State of Oregon
Department of Geology and Mineral Industries
Vicki S. McConnell, State Geologist

Open-File Report O-08-02

BEACH AND SHORELINE RESPONSE DUE TO DUNE LOWERING ON THE ELK RIVER SPIT, CURRY COUNTY, OREGON

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2008

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NOTICE
The results and conclusions of this report are necessarily based on limited geologic and geophysical data. At any given site in any map area, site-specific data could give results that differ from those shown in this report. This report cannot replace site-specific investigations. The hazards of an individual site should be assessed through geotechnical or engineering geology investigation by qualified practitioners.

Cover photo: Southwest view overlooking the Elk River spit showing the area of dune lowering (photo right-center) relative to the area of natural spit overtopping and breaching (area of bare sand, mid-photo).

Oregon Department of Geology and Mineral Industries Open-File Report O-08-02
Published in conformance with ORS 516.030

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TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

The Oregon Department of Geology and Mineral Industries (DOGAMI) was commissioned by the U.S. Fish and Wildlife Service (USFWS) to carry out a beach monitoring study of the effects of dune lowering undertaken on the Elk River Spit in July-August 2006. The purpose of the dune lowering is to rehabilitate portions of the spit for the purposes of developing a Western Snowy Plover breeding habitat.

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 and others, 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 these birds prefer.

The Elk River Spit is located midway 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 (6.6 mi). 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 m (2.3 mi) long and covers an area of 90 hectares (220 acres). The approach used to rehabilitate a dune system involves removing dune vegetation (mainly European beach grass) with the aide of bulldozers, and, at the same time, lowering the foredune elevation by pushing the sand seaward onto the beach, thereby increasing the likelihood of wave overwash during major winter storms.

To identify an appropriate elevation to which the dune could be lowered, Allan (2004) undertook a study of the spit geomorphology and susceptibility of the spit to periodic wave overtopping. From this work it was concluded that the spit could be lowered to an elevation of approximately 5.5 m relative to the North American Vertical Datum of 1988 (NAVD88). NAVD88 is located approximately 0.151 m (0.5 ft) above Mean Lower Low Water (MLLW). At this elevation, the spit was expected to be overtopped some 4–8 % of the time, with the bulk of the overtopping occurring during the months of December and January. Furthermore, dune lowering would result in the reintroduction of an estimated 178,600 m^3 (233,600 yd^3) of sediment to the littoral system.

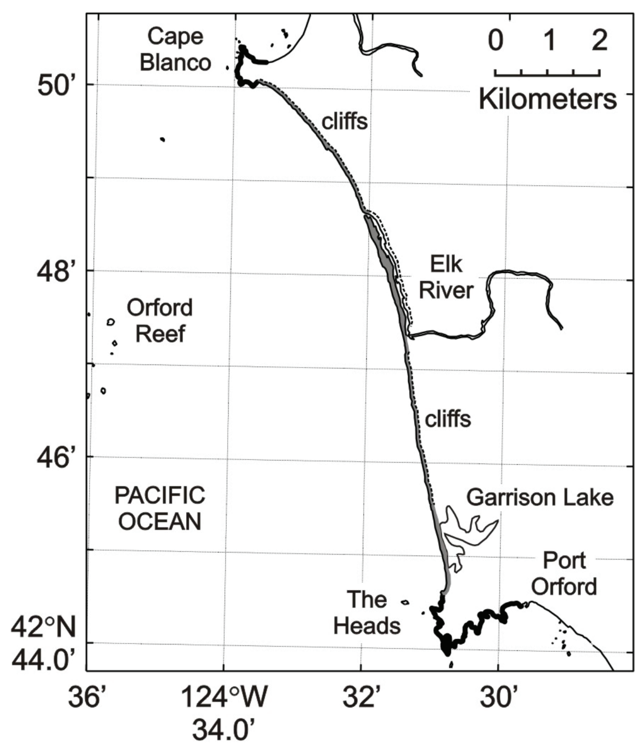

Figure 1. Location of the Port Orford, Oregon, littoral cell. Dashed lines indicate cliffs; shaded area denotes sandy beach, and bold lines denote headlands.

In response to input from local residents, the South Coast Watershed Council, the Oregon State Parks and Recreation Department (OPRD), and the USFWS, the decision was made to initially lower the dune crest elevation to 7 m (23 ft), thereby creating a "phased" approach to dune lowering. The purpose of this was to implement a monitoring study to determine if dune lowering would adversely impact beach and spit dynamics and to document the overall response of the beach over time. Assuming the effects of dune lowering do not adversely impact the beach and spit geomorphology, a second lowering phase is set to occur in 2007 that would result in the dune elevation being lowered an additional 1.5 m (5 ft) to the design elevation of ~5.5 m (18 ft). The objective of this report is to describe the monitoring program established along the Elk River Spit and results from several months of beach monitoring.

Objectives of this study include the following:

- Expand the existing six-site beach survey network established by Allan (2004) to include four additional transects, bringing the total number of transects to 10.[1] The beach surveying will be undertaken using a Trimble 5700/5800 Real Time Kinematic Differential Global Positioning System (RTK-DGPS).
- Install three permanent benchmarks on either the spit or the McKenzie property located adjacent to the spit. These monuments will provide survey control for the RTK-DGPS surveying. From these control points it will be possible to establish additional temporary survey monuments wherever needed.
- Undertake beach surveys at the following times:
  - pre-construction (spring/early summer 2006). Preferably, this would be completed just prior to commencing dune scalping;
  - post-construction follow-up (depending on conditions, within 2–4 weeks after the initial dune is lowered to 7 m (23 ft);
  - late 2006-2007 winter (March-April 2007);
  - post-construction follow-up (depending on conditions, within 2–4 weeks after the initial dune lowered to 5.5 m (18 ft). This will occur sometime around early summer-late fall 2007;
  - late 2007-2008 winter (March-April 2008);
- Utilize topographic monitoring along the Elk River spit. This approach involves mounting a Trimble 5800 rover GPS unit onto an all-terrain vehicle (ATV) vehicle and driving contour lines along the shore. This technique of shoreline mapping has been shown to be effective on the northern Oregon coast for mapping large sections of shore (up to 4 km long) in the space of several hours. Point densities using this approach are approximately 1 point every 3 to 5 m, which is sufficient for identifying large-scale beach responses including the movement of sand along the shore. At the time, it was unclear to what extent this approach could be used effectively due to the steep beach and dynamic nature of the surf characteristic along the Elk River spit. Following our initial site visit in July 2006, an alternative approach was adopted that included a topographic survey of the 3-m contour elevation over time. While this latter approach is unable to yield the level of detailed three-dimensional information that could be provided by the topographic mapping, the revised approach would still allow for tracking the along shore response of the beach; and,
- Produce a short report summarizing the main findings of the study.

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

1. Note: this objective was subsequently modified in July 2006 following our initial site visit; the number of transects was increased to 23 sites in order to provide a dense enough beach survey network.

STUDY AREA

The Oregon coast can be broadly characterized as consisting of long stretches of sandy beaches 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 km (6.8 mi) stretch of coast, includes the Elk River Spit and extends from the Port Orford headland at its southern end to Cape Blanco at 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, 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 processes (waves, currents, and tides) that drive coastal change and the underlying geological and geomorphological characteristics of 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, eroding sediments elsewhere.

