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COAST HAZARDS AND MANAGEMENT ISSUES ON THE OREGON COAST

Coastal Workshop, Lincoln City, Oregon
Field Trip to the Oregon Coast
29 April 2004

By

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2004

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Coastal Field Office
&
Department of Land Conservation and Development,
Oregon State Parks and Recreation Department

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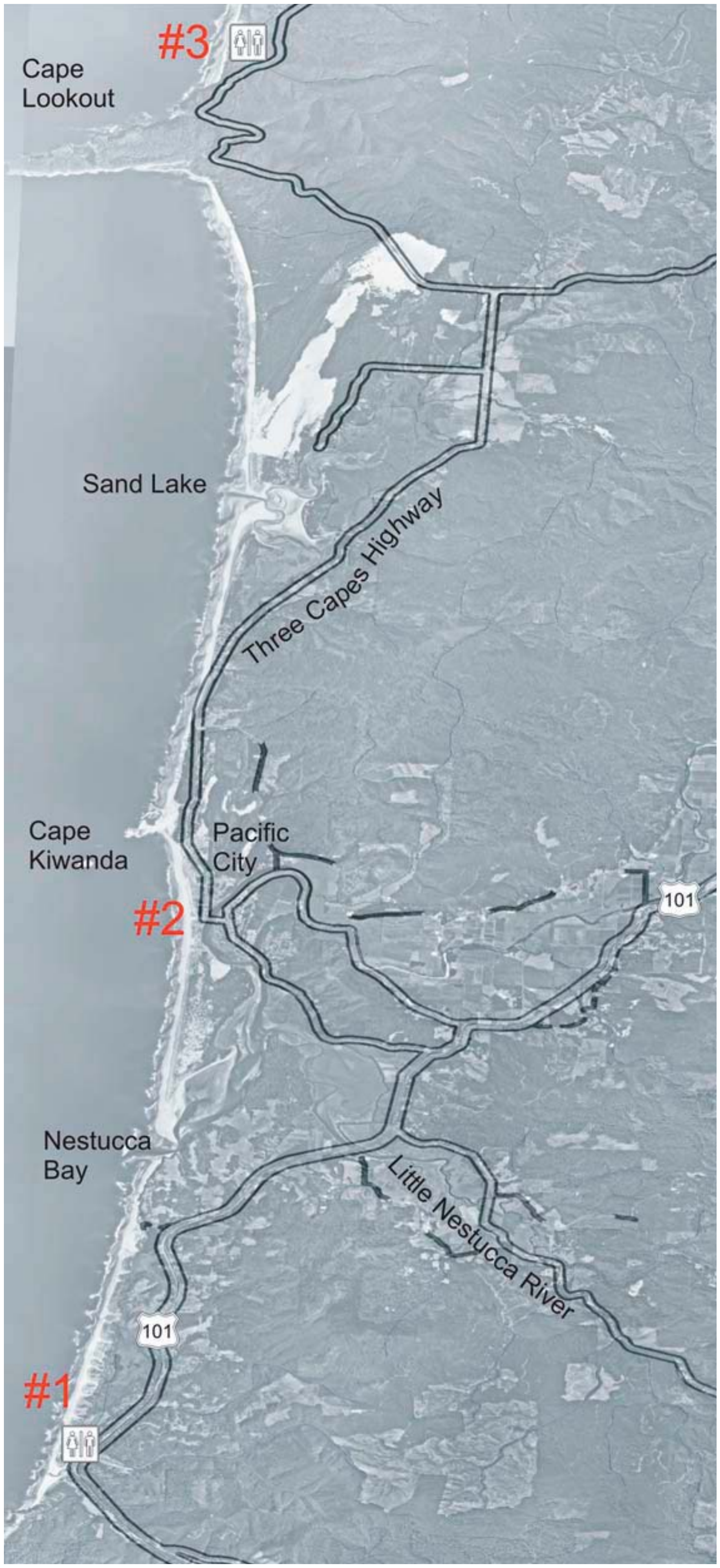
Field Trip Itinerary

(field trip stop times are approximate)

1:00 p.m.	Check in for field Trip (front entrance of Motel)
1:15	Depart Motel for Neskowin
1:45	**Stop 1: Neskowin -** Enhanced erosion along the Oregon Coast
2:45	**Stop 2: Pacific City** – Development on Dunes, Sand Accumulation, Setbacks
3:15	**Stop 4: Cape Lookout State Park** – Erosion and El Niño Events
4:00	Depart Cape Lookout State Park for Motel
5:00	Arrive Motel

