Coastal Erosion Assessment for Maine FIRMs and Map Modernization Plan

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I. Introduction

Coastal erosion constantly reshapes the Maine shoreline. As erosion occurs, it changes the topography of the intertidal zone and upland areas. Over time, erosion of upland areas results in shoreline recession. Erosion rates along the southern Maine coast have been measured as high as 3 feet per year and erosion affects both sandy beach shorelines and soft sedimentary bluff shorelines. Shoreline recession is accompanied by an increase in coastal vulnerability to flooding, wave action, and an overall increase in the potential for property damage. Changes in shoreline position and topography alter the extent of wave-runup and change coastal flood hazard areas. Flood zones represented in Flood Insurance Rate Maps (FIRMs) can become out of date in areas where shoreline change is significant.

The purpose of this report is to assess which coastal areas, and hence FIRMs, are subject to erosion and shoreline change to such a degree that the existing flood maps are now or are soon to become obsolete. This information will be used to help the State of Maine prioritize areas that need map modernization in coming years as part of the Federal Emergency Management Agency (FEMA) Map Modernization Plan for FIRMs.

II. Beach and bluff erosion processes along the Maine coast

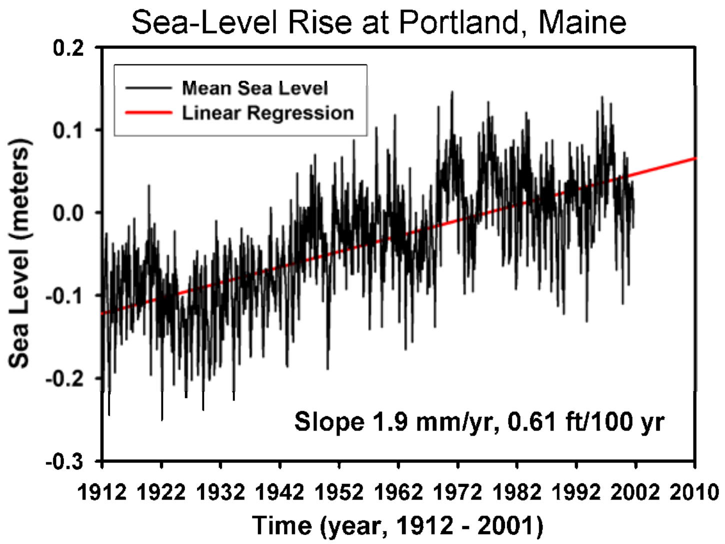
A. An Eroding Coast

Coastal erosion in Maine occurs primarily where sediment is present along the shoreline at or near the high tide line. *Over half* of the Maine coast has sediments in and above the intertidal zone and is vulnerable to shoreline change due to erosion (Dickson, 2001b). Glacial and marine processes deposited sediment that makes up the “soft” coast during the last 20,000 years. Consequently, the sediment along the shore is geologically young compared to many non-glaciated coasts in the United States. These glacial and post-glacial sediments have not yet been hardened into solid rock so very little force from coastal processes is needed to reshape the shoreline. Much of the Maine coast is experiencing shoreline change due to the abundance of soft sediments along the shore.

Bluff erosion and gravel beach formation at Fletcher Neck in Biddeford. Maine Geological Survey file photo.

B. Sea Level

The most important force causing shoreline change is the rise in sea level. As in many places along the U.S. East Coast, the ocean has been rising at a rate of about 2 mm/year for at least a century. In Portland, the rate of sea-level rise since 1912 has been about 1.9 mm/yr (0.61 feet/century; see figure below). While the rate of rise is not constant, the long-term trend is upward. As mean sea level rises, so does the height of the tides and the areas along the shoreline that can experience wave action and flooding.



Sea level variation through time at Portland, Maine (NOAA tide station No. 841850) showing the long-term trend in a linear regression. Slope = 1.87 mm/yr or 0.61 ft/century, $r^2 = 0.46$. Source: S. M. Dickson, Maine Geological Survey, August 12, 2002.

C. Rising Floodplains

With simple sea-level rise, the coastal floodplain also rises. For example, in southern Maine, the salt marsh environment behind barrier beaches is generally an A-Zone (100-yr flood hazard area). The B-Zone (500-yr flood hazard area) is commonly about 6 inches higher than the A-Zone. So, the sea-level rise that has occurred in southern Maine since 1912 would have changed a 1912 back barrier marsh A-Zone to a B-Zone. Even in the absence of coastal erosion, a rising sea will gradually change the elevation of the floodplains and necessitate remapping of flood hazard areas.

D. Causes of Shoreline Change

Natural processes and human activities cause shoreline change. In addition to the gradual rise of the sea, other natural processes affect the position of the shoreline. The most important of the natural processes are waves, tides, and storm surge.

1. Waves. On a daily basis, waves and tides redistribute sediment along the shoreline. Waves that reach a shoreline at an angle produce a current that carries sediment along the shoreline. This sediment transport undercuts coastal bluffs and moves beach sand parallel to shore. Many shoreline areas have a predominant wave attack and thus a dominant sediment transport direction (e.g. Higgins Beach, Scarborough and Great Hill, Kennebunk). In an area with a natural balance of sediment supply and removal, the shoreline position remains stable. Along most Maine shorelines, however, the sediment budget is not balanced and there are areas of erosion and areas of accretion caused by waves.

2. Tidal Currents. Tides are also an important natural force that causes shoreline change. Tides flow in and out of estuaries and transport sediment along the margins of channels leading to and from the ocean. Tidal currents predominantly carry sediment from the ocean shoreline into the estuary in most Maine locations (e.g. the Kennebunk, Scarborough, and Webhannet Rivers). In a few places sediment is carried to the sea from an estuary. The Saco and Kennebec Rivers deliver sand to the coast. In either case, tidal currents continually alter shorelines and coastal floodplains in and around estuaries.

3. Flooding. Storm surge is the natural elevation of the sea due to the influence of wind and atmospheric pressure near the coast. Coastal flooding results from storm surge and surge statistics define the 100-year floodplain. Storm surge is also important in changing the shape of the shoreline. An elevated sea combined with storm waves results in erosion of frontal dunes and coastal bluffs. Single storm events can cause tens of feet of dunes to erode (e.g. February 1978 Blizzard and October 1991 “Perfect” Storm). In general, such dune erosion is seasonal and most loss from storms is replaced in a year. A storm with a 10- to 100-year recurrence interval may permanently change the location and elevation of the frontal dune and permanently shift the beach profile inland. After significant storms, coastal floodplain boundaries along Maine beaches are likely to have moved inland permanently. Prioritization for remapping flood hazard areas along beaches should consider the age of the map relative to the timing of significant storms.

4. Coastal Engineering. Human activity is a dominant force affecting the shoreline position and rates of shoreline change. The two primary actions that affect erosion and accretion are the engineering of seawalls and jetties. Seawalls are prevalent along about half of the beach shorelines. A significant, but yet undetermined, percentage of bluff shoreline is also armored to prevent shoreline change. In both coastal settings, the stabilized shore prevents the high tide line from moving inland. In fixing the shoreline, the natural release of sediment from the bluff or dune is prevented and the local sediment budget is permanently altered with consequences for adjacent shoreline stability.

a. Seawalls. Seawalls on beaches prevent the natural exchange of sand between the beach and dune. In many locations, seawalls prevent the process of minor coastal flooding and sand deposition on the frontal dune ridge. Thus, over time, frontal *dunes with seawalls may not build up* a ridge that is sufficiently high - as the floodplain creeps up with sea-level rise – to maintain a constant flood hazard at a particular location in the dunes. Frontal dune areas that may have been X-Zones in the past may become AO-Zones due to the lack of sand transport in a landward direction prevented by seawalls.

Storm wave impact on a wooden sea wall at Camp Ellis in Saco. Photo by S. M. Dickson.

Seawalls also alter the rate of sand transport along the beach. By causing increased wave reflection, the amount of sand resuspended in the water in front of a seawall can increase and lead to more sand being carried in an alongshore direction, away from the beach profile. The increase in alongshore-sand transport can be 10 times that which occurs in a natural beach and dune system. Seawalls can significantly alter the local sand budget of beaches. An effect of seawalls can be to *alter the orientation of the shoreline* and thus the way waves break and run up the beach and cause coastal flooding.

The third way that seawalls affect coastal flood hazards is by creating a beach profile that is out of equilibrium. On beaches where seawalls have regularly reflected waves for several decades or more, the natural inland migration of the beach has not taken place. Instead, the beach seaward of the wall has lowered while the dune behind the wall has remained static. Compared to a natural beach profile in an adjacent area, the amount of disequilibrium can be on the order of 50 feet. The *artificially lowered beach profile* influences the height of the 100-year wave envelope and wave runup elevation. These factors, in turn, affect the inland extent of flooding and the need to reevaluate flood hazard areas.

b. Jetties. Jetties are engineered structures that flank tidal channels adjacent to beaches. They are installed to stop natural shoreline change where beaches meet a tidal inlet in order to provide better navigation. Maine has jetties on both shores of the Webhannet River (Wells), on both shores of the Kennebunk River, and both shores of the Saco River. There is only one jetty at the southern side of the Scarborough River. Within the estuary, both shores of the Goosefare Brook (Saco and Old Orchard Beach) are also stabilized. All of the major jetties at rivers in Maine have significantly altered local sand budgets and shoreline change.

The north jetty/breakwater of the Saco River. The community of Camp Ellis (City of Saco) is in the background. Photo by S. M. Dickson.

c. Dredging. Dredging for navigation also influences shoreline positions. Unstable sandy channels adjacent to beaches have had regular and recurring maintenance dredging for many decades. The cumulative amount of sediment redistribution due to dredging is as significant as or more significant than natural processes in most local sediment budgets.

E. Cumulative Human Action

The combined influence of jetty engineering, seawalls, and dredging has accelerated shoreline change and the inland positions of floodplains in Maine in the last century. In the last 40 years, up to 2 million cubic yards of sand have been moved in the Wells Embayment (Ogunquit to Kennebunkport) under the influence of human activity and dramatic shoreline changes resulted. In the last century, about 4 million cubic yards of beach sand moved north in Saco Bay from Saco to Scarborough. This movement was away from a jetty at the Saco River and toward the jetty at the Scarborough River. The rate of sand movement north in the bay is about 3 times the natural rate that existed prior to jetty and seawall construction in Saco. Over 30 houses in Saco have been destroyed by the combination of shoreline change and coastal flooding that is attributed primarily to human activity.

III. Erosion mapping methods and Maine data sets

A. Historical Shoreline Change Analysis

1. Map Analysis. Maps and nautical charts can be examined or superimposed to compare changes to the shoreline. Early charts and maps of Maine are available in digital form from the National Ocean Service and at the Osher Map Library of the University of Southern Maine in Portland. In Maine this type of analysis is used to understand large-scale changes to the shoreline such as the closure of a tidal inlet (Little River, Scarborough) or the presence of a large tidal delta (Saco River) in the last two centuries. The large-scale shoreline morphology mapped in early charts can be useful in generating coastal sediment budgets and examining conditions prior to human influence. These early maps and charts are not useful for exact shoreline change rate calculations because of the level of geographic control results in errors that exceed the absolute amount of shoreline change in many Maine locations.

2. Air Photo Analysis. Erosion can be detected by comparing sequential shoreline positions in vertical air photos. This approach uses various analytical methods and equipment to superimpose shorelines on a map and then to calculate an erosion rate. One way is to compare the earliest and most recent pairs of photos. This approach uses the longest span of years to determine an erosion or accretion rate. This "**end point**" method can be a reliable proxy for predicting shoreline change in locations that have a steady, chronic erosion problem (e.g. Higgins Beach, Scarborough).