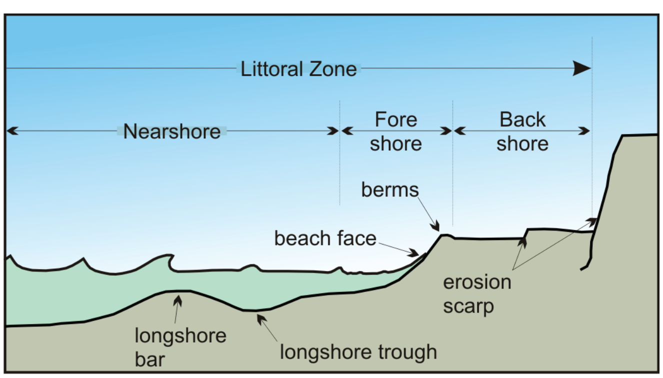

Figure 2. Terminology used to define aspects of the beach (Komar, 1998).

Because beaches are composed of loose material, they are able to respond and adjust their morphology rapidly in intervals of time ranging on the order of seconds to several years, in response to storm events, enhanced periods of storm activity (e.g., the 1982-1983 and 1997-1998 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 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) and the longer-term changes, which are dependant on the state of balance or imbalance among the various elements of the sediment budget. From a shore management perspective it is important to clearly distinguish shorter temporal beach changes from longer-term adjustments as the latter have very different implications for land use adjacent to any water body. In this way costly shoreline erosion and other hazards can be mitigated, 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, as no study has been undertaken on 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 and again during the 2005-2006 winter, and resulted in the foredune being breached at its southern end (Figure 3) (Scott Mckenzie, personal communication, 2006).
- 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

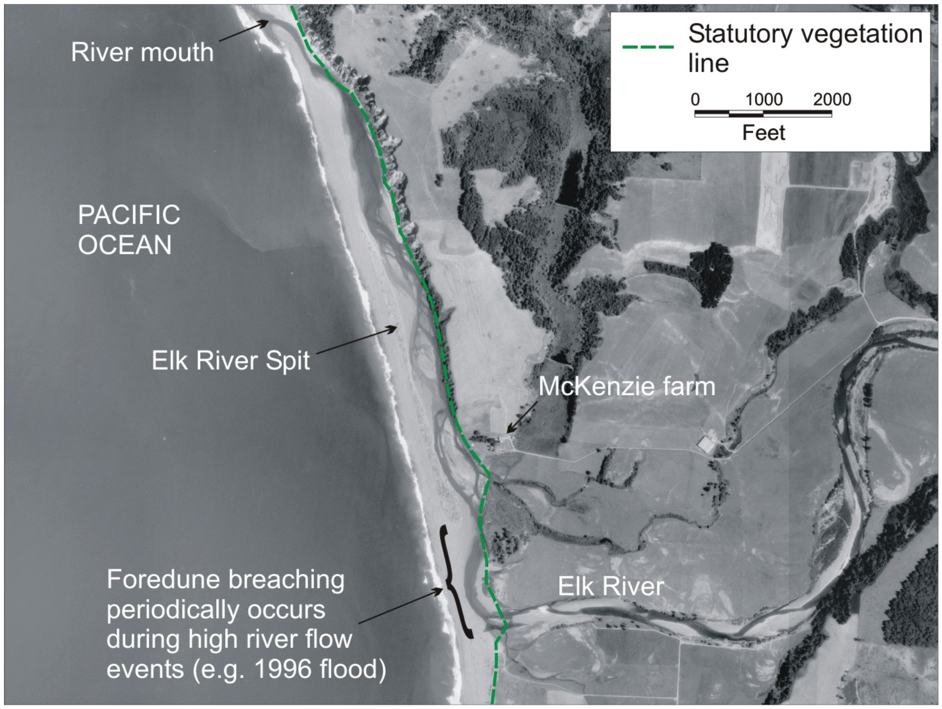

Figure 3. Aerial photograph of the Elk River Spit showing the location of the river mouth in 2000, and in the south where the river periodically breaches the foredune during high flow events.

sands and gravels that overly Tertiary and pre-Tertiary bedrock (Beaulieu and Hughes, 1976). The heights of the bluffs are variable and include a number of large gullies, particularly along the cliffs north of Paradise Point 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 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, personal communication, 2004); and,

- 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 (Allan and others, 2003). 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 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 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 forming north of the Elk River mouth (Allan, 2004). 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 overtopping 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, which 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 steeply sloping (3.2° [1-on-18] to 14° [1-on-4]) and 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), 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, from data collected in this study the seasonal variability on the Elk River Spit appears to be lower, varying by some 20–30 m (65–98 ft). These smaller beach excursions are likely to be a function of the position of the spit, which is 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 winter months wave energy (proportional to the square of the wave height) increases substantially, eroding the beaches, whereas during summer much lower wave energies enable eroded sand to migrate back onshore, rebuilding the beach face. The dynamics and processes driving coastal change on Pacific Northwest beaches and specifically on the Elk River Spit is described by Allan (2004).

METHODOLOGY

Elk River Spit Beach Monitoring Network

Beach profiles oriented perpendicular to the shoreline can be surveyed using a variety of approaches, including a simple graduated rod and chain, surveying level and staff, total station theodolite and reflective prism, light detection and ranging (LIDAR), and real-time kinematic differential global positioning system (RTK-DGPS) technology.

Traditional techniques such as leveling instruments and total stations are capable of providing accurate representations of the morphology of a beach but are demanding in terms of time and effort. For example, typical surveys undertaken with a total station theodolite may take anywhere from 30 to 60 minutes to complete, which reduces the capacity of the surveyor to develop a spatially dense profile network. At the other end of the spectrum, high-resolution topographic surveys of the beach derived from LIDAR are ideal for capturing the three-dimensional state of the beach over an extended length of coast within a matter of hours; other forms of LIDAR technology are now being used to measure nearshore bathymetry but are dependent on water clarity. However, LIDAR technology remains expensive and is impractical along small segments of shore. More importantly, the high costs of LIDAR effectively limit the temporal resolution of the surveys and hence the ability of the end-user to understand short-term changes in the beach morphology (Bernstein and others, 2003). Within this range of technologies, the application of RTK-DGPS for surveying the morphology of both the subaerial and subaqueous portions of the beach has effectively become the accepted standard (Morton and others, 1993; Ruggiero and others, 2005).

The global positioning system (GPS) is a worldwide radio-navigation system formed from a constellation of 24 satellites and their ground stations, originally developed by the U.S. Department of Defense. In its simplest form, GPS can be thought of as triangulation, with GPS satellites acting as reference points that enable users with off-the-shelf, hand-held GPS receivers to calculate their positions to within several meters. Survey-grade GPS receivers are capable of providing positional and elevation measurements accurate to one centimeter. At least four satellites are needed mathematically to determine exact position, although more satellites are generally available. The process is complicated because all GPS receivers are subject to error, which can significantly degrade the accuracy of the derived position. These errors include the GPS satellite orbit and clock drift plus signal delays caused by the atmosphere and ionosphere and multipath effects (where the signals bounce off features and create a messy signal). For example, hand-held autonomous receivers have positional accuracies that are typically less than about 10 m (~30 ft) but can be improved to less than 5 m (~15 ft) using the Wide Area Augmentation System (WAAS). The WAAS system is essentially a form of differential correction that accounts for the above errors, which is then broadcast through one of two geostationary satellites to WAAS-enabled GPS receivers.

Greater survey accuracies are achieved with differential GPS (DGPS), which uses two or more GPS receivers to simultaneously track the same satellites, enabling comparisons to be made between two sets of observations. One receiver is typically located over a known reference point, and the position of an unknown point is determined relative to the reference point. With more sophisticated 24-channel, dual-frequency RTK-DGPS receivers, positional accuracies can be improved to the subcentimeter level when operating in static mode and to within a few centimeters when in RTK mode (i.e., as the rover GPS is moved about).