Route Map


#3
Cape
Lookout
Sand Lake
Three Capes Highway
Cape
Kiwanda
Pacific
City
#2
101
Nestucca
Bay
Little Nestucca River
101
#1

INTRODUCTION

Development along the Oregon coast is threatened by a variety of natural hazards, including erosion, landslides, earthquakes, and tsunamis. Interactions between hazards and development have increased in recent years due to poor development practices and an intensification of the erosion processes. This intensification of erosion is in part associated with the unusually strong El Niños of 1982-83 and 1997-98, together with a progressive increase in the strengths of storms and the sizes of waves they generate (Allan and Komar, 2000), an increase that has persisted for some 25 to 50 years (Graham and Diaz, 2001). The most recent phase of erosion is the result of a "one-two punch"—the 1997-98 El Niño followed in the next year by a series of unprecedented storms.

This field trip along the north-central Oregon coast will visit a three sites that illustrate this conflict between the ocean hazards and our attempt to develop the coast. Both sides of the conflict will be examined, with discussions of what we have learned about the ocean processes that produce elevated tides and high wave-swash runup levels, resulting in the erosion of foredunes and sea cliffs, leading to property losses. That research has supported the development of improved methodologies for the establishment of erosion-hazard zones or setbacks. A major problem is the protection of already established developments, ranging from private homes to State parks. The sites visited illustrate the range of responses, from the proliferation of massive riprap revetments at Neskowin to the attempt at Cape Lookout State Park to use an innovative "natural" approach for shore protection, a "dynamic" cobble revetment and an artificial dune that contains a core of sand-filled geotextile bags.

An extreme hazard hovering over the Oregon coast is the potential for another subduction earthquake and giant tsunami, the last occurrence having been 300 years ago. The repeat of such an extreme event represents the ultimate hazard to the development on the coast, but we cannot be certain when such an event will occur once again.

STOP #1 — NESKOWIN

Neskowin is a long-established community, initially of relatively modest beach cottages and small homes, but in recent years it is increasingly dominated by larger homes, motels and condominiums, becoming more of a resort community with golf courses. For most of its history, the primary "hazard" in Neskowin was a problem with too much sand, especially for homes unwisely built within the dunes backing the beach **(Figure 1)**. At minimum the accumulating sand in the dunes built up to the extent that people could no longer view the ocean through their picture windows; worse was when the sand began to bury their homes. This began to change during the winter of 1982-83 during our first

Figure 1. Neskowin in the 1960s (Oregon Department of Transportation photo).

major El Niño, but particularly so in the late 1990s with the occurrence of the 1997-98 El Niño followed by the 1998-99 La Niña that collectively produced five 100-year storms, which eroded the dunes and threatened homes.

Neskowin is a classic example of “hot spot” erosion during an El Niño, a pattern that exists all along the Oregon coast. The advent of an El Niño affects a range of coastal processes and conditions, including bringing about a rise in the monthly-mean sea level caused in part by the generation of warmer offshore water and its thermal expansion. The result is that during an El Niño the measured tides are some 0.5 to 0.6 meters (1.5 to 2.0 ft) higher than predicted **(Figure 2)**. This occurs all along the coast, raising water levels so the shoreline is significantly closer to coastal properties, increasing the likelihood of their erosion whenever a storm occurs. The “hot spot” localized erosion during an El Niño is more the result of the southward displacement of the winter storm paths so they cross the coast of central California rather than the Pacific Northwest as they generally do during normal years. This southward displacement of the storms during an El

Niño results in the arrival of high waves along the Oregon coast from a more southwesterly quadrant, producing an unusual northward transport of sand on the beaches. This is illustrated schematically in **Figure 3**, contrasting “Normal” and “El Niño” years. The Oregon coast consists of a series of littoral cells, stretches of sandy beach that are largely isolated from one another by rocky headlands. During a normal year there is a seasonal shift in the longshore sand movement, north during the winter when the strongest storm waves arrive from the southwest, with the sand returning to the south during the summer when the waves arrive from the northwest; there is an approximate equilibrium balance between this north and southward movement of beach sand, with essentially a zero net littoral drift. This changes during an El Niño

