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Department of Geology and Mineral Industries
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Open-File Report

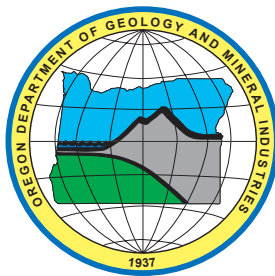
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**AN EVALUATION OF THE RISKS FROM STORM EROSION
AND OVERWASH OF THE ELK RIVER SPIT, OREGON,
ASSOCIATED WITH RESTORING WESTERN
SNOWY PLOVER BREEDING HABITAT:**

TECHNICAL REPORT TO THE U.S. FISH & WILDLIFE SERVICE

By

Jonathan C. Allan



2004



Photo is from Oregon Department of Geology archives and was taken at Elk River Spit.

NOTICE

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1.0 EXECUTIVE SUMMARY

Investigations have been undertaken along the Elk River Spit to assess the physical processes affecting its morphology, stability, and for determining an appropriate spit crest elevation to allow for periodic dune over-topping by wave swash. This analysis is important for the purposes of developing a Western Snowy Plover breeding habitat on the spit, since these birds typically nest in flat, open areas with sandy or saline substrates where vegetation and driftwood are usually sparse or absent (USFWS, 2001). The main findings of this study include:

- The Elk River beach consists of coarse sand, which results in a steep (typical slopes of 4° (1-on-14) to 7.1° (1-on-8)), intermediate to reflective beach system that is exceedingly dynamic (responds rapidly) to ocean waves and currents.
- There is a noticeable change in the mean grain-size with northward progress along the spit, with the sediments adjacent to the river mouth being noticeably finer when compared with the sand near the base of the spit and further south near Garrison Lake.
- The mouth of the Elk River has migrated northward by some 1,067 m (3,500 ft) since the late 1920s, at an average rate of 14.5 m/year (47.6 ft/year).
- Accompanying the northward extension of the Elk River mouth has been considerable aggradation along the foredune, which has resulted in the dune elevation having been raised from approximately 5.6 m NAVD88 (18 ft) in 1967 to an elevation of around 8 – 10 m (26 – 33 ft) in 2002.
- Aggradation of the Elk River Spit has been aided by the explosive growth of European beach grass, which has resulted in the growth of a high foredune, effectively eliminating the occurrence of wave over-topping along much of the spit.
- The highest point on the Elk River Spit is 11.7 m NAVD88 (38.4 ft) and is based on the September 2002 LIDAR flight of the Oregon coast.
- An analysis of the alongshore distribution of the beach/dune junction (an erosion reference point cut by high wave runup events) along the Port Orford littoral cell reveals that wave runup is capable of reaching an elevation of 5 – 7 m, which periodically results in wave overwash at the base of the Elk River Spit.
- Analyses of the calculated total water levels (T_{WL} , combined wave runup plus the tidal elevation for the period July 1987 to March 2003) on the spit based on an average beach slope of 0.084, and a maximum slope of 0.125 confirm that the total water levels during major storms may reach an elevation of 8.8 to 10 m NAVD88 (28.9 – 32.8 ft) and are consistent with observations of wave runup on beaches with similar slopes on the northern Oregon coast.
- The median total water level calculated for the Elk River Spit ranges from 3.4 to 3.8 m NAVD88 (11.2 – 12.5 ft). For 25 percent of the time the total water levels exceeded an elevation of 4.1 m (13.5 ft), and for 10 percent of the time they exceed an elevation of 4.8 m NAVD88 (15.7 ft). For 5 percent of the time, the total water levels exceeded an elevation of 5.2 m (17.1 ft).

- Lowering the Elk River Spit to an elevation of 5.5 m (18 ft) will result in the dune being over-topped for about 4 – 8 percent of the time, with the bulk of the over-topping occurring during the months of December and January.
- During a typical winter, it can be expected that total water levels exceeding 5.5 m (18 ft) will result in periodic (~100 to 300 hours) over-topping of the spit during a typical winter. Lower elevations would produce more frequent over-topping, but the effects of the increased frequency of over-topping on the stability of the spit are uncertain.
- Lowering the spit to 5.5 m should not adversely influence Plover nesting, since the incidence of high total water levels during the critical nesting period (i.e., March to September) is extremely low.
- Analyses of the total volume of sand needed to be removed from the spit based on a lowered dune crest elevation of 5.5 m is on the order of 178,600 m³ (233,600 yards³).
- In order to accomplish the dune rehabilitation work, it is recommended that such work be done in stages beginning near the base of the Elk River spit (i.e., from where it bends to the north and runs parallel with the ocean) to profile Elk 2.
- Ideally, the dune rehabilitation work should be undertaken during late spring and into summer in order to maximize the southward transport of beach sediments by waves and wind.

Monitoring of the dune rehabilitation work is essential to the success of this proposed project. Monitoring should include pre- and post-grading surveys of the area targeted. Additional monitoring efforts should also be periodically undertaken (e.g., at quarterly intervals during the first year and then bi-annually thereafter). In particular, follow-up surveys should be undertaken of the Elk River beach monitoring network following major storm events.

2.0 INTRODUCTION

The Oregon Department of Geology and Mineral Industries (DOGAMI) has been commissioned by the U.S. Fish & Wildlife Service (USFWS) to carry out an assessment of the geologic risk associated with restoring the Elk River Spit for the purposes of developing a Western Snowy Plover breeding habitat on the spit. The general objective of this study is to provide an assessment of the dune and beach morphology of the Elk River Spit and an evaluation of the relative risks involved in modifying those environments to enhance plover habitat. Such an assessment includes providing a synthesis of various historical and contemporary sources of beach morphology information (e.g. aerial photographs, National Ocean Service (NOS) Topographic “T” Sheets, Light Detection and Ranging (LIDAR) Data, and up-to-date beach survey information), and an analysis of the incidence for wave runup and over-topping on the spit.

The Pacific coast population of the Western Snowy Plover (*Charadrius alexandrinus nivosus*) is listed as threatened under the Endangered Species Act. Western Snowy Plover breed primarily on coastal beaches from southern Washington to southern Baja California. They breed and winter along the Oregon Coast, which is located at the more northern extent of their range. The birds are currently found at nine sites along the south central Oregon Coast between Cape Blanco and Heceta Head. However, they were historically found at more than 20 sites along the coast from Pistol River to the Columbia River. Current estimates indicated that about 110 birds breed in this area and about 70 birds are present during the winter.

Snowy Plover typically nest in flat, open areas having sandy or saline substrates, where vegetation and driftwood are usually sparse or absent (USFWS, 2001). They start breeding behavior as early as February but initiate nests between March 15 and September 15 with most nesting activity occurring in June (Castelein et al. 2000). The eggs are laid directly on the sand in a shallow scrape or depression lined with beach debris. The nests are placed above the wrack line within

several hundred meters of the water. Snowy Plover breeding habitat is artificially created by removing the vegetation and lowering the foredune to increase the incidence of wave overwash during winter storms. This creates the large, bare sand areas they prefer.

The Elk River Spit is located mid-way along the Port Orford littoral cell (Figure 1), and is bounded by the Port Orford headland (The Heads) in the south and Cape Blanco in the north, with a total shoreline length of 11 km. The Elk River Spit has been identified by the USFWS in their recovery plan for the western Snowy Plover as an area that should be restored and managed as breeding and wintering habitat (USFWS, 2001). The identified recovery area is approximately 3,700 meters (2.3 miles) long, and covers an area of 90 hectares (220 acres).

Two of the spits landowners have expressed an interest in restoring it for the purposes of developing a Snowy Plover habitat. The approach presently used by the USFWS is to remove European beach grass from the dune system and to modify the beach morphology by grading or dune scalping to increase the likelihood of wave overwash during winter storms. Typically, dune restoration is completed mechanically by removing the vegetation using bulldozers and lowering the foredune by pushing the sand seaward onto the beach. Thus, an evaluation of the Elk River Spit is necessary in order to provide an understanding of:

- The existing beach and dune geomorphology (i.e., beach slopes, dune crest elevation, changes in the spit morphology and temporal and spatial characteristics of the beach) and the processes (e.g. waves, tides, and currents) in the vicinity of the proposed restoration area;
- The alternatives available to restore and maintain Snowy Plover habitat; and,

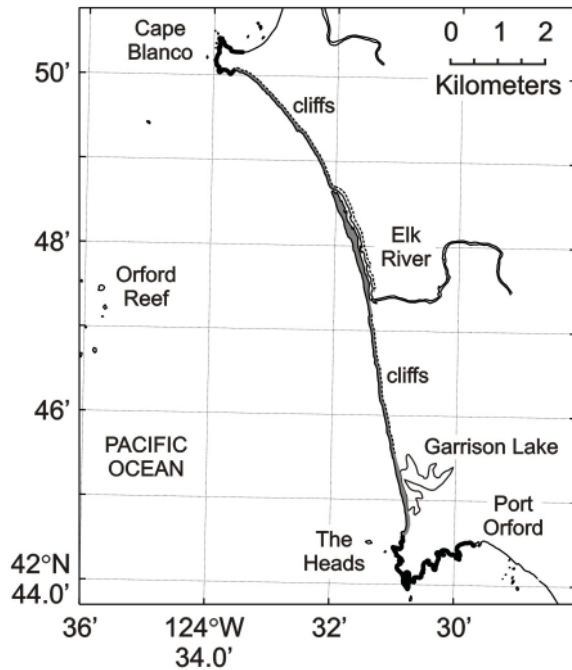


Figure 1. The Port Orford littoral cell. Note: dashed lines indicate cliffs, shaded area denotes sandy beach.

- The likely impact of the dune restoration work on the adjacent beach, dune and upland areas.

This study has several objectives which include the following:

- Investigate the general geomorphic features of Snowy Plover habitat by assessing beach characteristics preferred by Snowy Plover and by visiting the BLM New River, where active dune restoration is occurring;
- Describe the littoral processes (erosion and accretion) in the vicinity of the Elk River Spit based on existing information. These processes include wave and tide conditions, wave runup, the total water levels (wave runup plus the tidal elevation) and the predominant patterns of sediment transport in the Port Orford cell;

- Assess the alternatives available to restore and maintain Snowy Plover habitat (e.g., no action, remove vegetation, remove vegetation and grade foredune) using LIDAR topographic mapping, predictive models, aerial photographic analysis, field investigation, or other means;
- Establish a beach profile monitoring network along the Elk River Spit. The monitoring network will consist of a minimum of three transects;
- Evaluate the risk of increased erosion to upland areas, the changes that may occur to the river orientation and the effect on sand erosion/accretion within the littoral cell; and
- Conduct post-project monitoring to determine the effectiveness of the restoration work.

This project involves the cooperative efforts of the DOGAMI, private landowners (the Wahl and McKenzie families), Oregon Department of Parks and Recreation (OPRD) and the South Coast Watershed Council.

3.0 BEACH PROCESSES ON THE OREGON COAST

3.1 Introduction

The Oregon coast can be broadly characterized as consisting of long stretches of sandy beaches that are bounded by resistant headlands. These types of systems are referred to as littoral cells (Komar, 1997), and include both a cross-shore distance (littoral zone, Figure 2) and a longshore extent. The Port Orford littoral cell, an 11 kilometer (6.8 miles) long stretch of coast includes the Elk River Spit, and extends from the Port Orford Heads at its southern end, while Cape Blanco forms the northern boundary. Because the headlands extend into deep-water, wave processes are generally regarded as unable to transport beach sediment around the ends of the headlands. As a result, the headlands essentially form a natural barrier for sediment transport, preventing sand exchange between adjacent littoral cells. Thus, a littoral cell is essentially a self-contained compartment, deriving all of its sediments from within that cell.

Beaches composed of loose sediments are among the most dynamic and changeable of all landform types, responding to a myriad of complex variables that reflect the interaction of the processes that drive coastal change (waves, currents and tides) and the underlying geological and geomorphological characteristics of the beaches (e.g., sediment grain-size, shoreline orientation, beach width, sand supply and losses etc.). Coastal processes (waves, currents, and tides) have a

threefold role in contributing to the morphology and position of the beach. These include:

- 1) Promoting the supply of sediments to the beach system for beach construction;
- 2) Transferring sediments through the beach system, and;
- 3) Ultimately, processes can lead to the removal of sediments elsewhere through the process of erosion.

Since beaches are comprised of loose material, they are able to respond and adjust their morphology rapidly in intervals of time ranging in the order of seconds to several years, in response to storm events, enhanced periods of storm activity (e.g., the 1982-83 and 1997-98 El Niños), changes in beach material, and variations in water levels. Longer term adjustments may also be perceived in the beaches and may be related to a change in sea level.

Integral to an understanding of coastal change along the Elk River Spit is the concept of the beach sediment budget. This concept is analogous to an accounting system such that an assessment is made of the amount of sediment that is arriving at a beach (credits) with that which is removed (debits) and equating these to the net gain or loss (balance of sediments) for a given beach (Komar, 1998). Thus, the balance of sediments should approximately equal the local beach erosion or accretion.

A clear distinction can be made between movements in the beach form (its height and width) over short time scales (in response to variations in waves and currents), from the longer-term changes, which are dependant on the state of balance or imbalance among the various elements of the sediment budget.

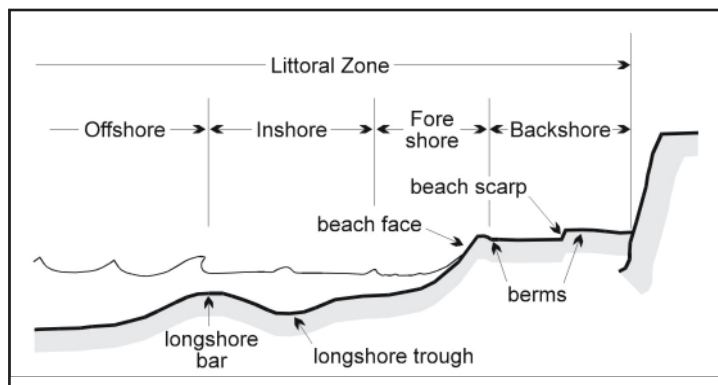


Figure 2. Terminology used to define aspects of the beach (Komar, 1998b).

From a shore management perspective it is important to clearly distinguish the shorter temporal beach changes from the longer-term adjustments since they have very different implications for land-use adjacent to any water body. In this way costly shoreline erosion and other hazards can be mitigated or avoided altogether, or at least anticipated and properly provided for. Unfortunately, for the purposes of this report, it is not possible to develop a detailed sediment budget for the Port Orford littoral cell, since no study has been undertaken of the dynamics and volumes of sediment transport, inputs and losses along the cell. However, within the cell beach sand is probably derived from a variety of sources, including:

- The Elk River during high-river flow events. The most recent high magnitude event occurred in 1996, which resulted in the foredune being breached at its southern end (Figure 3) (Scott McKenzie 2003 pers comm.).
- The erosion of coastal bluffs located between Cape Blanco and the Elk River mouth and between Paradise Point Road

located just north of Garrison Lake (Figure 1) and the Elk River Spit. These bluffs consist of marine terrace deposits composed of sands and gravels that overly Tertiary and pre-Tertiary bedrock (Beaulieu and Hughes, 1976). The height of the bluffs are variable and include a number of large gullies, particularly along the cliffs north of Paradise Pt. Road that are subject to mass movements. These processes are capable of releasing significant quantities of coarse sand, granules and pebbles onto the beach. A recent example of this process is the erosion of the high bluffs at Paradise Point State Park, which has injected a considerable amount of sediment into the littoral system (P.D. Komar 2004 pers comm.); and,

- From erosion of dunes along the coast.