On July 11–13, 2006, we visited the field site to undertake an initial survey of the beach. The broad purpose of this initial phase of the work was to:

- Establish three survey control monuments adjacent to the Elk River Spit used for calibration of the GPS survey;
- Finalize the locations of the beach profile survey network;
- Undertake the initial survey of the beach profiles sites; and,
- Determine whether it would be feasible to undertake topographic surveys of the beach using the RTK-DGPS mounted on an ATV, or instead focus on surveys of a specific contour.

Figure 4 shows the general layout of the final survey network, which consists of 23 profiles sites that extend from just south of the "elbow" (i.e., where the river turns north along the spit) to the spit tip. The decision to increase the number of survey transects came at the expense of eliminating the topographic survey due to the large amount of time required to do such surveys and the potential hardship to the equipment. To compensate for the loss of the topographic survey and to capture the alongshore response of the beach, it was decided that a survey of the 3-m (9 ft) contour elevation would be undertaken during each field campaign. The 3-m contour was chosen as it reflects the response of the beach just above MHHW and captures any alongshore response of the beach to the introduction of sediment derived from dune lowering.

Three survey benchmarks (SCOTT, FRED, and KNAPP) were eventually established adjacent to the Elk River Spit to serve as GPS control for the beach profile surveys (Figure 4). The benchmarks were constructed by first digging 1-m (3.3 ft) deep, 25-cm (10-in) diameter holes, into which aluminum sectional rods were inserted and hammered to additional depths of approximately 4–8 m (12–24 ft). The rods were then capped with a 2½-in (6.4 cm) aluminum cap (bearing a Oregon Department of Geology and Mineral Industries stamp on top), and concreted in place. A fourth monument (PO41), previously established by the Oregon Department of Transportation (ODOT) for the purpose of surveying in the 1967 Statutory Vegetation Line, was also adopted for the purposes of this study.

Precise coordinates and elevations were determined for the Elk River GPS control sites using a Trimble® 5700/5800 Total Station Global Positioning System. This system consists of a GPS base station (5700 unit), Zephyr™ Geodetic antenna, TRIMTALK™ 3 radio, and 5800 "rover." The 5700 base station was mounted on a fixed height (2.0 m) tripod and located over the SCOTT benchmark. For the purposes of this study, we used several benchmarks established by the National Geodetic Survey (NGS) of the National Oceanic and Atmospheric Administration (NOAA) to calibrate the GPS survey. Two of the survey monuments are characterized by horizontal order "A" and first-order vertical control. NGS monument BLCO is located about 6.4 km north of Port Orford, and NGS monument 943 Tidal L is located adjacent to the port of Port Orford. Additional control was provided by three other monuments: 943 Tidal 4, a first-order vertical control site operated by NGS, Y757, a first-order vertical control site operated by ODOT, and Battle, a PK-nail installed and surveyed in by DOGAMI staff. Initial coordinates were established by undertaking 180 GPS epoch measurements on each of the control monuments (SCOTT, FRED, and KNAPP), and then performing a GPS site calibra-

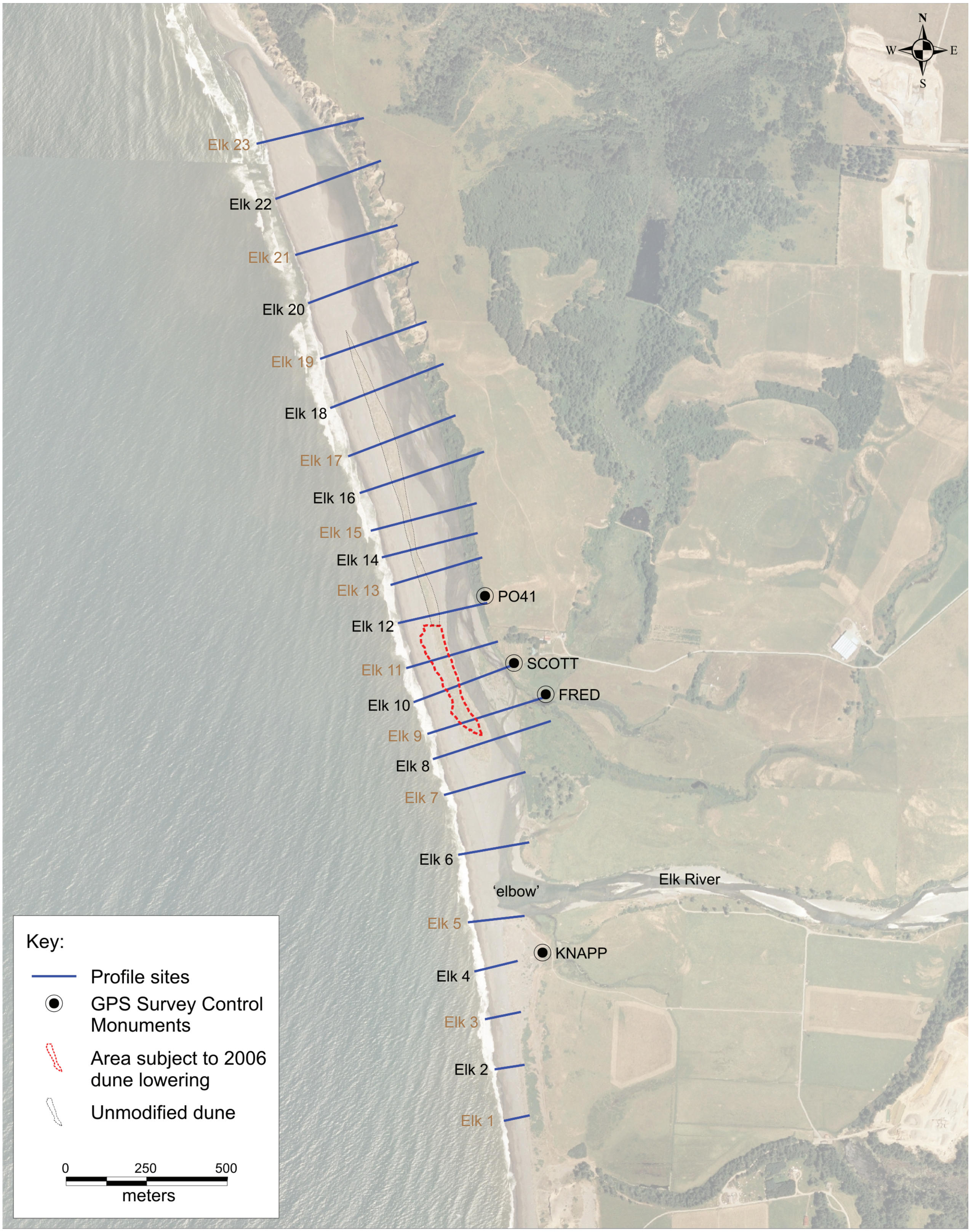

Figure 4. The Elk River, Oregon, beach monitoring network and global positioning system control monuments overlaid on a 2005 color orthorectified aerial image (image source: http://gis.oregon.gov/DAS/EISPD/GEO/fit/orthoimagery/OrthoFrame.shtml).

tion relative to the other known NGS benchmarks. This step is critical to eliminate various survey errors. For example, Trimble reports that the 5700/5800 GPS system has horizontal errors of approximately ±1 cm + 1 ppm (parts per million × the baseline length) and ±2 cm in the vertical (Trimble Navigation System, 2005). These errors may be compounded by other factors such as poor satellite geometry, multipath, and poor atmospheric conditions, combining to increase the total error to several centimeters. Thus, the site calibration process is fundamental in order to minimize these uncertainties (Ruggiero and others, 2005). Coordinate information for each of the benchmarks was ultimately expressed in the Oregon State Plane (southern zone, meters) coordinate system, while elevations were relative to the North American Vertical Datum of 1988 (NAVD88).

