State of Oregon
Department of Geology and Mineral Industries
Donald A. Hull, State Geologist

Erosion and Flood Hazard Map of the Gleneden Beach-Siletz Spit Area, Coastal Lincoln County, Oregon

OFR O-97-17

By George R. Priest

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EXPLANATION

Erosion Hazard Area (EHA). Shows possible change of position during the next 60 years of an erosion reference feature (ERF) consisting of the seaward edge of a bluff, landslide headwall, or semi-permanent vegetation line on dunes or alluvium. The current position of the ERF is the seaward edge of the EHA. The EHA is directly related to coastal erosion processes. Where erosion rates are low, the width of the EHA may approach zero at the map scale and be indistinguishable from the ERF.

Indicates that the ERF is currently the headwall of an active or potentially active landslide. Note that the EHA in adjacent areas with the same mean erosion rate may reflect historical retreat of the headwalls of landslides now removed by erosion.

(EL 30) Base flood elevation in feet, where uniform within the flood zone.

Zone V9
(EL 29)

Present day and 60-year positions of the 100-year flood zone boundary or V-zone boundary. Present day position is taken from Federal Insurance Rate Maps (FIRM's) and Flood Hazard Boundary Map (FHBM) panels (FIRM's and FHBM's) dated 1991 and 1992 by the Federal Emergency Management Agency, National Flood Insurance Program. Bold perpendicular lines separate areas of differing base flood elevations. Zone labels are as follows:

Zone	
A	Areas of 100-year flood; base flood elevations and flood hazard factors not determined.
AO	Areas of 100-year shallow flooding where depths are between one (1) and three (3) feet; base flood elevations are shown, but no flood hazard factors are determined.
A1-A30	Areas of 100-year flood; base flood elevations and flood hazard factors determined.
V	Areas of 100-year coastal flood with velocity (wave action); base flood elevations and flood hazard factors not determined.
V1-V30	Areas of 100-year coastal flood with velocity (wave action); base flood elevations and flood hazard factors determined.

0.7 to 2.0 ft/yr (1.4)

Generalized erosion rates -- Range of erosion rate (negative sign indicates erosion) at one standard deviation from the mean; mean is in parentheses; applicable to the shoreline segment marked by the arrows perpendicular to the shoreline.
"No data" means there was no accurate shoreline erosion data. EHA established by other means (see "Notes to the User" below).

NOTES TO THE USER

Mapped flood zones have been modified in some areas to better match the updated base maps of this study. The flood maps of this study should not be used in place of the official FEMA FIRM's or FHBM's. The flood boundaries mapped here were produced for a FEMA-sponsored statistical analysis of potential flood insurance losses; not for any other purpose.

Oregon Department of Geology and Mineral Industries Open-File Report O-94-11 and appropriate geologic hazard maps from the series of maps numbered O-94-12 through 21, O-94-27 through 30, or O-97-6 through O-97-10 should be utilized with this map to provide detailed information on the underlying erosion rate data. Open-File Report O-97-11 documents the mapping method and objectives.

Erosion rates estimated from data in Open-File Report O-94-11

Mapping of EHA's by George R. Priest,
Oregon Department of Geology and Mineral Industries

Reviewed by J.J. Marra, Shoreland Solutions;
Richard W. Rinne, AGRA Earth & Environmental, Inc.; and
Charles I. Rosenfeld, Department of Geosciences, Oregon State University

Field work conducted 1991 through 1993 and 1996.

Scale 1:4800

Contour interval: 5 feet

Horizontal datum: 1983 North American Datum

Vertical datum: 1929 North American Datum

Base map is a 1993 orthophotograph; photography was produced from a positionally corrected flight in the late summer of 1993; the flight was conducted by Spencer B. Gross, Inc. in cooperation with Bergman Photographic Services, both of Portland, Oregon.

This study was supported by Federal Emergency Management Agency (FEMA) Cooperative Agreements EMW-91-K-3576 and EMW-96-CA-0225. Additional funding was provided by the Oregon Department of Geology and Mineral Industries and the Oregon Coastal Management Program, Oregon Department of Land Conservation and Development, from funds provided by the Oregon Legislature, U.S. Department of Commerce National Oceanographic and Atmospheric Administration office of Coastal Resource Management under Section 306 Coastal Zone Management grants, and Section 309 Program Enhancement grants.

DISCLAIMER: The Oregon Department of Geology and Mineral Industries is publishing this paper because the subject matter is consistent with the mission of the Department. To facilitate timely distribution of information, this report has not been edited to our usual standards.

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OPEN-FILE REPORT O-97-11

COASTAL SHORELINE CHANGE STUDY NORTHERN AND CENTRAL LINCOLN COUNTY, OREGON

Prepared by

George R. Priest
Oregon Department of Geology and Mineral Industries

November 1997

NOTICE

The Oregon Department of Geology and Mineral Industries is publishing this paper because the information furthers the mission of the Department. To facilitate timely distribution of the information this report has not been edited to our usual standards.

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COASTAL SHORELINE CHANGE STUDY
NORTHERN AND CENTRAL LINCOLN COUNTY, OREGON

1. EXECUTIVE SUMMARY

The Oregon Department of Geology and Mineral Industries (DOGAMI) used coastal erosion rate data to produce maps of current and 60-year positions of an erosion reference feature (ERF) and 100-year coastal flood zone for 31 miles of the Lincoln County, Oregon, shoreline. The study was conducted to provide the Federal Emergency Management Agency with data for estimating insurance costs to the federal government should it provide coastal erosion coverage to coastal residents. Depending on the shoreline geology, the ERF is (1) the top of the bluff, (2) the headwall above landslides, (3) the seaward edge of stable vegetation on sediment at the mouths of streams, or (4) the seaward edge of stable vegetation on dunes. The present and 60-year positions of the ERF bound an erosion hazard area (EHA). The EHA width was in general added to the current position of the 100-year flood zone boundary to estimate the position of the zone 60 years from now.

The width of the EHA was estimated from a 1991-1993 study of coastal erosion. The 1991-1993 study clearly shows that average erosion rates are low and 60-year EHA's narrow ($\leq$40 feet) for most of this bluffed coastline. Areas with wider EHA's are either bluffs subject to deep bedrock landslides or dune-backed shorelines. The former varied from 54 to 114 feet, while the latter had widths from 25 feet to hundreds of feet.

Even though the EHA's are narrow for much of the study area, a historic pattern of building very close to the bluff edge on this coastline will lead to significant property losses, unless erosion mitigation measures are taken. The pattern that has prevailed in Oregon is to utilize shoreline protection structures such as rip rap or sea walls to save property subject to gradual bluff or dune retreat. This has led to steadily increasing lengths of armored shoreline. Shoreline protection has been ineffective in areas with deep bedrock landslides, so mitigation will not likely change the property loss prediction of the EHA in those areas.

Owing to the fluctuating position of the shoreline on dune-backed beaches, it was necessary to develop a new concept termed a zone of shoreline instability. This zone defines an area where the shoreline fluctuates over some time interval in duned environments. It is based on abrupt changes in the density of vegetation, erosion patterns from historical photography, and geologic judgment. In some cases, such as sand spits over multi-decadal time periods, the zone of shoreline instability can be hundreds of feet wide. Where established by vegetative density change, a 60-year EHA was estimated by assuming that the current width of the zone of beach grasses (versus more permanent shrubs) is a zone of instability and could translate landward at least one more full width over the next 60 years. In other areas with better historical or oceanographic data, the 60-year EHA was established with these other data.