Another method uses a time series of shoreline positions taken from many air photos. At any particular location, the horizontal position over time is used to calculate a **linear regression** or "best fit" to the data. This approach is favorable to reduce the influence of erosion and accretion cycles that may exist on a beach (e.g. Popham Beach, Phippsburg or Goose Rocks Beach, Kennebunkport).

3. Shoreline Proxies. Erosion rate measurements (using either the end point or regression method) rely on one of several proxies for a shoreline position. The optimal proxy is the seaward edge of dune vegetation since it fluctuates gradually over a year. Alternatively, the position of the high-tide line or wet-dry beach line can be estimated in some air photos, but this position changes daily and seasonally.

In Maine, the fortnightly variation of the tides creates water elevation differences of over one foot in the level of "high tide." The spring-neap tidal height differences result in a horizontal shift of the wet-dry beach over 10 feet in just two weeks. Consequently, to use historical air photos, the monthly variation in the tides must be known as well as the slope of the beach in the photos in order to interpret the shoreline proxy of the "high-tide" line or the wet-dry line.

4. Errors. There are horizontal errors introduced by the process of digitizing any shoreline proxy and in calculating an erosion rate. In areas where the long-term erosion rate is slow (perhaps less than 1 foot in 2 years), the absolute distance eroded may not exceed the analytical errors that propagate through mathematical calculation of an erosion rate. Cumulative errors may exceed the amount of shoreline change (Crowell et al. 1991). In some locations, low erosion rates cannot be discerned from short-term temporal variation of the beach.

5. Maine Studies. In the early 1990s, the Maine Geological Survey used the end point method to compare 1953 and 1991 shorelines along most of the large beaches. This study used the leading edge of dune vegetation as a shoreline proxy. In areas without natural dunes, seawalls were digitized. A novel approach using an analytical stereoplotter was used that reduced horizontal errors and resulted in a geographic information system (GIS) map with both shorelines displayed (Duffy and Dickson, 1995). The results are only useful in areas without seawalls, but they do provide data on the natural rate of dune erosion or accretion over a period of 38 years.

One drawback of this data set is that the 1991 photos were taken about 3 weeks after a major storm (October 1991 "Perfect" Storm). Some scientists have suggested that the most robust shoreline change analysis should avoid using photographs taken after storms. At the time of the Maine study, there were no more recent or better quality photos to use than the 1991 set so, despite the influence of the storm on, the dune line was mapped for comparison.

A series of air photos and geomorphology from early nautical charts was used by Bruce Nelson (1979) to examine historical shoreline change of Maine beaches. His work only exists as small-scale maps from his thesis; the original large-scale maps no longer exist. Nelson used a Zoom-Transfer Scope in order to map sequential shorelines. Despite the passage of twenty-four years, his analysis and results are still very useful for understanding shoreline change. Nelson concluded that most natural beaches have a shoreline retreat rate of about *1 foot per year*. As in the MGS study mentioned above (Duffy and Dickson, 1995), there are areas where seawalls are present in all the old photographs so horizontal erosion could not be measured.

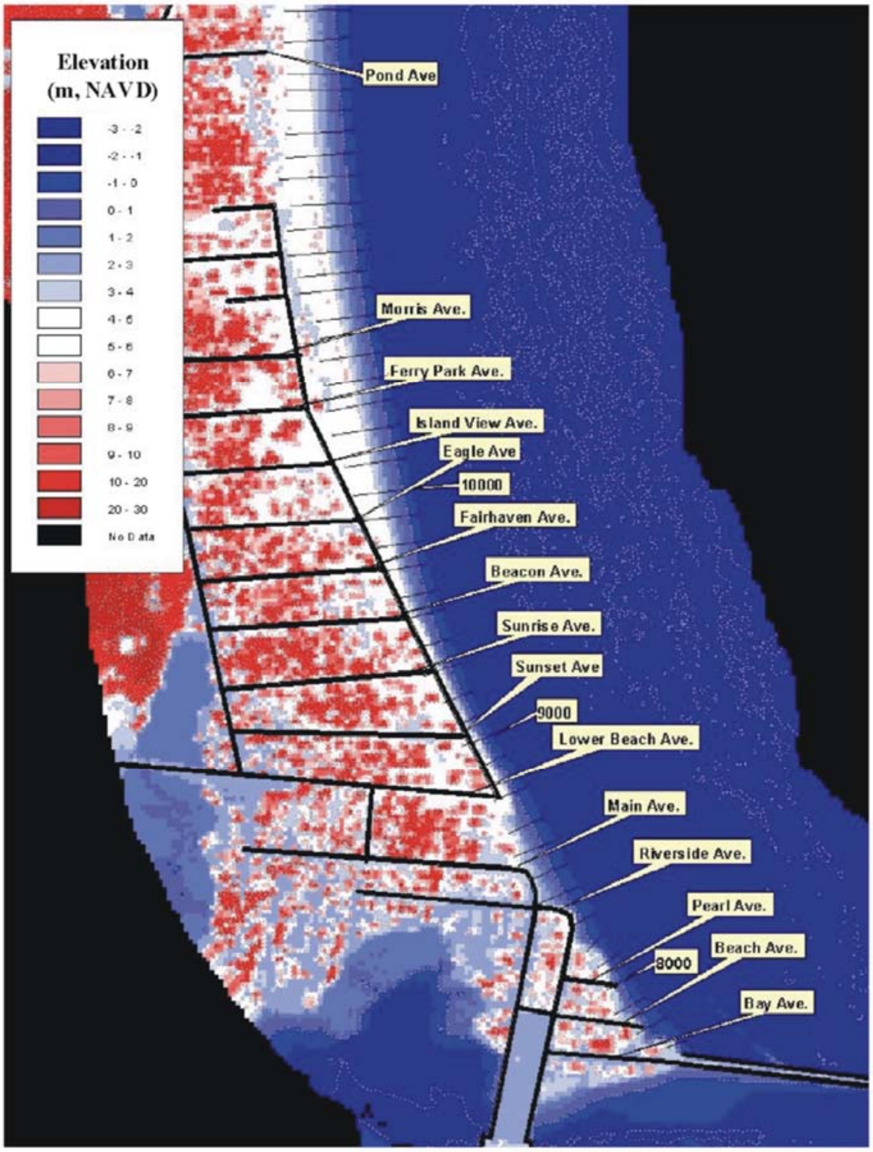
B. Beach Profile Monitoring

Since 1999 Maine has had teams of volunteers profiling several Maine beaches (Heinze, et al., 2002; Hill et al., 2002). Using the Emery method once a month, these teams record elevation changes to the beaches. Some of these measurements are in natural settings and others are seaward of seawalls or adjacent to jetties. Results of these surveys continue to be analyzed. In the first two years of data it was determined that there is a large annual elevation change in many beaches, including those with seawalls. Over two years, however, the profiles did not show an equilibrium or stable condition (State of Maine Beach Profiling Project, 2003). A considerable difference in the volume of sand was found on the beaches from one summer to another.

The implications from the topographic analyses of this data set are important to floodplain mapping. Shore-normal beach profiles used in wave runup models could generate different results depending on the year or season that the profile was made. In some locations the vertical change through a year can be as much as a meter. This profile variability has a bearing on the certainty of selecting an appropriate coastal flood profile and hence on accurately projecting flood hazard areas in the dunes. From what is understood of the seasonal changes to the beach, flood hazard areas based on a topographic profile of August elevations underestimate flood hazards in February, a time when flooding is most likely to take place. The most valuable aspect of this beach profile data set for floodplain mapping is in understanding site-specific seasonality in beach elevations.

C. Topographic Change Analysis

High-resolution topographic data for southern Maine is available from the National Ocean Service. A 2000 LIDAR data is the first in what may be repeated surveys every few years. MGS proposed to NOS that the southern Maine coast be resurveyed in the next year and NOS is currently planning flight options to accommodate this request. When this second survey is completed, and others are made in the future, this 3-D approach to analyzing shoreline change will be far superior to that using 2-D historical air photos. Together, the two methods will better define the rate and character of shoreline recession in both the long- and short-term.



LIDAR topography from NOAA of the Camp Ellis region used to generate beach profiles and evaluate the elevation of dunes relative to base flood elevations. Graphic by P. A. Slovinsky, Maine Geological Survey. See Slovinsky and Dickson (2003) for more applications of this data.

Repeated LIDAR surveys have been used to measure shoreline change and to calculate erosion rates. Since the data have a vertical (as well as horizontal) component, equal elevation contours can be delineated and changes at a particular elevation mapped. This allows several shoreline proxies, such as mean sea level (MSL) and mean high water (MHW), can be extracted from the data. Temporal changes to dune ridge elevations can also be analyzed so trends relative to floodplain elevations can also be computed (e.g. is the frontal dune ridge getting lower over time; will the dune ridge remain above the V-Zone FHA in the next 10 years?).

Georeferenced, three-dimensional data have been used by MGS to examine beach and dune profiles in relation to flood elevations from FIRMs (Slovinsky and Dickson, 2003). This study indicates areas of vulnerability to flooding, and when combined with historical shoreline change rates, indicates which areas are most likely to need mitigation for combined flood and erosion hazards. This work also serves as a good example of how shorelines can be ranked and compared to determine where both flooding and erosion increase the priority for revising FIRMs.

D. Shoreline Change and Remapping FIRMs

In order to do a sophisticated erosion analysis and to generate accurate erosion rates it is essential to understand the temporal and seasonal changes of shoreline positions taken from historic air photographs or recent detailed topographic analyses. Sound erosion rates must be generated with a minimum error in order to distinguish areas that are eroding slowly from those that are not. Most importantly, accurate erosion rates are necessary to predict when FIRMs need to be remapped.

IV. Suitability of Maine data for Erosion Hazard Area (EHA) determinations and Erosion Rate Analysis

A. Previous Work

Maine data on shoreline change is variable from one geographic area to another. This variability is due to the availability of historical data and its application by scientists for specific studies. Work to date has shown that shoreline change occurs along all of Maine's beaches at different rates. The average shoreline recession rate for natural dune areas has been calculated at 1 foot per year (Nelson, 1979) using historical data from air photos at many locations.

Of course, those areas with no change at a seawall may have had significant change to the elevation of the beach. In fact it is quite likely that the beach lost sand and became lower during the decades while the seawall was active. Consequently, it is misleading to assume that “no change” represents a static shore-normal profile and thus a static condition for estimating wave runup and coastal flood profiles.