Having established the coordinate information for the control monuments adjacent to the spit, we began beach surveying July 12-13, 2006. Survey control was provided by the four benchmarks located adjacent to the spit. Each of the monuments was reoccupied using the same procedures described previously, and a site calibration was once again performed. Once the local site calibration was completed, cross-shore beach profiles were surveyed by an operator with the 5800 GPS rover unit mounted on a backpack (Figure 5). This process was typically undertaken during periods of low tide. The approach generally was to walk from the landward edge of the primary dune or river edge, down the beach face, and out into the swash zone. A straight line perpendicular to the shore was achieved by navigating along a predetermined line displayed on a hand-held Trimble TSCe™ computer connected to the 5800 rover. The computer shows the position of the operator relative to the survey line and indicates the deviation of the GPS operator from the line. The horizontal variability during and between subsequent surveys is generally minor, approximately 1 m (3 ft) (i.e., about ±0.5 m either side of the line) and typically results in negligible vertical uncertainties due to the relatively uniform nature of beaches characteristic of much of the Oregon coast (Ruggiero and others, 2005). The survey was subsequently repeated on September 20, 2006 (post-dune lowering survey), and again on November 20, 2006; January 24, 2007; and April 17, 2007. According to pre-

Figure 5. Beach surveys were undertaken by walking lines perpendicular to the waters edge, navigating along a predetermined line identified on a hand-held TSCe Trimble computer, connected to the Trimble 5800 GPS rover. Example here is of R. Hart undertaking a profile survey of the beach at Cape Lookout State Park.

vious research, this method of surveying can reliably detect elevation changes on the order of 4-5 cm, that is, well below normal seasonal changes in beach elevation, which typically varies by 1 to 2 m (3 to 6 ft) (Ruggiero and others, 2005; Shih and Komar, 1994).

The collected GPS data were subsequently processed using the Trimble Geomatics Office™ suite of software. The first stage involves a re-examination of the site calibration undertaken on the TSCe computer. A three-parameter least-squares fit was then applied to adjust all data points collected during the survey to the local coordinate system established for the Elk River Spit and to reduce any errors that may have occurred as a result of inaccuracies due to the GPS units. The processed profile data were then exported for subsequent analysis.

Additional beach morphology information was derived from a September 2002 LIDAR survey of the Oregon coast that included the Port Orford littoral cell. These data were flown by the USGS, NASA, and NOAA as part of a national assessment of coastal change and have been used to supplement the GPS beach monitoring and topographic surveys undertaken along the Elk River Spit. The advantage of LIDAR data set is that it provides another measure of the response of the beach, in this case, the end of the 2002 summer, which extends our knowledge of the typical beach response along the spit.

Analysis of the beach survey data involved several stages. The data were first imported into MATLAB™[2] using a customized script. A least-squares linear regression was then fit to the profile data. The purpose of this step is to examine the processed data and eliminate data points that exceed a ±0.5-m threshold on either side of the predetermined profile line. The data were then exported into a Microsoft Excel® database for archiving. A second MATLAB script used the Excel profile database to plot the latest survey data (relative to the earlier surveys) and to output the generated image as a Portable Network Graphics (.png) file. A third script examined the profile data and quantified the changes that occurred at selected contour elevations; for this study, temporal trends were developed for all contours between the 1-m and 6-m elevations and for all available data. Finally, the processed contour data were plotted against time and were exported as a .png file for additional analysis.

Contour surveys on the Elk River Spit

Beach profile surveys provide important information about the two-dimensional response of the beach as a result of variations in the incident wave energy, nearshore currents, tides, and sediment supply. However, because transect locations are typically located a few hundred meters or more apart, profile surveys are unable to account for the alongshore variability in shoreline response that may reflect development of large morphodynamic features such as rip embayments, beach cusps, and alongshore transport of sediment. To complement the beach profile surveys initiated along the Elk River Spit, a contour survey of the 3-m elevation was also undertaken to better document the spatial variability of the beach response and, potentially, the movement of sediment along the spit.

In order to undertake the contour mapping, the 5800 GPS rover unit was mounted on top of a six-wheel ARGO ATV. The height of the rover unit was then measured relative to the ground and input into the TSCe computer. Next, the ATV vehicle was driven along the 3-m contour elevation at a slow rate that enabled point samples to be measured roughly every 1 to 2 meters. The survey typically extended from just south of the "elbow" depicted in Figure 4 northward to the spit tip and was carried out on the same day as the beach profiling. The data were again processed using the same procedures described above and, eventually, were exported to a Geographical Information System for additional analysis.

2. Computer programming languages.

RESULTS

A variety of approaches may be used to view and to analyze beach morphology measured by the surveys. The traditional approach simply examines the temporal and spatial variability of graphed beach profiles (cross-sections). Other approaches include examining changes at specific contour elevations (also known as excursion distance analysis, or EDA), undertaking volumetric calculations, or examining alongshore changes that could have occurred. However, the latter approach may only be meaningful if the spacing between the beach profiles is sufficiently dense.

Figure 6 shows a frequency distribution plot for the hourly significant wave heights from January 1, 2006, to April 30, 2007, measured offshore from Port Orford (National Data Buoy Center (NDBC) wave buoy #46015) and compared with the long-term (1987–2003) curve measured by the Newport wave buoy (NDBC buoy #46050). Allan (2004) demonstrated that wave measurements made by the two buoy instruments are strongly correlated. As can be seen in Figure 6, wave conditions during the 2006-2007 period were broadly similar to the long-term curve, with the exception that the lower (<7 m) wave heights tended to be shifted to the right (i.e., to slightly higher wave heights), and there were few large (> 8 m) storm wave events in the 2006-2007 winter.

Figure 7 is a plot of the hourly significant wave heights for the period January 1, 2006, to April 30, 2007, measured offshore from Port Orford. As can be seen in the plot, the significant wave heights in the 2006-2007 winter peaked in December 2006 through January 2007. Interestingly, conditions in mid January to February were mild, characterized by very low wave energy conditions, comparable to conditions typical of the summer season.

Figures 8 and 9 show the response based on all surveys to date at four selected beach profile sites; site locations are indicated in Figure 4. As noted previously, in each case the data set has been supplemented with topographic information derived from the 2002 LIDAR survey of the Oregon coast. Elk 1 is located at the southern end of the spit. Foredune elevations in this area are typically on the order of 10 m (33 ft) high. The