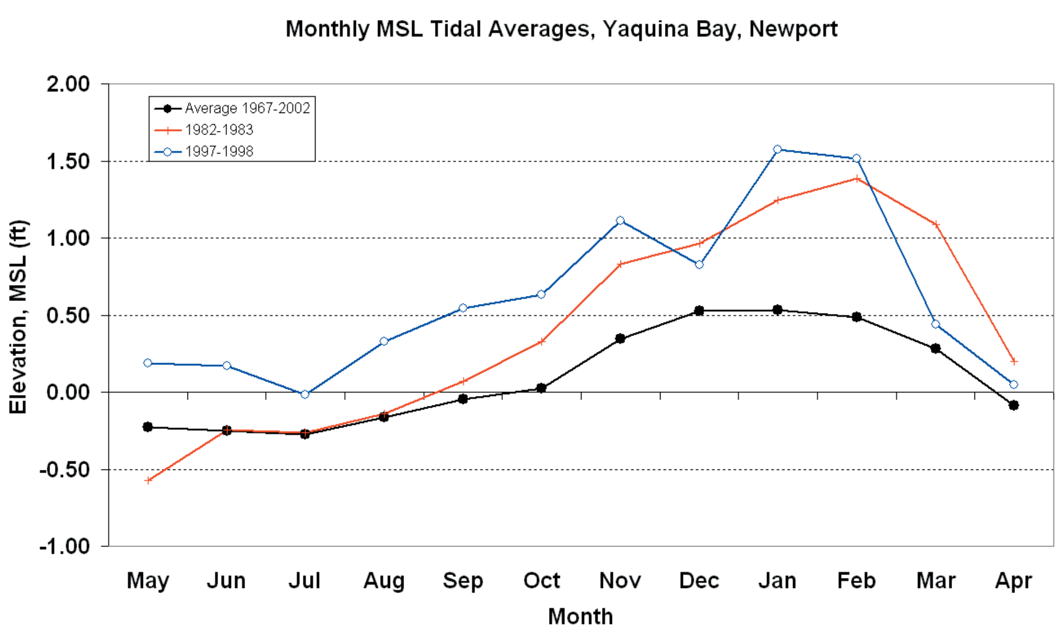


Figure 2. Mean monthly sea level at Newport, Oregon showing elevated water levels during the 1982-83 and 1997-98 El Niños.

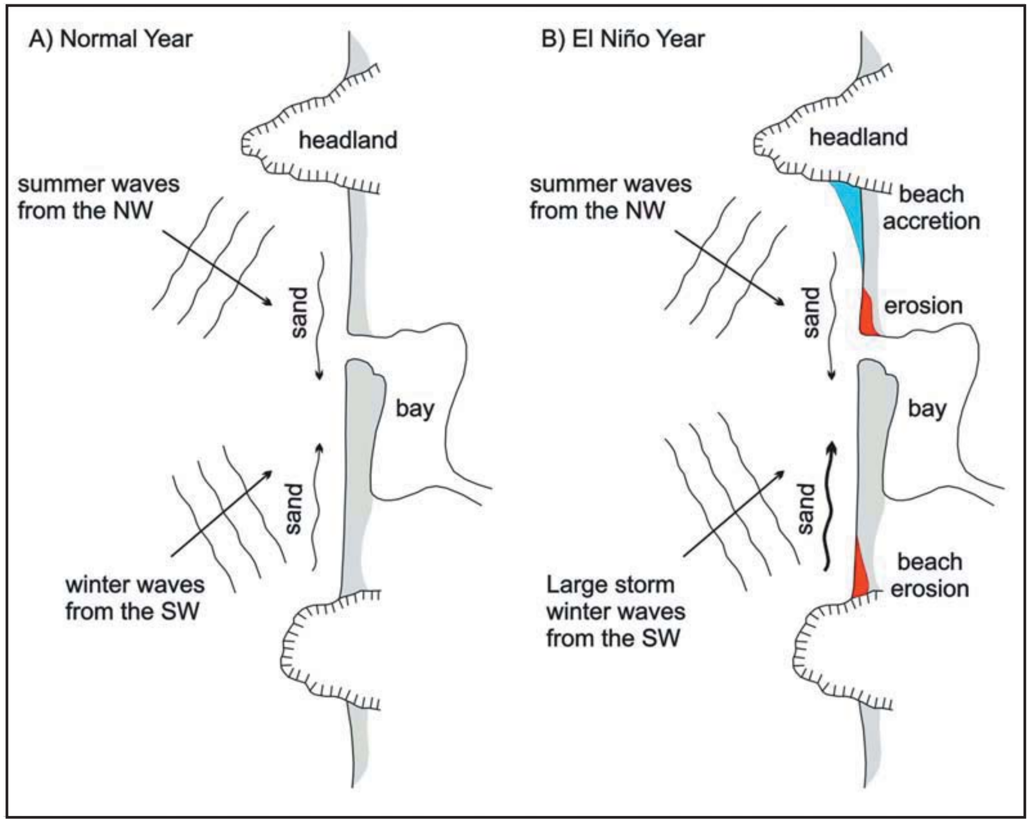


Figure 3. The seasonality of wave conditions and longshore sediment movement during Normal versus El Niño years, with the creation of "hot-spot" erosion sites in an El Niño (Komar, 1998).

