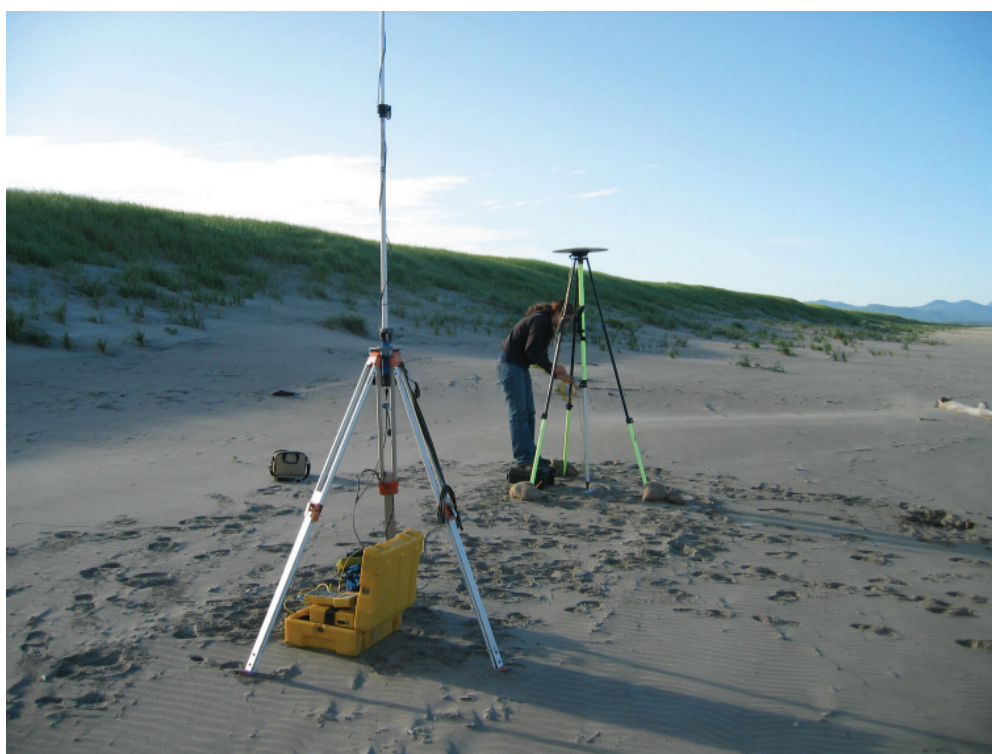


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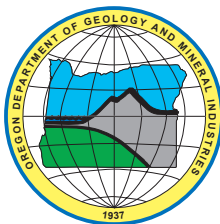
**Open-File Report O-07-01**

# **ASSESSING THE TEMPORAL AND SPATIAL VARIABILITY OF COASTAL CHANGE IN THE NESKOWIN LITTORAL CELL: DEVELOPING A COMPREHENSIVE MONITORING PROGRAM FOR OREGON BEACHES**

**TECHNICAL REPORT TO THE OREGON DEPARTMENT OF LAND CONSERVATION AND DEVELOPMENT**



By  
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## EXECUTIVE SUMMARY

This report describes the procedures used to establish a comprehensive beach and shoreline observation system in the Neskowin littoral cell, located on the northern Oregon coast. The fundamental objective of such a monitoring program is to begin to document the response of Oregon's beaches to various climatological and oceanographic processes, including the effects of major storms, climate events such as El Niños, and longer-term impacts associated with climate change and sea level rise, which ultimately may affect the stability or instability of Oregon's beaches. Understanding these responses is critical for effectively managing Oregon's valuable beach resource.

Beach monitoring was undertaken in the Neskowin littoral cell using a Trimble 5700/5800 Real-Time Kinematic Differential Global Positioning System (RTK-DGPS). The monitoring network consists of 15 beach profile sites; seven of these are located south of the Nestucca Bay mouth, while the remaining eight sites are dispersed along Nestucca Spit. Our beach monitoring efforts thus far have identified a number of interesting aspects of large-scale beach responses, including:

- The beaches along the Neskowin shore (south of the estuary mouth) are presently in an erosional phase, with the mean shoreline receding landward since at least 1997, with no evidence for recovery at this stage.
- Beaches along Nestucca Spit have mainly been accreting. However, accretion in the north is confined entirely to a gradual build-up of sand on the primary frontal dune raising its crest elevation over time. As a result, although this section of shore has accreted slightly during the past decade, accretion has not led to a change in the position of the mean shoreline (i.e., the shoreline has not prograded seaward).

- The beaches remain in a state of net deficit compared to their condition in 1997, with the estimated loss of sand as of June 2006 being on the order of 1 to 1.5 million m<sup>3</sup> (1.3 to 2.0 million yd<sup>3</sup>) of sand. Whether the beach recovers fully and how long it takes remain important scientific and management questions, which will be answered as the beaches are monitored.
- Analyses of alongshore responses of selected beach contour elevations indicate that the littoral cell was not greatly affected by the 1997-1998 El Niño. In contrast, erosion caused by the 1998-1999 winter was more extensive; parts of the Neskowin shore eroded landward by as much as 50 m (approximately 150 ft).
- Post-storm recovery has been slow, with little evidence of significant sand build-up having occurred on the upper beach face (i.e., the dune face). This is despite the fact that a significant volume of sand has clearly migrated back onto the lower beach face (i.e., below the 3-m contour elevation). The lack of sand accumulation high on the beach face suggests that the present climate may not be conducive for transporting sand landward from the beach face.
- The most recent survey confirms that there has been a large redistribution in the sand budget, with much of the sand having been transported northward along the littoral cell (i.e., toward Nestucca Spit).

As future surveys are conducted and analyzed, the patterns of sand transport within the Neskowin littoral cell (and elsewhere) will become clearer. Of importance, we now have a system in place that can be used to better document and understand changing beach morphodynamics, including the tracking of large-scale sand movements within the cell, the effects of future storms, and any post-storm recovery.

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## INTRODUCTION

Over the past century, the Oregon coast has undergone several periods of major coastal erosion in which the mean shoreline position retreated landward, encroaching on homes built atop dunes and coastal bluffs and, in several cases, resulting in the destruction of homes. The most notable of these events took place in 1934, 1939, 1958, 1960, 1967 (Dicken and others, 1961; Stembridge, 1975), the winters of 1972–1973, 1982–1983 (Komar, 1997), and, most recently, in 1997–1999 (Allan and others, 2003). Of these, it is generally thought that the winter of 1938–1939—specifically, a storm in January 1939—was probably the worst on record (Dr. Paul Komar, personal communication, 2006). This storm resulted in extensive coast-wide erosion (e.g., Netarts Spit was breached at several locations), along with the flooding inundation of several communities (e.g., Seaside, Cannon Beach, Rockaway, and Waldport), as ocean waves accompanied high water levels (Stembridge, 1975). The effects of the January 1939 storm were captured in the 1939 suite of aerial photographs flown by the US Army Corps of Engineers (USACE), but these photos have never been orthorectified, making it difficult to interpret the true extent of the storm’s impact on the coast.

An assessment of how Oregon beaches respond to storms could not be fully documented until the late 1990s, when a joint venture between the U.S. Geological Survey (USGS), the National Aeronautics and Space Administration (NASA), and the National Oceanic and Atmospheric Administration (NOAA) used Light Detection and Ranging (LIDAR) technology to measure the topography of U.S. coastal beaches. On the Oregon coast, the results of such surveys have been published in several papers (Allan and Hart, 2005; Allan and Komar, 2005; Allan and others, 2003, 2004; Revell and others, 2002; Revell and Marra, 2002). However, while LIDAR provides an unprecedented amount of quantitative information that may be used to assess beach morphodynamics, on the Oregon coast such data sets have been collected on only three occasions: 1997, 1998, and in 2002. No additional measurements are scheduled until 2008, and given the present high costs of LIDAR surveys, the expectation is that LIDAR will be flown only approximately every five years. As a result, the temporal scale of the LIDAR surveys is presently insufficient to adequately characterize the

short-term and to a lesser extent the long-term trends of beaches.

The purpose of this report is to describe an effort by staff from the Coastal Field Office of the Oregon Department of Geology and Mineral Industries (DOGAMI) to develop a comprehensive beach observation program, capable of providing high-quality quantitative data on the response of Oregon beaches at spatial and temporal scales that are of most value to coastal resource managers and the public-at-large. Such data, supplemented by analyses of the LIDAR surveys taken in 1997, 1998, and 2002, are beginning to yield important insights on how Oregon beaches respond to storms, and how the beaches may be recovering from those events. Finally, the approach and results described here reflect an expansion of a larger cooperative venture to establish a “Pilot Coastal Ocean Observatory for the Estuaries and Shores of Oregon and Washington” that includes ongoing beach monitoring in the Rockaway littoral cell and on the Clatsop Plains (<http://www.oregongeology.com/sub/nanoos1/index.htm>).

### Management Needs

Management of Oregon beaches and dunes falls under the jurisdiction of the Oregon Parks and Recreation Department (OPRD), the Oregon Department of Land Conservation Development (DLCD) agency through its Coastal Management Program, and local jurisdictions through their comprehensive plans and land-use ordinances. OPRD has jurisdiction over the active beach up to the Statutory Vegetation Line (surveyed in 1967) or the existing vegetation line, whichever is located most landward, and thereby controls the permitting of structures used to protect ocean shore property. DLCD works with the planning departments of local jurisdictions to preserve Oregon beaches and dunes by ensuring that local departments apply standards for siting development as required by specific statewide planning goals that are incorporated into local comprehensive plans. The DLCD provides technical assistance to local jurisdictions in the form of model ordinances, as well as support for improved and updated mapping and inventories.



The permitting of new ocean shore development by state and local jurisdictions is based on the best available knowledge and, in some cases, site investigations of specific locations. Although the information collected through these efforts meets the standards required by agencies, at times the information is piecemeal and does not always reflect an adequate understanding of the processes affecting the property for making sound decisions (e.g., site-specific studies on dune-backed beaches tend to be too narrowly focused, thereby ignoring the larger picture). Specifically, the information presented often does not fully take into account the high-magnitude episodic nature of North Pacific extratropical storms, the long-term processes that may impact the property, the manner in which the proposed alterations might affect the system, or the effect those alterations could have on adjacent properties. State and local agencies are therefore relegated to making decisions about ocean shore development, with only a partial understanding of their potential impacts. Those decisions will affect not only the relative level of risk posed to that development but also the long-term integrity of ocean shore resources and a variety of public recreational assets. Improved baseline data and analysis of beach morphodynamics will enable state agencies and local governments to better predict future shoreline positions and will provide the quantitative basis for establishing scientifically defensible coastal-hazard setback lines.

New baseline data and recurrent surveys will help coastal managers resolve short- and long-term specific planning issues including:

- What are the spatial and temporal responses of beaches to major winter storms in the Pacific Northwest (PNW) and to climate events such as El Niños and La Niñas?
- Over what temporal scales do beaches recover from winter storms, El Niños, or persistent El Niño conditions that characterize the warm phase of the Pacific Decadal Oscillation? Do beaches fully recover?
- How can we improve on existing process/response models so they adequately account for the erosion of PNW beaches? Present models were developed mainly for U.S. east coast wave and sediment transport conditions, rather than the significantly different conditions in the PNW. The wave climate in the PNW is far more severe, and, unlike the unidirectional longshore movement of beach sediment typical of the U.S. east and Gulf coasts, Oregon beach sand oscillates from south to north, winter to summer, within its headland-bounded littoral cells.
- What are the cumulative effects of the increasing storm wave height, increasing armoring of shorelines, and possible accelerating sea level rise on erosion rate predictions for bluffs and dunes? Is past practice of using historical data (air photos, surveys) to make erosion predictions defensible? If not, what quantitative approach should take its place? Can a numerically based model be developed that adequately handles all of the forcing that affects coastal change in the PNW?
- The loss of large volumes of sediment from several littoral cells on the northern Oregon coast in recent years (e.g., Netarts and Rockaway) raises obvious questions: why are the beaches eroding, where has the sand gone, and will it return?
- What are the spatial and temporal morphological characteristics of rip embayments on PNW beaches? What are the “hotspot” erosion impacts of rip embayments on dunes and beaches? How often do these rip embayments occur at a particular site on the coast, and what is the long-term effect on bluff erosion rates?
- How has the morphology of Oregon beaches changed since the 1960s (i.e., when the coastline was last surveyed)?
- What are the implications of climate change to Oregon beaches as a result of increased storminess, the greater heights of waves the storms generate, and sea level rise?