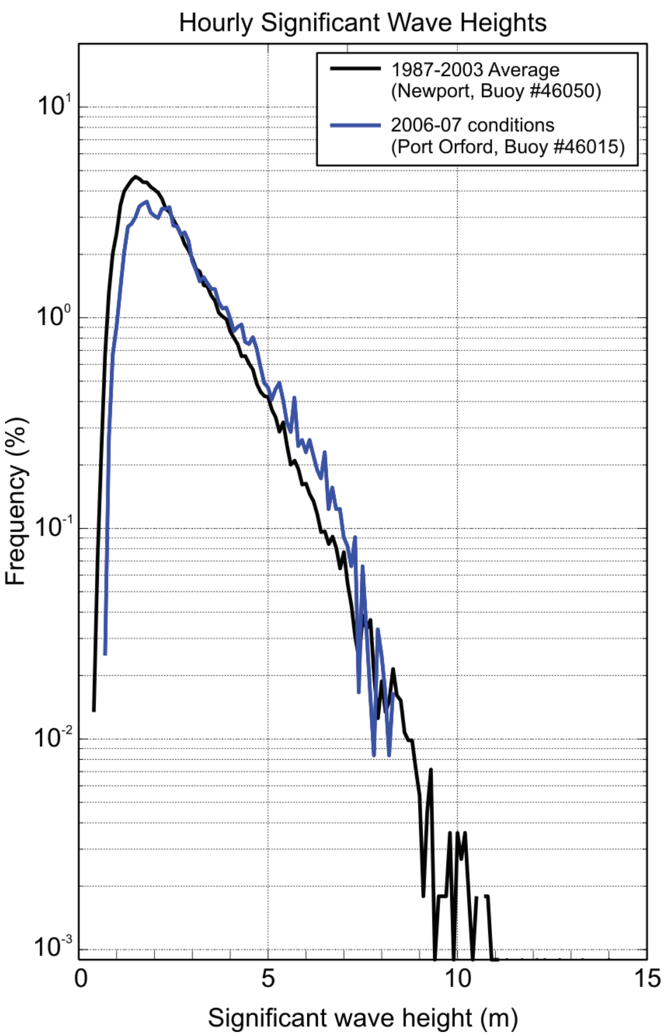

Figure 6. Frequency distribution plot depicting measured significant wave heights for the 2006-2007 period (blue line) relative to the long-term (1987–2003) curve (black line) offshore from Port Orford.

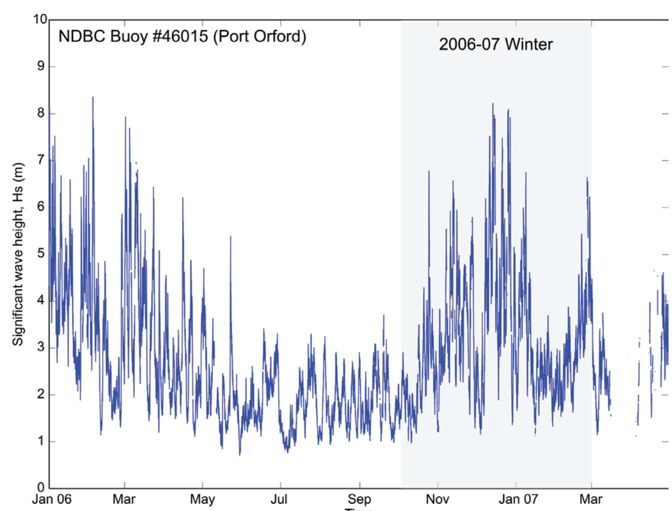

Figure 7. Hourly significant wave heights measured by the Port Orford NDBC wave buoy. Period shown is for January 1, 2006, to April 30, 2007. Note the 2006-2007 winter period is depicted by the grey band.

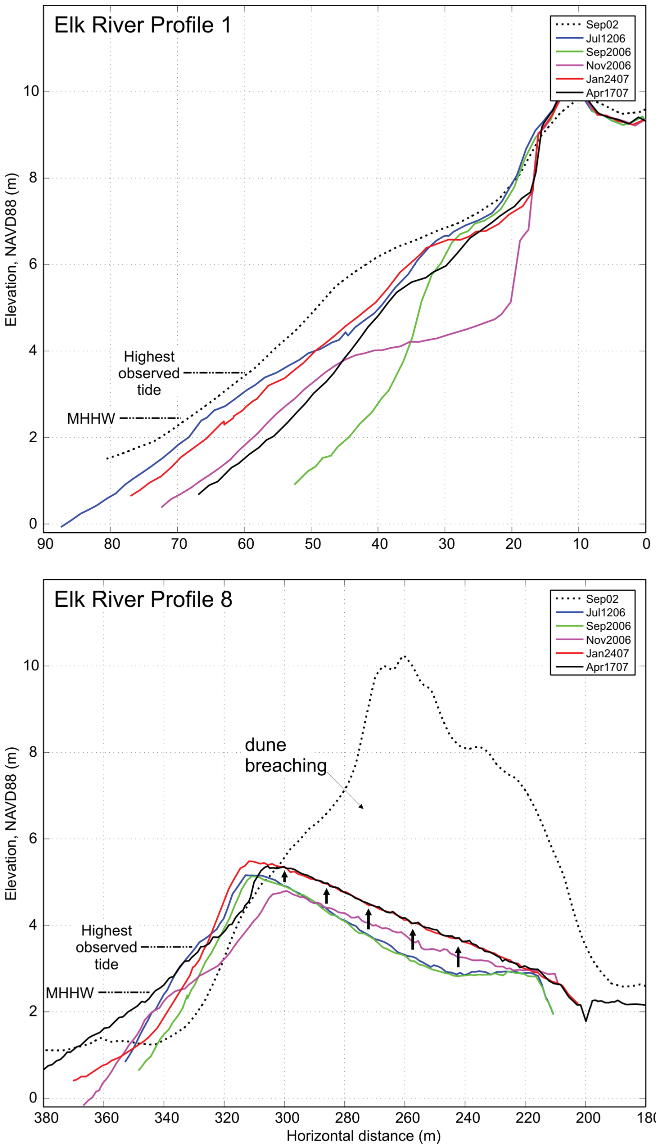

Figure 8. Beach profile responses determined for the Elk River profile 1 and 8 sites. Site locations are depicted in Figure 4.

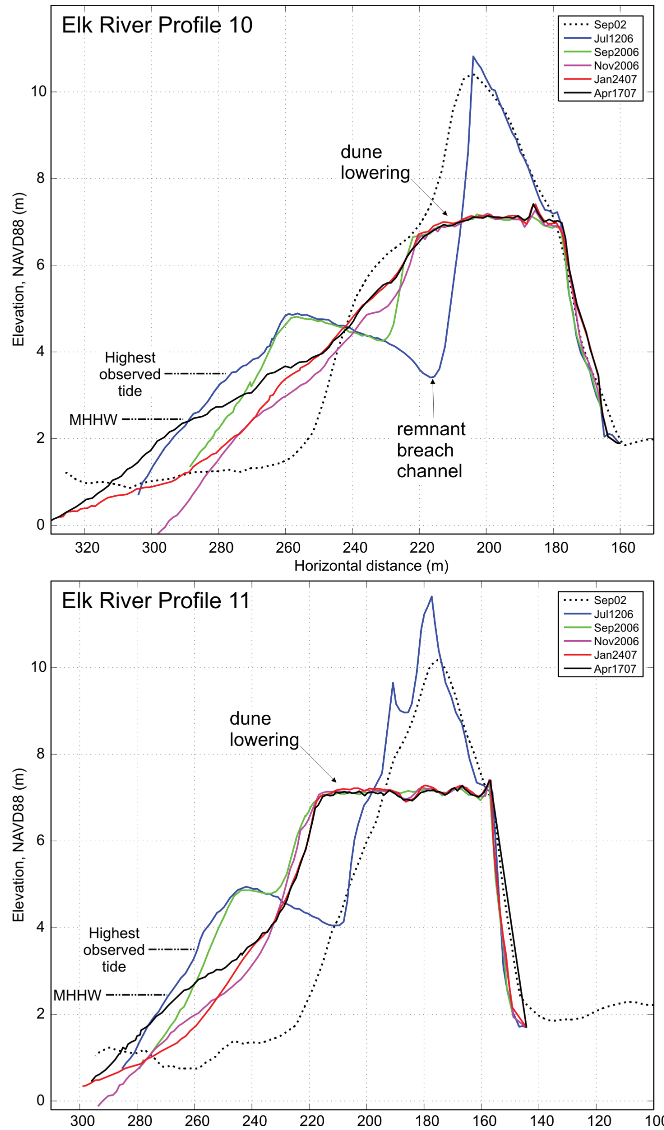

Figure 9. Beach profile responses determined for the Elk River profile 10 and 11 sites. Site locations are depicted in Figure 4.

beach is essentially composed of coarse sand and granules and as a result is characterized by a relatively steep (mean slope of ~7.4°) beach face. As can be seen in Figure 8, this section of the beach lost a small amount of its volume between 2002 and our initial survey in July 2006. With progress into winter, the site continued to loose additional sand as the beach face receded landward (~ −10 to −25 m (−33 to −82 ft) of erosion). Interestingly, much of this occurred over the summer months, which is unusual as wave energy levels during the summer are typically much lower than in winter. Erosion of this site reached its peak in November 2006, when the upper beach face was cut back about 15 m (49 ft), where it formed a 4-m (13 ft) vertical scarp. This was probably caused by a series of early winter storms that affected the area in late October through early November (Figure 7). However, by January 2007 the beach face had essentially rebuilt to the extent that its morphology and volume were comparable to the initial July 2006 survey.

