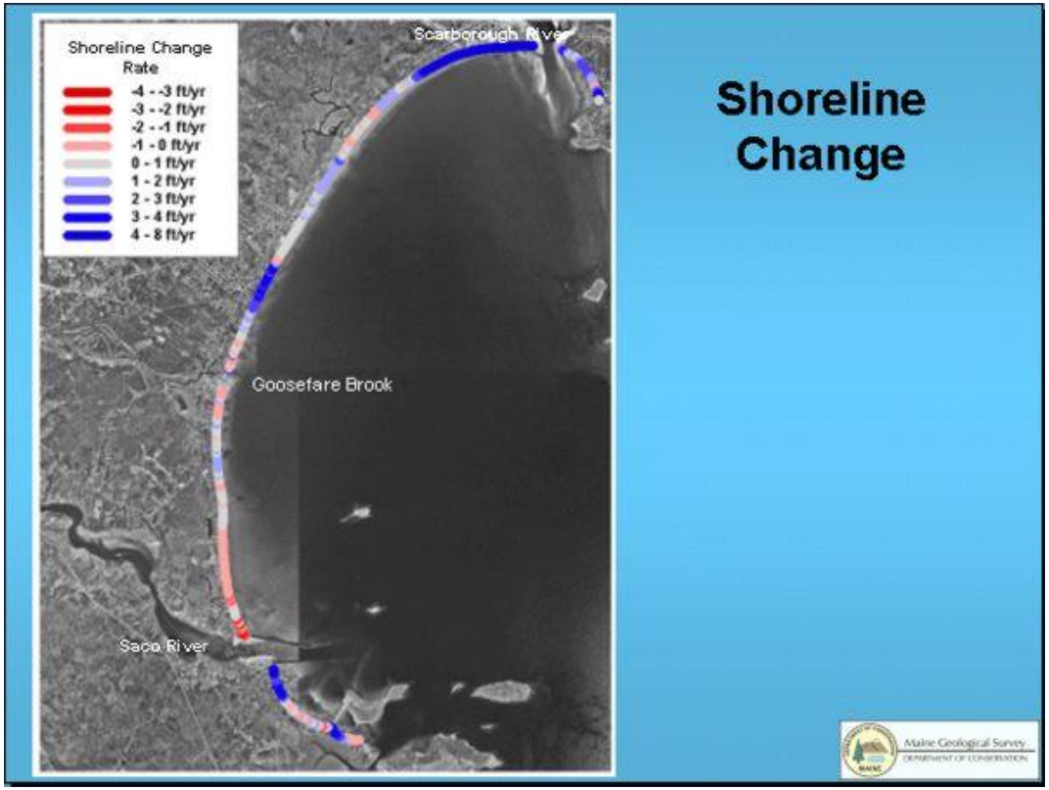
In general, sediment moves from south to north along Saco Bay. Historically, the Saco River was a major source of sediment to the bay. About 4,000,000 cubic yards of beach sand moved north (1859-1955), from the vicinity the Saco River jetty to the Scarborough River tidal inlet.

Saco Bay Regions



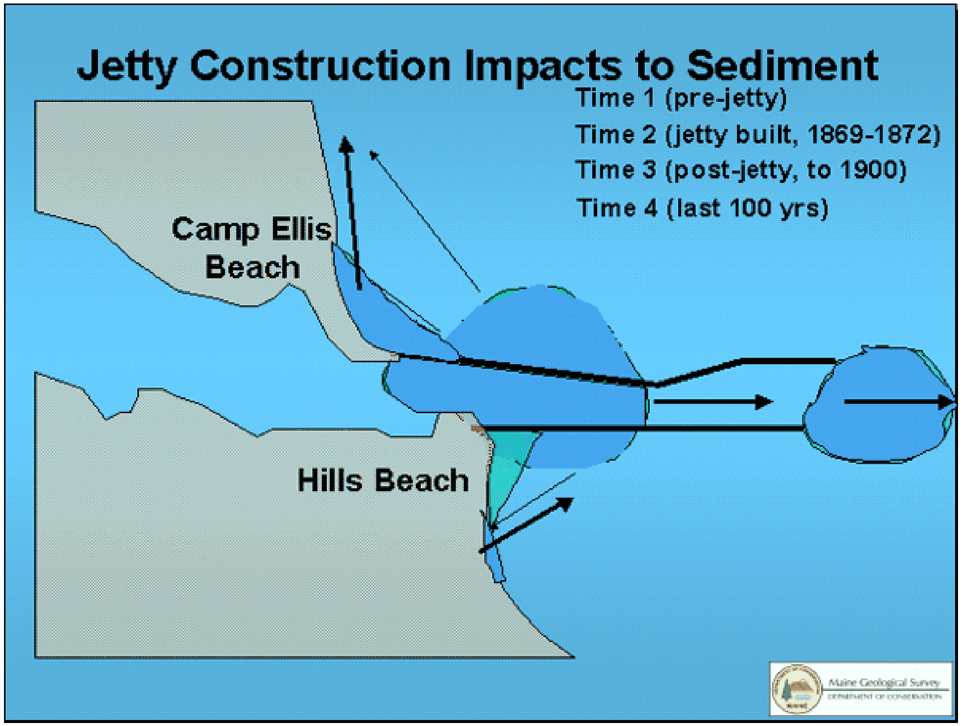
Based on an analysis of beach profile shapes and shoreline change rates, the Maine Geological Survey grouped beaches along Saco Bay into 4 general regions. These are shown in this illustration. Region 1 is comprised of Hills Beach, and is south of the existing Saco river jetties. Region 2 is comprised of communities between the northern Saco River jetty and Goosefare Brook. Region 3 extends from Goosefare Brook to the Scarborough River, and Region 4 is comprised of Western Beach, east of the Scarborough River.

Saco Bay Shoreline Change



This figure shows differences in shoreline change (1962-1995) along Saco Bay (red areas highlight highly erosive areas, while dark blue show highly accretive areas). Substantial erosion occurred in southern end of Region 2 (Camp Ellis), while substantial accretion occurred at the northern ends of Region 1 and Region 3. The general pattern confirms a northerly sediment transport direction in Saco Bay.