Integral to answering many of these questions and to making informed decisions based on technically sound and legally defensible information is an understanding of the scales of morphodynamic variability within the coastal zone. Comprehensive beach monitoring programs have enhanced decision-making in the coastal zones of populous states such as Florida (Office of Beaches and Coastal Systems, 2001), South Carolina (Gayes and others, 2001), and Texas (Morton, 1997). These programs typically include the collection of topographic and bathymetric surveys, remote sensing of shoreline positions (aerial photography or LIDAR), and measurements of environmental processes such as currents, waves, and sediment transport. Over time

such datasets prove critical in calibrating predictive models of shoreline change, in the design of shore-protection measures, and in determining regional sediment budgets (Gayes and others, 2001).

A major goal of this study is the development of a comprehensive shoreline observation network (CSON) for the Neskowin cell that will complement existing efforts in the Rockaway littoral cell (<http://www.oregongeology.com/sub/nanoos1/index.htm>). The specific objectives of the current project are:

1. Establish a comprehensive shoreline observation network along the Neskowin littoral cell. Network activities include:
  - a. Setting up at least 12 beach profile stations located approximately 1 km apart;
  - b. Identifying appropriate sites for the establishment of permanently monumented GPS survey benchmarks (at least six sites are required), installing the monuments consistent with existing approaches used along the Rockaway littoral cell, and undertaking surveys to establish precise locations and elevations of the monuments (these monuments will provide GPS control for the established survey network); and,
  - c. Periodically resurveying the pilot Neskowin shoreline observation network to assess the response of the beaches to North Pacific winter storms over a one-year period. Beach surveys will be undertaken on a quarterly basis and or after major storms.
2. Expand the existing Oregon beach observation website (<http://www.oregongeology.com/sub/nanoos1/index.htm>) to include the Neskowin beach observation network and to provide additional improvements to the readability and usability of the website.
3. Disseminate beach state/change data and products among coastal managers and regulatory authorities in appropriate formats. Beach state data (i.e., beach slope, tidal-based shoreline proxies, and dune height/position) will be extracted from the beach profiling to enhance the conceptual understanding of Oregon beaches and to refine existing predictions of future coastal change and hazards.

## Background

Beaches composed of loose sediments are among the most dynamic and changeable of all landforms, responding to a myriad of complex variables that reflect the interaction of processes that drive coastal change (waves, currents, and tides) and the underlying geological and geomorphological characteristics of beaches (sediment grain size, shoreline orientation, beach width, sand supply and losses, etc.). These factors contribute to the morphology and position of the beach by:

1. Promoting the supply of sediments to the coast for beach construction;
2. Transferring sediments through the system; and, ultimately,
3. Removing sediments through the process of erosion.

Because beaches are composed of loose material, they are able to respond and adjust their morphology rapidly in intervals of time ranging from seconds to days to years, in response to individual storm events, enhanced periods of storm activity, and increased water levels (e.g., the 1982-1983 and 1997-1998 El Niños).

Beginning with the 1997/98 El Niño, the Oregon coast experienced a series of unusually severe storms characterized by over 20 storms during which deep-water significant wave heights exceeded 6 m for 9 hours or longer. Prior to the 1997/98 winter the largest number of major storms experienced in a single season was 10 to 12, which occurred in the early 1980s (1982–1986). Furthermore, on the basis of wave data up through 1996, researchers had calculated 100-year storm waves to be around 10 m (33 ft) for the Oregon coast. However, an event on November 19-20, 1997, exceeded that projection, and wave conditions were far worse the following winter, 1998-1999. Twenty-two major storms occurred. Four storms generated deep-water significant wave heights over 10 m, and the largest generated wave heights of 14.1 m (47 ft). When wave energy of this magnitude (approximately proportional to the square of the wave height) is expended on the low sloping beaches characteristic of the Oregon coast, especially at times of elevated ocean water levels, these storms have the potential for cre-



ating extreme hazards to developments in foredunes and atop sea cliffs backing the beaches. For example, the cumulative impact of these recent extreme storms along the Neskowin and Netarts littoral cells in Tillamook county resulted in the foredune retreating landward by on average 11.5 m (38 ft) and 15.6 m (49 ft), respectively, and as much as 55 m (180 ft) in some locations, damaging properties fronting the eroding shore (Allan and others, 2004). In response to the erosion, property owners have resorted to using riprap to safeguard their properties. After extreme erosional events there is usually a period lasting several years during which dunes rebuild until they are eroded by another storm (Allan and others, 2003). How long this process takes is not known for the Oregon coast.

Longer-term adjustments of beaches may also result from changes in sediment supply or mean sea level. However, attempts to quantify these processes suggest that erosion due to rising sea level is considerably less than erosion due to individual storms or storms-in-series.

The monitoring of two-dimensional beach profiles over time provides an important means of understanding the morphodynamics of beaches and the processes that influence net volumetric gains or losses of sediment (Morton and others, 1993; Ruggiero and Voigt, 2000). Beach monitoring is capable of revealing a variety of information concerning short-term trends in beach stability, such as the seasonal response of a beach to prevailing wave energy, responses due to individual storms, or “hotspot” erosion associated with rip embayments. Over sufficiently long periods, beach monitoring can help us learn about the long-term response of a particular coast, such as progradation (seaward advance of the mean shoreline) or recession (landward retreat), attributed to variations in sediment supply, storminess, human impacts, and, ultimately, as a result of a progressive increase in mean sea level.

## Methodology

Beach profiles that are oriented perpendicular to the shoreline (Figure 1) 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, 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; this 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 day; other forms of LIDAR technology are now being used to measure nearshore bathymetry but are dependent on water clarity. However, the technology remains expensive and is impractical along small segments of shore. More importantly, the high cost of LIDAR effectively limits 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 sub-aerial and sub-aqueous portions of the beach has effectively become the accepted standard (Bernstein and others, 2003; Morton and others, 1993; Ruggiero and others, 2005; Ruggiero and Voigt, 2000).

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 Department of Defense. In its simplest form, GPS can be thought of as triangulation with GPS satellites acting as reference points, enabling users to calculate their position to within several meters (e.g., off-the-shelf handheld units). Survey-grade GPS units can provide positional and elevation measurements accurate to 1 cm. At least four satellites are needed mathematically to determine exact position, although more satellites are generally available. The process is complicated, as 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 signals bounce off features and create a messy signal). For example, handheld autonomous receivers

have positional accuracies 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). WAAS is essentially a form of differential correction that accounts for the above errors. The corrected data are then broadcast through one of two geostationary satellites to WAAS-enabled GPS receivers.

Greater survey accuracies are achieved with differential GPS (DGPS). DGPS uses two or more GPS receivers to track simultaneously 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 the 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).

To establish a dense GPS beach monitoring network, we initially identified the approximate locations of the profile sites used in this study in a Geographical Information System (GIS). A reconnaissance trip was undertaken in early January 2006 to field check the proposed sites and to identify potential benchmark



Figure 1. Map of the Neskowin littoral cell beach monitoring network showing the location of the GPS survey control benchmarks and beach profile transects, which are located perpendicular to the shoreline.



locations. Figure 1 shows the general layout of the final survey network, which consists of eight sites between Neskowin and the Nestucca estuary mouth and seven sites located along Nestucca Spit further to the north (i.e., three more sites than originally proposed). We then installed eight permanently monumented benchmarks along the Neskowin cell to serve as GPS control for the beach profile surveys (Figure 1). The benchmarks were installed during the latter half of January 2006 and were divided evenly between the two shore-line segments. The benchmarks were constructed by first digging 1-m deep, 10-in (25-cm) diameter holes, into which aluminum sectional rods were inserted and hammered to additional depths of approximately 4–8 m (12–24 ft, Figure 2). The rods were then capped with a 2.5-inch aluminum cap (with an Oregon Department of Geology and Mineral Industries stamp on top), and concreted in place. One of the benchmarks (Cntrl 5) consists of a 3-inch (7.62 cm) diameter brass cap that was drilled and glued (we used a fast-setting

Power Fast™ epoxy cement) into a sandstone outcrop located just north of the Winema Christian Camp.

Precise coordinates and elevations were determined for the Neskowin GPS control sites using a Trimble™ 5700/5800 Total Station Global Positioning System (GPS). 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 a known geodetic survey monument to establish precise survey control. For the purposes of this study, we used several National Geodetic Survey benchmarks, including ‘Nesk,’ ‘Isle,’ and ‘Beaver,’ with additional control provided by three Continuously Operating Reference (CORS) GPS Stations that were closest to our study area. Static GPS surveys of the new monuments were initially undertaken on February 14, 2006, and typically involved occupation times of 15–20 minutes at each site (Figure 3). This approach enabled multiple baselines to be established from known survey bench-



Figure 2. Installation of sectional aluminum rods to be used as benchmarks in the town of Rockaway in Tillamook county.



Figure 3. Static GPS occupations were used to determine precise coordinates and elevations at each benchmark site. GPS occupations typically ran for 15–20 minutes and were post-processed using National Geodetic Survey (NGS) benchmarks and Continuously Operating Reference Stations (CORS).



marks to the unknown monuments, which produced excellent survey control. Coordinate information for each of the benchmarks was determined both in geographic coordinates and in the Oregon State Plane (northern zone, meters) coordinate system. All elevations are expressed in the North American Vertical Datum of 1988 (NAVD88). The survey was repeated two days later, on February 16, to verify the accuracy of the initial GPS occupations and to identify any survey errors. This approach yielded horizontal errors that averaged  $\pm 0.004$  mm and a vertical error of  $\pm 0.009$  mm, indicating a high level of precision.

Having derived coordinates and elevations for each of the GPS control benchmark sites, surveying of the beach profiles commenced on March 30 (Neskowin shore) and March 31 (Nestucca Shore) of 2006. Surveying was accomplished by locating the 5700 base station either on or adjacent to one of the benchmarks and then performing a site calibration on the remaining benchmarks to establish a local coordinate system. This step is critical in order to eliminate various survey errors. For example, Trimble reports that the 5700/5800 GPS system has horizontal errors of approximately  $\pm 1$  cm + 1 ppm (parts per million  $\times$  the baseline length) and a vertical error of  $\pm 2$  cm (Trimble Navigation Limited, 2005). These errors may be compounded by other factors such as poor satellite geom-

etry, multipath, and poor atmospheric conditions, combining to increase the total error to several centimeters. Thus, the site calibration process is critical in order to minimize these uncertainties (Ruggiero and others, 2005).

Once the local site calibration was completed, cross-shore beach profiles were surveyed with the 5800 GPS rover unit mounted on a backpack (Figure 4). This process was typically undertaken during low tide. The approach generally was to walk from the landward edge of the primary dune, over the dune crest, down the beach face, and out into the ocean to approximately wading depth. 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  $\pm 0.5$  m either side of the line) and, typically, results in negligible vertical uncertainties due to the wide, gently sloping beaches characteristic of much of the Oregon coast (Ruggiero and others, 2005). The surveys were repeated on approximately a quarterly basis and/or after major storms. According to previous research, this method 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 1–2 m (3–6 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 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 Neskowin area and to reduce any errors that may have occurred as a result of the GPS units. The reduced profile data were then exported for subsequent analysis.

Analysis of the beach survey data involved several stages. First, data were imported into MATLAB<sup>®</sup> using a customized script. A least-squares linear regression was then fit to the profile data. The purpose of this script is to examine the reduced data and to eliminate



Figure 4. Profile surveys being undertaken using a Trimble 5800 GPS rover mounted on a backpack.

\* A high-level computer programming language.

data points that exceed a  $\pm 0.5$ -m threshold on either side of the predetermined profile line. The data are then exported into a Microsoft Excel spreadsheet for archiving purposes. A second MATLAB script uses the Excel profile data to plot the latest survey data (relative to the earlier surveys) and outputs the generated figure as a Portable Network Graphics image file. A third script examines the profile data and quantifies changes that have occurred at selected contour eleva-

tions. For this study temporal trends are developed for all contours between 1-m and 6-m elevations and for all available data. Finally, the reduced contour data are plotted against time and exported as a Portable Network Graphics image file for additional analysis. After analysis is complete, images are displayed on the Department of Geology's website (<http://www.oregongeology.com/sub/nanoos1/index.htm>) for online access.

## RESULTS

A variety of approaches may be used to view and analyze the beach morphology measured by the surveys. This includes the traditional approach of simply examining the temporal and spatial variability of graphed beach profiles. Other approaches include examining the 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.

### Beach profiles

Beach profiles provide important information concerning the temporal (time) and spatial (cross-shore) variability in the shape of a section of beach. The information derived from repeated surveys provides a measure of beach response to variations in wave energy (e.g., winter versus summer wave conditions), which is reflected in accretion of the beach during the summer and erosion in winter. These data may also contain important information on how the beach responds to major storms, such as during the extreme 1997-1998 and 1998-1999 winters, including dune or bluff erosion, data that are extremely useful when designating hazard zones along the coast. Given the short period in which beach profiles have been surveyed along the Neskowin cell, information derived from Light Detection and Ranging (LIDAR) topographic surveys has been used to supplement the measured beach monitoring data. Along the Neskowin cell, airborne LIDAR beach elevation data were obtained in October 1997 (pre El Niño), April 1998 (post El Niño), and in September 2002 (Allan and Hart, 2005). When combined,

the LIDAR and RTK-DGPS data provide information spanning almost a decade on the morphodynamics of the beach in the Neskowin littoral cell.