Elk 8 is located approximately 400 m (1300 ft) north of the "elbow" and characterizes the area of the spit that periodically breaches naturally (Figures 8 and 4). In fact, this section of the spit was breached in the 2005-2006 winter and resulted in approximately 100 m (300 ft) of the southern end of the vegetated dune being eroded and removed (Figure 8); note the change in profile morphology between 2002 and 2006. From the time of the initial survey in July, the breached area has infilled due to wave overwash of the beach berm, which has carried sand over the berm and landward. As can be seen in Figure 8, landward of the berm crest, the beach has effectively aggraded vertically by some 0.5 to 1.0 m (1.6 to 3.3 ft). Our most recent survey, undertaken in April 2007, indicated that the crest of the berm was raised about 0.25 m, with its elevation now located at ~5.5 m (18 ft) NAVD88. Interestingly, most of the aggradation occurred between November 2006 and January 2007. Since January 2007 the berm has not aggraded vertically; instead, it has prograded seaward. This last response suggests that wave conditions after January were much lower (Figure 7), so that the wave runup was unable to overtop the berm crest. These latter responses appear to reinforce the work of Allan (2004) that a crest elevation of ~5.5 m to 6.0 m (18 to 19.7 ft) is probably ideal, allowing for some periodic overtopping of the spit.

Figure 9 shows the response of the beach and dune in the area that was effectively lowered in late July and early August 2006. Apart from the dune lowering, the most noticeable response identified on the beach is the effect of the natural breach of the spit by the Elk River, which resulted in the elimination of a substantial amount of the dune north of the profile 7 site and south of profile 10. As can be seen at the profile 10 site (Figure 9), following the spit breach, the river mouth began to migrate northward where it was eventually pushed up against the dune. This resulted in the characteristic pattern of erosion shown in Figure 9, whereby the dune became truncated.

Approximately 370 m (1,214 ft) of dune was lowered in late July and early August 2006; the total area of beach and dune affected (Figure 4), including the placed sand, was approximately 18,000 m^2 (21,530 yd^2). With the lowering of the dune to 7.0 m NAVD88, sand was pushed seaward, which caused the dune face to advance by approximately 20 m (65 ft) between profiles 10 and 12 and about 10 m (33 ft) between profiles 9 and 10. It is estimated that approximately 22,000 m^3 (~28,800 yd^3) of sand was moved during this initial phase of dune lowering. Additional dune crest lowering down to the 6.0-m (19.6 ft) contour elevation would require removal of an additional 20,000 m^3 (~26,200 yd^3) of sand; dune crest lowering to the 5.5-m (18 ft) contour elevation would require removal of ~30,000 m^3 (~39,200 yd^3) of sand.

As can be seen for the two profile sites shown in Figure 9, the effect of the dune lowering has had a minimal impact to the beach morphodynamics, with the natural level of variability (vertical and horizontal profile excursions) dominating the response at each of the transect sites. At those transect sites that span the area of dune lowering, the beach face was characterized by a prominent berm that formed prior to lowering of the dune. This again is a typical response of beaches in this area that reflects post-winter rebuilding of the beach face. Furthermore, it can be seen that the beach face had prograded significantly between 2002 and July 2006, which caused the beach face to advance seaward by up to 40 m (130 ft); further discussion of the alongshore change in shoreline response is described below. With progress into winter, the beach and reconstructed dune experienced only minor erosion between September and November 2006, probably due to the relatively wide beach present at the time in front of the dune. After November, sand accumulated in front of the profile 10 site, which caused the beach to prograde slightly seaward. This response may be due to a combination of alongshore and cross-shore transport of sediment at this site. As of April 2007, the upper part of the beach face (> 4 m elevation) had changed very little from the January 2007 survey, while the lower beach face had begun to rebuild. This latter response is consistent with the transition from higher wave energy conditions in winter to lower wave energy levels in summer. To the north, the response at profile 11 site was relatively similar to profile 10 site, with the exception that the reconstructed dune did experience a small amount of erosion between November 2006 and April 2007. It is probable that this response is due to the greater westerly extent of the reconstructed dune in the north, relative to the south, placing the dune face closer to ocean waves. In fact, erosion of the dune face characterized the overall response of the beach and spit morphodynamics north of profile 11.

Figures 10, 11, and 12 show the results of the beach mapping undertaken along the 3-m contour elevations with the aide of RTK-DGPS mounted on top of an ATV vehicle. Figure 10 shows the response of the