With respect to the last point, the Port Orford littoral cell has experienced tremendous erosion at the south end of the cell (adjacent to Garrison Lake) that has resulted in the insertion of a considerable volume of

sand to the littoral system. Thus, the erosion of the beach adjacent to Garrison Lake has effectively become a significant source in the sediment budget for the remainder of the beaches to the north, including the Elk River Spit. In addition, while the erosion of dunes may at times reflect a sediment source to the remainder of the cell, dunes may also act as a major sink for beach sediments (i.e., a point of sediment accumulation) as the material is blown

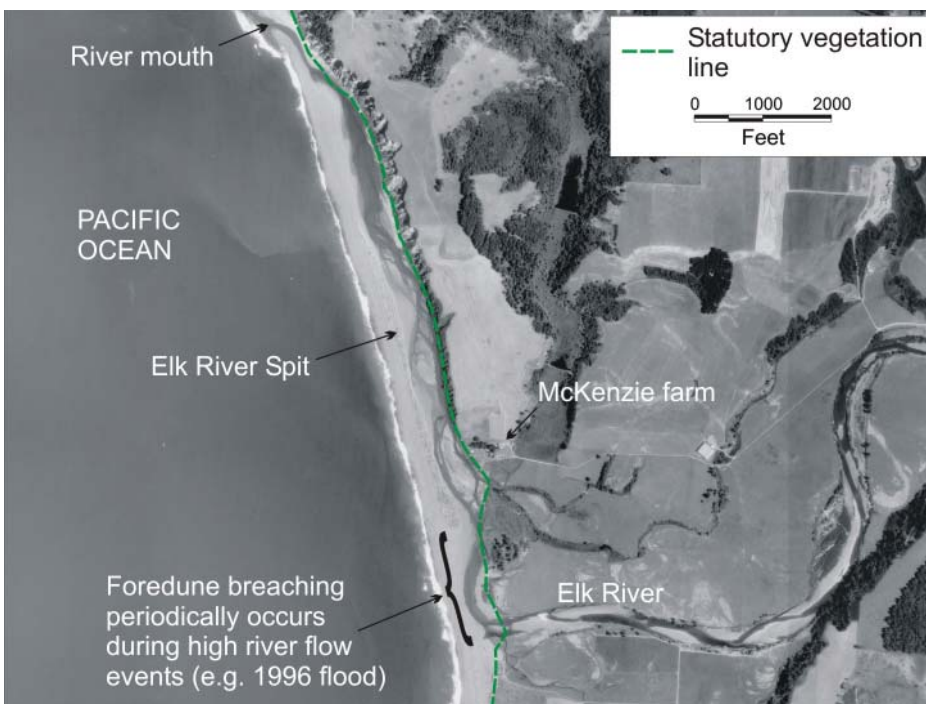


Figure 3 Aerial photograph of the Elk River Spit showing the current location of the river mouth in 2000, and in the south where the river periodically breaches the foredune during high flow events.

inland onto the dunes. The best example of this is the considerable accumulation of sediment along the Elk River Spit since the late 1960s and along the large dunes that are forming north of the Elk River mouth. These changes have been greatly facilitated by the proliferation of European beach grass (*Ammophila arenaria*) during the last 50 years. Some loss of sediment may also take place in response to periodic wave over-topping of the barrier beach adjacent to Garrison Lake, which carries sand into the lake.

Oregon's beaches can be broadly classified into two predominant types using the classification of Wright and Short (1983):

- Dissipative beaches are those that contain predominantly fine sands, are gently sloping (typical slopes range from 1.1° (1-on-50) to 2.9° (1-on-20)) and have wide surf zones that dissipate the wave energy as waves break and approach the shore.
- Intermediate to reflective beaches, which contain coarse sand and gravel, are steep sloping (3.2° (1-on-18) to 14° (1-on-4)), have narrow surf zones or in some circumstances a single breaker line so that wave breaking occurs very close to or directly on the beach face.

The Elk River Spit beach falls under the latter category and is therefore intermediate to reflective in the classification of Wright and Short (1983). These types of beaches are exceedingly dynamic, responding rapidly to variations in the offshore wave energy. For example, data presented by Allan and others (2003) indicate that the mean position of the Agate Beach shoreline located north of the Port Orford Heads and adjacent to Garrison Lake (Figure 1), where the shoreline is defined as the location of the Mean Higher High Water (MHHW) contour elevation located at a height of 2.1 m ((6.9 ft) NAVD'88 based on the Port Orford tide gauge) varies by some 60 – 70 m (190 – 230 ft) between summer and winter, with the beach face eroding and rebuilding

by this amount. In contrast, the seasonal variability on the Elk River Spit appears to be lower varying by some 10 – 20 m (33 – 66 ft). These smaller beach excursions are likely to be a function of the position of the spit, located midway along the littoral cell, so that its beaches are influenced by a constant flux of sediment moving in both northerly and southerly directions. The driving force behind these variations is the seasonal change in the offshore wave climate. As a result, during the winter months the wave energy (proportional to the square of the wave height) increases substantially eroding the beaches, while the summer months are characterized by much lower wave energies that enable the eroded sand to migrate back onshore, rebuilding the beach face.

Terminology used to describe the form of a beach is shown in Figure 2, while the specific zones within which important coastal processes are operating are presented in Figure 4. As indicated in both Figures, a typical beach cross-section comprises both a sub-aerial component (the beach foreshore and backshore) and an underwater component that includes the nearshore and offshore zones. Furthermore, the visible sandy foreshore comprises only a small portion of an onshore-offshore sand exchange system that extends well to seaward. Thus, the cross-shore extent of the littoral zone extends from the backshore (which may encompass a dune field, beach ridge, sea-cliffs etc.), seaward to some limiting depth where underwater bed changes tend to be minimal. The seaward limit of onshore-offshore sand exchange can be estimated empirically

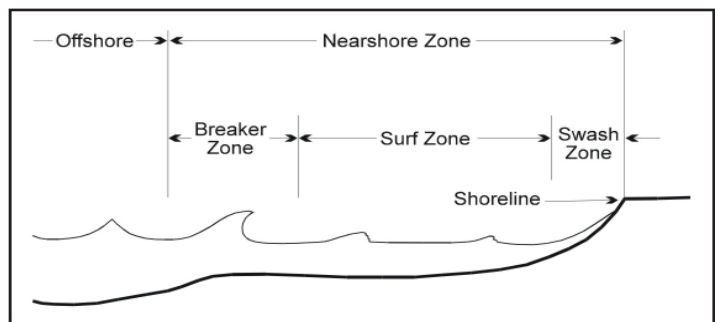


Figure 4. Terminology used to describe the various process zones in the nearshore (Komar, 1998b).

ically using formulas developed by coastal engineers based on the offshore wave climate. These calculations suggest that the seaward limit of the littoral zone calculated for the Oregon coast extends out to a depth that ranges from 10 – 14 m (33 – 46 ft).

3.2 Longshore Sediment Transport

Within the littoral zone, a distinction can be made between sand movement that is directed in primarily onshore-offshore directions (cross-shore sediment transport), and the movement of sand parallel to the beach (longshore transport). The latter process can be especially significant and is dependent on the direction at which waves approach the shore. When waves approach the shore at some angle, longshore currents are formed. These currents are confined to a narrow zone landward of the breaker zone and can be responsible for the movement of substantial volumes of sand along the shore. Along the Oregon coast, the role of longshore currents is especially important due to a seasonal variation in the direction of wave approach between summer and winter (Figure 5A). During a “normal year”, summer waves approach the coast from the northwest, driving sand towards the south-

ern ends of Oregon’s littoral cells. This process is further aided by strong north to northwesterly winds that develop throughout the summer that are further capable of transporting large volumes of dune sand towards the south and also landward to form dunes. In contrast, the arrival of large waves from the southwest during the winter results in a reversal in the net sand transport direction, which is now directed toward the north and can erode the dunes. Thus, over several normal years there is a net equilibrium balance so that the net sand transport is close to zero (i.e., there is no net long-term build up (accretion) of sediment at either end of the littoral cells) (Komar, 1986).

Periodically, the volume and direction of sand transported along Oregon’s littoral cells may be augmented due to the occurrence of an El Niño. El Niños typically occur at intervals of 5 to 6 years, but may recur on 2 to 7 year cycles. In the past two decades there have been seven El Niños, with the 1982-83 and 1997-98 events having been the strongest on record, while the period between 1990 and 1995 was characterized by persistent El Niño conditions, the longest on record (Trenberth, 1999). The 1982-83 and 1997-98 El Niños were particularly significant events

producing some of the most extreme erosion occurrences on the Oregon coast (Komar, 1986; Allan and Komar, 2002; Revell and others, 2002), including significant beach erosion adjacent to Garrison Lake located at the south end of the Port Orford cell (Komar, 1998a; Allan and others, 2003).

El Niños impact Oregon’s beaches in a variety of ways, most notably by elevating the mean water levels that cause the measured tides to be much higher than usual. Under

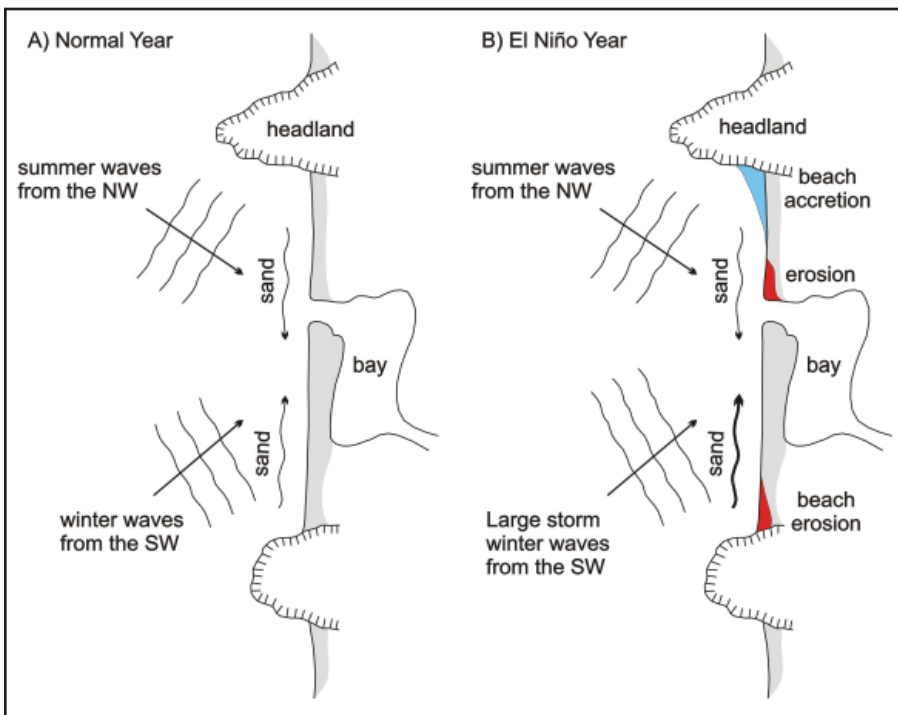


Figure 5. The alongshore-seasonal movement of beach sediments on the Oregon coast for A) a typical year and B) an El Niño year (Komar, 1998a).

normal conditions, the Oregon coast experiences a seasonal variation in its monthly mean water levels. During the summer water levels tend to be lowest, a result of coastal upwelling that produces cold, dense water, which depresses water levels along the coast. With the onset of winter, the upwelling process breaks down and ocean temperatures are much warmer, and its thermal expansion causes the level of the sea to be elevated by some 0.2 m (0.6 ft), with the highest water levels achieved in December and January (Allan and others, 2003). During an El Niño, however, ocean temperatures are further enhanced due to the release of a warm pool of ocean water that emanates from the tropics. The arrival of this warm pool along the Oregon coast during the winter further elevates the ocean surface by an additional 0.3 m (1 ft). Thus, an El Niño may produce an increase in the winter water levels by as much as 0.5 m (1.6 ft), greatly enhancing the capacity of waves to erode beaches and dunes during those months.

Aside from changes to the mean water levels along the coast, during an El Niño there is also a southward displacement of the storm tracks so they mainly cross the coast of central California (Seymour, 1996). As a result, storm waves reach the Oregon coast from a more southwesterly quadrant, creating an abnormally large northward transport of sand within its littoral cells. This creates “hotspot” erosion at the southern ends of the cells, north of the bounding headlands and also north of migrating inlets, shown conceptually in Figure 5B. The opposite response is found south of the headlands, where the northward displaced sand accumulates, causing the coast there to locally advance seaward (Figure 5B).

A detailed documentation of this northward sand displacement and hotspot erosion became possible during the 1997/98 El Niño using LIDAR data, a remote sensing technology developed by the U.S. Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA) to collect topographic data (position and elevation) of the beach. Additional information on LIDAR and its application can be found at the NOAA Coastal Service Center website

<http://www.csc.noaa.gov/crs/tcm/index.html> and is discussed in detail by Brock and others (2002) and Stockdon and others (2002). Analyses by Revell and others (2002) used the fall-1997 versus spring-1998 LIDAR data to measure the vertical and volumetric changes in the beach that occurred during the El Niño winter along the length of the Netarts Littoral Cell in Tillamook County, documenting a clear pattern of northward sand transport in response to the southwest approach of El Niño storm waves. Allan and others (2003) undertook additional analyses of the LIDAR data in the Netarts cell quantifying the “hotspot” erosion effect along the south end of the cell (Figure 6). Apparent in the figure is the concentrated zone of erosion along the southern 3 kilometers (1.9 miles) of shoreline, where negative values indicate erosion while positive values indicate accretion. The “hotspot” erosion effect is greatest along the southern 1 – 2 kilometers (0.6 – 1.2 miles) of the coast where it reaches about -20 m (-65 ft) and progressively decreases northward along the spit. Figure 6 also demonstrates the northward transport of sediment along the cell, as conceptualized in Figure 5, with the shoreline having prograded seaward by some 10 m (33 ft) along the northern extent of the spit, and by several meters north of the mouth of Netarts Bay.

Unfortunately, the USGS and NASA did not undertake LIDAR measurements of the beach topography along the Port Orford littoral cell in 1997 (i.e., pre El Niño), though they did measure the beach topography in April 1998. As a result, it is not possible to demonstrate the hotspot erosion effect using pre and post El Niño LIDAR data. However, aerial photography flights have been undertaken on several occasions over the past 30 years that can be used to assess the shoreline responses along the southern end of the Port Orford cell. Analyses of these data have been undertaken by Allan and others (2003) adjacent to Garrison Lake for the following years; 1927, 1976, 1982, 1986, 1994, 1998 (Figure 7). Of note is the landward position of the shorelines in 1986 and 1998. The 1986 shoreline occurred a few years after the major 1982/83 El Niño, while the 1998 shoreline documents the response to the 1997/98 El Niño event. Interestingly,

the shoreline response for both years is almost identical with the coast eroding landward by some 80 to 110 m (260 – 360 ft). These are extremely large shoreline movements though not unexpected for coarse-grained beaches exposed to such an energetic wave environment. Furthermore, the shoreline responses again

demonstrate the “hotspot” erosion effect at the south end of the Port Orford cell, with the amount of erosion progressively decreasing to the north, where some accretion may have occurred as found in the Netarts cell (Figure 6).

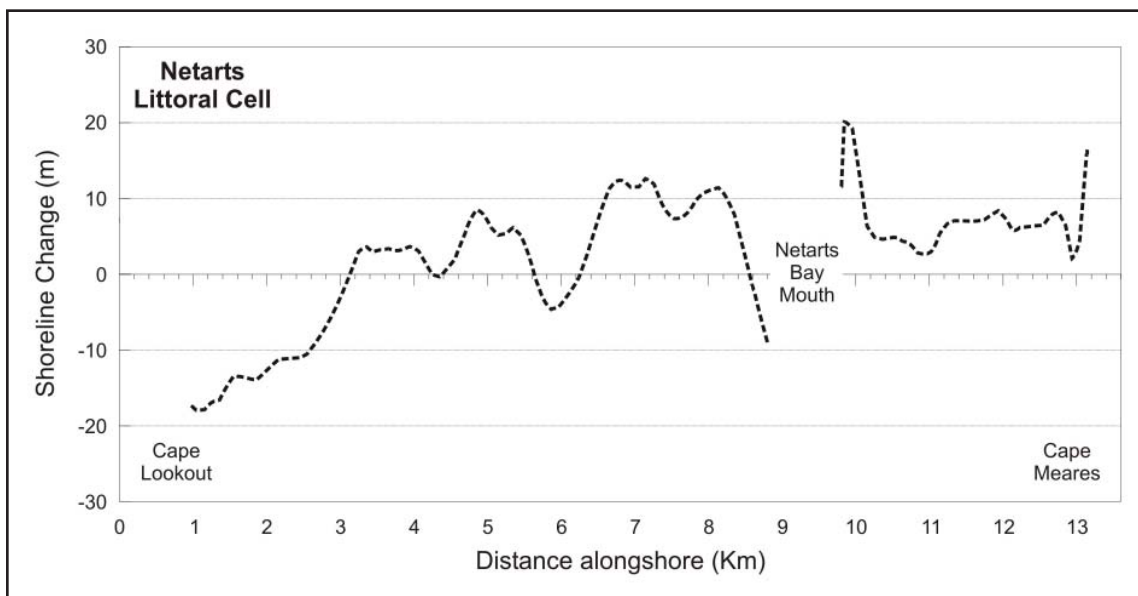


Figure 6. Example of the “hotspot” erosion effect identified in the Netarts littoral cell in Tillamook County (after Allan and others, 2003).