Beach morphological changes for three of the study sites located between Neskowin and the Nestucca estuary are presented in Figure 5. The approximate locations of these sites are identified in Figure 1. Figure 6 documents the measured responses at three sites along Nestucca Spit, and Appendix B summarizes the profile information.

As can be seen for profile 1 located at the southern end of the littoral cell, the beach has undergone significant erosion since 1997 (Figure 5). However, although some of the erosion occurred during the 1998-1999 winter (as depicted by the 2002 LIDAR profile) due to the large number of major storms that occurred, the greatest changes have in fact occurred since 2002. Today, this beach is backed by an extensive riprap wall, and is therefore unlikely to erode any further landward in the immediate future. However, future surveys of this site may be able to capture any "active erosion effects" associated with scour along the toe of the riprap revetment, due to the reflection of wave energy from the revetment. Further north at profile 4, erosion also dominated the overall response of the beach during the past decade. In contrast to profile 1, however, most of the erosion depicted in profile 4 occurred between 1997 and 2002. Wave activity during the past four years has resulted in only minor erosion to the dune face; most erosion has been confined to the upper beach face (i.e., the portion of beach located between the 5- and 6-m contour elevations). In fact, with the exception of profile 3, erosion is the dominant response for the Neskowin shore south of profile 7. While the beach at profile 7 did experience some erosion as a result of the extreme winter storms



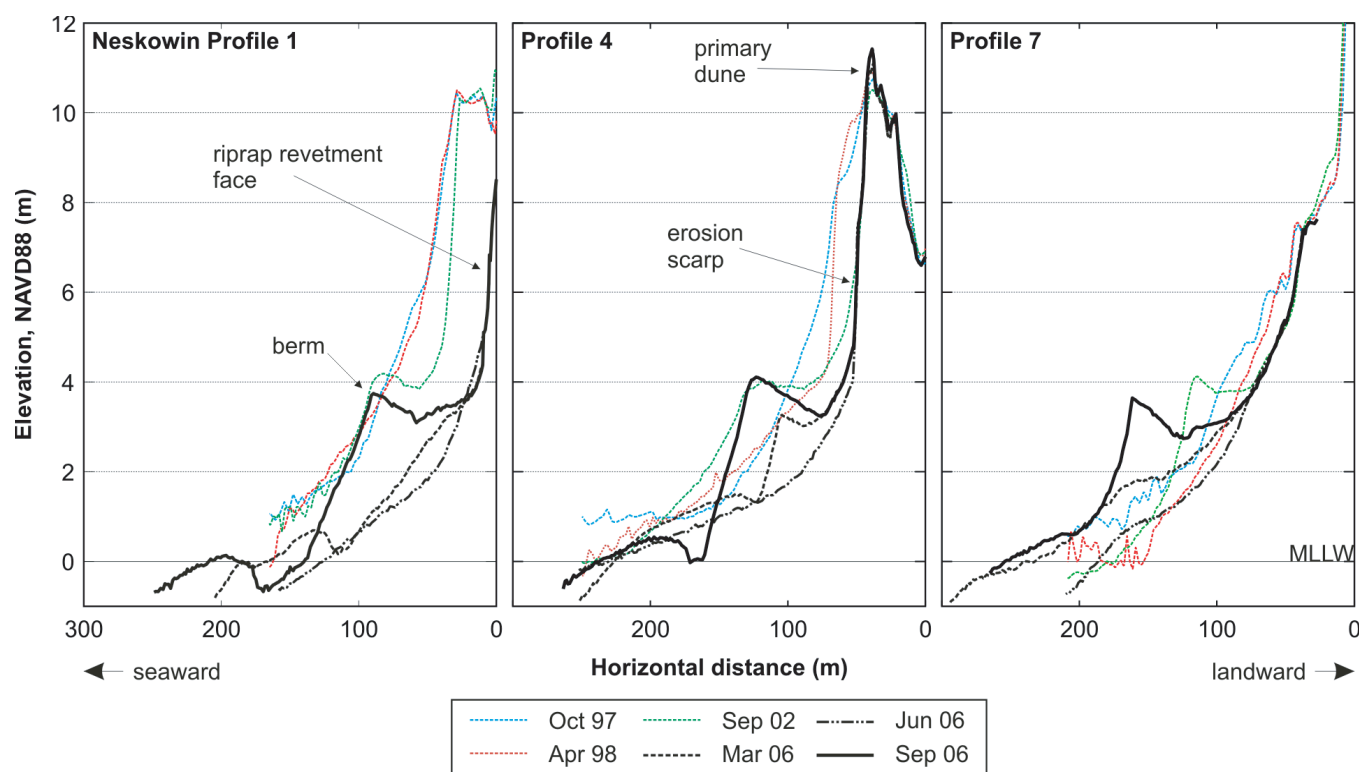


Figure 5. Sample beach profile changes derived for the Neskowin shore. Profile site locations are given in Figure 1. NAVD is North American Vertical Datum of 1988. MLLW is the Mean Lower Low Water mark

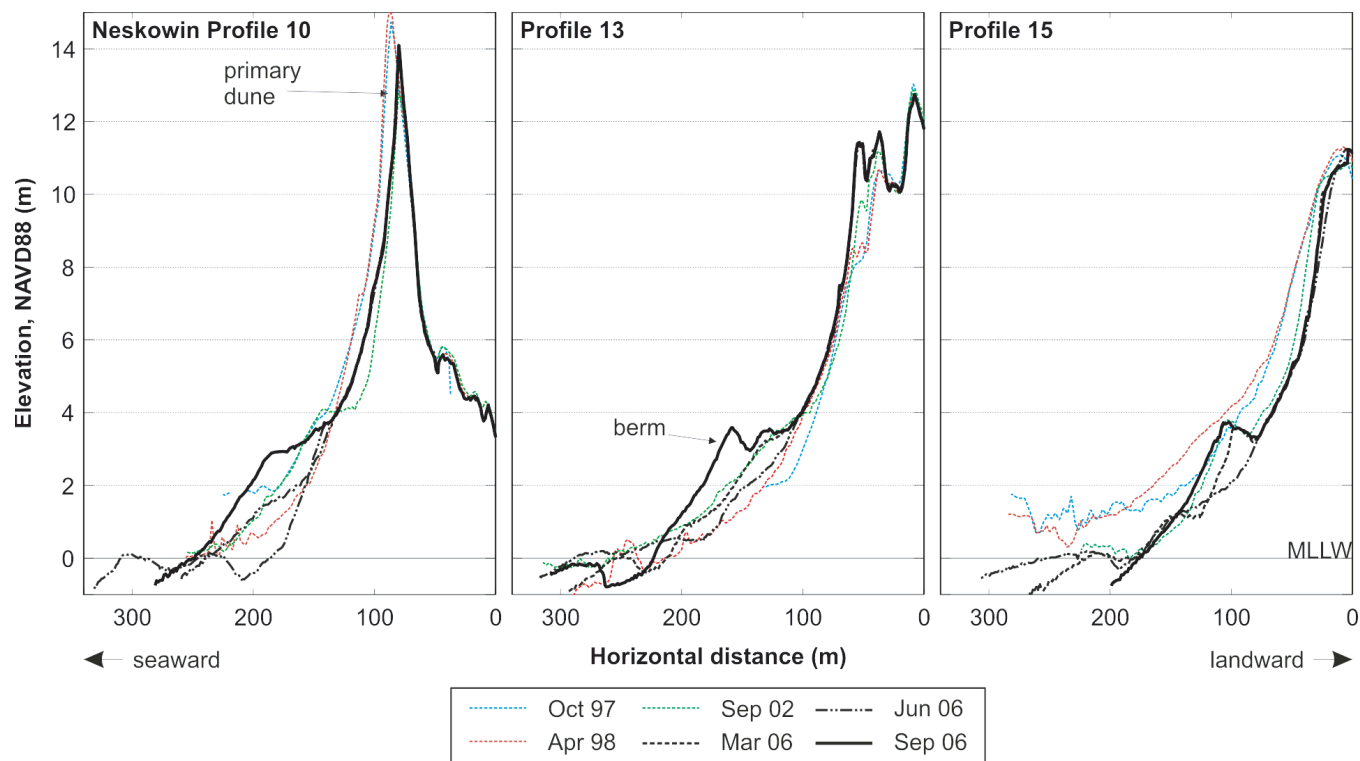


Figure 6. Sample beach profile changes derived for Nestucca Spit. Profile site locations are given in Figure 1. NAVD is North American Vertical Datum of 1988. MLLW is the Mean Lower Low Water mark.

of the late 1990s, this site has undergone little change since then (Figure 5). Further north at profile 8, the response of the beach has been the reverse, with the mean shoreline position having prograded (advanced) seaward, resulting in the development of a new frontal foredune seaward of a bluff.

Beaches along the northern half of the Neskowin littoral cell are characterized by erosional responses due to the major storms of the late 1990s as well as foredune aggradation. Figure 6 depicts the measured changes derived from three example profiles: 10, 13, and 15. Beginning in the south, profile 10 is characterized by a high, narrow, primary dune with a crest elevation of approximately 14 m (46 ft). The dune did not sustain any erosion as a result of the 1997-1998 El Niño winter but did experience significant erosion during the following 1998-1999 winter season. However, since 1999 the dune face has aggraded slightly, with rebuilding confined to the upper portion of the beach face (i.e., between the 4- and 7-m contour elevations; Figure 6). Further north, the predominant beach response has been accretion. For example, profile 13 reveals that the seaward face of the dune has aggraded vertically (Figure 6). This response typifies the morphological changes identified from profiles 11 to 14. In the far north, profile 15 remains in an eroded state, not having undergone any rebuilding since the storms of the late 1990s. In fact, this site has undergone additional erosion since 2002.

The above responses are further reinforced through an analysis of beach volume changes derived from the LIDAR beach morphodynamic database developed by Allan and Hart (2005). However, given that these data are for 1997, 1998, and 2002, estimates of net beach volume losses and gains are probably underestimated when compared with the more recent beach and dune changes measured by RTK-DGPS. The LIDAR beach profile data were reanalyzed using a volume calculation script developed in MATLAB. Essentially, the script calls on the user to designate a landward and seaward point, which are used to define the bounding box in which the volume calculation is performed. Typically, the seaward extent of the box was located close to the 1-m elevation contour, while the landward side extended onto the primary dune. Figure 7 presents the alongshore volume changes derived for the Neskowin littoral cell for three time intervals: the upper plot depicts volume changes that occurred between

1997-1998 (red line) and 1998-2002 (black line), while the lower plot shows the net change from 1997-2002 (cyan line). The data have been further smoothed using a 500-m moving average to eliminate minor local variations in the shoreline configuration. In all cases, we have used the 1997 LIDAR data as the reference point from which all changes have been related.

Analysis of the volume change calculations indicate that the 1997-1998 El Niño resulted in significant erosion along the entire shore. Greatest sand volume losses occurred in the south near the town of Neskowin and along the southern end of Nestucca Spit, while the northern end of the littoral cell was predominantly characterized by net gains of sand (Figure 7). However, sediment volume gains in the north are small compared to the net losses observed along the bulk of the shore. Summing the volume changes along the shore reveals that erosion of the beach and dune during the 1997-1998 El Niño resulted in the removal of some 728,000 m<sup>3</sup> (952,000 yd<sup>3</sup>) of sand, the bulk of which was probably carried offshore. Between 1998 and 2002 (black line), sand began to migrate back onto the beach where it accumulated as a berm (e.g., Figures 5 and 6). The bulk of the accretion occurred along Nestucca Spit, likely due to the northward transport of sand as a result of the combined effect of the 1997-1998 El Niño winter storms and the more extreme winter storms of 1998-1999, which produced large waves out of the southwest. Some accretion also occurred in the far south near Neskowin. In contrast, erosion dominated the rest of the Neskowin shore. Near Pacific City in the far north, a large rip embayment formed and likely contributed to erosion of the beach there (recall that this area had previously accumulated a small amount of sand). The net change for this latter interval was one of accretion, with the beach having gained approximately 184,000 m<sup>3</sup> (240,700 yd<sup>3</sup>) of sand. Finally, the lower plot in Figure 7 reveals the net change from 1997 to 2002. The plotted line indicates that as of 2002 much of the shoreline was characterized by a net deficit of sand, while a few areas had gained material (e.g., adjacent to the Nestucca estuary mouth and the dunes seaward of Pacific City). The total sand volume change for this period was -784,000 m<sup>3</sup> (-1,025,500 yd<sup>3</sup>) of sand, a net loss. As the latest survey results indicate additional erosion along the Neskowin shore, with only minor gains on the dunes along Nestucca Spit, it is likely that the beach remains in a state of net