Jetty Impacts



This slide provides an illustration showing how the construction of jetties (1869) to stabilize the entrance to the Saco River impacted the adjacent shorelines. Time 1 (Pre-Jetty): Prior to 1869, sediment would flow down the Saco River and into a large ebb-tidal delta at its mouth. Occasionally, based on incoming wave directions, sediment would be pushed either northward (dominantly), or southward, feeding the adjoining beaches (see arrows). Time 2 (Jetty Built - 1869-1872): Once the jetties were constructed, the ebb-delta was bisected by the jetties. Time 3 (Post Jetty, to 1900): Dredging of the channel caused a new delta to form farther offshore. Bisection of the original ebb-tidal shoal left sand shoals on the north and south sides of the jetties. Waves pushed these shoals landward, leading to accretion of the beach until about 1900. Time 4 (Last 100 years): After 1900 however, no new sediment was making it to adjacent beaches because of damming up-river and the fact that the jetties now diverted sediment much farther offshore. The beach started to erode, and continues to do so on the order of 2-3 feet/year.

1995 Aerial Photo

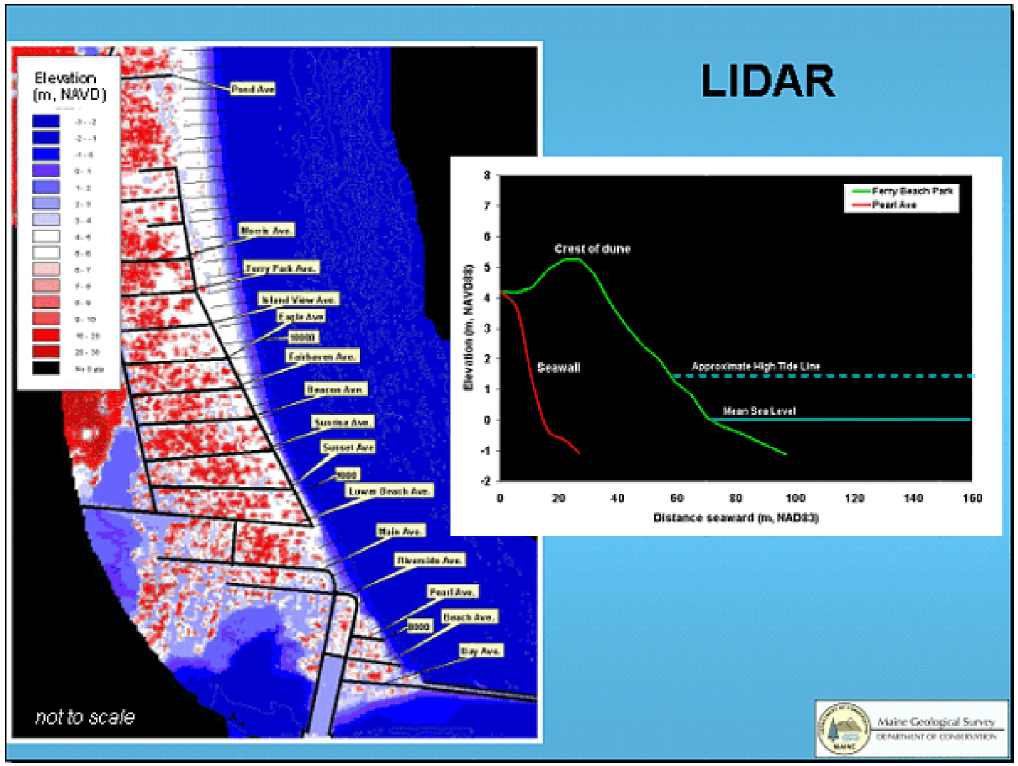
1995 aerial photograph of the Saco River jetties and Camp Ellis. Incoming waves during northeast storms (blue arrows) reflect off of the northern jetty and focus wave energy along Camp Ellis Beach. Erosion rates immediately adjacent to the jetty are on the order of 2-3 feet/year, and 1-2 feet/year farther north. A deep trough adjacent to the jetty is highlighted in yellow.

Property Loss at Camp Ellis

Photo by S. M. Dickson

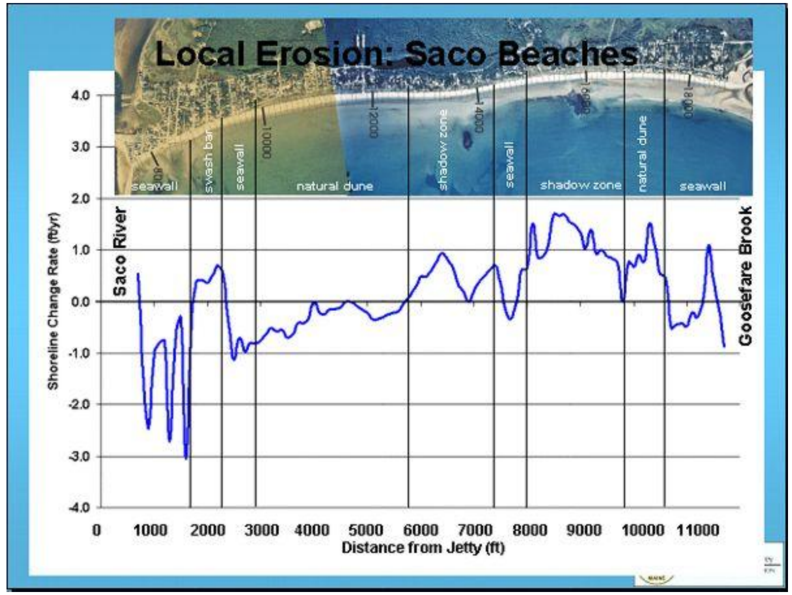
This slide shows historic loss of property in Camp Ellis. The 1908 shoreline (dashed line) is shown along with a 1908 tax map. The 1998 shoreline (solid line) is shown, with all tax lots currently underwater shown in blue. 36 developed lots have been lost in less than 100 years.