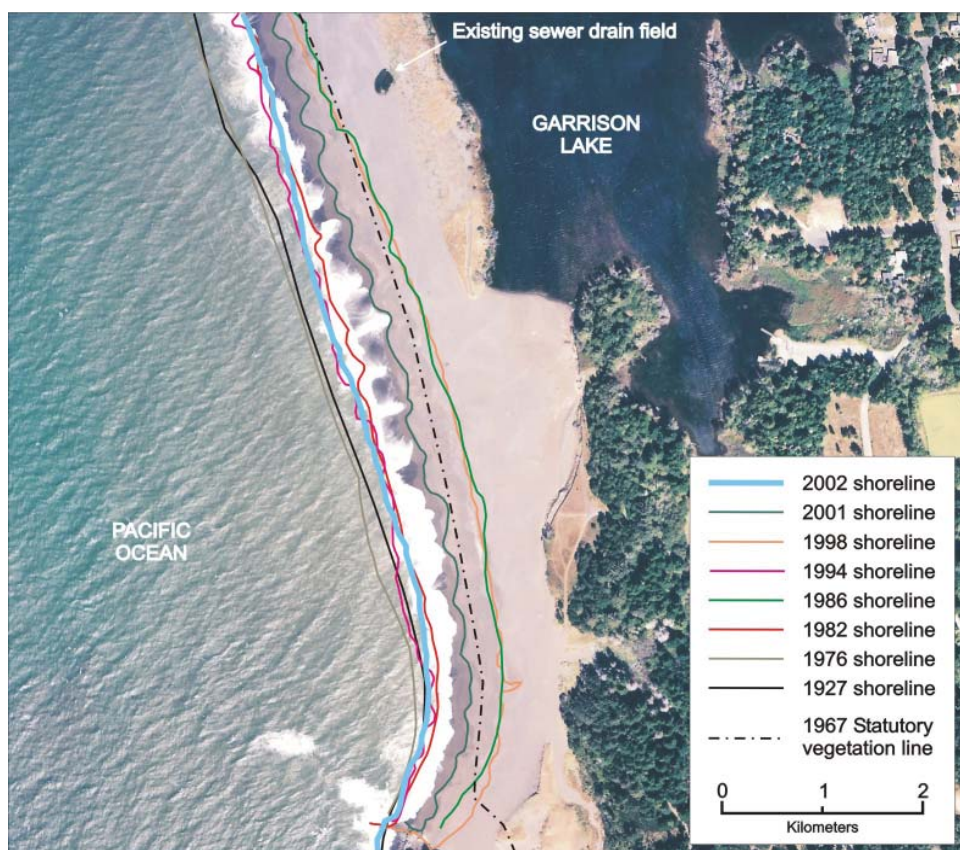


Figure 7. Shoreline changes along the Garrison Lake beach demonstrating the “hotspot” erosion effect along the south end of the cell and more recent seaward progradation (rebuilding) of the beachface as demonstrated by the 2002 shoreline (after Allan and others, 2003).

3.3 Pacific Northwest Wave Climate

The wave climate offshore from the Oregon coast is one of the most extreme in the world, with winter storm waves regularly reaching heights in excess of several meters. This is because the storm systems emanating from the North Pacific travel over fetches that are typically a few thousand miles in length and are also characterized by strong winds, the two factors that account for the development of large wave heights and long wave periods (Tillotson and Komar, 1997). These storm systems originate near Japan or off the Kamchatka Peninsula in Russia, and typically travel in a southeasterly direction across the North Pacific towards the Gulf of Alaska, eventually crossing the coasts of Oregon and Washington or along the shores of British Columbia in Canada (NMC, 1961; Tillotson and Komar, 1997).

The degree to which North Pacific storms affect the PNW depends not only on the intensity of the storms but also on the intensity of the Pacific High and Aleutian Low atmospheric systems. During the summer months, the Pacific High moves northwards so that only a few storms approach the PNW, and those that do tend to be weak. While storm waves during the summer months are relatively rare (i.e., locally generated wind waves predominate throughout the summer), long period swell waves may still be experienced throughout the summer. These latter waves are likely generated by storms located in the far North Pacific (e.g., near the Aleutians) or from storm systems that develop in the Southern Hemisphere during their winter (i.e., winter storms that occur offshore from the New Zealand coast).

With the onset of winter, the Pacific High is displaced to the south, while the Aleutian Low atmospheric system deepens. It is the combined effect of these two systems and the location and strength of the jet stream that contributes to the development of intense storms (termed extratropical storms) in the PNW. These storm systems develop in the form of rapidly moving intense frontal systems, or low pressure systems, and periodically as severe outbreaks, or extratropi-

cal “bombs”. These latter storm systems develop rapidly and are characterized by a dramatic drop in atmospheric pressure (typically greater than 24 mb over a 24 hour period) (Sanders and Gyakum, 1980). Although North Pacific storms rarely acquire wind strengths comparable to hurricanes, their influence is often more widespread, affecting stretches of coast up to 1,500 km in length and can produce extreme wave heights (significant wave heights of 10 to 14 meters) on a fairly regular basis during the winter months.

3.3.1 Sources of Wave Measurements

Wave statistics (heights and periods) and some meteorological information have been measured in the North Pacific using wave buoys and sensor arrays since the mid 1970s. The data have been collected by the National Oceanic and Atmospheric Administration (NOAA), which operates the National Data Buoy Center (NDBC), and by the Coastal Data Information Program (CDIP) of Scripps Institution of Oceanography. The buoys cover the region between the Gulf of Alaska and Southern California, and are located in both deep and shallow water. The NDBC operates some 30 stations along the West Coast of North America, while CDIP has at various times carried out wave measurements at 80 stations. However, there are currently no CDIP buoys installed close to the Elk River Spit, with the nearest deployment having occurred offshore from Bandon. In addition, the CDIP datasets tend to be characterized by short bursts of sampling (i.e., project specific) and long durations of no measurements so that the data tends to have significant gaps in the records. As a result, for the purposes of this report the CDIP dataset has not been used.

Wave measurements by NDBC are obtained hourly, and are transmitted via satellite to the laboratory for analysis of the wave energy spectra, significant wave heights and peak spectral wave periods. These data can be obtained directly from the NDBC through their website <<http://seaboard.ndbc.noaa.gov/Maps/Northwest.shtml>>. Data measured by the Newport (#46050) and Port Orford buoys (#46015) are especially pertinent since these sites are located close to the Oregon

coast (Figure 8), with the Port Orford buoy being particularly relevant since it is located some 27.5 km (17 miles) offshore from the Port Orford Heads and is the closest buoy to the Elk River Spit. However, a limitation of the Port Orford buoy is that it has only been operational since July 2002 and as a result has a very short record, while the Newport buoy has data extending back to the mid 1980s. Table 1 describes the general characteristics of each of the wave buoys,

and includes their World Meteorological Organization station names, locations, water depths, and type of buoy.

3.3.2 Wave Climate Characteristics

To assess the relationship between waves measured by the Newport buoy and those sampled at Port Orford, a step-wise linear regression was undertaken of the daily average wave heights for the period July 2002 to March 2003. The result of the correlation is shown in Figure 9. Apparent from the figure is the close correlation ($R^2 = 0.91$) in the wave heights measured at the two buoy sites. The linear fit also indicates that waves measured at Port Orford during the 2002-03 interval were slightly larger than those measured at Newport. This is especially true as the significant wave heights increase above a height of about 4 m (13 ft). The results suggest that it is reasonable to use wave data measured offshore from Newport to infer the wave climate offshore from the Port Orford littoral cell and therefore to model the wave runup characteristics on the Elk River Spit.

There is a strong seasonality to the wave climate along the Oregon Coast, with the strongest storms and largest generated waves occurring in the winter months. This has been shown, for example, by Tillotson and Komar (1997) and Allan and Komar (2000b). Figures 10 and 11 present the monthly average deep-water significant wave heights (H_s) and peak spectral wave periods (T_p) for the Newport buoy. The graphs clearly show a prominent cycle in the mean monthly

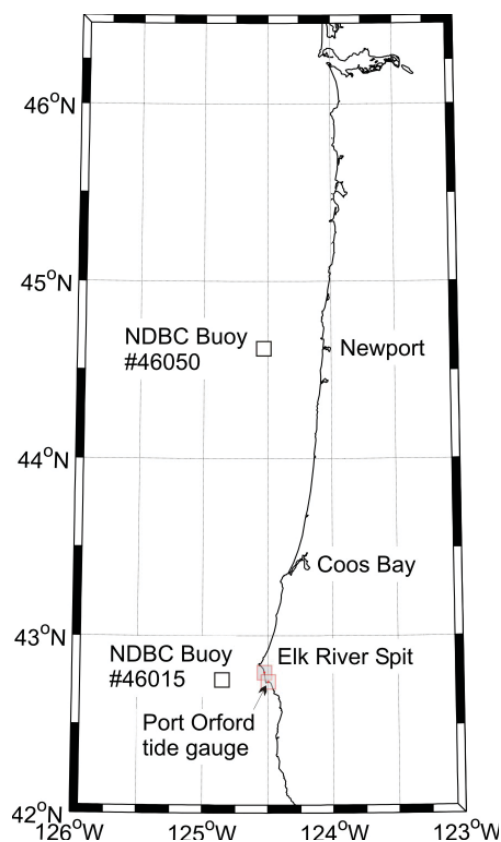


Figure 8. Location of NDBC wave buoys and the Port Orford tide gauge.

Table 1. Wave buoy site characteristics.

Station Name	Location	Water Depth (m)	Period of Operation	System
46050	Newport (Lat. 44°37'16"N; Long. 124°31'42"W)	130	1987 - present	3-meter discus buoy
46015	Port Orford (Lat. 42°44'00"N; Long. 124°50'30"W)	448	2002 - present	3-meter discus buoy

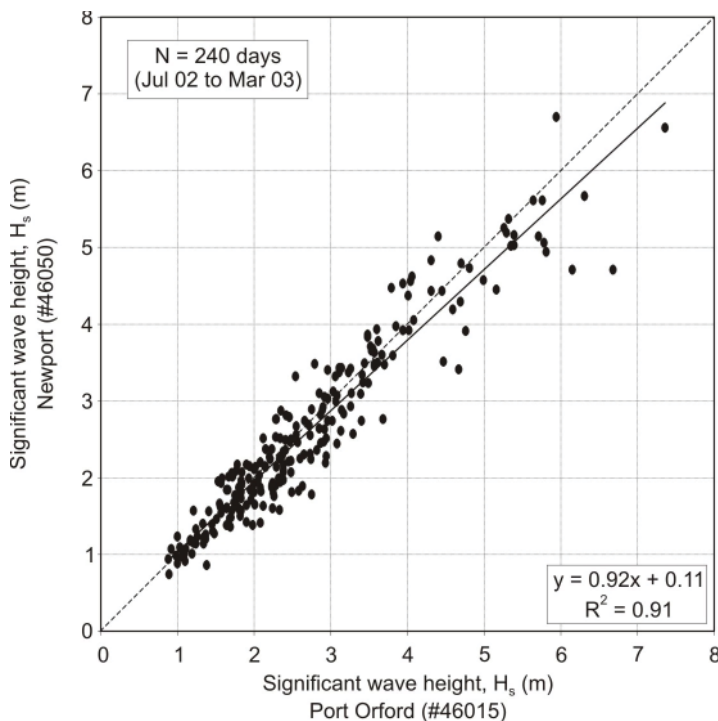


Figure 9. Correlation of the daily average significant wave heights between the Newport NDBC wave buoy (#46050) and the Port Orford (#46015) buoy.

wave heights and peak wave periods. Waves are characteristically smallest (<2.0 m (6.6 ft)) between June and September, reaching a minimum in August (Figure 10). The range (+/- 1 standard deviation) of wave heights during July and August is generally less than 0.17 m (0.6 ft). This suggests that during the summer, the West Coast is characterized by relatively similar conditions for wave generation, likely by local winds that blow over short fetches. During the winter, wave heights typically range from 3 to 4 m (9.8 - 13.1 ft). However, during major winter storms, wave heights in excess of 7 m (23 ft) are not uncommon, with the most extreme storms producing deep-water significant wave heights on the order of 14 to 15 m (45.9 - 49.2 ft) (Allan and Komar, 2002). A similar pattern can be seen for the peak wave periods (Figure 11), such that during the summer the periods are typically less than 9.5 sec, reaching a minimum of 8.4 sec in July. Wave periods tend to be longest in December and January and range from 12 to 14 sec on average and may reach as much as 25 seconds during major storm events.

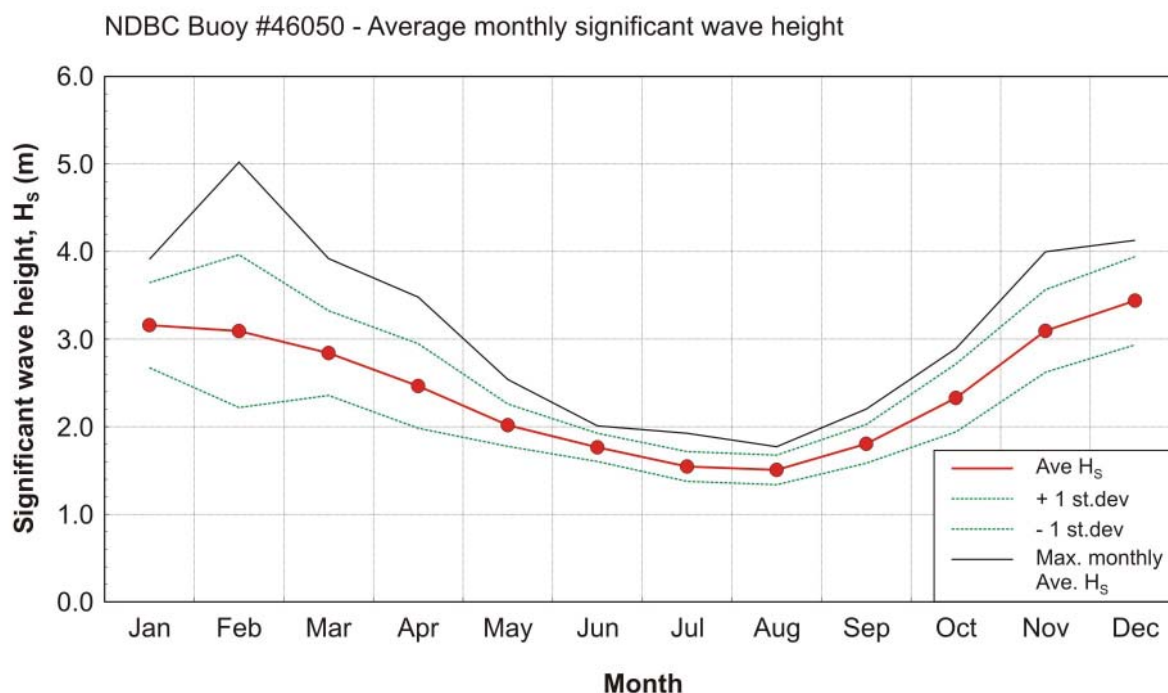


Figure 10. Monthly averages of the significant wave height (1987 – 2001). The graph shows the average monthly significant wave height, the monthly average maximum significant wave height, and the range (+/- 1 standard deviation) for each month.

Beginning with the 1997-98 winter, an El Niño, the Oregon coast experienced over 20 large storms when the deep-water significant wave heights exceeded 6 m (20 ft) for 9 hours or longer (Allan and Komar, 2000a); prior to the 1997/98 winter the maximum number of storms experienced using the above criteria was 10 – 12, which occurred in the early 1980s, highlighting the unusual nature of the 1997/98 winter. These storms affected shipping and produced considerable beach and property erosion along the coasts of Oregon and Washington. Based on wave data up through 1996, Ruggiero and others (1996) had calculated the 100-year storm wave to be around 10 m (33 ft) for the Oregon coast. A storm on 19-20 November 1997 exceeded that projection. Wave conditions were far worse during the following 1998/99 La Niña winter, when 17 to 22 major storms occurred off the PNW coast, with four having generated deep-water significant wave heights equal to or greater than the 10 m (33 ft) projected 100-year occurrence. The largest storm developed on 2-4 March 1999, generating 14.1 m (46 ft) deep-water significant wave heights. Thus, the PNW received a “one-two punch” from the successive El Niño and La Niña winters, with severe cumulative erosion of the coast (Allan and Komar, 2002). At Port Orford the beach responded signifi-

cantly, with the foredune at the southern end of the Port Orford cell having eroded landward by some 60 m (Allan and others, 2003). Between major storms, the reduced wave energies permitted beach rebuilding, with the shoreline prograding (advancing) seaward and with foredunes rebuilding (Komar, 1997; Allan and Priest, 2001; Allan and others, 2003). This latter process, however, is much slower so that the foredunes may take several years to a few decades to rebuild.