with the more southwesterly approach of waves as illustrated in **Figure 3**, producing an unusually large northward displacement of sand and leading to "hot spot" erosion at the south ends of the littoral cells, to the north of the headlands, and at inlets that are free to migrate to the north.

Located just north of Cascade Head, Neskowin is within a "hot spot" erosion zone during an El Niño. Accordingly, its erosion problems in recent decades are mainly a response to the unusually strong El Niños of 1982-83 and 1997-98. During each El Niño winter the northward movement of sand on the beach resulted in a significant reduction in the elevation of the beach along the length of the community, with dune erosion occurring at times of storms when the runup of the waves at the shore combined with the enhanced tidal elevations also associated with the El Niño. The erosion rapidly removed the sand that had accumulated over many decades, for the first time representing a threat to shore-front homes in Neskowin.

A detailed documentation of this northward sand displacement and hot spot erosion along Oregon's pocket beach littoral cells became possible during the 1997/98 El Niño using LIDAR data, a remote sensing technology developed by the U.S. Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA) to collect topographic data (position and elevation) of the beach. Using the fall-1997 versus spring-1998 LIDAR data, Revell and others (2002) measured the vertical and volumetric changes in the beach that occurred during the El Niño winter along the length of the Netarts Cell in Tillamook County, documenting a clear pattern of northward sand transport in response to the southwest approach of El Niño storm waves. Additional analyses were undertaken by Allan and others (2003) to measure the El Niño shoreline response along the Netarts Cell **(Figure 4A)**, where negative and positive values respectively indicate erosion and accretion. Their results revealed the spatial extent of the "hot spot" erosion, with the southern 3 kilometers (1.9 miles) of the spit eroding by up to 25 m (82 ft) and progressively decreasing northward along the spit. Similar analyses have been undertaken for the Neskowin Cell **(Figure 4B)**. However, the pattern is more complicated, as indicated by the considerable along shore variability in the beach response, ranging from extreme erosion (-37 m (-120 ft)) adjacent to Cascade Head in the south, to accretion at Pacific City (+32 m (+105 ft)). The alongshore variability in the shoreline response shown in **Figure 4** is likely due to the presence of rip current embayments, that result in localized "hot spots" of erosion.

Much of the erosion impact actually came during the winter of 1998-99, the year following the strong El Niño of 1997-98. Our experience is that following the northward displacement of beach sand within the littoral cells during an El Niño, it may take several years for it to return to the south, to restore the long-term equilibrium. This was likely the case at Neskowin, such that the beach elevation was still abnormally low at the onset of 1998-99 winter, with the expectation of another series of winter storms. But that winter turned out to be extraordinary in the severity of its storms. In a study completed in 1996, Ruggiero and others (1996) analyzed measurements of waves by offshore buoys collected up to that time and arrived at a projection that the 100-year storm would generate a deep-water significant wave height of about 10 m (33 ft). During the winter of 1998-99 there were four storms that reached or exceeded that prediction! The worst occurred on 2-4 March 1999, when the deep-water significant wave height reached 14.1 m (45 ft) (Allan and Komar, 2002b). This truly represented a "one-two punch", with a winter of extraordinary storms following the El Niño winter. That winter of unusually severe storms was a La Niña period, when the storm paths generally cross the Pacific Northwest. This might be expected to produce higher wave conditions along the Oregon coast, but it actually is the "normal" condition, so the question remains as to why 1998-99