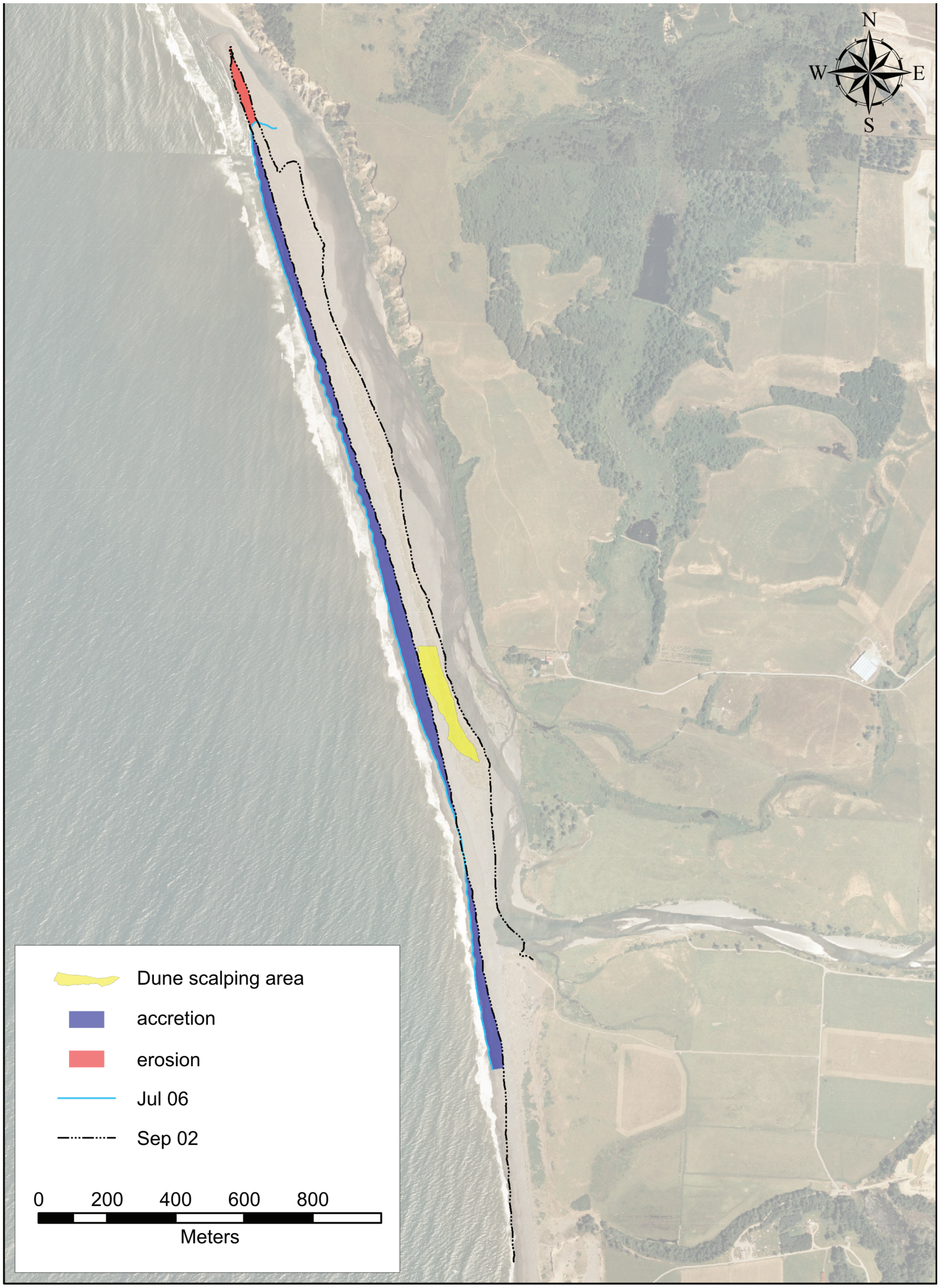

Figure 10. 3-m contour elevation response derived from Light Detection and Ranging (LIDAR) survey data and Real Time Kinematic Differential Global Positioning System (RTK-DGPS) survey data between September 2002 and July 2006 for the Elk River, Oregon, beach monitoring network area. Positive gains in the beach are shown in blue; negative gains (erosion) are shown in red. (Aerial image source: http://gis.oregon.gov/DAS/EISPD/GEO/fit/orthoimagery/OrthoFrame.shtml)

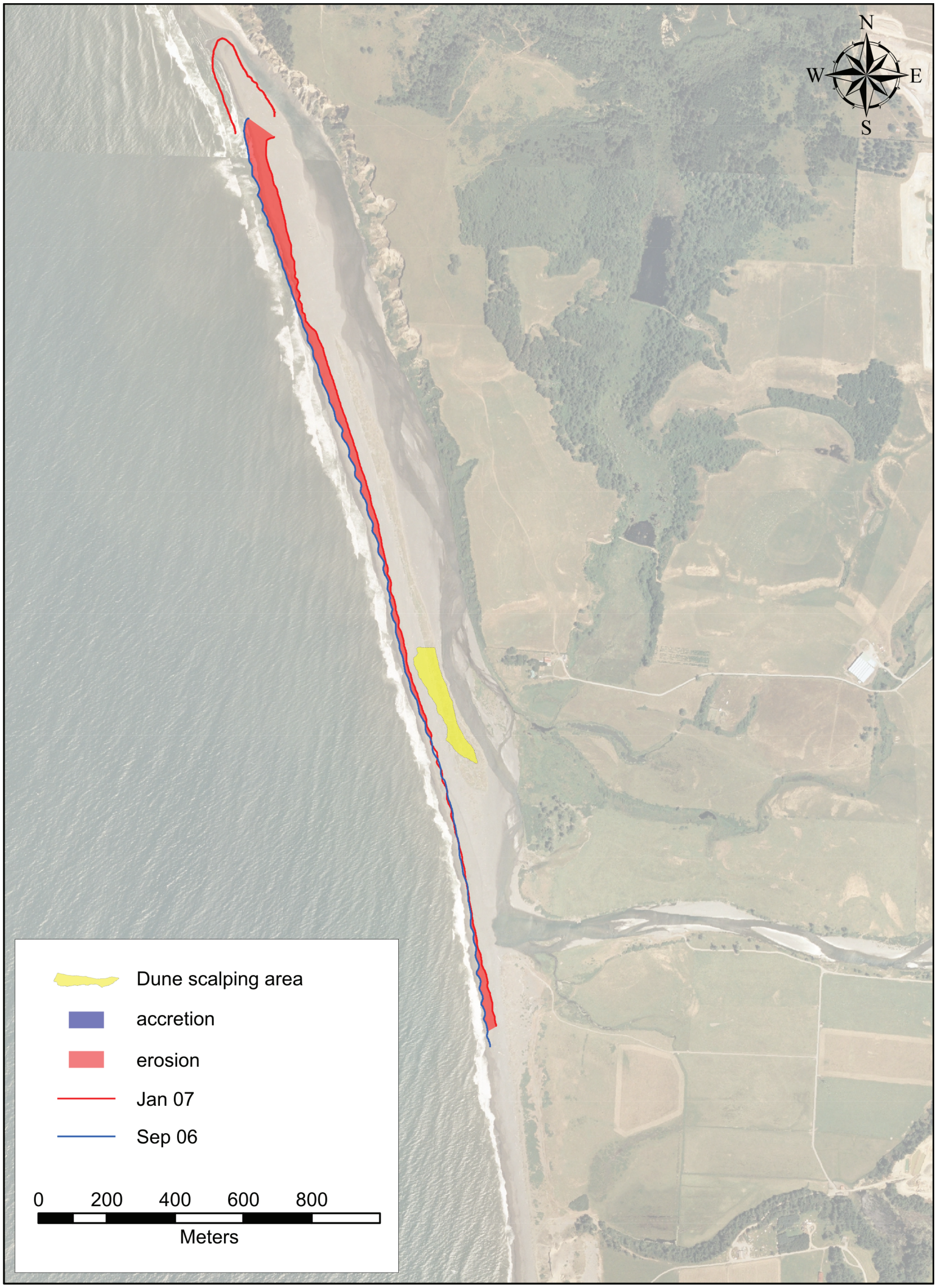

Figure 11. 3-m contour elevation response derived from Light Detection and Ranging (LIDAR) survey data and Real Time Kinematic Differential Global Positioning System (RTK-DGPS) survey data between September 2006 and January 2007 for the Elk River, Oregon, beach monitoring network area. Positive gains in the beach are shown in blue; negative gains (erosion) are shown in red. (image source: http://gis.oregon.gov/DAS/EISPD/GEO/fit/orthoimagery/OrthoFrame.shtml)