3.4 Tides

Measurements of tides on the Oregon coast are available from gauges located at four locations: the Columbia River (Astoria), Yaquina Bay (Newport), Charleston (Coos Bay) and Port Orford. The long-term record from Crescent City, California, is also useful in analyses of tides on the southern Oregon coast. Tides along the Oregon coast are classified as moderate, with a maximum range of up to 4.3 m (14 ft) and an average range of about 1.8 m (6 ft) (Komar 1997). There are two highs and two lows each day, with successive highs (or lows) usually having markedly different levels (Figure 12). Tidal elevations are given in reference to the mean of the lower low water

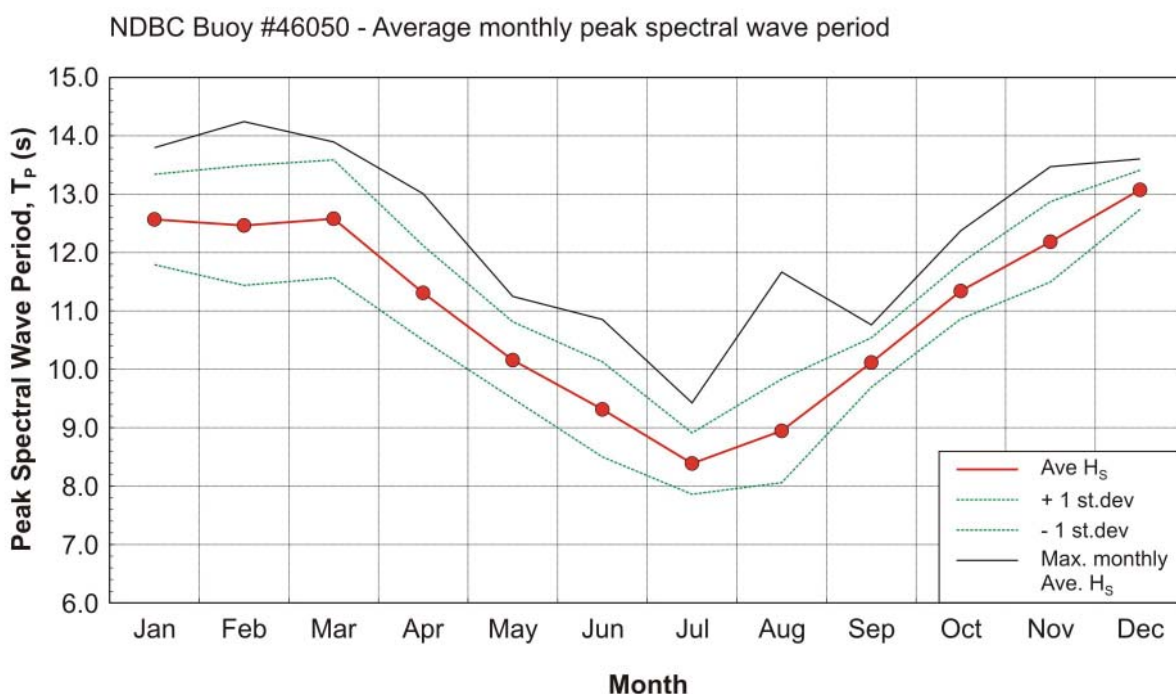


Figure 11. Monthly averages of the peak spectral wave period (1987 – 2001). The graph shows the average peak spectral wave period, the monthly average maximum peak spectral wave period, and the range (+/- 1 standard deviation) for each month.

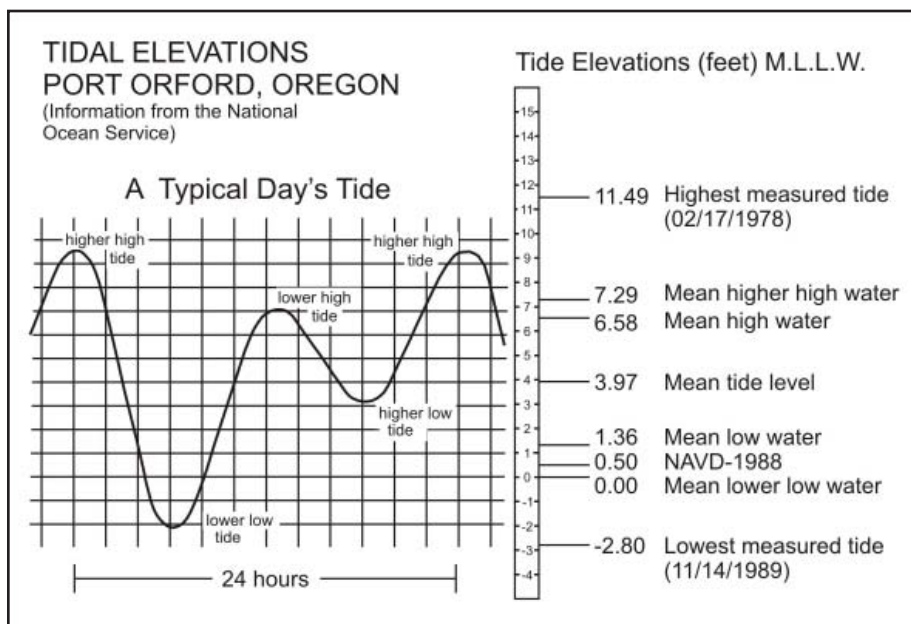


Figure 12. Daily tidal elevations measured in Port Orford on the southern Oregon coast. Data from the National Ocean Service <<http://www.co-ops.nos.noaa.gov/>>.

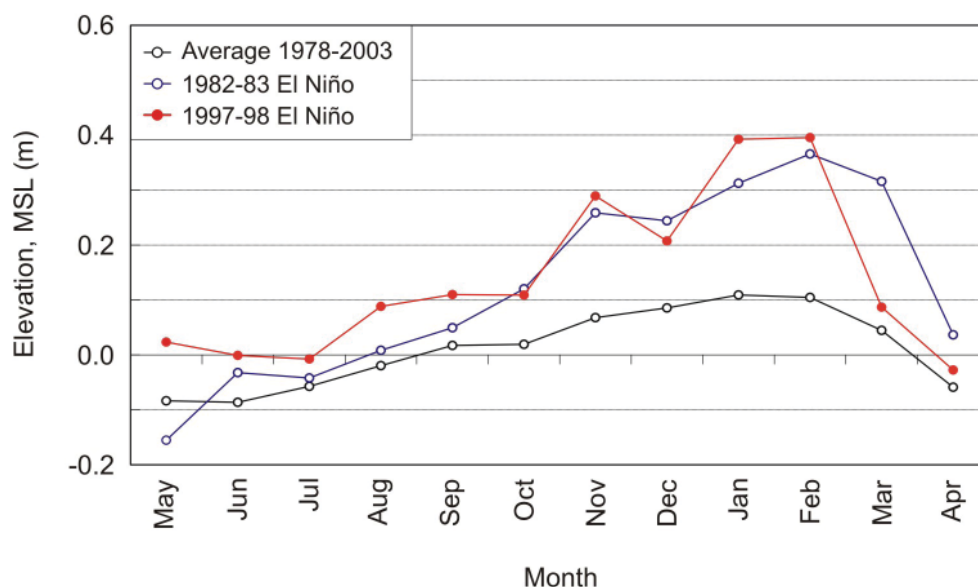
¹The difference in height between mean high water and mean low water.

²The difference in height between mean higher high water and mean lower low water.

levels (MLLW). As a result, most tidal elevations are positive numbers with only the most extreme lower lows having negative values. Figure 12 shows the daily tidal elevations derived from the Port Orford tide gauge (#9431647). Tides at Port Orford have a mean range¹ of 1.6 m (5.21 ft) and a diurnal range² of 2.2 m (7.28 ft). The highest tide measured at Port Orford reached 3.5 m (11.49 ft) and was recorded in February 1978 during the peak of the 1977-78 El Niño.

The actual level of the measured tide can be considerably higher than the predicted level provided in standard Tide

Figure 13. Mean monthly tides determined from the Port Orford tide gauge, Oregon expressed as a long-term average and as monthly averages for the 1982-82 and 1997-98 El Niños.



Tables, and is a function of a variety of atmospheric and oceanographic forces, which ultimately combine to raise the mean elevation of the sea. These latter processes also vary over a wide range of timescales, and may have quite different effects on the coastal environment. For example, strong onshore winds coupled with the extreme low atmospheric pressures associated with a major storm can cause the water surface to be raised along the shore as a storm surge. However, during the summer months these processes can be essentially ignored due to the absence of major storms systems. The El Niño climate phenomena may also super-elevate mean water levels for a period of a few months and are described below.

On the Oregon coast, tides tend to be enhanced during the winter months due to warmer water temperatures and the presence of northward flowing ocean currents that raise water levels along the shore. This effect can be seen in the monthly averaged water levels (Figure 13), derived from the Port Orford tide gauge, but where the averaging

process has removed the water-level variations of the tides, yielding a mean water level for the entire month. Based on 26 years of data, the results in Figure 13 show that on average monthly-mean water levels during the winter are nearly 20 cm (0.7 ft) higher than in the summer. Water levels are most extreme during El Niños, due to an intensification of the processes, and are largely due to enhanced ocean sea surface temperatures offshore from the Oregon coast. This occurred particularly during the unusually strong 1982-83 and 1997-98 El Niños; as seen in Figure 13, water levels during those climate events were approximately 40 to 50 cm (1.3 – 1.6 ft) higher in the winter than during the preceding summer. The importance of this is that all tides would be elevated by that amount, low tides as well as high tides, enabling wave swash processes to reach much higher elevations on the beach. The patterns shown in Figure 13 are consistent with the findings of Huyer and others (1983), Komar (1986) and Allan and Komar (2002) based on analyses of the Yaquina Bay (Newport) tide gauge.

4.0 METHODS – MORPHOLOGY SURVEYS AND WAVE RUNUP CALCULATIONS

A variety of techniques have been used to provide a documentation of the coastal geomorphology of the Elk River Spit, analyses of the waves and tides that affect its morphology, and the likely effects of rehabilitating the spit for the purposes of Snowy Plover habitat. These include:

- Creation of a beach profile monitoring network along the Elk River Spit;
- Analyses of 1998 and 2002 LIDAR beach topography data;
- Analyses of historical shoreline information;
- Analyses of the potential for wave runup and over-topping along the spit under a range of conditions.

One additional objective of this study was to undertake an evaluation of the general geomorphic features of Snowy Plover habitat by visiting the New River Spit, where active dune restoration is occurring by the Oregon Bureau of Land Management (BLM). In July 2003, a trip was scheduled to the New River dune res-

toration area. Unfortunately, however, we were unable to visit the BLM site so that this aspect of the study could not be completed.

4.1 Beach Profile Surveys

In July 2003, a beach profile network was established along the Elk River Spit (Figure 14A). The network consists of 6 profiles (cross-sections) that provide a measurement of the beach morphology. Beach surveys therefore provide a snapshot of the shape of the beach for that individual survey (e.g., height of the dune crest, beach slope, presence or absence of any erosion scarps, volume of sand, information on swash runup limits etc.). Subsequent re-surveys of the profiles will provide an insight into the spatial and temporal behavior of the beach as it responds to variations in waves and tides. In addition, the network will provide an important means to quantify the volume of sand that will need to be removed from the foredune, to lower the dune crest elevation as part of the spit rehabilitation work, and any subsequent maintenance requirements that will periodically need to be undertaken to maintain the dune crest at the desired elevation. For the purposes of this study a second re-survey of the profile sites was completed on 30 March 2004

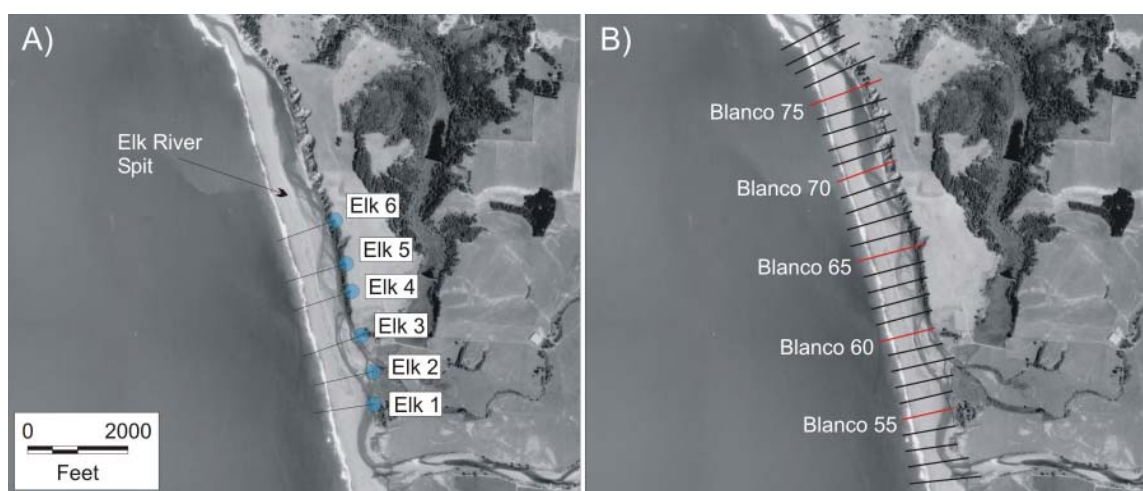


Figure 14. A) Locations of the Elk River beach monitoring network established in July 2003. B) Beach profiles established as a Geographical Information Systems (GIS) virtual database. These latter profiles have been used to assess shoreline changes in 1967-68 and in 2002.

and provides some measure of the response of the beach to the 2003-04 winter season.

Surveying the beach profiles was accomplished using a Sokkia “Set 500” Total Station theodolite. Each profile site has been referenced to a benchmark (i.e., a survey monument having a known location and elevation, serving as a reference point for subsequent surveys) installed either on the spit, or landward of the Elk River. The benchmarks consist of 5 foot long steel “T-bars” hammered into the dune, with their elevations established relative to the height of the tide at the time of the survey. However, due to uncertainty in the accuracy of this approach, it is recommended that precise elevations eventually be established for each of the benchmarks with the aide of a Global Positioning System (GPS). To minimize the risk of damage or loss of the benchmarks on the spit, secondary benchmarks were established along the bluffs landward of the Elk River. Profiles 1, 2 and 3 benchmarks are located east of the Elk River, while profiles 4, 5, and 6 have benchmarks on the spit and east of the river on the bluff. More detailed information regarding the locations of the profile sites is provided in Appendix A.

4.2 Light Detection and Ranging (LIDAR) Data

Additional information on the spatial and temporal variability of the Elk River beach and the volume of sand contained on the spit was undertaken from an analysis of 1998 and 2002 LIDAR topographic beach data measured by the U.S. Geological Survey (USGS) and NASA. LIDAR is a remote sensing approach consisting of x, y, and z values of land topography that are derived using a laser ranging system mounted on board a De Havilland Twin Otter aircraft. The LIDAR data were obtained from the National Oceanic and Atmospheric Administration’s (NOAA) Coastal Service Center (CSC) operated in tandem with the USGS and NASA. More detailed information on how the beach topography measurements are derived and processed are covered by Brock and others (2002). The LIDAR data have a vertical accuracy of approximately 0.1 m, while the horizontal accuracy of these measurements is about 1.4 m. All LIDAR data obtained from the

CSC are in the 1983 Oregon State Plane Coordinate system, while the elevations are relative to the North American Vertical Datum of 1988 (NAVD’ 88).

The LIDAR data were analyzed using a triangulation approach to generate a grid data set. This process was accomplished using VERTICAL MAPPER (contour modeling and display software), which operates seamlessly within MAPINFO’s Geographical Information System (GIS) software. Having generated a grid dataset, cross-sections of the beach morphology were constructed at 100 m intervals along the Elk River Spit (Figure 14B). The transects were then used to extract various beach and dune morphological features (e.g. erosion scarps, dune crest, beach slope etc.) for both the 1998 and 2002 LIDAR flights.