Areas with shoreline protection structures (SPS) were assumed to retreat at the same rate as adjacent unprotected shorelines unless all of the following criteria were met:

1. The SPS had to be substantial. Rip rap had to be stacked nearly to the top of the bluff or dune. All sea walls constructed of concrete or concrete-reinforced masonry were deemed substantial.
2. The SPS had to extend at least 500 feet along bluffed shorelines. On dune-backed shorelines the SPS had to extend at least 1000 feet and be at least 100 feet from the end of the SPS terminating at dunes.
3. There had to be good evidence that the SPS or identically constructed adjacent SPS had lasted a decade or more with little or no damage.
4. There could be no active or potentially active mass movement zones behind the SPS.

The width of the EHA is very uncertain owing to large uncertainties in the estimates of erosion rate. In most areas the uncertainties in the erosion rates at the 68 percent confidence level approach 100 percent of the average rate. Additional uncertainties arise from the possibility that the coast could be affected by earthquake-induced regional subsidence in the next 60 years. Such subsidence would increase erosion rates and base flood elevations.

This bluffed study area is representative of most but not all of the Pacific Northwest coast. Large stretches of Pacific Northwest coastline are composed of dune-backed beaches. Examples are areas flanking the mouth of the Columbia River and the south central Oregon coast. Much of the coastline is rising faster than or at the same rate as eustatic sea level rise, and rivers like the Columbia deliver large quantities of sediment. This combination causes many of these duned shorelines to be relatively stable or to advance seaward. This situation would no doubt be rapidly reversed should a great earthquake cause subsidence.

Costs for the study were increased by the need to (1) modify 100-year flood zones from the original Flood Insurance Rate Maps, (2) produce detailed photographic base maps, (3) map the headwalls of sea cliff landslides to define the ERF, and (4) measure very low erosion rates (<1 ft/yr.) with field-intensive house-to-bluff measurements. These costs might be reduced by use of emerging digital technologies and GPS-controlled rectification of aerial photography.

2. INTRODUCTION

The Oregon Department of Geology and Mineral Industries (DOGAMI) used coastal erosion rate data to produce maps of current and 60-year positions of the coastline and 100-year coastal flood zones in northern and central Lincoln County, Oregon. Nineteen 1:4800 (1" = 400')-scale maps illustrate the current and 60-year positions of an erosion reference feature (ERF) and the 100-year coastal flood zone or storm wave velocity zone (V zone) (Appendix B; Figures 1 and 2). The 60-year positions were estimated from a 1991-1993 study of coastal erosion (Priest and others, 1993; 1994)supported by the Federal Emergency Management Agency (FEMA). National Flood Insurance Program (NFIP), and the Department of Land Conservation and Development (DLCD) under the auspices of the National Oceanographic and Atmospheric Administration (NOAA) Coastal 309 program. The 1991-1993 study was published as 19 geologic hazard maps (Open-File Reports O-94-12 to O-94-30) and as a report (DOGAMI Open-File Report O-94-11; Priest and others, 1994). These same map bases are used here with the same numbering system (Figures 1 and 2).

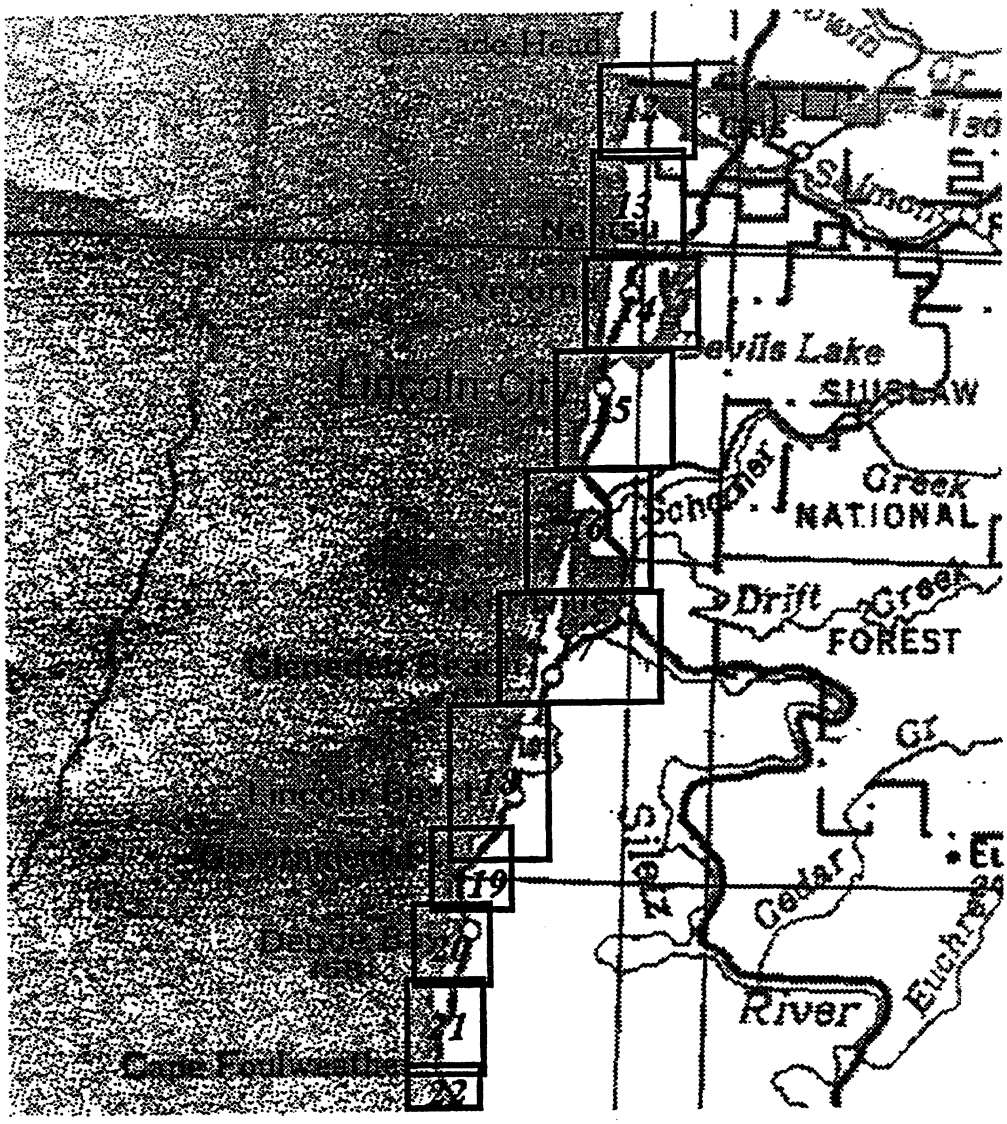

Figure 1. Location index for maps numbered O-97-12 through O-97-21.