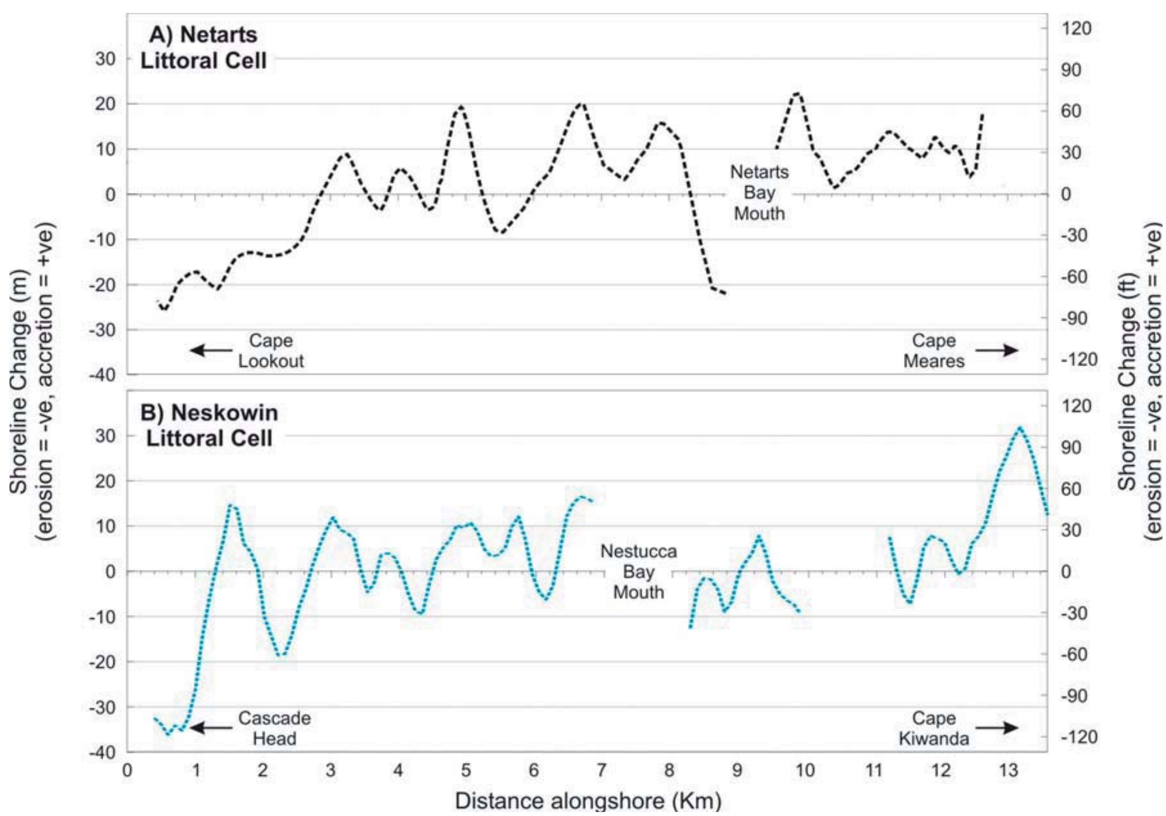


Figure 4. Shoreline variability along the Netarts and Neskowin littoral cells showing the "hot spot" erosion effect caused by the 1997-98 El Niño.

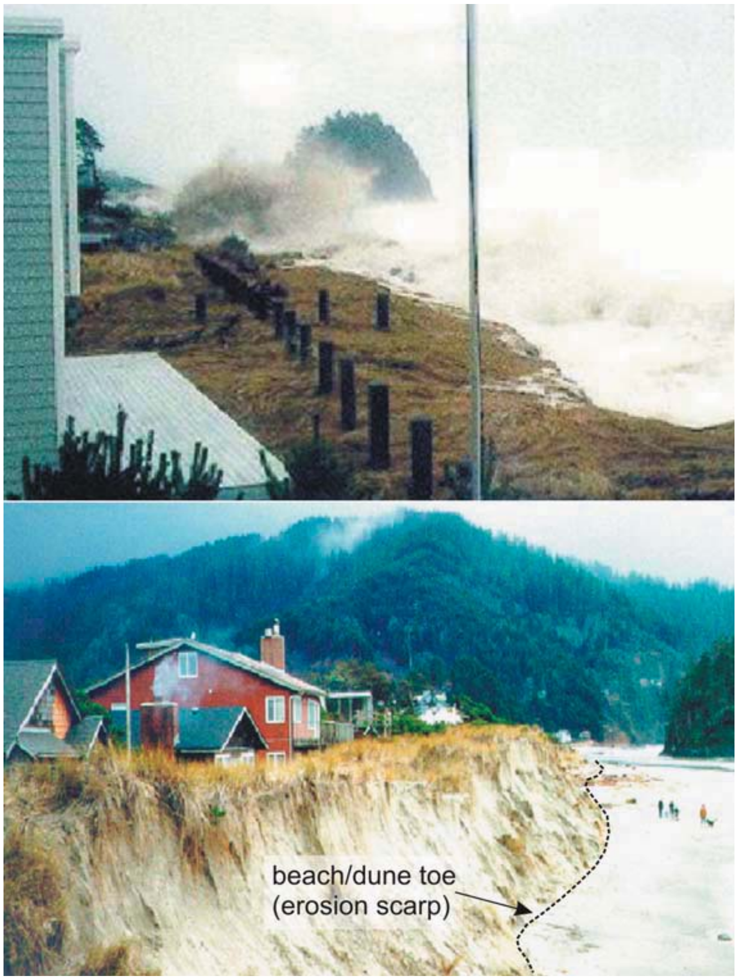
was so abnormal. The cause is still under investigation, but it is clear that the severity of those storms and heights of their generated waves is part of an increase that has persisted for at least 25 years at mid latitudes in the North Pacific, which have been documented using NOAA buoy data (Allan and Komar, 2000; in press).