LIDAR was also used to derive a mean shoreline position along the Port Orford cell. Technically, the shoreline is the line of intersection defined by land, sea, and air and its position in space is a function of the interaction between wave and current processes, sea level variability, sediment supply, coastal geology and geomorphology and human intervention (Anders and Byrnes, 1991). Historical and contemporary information on the position of shorelines may be derived from a variety of sources including National Ocean Service (NOS) topographic “T” sheets, aerial photographs, GPS, or most recently LIDAR data (Moore, 2000; Zhang and others, 2002). T-sheets are detailed records of surveys that were undertaken to provide information on the location of shorelines for use on navigation charts issued by the NOS (formerly the U.S. Coast & Geodetic Survey). NOS surveyors used planetable-based ground surveys to derive a Mean High Water Line (MHWL) that was essentially based on the location of an everyday high tide rack line.

To identify the location of the shoreline from the LIDAR data, the data were first reduced to a tidal datum, in this case the Mean Lower Low Water (MLLW) tidal datum determined from the Port Orford tide gauge (Figure 8). To derive a tidal-based datum shoreline position, the elevation data was contoured and the mean higher high water (MHHW) contour

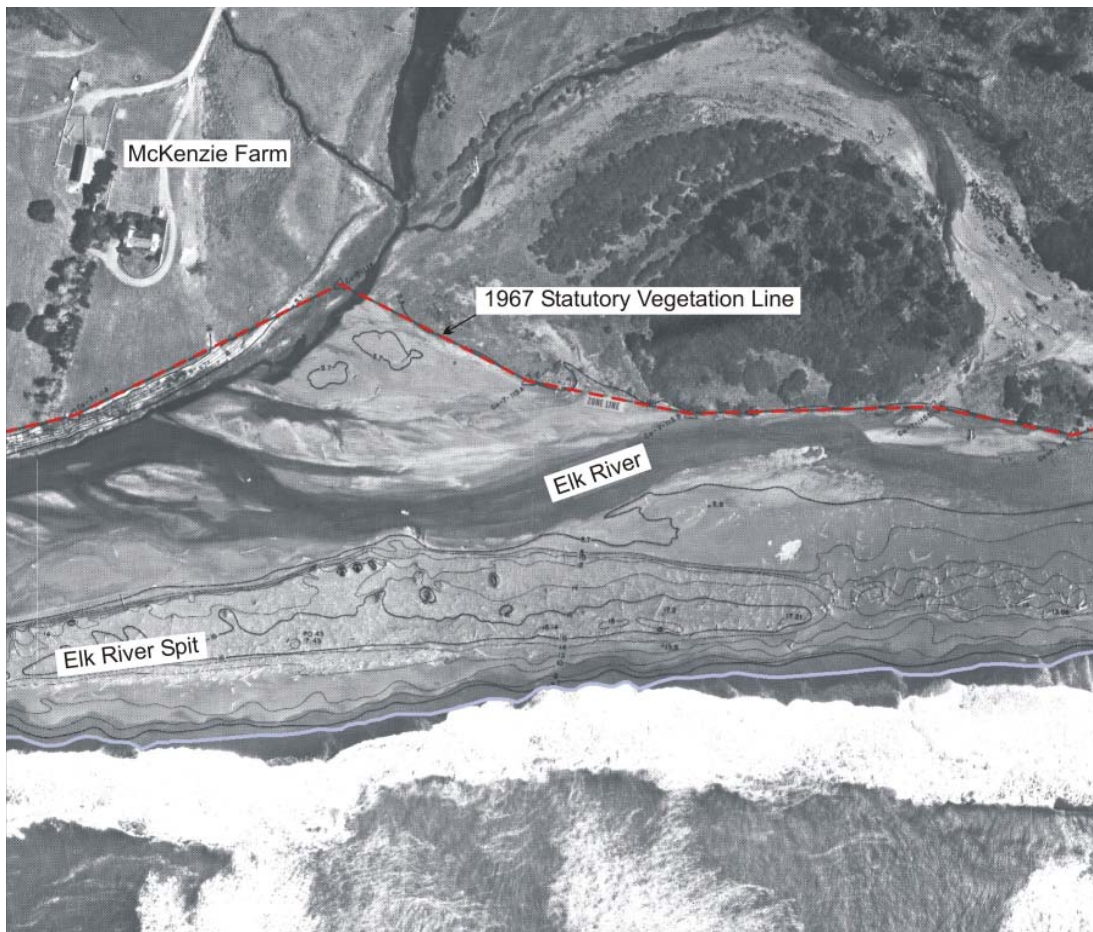
level located at an elevation of 2.22 m above MLLW was identified as a representative shoreline position for the Elk River Spit. This approach was accomplished for both the 1998 (post 1997-98 El Niño) and 2002 LIDAR flights. We have relied on the MHHW tidal-based shoreline, as opposed to a mean high water (MHW) shoreline position, since recent studies (e.g. Shoreline Change Conference, 2002; Ruggiero and others, 2003) indicate that the MHHW shoreline most closely approximates the high water line (or rack line) used by NOAA's early National Ocean Service (NOS) surveyors.

4.3 Aerial Photography and Historical Maps

Contemporary digital orthophoto quadrangles (DOQ) flown in 2000-01 along the Oregon coast were obtained from the Oregon Geospatial Enterprise Office <<http://www.gis.state.or.us/>>. The orthophotos provide the base information on which other data infor-

mation layers (e.g. historical shorelines, LIDAR data, and profile locations etc) have been overlaid using the MAPINO GIS software. Orthophotos flown by the USGS in 1994 were also used to assess the variability of the shoreline along the Elk River Spit.

Historical shoreline information has been derived from a 1928 NOS "T-Sheet" that was surveyed along the Port Orford cell. Additional beach and shoreline information was also derived from both land-based and aerial surveys of the Elk River Spit in 1967 by the Oregon State Highway Department (now ODOT) to establish the State's "statutory vegetation line", the beach-zone boundary that is used to differentiate between upland properties and the state-owned or regulated beach (Figure 15). As surveyed in 1967, the statutory vegetation line generally corresponded with the line of vegetation where dunes back beaches, or extended along the toe of coastal bluffs (Komar and others, 2001).



In the absence of GPS ground control points, rectification of the 1967 images was accomplished using MAPINFO's photo registration module, which allows aerial photos to be "rubber-sheeted" to a particular coordinate system based on identified map control points (MCP's, e.g., buildings, road junctions, and water tanks). The MCP data are used by the GIS software to calculate the transformations necessary to change a map's projection and scale. For the purposes of this study, the 1967 aerials were registered using the statutory vegetation line survey control points established by the Oregon State Highway Department surveyors (described in ORS 390.770) in 1967. Having registered the aerials, it is then possible to interpolate the morphology of the spit based on the 2 ft contours delineated on the aerial photographs. The accuracy of registering the 1967 aerial photographs was determined from comparing various features on the registered images with similar features that could be identified on the 2000-01 digital orthophotos. This process revealed that the 1967 aerials typically landed to within approximately 8 m (26.2 ft) of similar features on the more recent 2000-01 photographs.

4.4 Wave Runup and Over-Topping Estimates

Along the Pacific Northwest coast of Oregon, it is well recognized that for dune erosion to occur on sandy beaches, the total water level (T_{WL}) produced by the combined effect of wave runup (R) plus the tidal elevation (E_t), must exceed the elevation of the beach-dune junction (E_j) (Shih and Komar, 1994; Komar and others, 1999; Sallenger 2000). Similarly, the occurrence of spit over-topping is controlled in part by the height of the foredune or the barrier berm and the off-shore wave climate generated by the passage of a major storm. This basic concept is depicted in Figure 16. In its simplest form, the more extreme the total water level elevation, the greater the resulting erosion that occurs along both dunes and bluffs. As the total water levels reaches and begins to exceed the foredune crest, overwash occurs, which may further help to erode the beach and the foredune. This approach may therefore be used at the Elk River Spit to determine a suitable elevation in which to lower the foredune. However,

instead of estimating the amount of erosion that might occur in response to high water levels, the distribution and spatial and temporal variability of the calculated total water levels can be related to the existing beach morphology to determine the ideal foredune elevation that would allow for occasional over-topping, without destabilizing the spit.

In a sense the conceptual model portrayed in Figure 16 is akin to the storm impact scale developed by Sallenger (2000), which couples the forcing processes associated with a major storm and the geomorphological characteristics of the coast, and has been used to measure the likely impact of tropical and extra-tropical storms along the barrier islands of the U.S. East Coast. The model defines four regimes based on variations in the upper and lower limits of the total water levels produced during a storm (R_{HIGH} and R_{LOW}) relative to the dune crest elevation (D_{HIGH}) and the beach-dune junction (termed D_{LOW} by Sallenger). Based on the ratios of these variables, Sallenger (2000) identified four regimes, which were respectively termed swash, collision, overwash and inundation. During storms, the beaches of Oregon typically fall under the collision regime, which reflects conditions when the wave runup collides directly with the base of the dune forcing dune erosion (i.e., upper diagram in Figure 16). However, at some locations including portions of the Elk River Spit, these same conditions may result in R_{HIGH} exceeding D_{HIGH} (i.e., the dune or berm crest) producing overwash (lower diagram in Figure 16). Along the U.S. East Coast, overwash of the barrier islands has often resulted in the landward migration of the barrier. While such effects could occur briefly on the Elk River Spit, the landward movement of the spit is counteracted by the effects of the Elk River, which erodes the barrier spit along its landward edge, limiting its eastward movement, and eventually returning the eroded sediments to the ocean via the rivers mouth.

Measurements of wave runup along the Oregon Coast under a range of wave conditions and beach slopes (Ruggiero and others, 1996; Ruggiero and others,

2001) have yielded the following relationship

$$R_{2\%} = 0.27 (S H_{so} L_o)^{1/2} \quad (1)$$

for estimating the 2% exceedence runup (R) elevation, where S is the beach slope ($\tan \beta$), H_{so} is the deep-water significant wave height, L_o is the deep-water wave length given by $L_o = (g/2\pi)T^2$ where T is the wave period, and g is acceleration due to gravity (9.81 m/s^2). Therefore, estimates of the wave runup elevations depend on an availability of data for the wave heights and periods, and surveys of the beach profile.

To calculate the total water levels (T_{WL}) for the Elk River Spit, all hourly wave data (derived from the Newport buoy for the period July 1987 to March 2003) and tide statistics (Port Orford) were compiled in a spreadsheet. The data were eventually analyzed

in MATLAB to yield a frequency distribution of all hourly total water levels. Additional analyses included:

- Assessing the calculated total water levels for just the winter months (October to March);
- Assessing the monthly and seasonal variability of the calculated total water levels; and,
- Using standard techniques of extreme value analyses to determine the 10- through 100-year extreme total water levels. The extreme value analysis was undertaken using the Coastal Engineering Design & Analysis System (CEDAS) software developed by the U.S. Army Corps of Engineers.

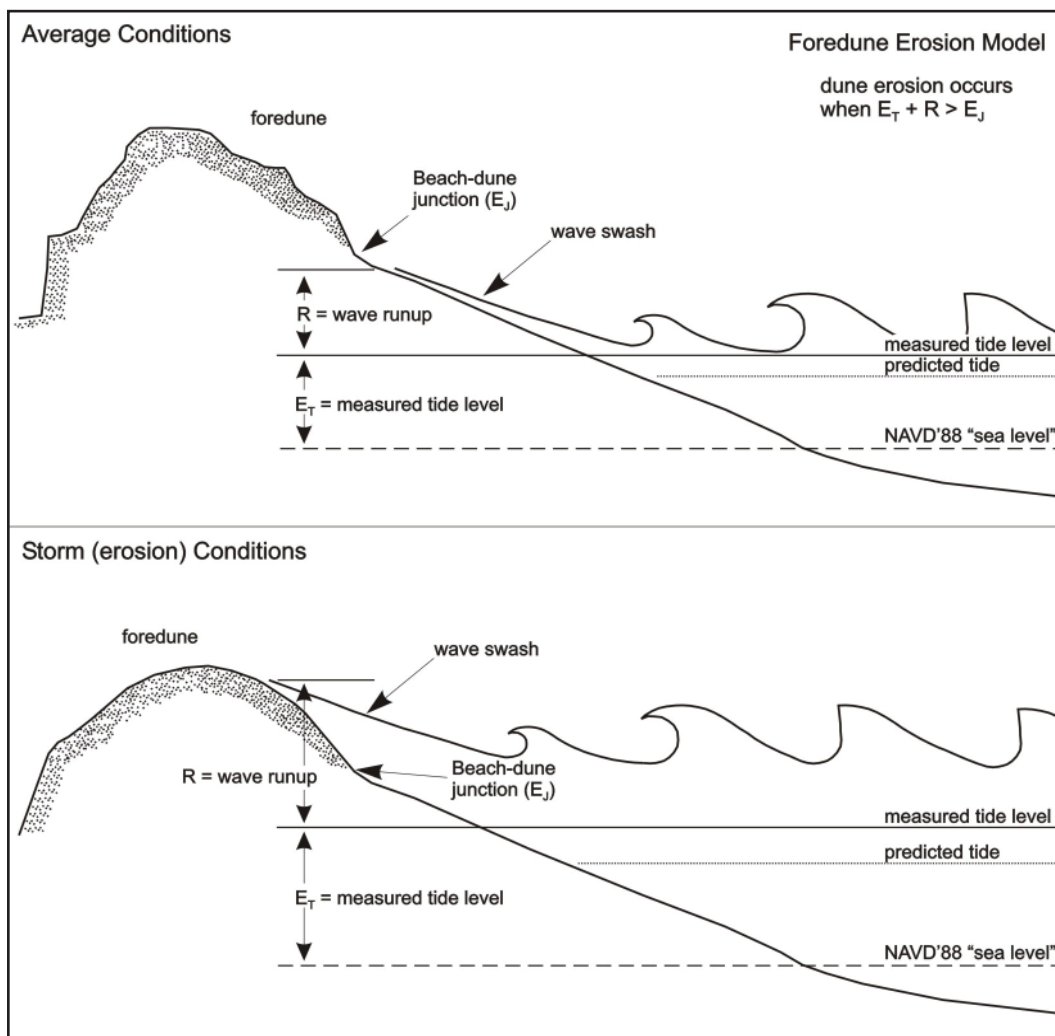


Figure 16. (Upper) The top figure shows a foredune exposed to typical wave runup (R) and tidal (E_T) conditions, which may result in erosion of the foredune toe (E_j). **(Lower)** During large storms and elevated water levels, wave runup is able to reach much higher elevations on the backshore ($> E_j$) eroding the foredune. Furthermore, waves may also occasionally overtop the foredune lowering the dune (After Komar and others, 1999).

5.0 RESULTS

5.1 Introduction

The ideal habitat recognized for the Western Snowy Plover consists of sandy beaches characterized by large areas of bare sand (i.e., devoid of dune grass) that may be adjacent to the high-tide flotsam line. These conditions are considered to be ideal since the birds are able to forage close to their nests, while the exposed sandy beach enhances the Plovers chances when responding to predators. Such an environment may be maintained naturally by allowing the dune to be periodically over-topped during storms, which helps to reduce the vertical aggradation of the dune and the return of the European beach grass now prevalent along much of the Oregon coast.

In order to facilitate such conditions along the Elk River Spit, analyses have been undertaken related to evaluations of the spit morphology, the long-term physiographic changes of the spit, and the erosion processes (i.e., wave runup and tides) that influence the contemporary beach and dune morphology. In particular, analyses of the historic 1967 aerial photographs are especially pertinent since these photos contain useful information on the morphology of the beach in the form of 2 ft contours (Figure 16), while also providing an insight into the morphology of the dune prior to the expansion of European beach grass. For example, Figure 16 (including similar images to the north) indicates that the foredune in 1967 had an elevation that was no more than 5.5 m high (18 ft) and had been affected by recent high wave runup events that had led to the foredune being over-topped at a number of locations. Evidence for this included the presence of washover sediment lobes and flotsam along the dune crest and on the landward side of the spit (Figure 16). This suggests at the outset that lowering the dune to around 5 – 6 m (16.4 – 19.7 ft) will likely produce the desired occurrence of spit over-topping without degrading its stability. However, verification of this process can only be accomplished after having undertaken a detailed analysis of all available information, particularly the temporal incidence of wave runup

and over-topping of the spit. As indicated in the bottom diagram of Figure 16, of particular interest is the amount of time in which the total water levels produced by the combined effect of a high tide (elevation E_T) plus the wave runup (R), exceeds the crest of the existing foredune or berm crest resulting in overwash. Critical to this approach is therefore determining how often the Elk River Spit will be overtopped at various contour elevations. It is only after having undertaken these evaluations that a lower “designed” foredune crest (constructed D_{HIGH}) can be recommended.