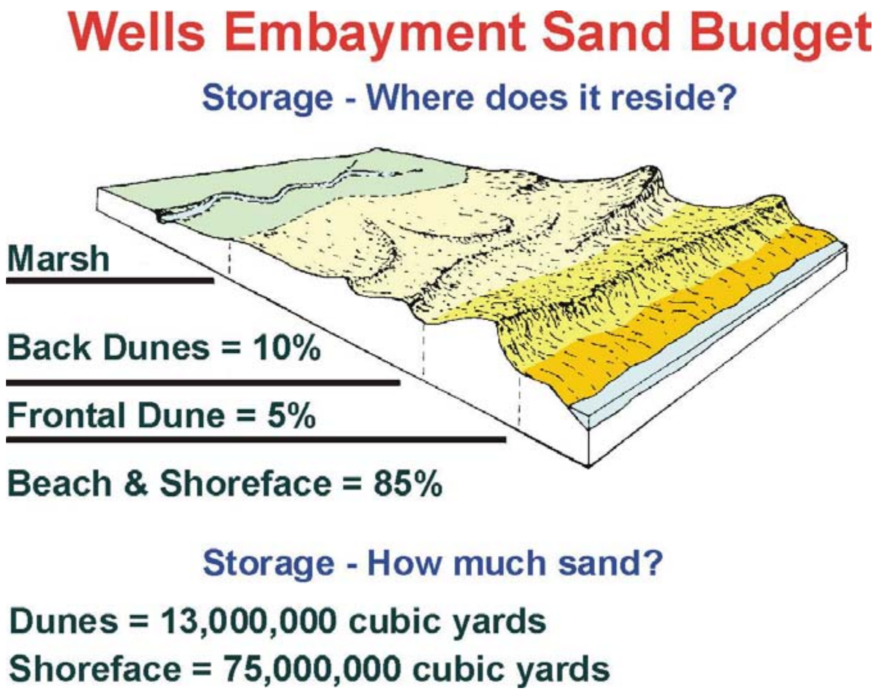
Recent analysis of Saco Bay by Slovinsky and Dickson (2003) serves to illustrate the potential for examining EHAs using historical air photos and LIDAR data. By projecting shoreline change onto beach profiles generated from LIDAR topography, volume estimates of sand loss or gain were generated to calculate sand budgets for discrete shoreline segments and littoral cells. This information is then useful in understanding the cause(s) of shoreline change and to understand if the sediment budget for a region is in balance. The budget approach also allows comparison of human activities, such as dredging, to be compared to natural rates of sand movement.

A Maine Geological Survey investigation of regional sediment budgets over the last 50 to 100 years has found a profound influence on sand loss and accumulation due to human activity. Over the time frame of air photos commonly used to determine EHAs, there have been larger changes to the shoreline from anthropogenic factors than from natural ones. Consequently, the first data needed for interpreting shoreline change (and if it will be sustained) to project future EHAs is to construct and interpret a sediment budget based on historical data. Two examples serve to illustrate the profound impact of humans on shoreline change.

B. Wells Embayment

The sand budget for Wells Embayment (Ogunquit, Wells, Kennebunk, and Kennebunkport) is very revealing of the influence of human activity on shoreline change. In terms of sand volumes, about 15% of the coastal barrier sand is on land (see the figure and table below). About 4.2 million cubic yards of sand is in the frontal dune and 9.0 million cubic yards are in the back dunes. An enormous 75 million cubic yards are in the submerged shoreface seaward of the beaches.

Analysis of dredging records and shoreline change indicate that human activity has resulted in the accelerated movement of up to 2 million cubic yards of sand in the Wells Embayment in the just last 40 years. This human influence is approximately equivalent to moving half of the frontal dune ridge in the entire bay. Consequently, there is no doubt that coastal engineering and dredging practices must be considered in projecting EHAs in this region.



Wells Embayment Sand Budget

Storage - Where does it reside?

Storage - How much sand?

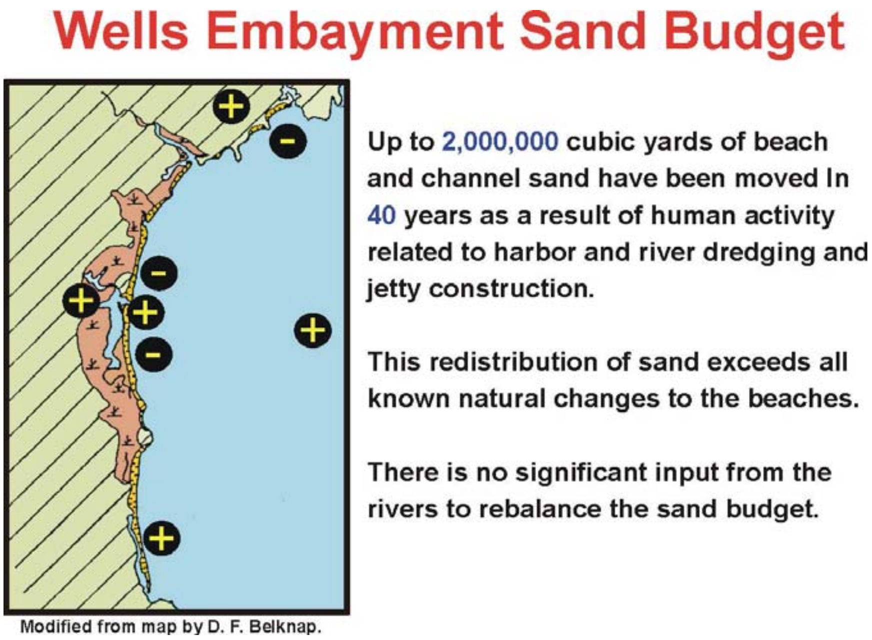
Dunes = 13,000,000 cubic yards
Shoreface = 75,000,000 cubic yards

Wells Embayment Sand Budget

Geological Environment	Percent of volume	Volume (million m^3)	Volume (million yd^3)
Dune Sand Volumes			
Frontal Dune	32%	3	4
Back Dune	68%	6	9
Total Dune	100%	10	13
Coastal Barrier Sand Volumes			
Dune Sand	15%	10	13
Shoreface (beach)	85%	57	75
Total Barrier	100%	67	88
Marine Sand Volumes			
Shoreface (beach)	59%	57	75
Bald Head Deposit	9%	9	12
Offshore Sand, Thin	32%	32	42
Total Marine Sand	100%	98	129
Total Sand in Wells Bay, All Sources			
Coastal Barrier	62%	67	88
Bald Head Deposit	8%	9	12
Offshore Sand	30%	32	42
Total Bay Sand	100%	108	142

Sand Budget Notes:

1. Conversion factor 1.307 yd^3/m^3; rounding errors may introduce some variability between metric and English units. One acre = 4840 yd^2 = 4047 m^2.
2. Dune sand volumes based on MGS Coastal Sand Dune Maps, flood zone elevations, topography, and work of Montello et al., (1992) and calculated by S. Dickson, 2000.
3. Marine sand volumes based on Miller (1998) and interpretation of his results by S. Dickson, 3/28/01; revised by S. Dickson, D. Belknap, and J. Kelley, from 5/3/01 correspondence.
4. No estimates include sand volumes in estuarine channels. These channel sands include marginal bars and tidal deltas. There are 5 tidal inlets and associated sand bars in Wells Embayment that might include, in aggregate, about 1 million cubic yards of sand.



Wells Embayment Sand Budget

Up to 2,000,000 cubic yards of beach and channel sand have been moved In 40 years as a result of human activity related to harbor and river dredging and jetty construction.

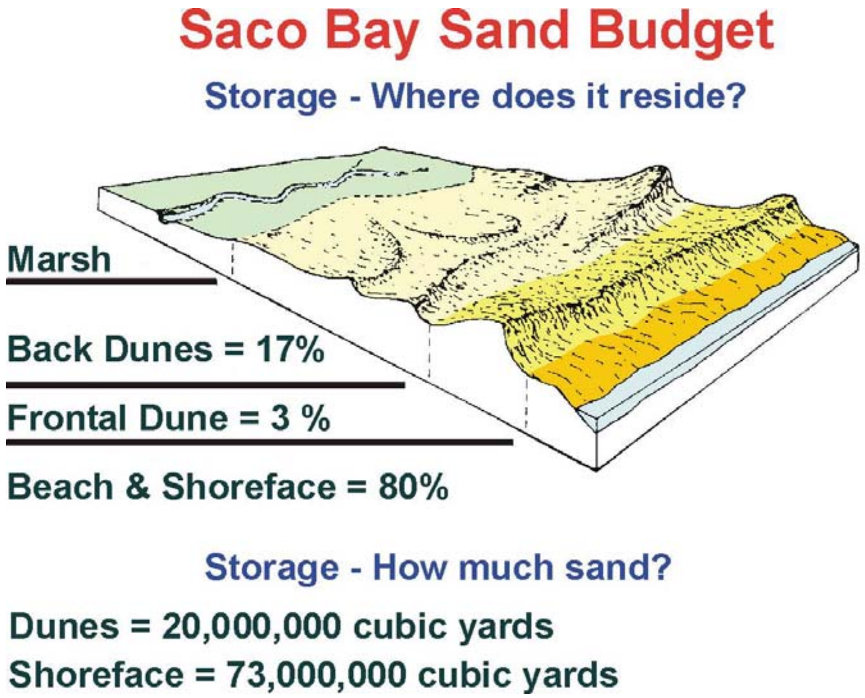
This redistribution of sand exceeds all known natural changes to the beaches.

There is no significant input from the rivers to rebalance the sand budget.

Modified from map by D. F. Belknap.

C. Saco Bay

The sand budget for Saco Bay is very different from that in Wells Embayment. In Saco Bay the frontal dune contains about 3.3 million cubic yards of sand while the back dune has 16.2 million cubic yards. Offshore, the shoreface contains 73 million cubic yards. As in the Wells Embayment, over 75% of the sand in the system is offshore. The most impressive change to the bay has come from a northward transport of sand from the Saco River ebb-tidal delta to the Scarborough ebb-tidal delta and Pine Point. In the century from 1859 to 1955, over 4 million cubic yards of sand moved from the southern to the northern end of Saco Bay (Kelley et al., 1995). The rate of transport north accelerated 300% after the federal jetties were constructed at the mouth of the Saco River. In other words, the human influence on the shorelines and sand budget of Saco Bay overwhelmed the natural processes and thus EHAs in the bay are dominantly anthropogenic.



Saco Bay Sand Budget

Storage - Where does it reside?

Marsh

Back Dunes = 17%

Frontal Dune = 3 %

Beach & Shoreface = 80%

Storage - How much sand?

Dunes = 20,000,000 cubic yards

Shoreface = 73,000,000 cubic yards

Saco Bay Sand Budget

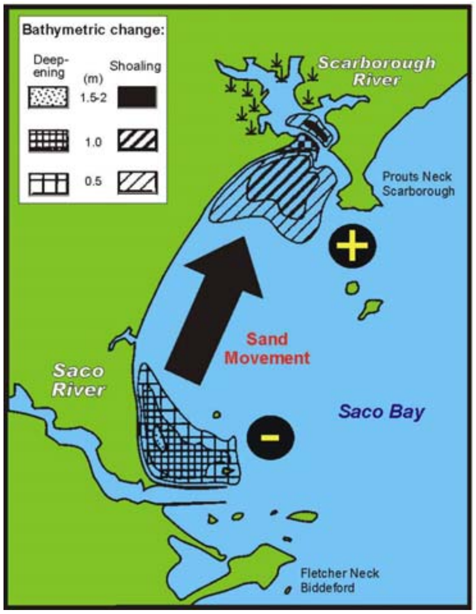
Geological Environment	Percent of volume	Volume (million m^3)	Volume (million yd^3)
Dune Sand Volumes			
Frontal Dune	17%	2.5	3.3
Back Dune	83%	12.4	16.2
Total Dune	100%	14.9	19.5
Coastal Barrier Sand Volumes			
Dune Sand	21%	15	20
Shoreface (beach)	79%	56	73
Total Barrier	100%	71	93
Marine Sand Volumes			
Shoreface (beach)	%	56	73
Offshore Sand, Thin	%		
Total Marine Sand	100%		
Total Sand in Saco Bay, All Sources			
Coastal Barrier	%	71	93
Offshore Sand	%		
Total Bay Sand	100%		

Saco Bay Sand Budget (continued)

Dune Area (Map-Based)	Vol. (mill. m^3)	Vol. (mill. yd^3)	Vol. %
Frontal Dune	117.7 (13.2%)	2.52	16.8%
Back Dune	771.4 (86.8%)	12.43	83.2%
Total Dune	889.1	14.95	100.0%

Sand Budget Notes:

1. Conversion factor 1.307 yd^3/m^3; rounding errors may introduce some variability between metric and English units. One acre = 4840 yd^2 = 4047 m^2.
2. Volumes based on thicknesses of 4.5 m in High Hazard Area (frontal dune and A-Zone); 5.5 m in Intermediate Hazard Area (frontal dune and C-Zone); 4.0 m in Low Hazard Area (back dune and A-Zone); and 5.0 m in Very Low Hazard Area (back dune and C-Zone).