Camp Ellis LiDAR



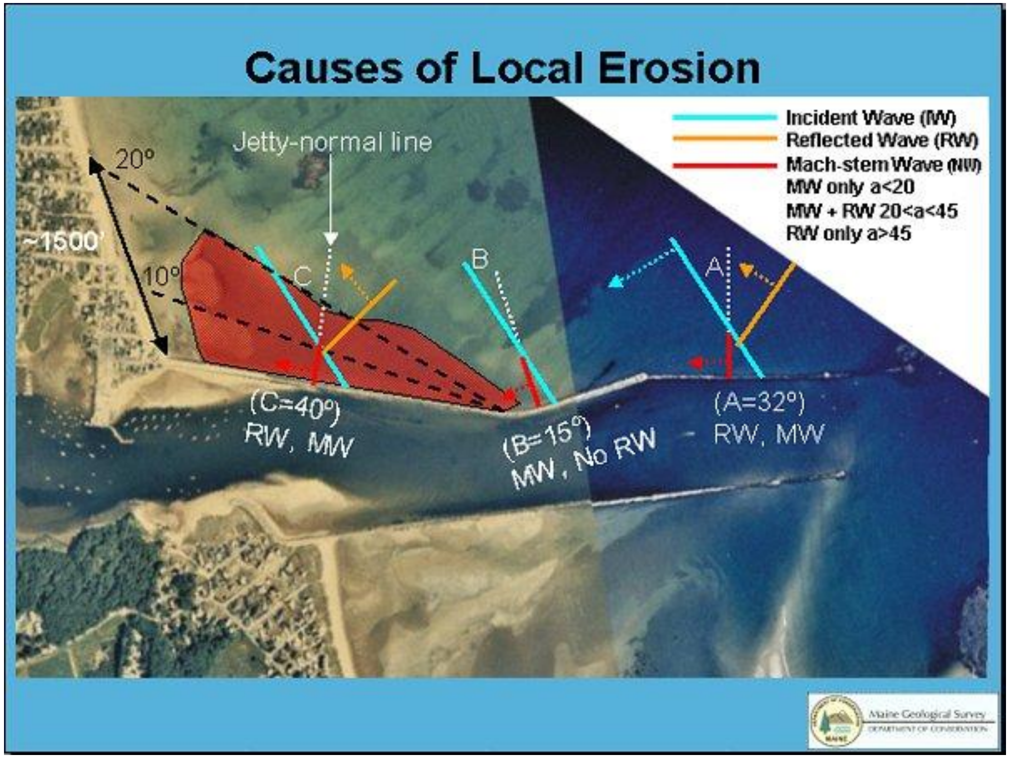
Light Detection and Ranging (LIDAR) data was used to create this image showing topography along Camp Ellis Beach. Beach profiles from Ferry Beach Park (north of Pond Avenue) and Pearl Avenue (near jetty) show the differences in topography of the beaches. At Pearl Avenue, a large, steep seawall protects properties immediately adjacent to the shoreline. In comparison, the natural profile at Ferry Beach Park shows a well developed dune, and much more gradual slope.

Shoreline Stabilization



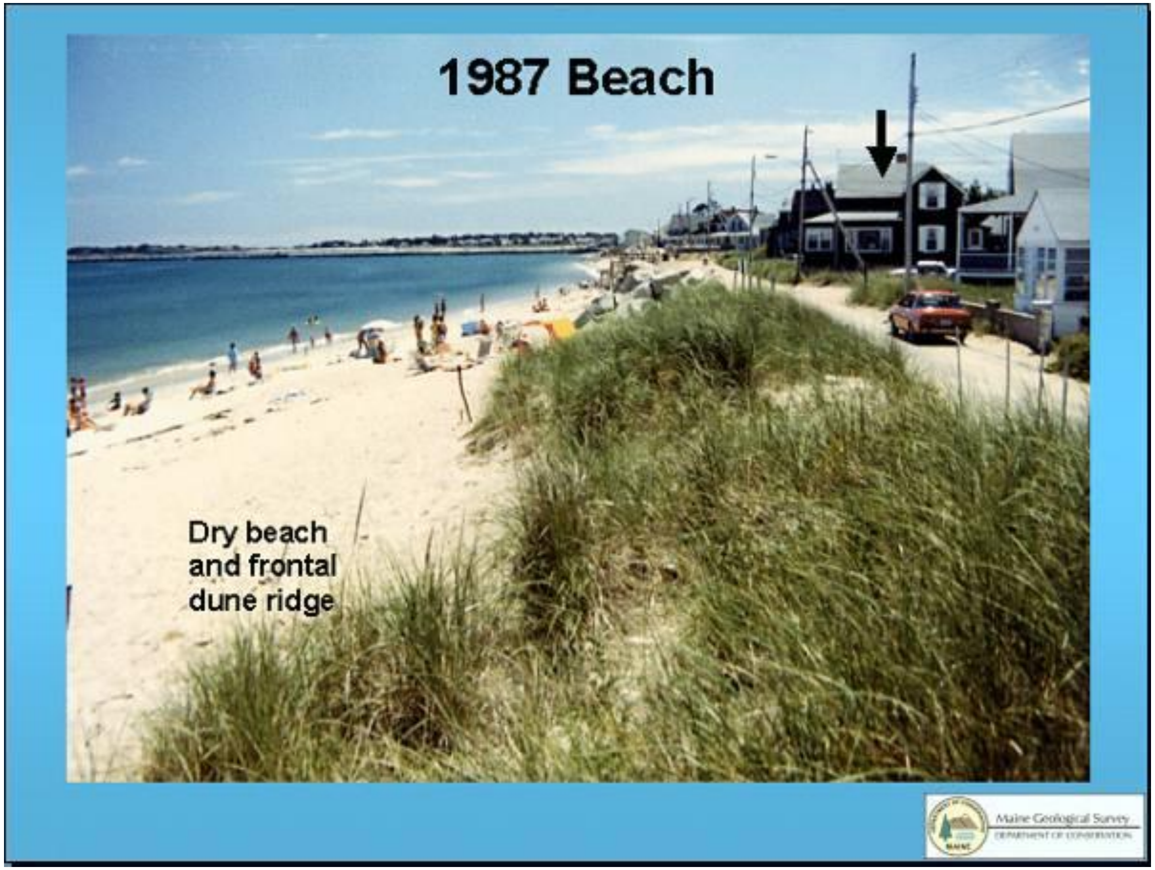
This slide shows the influence of shoreline stabilization (jetties and seawalls) and underlying geology on shoreline change (1962-1995) along the stretch of beach from Camp Ellis to Goosefare Brook (left-right). Closest to the jetty, the beach is heavily seawalled and is highly erosive. A small section of unstabilized shoreline, where a swash bar attaches to shore, has a slight accretive trend, which reverts back to an erosive trend along shoreline fronted by large seawalls. Downdrift from this (right) is a large stretch of natural beach within which a nodal point occurs - that is the trend switches from dominantly erosive to dominantly accretive. This occurs about 6,000 ft north of the jetty, and is visible as a small bulge in the shoreline. This is due to a shadow zone created by a large rock outcrop in the surf zone. An additional shadow zone, also created by an outcrop, is visible farther down the beach.