5.2 Historic and Contemporary Spit Morphologic Changes

The Elk River Spit is located midway along the Port Orford Cell and is approximately 2.8 km (1.74 miles) in length. The spit is bounded on its eastern side by a prominent line of bluffs, which increase in height from several meters in the south to over 70 m (230 ft) high in the north adjacent to the river mouth (Figure 17). Erosion of the coastal bluffs that back the river is clearly evident at the spits northern end, which is likely the product of the spit having migrated northward causing the river to butt up against the bluffs eroding their toe. Although the mouth of the river occurs at the spits northern end, the spit may occasionally be breached near its base in the south (Figure 3). The most recent high magnitude event that contributed to spit breaching occurred in 1996 (Scott McKenzie 2003 pers comm.). However, this latter process is temporary so that the mouth closes rapidly with the river returning to its normal pattern of draining in the north. Such processes are not uncommon on the Oregon coast having also been observed on the New River Spit to the north, an area frequented by the Western Snowy Plover (Komar and others, 2001). The Elk River Spit is also periodically over-washed at its base and tip by ocean waves, carrying with it sand and flotsam over the dune and into the river channel.

Unlike much of the central to northern Oregon coast, the Port Orford cell is comprised of mixed sand and

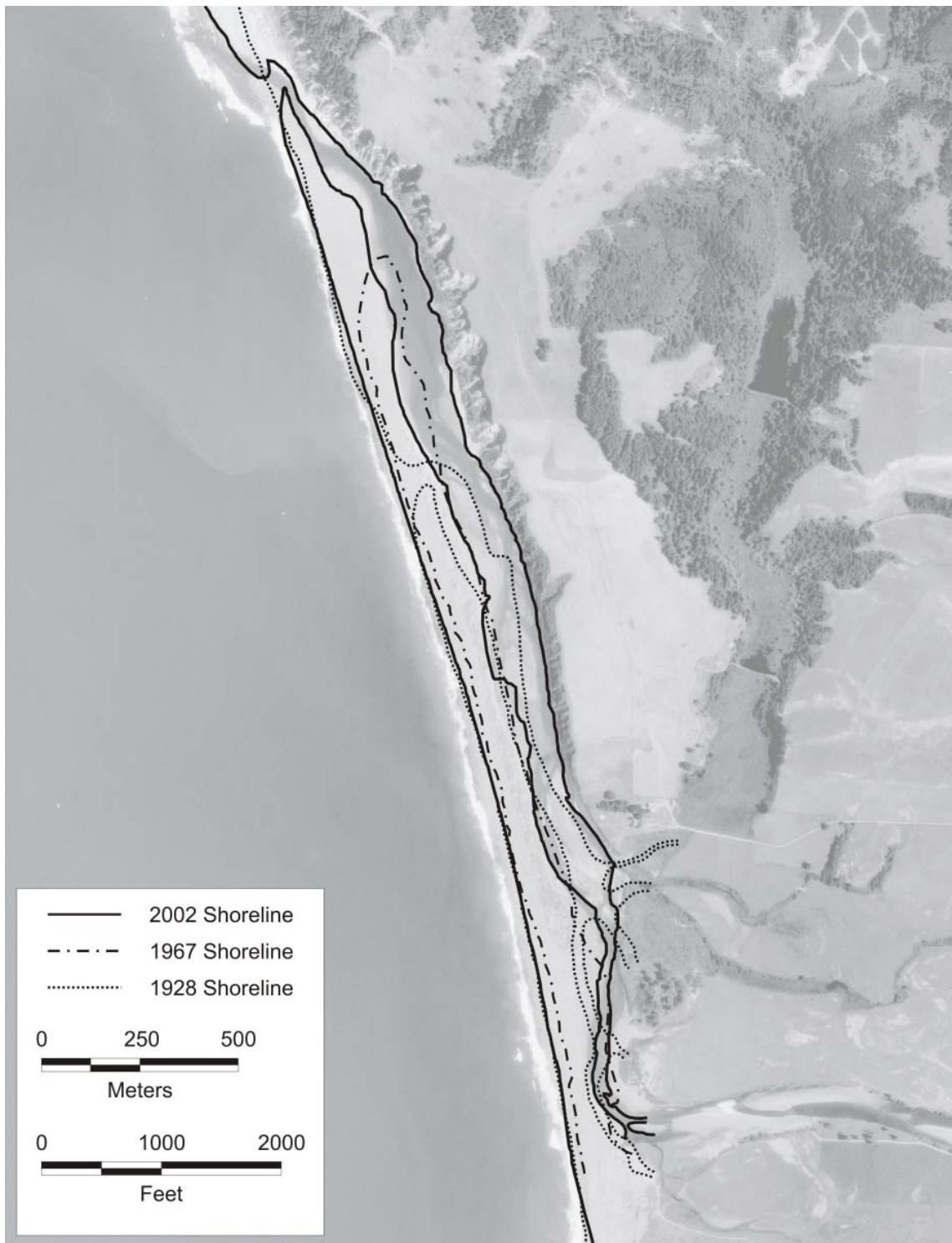


Figure 17. Locations of the mouth of the Elk River Spit as it migrated to the north.

gravel that results in steep beaches and narrow surf zones, which contributes to a highly dynamic coastal system (Allan and others, 2003). The beach along the Elk River Spit is no different in this regard consisting of coarse sand, which results in a steep (typical slopes

of 4° (1-on-14) to 7.1° (1-on-8)), intermediate to reflective beach using the classification of Wright and Short (1983). While the sand is typically coarse, there is a noticeable change in the grain-size with progress toward the north. Although we did not undertake

sediment sampling as part of this study to verify this pattern, it was noticeable from our reconnaissance visit to the spit in July 2003 and again in March 2004. Furthermore, our field observations are supported by grain-size analyses undertaken by Peterson and others (1994) along the Port Orford Littoral cell. Thus the mean grain-size adjacent to the mouth of the river is noticeably finer when compared with the sand near the base of the spit and further south near Garrison Lake. As a result, it was apparent that the beach adjacent to the river mouth has a tendency to be intermediate to dissipative, while the beach further south is intermediate to reflective.

Since the late 1920's, the Elk River Spit has been vertically aggrading as well as growing (prograding) toward the north. A plot of the time history of shoreline changes on the spit is presented in Figure 17 for 1928, 1967 and 2002, while the results of the changes are summarized in Table 2. Apparent from Table 2 is that the mouth of the river has steadily migrated toward the north, averaging about 14.5 m/year (47.6 ft/year) since 1928. However, as noted by Komar et al. (2001), this type of analysis presents a somewhat simplistic picture of how the spit has changed over time since the growth is more likely to be episodic as the beaches respond to extreme storms, major El Niño events, or variations in long-term climate cycles such as the Pacific Decadal Oscillation (PDO) that strongly influence the net movement of sediments along the beach. One important effect of the river mouth having migrated northward is that the river channel is now pushed up against the high bluffs. This has resulted in the toe of the bluff being undermined and eroded,

while also periodically allowing waves to break close to the river mouth due to the deeper water around the channel, further exacerbating the erosion of the bluff toe.

As a result of its northward migration, the region around the spit tip is younger compared with the more southerly portions. Thus, the south-central portion of the spit has been able to aggrade vertically (Figure 18, upper), to form a high, prominent dune system (Figure 19), effectively preventing overwash during storms. In part, this has been aided by the expansion of European beach grass (*Ammophila arenaria*) along the spit, which has helped to trap sand transported by waves and especially wind, decreasing the natural movement of sand along the littoral cell. In contrast, the northern 914 m (3,000 ft) of the spit is characterized by low, hummocky dunes, separated by zones where ocean waves actively washover the lower elevations of the spit tip (Figure 18, lower).

The vertical accretion of the spit is documented by surveys of the beach and foredune in Figure 19, which shows the crest elevation of the dune in 2002 and in 1967 and are relative to the North American Vertical Datum of 1988 (NAVD88). Apparent from the figure is that the dune crest has increased by about 1 – 5 m (3 – 16 ft) along much of the spit. Figure 19 also shows the area where the river periodically breaches the dune during floods in an area where the dune elevation is around 5.5 m (18 ft).

Included in Figure 19 is the spatial distribution of the beach/dune junction (E_j) elevation along the littoral

Table 2. Summary of change in spit length on the Elk River Spit since 1928. Distances are measured from the bend in the river in the south and the spit tip in the north.

<i>Year</i>	<i>Interval (years)</i>	<i>Spit length m (ft)</i>	<i>Net Change m (ft)</i>	<i>Average change rate m/year (ft/year)</i>
1928	0	1790.1 (5873.0)	-	-
1967	39	2308.1 (7572.5)	518.2 (1700.0)	13.3 (43.6)
2002	35	2860.2 (9383.7)	552.0 (1811.1)	15.8 (51.8)



Figure 18. (Upper) View looking toward the south-central portion of the Elk River Spit highlighting the well-developed foredune covered with European beach grass, and the section of spit that is periodically breached by the river during flood events. (Lower) The northern 3,000 ft of the spit tip that is characterized by low (< 5.0 m (16 ft) elevation) hummocky dunes and subject to wave overwash.

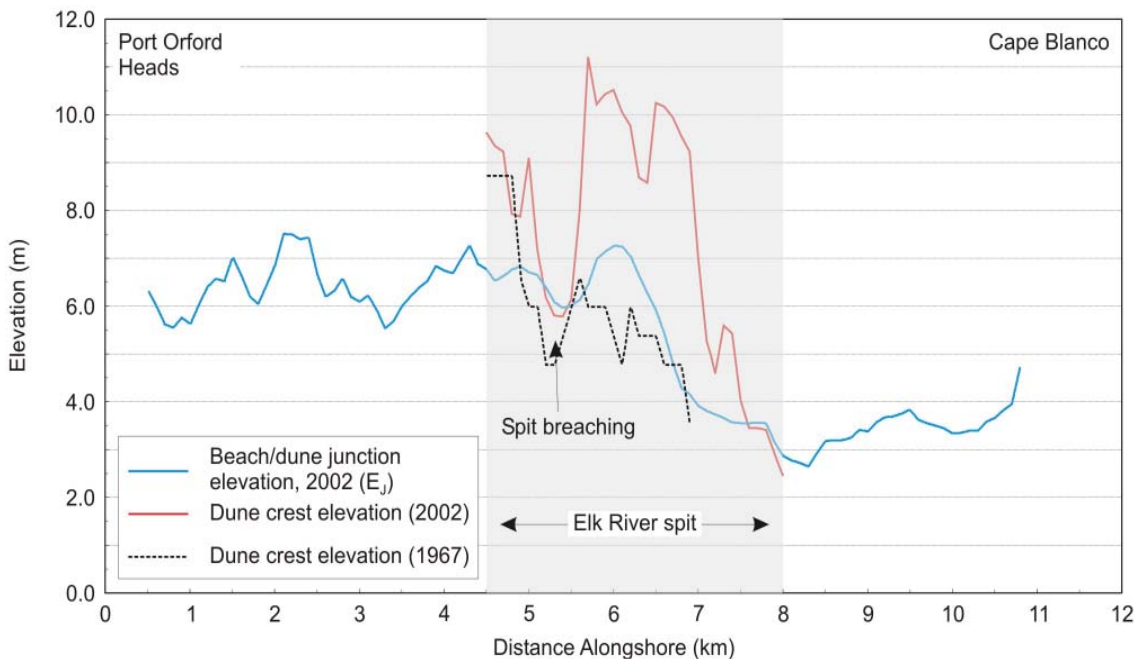


Figure 19. Changes in the dune crest elevation along the Elk River Spit since 1967, and the contemporary beach/dune junction elevation as at 2002. Note that the vertical elevation is relative to the NAVD88.

cell. Recall that the beach/dune junction is a reference point on the beach that is formed by the erosion of the dune in response to wave swash processes. As a result, these data provide a physical measurement of how high waves may reach on the beach face. According to Figure 19, the southern half of the Port Orford cell is characterized by E_j elevations that range from 5.5 to 7.5 m NAVD88 (18 – 24.6 ft), while the northern half of the cell is characterized by much lower elevations (2.5 to 4.5 m (8.2 – 14.8 ft)). A reconnaissance visit to the site in March 2004 revealed significant amounts of flotsam on the landward side of the spit, adjacent to where the river periodically breaches the dune (at ~5 – 5.5 km in Figure 19), indicating that this section of the spit is prone to over-topping during high-energy wave events. According to Mr. Scott McKenzie (2004 pers comm.), the spit adjacent to Elk 1 was over-topped on a number of occasions during the 2003-04 winter season. This suggests that lowering the dune to an elevation of 5 – 7 m (16.5 – 23 ft) would guarantee some over-topping of the spit during at least high-energy wave events. Thus, the estimates of wave runup provided by the E_j elevations are consistent with the observations of Mr. Mckenzie. The lower E_j elevations in the north are puzzling, as they suggest that the dunes and bluffs north of the Elk River mouth would be under constant wave attack and therefore subject to significant rates of erosion. One possible explanation for this pattern is that the lower E_j 's is probably due to a change in the mean grain-size along the beach. Finer grained sand leads to more dissipative beaches, which more efficiently reduce the swash elevation. As noted earlier, our reconnaissance trip to the Elk River revealed a gradual decrease in the mean grain-size from profile Elk 5 north, resulting in the formation of wide, gently sloping beaches with lower beach crest elevations. In addition, these changes are also similar to observations by Komar and others (2001) for the New River Spit, indicating a preferential sorting of the mean grain-size with northward progress along the spit.

Figures 20 and 21 show the results of the 2003-04 beach surveying along the spit. The highest point on the dune is 11.7 m NAVD88 (38.4 ft) and is adjacent

to Elk 2 (Figure 14), near the south-central portion of the spit, with the elevations progressively decreasing toward the north.

As noted previously, south of Elk 1, the crest of the beach varies from 5 – 7 m (16.5 – 23 ft) and is due to the river having periodically breached the spit during floods (Figure 18, 19). The profiles also demonstrate little overall change in the morphology of the dune over the 2003-04 winter, with the most significant changes occurring below about 6 m (19.7 ft). Of interest, apart from Elk 6 in the north, the bulk of the beach prograded (advanced) seaward over the winter. This is somewhat surprising since Oregon's beaches typically erode during the winter in response to the increase in wave energy and then rebuild in the summer months as the wave energy decreases. However, as noted previously, the position of the spit approximately midway along the cell likely helps to minimize the erosion as sand is in a constant state of flux along this section of shore (i.e., moving in both directions). Furthermore, these changes may also be caused by the presence of rip embayments, which produces scouring of the beach face in one location, while the adjacent beach bounding the rip embayment may aggrade.

Needed for calculating the wave runup along the spit is a measure of the beach slopes. The slope of the beach was determined by fitting a linear regression through the survey data, and covers the beach face from the beach-dune junction (E_j) or berm crest seaward to the limit of the survey. These data are provided in Figures 20 and 21 and will be used in the calculation of the wave runup using equation 1. In general, the beach is steepest in the south at Elk 1 ($S = 0.125$ or 7.12°) and progressively decreases to the north, with the lowest slope identified at Elk 6 ($S = 0.063$ or 3.60°). This progressive decrease in the beach slope is consistent with the March 2004 reconnaissance observations, which revealed that the mean grain-size appears to decrease to the north, since the slope of a beach and grain-size are strongly related (Shepard, 1973; Komar, 1998).