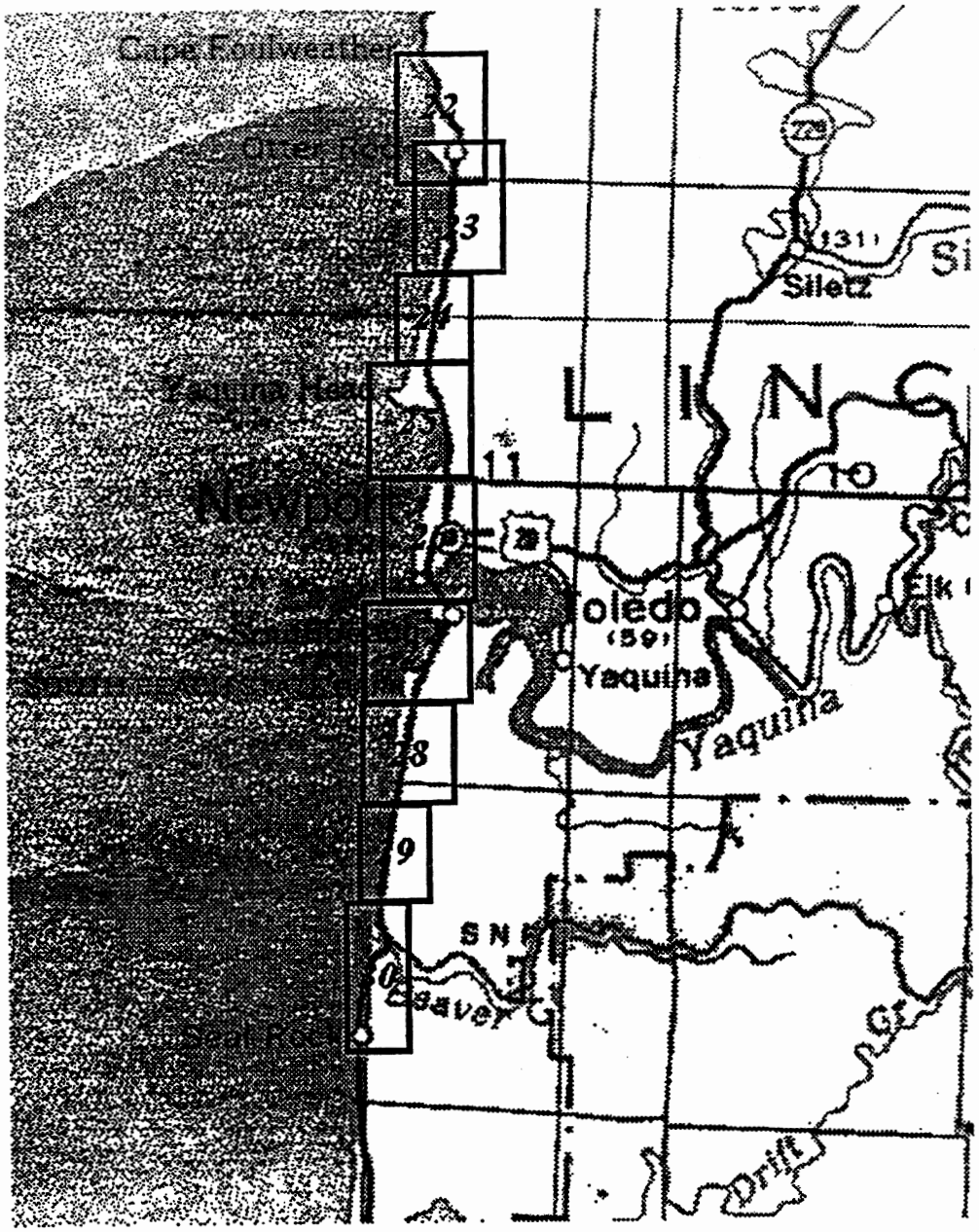

Figure 2. Location index for Open-File Report maps numbered O-97-22 through O-97-30.

The 1991-1993 pilot study was initiated by FEMA in order to evaluate implementation techniques for Section 544 (Upton/Jones Amendment) of the National Flood Insurance Act. The Act allows payment of flood insurance claims for undamaged structures that are threatened by erosion and subject to imminent collapse.

The present study was prompted by passage of the National Flood Insurance Reform Act (NFIRA) on September 23, 1994. Section 557 of the Act, "Evaluation of Erosion Hazards," mandates that a study be conducted that considers the various effects that erosion has on the NFIP its policyholders, and communities[1] prone to erosion. As part of this effort, the legislation states that FEMA may map a statistically valid and representative number of communities with erosion hazard areas (EHA's) throughout the United States, including the Atlantic, Gulf, and Pacific coasts, as well as the Great Lakes. Information obtained from this mapping effort will be used to develop an estimate of the amount of flood insurance claims under the NFIP that are attributable to erosion. FEMA intends to work with state coastal zone management programs in the conduct of mapping EHA's.

3. ANALYTICAL METHOD

3.1 Mapping the Erosion Reference Feature

An erosion reference feature (ERF) was mapped along 31 miles of the Oregon coast from Cascade Head on the north to Seal Rocks on the south (Figures 1 and 2). The ERF on bluffed shorelines is defined as the break in slope that results directly from wave erosion or from mass movements triggered by wave erosion (Figure 3). On bluffed shorelines with zones of mass movement (i.e. earth flows, landslides, slumps, or translational slide blocks) the ERF is the top of the headwall (Figure 3).

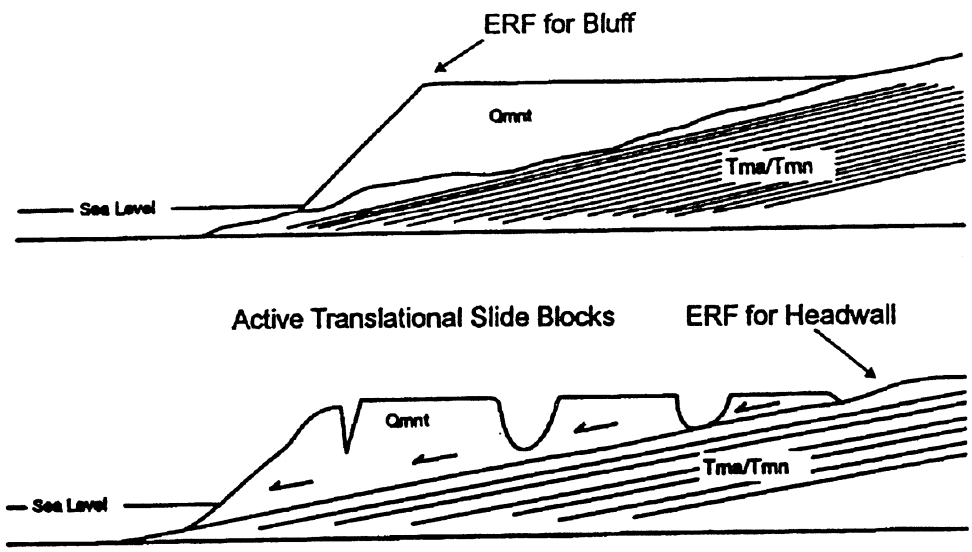

Figure 3. Erosion reference feature (ERF) for a bluff (top) and a landslide (bottom). Figure is modified from Rinne (1992).