Saco Bay Sand Budget

About 4,000,000 cubic yards of beach sand moved north in 100 years (1859-1955) from the vicinity of the Saco River jetty to the Scarborough River tidal inlet. This is about 3 times the pre-jetty transport rate and also about 3 times the sand resupply rate of the Saco River.

Modified from Kelley, *et al.*, 1995, *A Sand Budget for Saco Bay, Maine*, Maine Geological Survey, Open-File Report 95-1, Figure 16, by S. M. D., MGS.

V. Assessment of data gaps that would improve EHA assessments

The largest data gap that exists in Maine is in the ability to construct EHA determinations in areas where seawalls have been in place since the 1940s. As listed in the table below, 30 to 40% of Maine beach shorelines have seawalls that preclude horizontal measurements of erosion rates based on mapping the leading edge of vegetation as a shoreline proxy. These engineered dunes are almost always seaward of structures that may, at some time, become threatened by erosion. It seems logical that seawalls were first built due to the threat of erosion to buildings in the dunes. Given that most shoreline data indicates the natural trend is for the dunes to erode and shoreline to recede inland, the erosion threat to these developed areas are probably larger today than it has been in the past.

In his study, Nelson (1979) examined 30 miles (49 km) of beach both with and without seawalls. Of those miles, 31% had active seawalls where no erosion or accretion could be measured. An additional 8% of shorelines examined had seawalls, yet these areas experienced accretion in front of the walls. Another 31% had no seawalls and experienced shoreline recession (erosion) while 17% of natural dunes experienced accretion. The remaining 12% of the natural shorelines showed stability.

Shoreline Environment	Condition	Amount	FIRM Affected
Natural beach and dune	Eroding	31%	Yes
Natural beach and dune	Accreting	17%	Yes
Natural beach and dune	Stable	12%	No
Seawall, active	No change	31%	Yes
Seawall, inactive	Accreting	8%	Yes

In a recent analysis by the Maine Geological Survey (Slovinsky and Dickson, 2003), a method of shoreline change and topographic analysis confirmed that there are a number of dune areas where structures in Saco Bay could be threatened by erosion in the next century. This analysis is based on only two sets of historical air photographs to determine shoreline change through the end point method. Consequently it is needs to be strengthened and made more accurate through the use of additional air photos and a linear regression analysis. In future studies, the analysis should be performed in a geographic information system (GIS) and not in a graphics software program. Nevertheless, the approach demonstrated that there is a significant need to continue with erosion rate calculations and sediment budget analyses because there are properties at risk.

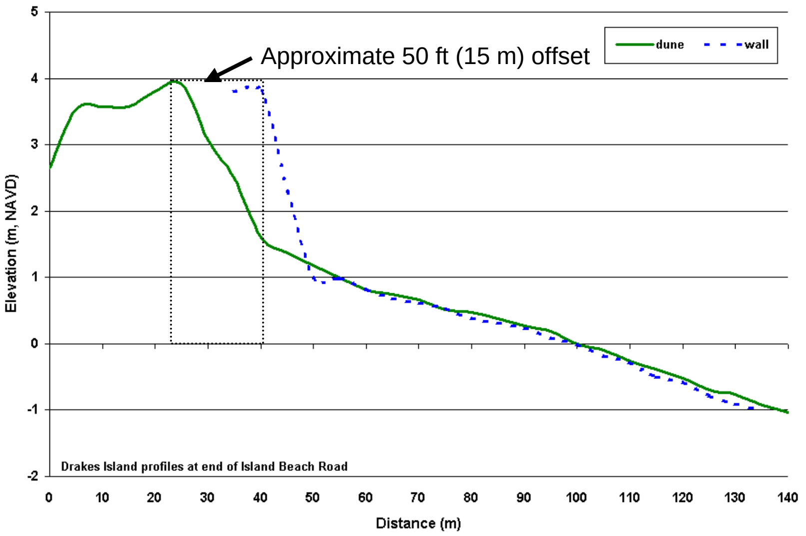
In 2003 digital high-resolution aerial photographs of southern Maine were acquired. These images of the beaches will become available as a georeferenced mosaic for use in a GIS. This new “base” will be ideal for registering and comparing historical air photos for future EHA analysis. This new data set will provide a contemporary shoreline (the previous high quality air photo used by MGS was 1995) and data gap of 8 years will be filled shortly.

In 2003 or 2004 NOAA plans to acquire another LIDAR survey of southern Maine beaches for MGS to use. Flight planning is currently in progress and the State of Maine will receive the data once it is processed. This data will improve EHA determinations in two ways. First, it will allow calculation of topographic changes that have occurred to the beaches and dunes over a 4 year period (since the September 2000 LIDAR flight). This comparison will allow estimation of the horizontal movement of various elevations of the beach such as the mean high water (MHW) line or the mean sea level (MSL) line as well as various elevations of the seaward slope of the frontal dune. The data will allow a comparison of the vertical elevation of the beach seaward of the seawalls. These data, in turn might be linked to beach profile data collected by volunteers around during the year so seasonal variation in elevation can be compared to LIDAR elevation changes.

Second, the LIDAR data will be closely spaced in time to the new set of digital air photographs of the coast so features such as new structures and changes to engineering can be visually compared and interpreted. This pair of data will enable beach profiles to be constructed and the elevation of the land and engineering structures to be compared to the FHA elevations along the beach front. These parameters, along with distances of the shoreline proxies to habitable structures will allow a better GIS estimate of what is at risk due to erosion in various time frames (30-, 60-, 100-year periods).

Another data gap that needs to be filled is to scan and orthorectify historical air photos. Until the historical photos can be placed in an earth coordinate system with a high degree of accuracy, the measurement and calculation of shoreline change rates in Maine will have errors that exceed the real change in many locations. Currently, the digital data needed for precise shoreline change mapping is not available.

Lastly, the Maine Geological Survey has explored new methods of estimating how much shoreline recession would have occurred in a particular location if seawalls had not been built. The approach is new and holds promise to overcome some of the difficulties present with historical photo analysis along a shoreline with seawalls. Using LIDAR topographic profiles from a natural dune system that most closely represents the beach in a particular area, the profile can be matched throughout its mid- to low-tide levels to those in adjacent beaches with seawalls. By matching the lower portion of beach profiles, the offset in the upper profiles can be examined. This offset can project the landward position of the frontal dune in an area that has been fixed due to seawalls and development. This concept is illustrated with data from Wells Beach in the figure below. The apparent offset is on the order of 50 feet (15 m) and represents what erosion would have taken place without the coastal engineering structure. This offset can be used, along with the age of the seawall, to determine an erosion rate. Since most seawalls in Maine were built in the 1940s and 1950s, the time frame for calculating this proxy for shoreline erosion is on the order of half a century, or about equivalent to the period for which aerial photographs have been available.



Apparent shoreline offset between beach profiles 200 feet apart along Drakes Island Beach in Wells is shown in the figure above. A “stabilized” profile at the end of Island Beach Road (blue dashed) includes a seawall protecting a home in the frontal dune. The second, a “natural” profile from approximately 200 feet north, includes only sand dune. There is an approximate 15 m offset between the crests of the two profiles, indicating that the shoreline, in absence of the seawall, would most likely be located approximately 50 ft landward. Maine Geological Survey graphic by P. A. Slovinsky.

VI. Spatial analysis of large beach systems that may have experienced shoreline changes significant enough to result in FIRMs being out of date

A. Ranking FIRMs using Shoreline Change

Large beach systems in Maine have undergone significant shoreline excursions in the past. Extrapolating from Nelson's (1979) work tabulated in the section above, 87% of beach areas are dynamic enough to result in an alteration of the beach profiles and hence the location and elevation of coastal flood hazard areas. By this estimate, there are 26 miles of Maine shoreline that could have FIRM panels made out of date by shoreline change.

The most important question about the effects of shoreline change on a FIRM are related to the rate at which physical changes are taking place versus the age of the FIRM panel itself. If, for example, the FIRM is only 2 years old, then shoreline change of 1 foot per year is unlikely to have made the map obsolete. However, if the map is 15 to 20 years old and the erosion or accretion rate is 1 foot per year, then flood hazards are likely to be very different today than when the map was generated.

Using shoreline change data from Nelson (1979) and the Maine Geological Survey's archive, FIRM panels with beaches in York, Cumberland, and Sagadahoc Counties were examined to calculate *which areas have experienced the most change since the maps were created*. In this analysis, it was assumed that the FIRM date was close to the age of the physical conditions used to determine FHAs. It is possible that some of these dates are much more recent than the actual data used to make the map since some panels may have been updated in just one geographic area. Consequently, this analysis may underestimate the need to update some FIRMs.

To determine how out of date a panel might be, the highest known erosion rate was assumed for the calculation. For example, the use of an erosion rate of 2 feet per year does not indicate that all of the shorelines on the panel are eroding at that rate. This erosion rate is the best estimate to determine the "worst case" at any one location within an individual panel. The erosion rate multiplied by the number of years since the panel was produced is used for duration to apply the erosion rate. For example, an erosion rate of 1 foot per year for 11 years results in a net horizontal shoreline change of 11 feet. The results are presented in the table below.

Community	Panel	Community Name	County	Beach Name	Age	Erosion Rate (ft/yr)	Shore Change (ft)
230145	5	Biddeford, City of	York	Hills Beach	19	3	57
230145	6	Biddeford, City of	York	Hills and Mile Stretch Beaches	19	-2	-38
230052	23	Scarborough, Town of	Cumberland	Pine Point	11	3	33
230120	12	Phippsburg, Town of	Sagadahoc	Popham/Hunnewell Beaches	11	-2	-22
230052	22	Scarborough, Town of	Cumberland	Higgins/Scarborough Beach	11	-2	-22
230170	7	Kennebunkport, Town of	York	Nessler and Marshall Points/Goose Rocks Beach	20	-1	-20
230170	8	Kennebunkport, Town of	York	Goose Rocks Beach	20	-1	-20
230145	11	Biddeford, City of	York	Fortunes Rocks Beach/Horseshoe Cove	19	-1	-19
230153	3	Old Orchard Beach, Town of	York	Ocean Park/Old Orchard Beach	19	1	19
230053	9	South Portland, City of	Cumberland	Willard Beach	18	-1	-18
230171	3	Kittery, Town of	York	Gerrish/Cutts Islands	17	-1	-17
230171	6	Kittery, Town of	York	Gerrish Island	17	-1	-17
230043	3	Cape Elizabeth, Town of	Cumberland	Main/Strawberry Hill Beaches	11	-1	-11
230043	11	Cape Elizabeth, Town of	Cumberland	Crescent Beach	11	-1	-11
230162	21	Cumberland, Town of	Cumberland	Jenks Landing/Great Chebeague Is.	11	-1	-11
230162	23	Cumberland, Town of	Cumberland	Jenks Landing/Great Chebeague Is.	11	-1	-11
230201	9	Georgetown, Town of	Sagadahoc	Half Mile/Mile Beaches	11	-1	-11
230151	14	Kennebunk, Town of	York	Crescent Surf/Parsons Beach	11	-1	-11
230151	15	Kennebunk, Town of	York	Parsons/Kennebunk/Goochs Beaches	11	-1	-11
230632	3	Ogunquit, Town of	York	Ogunquit Beach	11	-1	-11
230120	11	Phippsburg, Town of	Sagadahoc	Head Beach/Small Point Beach	11	-1	-11
230155	29	Saco, City of	York	Camp Ellis/Ferry Beach	5	-2	-10
230170	3	Kennebunkport, Town of	York	Pocket Beach/Cape Arundel	20	-0.5	-10
230052	24	Scarborough, Town of	Cumberland	Scarborough/Western Beach	11	1	11

In the table above, the greatest absolute amount of shoreline change is used to rank the results. In terms of coastal flood hazards, however, it is most likely that only those eroding (negative value) shorelines are areas where the flood hazard is likely to increase. Over time, the flood hazard in accreting areas should be declining, all other factors being equal. In order to evaluate a particular panel (as mentioned above) the greatest amount of shoreline change was used. In some cases, however there are portions of the panel that are eroding and areas that are accreting. A high erosion or accretion rate should be taken as a sign of a large disruption in the coastal sediment budget. A panel with a large change should be recognized as having had significant changes to coastal topography that will affect wave approach and runup during a 100-year storm. Consequently, even if a panel is identified as accreting (more than eroding) remapping is justified based on the potential for significant hydrodynamic changes along the shoreline since the map was first produced.