Causes of Erosion



The causes of local erosion at Camp Ellis Beach have to do with a lack of natural sediment supply (cut off from the river), stabilization structures (the beach is heavily seawalled from the jetty northward), and a combination of reflected wave energy and Mach Stem waves (Perroud, 1957). This slide shows the effects of reflected waves and the formation of Mach Stem waves, which travel along the jetty and can build to almost twice the incident wave height. When an incident wave (IW, blue line) approaches from the northeast and strikes the jetty, it forms an angle with the jetty at locations A, B, and C. The angle dictates which type of wave forms; either a normal reflected wave (RW, orange line), a Mach Stem wave (MW, red line), or both. It appears that both Mach Stem and reflected waves occur on the outer jetty (A), while only a Mach Stem wave is created on the middle section (B). Along the inner section (C), both Mach Stem and reflected waves area created. Mach stem waves can only travel at 10º from their point of origin (dashed line). The trough just north of the inner portion of the jetty is at about 20º from the bend in the jetty, indicating that a combination of reflected and Mach stem wave energy may be responsible for its formation.

Camp Ellis Beach 1987



We now look at a time-series of photographs along Camp Ellis Beach. Photograph (looking south) from 1987 shows the northern portion of Camp Ellis Beach. Note the black arrow showing a house for reference. There is a dry beach and well developed dune visible, and the seawall ends in-line with the reference brown house.

Camp Ellis Beach 2002

Photograph from November, 2002 after a minor northeast storm. Note the eroded dune and settled seawall. The seawall has been extended north since 1987. The large pile of sand was placed by the City of Saco to attempt to mitigate end-erosion occurring at the end of the sea walls.

Camp Ellis Beach 2003

Photograph from March 2003 showing the same section of beach and continued efforts to "plug" end-effect erosion at the northern terminus of the seawalls. Compare this slide with the photograph from 1987 (page 26).

Camp Ellis Beach March 2, 2004

Photograph from March 2, 2004 showing the same section of beach from slightly farther north. Note erosion of dune along the shoreline.

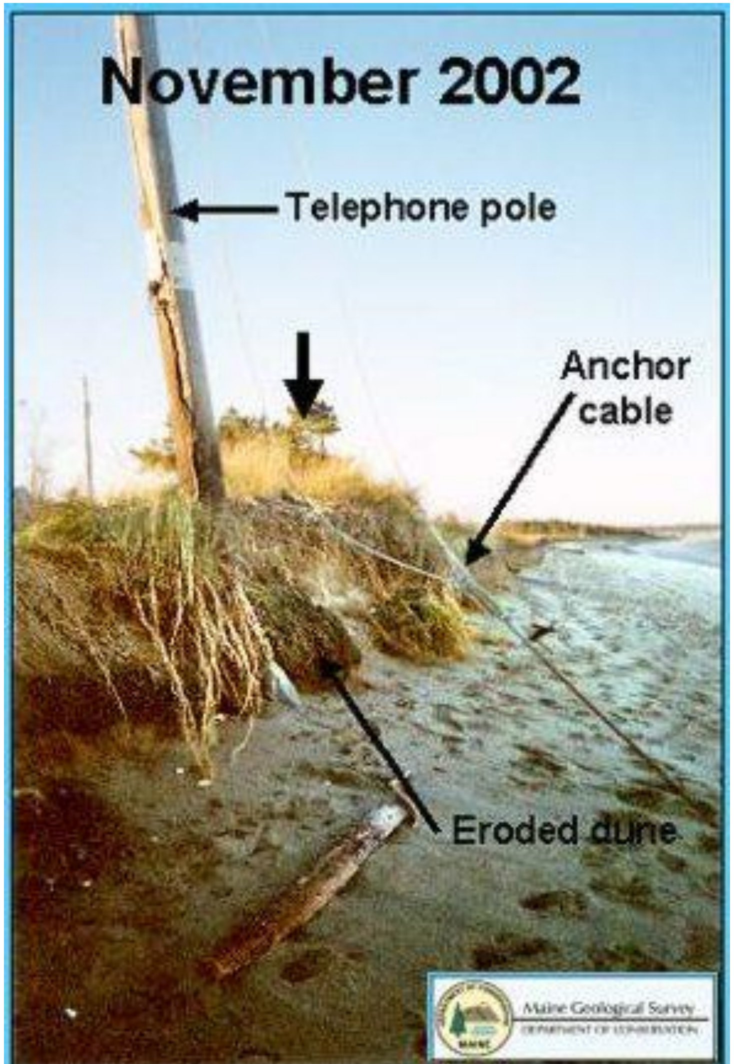
Camp Ellis Beach March 12, 2004

Photograph from March 12, 2004 after a northeast storm. Note full erosion of fill sand at the end of the seawall and seawall settlement.

Camp Ellis Beach April 2004

Photograph from April 5, 2004 after a second storm. Note the presence of heavy minerals (pinkish color) that have settled out on the upper portion of the beach. This minor storm actually helped move sand landward on the beach profile.