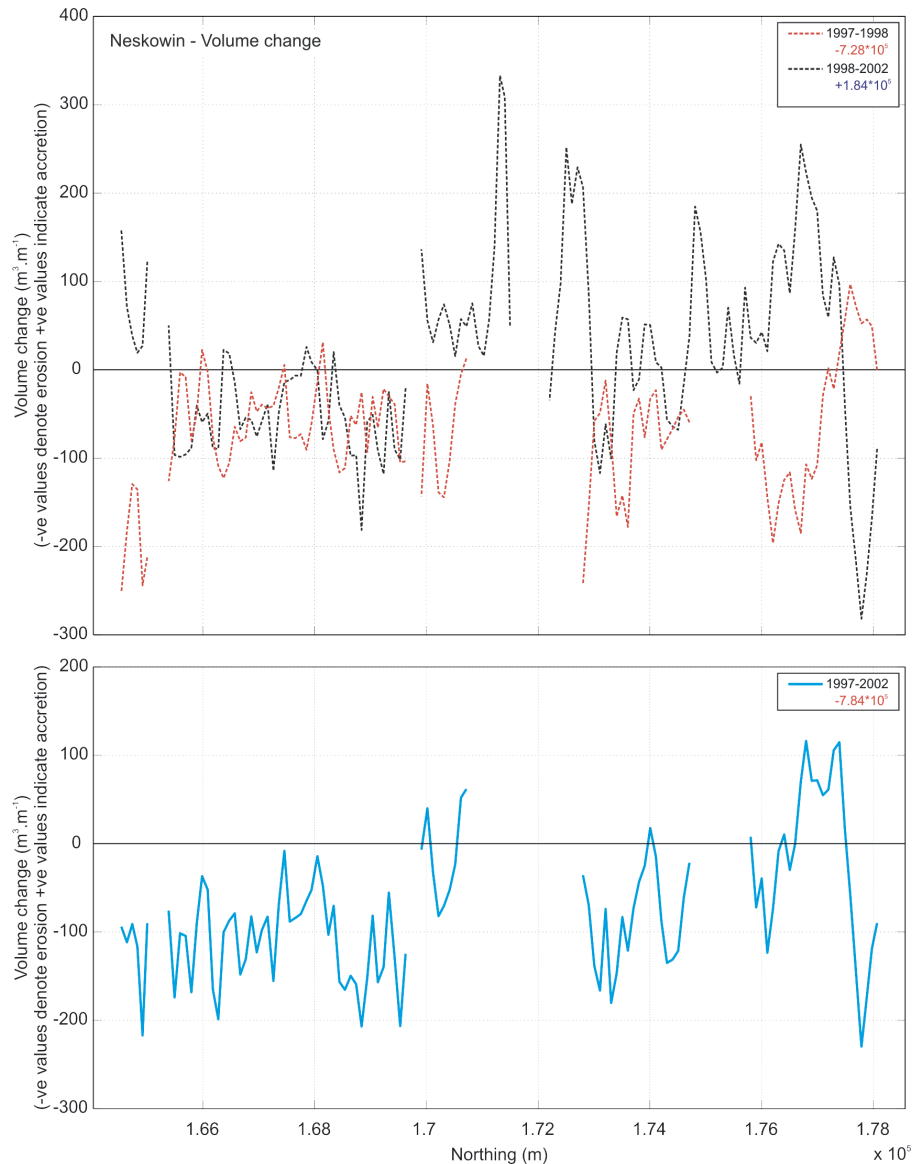


Figure 7. Alongshore beach volume changes derived from an analysis of available LIDAR data for Neskowin littoral cell. Data are derived from a re-analysis of LIDAR beach profile changes originally developed by Allan and Hart (2005).

deficit compared to conditions in 1997, with total sand loss as of June 2006 estimated to be about 1 to 1.5 million  $\text{m}^3$  (1.3 to 2.0 million  $\text{yd}^3$ ).

In summary, the measured responses identified by the combined LIDAR and RTK-DGPS survey data indicate that beaches along the Neskowin shore have continued to erode over time, with no evidence of recovery at this stage. Conversely, beaches along Nestucca Spit have been mainly accreting. However, accretion in the north has been confined to a gradual build-up of sand on the primary frontal dune, raising its crest elevation over time. As a result, although this section

of shore has accreted slightly over the past decade, this has not been translated to a change in the position of the mean shoreline (i.e., the shoreline has not prograded seaward). Furthermore, beaches along the littoral cell remain in a state of net deficit compared to their condition in 1997, with estimated sand loss as of June 2006 of about 1 to 1.5 million  $\text{m}^3$  (1.3 to 2.0 million  $\text{yd}^3$ ) of sand. Whether the beach recovers fully and how long recovery might take remain important and interesting scientific and management questions, which can be answered only as beaches continue to be monitored.

## Excursion distance analysis

A major limitation of conventional two-dimensional beach profile plots is that as more surveys are completed, interpreting changes becomes difficult owing to overlapping and merging profile lines. Excursion distance analysis (EDA) can resolve this problem as it depicts changes in beach position (i.e., excursions) for different contour elevations against time (Winton and others, 1981). In this respect, EDA is analogous to a 'time stack' of how the beach responds to variations in the incident wave energy, currents, and the sediment budget. As more survey data are acquired, it may become possible to model the responses of specific contours. For example, fitting a stepwise linear regression to the data can be used to extrapolate shoreline change rates for a particular site. Hence, EDA provides a simple but powerful way to analyze large amounts of beach profile data.

Figure 8 provides an example of the application of the technique for four of the beach profile sites: 1, 7, 10, and 13. Markers (black dots) identified on the lines in Figure 8 reflect when actual beach surveys were undertaken. Because the 1997 LIDAR data reflect the earliest complete survey of beach morphology in the Neskowin littoral cell, all subsequent changes have been made relative to that survey (i.e., the 1997 data become zero and future changes will vary relative to it). A positive change therefore represents accretion and a seaward shift of the profile at that elevation, whereas a negative change indicates erosion and a landward shift of the profile.

The orientation of the lines depicted in Figure 8 provides direct information on how the beach responds over time. For example, lines that deviate to the right of the zero line indicate that the beach is accreting at that contour elevation, whereas lines and points left of the zero line indicate that the site is eroding. As more contour elevations are examined down the beach face, the spacing and orientation of the lines begin to reveal more information about how the beach is responding. For example, the convergence of contour lines indicates that the beach is steepening, while diverging lines indicate that the beach is flattening. Depending on the frequency with which the surveys have been carried out, such plots can highlight the seasonal response of the beach between summer and winter as well as any longer-term evidence of coastal change. In

generating Figure 8, we have focused on four specific contour elevations due to their proximity to features of interest, including the dune toe (e.g., the 6.0-m and 5.0-m contours) or to the Mean Higher High Water (MHHW) mark (e.g., the 3.0-m contour).

As can be seen at the 6-m and 5-m contour elevations in Figure 8, erosion has dominated the response of the beach at the very south end of the cell at profile 1, with the dune toe having eroded landward by some 50 m (approximately 150 ft) since 1997. Interestingly, the bulk of the erosion occurring at this site took place between 2002 and 2006, when surveying began. Given that the frequency and magnitude of storms impacting the Oregon coast during this period were generally lower compared to those that affected the area in the late 1990s, this perhaps implies that other factors contributed to (or enhanced) the erosion at Neskowin (e.g., the development of rip embayments or "active erosion" caused by the presence of riprap structures). The extent of dune toe erosion progressively decreases northward, reaching a stable position midway on the Nestucca Spit.

The responses shown for the lower-contour elevations (i.e., the 3-m and 4-m elevations) indicate the occurrence of a lot more variability (Figure 8), with data points fluctuating over large excursion distances. This type of response is expected because this part of the beach is more frequently worked on by waves and currents, while the higher-contour elevations respond primarily to major storms. In this respect, the higher-contour rather than the lower-contour elevations provide a better measure of long-term behavior of the beach face. In time, as more surveys are obtained, the lower-contour plots will reveal the seasonal excursions of the beach face.

## Alongshore variability

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 respon-

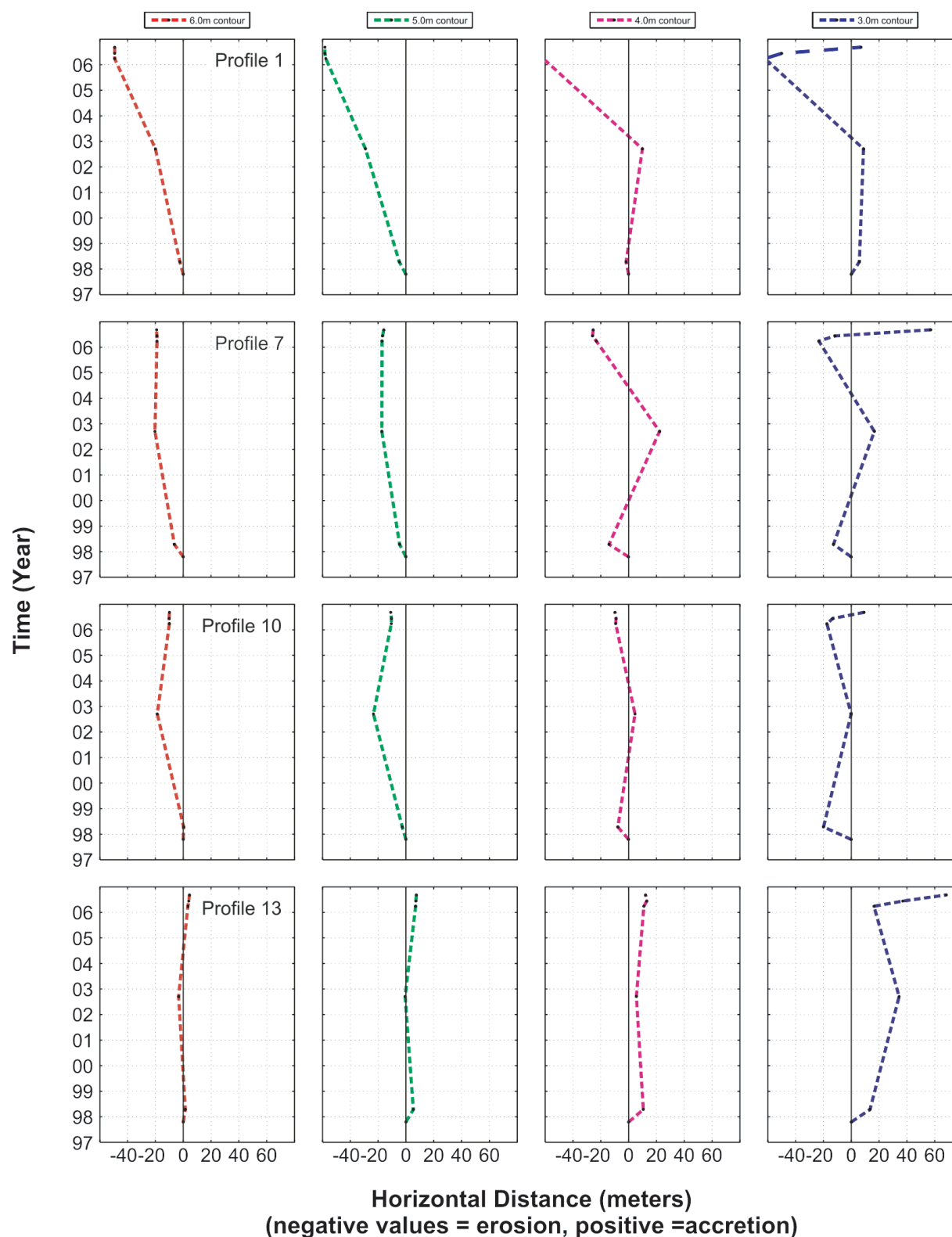


Figure 8. Excursion distance analysis (EDA) plots for several sites along the Neskowin cell. The time changes depicted in the plots are derived from four specific beach contour elevations: the dune toe (the 6.0-m and 5.0-m contour) and the Mean Higher High Water (MHHW) mark (the 3.0-m contour). The 4.0-m contour elevation represents a transition zone between the lower and upper beach face.



sible 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. During a “normal year,” summer waves approach the coast from the northwest, driving sand toward the southern 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 toward the south and also landward to form dunes. In contrast, the arrival of large waves from the west to 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 beaches and 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 a littoral cell) (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. This occurs because the storm tracks during an El Niño are displaced further to the south so they mainly cross the coast of central California (Seymour, 1996). As a result, storm waves reach the Oregon coast from a more southwesterly direction, creating an abnormally large northward transport of sand within Oregon’s littoral cells. This creates “hotspot” erosion at the southern ends of the cells, north of the bounding headlands, and also north of migrating inlets. The opposite response is found south of the headlands, where the northward displaced sand accumulates, causing the coast there to locally advance seaward. Detailed documentation of this northward sand displacement and hotspot erosion became possible during the 1997-1998 El Niño through the use of LIDAR data. For example, analyses by Revell and others (2002) used fall 1997 versus spring 1998 LIDAR data to measure 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 LIDAR data for the Netarts cell, observing that the hotspot erosion effect was greatest along the southern 1-2 km (0.6-1.2 mi) of the coast, with the mean

shoreline having eroded landward by about 20 m (65 ft), with the degree of erosion progressively decreasing northward along the spit. North of Netarts Bay, the mean shoreline was found to have prograded seaward by some 10 m (33 ft).