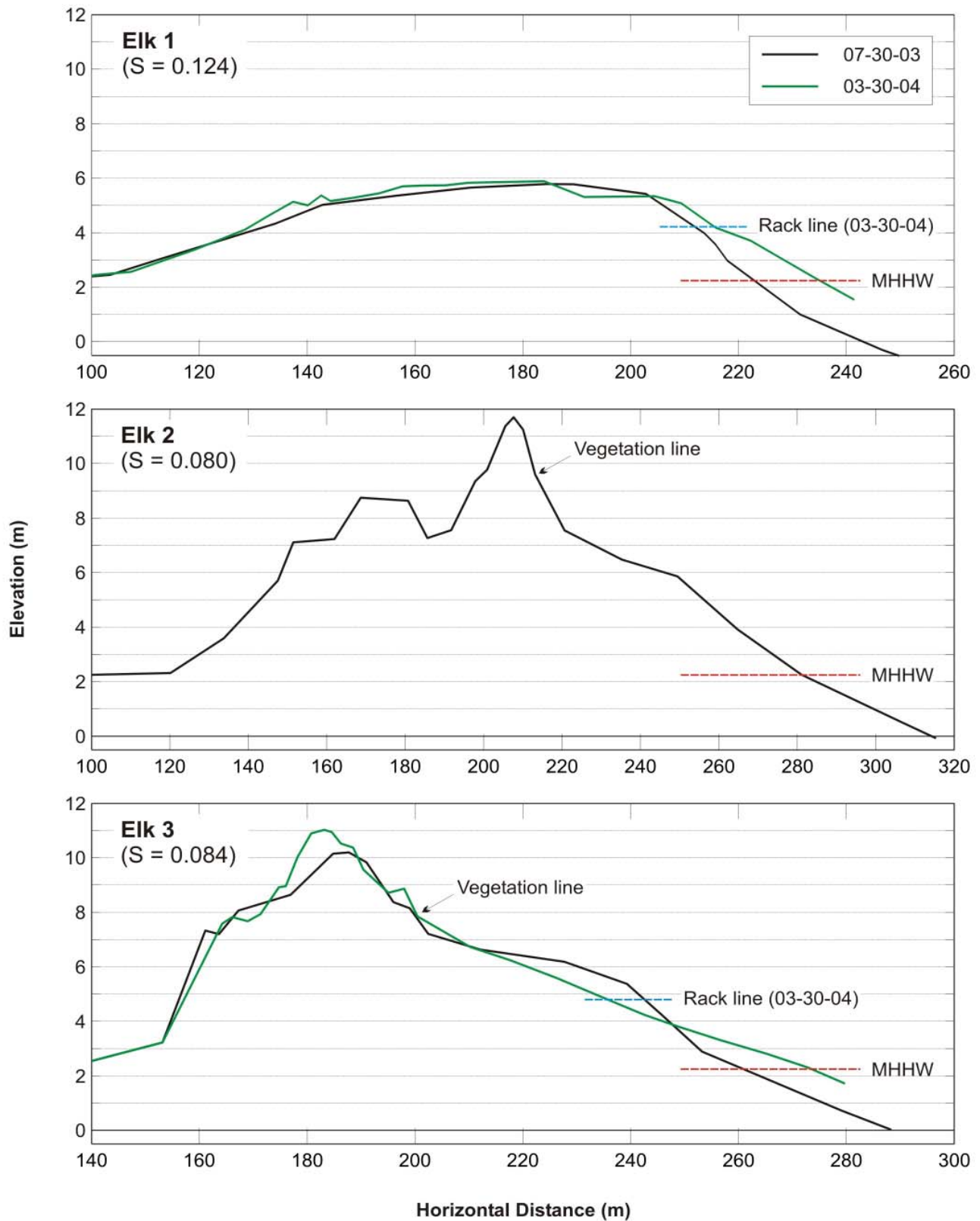


Figure 20. Results of the beach profile surveying along the Elk River Spit (Elk 1 to 3). S is the tangent of the beach slope angle. Note: the March 2004 survey data is unavailable for Elk 2 due to a problem with the survey data.

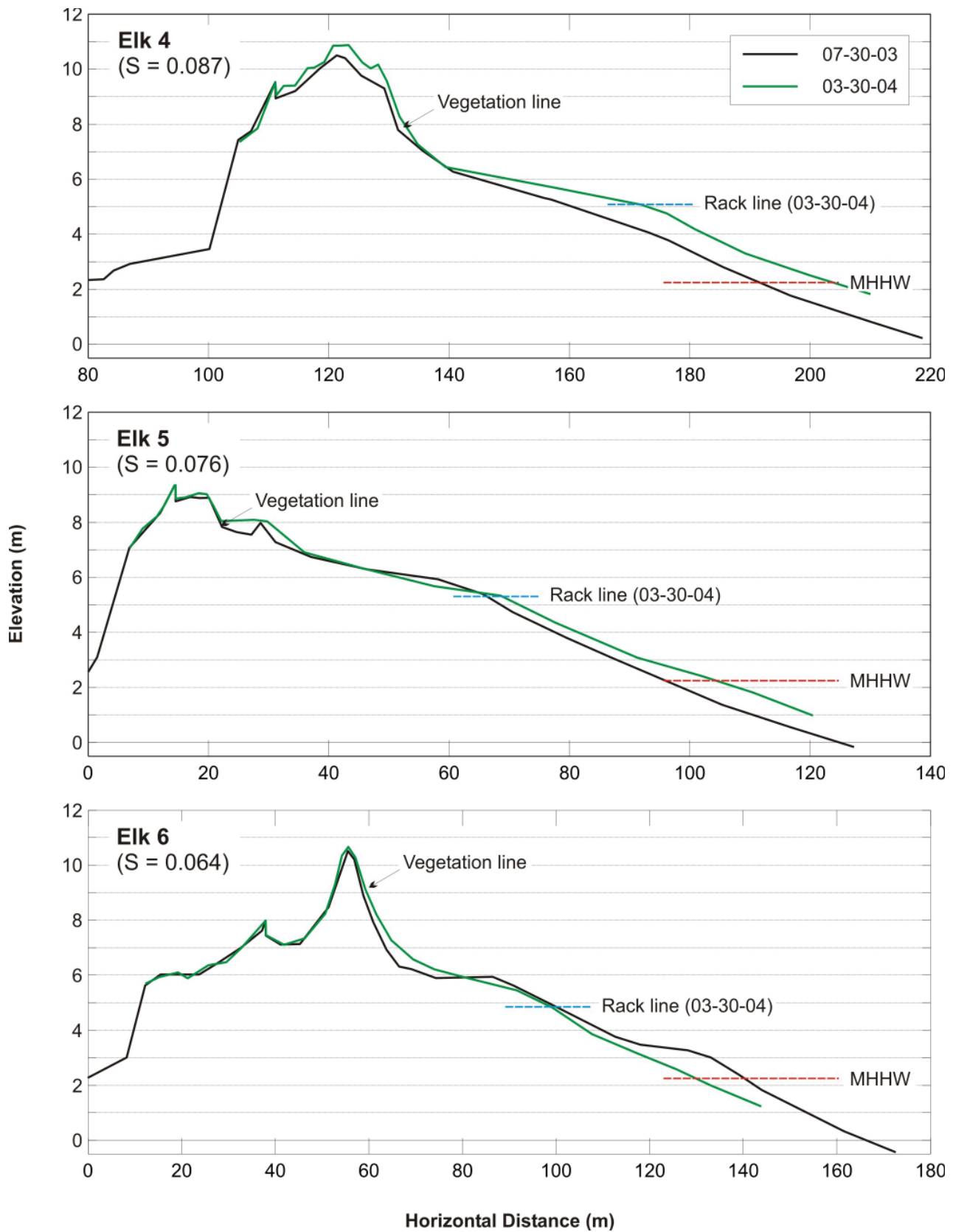


Figure 21. Results of the beach profile surveying along the Elk River Spit (Elk 4 to 6). S is the tangent of the beach slope angle.

5.3 Wave Runup Calculations

The analyses of the coastal geomorphology along the Elk River Spit suggest that during major storms the swash of the waves is capable of reaching elevations in excess of several meters, causing the dune to be overtopped along its southern and northern extremities. The purpose of this section is to provide a more rigorous assessment of the total water levels (wave runup plus tidal elevations), to better define how high the dune can be and still experience enough overwash to maintain good plover habitat. Initial efforts focused on modeling the 10 through 100-year extreme total water levels for the Elk River Spit. However, the analyses revealed that the spit could experience total water levels of around 7 m (23 ft) annually, while the 100-year total water level is estimated to reach 9.5 m NAVD88 (31.2 ft). As a result, this type of analysis does not necessarily assist in defining a dune elevation that would allow for more frequent over-topping (i.e., some percentage of time per month).

The approach taken was to model all hourly total water levels (calculated wave runup using equation 1 plus the tidal elevation), and to focus primarily on the results for the winter months (i.e., October through March). These data span the period from July 1987 to March 2003. The decision to use data from the winter months was based on the fact that during the summer the total water levels tend to be much lower so that opportunities for over-topping of the spit would be accordingly less. Analysis of the total water levels was calculated using Equation 1 and was undertaken in MATLAB. The data were then binned at 0.1 m (0.3 ft) intervals to develop a frequency distribution plot of the binned total water levels. The results of this step are presented in Figure 22 and are based on two different beach slopes ($S = 0.084$ and 0.125), representing the average and maximum beach slopes derived from the beach surveying. Figure 22 also contains a cumulative frequency plot of the modeled total water levels.

Figure 22 reveals that the calculated total water levels (T_{WL}) reached a maximum elevation of 8.8 m NAVD88 (28.9 ft) based on all the available wave

data and for a beach slope of $S = 0.084$ (average beach slope for the spit), while the steeper beaches ($S = 0.125$) produced a maximum T_{WL} of 10.0 m (32.8 ft). These estimates of the total water levels are consistent with observations of wave runup on beaches with similar slopes at Cape Lookout State Park on the northern Oregon coast (Allan and others, in press, Allan and Komar, 2004). The median T_{WL} calculated for the Elk River Spit ranges from 3.4 to 3.8 m NAVD88 (11.2 – 12.5 ft). According to Figure 22, for 25 percent of the time the total water levels exceeded an elevation of 4.1 m (13.5 ft), and for 10 percent of the time they exceed an elevation of 4.8 m NAVD88 (15.7 ft). For 5 percent of the time, the TWL exceeds an elevation of 5.2 m (17.1 ft). Based on these data, lowering the dune to an elevation of ~4.5 m (14.8 ft) would likely result in the spit being overtopped about 15 – 25 percent of the time (i.e. about 500 – 900 hours per winter season). While the effect of such action cannot be properly assessed here (i.e., it would require sophisticated numerical modeling), it is probable that it would result in the spit becoming unstable. Conversely, lowering the dune to 5.5 m (18 ft) would cause the spit to be overtopped about 4 – 8 percent of the time (i.e., about 140 – 280 hours per winter season), which is less likely to result in the spit becoming unstable, particularly given that this is analogous to the historical dune crest elevation in 1967.

Additional analyses have been undertaken to assess the variability of the monthly total water levels for the Elk River Spit based on a dune crest of 5.5 m (18 ft). These data are presented in Figure 23 and are based on the average beach slope determined for the spit (i.e., $S = 0.084$). Similar analyses were also undertaken based on the steeper beach slope of $S = 0.125$. The results of the analysis are summarized in Table 3. As expected, the winter months produce the greatest number of hours (expressed as percentages) in which the total water levels exceed a dune crest of 5.5 m (18 ft), while the occurrence of similar conditions during the summer is rare (Figure 23, Table 3). Total water levels exceeding 5.5 m (18 ft) is most frequent in December and to a lesser extent in January, coincident with the period when the highest waves are produced (i.e.,

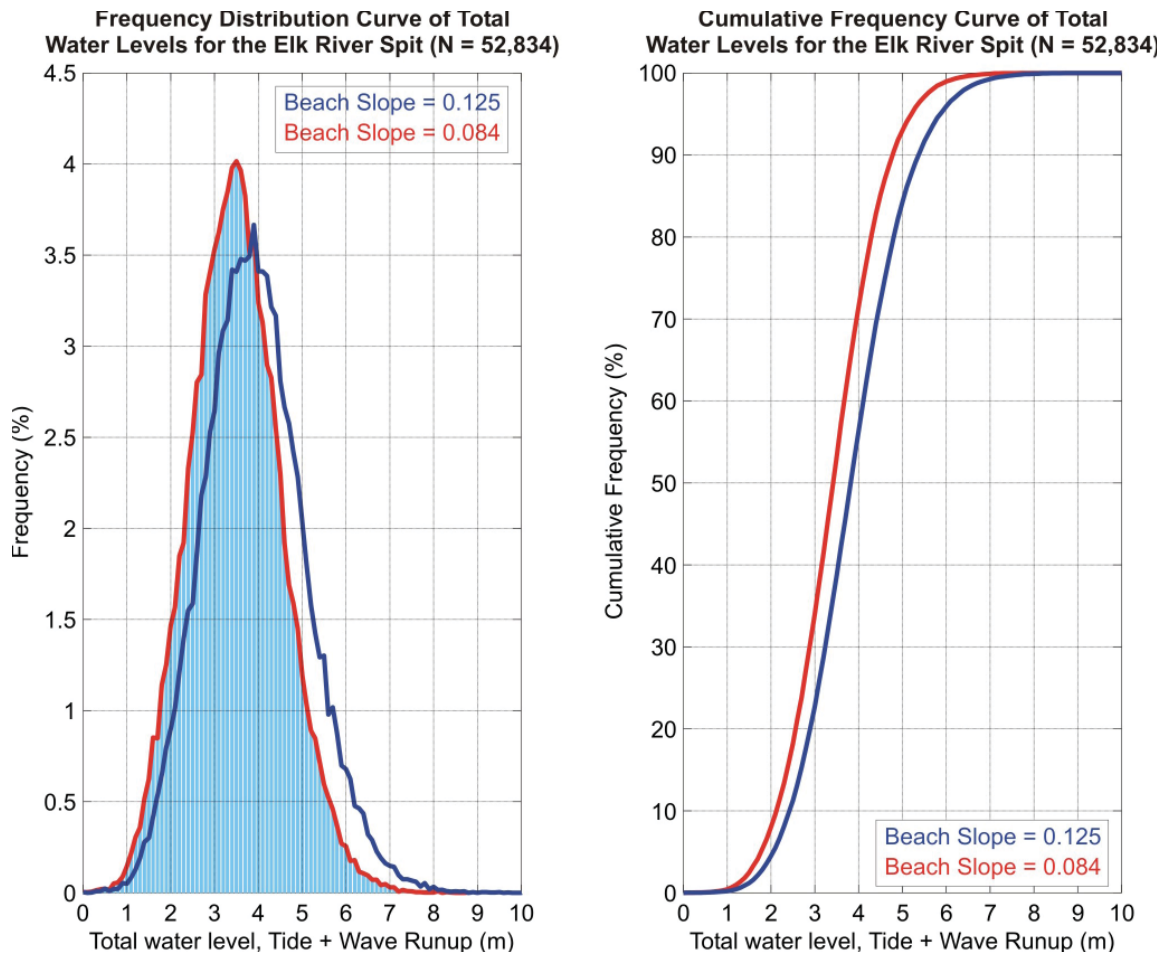


Figure 22. Calculated winter total water levels for the Elk River Spit based on an average ($S = 0.084$) and steep ($S = 0.125$) beach slope expressed as a frequency distribution and a cumulative frequency curve. Note: Data span the period from July 1987 to March 2003.

the peak of the winter) along the Oregon coast. The analyses presented in Table 3 also indicate that during a typical winter, T_{WL} exceeding 5.5 m (18 ft) is likely to occur over a period of about 111 hours, based on an average beach slope of $S = 0.084$, and for about 315 hours on steeper beaches present along the spit.

The monthly total water level results presented in Table 3 are also important for evaluating their likely impact on the Western Snowy Plover during the nesting season (i.e., assuming the dune is lowered to 5.5 m). Plovers typically begin nesting during late winter and early Autumn (i.e., between March and September) with most nesting activity occurring in June (Castelein and others 2000). Table 3 indicates that total water levels exceeding 5.5 m (18 ft) are essential-

ly negligible during the spring and summer, while the incidence of total water levels exceeding 5.5 m during March (i.e., late winter) is low, ranging from 2.3 to 7.6 percent of the time. In this regard, it can be concluded that lowering the spit to 5.5 m should not adversely influence Plover nesting, since the incidence of high total water levels during the critical nesting period is extremely low.