Camp Ellis Beach November 2002

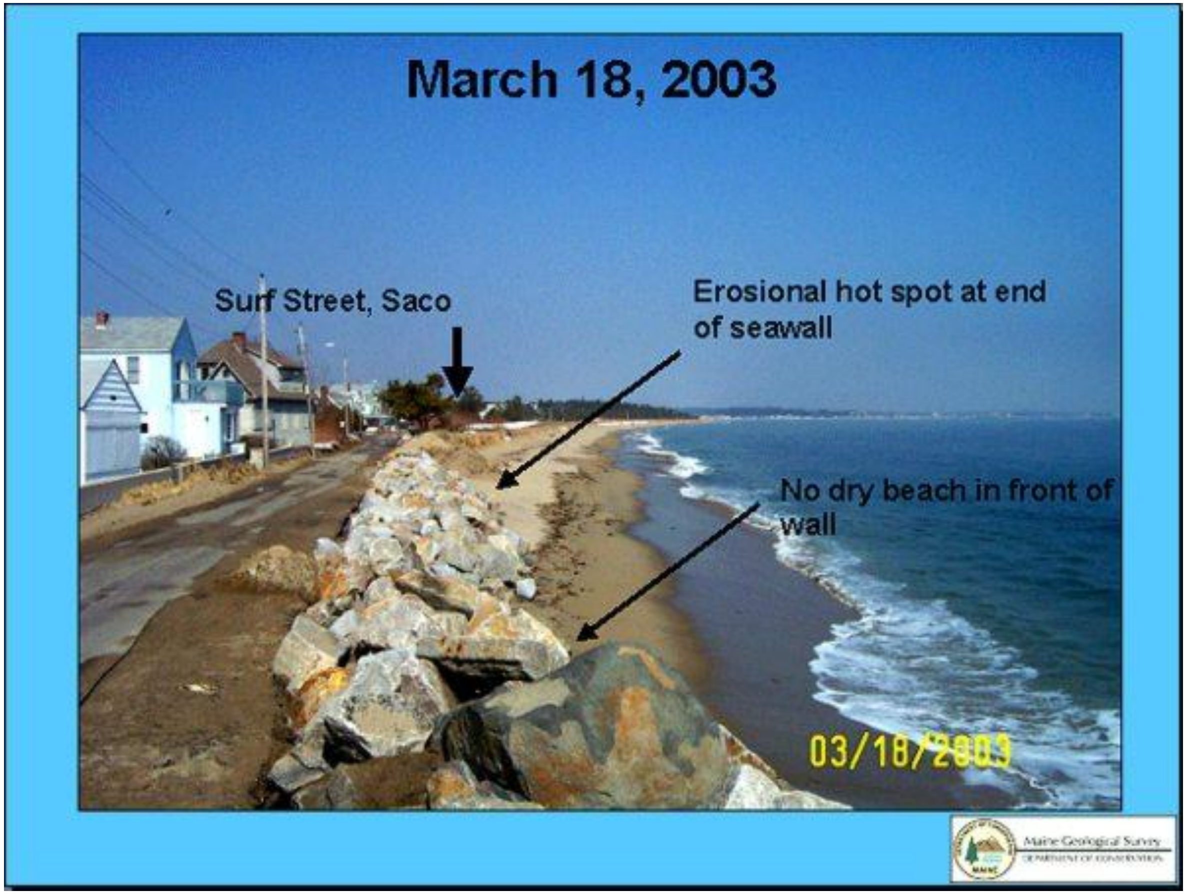


Photograph (looking north) of eroded dune and exposed cable, collapsing telephone pole just north of the end of the seawalls, after the November 2002 storm. Arrow shows a pine tree for reference.

Camp Ellis Seawall January 2003

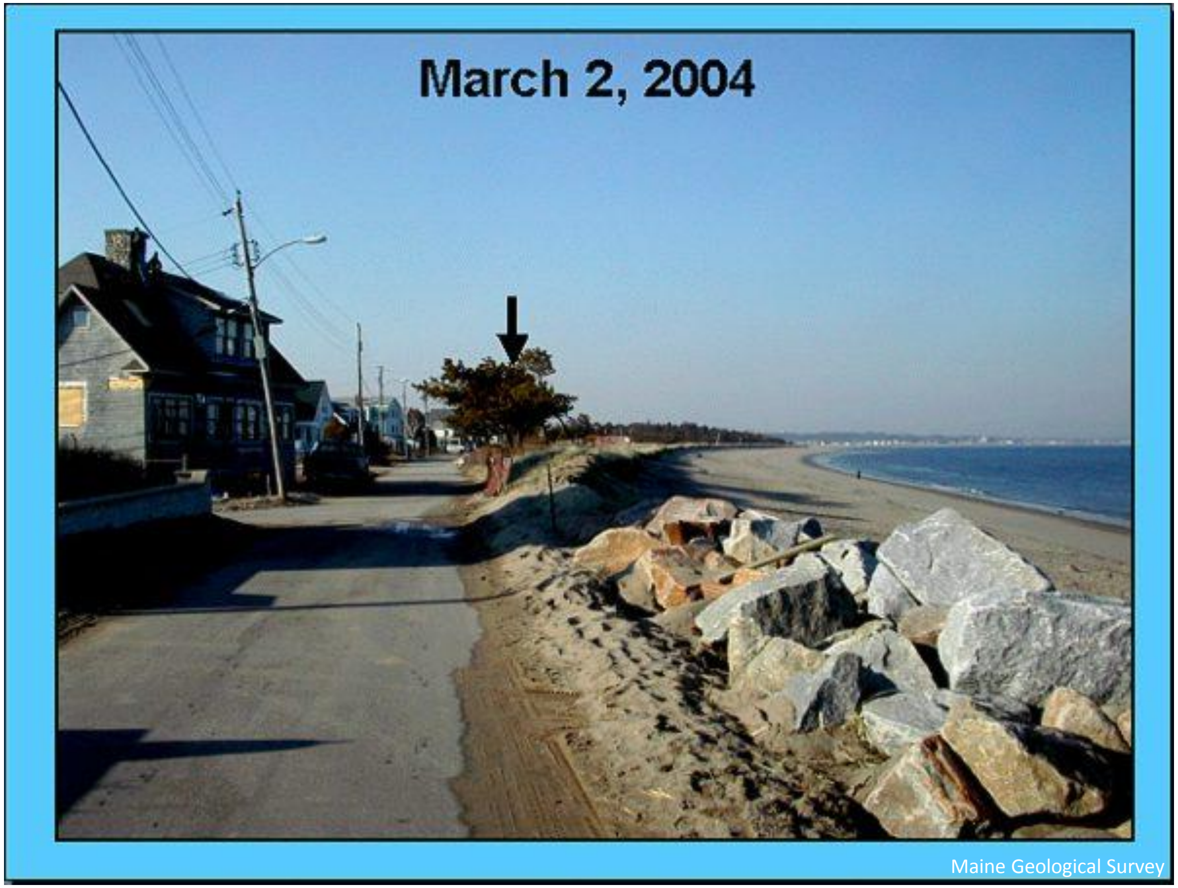
Photograph during January 2003 northeast storm showing erosion and overwash of the artificial fill area, and erosion of natural dune area north of the seawalls.