The community of Neskowin was particularly hard hit by the one-two punch of the 1997-98 El Niño and 1998-99 winter of extreme storms. The 1997-98 El Niño storms transported much of the sand fronting the dunes to the north, resulting in a lowering of the beach elevation. At the very south end of the cell adjacent to Cascade Head, an old forest of tree tops, long submerged by rising sea level, emerged as the beach lowered **(Figure 5)**. During the 1998-99 La Niña winter, storm waves directly attacked and removed the fronting dunes, threatening the homes just behind **(Figure 6)**.

Unfortunately, the extent of the erosion caused by the extreme 1998-99 storms was not measured due to a lack of beach survey monitoring networks along the Oregon coast. However, in September 2002 the USGS and NASA flew a third LIDAR flight along the U.S. West Coast, providing coastal researchers with the necessary information to undertake an up-to-date assessment of the extent of erosion at Neskowin for the period 1998 to 2002. We have examined these data for the Neskowin Cell, by focusing on the change in position of the beach/dune toe (i.e. the base of the erosion scarp shown in **Figure 6** (lower)) between 1998 and 2002 **(Figure 7)**, demonstrating the cumulative effect of the winter storms over the past 4 years. As shown in **Figure 7**, the Neskowin Cell has undergone considerable dune erosion since 1998, with the beach/dune toe having been eroded landward by on average 11.5 m (38 ft), and as much as 55 m (180 ft) adjacent to the mouth of the Nestucca Bay. Dune erosion has been particularly severe near Winema Beach, (4 – 5 kilometers north of Neskowin **(Figure 7)**), and at the north end of the cell at Pacific City, where the presence of a rip embayment eroded the dune by as much as 40 m (130 ft). Given the severity of the storms in 1998-99 compared with the last 3 years, we can speculate that the bulk of the erosion shown in **Figure 7** was likely the product of the 1998-99 La Niña winter storms.

The extreme erosion at Neskowin has necessitated emergency riprap placement, which is authorized under Oregon's 1967 Beach Law **(Figure 8, upper)**. Following the emergency, property owners were required to go through the normal shore protection

Figure 5. Exposed buried forest at Neskowin as a result of hotspot erosion during the late 1990's (Photo courtesy of Roger Hart, DOGAMI).



permit process, whereby regular permits were granted and riprap was placed along much of the developed shoreline **(Figure 8, lower)**. By 2003, approximately 14.5% of the Neskowin littoral cell (i.e. from Cascade Head to Cape Kiwanda) has been hardened **(Figure 9)**, with most of the structures (8.2%) having been built at Neskowin.

The permitting process at Neskowin illustrates a beach management issue that has long been controversial in Oregon. The Oregon Coastal Management Program, approved in 1977 pursuant to the 1972 Coastal Zone Management Act, contains a provision prohibiting hard shore protection structures on the oceanfront where development did not exist on January 1, 1977. “Development” means houses, commercial and industrial buildings, and vacant subdivision lots which were physically improved by the construction of streets and provision of utilities.” The upshot of this requirement is that

Figure 6. (upper): Storm waves along the Neskowin shoreline, March 1999. (lower): Erosion at Neskowin resulting from the winter 1999 storms (Oregon Parks and Recreation Department photo).