[1] FEMA focused on counties instead of communities

On duned shorelines or shorelines at the mouths of drainages the ERF is defined as the seaward limit of stable long term vegetation. Hence, at a bluffed shoreline cut by a drainage, the ERF is drawn from the top of the bluff, down the side of the drainage to the seaward limit of stable vegetation on the alluvial deposits; then back up the side of the drainage to the top of the bluff. The line between the alluvial deposits and the bluff top is carefully placed at the transition between erosion from fluvial/estuarine versus marine processes.

Mapping of the ERF was accomplished by stereoscopic viewing of aerial photographs supplemented by field mapping during the summer of 1996. The ERF was then transferred by inspection to nineteen 1:4800-scale photographic base maps produced from the same aerial photographs. Fourteen of the 19 maps are rectified orthophotographs which cover virtually all of the sandy beach areas. The other five maps cover rocky headlands with insignificant sandy beaches and erosion rates on the order of 0.1 ft/yr. or less. The geographic location data and status of the maps, whether orthographic or non-rectified, is given in Table 1 of Appendix 2.

3.2 Mapping the 60-year Position of the ERF

3.2.1 Shorelines Without Shoreline Protection Structures (SPS)

The area between the ERF and 60-year position of the ERF is referred to as the 60-year erosion hazard area or EHA. . There are many techniques for calculating an EHA (e.g. Shoreland Solutions, 1994; Komar and others, 1997), but most require more detailed, site specific data than available for this study. In this study the 60-year position of the ERF at bluffs and bluff-bounded small drainages was determined by multiplying by 60 the mean erosion rate (in feet per year) determined by Priest and others (1994) and plotting the horizontal offset at the map scale. Owing to scaling errors and scatter, the error in the erosion rates at 68 percent confidence is about 80-100 percent of the mean for most shoreline segments. This error should be borne in mind when evaluating the significance of the EHA.

At the 1:4800 scale, the ERF position could not be specified closer than ±0.01 inches, which corresponds to the error in drawing lines in multiple trials. This error translates to ±4 feet on the ground or ±0.07 feet per year for 60 years. Hence the EHA was mapped with a zero width, where mean erosion rates were less than 0.14 feet per year.

Estimation of the 60-year position of the ERF at duned shorelines required considerable geologic judgment, since these shorelines have highly variable shoreline change rates, shifting from accretion to erosion on seasonal, annual, and decadal time scales. Over several decades, the duned shorelines do not in general retreat any faster than the bluffs to which they are "pinned," but positional changes much larger than predicted from bluff erosion occur on shorter time scales as a result of storm cycles and sedimentation changes. Hence a new concept needed to be developed to address this unique behavior.

A zone of <u>shoreline</u> <u>instability</u> was mapped in duned areas. The zone is defined as a duned area, which from observations or from geologic inference, is thought to be a possible future location of the coastal shoreline. The landward limit of this zone was inferred to be the location of the 60-year shoreline for the purposes of this study.

The zone of instability at dune-backed shorelines was in general inferred from erosion rate data based on changes in position of the storm surge penetration line between historical aerial photography flown in 1939, 1967, and 1991 (Priest and others, 1993; 1994). This data was supplemented by qualitative observations of the density of vegetation and the presence or absence of an indurated or semi-indurated bluff behind the duned area. Sharp decreases in the density of vegetation from grasses to more permanent shrubs and trees frequently mark the current landward boundaries of zones of shoreline instability. The grassy areas are zones of shoreline change on unknown time scales in many cases difficult to judge from the observation window afforded by the historical photography. In some cases the zones of vegetation were the best data available. In these cases, an EHA was mapped by assuming that the ERF was at the seaward edge of the grassy zone and the EHA the same width as the current zone of grassy dune (Figure 4). The assumption is that the tree and shrub zone takes decades to develop and will persist for 60 years.

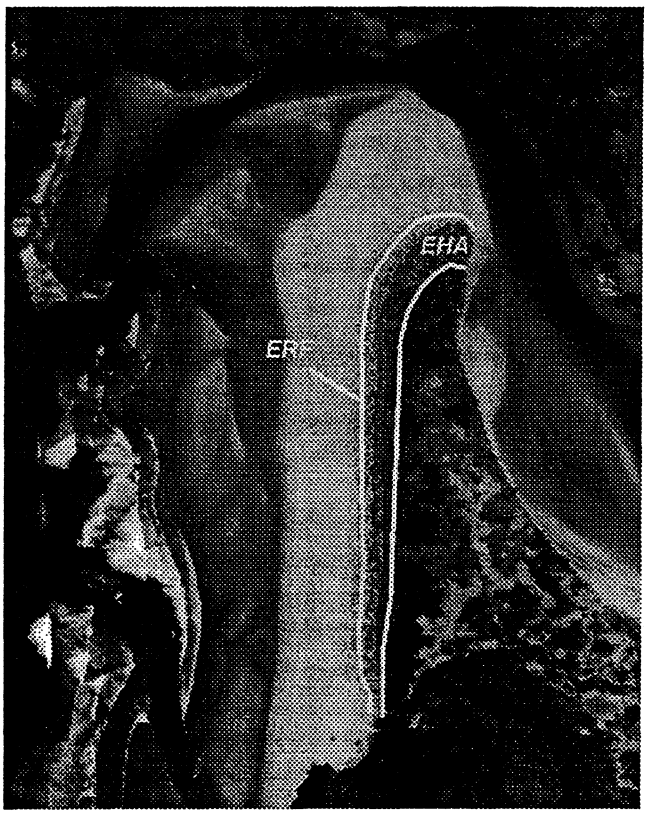

Figure 4. Salmon River estuary showing the EHA defined by placing the ERF at the seaward edge of stable beach grass and the 60-year ERF at the edge of the zone of stable trees and shrubs. The assumption is that the shrub and tree zone took decades to develop and will persist.

On the other hand, duned beaches backed by bedrock bluffs will not participate in shoreline excursions significantly wider than the bluff edge, if the base of the bluff is close to the estimated dune EHA. The landward limit of the EHA was set at the base of the bedrock bluffs in those cases. At some point the width of the dunes fronting a bluff becomes insignificant relative to the EHA for duned shorelines in the area. The ERF was translated to the top of the bluff and the EHA established from bluff erosion rates in these areas. Again, these transitions were a matter of judgment based on local factors.

3.2.2 Shorelines With SPS

SPS-armored shorelines were assumed to retreat at the same rate as adjacent unprotected shorelines unless all of the following criteria were met:

1. The SPS had to be substantial. Rip rap had to be stacked nearly to the top of the bluff or dune. All sea walls constructed of concrete or concrete-reinforced masonry were deemed substantial.
2. The SPS had to extend at least 500 feet along bluffed shorelines. On dune-backed shorelines the SPS had to extend at least 1000 feet along the shoreline. The last 100 feet from the end of any SPS terminating at dunes was considered unstable, owing to the likelihood of erosion from the side.
3. There had to be good evidence that the SPS or identically constructed adjacent SPS had lasted a decade or more with little or no damage.
4. There could be no active or potentially active mass movement zones behind the SPS.