B. Shoreline Change over 40 Feet

1. Hills Beach. The greatest amount of shoreline change was due to accretion, not erosion, along Hills Beach in the City of Biddeford. Hills Beach was also the location with the greatest negative amount of shoreline change. The history of shoreline change and relationship of the dune elevations to flood elevations has been examined for this area and all of Saco Bay by

Slovinsky and Dickson (2003). In this study, both Camp Ellis Beach (City of Saco) and Hills Beach were found to be areas with significant risk to property due to erosion, flood elevation, dune topography, coastal engineering, and distance of habitable structures from the high tide line. Changes on **FIRM 230145, Panel 5** are immediately adjacent to the south jetty of the Saco River. Disruption to the sediment budget is due to the federal jetties at the mouth of the Saco River and their influence on waves and sand transport. Movement of sand within the area sheltered by the jetty is expected to continue in the next decade at the same rate.

C. Shoreline Change Over 30 Feet

1. Hills Beach. Adjacent to the panel described above is a portion of Hills Beach that has a slower accretion rate as well as an erosion rate as high as 2 feet per year. **FIRM 230145, Panel 6** has a 1984 date and thus an age of 19 years. Erosion in this panel has appeared to be chronic. Homes along the frontal dune have been armored with high seawalls. The beach profile at this erosion-prone area is steep through the upper half of the intertidal profile and thus waves can have a large force upon the seawalls during storms and under conditions of high tide.

2. Mile Stretch Beach. Parts of this beach are on **FIRM 230145, Panel 6** that includes Hills Beach. Mile Stretch Beach has a slower erosion rate, on the order of 1 foot per year and a history of shoreline armoring in response to chronic shoreline recession. The sand supply to Mile Stretch Beach is limited both offshore and from any upland sources and there are exposures of back-barrier salt marsh peat on the beach in some locations due to the beach and dune migrating inland over the last few thousand years (Hulmes, 1980; 1981).

3. Pine Point Beach. At the northern end of Saco Bay, Pine Point Beach is the northern terminus of a seven-mile beach system that begins at the mouth of the Saco River. The northern end of the bay is the recipient of longshore drift (sand transport by waves and currents along the beach). **FIRM 230052, Panel 23** in the Town of Scarborough has undergone as much as 33 feet of accretion since the area was mapped. The positive sand budget in this panel is due to the accumulation of sand adjacent to the federal jetty along the south side of the Scarborough River tidal inlet (Dickson et al., 1993; Farrell, 1972; Kelley et al, 1995; Nelson, 1979; Slovinsky and Dickson, 2003). Shoreline progradation has filled an area adjacent to the jetty to such an extent that the shoreline may be becoming less progradational in the future. In fact, over the last decade there have been episodes of significant short-term erosion of the frontal dune at Pine Point. These recent changes are most likely due to wave shoaling and refraction on the ebb-tidal delta of the Scarborough River, as sand has accumulated offshore. Consequently, the pattern of wave runup and flooding may have significantly changed since the panel was mapped in 1992.

D. Shoreline Change Over 20 Feet

1. Popham and Hunnewell Beaches. The most complex beach system in Maine is located in the mid-coast near the mouth of the Kennebec River. Sand delivered to the sea by the Kennebec River has resulted in large dunes at Popham and Hunnewell Beaches (FitzGerald et al, 1989). Despite a history of progradation over the last few thousand years, both Popham and Hunnewell Beaches undergo cycles of accretion and erosion that can move the shoreline position 200 to 300 feet in a decade. The cyclic nature of shoreline change can be attributed to coastal currents that form a clockwise gyre along the beaches (FitzGerald and Fink, 1987) and the periodic switching of the tidal channel and sand bars at the mouth of the Morse River (Goldschmidt, 1989; Goldschmidt and FitzGerald, 1989). Dune scarps located along Popham and Hunnewell Beaches represent the farthest inland limits of erosion and shoreline change. Repetitive cycles of erosion could return the shoreline to former positions so the inland historical erosion limit is an excellent erosion reference feature for evaluating the dunes for flood hazards in this area. Erosion hazard mapping at this area is critical to understanding the risk to properties in the dunes. Both Popham and Hunnewell Beaches are part of the Coastal Barrier Resources System Unit ME16/16P (Dickson 2002b). **FIRM 230120, Panel 12** was last mapped in 1992 and since that time there have been shoreline changes in excess of 20 feet along the mean high water line. This beach is likely to be the most problematic one in the State of Maine for map updating since the shoreline can change significantly in the time it takes to revise a FIRM.

Two homes on Hunnewell Beach that were damaged by erosion and flooding and subsequently moved landward and elevated on posts. Photo by S. M. Dickson.

2. Higgins Beach. In Scarborough, Higgins Beach is an isolated beach and dune system fronting the Spurwink River marsh. The tidal inlet is down drift from the beach and sand has continued to prograde in the form of a spit and dune system over the last century. Net sand transport is northeast toward the inlet. The local sand budget has no new supply of sand to the beach system so sediment removed from the southwest end of the beach is not replaced. This net loss of sand was documented by Timson and Lerman (1980) in the Higgins Beach Management Plan. For the plan, shoreline recession rates were calculated using historical shoreline positions and range from 1 to over 5 feet per year along the beach. Nelson (1979) determined the erosion rate of 1 to 1.5 feet per year over most of its length with greater variability at the spit end. The dunes are densely developed and properties have been destroyed by erosion. Chronic erosion has resulted in many seawalls being built along the frontal dune. Many of these shoreline stabilization structures are not as high as the 100-year coastal floodplain and waves can overtop the walls and reach some structures. The October 1991 “Perfect” Storm caused property damage due to wave action in the dunes. **FIRM 230052, Panel 22** was last mapped in 1992. In this analysis an average erosion rate for the FIRM was 2 feet per year; however, this analysis may underestimate the need for remapping this panel if erosion has proceeded at a faster rate in the last decade.

Higgins Beach after the 1991 Perfect Storm. Coastal flooding overtopped the seawall and waves damaged several homes. Photo by S. M. Dickson, 11/01/91.

3. Goose Rocks Beach. Another isolated beach and dune system is located in Goosefare Bay in Kennebunkport. Goose Rocks Beach is a sandy pocket beach system with an arcuate shoreline due to wave refraction around offshore islands and shoals. At either end of the beach are tidal inlets (Little and Batson Rivers) with dynamic beach spits and back barrier salt marshes. Southwest of the sand beach is a headland with mixed sand and gravel beaches on Nessler and Marshall Points. Sand along Goose Rocks Beach is very dynamic and moves from one end of the beach to another. Nelson (1979) documented shoreline change within the bay and relict shorelines within the dunes along about 75% of the length of the beach. In parts of the dunes, the historical erosion limit is landward of houses. About 70% of the shoreline is armored with a riprap seawall (Nelson, 1979). The sand budget for the bay has not been studied. However, there are no new significant sources of sand to replace sediment transported into the tidal inlets or eroded from the beach and carried to offshore sand bars. This beach system has a tendency to erode and accrete over a decade, but to a lesser extent than at Popham and Hunnewell Beaches because the bay is more sheltered and there is less influence from the river systems. **FIRM 230170, Panels 7 and 8** were last mapped in 1983. These are the oldest FIRMS evaluated in this report.

E. Shoreline Change Over 10 Feet

1. Fortunes Rocks Beach. In Biddeford, Fortunes Rocks Beach fronts The Pool and uplands. The beach continues northeast to become Mile Stretch Beach (mentioned above with Hills Beach). South of the long strand of sandy beach are three pocket sand and gravel beaches: Horseshoe Cove, New Barn Cove, and Curtis Cove. All of the pocket beaches have gravel overwash deposits on and behind the frontal dune ridge. Duffy et al. (1989) documented exposed salt marsh peat on the beach profile of Horseshoe Cove. Hulmes (1980) documented long-term erosion along Fortunes Rocks and Mile Stretch Beach (mentioned above). Seawalls front most of the southern portion of Fortunes Rocks Beach and, consequently, Nelson (1979) was unable to determine a rate for shoreline change. Along the natural shoreline, Nelson measured about 1.6 feet per year recession. This beach appears to have chronic sand loss and net shoreline recession and or active seawalls along the frontal dune ridge. **FIRM 230145, Panel 11** was last mapped 19 years ago in 1984. The present beach profile and conditions for wave runup are probably quite different from when the FIRM was last mapped.

2. Old Orchard Beach and Ocean Park. The Ocean Park section of Old Orchard Beach is flanked by the Goosefare Brook tidal inlet to the south and continues with the long strand of central Old Orchard Beach to the north. The shoreline along the north shore of Goosefare Brook is stabilized with a riprap wall to reduce channel meandering. The ocean shoreline is relatively stable to accretional (Nelson, 1979; Slovinsky and Dickson, 2003). Beneath the dunes at Ocean Park is buried a pipeline that extends offshore to an outfall for the Old Orchard Beach sewage treatment facility. Along the central section of Old Orchard Beach there are artificial frontal dunes that contain buried sewer pipelines that service the dune neighborhoods. A dune management plan was established in the 1980s (Timson and Denison, 1986) and has succeeded in stabilizing much of the Old Orchard Beach dunes. The apparent shoreline accretion in the segment of Saco Bay is due, in part, to dune restoration and management so the apparent shoreline change used in this report is a function of the management action. **FIRM 230153, Panel 3** was last mapped 19 years ago in 1984.

3. Willard Beach. An arcuate pocket beach in Simonton Cove in South Portland is known as Willard Beach. This urban setting has dense residential development in coastal sand dunes. Beach erosion, perhaps due to poor dune management over the last century, was studied by the U.S. Army Corps of Engineers (1982) with the goal of reducing beach loss and property damage. The Corps estimated an erosion rate of 0.65 to 1.0 feet per year using historical shoreline positions. The Corps report also determined that the beach profile may have become steeper from 1853 to 1941. This change in nearshore elevations may be indicative of a negative sediment budget for the cove. For planning purposes, this report followed the guidance of the Corps report and assumed a 1 foot per year erosion rate. In the last two years there has been a concerted effort by the local community to restore the frontal dunes to preserve the beach and protect development. Dunes are currently getting higher and wider as a result of this effort. The Maine Geological Survey is currently in the process of creating a map of the coastal sand dune system for Willard Beach and the City of South Portland has adopted a beach and dune management plan. **FIRM 230053, Panel 9** was last mapped 18 years ago in 1985 and current conditions are quite different along the beach profile and in the elevation of the dunes.