This section examines the alongshore response of the beach in the Neskowin littoral cell to better understand where the sediment has been transported. However, because beach profile surveys have not been extended out through the breaker zone, only the sub-aerial portion of the beach system can be assessed. It is therefore not possible to make a definitive statement on sediment movement in the Neskowin cell. Figure 9 shows the alongshore changes in the 3-m and 6-m contour excursions for three time intervals: post 1997-1998 El Niño winter, post 1998-1999 winter (determined by 2002 LIDAR survey data), and following the 2002 LIDAR survey up to the present (i.e., September 2006).

As noted previously, the expected pattern of shoreline response during an El Niño is one of erosion at the south end of the littoral cell and accretion in the north. However, Figure 9 does not appear to indicate this pattern for the Neskowin cell—instead, it shows generally minor erosion in the south, extending along much of the shore. The average dune erosion during this period was about 8.2 m (26.9 ft), with some evidence of accretion in the north. Nevertheless, although it is not immediately apparent in Figure 9, results from the volume change analysis (Figure 7) do indicate that the extreme southern end of the Neskowin cell (i.e., south of Proposal Rock) was characterized by significant “hotspot” erosion that is somewhat consistent with the expected pattern of shoreline response during an El Niño.

The 2002 LIDAR data reveal a different story, with much of the shore south of Nestucca Bay having experienced significant erosion (as seen for the 6-m contour), and with the greatest erosion having occurred just north of Proposal Rock. For the same period, Nestucca Spit experienced only minor dune erosion. Figure 9 indicates several to as much as 50 meters (approximately 150 ft) of dune retreat at the south end of the cell; the cumulative dune erosion for the period 1997–2002 in the Neskowin littoral cell was 11.5 m (38 ft). This response contrasts with changes measured on the lower beach face, which suggests that a considerable amount of sand was removed offshore following the 1999 winter storms and transported north along the

shore, where the sand has accumulated immediately south of the estuary mouth (shown by the progradation of the 3-m contour elevation for 2002 in Figure 9) as well as along most of Nestucca Spit. This pattern of response is more akin to the expected El Niño effect, whereby sand is eroded from the dunes at the south end of the cell, removed offshore, and then redistributed northwards along the shore. This perhaps implies a delay in the overall beach response.

The most recent beach surveys indicate that dune erosion has continued at the south end of the cell, while dune rebuilding has begun to occur along Nestucca Spit (Figure 9). Furthermore, the September 2006 survey indicates that a considerable amount of sand has accumulated south of the Nestucca estuary mouth and along much of Nestucca Spit. This is again depicted by the ongoing seaward progradation of the

3-m beach contour since September 2002 (Figure 9) and strongly points to a very large northward redistribution of sand in recent years. Nevertheless, with the exception of Nestucca Spit, where some sand has aggraded on the foredune, the most recent survey indicates that little sand has been transported to the upper beach face (particularly along the Neskowin shore), where the sand is needed to protect the dunes from future erosion events. This lack of aggradation to the upper beach face is despite the fact that sand has begun to aggrade on the lower beach face since 2002, as beach survey data reveal. Accordingly, much of the shore between Neskowin and the Nestucca estuary mouth will probably continue to be highly susceptible to major storm erosion events and will likely remain so until sand from the north end of the cell has returned to the south.

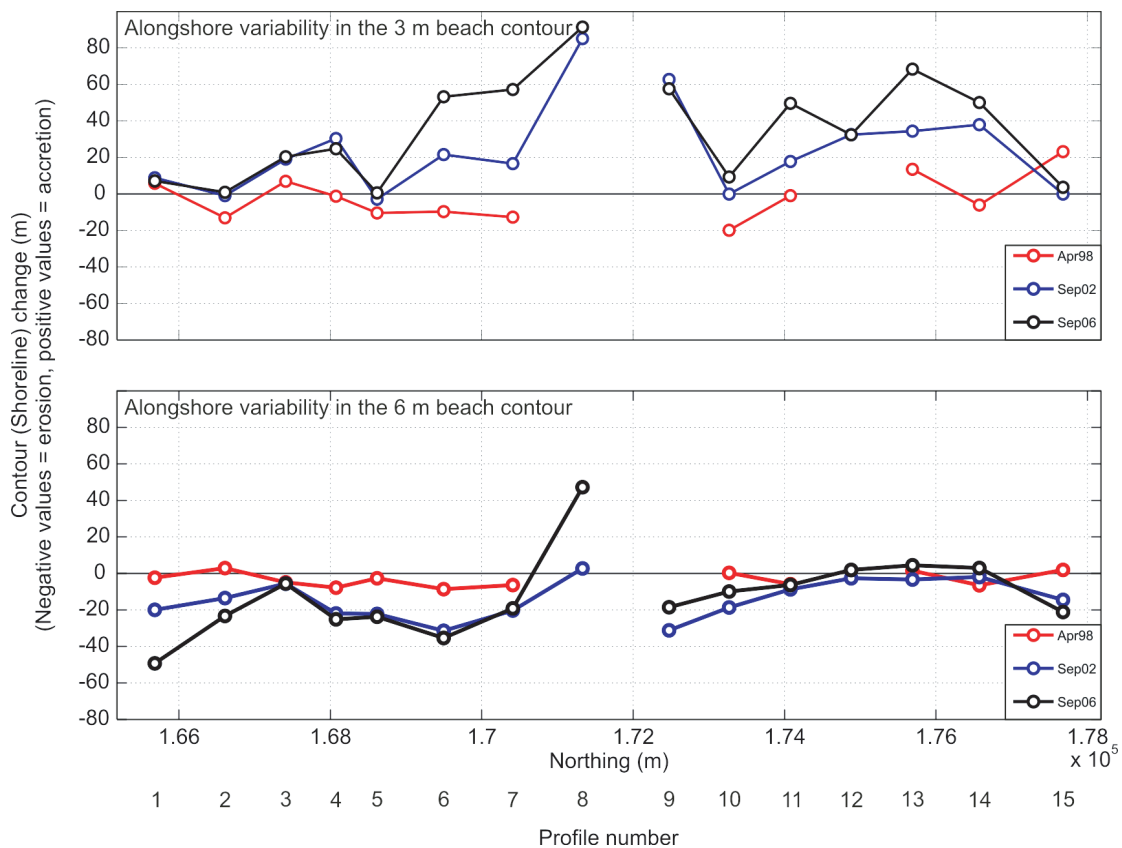


Figure 9. Alongshore variability in the response of the 3-m and 6-m beach contour elevations for three intervals: post 1997-1998 El Niño winter, post 1998-1999 winter (determined by 2002 LIDAR survey data), and following the 2002 LIDAR survey up to the present (i.e., September 2006). Profile 1 is located at the south end of the littoral cell at Neskowin, and Profile 15 is located adjacent to the Dory launching ramp in Pacific City.

## CONCLUSIONS

This report has presented the results of a collaborative effort by the Oregon Department of Geology and Mineral Industries (DOGAMI) and the Department of Land Conservation and Development (DLCD) to establish a comprehensive beach monitoring program along the Oregon coast, with the surveys used to document the short- and long-term responses of the beaches. The establishment and repeated monitoring of beach and shoreline observing systems such as the one established in the Neskowin littoral cell will provide critical information to scientists and coastal resource managers on the response of Oregon beaches to major storms, the effects of climate events such as El Niño Southern Oscillation (ENSO) phenomena, sediment transport patterns, variations in the beach sediment budget, and longer-term impacts associated with climate change and sea level rise.

A major aspect of this study and of a similar beach monitoring program underway to the north in the Rockaway and Clatsop littoral cells (<http://www.oregongeology.com/sub/nanoos1/index.htm>) is that as the beach survey data are collected, the information is placed on the agency's website for rapid access and viewing by other State agency officials, researchers, and the public-at-large. This approach has received considerable support and is rapidly gaining ground with the geotechnical community, which is beginning to use the measured information in their studies. In this respect alone, the beach monitoring effort has begun to pay off as officials are now able to respond to various beach erosion issues based on good scientific information.

Our beach monitoring efforts completed thus far along the Neskowin littoral cell have identified a number of interesting aspects of large-scale beach responses, including:

- The beaches along the Neskowin shore (south of the estuary mouth) have continued to erode over time, with no evidence for recovery at this stage.
- Beaches along Nestucca Spit mainly have been accreting. However, accretion in the north is confined entirely to a gradual build-up of sand on the primary frontal dune raising its crest elevation over time. As a result, although this section of shore has accreted slightly during the past

decade, accretion has not led to a change in the position of the mean shoreline (i.e., the shoreline has not prograded seaward).

- Beaches along the littoral cell remain in a state of net deficit compared to their condition in 1997; the estimated loss of sand as of June 2006 was on the order of 1 to 1.5 million m<sup>3</sup> (1.3 to 2.0 million yd<sup>3</sup>) of sand. Whether the beach recovers fully and how long it takes remain important scientific and management questions, which will be answered as the beaches are monitored.
- Analyses of the alongshore responses of selected beach contour elevations indicate that the littoral cell was not greatly affected by the 1997-1998 El Niño. In contrast, erosion caused by the 1998-1999 winter was more extensive; parts of the Neskowin shore eroded landward by as much as 50 m (approximately 150 ft).
- Post-storm recovery has been slow, with little evidence of significant sand build-up having occurred on the upper beach face (i.e., the dune face). This is despite the fact that a significant volume of sand has clearly migrated back onto the lower beach face (i.e., below the 3-m contour elevation). The lack of sand accumulation high on the beach face suggests that the present climate may not be conducive for transporting sand landward from the beach face.
- The most recent survey confirms that there has been a large redistribution in the sand budget, with much of the sand having been transported northward along the littoral cell (i.e., toward Nestucca Spit).

As additional surveys are conducted and analyzed, patterns of sand transport within the Neskowin littoral cell (and elsewhere) will become clearer. Of importance, we now have a system in place that can be used to better document and understand changing beach morphodynamics, including the tracking of large-scale sand movements within the cell, the effects of future storms, and any post-storm recovery. In time, such information can be used to further evaluate and refine coastal hazard "setback" zones that are being developed by the Oregon Department of Geology and Mineral Industries (DOGAMI).