If all of these criteria were met, then the shoreline armored with SPS was assumed to have a 60-year EHA of zero width.

3.3 Mapping the 100-year Flood Zone (V Zone)

The V-zone and fringing A zones were taken from published and digital FEMA Flood Insurance Rate Maps (FIRM's), modified for physiographic detail visible on the 1:4800 base maps and stereo pairs of aerial photographs. The need to modify all of the zones from the digitized FIRM data was a very time consuming part of the study. In a few cases the original digitized FIRM lines were displaced by a hundred feet or more north or south from actual physiographic features that they depict. However, in no case was adjustment of FIRM lines so large that developed areas were impacted that were not impacted by the original lines. The errors may be from a combination of the smaller scale of the FIRM maps (1:24,000 versus 1:4800 used here) and digitizing errors.

The base flood elevation for each flood zone is shown together with the geographic limits of that elevation. These limits or "gutter lines" are shown as a series of lines roughly perpendicular to the shoreline. Where base flood elevations were not known, the zone was designated simply as Zone V with no base flood elevation. Base flood elevations in these areas were estimated from adjacent areas, when inferring the positions on the photographic maps.

V and A zones are mapped only on the open coast where there was erosion rate data from Priest and others (1994). Where the available data justified it, the flood zones were mapped inland as much as 500 feet landward of the 60-year EHA.

3.4 Mapping the 60-year Position of the V Zone

The 60-year position of the V Zone and fringing A zones was inferred from the lateral change of the ERF and from local geomorphic conditions. In most cases the 60-year change in the ERF equaled the estimated change in the position of the flood zone. In some cases where there was a drainage intersecting a bluffed shoreline, the base flood elevation at the back of the drainage was judged to have little likelihood of shifting laterally over 60 years, even with modest bluff retreat. In these cases the 60-year position of the flooding zone at the back of the drainage was assumed to approximately equal the present position.

4. RESULTS

The 60-year position of the ERF and 100-year flood zone was little changed from the present position along most of the length of the coastline. Rocky headlands underlain by basaltic rocks had an EHA of zero width at the map scale of 1:4800. Bluffed beaches underlain by indurated or semi-indurated sedimentary rocks without deep bedrock landslides also had very narrow EHA's on the order of 40 feet or less, ($\leq$0.1 inch at the map scale). Since these bluffs are near vertical in most areas, the position of the ERF and 100-year flood zone in these areas is nearly identical on the maps. These two types of near vertical bluffs comprise about 60 percent of the coastline.

Bluffs with significant deep bedrock landslides comprised about 17 percent of the coastline. These areas had EHA's of 54-114 feet. The position of the ERF and flood zones are separated by fairly large lateral distances, because of the way that the ERF is defined (Figure 4). The base flood elevations were generally in the range of 30-40 feet, placing the boundary on the toe of large landslides, whereas the ERF was at the top of the headwall, as much as several hundred feet inland.

In some cases the present position of the headwall of landslides had to be remapped to a position different from that of Priest and others (1994), owing to refined field observations and mass movement since the 1993 mapping. The largest revision of this kind occurred in the community of Agate Beach immediately north of Yaquina Head. A large translational slide block there has begun to break utility lines and streets about 250 feet inland of the developed bluff edge. The ERF was mapped at the landward limit of this movement along a shoreline segment over 2000 feet long.

The widest EHA's occurred on dune-backed shorelines, which comprise about 19 percent of the study area. The zone of shoreline instability in these areas varied from widths on the order of 25 feet for very stable areas to several hundred feet at the end of Salishan Spit. The large zone of variability on the Spit is caused by erosion from both sides. The estuarine channel of the Siletz River lies on the back side, while a steep reflective beach lies on the seaward side (Figures 5 and 6; Komar and Rea, 1976).

Figure 5. Oblique aerial photograph of Salishan Spit in 1972 illustrating the stable forested portion versus the unstable, nearly barren end, where erosion occurs from both sides. The reflective beach is characterized by many deep rip current embayments, where most erosion occurs (photograph taken from Komar (1992a).

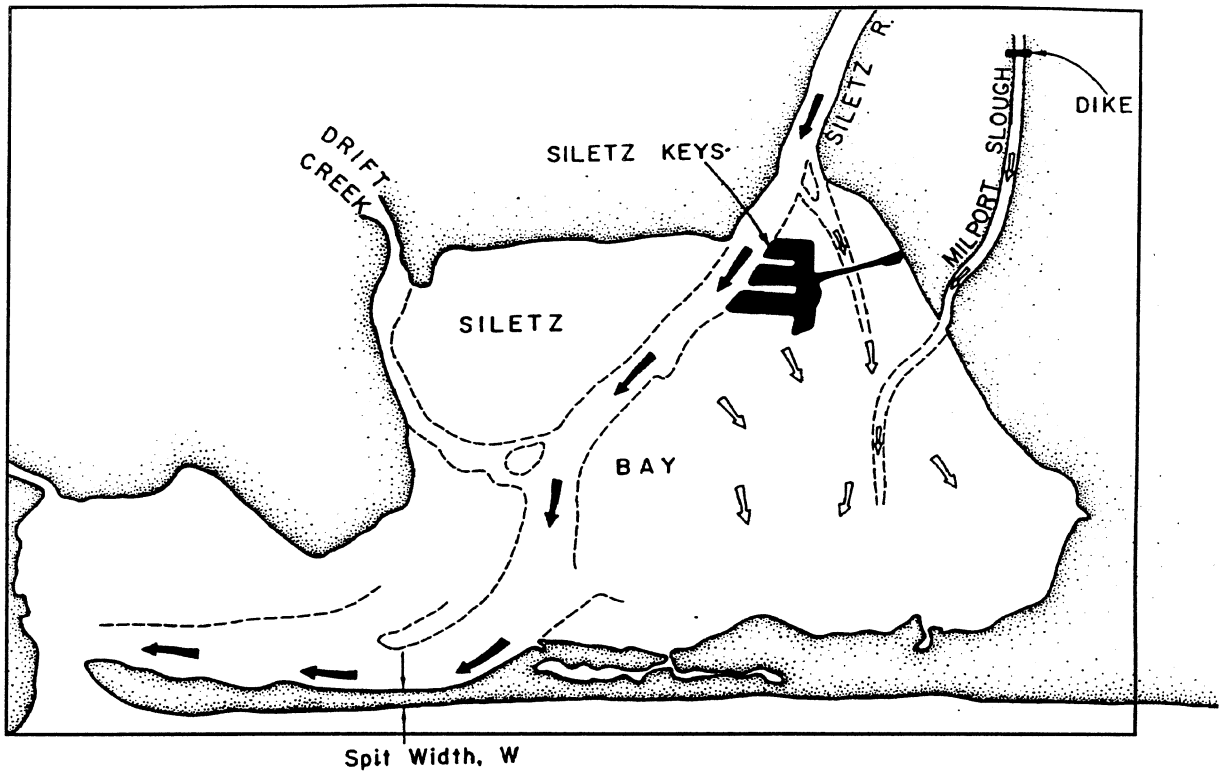

Figure 6. Circulation within Siletz Bay showing how erosion is focused on the thinnest part of the spit. Fills and dikes in the Siletz Keys-Millport Slough area aggravate the problem by preventing flood waters from spilling over into the south Bay. Figure from Komar and Rea (1976).