Willard Beach, South Portland has a dune management plan that has helped restore the frontal dune in the last few years. Photo by S. M. Dickson, 05/07/02.

4. Gerrish and Cutts Islands. A double beach and dune tombolo system connects a small rock ledge to Gerrish and Cutts Islands in Kittery. Seapoint Beach is on the northern side and connects to Cutts Island while Crescent Beach connects to Gerrish Island. Both Seapoint and Crescent Beaches are part of the Coastal Barrier Resources System Unit A09. These two beaches are exposed to high wave energy and, based on the presence of overwash deposits of sand and gravel, are likely to be transgressive and experiencing shoreline recession (Nelson, 1979). Nelson noted that the ridges were over topped by the January 9 and February 7, 1978 storms. Additional shoreline areas have gravel beaches and storm berms that are prone to shoreline recession in AO-Zone flood hazard areas. **FIRM 230171, Panels 3 and 6** were last mapped in 1986. The relatively undeveloped shoreline along the coastal barrier makes this area less in need of remapping than some other areas with more coastal development adjacent to eroding shorelines. It does serve to show how the shoreline of a mixed sand and gravel beach system responds episodically to large storms with coastal flooding.

Crescent Beach (left) and Seapoint Beach in Kittery is a mixed sand and gravel beach. Dune washover is common in large storms and shoreline change is probably episodic rather than gradual. Photo by S. M. Dickson.

5. Cape Elizabeth Beaches. Along the Cape Elizabeth shoreline are a series of small beaches sheltered by Richmond Island. Crescent Beach is the largest beach and dune system and part of a state park and makes up the Coastal Barrier Resources System Unit E-19/19P. Strawberry Hill Beach is a small double tombolo beach and back barrier marsh system with a cuspate foreland connected to a rock breakwater that extends to Richmond Island. Main Beach is a small pocket beach with a freshwater back barrier wetland west of Strawberry Hill beach and sheltered by Ram Island (Nelson and Fink, 1980). These latter beaches are Unit A06 of the Coastal Barrier Resources System. Little direct erosion rate data exists for these beaches so the natural background rate determined by Nelson (1979) of 1 foot per year was used in this analysis. **FIRM 230043, Panels 3 and 11** were last mapped in 1992. These dune systems are relatively undeveloped so shoreline change here is less significant than at other locations listed above.

6. Great Chebeague Island. The Jenks Landing Coastal Barrier Resources System Unit A05C is located on Great Chebeague Island in the Town of Cumberland. This Casco Bay location has three separate parts to the CBRS on Great Chebeague Island, each a mixed sand and gravel deposit related to accumulations of sediment from coastal bluff erosion

(Bryant et al., 2002a, b; Timson, 1976a, b). On the south western side of the island is Indian Point. This CBRS has a road out to the point that is vulnerable to shoreline change. The Jenks Landing CBRS area between Coleman and Johnson Coves is undeveloped and relatively sheltered by nearby islands. However, there are shoreline properties immediately adjacent to the south that could have flood hazard areas altered by shoreline recession. The Waldo Point portion of the CBRS is also undeveloped but faces northeast into the dominant storm wind and wave approach. Little direct erosion rate data exists for these beaches so the natural background rate determined by Nelson (1979) of 1 foot per year was used in this analysis. **FIRM 230162, Panels 21 and 23** were last mapped in 1992.

7. Mile and Half Mile Beaches. Reid State Park in Georgetown is the location of two large beach and dune systems: Mile and Half Mile Beaches. These natural dunes are some of the largest in Maine and the beaches are relatively linear compared to most systems bound by bedrock headlands. These beaches are part of the Coastal Barrier Resources System ME-15P called the Little River Unit after the tidal inlet adjacent to Half Mile Beach. Over centuries, these beach systems are transgressive and back barrier peat and tree stumps can be found on the intertidal portion of Mile Beach after winter erosion (Dickson, 2002a). Nelson (1979) estimated an erosion rate up to 1 foot per year for Mile Beach between 1940 and 1972. **FIRM 230201, Panel 9** was last mapped in 1992. Minimal coastal development exists along this public beach and it serves as a good reference for the rates of shoreline change in an area with little human influence on the sand budget.

8. Crescent Surf and Parsons Beaches. At the northern end of the Wells Embayment, Crescent Surf and Parsons Beaches in the Town of Kennebunk are two adjacent beaches that each has a dynamic spit end at a tidal inlet and each fronts a back barrier salt marsh system. These beaches are relatively natural with only a short segment of seawalls fronting Parsons Beach. At both beaches the spit ends tend to be more unstable and have had more shoreline recession than the middle portions that are anchored to a bedrock headland (Nelson, 1979). Erosion rates were determined by Nelson (1979) to range up to from near zero to over 2 feet per year (the latter from 1940 to 1953). Nelson found the most common rate of recession on Crescent Surf Beach to be 1 foot per year. There has been little interference with the local sand budget in the last 50 years along these shorelines, so the variability seen in Nelson's data may be a good indication of decadal variability in natural rates of shoreline recession in the Wells Embayment. There appears to have been episodes of rapid erosion followed by reduced recession or minor amounts of accretion in the last half century at these beaches. These beaches are part of the Coastal Barrier Resources System Unit A08. **FIRM 230151, Panels 14 and 15** were last mapped in 1992.

9. Ogunquit Beach. At the southern end of the Wells Embayment, Ogunquit Beach forms a long, linear beach and dune system with a large spit at the mouth of the Ogunquit River tidal inlet. Dunes along this beach are primarily artificial and were built in 1974 and 1975 by the Department of Agriculture's Soil Conservation Service. The dunes are cored with gravel and sand imported from an upland source. The top elevation of the dune exceeds the floodplain height and the seaward slope of the dunes is unnaturally steep. Near the middle of the beach, the Ogunquit sewer treatment plant is positioned behind a metal (sheet pile) seawall buried in the artificial dune. The treatment plant has a pipeline buried in the dunes and beneath the beach that extends out to sea where there is an ocean outfall of the treated effluent. Behind the dunes is an extensive back barrier salt marsh system. Erosion has removed part of the fontal dune in the last decade, although there are periods of dune accretion as a result of a relatively successful dune management plan by the Town of Ogunquit. Nelson (1979) found no significant erosional or accretional trend, although the data are strongly influenced by the dike construction in the 1970s. All of Ogunquit Beach is Unit ME-20P in the Coastal Barrier Resources System. **FIRM 230632, Panel 3** was last mapped in 1992.

Ogunquit Beach and River (top) and Moody Beach (Wells, foreground with houses). The sewer treatment plant is in the dunes above the parking lot and behind a metal seawall in the artificial frontal dune. Photo by S. M. Dickson.

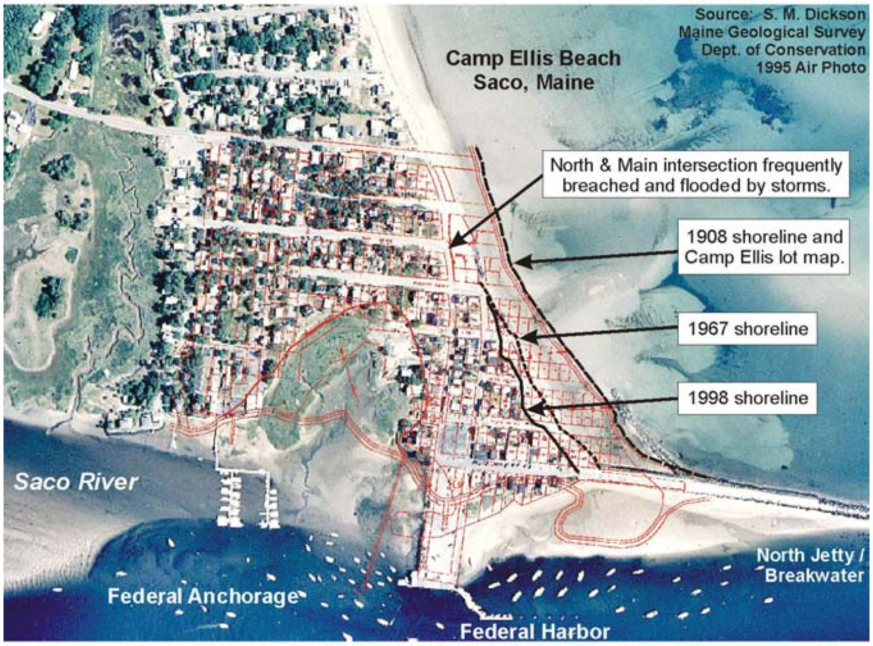
10. Goochs and Middle Beaches. Adjacent to the Kennebunk River, the Town of Kennebunk has Goochs Beach, a pocket beach, with a small active frontal dune adjacent to the federal jetty at the river mouth. The beach is primarily fronted by a wooden seawall that extends most of its length. The beach profile is low and, due to the lack of sand exchange with most of the dune system and repeated wave action on the seawall, has a minimal summer berm. Beach Avenue runs parallel to the beach on the frontal dune and sand is sealed beneath the road. This highly engineered beach has little opportunity to buffer storm flooding and waves can overtop the seawall and pass into Beach Avenue. Middle Beach is west of Goochs Beach and a mix of sand and gravel sediment. This beach also functions as a coarse-grained coastal barrier system. However, it too has an enormous seawall and Beach Avenue continues along the frontal dune. This area has also had many episodes of coastal flooding and seawall damage. Gravel from the beach tends to wash onto and across Beach Avenue and attempt to build a higher dune ridge where residential development now exists. No historical shoreline change measurements are available since this beach has been engineered since air photos were first taken. For this study it was assumed that the system seaward of the seawall would respond with an erosion rate of 1 foot per year. **FIRM 230151, Panel 15** was last mapped in 1992.

11. Head Beach and Small Point Beach. Small Point Beach, also known as Seawall Beach is a large natural barrier beach and dune system that fronts the Little River and Morse River tidal inlets and salt marshes. This dune system, like those at Reid State Park, has a linear shoreline and a large and wide frontal dune ridge. Nelson (1979) reported a long-term erosion rate of 1 to 1.5 feet per year and documented significant erosion (30 to 50 feet) of the frontal dune as a result of the large storms in the winter of 1978. Measurements of beach profiles have shown that a winter northeaster can lower the Small Point (Seawall) Beach profile by as much as 3 feet during a storm (Jones, 2000) so flood hazard calculations based on topographic profiles do need to anticipate brief vertical changes to the beach. Small Point Beach is part of Coastal Barrier Resources System Units ME-16 and 17. Head Beach is west of Small Point Beach and on the west side of the Small Point peninsula. This beach is a sandy pocket barrier beach with a salt marsh and tidal bay on the back side. The dunes are relatively undeveloped and minimally managed to control pedestrian traffic through the dunes. Head Beach is part of Coastal Barrier Resources System Units ME-A05B. **FIRM 230120, Panel 11** was last mapped in 1992.

Small Point (Seawall) Beach and the Little River inlet is in the foreground and Popham and Hunnewell Beaches are in the background on the far side of the Morse River inlet. Photo by S. M. Dickson.