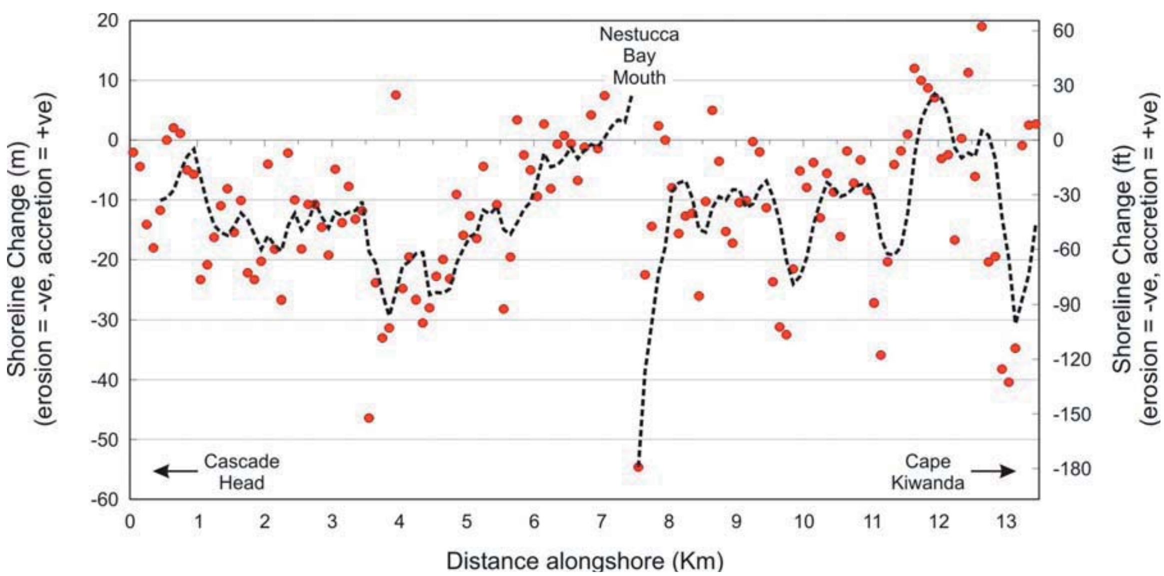


Figure 7. Positional changes in the beach/dune toe along the Neskowin Cell between 1998 and 2002. The dashed line is a 500 m moving average fitted to the data.

Figure 8. (upper): Emergency riprap in place along Neskowin shoreline, spring 1999 (Oregon Parks and Recreation Department photo). (lower): Final riprap structures at Neskowin in winter 2001 following regular permit process. Note that the structure has blocked lateral access along the beach at low tide due to enhanced erosion of the beach in front of the structure caused by the presence of a rip embayment and from wave reflection off the structures (Paul D. Komar photo).

old development gets protected when erosion strikes, but new development does not. Further, such areas have not been mapped and there is no requirement that developers or property sellers disclose this prohibition, setting up a classic “buyer beware” situation. One outcome of this policy is that in older developed areas along the coast—Lincoln City to the south of Neskowin is a good example—hard shore protection structures have proliferated such that by 2030, the entire cell is projected to be protected **(Figure 10)**

Figure 9. Expansion of riprap along the Neskowin shoreline since 1968. As at 2003, approximately 14.5% of the Neskowin cell had been "hardened".

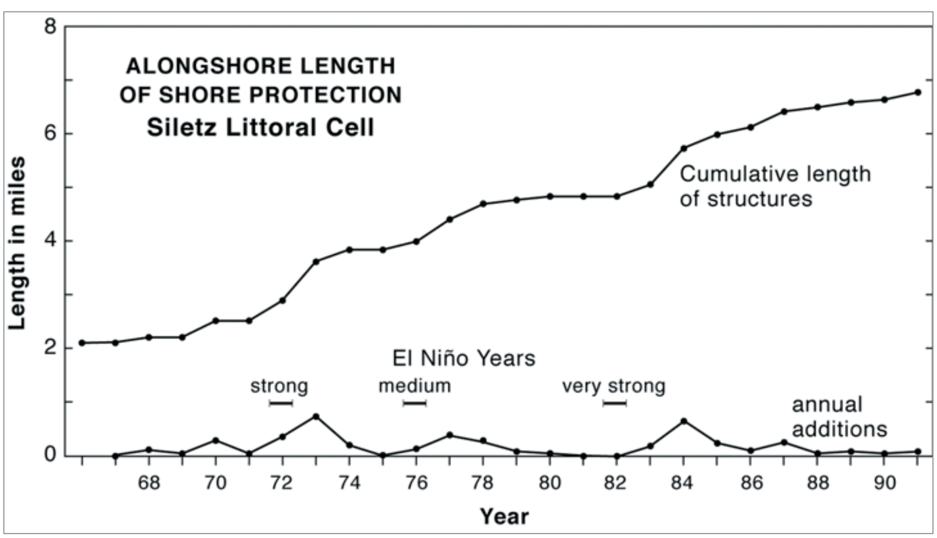


Figure 10. Cumulative and year-to-year length of shore protection structures constructed in the Siletz littoral cell and relationship to moderate (M), strong (S), and very strong (VS) El Niño events that occurred. The trend has accelerated in the last decade in part due to erosion during the 1997-98 El Niño and 1998-99 La Niña. (Good 1994).

resulting in the loss of the natural beach replenishment system afforded by bluff and dune erosion **(Figure 11)**. Another result of this policy is that the prohibition on hard shore protection structures comes under fire every time post-1977 development is threatened with erosion. This was not an issue at Neskowin, but it was at The Capes, in the Netarts Cell to the north.