The 100-year flood boundaries and ERF are not well correlated on dune-backed beaches, because they were defined and mapped in fundamentally different ways. The complexity of defining flood boundaries in these areas made it difficult refine them from the original 1:24,000-scale FIRM data. In many cases the FIRM lines were used with little modification, whereas the ERF and EHA were defined from the 1:4800-scale map base. In virtually all of the cases where the ERF and flood zone do not correlate well, the area is not populated owing to status as public beach or park.

The rest of the shoreline, about 4 percent, is comprised of the mouths of small creeks and rivers, where the ERF generally retreats at the same rate as the surrounding bluffs. The 100-year flood zones generally extend a few hundred feet inland from the ERF in these areas and do not change position significantly over 60-year time frames.

5. DISCUSSION

The analysis of the EHA and 60-year position of the 100-year coastal flood zone showed that for most of the Lincoln County the mean coastal retreat is small (EHA$\leq$40 feet). This does not mean

that there is no risk involved in these areas, because many buildings are within a few feet or tens of feet from the edge of sea cliffs (Figure 7). Likewise, the error (68 percent confidence) on the mean EHA width is on the order of 80-100 percent, so local property losses could be much higher or lower than the mean.

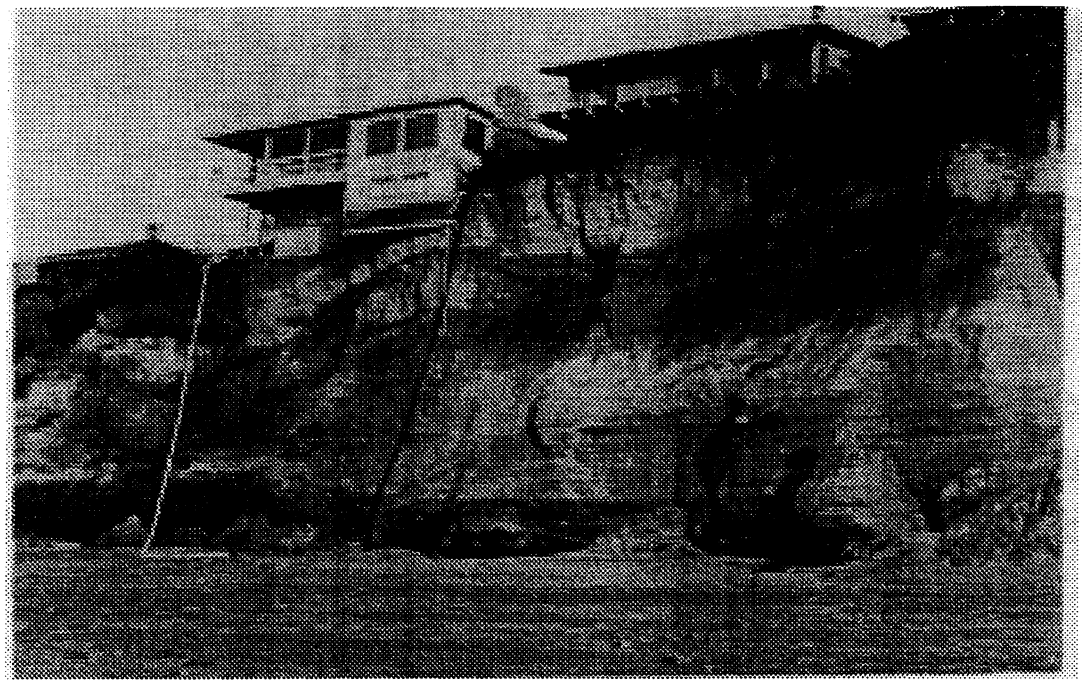

Figure 7. Gleneden Beach houses (northern part of the study area) built so close to the sea cliff that an episode of erosion nearly caused collapse of one structure during a single winter storm. Photograph taken from Komar (1992b).

Areas at highest risk are those with significant development at shorelines with landslides or unstable dunes. Developed shorelines with unstable dunes occur chiefly along Salishan Spit, where a significant number of homes could be in danger near the end of the spit. Developed shorelines with significant landslides include Moolack Beach, pocket beaches north and south of Devils Punch Bowl, and central Newport. One of the most worrisome areas is in the community of Agate Beach, immediately north of Yaquina Head. A translational slide block there extends over 2000 feet along the bluffline and reaches about 250 feet into a heavily developed neighborhood. Similar landward jumps in the headwall of the landslide can be expected in the future.

The episode of landslide erosion at Agate Beach illustrates the uncertainties in the EHA in areas with deep bedrock mass movements. The mean EHA in this area is 98 feet with an error (at 68 percent confidence) of 62 feet; yet the current movement involves 250 feet of the bluff moving episodically lateral distances of a few inches or feet as a more or less coherent block. The largest episodes of movement are generally associated with coastal storms, when the water table rises and wave action erodes the toe of the slope. However, in this early stage of the slope failure, which has been going on for over a decade, little damage has been done except at the margins of

the block. This block movement is on the same scale as block failures affecting the geologically similar Jumpoff Joe area, where whole neighborhoods began to slide seaward in the 1940's (Figures 8 and 9; Priest and others, 1993). The mean 60-year EHA at Jumpoff Joe is 81±38 feet. These data illustrate the potential problem with using mean erosion rates to predict episodic processes.

Figure 8. The 1942-43 landslide at Jumpoff Joe, Newport, Oregon showing destruction of homes at the headwall of the landslide. Photo taken from Lincoln County Historical Society.

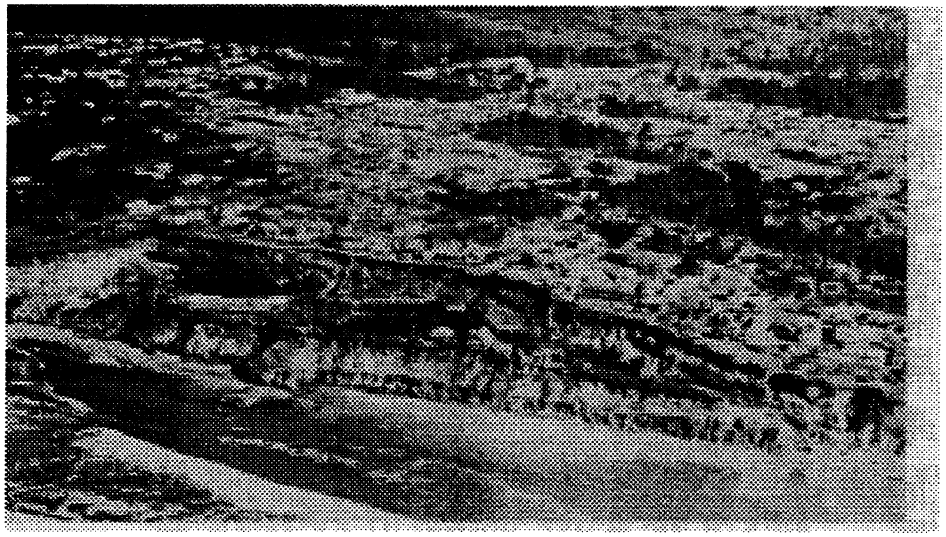

Figure 9. Oblique aerial photograph of central Newport taken in 1961 after the Jumpoff Joe slide block had moved further down slope and seaward than the initial movements in the 1940's. Photograph taken from the Lincoln County Historical Society.