12. Camp Ellis and Ferry Beach. The City of Saco has one long beach strand from the Goosefare Brook to the federal jetty/breakwater at the mouth of the Saco River. The residential and commercial community next to the jetty is called Camp Ellis. The beach adjacent to Camp Ellis has undergone significant land loss since early 1900. Over the last century as many as 36 properties have been lost to shoreline recession. Erosion rates are on the order of 2 to 3 feet per year next to the jetty and 1 to 2 feet per year north of the riprap along Surf Street (Duffy and Dickson, 1995, Kelley et al., 1995, Slovinsky and Dickson, 2003).

Past Shoreline Positions



Over 30 properties have been lost in less than 100 years. Historical lot map modified from Appendix E of the Saco Bay Regional Beach Management Plan, 2000. Shorelines mapped in 1998 by the Saco Bay Beach Erosion Committee.

Historic shoreline positions (black lines) and tax map lots (red) superimposed on a 1995 air photograph of Camp Ellis Beach in the City of Saco where the U.S. Army Corps of Engineers in conducing a Section 111 mitigation study.

This area is currently under investigation by the U.S. Army Corps of Engineers, New England District, as part of a Section 111 (Rivers and Harbors Act) study for mitigation of erosion caused by the federal jetty. Details about the history of the area can be found in Slovinsky and Dickson (2003). **FIRM 230155, Panel 29** was last mapped in 1998. The Kinney Shores section of Saco (**FIRM 230155, Panel 27**) has a lower erosion rate of about 1 foot per year with a net shoreline change of about 5 feet since the last FIRM was produced. Anticipated federal action to modify the jetty and to nourish the beach with sand may result in a significant alteration of the shoreline configuration on Panel 29 in the next 5 years.

Saco Bay and the Saco River mouth in the vicinity of Camp Ellis. The north jetty/breakwater is in the right foreground. Photo by S. M. Dickson.

13. Kennebunkport Pocket Beach. A small pocket beach is located just north of the federal jetty on the north side of the Kennbunk River tidal inlet in the Town of Kennebunkport. This small beach experiences storm wash over and may be erosional, in part, to a negative sand budget associated with dredging the Kennebunk River. For this analysis an erosion rate of just half a foot per year was assumed. However, it has been 20 years since **FIRM 230170, Panel 3** was produced so there is a potential for 10 feet of shoreline change in and around this location at the river mouth.

14. Scarborough and Western Beaches. North of Prouts Neck is Scarborough Beach. This relatively linear beach system is Unit A07 of the Coastal Barrier Resources System. The beach fronts a freshwater wetland in the back barrier environment. The shoreline is primarily sandy with a natural frontal dune. Along the southern end of the beach there are low-lying wooden seawalls. These seawalls are regularly overtopped by storm flooding and currents carry gravel cobbles up and over the walls to form a gravel ridge. Erosion on Scarborough Beach was examined by Nelson (1979) and there have been several episodes of erosion and accretion from 25 to 50 feet in either direction. There is some variability from year to year of the location of the widest portions of the beach suggesting that some of the sand is moved alongshore over a period of several years and then it returns.

Western Beach is on the western side of Prouts Neck and adjacent to the tidal inlet of the Scarborough River. The Scarborough River drains the largest back barrier salt marsh in southern Maine and there are strong tidal currents that pass through the inlet throat and near Western Beach. Western Beach has experienced surprisingly large variations in erosion and accretion. The beach is located in the down drift end of the Saco Bay littoral cell. Despite this fact, sand has been lost from the beach and dunes of Western Beach in the last decade. From 1953 to 1970 (Nelson, 1979) and from 1962 to 1995 (Slovinsky and Dickson, 2003) the shoreline moved seaward at a rate of a foot per year or more. The accretion that took place over these four decades may have been in response to (a) the construction of the federal jetty on the south side of the Scarborough River inlet at Pine Point and to (b) the regular maintenance dredging of the main channel of the ebb-tidal delta seaward of Western Beach. During a period after construction of the jetty sand was trapped next to the jetty on Pine Point and was unable to continue movement toward Western Beach. During the same interval of time, maintenance dredging may have prevented sand from bypassing the inlet channel to reach Western Beach. Also during these decades the ebb shoals expanded offshore and the main channel and associated bars extended farther east so longshore drift deposited sand in a new area away from Western Beach. For this analysis, a 1 foot per year accretion was used. However, the rates and direction of shoreline change at Western Beach are far from uniform and will likely change significantly in the near future as the sediment budget continues to adjust to natural processes and human activity. **FIRM 230052, Panel 24** was last mapped in 1992 and significant change has taken place since the FIRM was made.

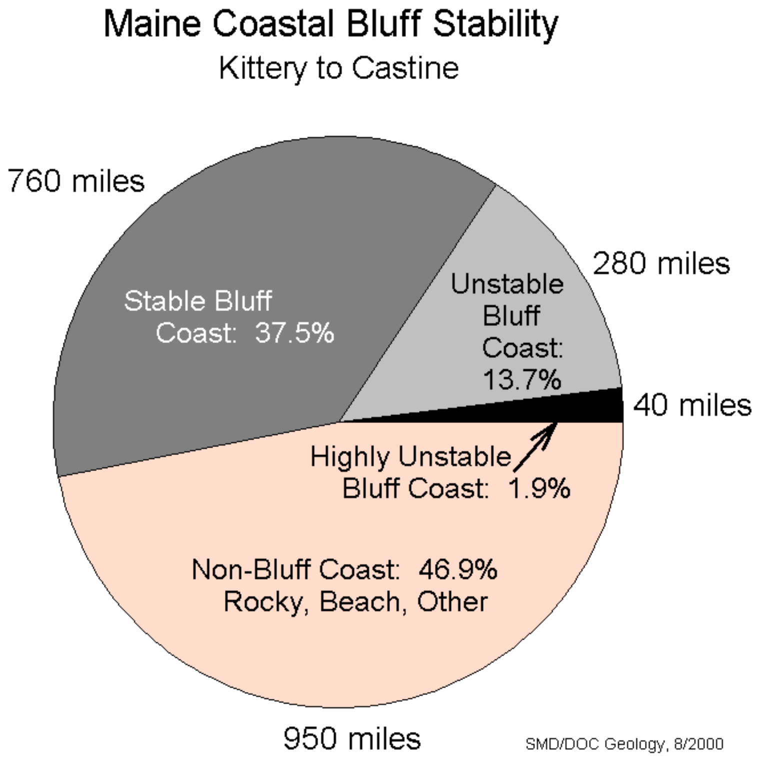
F. Shoreline Change Less than 10 Feet

Many other coastal FIRMs in southern Maine are changing due to erosion or accretion. These additional maps are identified below. Factors that contribute to their erosion rate are in a database that accompanies this report. These maps have less than 10 feet of shoreline change since they were made due to either the recent date of the map or the slow rate of shoreline change compared to those sites mentioned above. A number of the FIRMs for the City of Portland include islands in Casco Bay that are experiencing bluff erosion.

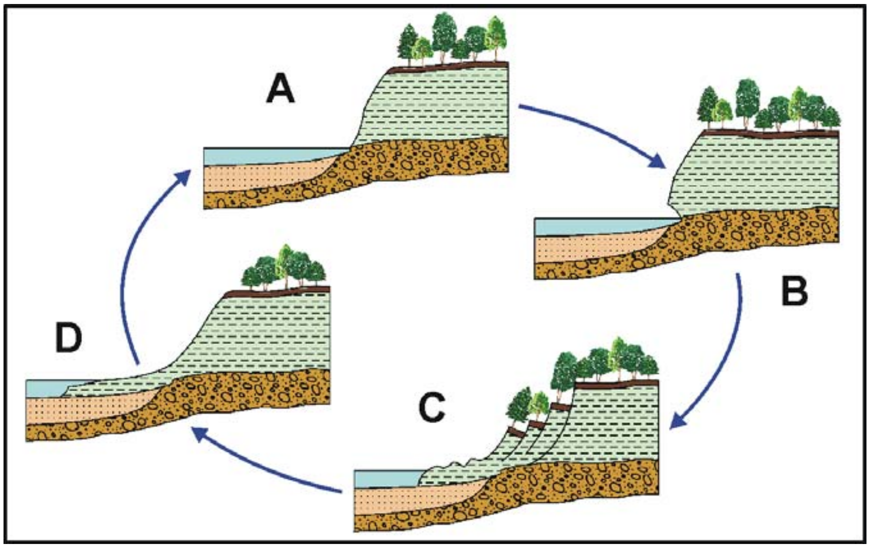
Community	Panel	Community Name	County	Beach Name	Age	Erosion Rate (ft/yr)	Shore Change (ft)
230170	6	Kennebunkport, Town of	York	Cleaves Cove/Cape Porpoise	15	-0.5	-7.5
230043	12	Cape Elizabeth, Town of	Cumberland	Staples Point -Smugglers Cove	11	-0.5	-5.5
230043	16	Cape Elizabeth, Town of	Cumberland	Pond Cove - Ship Cove	11	-0.5	-5.5
230201	6	Georgetown, Town of	Sagadahoc	Little River Marsh	11	-0.5	-5.5
230201	7	Georgetown, Town of	Sagadahoc	Little River Marsh	11	-0.5	-5.5
230169	13	Harpswell, Town of	Cumberland	Stover Point/Harpswell Neck	5	-1	-5
230169	14	Harpswell, Town of	Cumberland	Stover Point/Harpswell Neck	5	-1	-5
230051	8	Portland, City of	Cumberland	Great Diamond Is./Martin Pt.	5	-1	-5
230155	27	Saco, City of	York	Kinney Shores	5	-1	-5
230051	3	Portland, City of	Cumberland	Little Chebeague Is.	5	-0.5	-2.5
230051	4	Portland, City of	Cumberland	Little Chebeague/ Long/Crow/Hope/Cliff Is.	5	-0.5	-2.5
230051	5	Portland, City of	Cumberland	Cliff Is.	5	-0.5	-2.5
230051	9	Portland, City of	Cumberland	Great Diamond/Peaks/Long Is.	5	-0.5	-2.5
230051	10	Portland, City of	Cumberland	Cliff/Long Is.	5	-0.5	-2.5
230051	15	Portland, City of	Cumberland	Peaks/Cushing Is.	5	-0.5	-2.5
230051	17	Portland, City of	Cumberland	Cushing Is.	5	-0.5	-2.5
230159	13	York, Town of	York	Phillips Cove	1	-1	-1
230159	24	York, Town of	York	York Harbor and Beach	1	-1	-1
230159	26	York, Town of	York	Long Beach/Short Sands Beach/Cape Neddick Harbor	1	-1	-1
230159	28	York, Town of	York	Long Beach/Short Sands Beach/Cape Neddick Harbor	1	-1	-1
230159	32	York, Town of	York	Godfrey's Cove	1	-1	-1
230158	13	Wells, Town of	York	Drakes Island and Laudholm Beaches	0	-1	0
230158	21	Wells, Town of	York	Wells Beach/Fishermans Cove	0	-1	0
230158	23	Wells, Town of	York	Moody Beach and Point	0	-1	0
230051	11	Portland, City of	Cumberland	Jewell/Cliff Is.	5	0	0
230051	14	Portland, City of	Cumberland	Portland Harbor/Little Diamond/Cushing Is.	5	0	0
230051	16	Portland, City of	Cumberland	Inner Green Is./R.R. Yard	5	0	0
230145	1	Biddeford, City of	York	Stage Island/Fletcher Neck	19	0	0
230153	4	Old Orchard Beach, Town	York	Old Orchard Beach/Pine Point	19	0	0

VII. Summary of existing data on the severity of bluff erosion and how it might affect FIRMs

The "rocky" coast of Maine is much less stable than has been previously thought. Maine Geological Survey and University of Maine studies of coastal bluff processes and evolution have shown that bluffs are present along over half of the Maine coast (Dickson, 2001b; see figure below). Research has resulted in a series of maps that identify the location and severity of bluff erosion (Kelley and Dickson, 2000). Bluffs are classified using geomorphology and shoreline type. Examples of bluffs in Casco Bay can be found on maps by Bryant (2002a, b). Development occurs on bluffs that are eroding and, depending on the proximity of the bluff top to the structure, there can be buildings at risk of damage from the gradual loss of sediment from the bluff face. In Casco Bay, there are bluffs on the large islands such as Great Diamond and Peaks Islands where there are many ocean-front homes.