## REFERENCES

- Allan, J. C., and Hart, R., 2005, A geographical information system (GIS) data set of beach morphodynamics derived from 1997, 1998, and 2002 LIDAR data for the central to northern Oregon coast: Oregon Department of Geology and Mineral Industries Open-File Report O-05-09, 16 p.
- Allan, J. C., and Komar, P. D., 2005, Morphologies of beaches and dunes on the Oregon coast, with tests of the geometric dune-erosion model: Oregon Department of Geology and Mineral Industries Open-File Report O-05-08, 34 p.
- Allan, J. C., Komar, P. D., and Priest, G. R., 2003, Shoreline variability on the high-energy Oregon coast and its usefulness in erosion-hazard assessments, *in* Byrnes, M. R., Crowell, M., and Fowler, C., eds., *Shoreline mapping and change analysis: Technical considerations and management implications*: Journal of Coastal Research, Special Issue 38, p. 83–105.
- Allan, J. C., Komar, P. D., and Priest, G. R., 2004, Coast hazards and management issues on the Oregon coast: Coastal Workshop, Lincoln City, Oregon, Field Trip to the Oregon Coast, 29 April 2004: Oregon Department of Geology and Mineral Industries Open-File Report O-04-18, 24 p.
- Bernstein, D. J., and others, 2003, Survey design analysis for three-dimensional mapping of beach and nearshore morphology, Coastal Sediments '03: St. Petersburg, Fla., American Society of Civil Engineers, 12 p.
- Dicken, S. N., Johannessen, C. L., and Hanneson, B., 1961, Some recent physical changes of the Oregon coast: Eugene, University of Oregon Department of Geography.
- Gayes, P. T., and others, 2001, Systematic coastal monitoring: The S. Carolina coast (USA), Coastal Dynamics 2001, Proc. 4th Conf. on Coastal Dynamics, June 11–15, 2001, Lund, Sweden: American Society of Civil Engineers, p. 868–877.
- Komar, P. D., 1986, The 1982–83 El Niño and erosion on the coast of Oregon: *Shore and Beach*, v. 54, no. 2, 3–12.
- Komar, P. D., 1997, *The Pacific Northwest coast: Living with the shores of Oregon and Washington*: Durham and London, Duke University Press, 195 p.
- Morton, R. A., 1997, Gulf shoreline movement between Sabine Pass and The Brazos River, Texas: 1974 to 1996: Austin, University of Texas, Bureau of Economic Geology Geological Circular 97-3.
- Morton, R. A., Leach, M. P., Paine, J. G., and Cardoza, M. A., 1993, Monitoring beach changes using GPS surveying techniques: *Journal of Coastal Research*, v. 9, no. 3, 702–720.
- Office of Beaches and Coastal Systems, 2001, *Statewide Coastal Monitoring Program: vol. I, Regional data collection and processing plan*, March 2001: Tallahassee, Florida Department of Environmental Protection, 77 p. (<http://www.dep.state.fl.us/beaches/publications/pdf/monplan.pdf>)
- Revell, D. L., and Marra, J. J., 2002, An application of Lidar to multiple scales of shoreline change in Oregon, *in* Ewing, L., and Wallendorf, L., eds., *Solutions to coastal disasters '02*: San Diego, Calif., American Society of Chemical Engineers, p. 596–610.
- Revell, D., Komar, P. D., and Sallenger, A. H., 2002, An application of LIDAR to analyses of El Niño erosion in the Netarts littoral cell, Oregon: *Journal of Coastal Research*, v. 18, no. 4, 792–801.
- Ruggiero, P., and Voigt, B., 2000, Beach monitoring in the Columbia River littoral cell, 1997–2000: Olympia, Wash., Coastal Monitoring & Analysis Program, Washington Department of Ecology, Publication 00-06-026.
- Ruggiero, P., Kaminsky, G. M., Gelfenbaum, G., and Voight, B., 2005, Seasonal to interannual morphodynamics along a high-energy dissipative littoral cell: *Journal of Coastal Research*, v. 21, no. 3, 553–578.
- Seymour, R. J., 1996, Wave climate variability in Southern California: *Journal of Waterway, Port, Coastal and Ocean Engineering*, v. 122, 182–186.
- Shih, S.-M., and Komar, P. D., 1994, Sediments, beach morphology and sea-cliff erosion within an Oregon coast littoral cell: *Journal of Coastal Research*, v. 10, no. 1, 144–157.
- Stembridge, J. E., 1975, *Shoreline changes and physiographic hazards on the Oregon coast*: Eugene, University of Oregon, Ph.D. dissertation, 202 p.
- Trimble Navigation Limited, 2005, Trimble 5700 GPS system datasheet. ([http://trl.trimble.com/docushare/dsweb/Get/Document-163620/022543-074D\\_5700\\_GPS\\_DS\\_0706\\_lr.pdf](http://trl.trimble.com/docushare/dsweb/Get/Document-163620/022543-074D_5700_GPS_DS_0706_lr.pdf))
- Winton, T. C., Chou, I. B., Powell, G. M., and Crane, J. D., 1981, Analysis of coastal sediment transport processes from Wrightsville beach to Fort Fisher, North Carolina: Vicksburg, Miss., U.S. Army Coastal Engineering Research Centre Misc. Report 81-6.

## APPENDIX A: NESKOWIN LITTORAL CELL BENCHMARK LOCATIONS

Eight permanently monumented benchmarks were established along the Neskowin littoral cell. Figure 1 in the main text identifies their approximate locations, and Table A1 contains the specific coordinate and elevation information. These data are reported as is. Any additional questions concerning benchmark site coordinates and their accuracies should be directed to Dr. Jonathan Allan (telephone 541-574-6658).

Table A1. Coordinate and elevation information derived for GPS calibration control sites established along the Neskowin littoral cell.

Site	Eastings (m)	Northings (m)	Elevation (m)
Nesk Ctrl 1	2227540.692	177974.934	12.387
Nesk Ctrl 2	2227636.624	175375.114	7.118
Nesk Ctrl 3	2227495.161	174174.521	4.492
Nesk Ctrl 4	2227368.113	173001.601	4.874
Nesk Ctrl 5	2226885.830	170740.992	4.120
Nesk Ctrl 6	2226603.978	168908.375	8.221
Nesk Ctrl 7	2226438.219	167871.916	6.610
Nesk Ctrl 8	2225802.032	165471.955	9.524

Coordinates are in the Oregon State Plane Coordinate (northern zone) System, meters. Elevations are relative to the North American Vertical Datum of 1988 (NAVD88) vertical datum (meters).

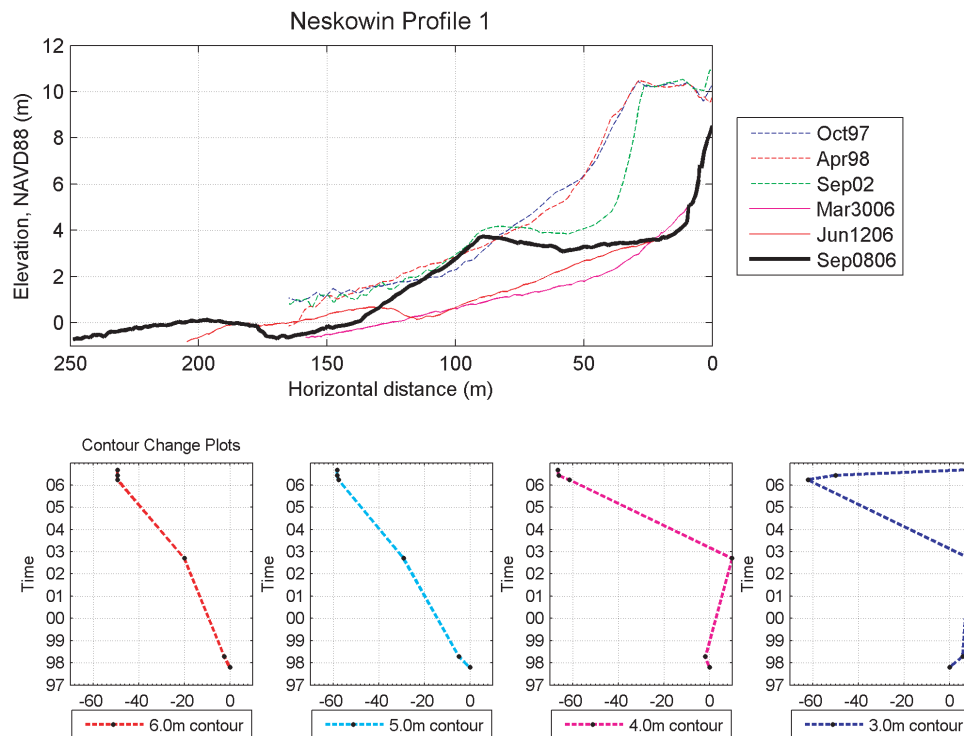


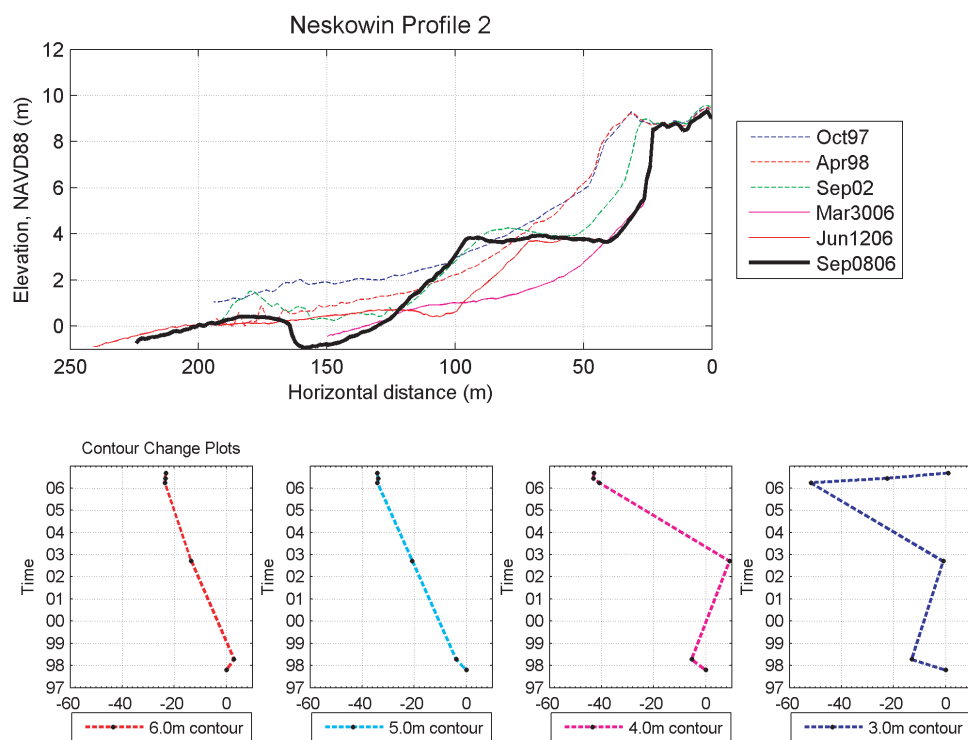
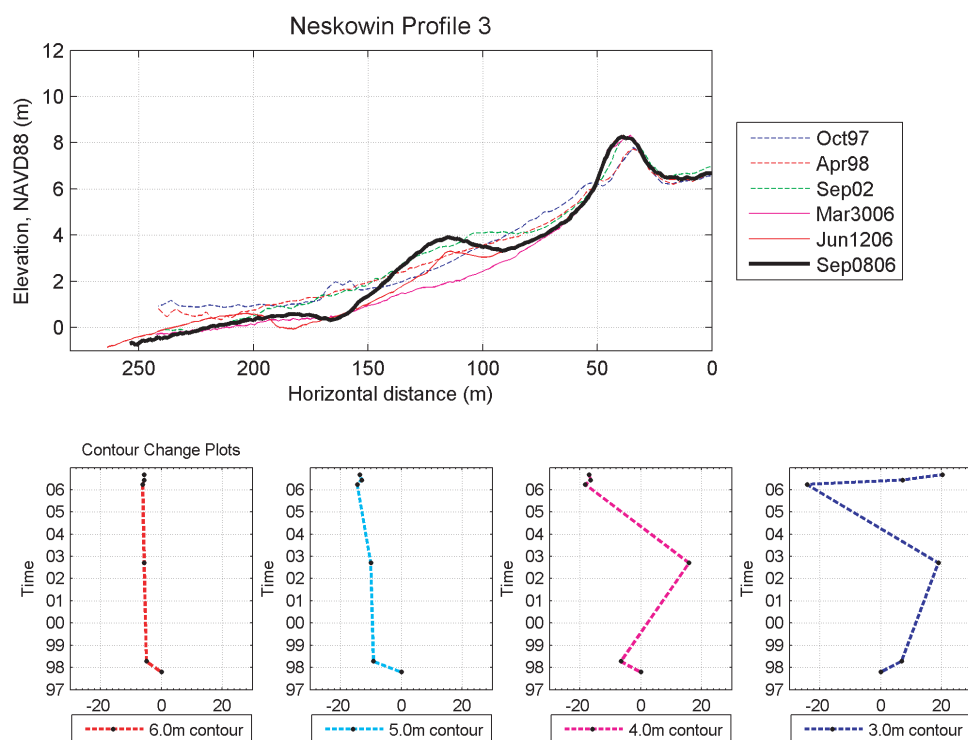
## APPENDIX B: NESKOWIN LITTORAL CELL BEACH PROFILE AND EDA “CONTOUR” PLOTS

Profiles 1–15 depict combined beach profile and excursion distance analysis “contour” plots. In each profile the upper plot is a conventional beach profile plot, which depicts the two-dimensional response of the beach to variations in incident wave energy, while the four lower plots reflect contours of greater interest due to their proximity to the dune toe (e.g., the

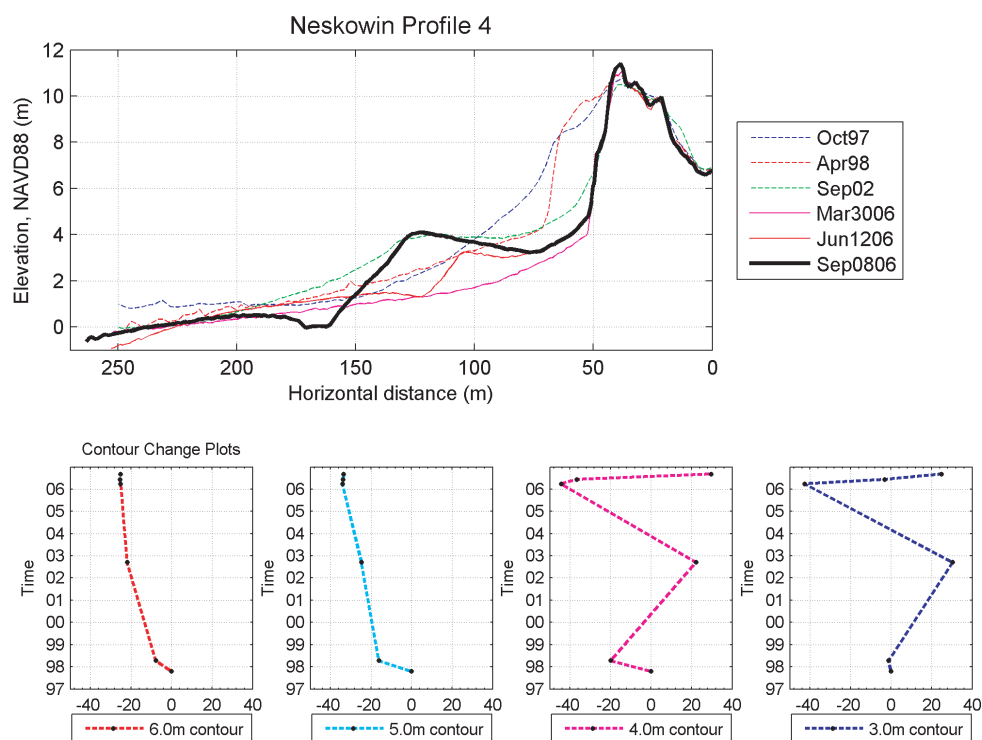
6.0-m and 5.0-m contour) or to Mean Higher High Water mark (e.g., the 3.0-m contour). The 1997 data have been used in the four lower plots as a baseline as this reflects the first comprehensive survey of the shape and position of the beach. NAVD88 is the North American Vertical Datum of 1988.