Camp Ellis Seawall March 2003



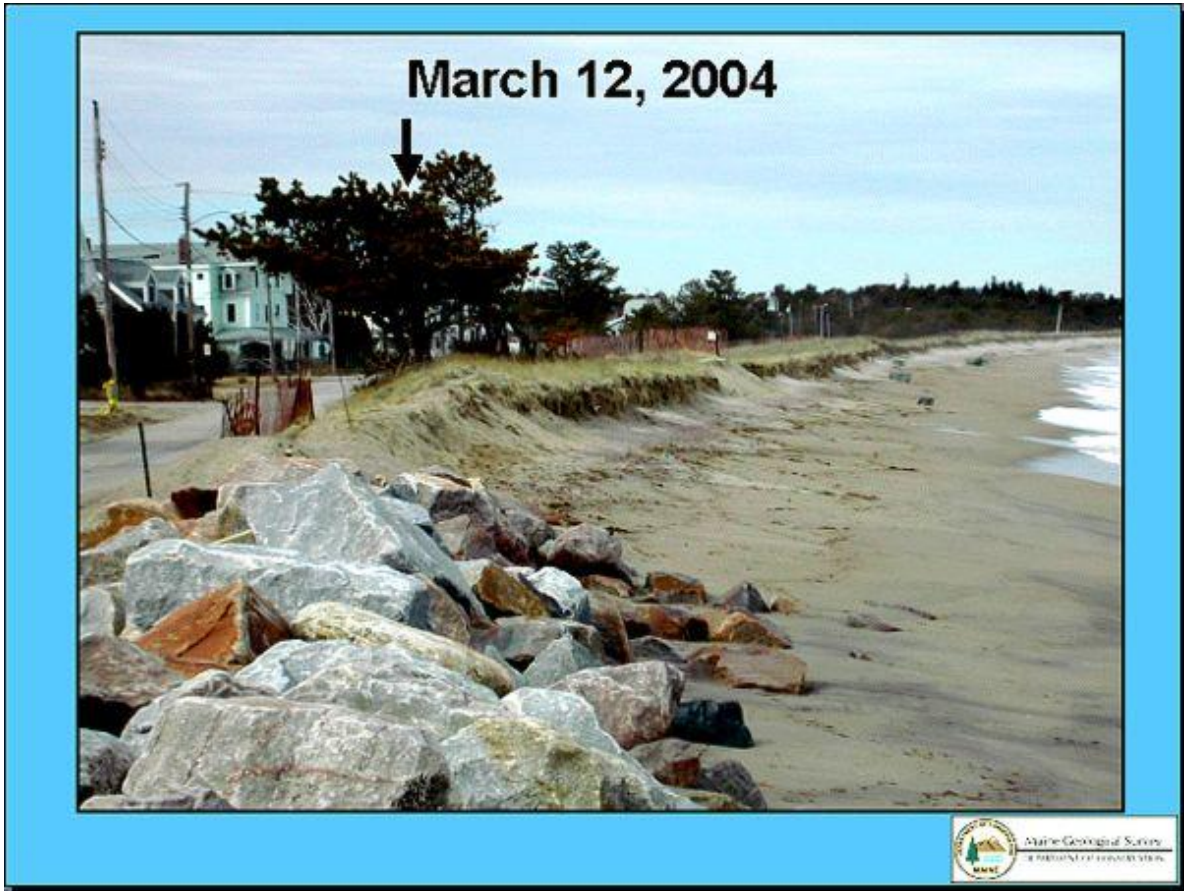
Photograph from March 2003 showing erosional hot spot at end of seawall.

Camp Ellis Seawall March 2, 2004



Photograph from March 2, 2004 of end of seawall.

Camp Ellis Seawall March 12, 2004



Photograph from March 12, 2004 after storm, looking north, at the erosional area north of the end of the seawalls. Note the washover of the erosion area and the scarping of the dune.

Camp Ellis Seawall April 2004

Photograph from April 5, 2004 showing overwash of fill area onto Surf Street.

Saco Bay Implementation Team

The Saco Bay Implementation Team (SBIT) is comprised of state and federal agencies, local stakeholders, and Congressional members. SBIT is working with the US Army Corps of Engineers to develop a solution to the problems at Camp Ellis. Under Section 111 of the Rivers and Harbors Act, the Army Corps is responsible for mitigation of erosion problems caused by a federal structure. The Team has gone through years of meetings. Recently, the Army Corps completed modeling efforts to look at various different structural alternatives to evaluate their effectiveness in decreasing wave energy at Camp Ellis.