One of the greatest sources of uncertainty in this study was in areas of shoreline protection. Of these areas, the most worrisome is that on Salishan Spit. The SPS there meets the criteria used here for lasting 60 years. The SPS appears to be substantial, extending to the top of the main foredunes and thousands of feet along the shoreline. It has also lasted through a number of large storm cycles over the last decade or so. As a result, this part of the spit was assigned an EHA width of zero. Nevertheless, the SPS there could be easily undermined, where not footed in bedrock. The extent of bedrock footings for SPS in the area is not known, but probably comprises a very small percentage of the shoreline, if any at all. SPS integrity in other areas is similarly uncertain, since in-depth investigation of the structures was beyond the scope of this study.

One of the most serious problems with use of the EHA to predict future property losses is the likelihood that property owners will intervene to stop the erosion. This has historically been the practice where bluff or dune erosion occurs by gradual retreat from wave action (Good, 1992). SPS is generally installed in these areas, particularly where adjacent property has a SPS. SPS has been ineffective in stopping erosion from deep bedrock landslides on high bluffs, so the EHA in these areas is more likely to give a better approximation of the actual future losses. Even in these areas, it may become economic to stabilize the landslides by expensive engineering techniques (e.g. dewatering and buttressing), as property values continue to escalate.

As a pilot study area, the Lincoln County area is not representative of all parts of the Oregon coastline. It is the site of explosive coastal development at the present time. The number of structures in danger from coastal erosion and flooding will thus increase rapidly in the future. The majority of the Oregon coastline is much less developed and under less development pressure, particularly on the south coast. Likewise, the area is not representative of large portions of the south central coastline that are dominated by dunes and insignificant shoreline development (Figure 10). Where homes are threatened on the south central coast, it is more likely from inundation by shifting dunes than shifting shorelines. Many duned areas on the northern Oregon coast in the Clatsop Spit area are also very sparsely populated and are subject to ongoing accretion from the large sediment load carried by the Columbia River. Any extrapolation of the results of this study to the coastline as a whole must take these factors into account.

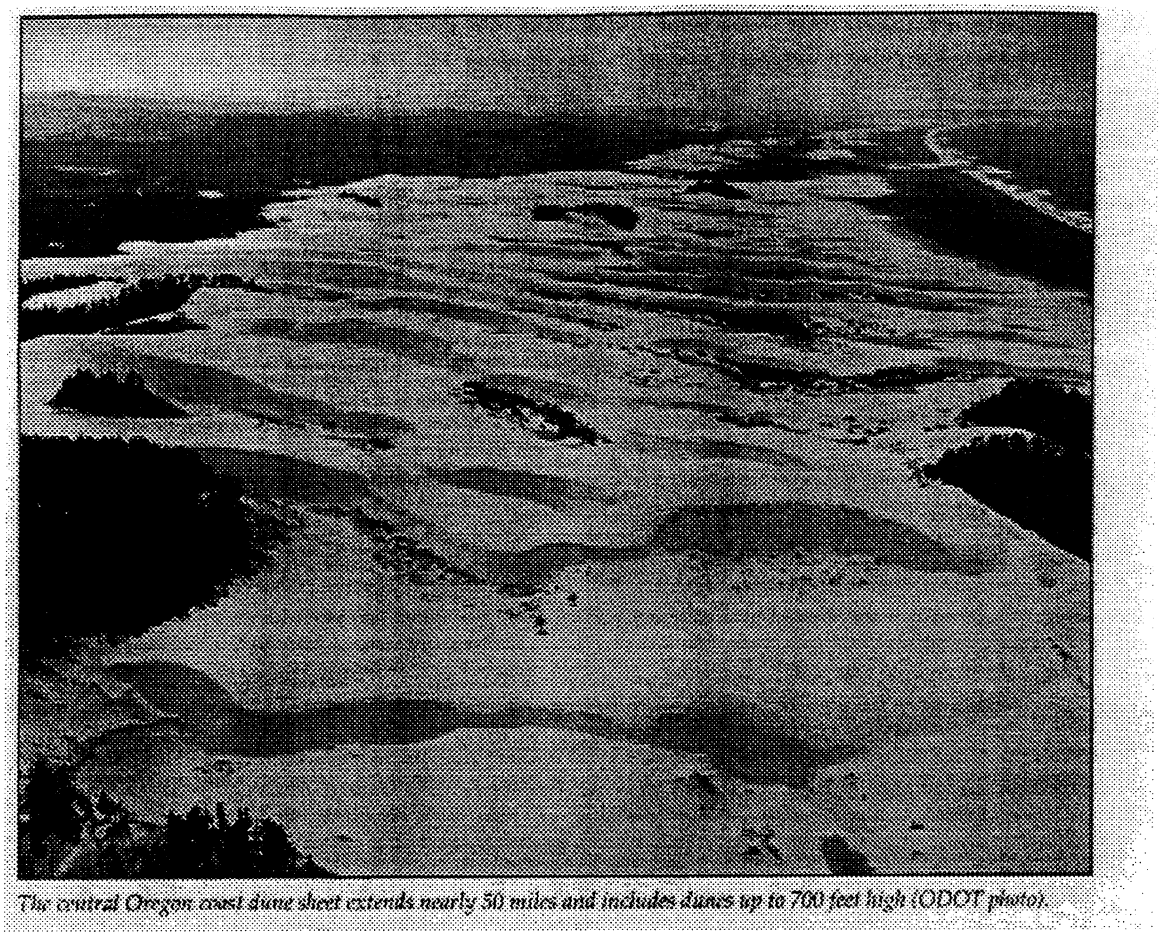

Figure 10. Oblique aerial photograph taken from Oregon Department of Transportation archives, showing a typical undeveloped dune-backed shoreline of the south central Oregon coast.

An additional uncertainty arises from the potential for earthquake-induced coastal subsidence. Current tectonic uplift is keeping pace with or outpacing eustatic sea level rise in many parts of the Oregon coast (Mitchell and others, 1994), but this is probably the result of interseismic strain accumulation on the subduction zone. When the strength limit of the rocks is reached, the subduction zone fault will rupture, reversing most of the accumulated uplift. Given that the last great earthquake was about 300 years ago (Nelson and others, 1995) and that recurrence is on the order of 330-560 years (Darienzo and Peterson, 1995; Geomatrix, 1995; Atwater and Hemphill-Haley, 1996), it is quite possible that subsidence could affect the coast in the next 60 years. Should this subsidence occur, then erosion rates would increase (Peterson and others, 1995) and base flood elevations would be increased about 2-3 feet in the study area (Priest and others, 1995).