The above analyses suggest that lowering the dune to an elevation of 5.5 m (18 ft) will result in periodic (~100 to 300 hours) over-topping of the spit during a typical winter. Lower elevations would produce more frequent over-topping, but the effects of the increased frequency of over-topping on the stability of the spit are uncertain. Given that the mean elevation of the

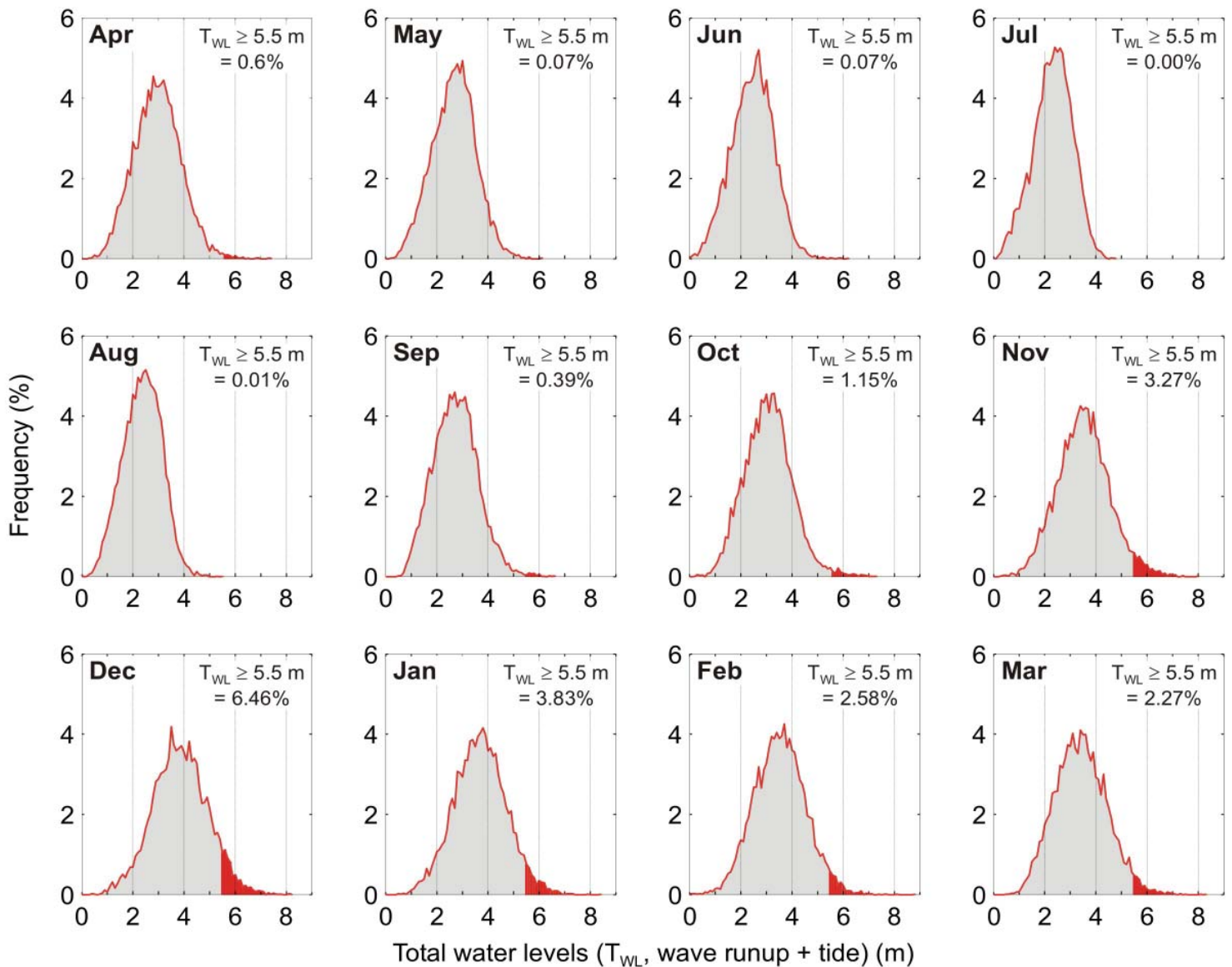


Figure 23. Variability in the monthly total water levels (T_{WL}) based on an average beach slope ($S = 0.084$). Note $N = 110,206$ hours and spans the period from July 1987 to March 2003.

spit in 1967 ranged from 4.8 to 6.6 m (15.7 – 21.7 ft), while the average dune crest was 5.6 m (18.4 ft), the analysis presented here appears to be reasonable. Thus, lowering the dune to an elevation of 5.5 m (18 ft) would simply result in the spit being returned to a condition similar to what it was in 1967 and certainly prior to the introduction of European beach grass. Furthermore, given that the spit morphology in 2002 is much wider than in 1967 (i.e., has greater sand volume), lowering the dune to 5.5 m would not be expected to result in a catastrophic failure of the spit.

5.4 Beach Sand Volume Estimates on the Elk River Spit

Analyses of the coastal geomorphology of the Elk River Spit and the calculated total water levels suggest that it is reasonable to lower the elevation of the spit to an elevation of 5.5 m (18 ft). With that in mind, this section provides a brief assessment of the volume of sand contained in the spit, and hence the volume of sand that will have to be moved. The analyses presented here have been derived from the 2002 LIDAR data and are conservative estimates of the volumes of

Table 3. Variability in the monthly total water levels (t_{wl}) based on 15 years of wave and tide data. Note that each month of data constitutes 100% of the data so that the monthly percentages reflect a portion of the months total water levels that exceed 5.5 M (18 ft).

<i>Month</i>	<i>All hours (N)</i>	<i>Hour/month $S = 0.084$</i>	<i>Hour/month $S = 0.125$</i>	<i>% $S = 0.084$</i>	<i>% $S = 0.125$</i>
April	7,888	47	159	0.60	2.02
May	9,199	6	41	0.07	0.45
June	9,202	6	15	0.07	0.16
July	10,790	0	0	0.00	0.00
August	10,404	1	3	0.01	0.03
September	9,889	39	106	0.39	1.07
October	9,914	114	299	1.15	3.02
November	9,117	298	784	3.27	8.60
December	7,867	508	1298	6.46	16.50
January	8,584	329	969	3.83	11.29
February	7,937	205	657	2.58	8.28
March	9,415	214	719	2.27	7.64

Note: ¹based on 15 years of hourly data

sand contained in the spit. The spatial extent of the 5.5 m (18 ft) contour elevation is shown graphically in Figure 24. Volume estimates have been calculated to the nearest 100 m³ and are based on defined sections along the spit that include the following sections:

- Elk River to profile Elk 1;
- Elk 1 to Elk 2;
- Elk 2 to Elk 3;

- Elk 3 to Elk 4;
- Elk 4 to Elk 5; and ,
- Elk 6 to the spit tip (Figure 14A).

The results of the analysis are presented in Table 4.

The above analyses indicate that approximately 178,600 m³ (233,600 yards³) of sand will need to be moved in or-

Table 4. Volume estimates of the amount of dune sand that will be required to be moved to lower the spit to an appropriate elevation (rounded to the nearest 100 m³).

<i>Contour Elevation (m)</i>	<i>≥ 5.0 m</i>	<i>≥ 5.5 m</i>	<i>≥ 6.0 m</i>
Elk River to Elk 1	13,400	4,900	900
Elk 1 to Elk 2	34,500	27,000	20,500
Elk 2 to 3	42,900	35,800	29,100
Elk 3 to 4	45,400	37,200	29,600
Elk 4 to 5	16,700	13,400	10,600
Elk 5 to 6	34,100	28,000	22,200
Elk 6 to spit tip	41,600	32,300	25,100
Total	228,600 m ³ (299,000 yards ³)	178,600 m ³ (233,600 yards ³)	138,000 m ³ (180,500 yards ³)

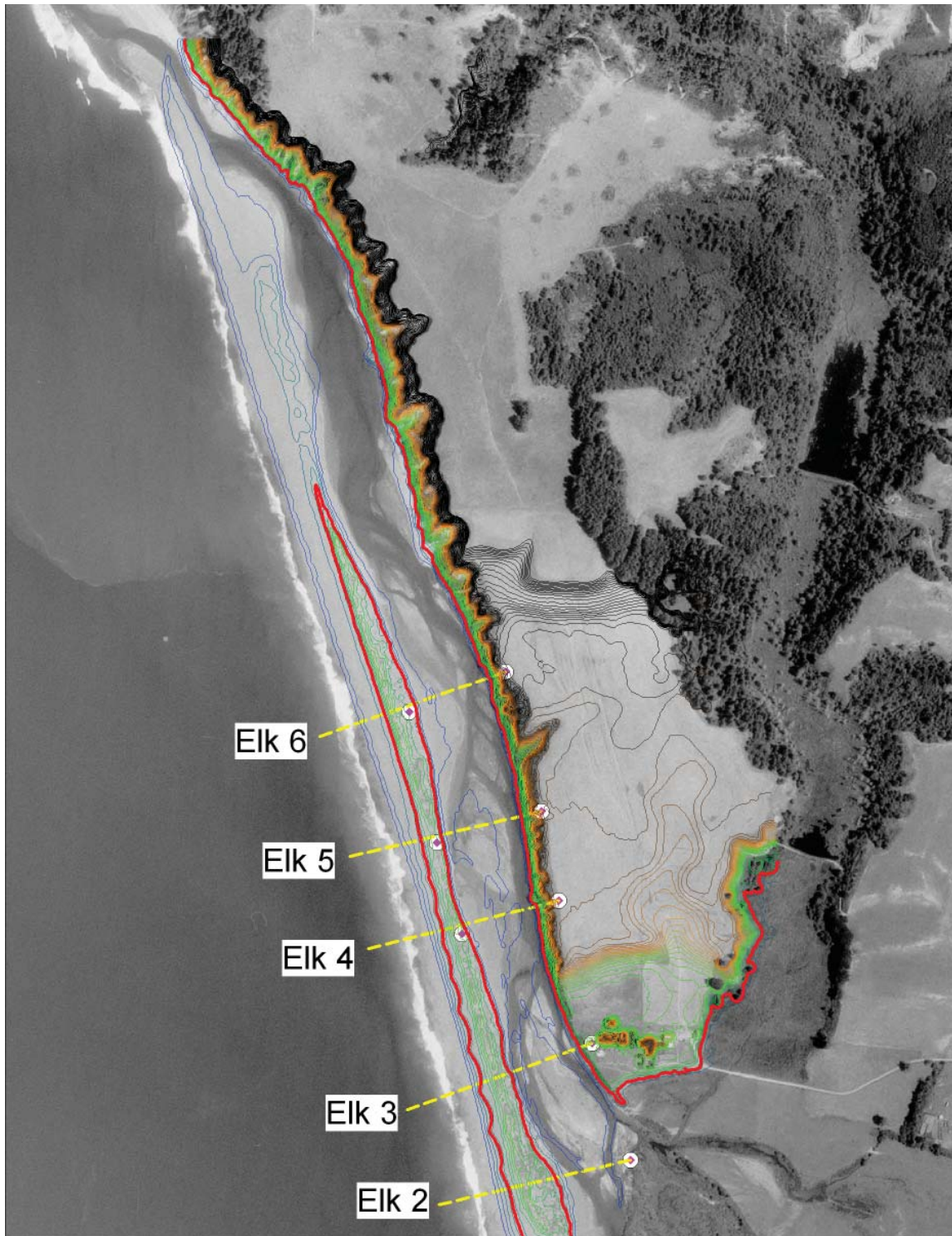


Figure 24. Mapped contours at 0.5 m intervals. The red line delineates the 5.5 m (18 ft) contour elevation.

der to lower the spit to an elevation of 5.5 m (18 ft). As a first step it is recommended that such work be done in stages beginning at the Elk River (i.e., from where it bends to the north and runs parallel with the ocean) to Elk 2. Furthermore, this will permit monitoring of the performance of the dune lowering to be assessed over one winter season, enabling a clearer understanding of the effect of dune rehabilitation on the stability of the remainder of the spit. Subsequent dune lowering may be staged after that.

5.5 Potential implications of lowering the spit crest elevation

Lowering the Elk River Spit to an elevation of 5.5 m (18 ft) is likely to have a number of potential effects on the littoral system and to the river. These include:

1. Moderate to large storms combined with high tidal elevations will result in the dune being periodically overtopped. During such events, the wave swash will carry sand and flotsam over the dune where it will accumulate on the landward side of the spit in the form of overwash deltas. As a result, it can be expected that some sand build-up will occur over time on the landward side of the spit. However, high winter discharges in the Elk River will periodically erode the accumulated sand and will transport the material back to the beach;
2. In response to the dune lowering, breaching may occur along the north-central section of the spit between Elk 4 and Elk 5, due to the narrowness of the spit (Figure 24). However, it is equally likely that this area will breach naturally regardless of any dune rehabilitation work. Depending on when such an event occurs, it is possible that storm waves and river flow could rapidly widen the opening and generally cause its expansion to the north because the winter storm waves predominantly arrive from the southwest, causing the northward migration of the opening (Komar and others, 2001). However, as observed on the New River spit by Komar and others (2001), a breach would likely close during the following summer as sand is carried into the opening by waves and currents;
3. Sand that is removed from the spit and pushed into the ocean will be redistributed along the littoral cell and reabsorbed by the coastal system. This is likely to benefit areas such as Garrison Lake near Port Orford (Figure 1), where extreme erosion has destroyed a significant portion of the foredune (Allan and others, 2003). Thus, sand removed from the Elk River Spit could be of considerable benefit to the Garrison Lake foredune, enabling the dune to re-build itself;
4. Sand pushed into the ocean could result in the occasional closure of the Elk River mouth. However, this process also occurs naturally. In response to the closure, the river may occasionally increase its elevation causing some minor flooding to low lying areas. However, as the hydraulic head increases the river will eventually punch through the spit re-establishing its natural outflow into the Pacific Ocean.

6..0 CONCLUSIONS

Investigations have been undertaken along the Elk River Spit to assess the physical processes affecting its morphology, stability, and for determining an appropriate spit crest elevation to allow for periodic dune over-topping by wave swash. This analysis is important for the purposes of developing a Western Snowy Plover breeding habitat on the spit, since these birds typically nest in flat, open areas with sandy or saline substrates where vegetation and driftwood are usually sparse or absent (USFWS, 2001).

This study has revealed that the spit has undergone substantial changes since the late 1920s, with the river mouth having migrated northward by some 1,067 m (3,500 ft) at an average rate of 14.5 m/year (47.6 ft/year). Associated with the northward extension of the Elk River mouth has been considerable aggradation along the foredune, which has resulted in the dune elevation having been raised from approximately 5.6 m NAVD88 (18 ft) to an elevation of around 8 – 10 m (26 – 33 ft) in 2002. These changes have been helped by the explosive growth of European beach grass along the Oregon coast, which has resulted in the growth of a high foredune, effectively eliminating the occurrence of wave over-topping along much of the spit.

A review of the coastal geomorphology of the spit indicates that wave runup is known to periodically overtop the spit to an elevation of 5 – 7 m. This observation agrees with an analysis of the calculated total water levels (T_{WL} , combined wave runup plus the tidal elevation) on the spit based on an average beach slope of 0.084, and a maximum slope of 0.125. These results indicate that lowering the dune to around 5.5 m (18 ft) will result in the dune being overtopped for about 4 – 8 percent of the time (i.e. about 140 – 280 hours per winter season), with the bulk of the over-topping occurring during the months of December and January. Lower elevations have been shown to result in significantly greater amounts of wave over-topping, however, such action could cause the spit to become unstable and is not recommended.

Finally, it is recommended that initial grading efforts be staggered along the Elk River Spit to enable careful assessment of the response of the beach, dune and spit to the rehabilitation work. In this regard, grading of the dune should include pre- and post-grading surveys of the area targeted. Additional monitoring efforts should also be periodically undertaken (e.g., at quarterly intervals during the first year and then bi-annually thereafter), particularly following major storm events. These data will greatly facilitate understanding of the spits response, enabling the Elk River Spit dune rehabilitation work to be more carefully managed.

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8.0 Appendix A

Information presented below describes the approximate coordinate position (± 4 m) of the Elk River survey benchmarks. The coordinate values are expressed in NAD83 format (decimal degrees) and were derived using a Garmin GPS III Plus hand-held global positioning system. Each benchmark consists of a steel “T-bar” fence post that was hammered into the ground. All surveys were taken from the top of the post.

<i>Profile</i>	<i>Latitude</i>	<i>Longitude</i>	<i>Profile Bearing</i>
1	N42.79263	W124.52308	239.5°
2	N42.79632	W124.52424	235°
3	N42.79866	W124.52516	228.5°
4 (East side of Spit foredune)	N42.79952	W124.52801	234°
5 (East side of Spit foredune)	N42.80168	W124.52877	235°
6 (East side of Spit foredune)	N42.80430	W124.53043	229°