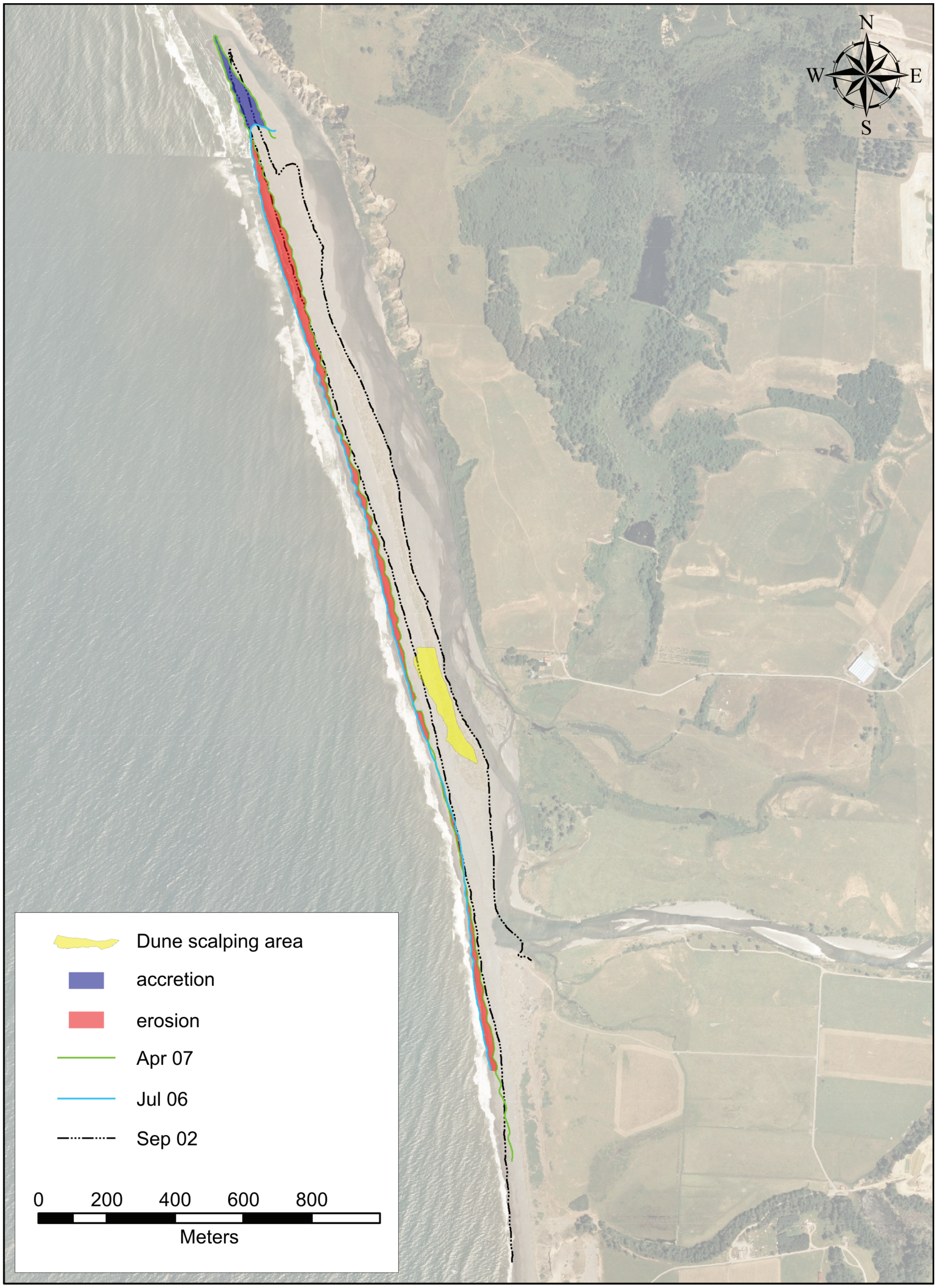

Figure 12. 3-m contour elevation response derived from Light Detection and Ranging (LIDAR) survey data and Real Time Kinematic Differential Global Positioning System (RTK-DGPS) survey data between July 2006 and April 2007 for the Elk River, Oregon, beach monitoring network area. Positive gains in the beach are shown in blue; negative gains (erosion) are shown in red. (image source: http://gis.oregon.gov/DAS/EISPD/GEO/fit/orthoimagery/OrthoFrame.shtml)

beach between 2002 and 2006, thus characterizing the state of the beach prior to the dune lowering. Figure 11 depicts the response of the beach between September 2006 and January 2007 (i.e., following the dune lowering); Figure 12 shows the net change between July 2006 and April 2007.

Figure 10 clearly indicates that the Elk River spit experienced significant aggradation and progradation of its beach face between 2002 and 2006. It is not immediately clear where the bulk of the sand came from, though several possibilities exist, including:

- Erosion of the barrier beach at the south end of the littoral cell adjacent to Garrison Lake, which occurred between 1997 and 1999 (Allan and others, 2003), and the subsequent redistribution of those sediments to the north;
- Erosion of the high bluffs north and to the west of the Elk River mouth;
- Effects from spit breaching, as occurred in the 2005-2006 winter, which is capable of reintroducing significant quantities of sediment to the littoral system; or,
- Some combination of all the above.

In all likelihood, shoreline changes seen between 2002 and 2006 reflect some combination of all the above inputs. Irrespective of this, it is immediately clear that the state of the beach prior to dune lowering was characterized by abundant sand (~+282,000 m^3 [+368,800 yd^3]). As a result, the addition of an estimated 22,000 m^3 of new sand derived from the dune lowering reflects a small proportion (7.8%) of the total sand budget along the spit for the period 2002 to 2006. Of interest, the beach immediately south of the lowered dune experienced very little change, as this is the portion of the spit that is periodically breached and overtopped.

Figure 11 captures the response of the beach over the 2006-2007 winter. As can be seen in Figure 11, essentially the entire spit was subject to erosion, with the greatest degree of erosion occurring in the north near the spit tip. This latter response is not surprising, as this portion of the spit is regularly washed over during the winter months due to its low elevation. South of the elbow, the beach was again characterized mainly by erosion responses. Figure 12 shows the net change between July 2006 and April 2007. Figure 12 reveals the effects of the post-winter rebuilding of the spit as sand is returned from nearshore bars to the beach face. In general, Figure 12 indicates that the bulk of the erosion was still centered in the north and extreme south, while the south-central portion of the spit experienced generally little change. Nevertheless, these results again demonstrate that the volume of sand present along the spit is much higher as of April 2007 compared with September 2002 when the LIDAR survey was undertaken. As a result, effects from the dune lowering to date are essentially negligible compared with the natural range of beach morphodynamics present on the spit

CONCLUSION

The purpose of this study was to establish a beach monitoring network along the Elk River spit in order to document the natural range of variability of the beach and to assess whether lowering of the dune to an elevation of 7.0 m (23 ft) NAVD88 would have an adverse impact on the beach system.

In late July and early August 2006, approximately 370 m of dune was eventually lowered, with the sand having been removed seaward where it was placed on the upper beach face. This process yielded approximately 22,000 m^3 of new sand, which is now available to wave and current processes for re-entrainment. To date, very little of this "extra" sand has been removed by wave and current processes; this response may be a function of the generally mild 2006-2007 winter season (particularly since mid January 2007) and the wide beach that characterizes the section of the shore seaward of the modified dune section. Nevertheless, as the beach and dunes are generally subject to large waves during the winter months, it is inevitable that the placed sand will eventually be redistributed elsewhere. Wave and tide conditions during the 2006-2007 winter did not result in any wave overtopping in the lowered dune section, although portions of the spit to the south of the modified dune did experience overtopping. As additional phases of dune lowering occur in the future, the process of periodic wave overtopping is likely to increase.

As a result of repeated surveys of the Elk River beach monitoring network and shoreline contour measurements using RTK-DGPS technology, it is abundantly clear that thus far the degree of natural variability of the spit greatly exceeds any effect associated with lowering of the dune. In fact, conditions immediately prior to the dune modification phase were characterized by abundant sand, with the beach essentially having gained some 282,000 m^3 (+368,800 yd^3) of sand since

2002. Consequently, the addition of an extra 22,000 m^3 of sand to the littoral system is essentially negligible at this stage. Nevertheless, as additional sections of dune are lowered, resulting in the introduction of ever larger quantities of sand, it is possible that we may begin to document changes to the morphodynamics of the spit and beach. To this end, we recommend continued periodic monitoring of the spit to further document future changes to the spit and beach.

Acknowledgements. This study was partially funded by a $5000 contract from the South Coast Watershed Council per an agreement letter dated July 13, 2006.

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