6. COST AND TIME ANALYSIS

Total cost to generate the erosion data and do the analysis of the 60-year changes is approximately $109,000. This figure is derived from the estimated cost of generating the erosion rate data and base maps from the previous FEMA-sponsored project in this area (Priest and others, 1993) combined with the budget of $40,000 for this project. The cost is therefore approximately $3,500 per mile for the 31 miles of coastline. A significant portion of this cost is tied to the need to generate base maps at a scale of 1:4800, considered the minimum needed to describe the erosion processes. The labor-intensive nature of the field work needed to measure the relatively low erosion rates and to map the complex landslide-prone areas accounts for much of the rest of the cost.

7. CONCLUSIONS

Whereas the study area is not representative of all parts of the Oregon coast, it is representative of the majority of the coastline of the Pacific Northwest. Large portions of this coast have bluffs cut by dune-fringed estuaries. Lincoln County is quite representative in this regard. The higher development pressure extant in this area relative to much of the rest of the coast is probably a harbinger of future trends, as the Pacific Northwest economy grows and continues to attract significant immigration.

The pilot study clearly shows that erosion rates are low and 60-year EHA's narrow ($\leq$40 feet) on this bluffed coastline, unless bluffs are subject to deep bedrock landslides. When landslides are present, hundreds of feet of the bluff can become unstable, as single translational or rotational slide blocks begin to move. The initial losses from this type of bluff failure are quite modest, consisting of intermittent damage to utility lines and building foundations at the margins, especially the headwall, of the mass movement. The initial stage may occur over one season or a few decades, episodes of largest movement correlating with storms that raise the water table and cause waves to erode the toe of the slope. As movement proceeds, however, essentially total destruction of structures on the moving material will eventually occur. Identification of areas vulnerable to this type of slope failure, even where the initial incipient ground cracks have begun to appear, requires careful field mapping by experienced geological personnel. Without this fundamental mapping, the ERF and erosion rates cannot be specified with any accuracy. The need for slope stability analysis is therefore a fundamental difference between the Pacific Northwest coast and duned coastlines that dominate many parts of the United States.

A significant portion of the Oregon coast is composed of dune-backed beaches similar to those in other parts of the United States, but with one important difference. These duned areas are attached to very slowly eroding bluffs, so the long term retreat is not larger than that of the bluffs. The duned environment is, however, highly responsive to subtle shifts in sand supply and to storm cycles. This leads to zones of shoreline fluctuation that may be much wider than the EHA of the adjacent bluffs. The EHA in these duned environments was therefore mapped as equivalent to the inferred zone of shoreline instability. This is a fundamentally different concept than the EHA for most duned coastlines in the southern and eastern US, which are characterized by large-scale coastal retreat driven by eustatic sea level rise and longshore current transport. Much of the Pacific Northwest coast, owing to relatively high rates of tectonic uplift, keeps pace with or exceeds the rate of eustatic sea level rise, leading to small headland-bounded littoral cells

that trap the sand (see Komar, 1992, for a summary). Areas with high sediment supply like those north and south of the Columbia River have accreting duned shorelines. In Alaska, southern British Columbia, Washington, Oregon, and northern California the tectonic uplift is temporary and is reversed suddenly, when great earthquakes occur at intervals of hundreds of years. Resulting coseismic subsidence floods some areas and increases shoreline erosion rates for decades after an earthquake.

Using the EHA to predict future property losses may be compromised by the likelihood that property owners will intervene to stop the erosion process with engineering techniques. This has been the case for most slowly eroding bluffs and duned areas along the Oregon coast. It has not been the case for high bluffs with deep bedrock landslides, but escalation of property values may make it economically feasible to intervene with engineering solutions, even in these areas.

8. SUGGESTIONS FOR FUTURE STUDIES

Future studies should focus on innovative means of measuring shoreline change with photogrammetric techniques. Stereoscopic viewing of digital aerial photographs should be explored for both mapping shoreline erosion and flood zones. Digital scanning of all historical aerial photography for the coast would be a worthwhile investment in this regard. While the initial investment would be high, the savings in labor costs, and increase in accuracy would justify the expenditure. Scanning the coast-wide photography flown in 1939 and 1967 is the minimum needed to do erosion rate analysis. Doing all of the scanning at once would yield an economy of scale.

An experiment should be done to evaluate rapid photographic rectification techniques. These techniques could be focused on just the portion of the historical or modern aerial photograph that contains the ERF. Use of moderately high precision (±4 ft) GPS-derived control points to achieve complete or partial rectification might be useful in this regard.

It is recommended that future FIRM maps be plotted and digitized on the best available base maps. In many cases local or state government has large-scale maps such as those produced for the 1991-1993 study (Priest and others, 1994). Use of these more accurate base maps for FIRM maps would have reduced the cost of this study and yielded FIRM's that would have been more useful to local government.

9. ACKNOWLEDGMENTS

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11. APPENDIX A: GEOGRAPHIC COORDINATES OF MAPS

Submitted separately from this report are nineteen 1:4800-scale orthophotographic and non-rectified photographic maps showing the EHA and projected change in the 100-year flood zone over the next 60 years. Corner coordinates for the orthophotographs are given in Table 1. Locations of the all maps are given in Figures 1 and 2. Field data for the maps is summarized by Priest and others (1993; 1994).

Table 1. Corner Coordinates (Eastings and Northings) for the rectified maps numbered 0-94-13 through 0-94-18 and 0-94-22 through 0-94-30. Maps numbered 0-94-19 through 0-94-21 are not orthophotographs. Coordinates are referenced to NAD83

Map No.	SE Corner Easting	SE Corner Northing	SW Corner Easting	SW Corner Northing	NW Corner Easting	NW Corner Northing	NE Corner Easting	NE Corner Northing
O-95-13	7291200.00	506896.25	7291200.00	517696.25	7306400.00	517696.25	7306400.00	506896.25
O-95-14	7288800.00	495296.25	7288800.00	506896.25	7304000.00	506896.25	7304000.00	495296.25
O-95-15	7286400.00	483696.25	7286400.00	495296.25	7301600.00	495296.25	7301600.00	483696.25
O-95-16	7284400.00	472096.25	7284400.00	483696.25	7299600.00	483696.25	7299600.00	472096.25
O-95-17	7284400.00	460496.25	7284400.00	472096.25	7299600.00	472096.25	7299600.00	460496.25
O-95-18	7289718.72	446496.25	7277718.72	446496.25	7277718.72	460496.25	7289718.72	460496.25
O-95-23	7282231.46	403668.83	7271831.46	403668.83	7271831.46	415268.83	7282231.46	415268.83
O-95-24	7281831.46	392068.83	7271431.46	392068.83	7271431.46	403668.83	7281831.46	403668.83
O-95-25	7281431.46	380468.83	7270631.46	380468.83	7270631.46	392068.83	7281431.46	392068.83
O-95-26	7280631.46	368868.83	7270231.46	368868.83	7270231.46	380468.83	7280631.46	380468.83
O-95-27	7279031.46	357268.83	7269431.46	357268.83	7269431.46	368868.83	7279031.46	368868.83
O-95-28	7277831.46	345668.83	7268663.57	345668.83	7268663.57	357268.83	7277831.46	357268.83
O-95-29	7275831.46	334068.48	7267016.42	334068.48	7267016.42	345668.83	7275831.46	345668.83
O-95-30	7273331.46	322553.32	7264454.17	322553.32	7264454.17	334068.83	7273331.46	334068.83