### Neskowin Beach Profile 1

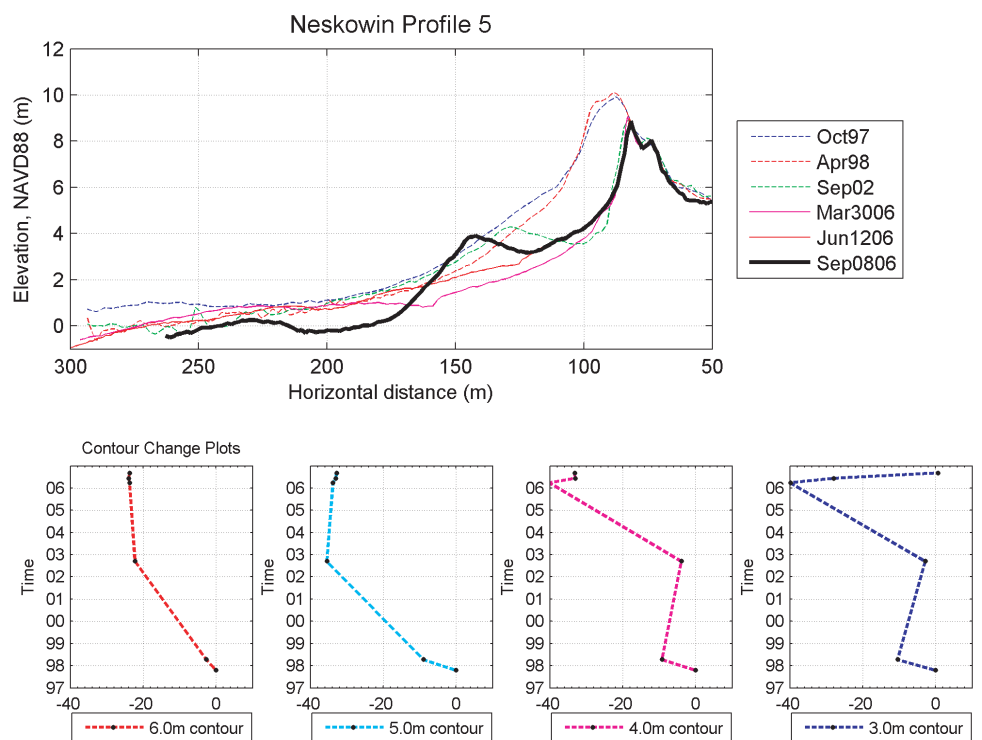


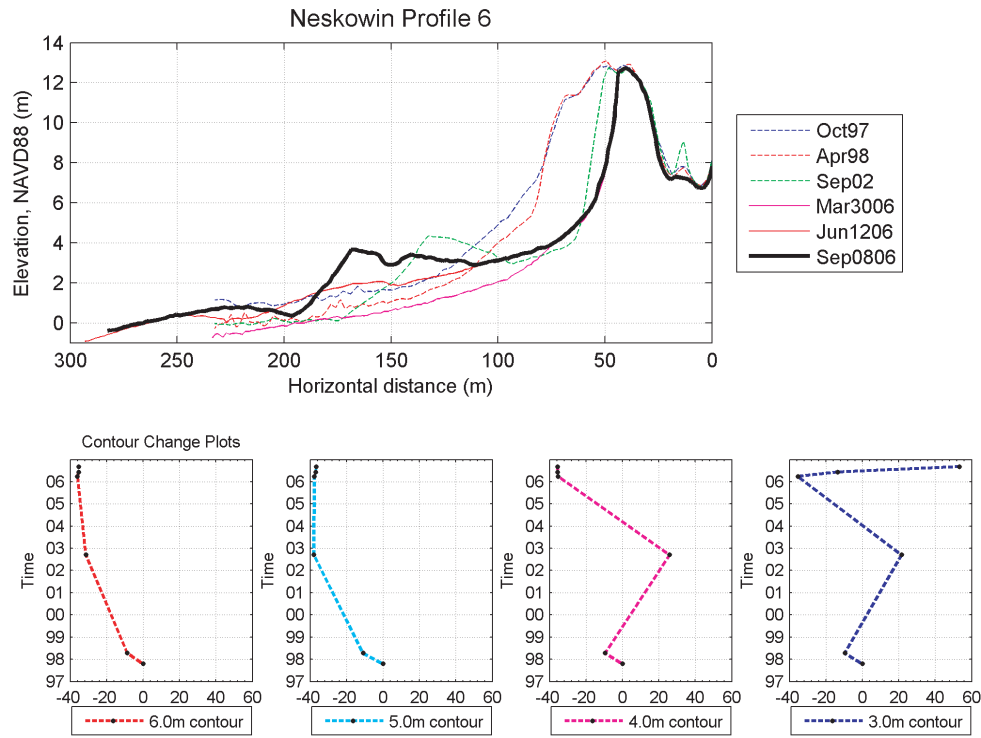
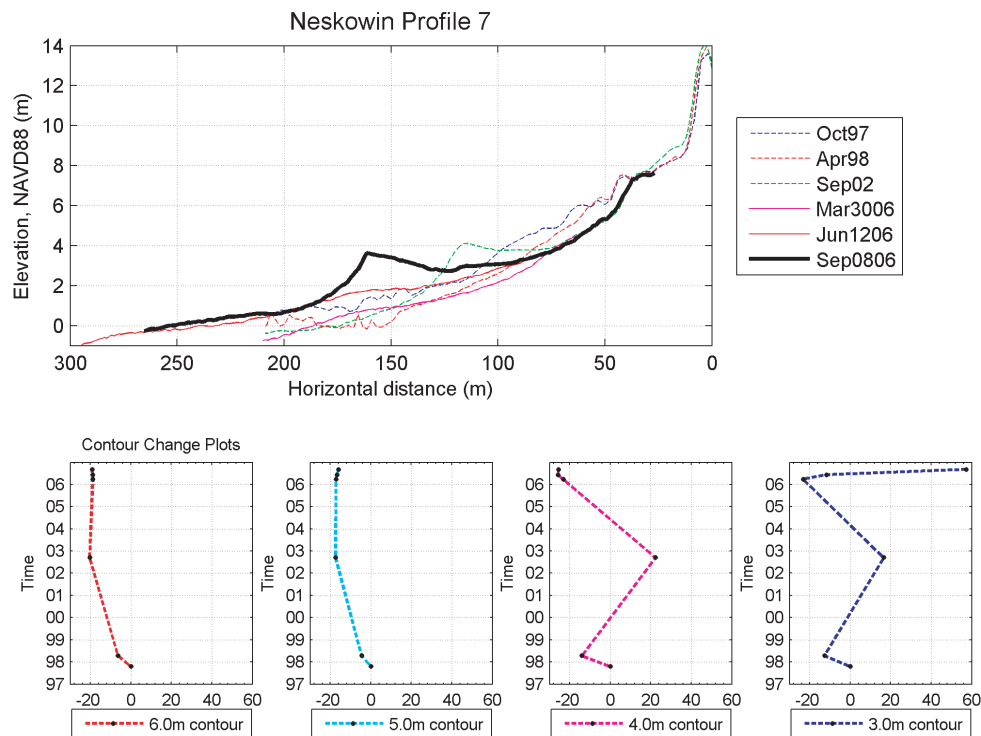
**Neskowin Beach Profile 2****Neskowin Beach Profile 3**

## Neskowin Beach Profile 4



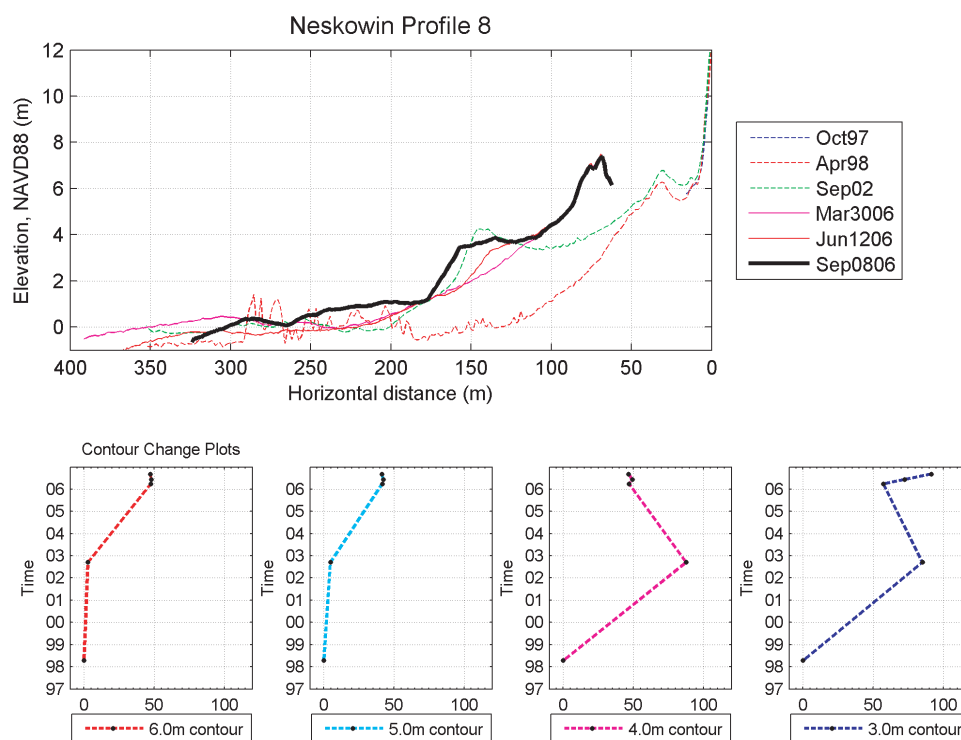
## Neskowin Beach Profile 5



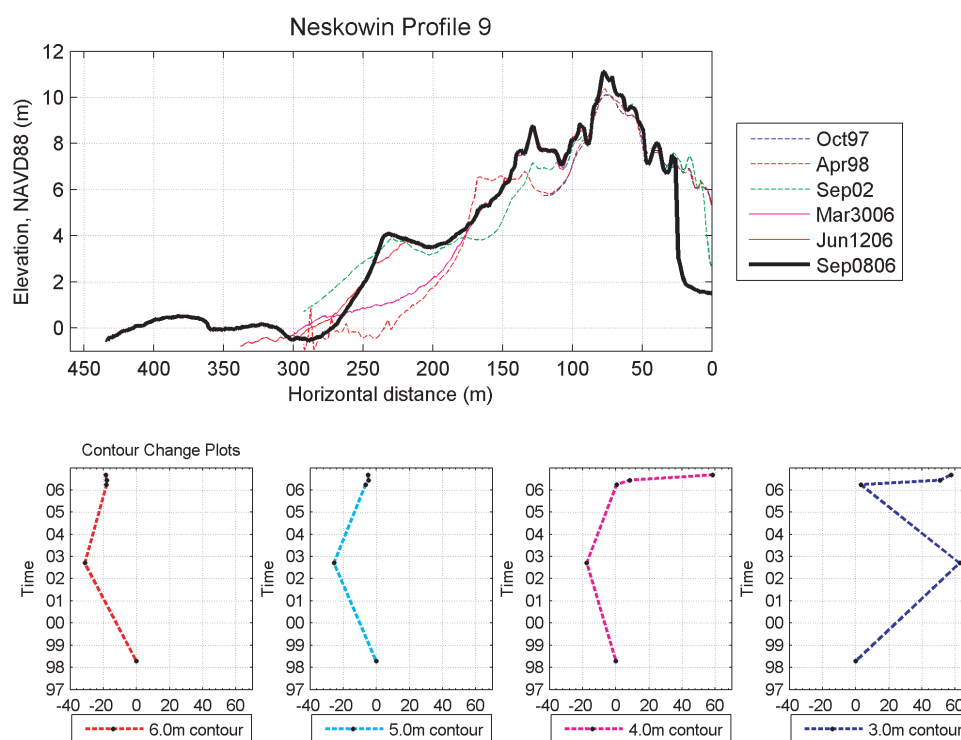
**Neskowin Beach Profile 6****Neskowin Beach Profile 7**