In addition to the chronic erosion that is common on the face of many bluffs, there is another process of internal mass movement of the land that places some structures at risk. Landslides, formed by the internal failure of sediments, tend to occur in areas where the sediments are (a) made of clay, (b) the clay thickness exceeds 20 feet, and (c) there is water saturating the ground. Factors that lead to landslides are described on the MGS Coastal Landslides map series (Dickson, 2001c) and include the slope of the bluff face, types of vegetation, depth to bedrock, sediment type, ground water level, weathering, and earthquakes. Land use that affects vegetation, surface or groundwater levels, and buildings that load the ground all can contribute to increase or decrease landslide risk.



The cycle of bluff erosion by marine proceeses (A to B) with wave undercutting and oversteepening of the bluff toe. In areas where the bluff is composed of clay with a thickness of 20 feet or more (C) there is a risk of internal failure and down slope movement in the form of a landslide. Tides and waves rework slumped deposits (D). In all areas with chronic bluff erosion and or landslides, the shoreline continues in a net landward direction and results in erosion hazards to bluff-top structures. Source: MGS Coastal Landslide Map series (Dickson, 2001c).

Shoreline engineering is sometimes used to stabilize the shoreline at the base of bluffs. This effort has been successful in some locations and not in others. In order to reduce the risk of landslides, bluffs are sometimes graded to a lower slope in order to relive the earth load within the sediments. The MGS map products provide an indication of which areas are vulnerable to bluff erosion and landslides. The risk to property from landslides is very real and the timing of failure is difficult to predict.

Landslide damage in Rockland, Maine in 1996. See Berry et al., (1996) and MGS (1997) for more information on the 1996 landslide. MGS file photo.

As with the beaches, bluff erosion is only a significant factor in making FIRMs obsolete if the rate of bluff erosion is rapid and there has been a significant amount of time between the last map and the current date. In this study, bluff erosion rates of about 0.5 feet per year were assumed for the City of Portland. The FIRMs for Portland are only 5 years old, so the absolute amount of land loss is only a few feet since the maps were made. By comparison, bluff erosion in the City of Portland is less of an issue for map modernization that beach erosion in some other southern Maine communities. Elsewhere in Maine, bluff erosion rates have been calculated at a few locations and are as high as 3 .5 feet per year (Smith, 1990).

VIII. FIRMs in York, Cumberland, and Sagadahoc Counties most likely to be obsolete or become outdated by shoreline change

The table below identifies the communities and panels that are most out of date in York, Cumberland, and Sagadahoc Counties base on shoreline change rates and the number of years that have passed since the maps were made.

Community	Panel	Community Name	County	FIRM Date	Age	Erosion Rate (ft/yr)	Shoreline (ft)
230145	5	Biddeford, City of	York	5/15/1984	19	3	57.0
230145	6	Biddeford, City of	York	5/15/1984	19	-2	-38.0
230052	23	Scarborough, Town of	Cumberland	4/2/1992	11	3	33.0
230120	12	Phippsburg, Town of	Sagadahoc	7/15/1992	11	-2	-22.0
230052	22	Scarborough, Town of	Cumberland	4/2/1992	11	-2	-22.0
230170	7	Kennebunkport, Town of	York	4/18/1983	20	-1	-20.0
230170	8	Kennebunkport, Town of	York	4/18/1983	20	-1	-20.0
230145	11	Biddeford, City of	York	5/15/1984	19	-1	-19.0
230153	3	Old Orchard Beach, Town of	York	7/5/1984	19	1	19.0
230053	9	South Portland, City of	Cumberland	4/17/1985	18	-1	-18.0
230171	3	Kittery, Town of	York	7/3/1986	17	-1	-17.0
230171	6	Kittery, Town of	York	7/3/1986	17	-1	-17.0
230043	3	Cape Elizabeth, Town of	Cumberland	7/15/1992	11	-1	-11.0
230043	11	Cape Elizabeth, Town of	Cumberland	7/15/1992	11	-1	-11.0
230162	21	Cumberland, Town of	Cumberland	7/15/1992	11	-1	-11.0
230162	23	Cumberland, Town of	Cumberland	7/15/1992	11	-1	-11.0
230201	9	Georgetown, Town of	Sagadahoc	7/15/1992	11	-1	-11.0

Community	Panel	Community Name	County	FIRM Date	Age	Erosion Rate (ft/yr)	Shoreline (ft)
230151	14	Kennebunk, Town of	York	7/15/1992	11	-1	-11.0
230151	15	Kennebunk, Town of	York	7/15/1992	11	-1	-11.0
230632	3	Ogunquit, Town of	York	7/15/1992	11	-1	-11.0
230120	11	Phippsburg, Town of	Sagadahoc	7/15/1992	11	-1	-11.0
230052	24	Scarborough, Town of	Cumberland	4/2/1992	11	1	11.0
230170	3	Kennebunkport, Town of	York	4/18/1983	20	-0.5	-10.0
230155	29	Saco, City of	York	3/16/1998	5	-2	-10.0
230170	6	Kennebunkport, Town of	York	7/4/1988	15	-0.5	-7.5
230043	12	Cape Elizabeth, Town of	Cumberland	7/15/1992	11	-0.5	-5.5
230043	16	Cape Elizabeth, Town of	Cumberland	7/15/1992	11	-0.5	-5.5
230201	6	Georgetown, Town of	Sagadahoc	7/15/1992	11	-0.5	-5.5
230201	7	Georgetown, Town of	Sagadahoc	7/15/1992	11	-0.5	-5.5
230169	13	Harpswell, Town of	Cumberland	7/20/1998	5	-1	-5.0
230169	14	Harpswell, Town of	Cumberland	7/20/1998	5	-1	-5.0
230051	8	Portland, City of	Cumberland	12/8/1998	5	-1	-5.0
230155	27	Saco, City of	York	3/16/1998	5	-1	-5.0
230051	3	Portland, City of	Cumberland	12/8/1998	5	-0.5	-2.5
230051	4	Portland, City of	Cumberland	12/8/1998	5	-0.5	-2.5
230051	5	Portland, City of	Cumberland	12/8/1998	5	-0.5	-2.5
230051	9	Portland, City of	Cumberland	12/8/1998	5	-0.5	-2.5
230051	10	Portland, City of	Cumberland	12/8/1998	5	-0.5	-2.5
230051	15	Portland, City of	Cumberland	12/8/1998	5	-0.5	-2.5
230051	17	Portland, City of	Cumberland	12/8/1998	5	-0.5	-2.5
230159	13	York, Town of	York	6/17/2002	1	-1	-1.0
230159	24	York, Town of	York	6/17/2002	1	-1	-1.0
230159	26	York, Town of	York	6/17/2002	1	-1	-1.0
230159	28	York, Town of	York	6/17/2002	1	-1	-1.0
230159	32	York, Town of	York	6/17/2002	1	-1	-1.0
230145	1	Biddeford, City of	York	5/15/1984	19	0	0.0
230153	4	Old Orchard Beach, Town of	York	7/5/1984	19	0	0.0
230051	11	Portland, City of	Cumberland	12/8/1998	5	0	0.0
230051	14	Portland, City of	Cumberland	12/8/1998	5	0	0.0
230051	16	Portland, City of	Cumberland	12/8/1998	5	0	0.0
230158	13	Wells, Town of	York	1/16/2003	0	-1	0.0
230158	21	Wells, Town of	York	1/16/2003	0	-1	0.0
230158	23	Wells, Town of	York	1/16/2003	0	-1	0.0

Based on the quantitative analysis, on past trends, a knowledge of the sand budget, human activities that have and will likely occur in these communities, and degree of coastal development, the communities need remapping first are ranked by priority in the table below. The first 4 municipalities stand out as most in need of map modernization. These are:

Rank	Municipality	County
1.	City of Biddeford	York
2.	Town of Scarborough	Cumberland
3.	Town of Kennebunkport	York
4.	City of South Portland	Cumberland
5.	Town of Old Orchard Beach	York
6.	Town of Phippsburg	Sagadahoc
7.	Town of Kennebunk	York
8.	Town of Ogunquit	York
9.	Town of Georgetown	Sagadahoc
10.	Town of Kittery	York
11.	City of Saco	York
12.	Town of Cape Elizabeth	Cumberland
13.	Town of Harpswell	Cumberland
14.	City of Portland	Cumberland
15.	Town of York	York
16.	Town of Cumberland	Cumberland

IX. Conclusions

This study has confirmed that shoreline change has occurred along many of Maine's beaches at a rate that has made a number of Flood Insurance Rate Maps in need of revision. The rate of erosion along many beaches is on the order of 1 foot per year, so any FIRM that is more than a decade old has the potential to be in need of updating if there are beaches present. Some of the FIRMs in York, Cumberland, and Sagadahoc Counties are more than 10 years old. The oldest maps are in the City of Biddeford; they are now 20 years old. The shoreline of Biddeford also has very significant beach erosion along heavily developed dunes, so it stands out as the community most in need of map modernization.

Within any particular community only some FIRM panels have beaches and erosion is not constant on any given FIRM panel. In order to prioritize the need for updating communities, the "worst case" in shoreline change on each panel was used to calculate an amount of change since the shoreline was made. This report identified individual panels that are most in need of revision. As might be expected from a panel-by-panel analysis, the maps most in need of revisions are not all in the same municipality. Only some of the panels in a community need to be remapped due to changes caused by erosion or accretion along the coast.

Analysis of coastal sediment budgets and their influence on shoreline positions has demonstrated the large role of human activities in affecting the erosion rate on beaches. The anthropogenic influence on the coastal sand budget in the Wells Embayment in the last 40 years is equivalent to redistributing half of the sand volume of the frontal dune. In Saco Bay the rate of longshore drift has accelerated 300% since the Saco River jetties were constructed. The jetty influence on the Saco Bay sand budget has been to move over 4,000,000 cubic yards of sand within the bay in the last century. This report demonstrated the importance of understanding coastal sediment budgets in order to correctly interpret historical air photos on which most Erosion Hazard Areas are based.

The ability to soundly project future EHAs to inland areas with development can be accomplished through the use of several data sets. Notably, high-resolution orthophotographs are needed for a base to register historical air photographs in a geographic information system. Maine should receive such a product within the next year. The advent of airborne laser (LIDAR) to measure beach and dune topography has allowed three-dimensional analysis of beaches and dunes for EHA assessments and sand budgets. Maine has had only one such survey, but efforts are underway to provide a second data set from which comparison for shoreline change and dune elevations can be measured over a period of about 4 years.

The Maine Geological Survey has begun to examine a new method of estimating the erosion hazard in areas that have been "stabilized" by seawalls. The comparison of LIDAR beach profiles seaward of natural and engineered dunes appears to be useful in determining how much "out of equilibrium" the engineered shoreline has become over the last half century as the beach profile has lowered and the dune profile behind a seawall has remained static. This new approach has the potential to complement traditional methods of estimating EHAs and to identify the hazard posed if there were to be a catastrophic failure of seawalls during a 100-year storm event.

X. Acknowledgement

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