Army Corps Scenarios

Alternative	Alternative Elimination and Summary
1	Northern Jetty Extension Removal
2	Northern Jetty Extension Removal and Jetty Lowering
3	750' Spur Groin
4	500' Spur Groin
5	Dual 500' Spur Groins
6	Additional configuration of best performing spur alternative
7	Optimized Spur Groin Alternative with Northern Jetty Extension Removal
8	Optimized Spur Groin Alternative with terminal groin
9	T-Head Groins
10	Secondary T-Head Layout
11	Offshore Breakwater
12	Combination of Spurs and Breakwater
13	Multiple Short Spur Groins
14	Offshore Borrow Pit
15	Borrow Pit and optimized Spur Groins
16	Jetty Roughening
17	Submerged Breakwater/Shoal

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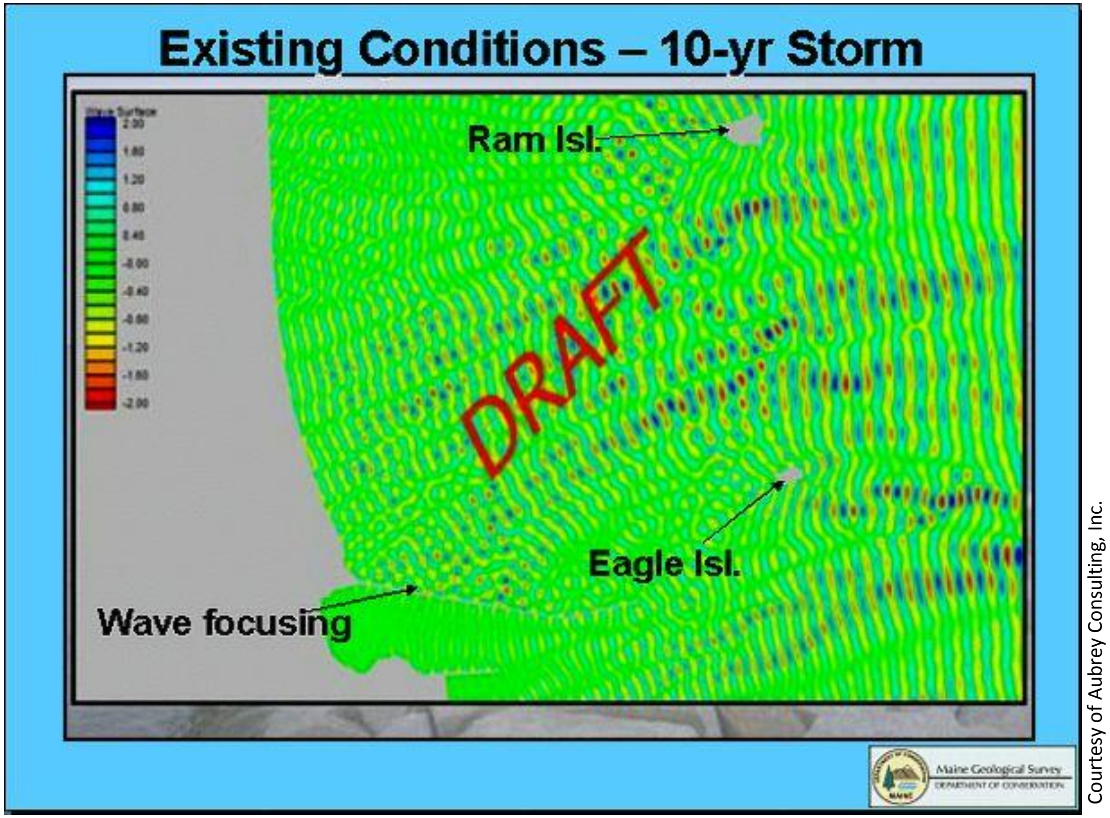
Alternatives

Maine Geological Survey
DEPARTMENT OF CONSERVATION

Courtesy of Aubrey Consulting, Inc.

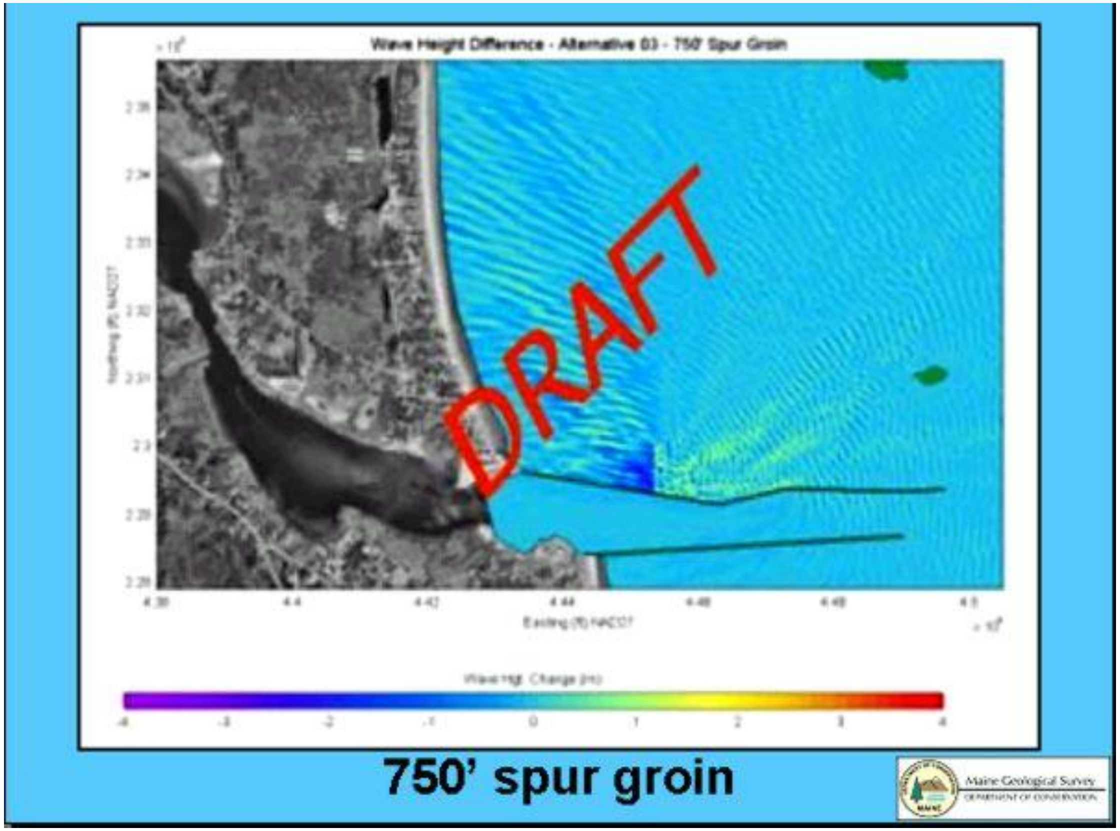
List of the scenarios modeled by the Army Corps as possible alternatives. Each alternative is combined with initial beach nourishment of 300,000 cubic yards of sand. Alternatives highlighted with an arrow were considered the "final four" and underwent more intense wave and sediment transport modeling.