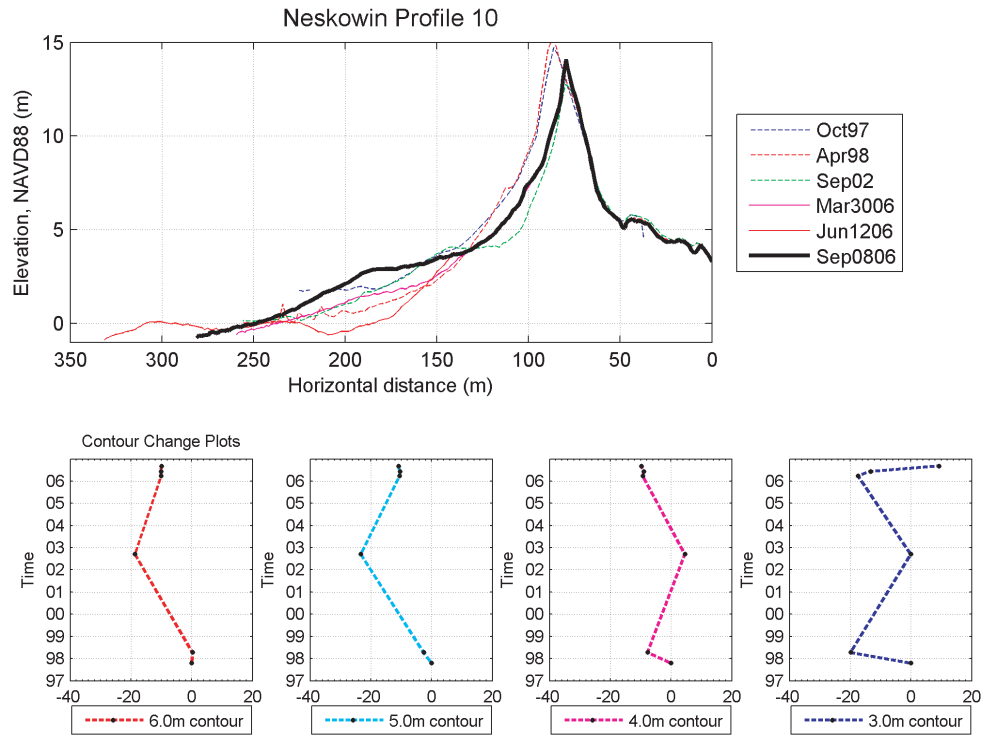
## Neskowin Beach Profile 8



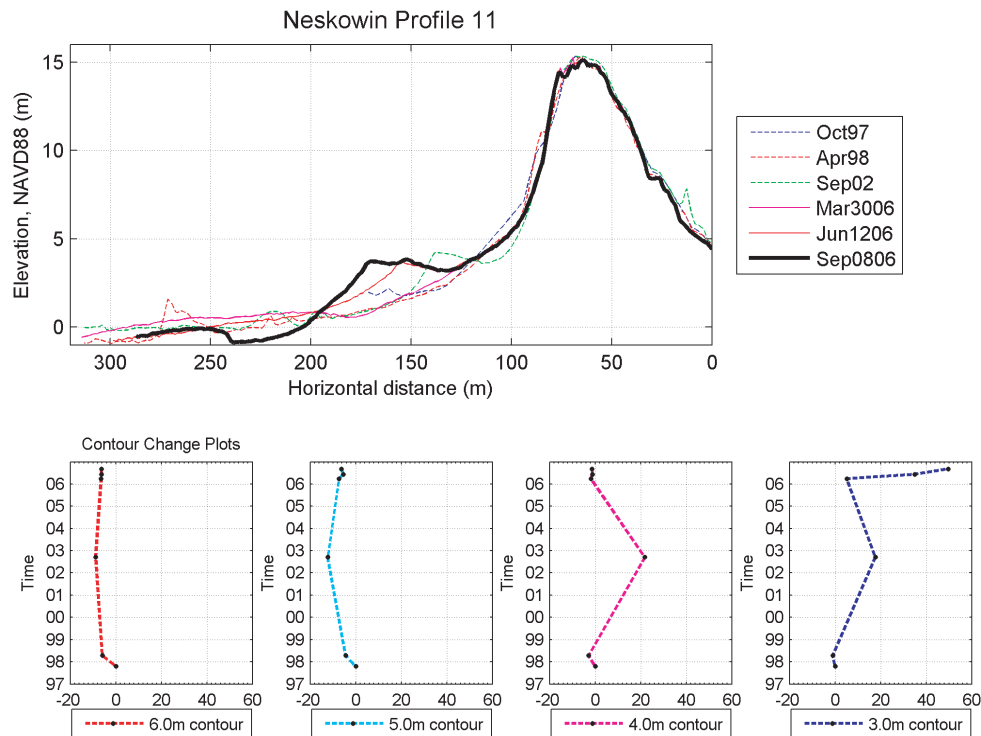
## Neskowin Beach Profile 9



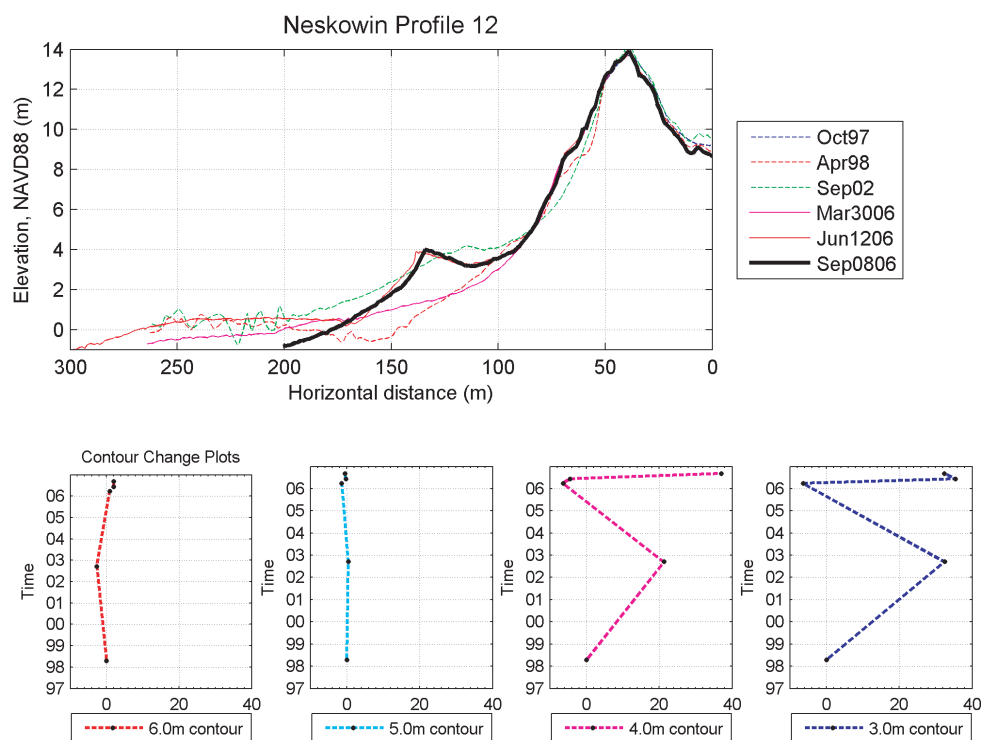
## Neskowin Beach Profile 10



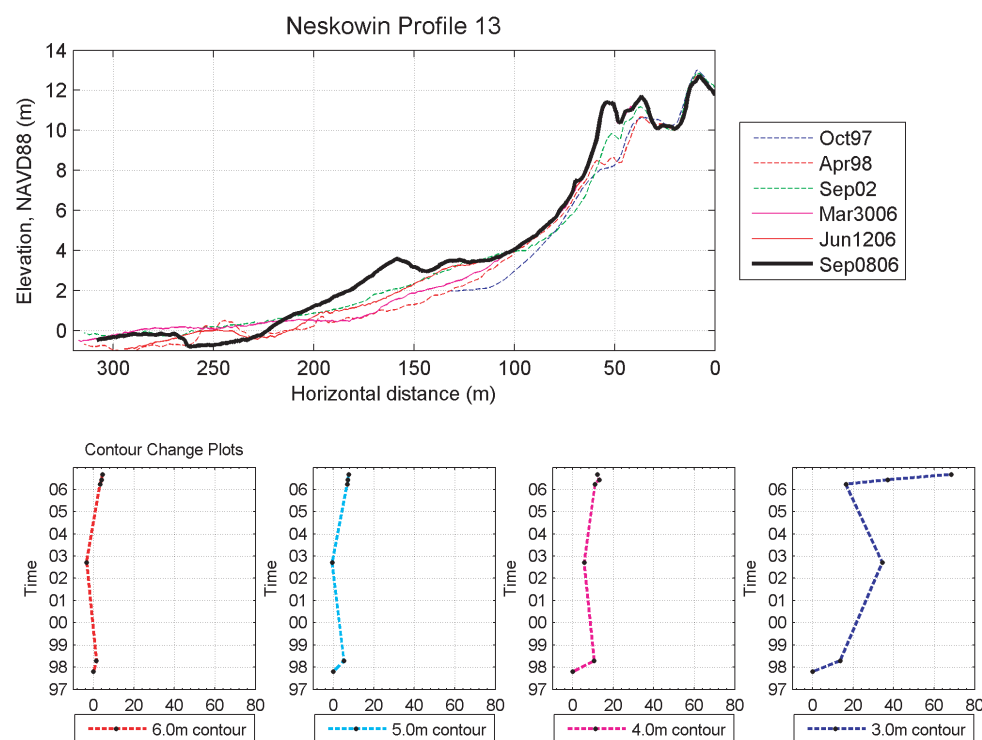
## Neskowin Beach Profile 11



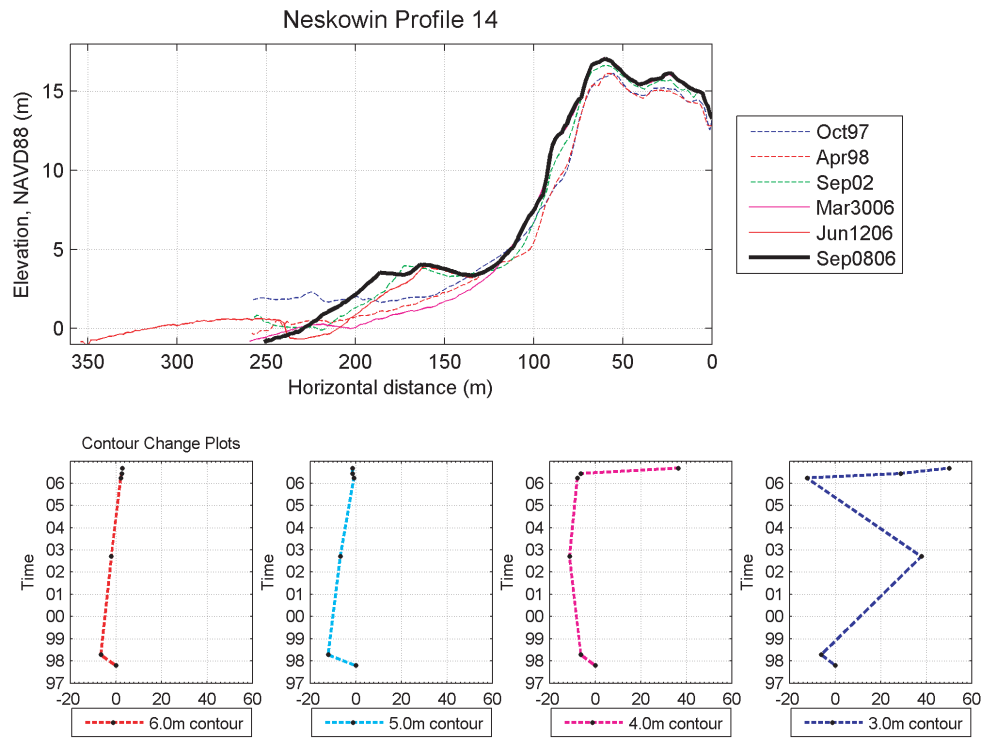
## Neskowin Beach Profile 12



## Neskowin Beach Profile 13



## Neskowin Beach Profile 14



## Neskowin Beach Profile 15