Ten-year Storm Simulation



This slide shows results of the nearshore wave model developed for Camp Ellis Beach, simulating the effects of wave approach during a 10-year storm. Note the line of waves passing between Ram and Eagle Islands and focusing directly onto Camp Ellis and the northern jetty. This focusing is due to a relatively deep trough that stretches between the islands

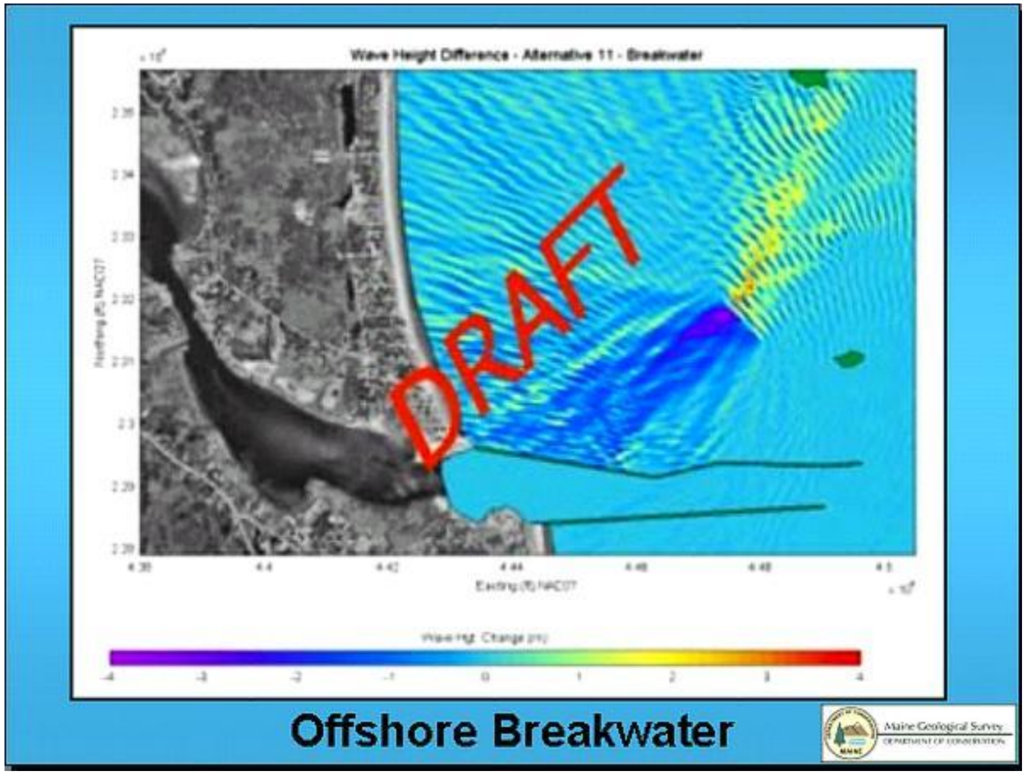
Simulation with Spur Jetty



Courtesy of Aubrey Consulting, Inc.).

Image showing the reduction of wave height in a 10-year storm with one of the final alternatives, a 750-foot spur jetty off of the existing northern jetty. Areas of dark blue and purple represent decreases in wave height from existing conditions. Green-yellow and reds indicate increases in wave height from existing conditions.

Simulation with Offshore Breakwater



Courtesy of Aubrey Consulting, Inc.

Image showing the reduction of wave height in a 10-year storm with one of the final alternatives, a 900-foot offshore breakwater located approximately 2,200 feet offshore. Areas of dark blue and purple represent decreases in wave height from existing conditions. Green-yellow and reds indicate increases in wave height from existing conditions. This alternative appears most promising in terms of wave height reduction.

Goodbye

Are we really saying goodbye to the beaches at Camp Ellis? We hope not. Stay with us and find out what is being proposed to lessen erosion and keep the beaches...

References

Dubois, R. N., 1992, A re-evaluation of Bruun's Rule and supporting evidence. Jour. Coastal Research, v. 8, p. 618-628.

Everts, C. H., 1987, Continental shelf evolution in response to a rise in sea level, *in* Sea-level Fluctuation and Coastal Evolution, Nummedal, D., Pilkey, O. H., and Howard, J. D., Eds., Society of Economic Paleontologists and Mineralogists, Tulsa, Oklahoma, p. 49-57.

Kelley, Joseph T., 1987, An inventory of coastal environments and classification of Maine's glaciated shoreline; in Fitzgerald, Duncan M., and Rosen, Peter S. (editors), Glaciated coasts: Academic Press, San Diego, California, p. 151-176

Kelley, J.T., and others, 1995, A sand budget for Saco Bay, Maine; Maine Geological Survey (Department of Conservation), Open-File Report 95-01, 40 p.

Perroud, P.H., 1957, The solitary wave reflection along a straight vertical wall at oblique incident, Ph.D. thesis, Univ. of California (unpublished); also, Inst. Engineering Research Technical Report No. 99-3.

U.S. Army Corps of Engineers, 1984, Shore Protection Manual (4th ed., 2 Vol.): U.S. Army Engineer Waterways Experiment Station, U.S. Government Printing Office, Washington, D.C.

Wells, J. T., 1995, Effects of sea level rise on coastal sedimentation and erosion, in: Climate Change - Impact on Coastal Habitation, D. Eisma, Ed. Lewis Publishers, Boca Raton, Florida, p. 111-136.