STOP #2 — PACIFIC CITY

The hazards associated with constructing homes in a foredune backing a beach were seen at Neskowin, but have been even more dramatic in Pacific City. At the time the homes were being constructed in the Kiwanda Beach development back in 1978, a February storm attacked the dunes upon which they were being built. While carpenters were still pounding nails, trucks hauled in huge quantities of rock to build one of the largest riprap revetments found on the Oregon coast, seen in the upper photograph of **Figure 12**. The structure saved the homes, but at a cost that must have reached hundreds of thousands of dollars. During the following summer sand returned to the beach as it always does, and onshore winds began to carry it into the eroded dunes, not distinguishing between natural areas versus those where the revetment had been constructed. By the end of the summer the revetment had been buried beneath the sand. The structure has not been seen again in the past 25 years since its burial. Sand continued to accumulate over the years, blasting the houses so their picture windows are now frosted, and eventually would have covered the homes were it not for the annual bulldozing efforts to remove it. This cannot be done willy-nilly, but instead requires the implementation of a community-wide dune management program, which must be approved by the State and local regulatory agencies. Clearly, building homes in foredunes is not smart, leading to a boom-and-bust cycle of sand accumulation, erosion, re-accumulation, going on forever. In order to avoid the hazards of building in foredunes, considerable research has been directed toward the development of methodologies for the establishment of erosion hazard zones or setbacks. The approach is based on an assessment of the potentially extreme water level due to the combined measured tide and storm-wave runup and application of the geometric dune-erosion model depicted in **Figure 13**. This model is "geometric" in the sense of involving the right triangle shown, whose horizontal side rises to the level produced by the total water level

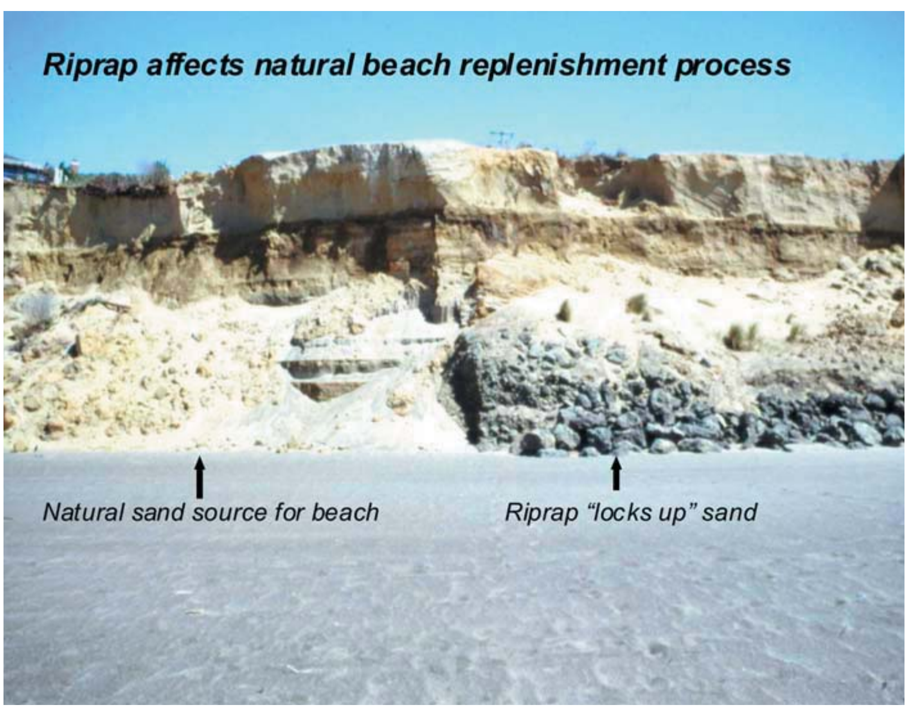


Figure 11. Eroding bluffs and dunes along much of the Oregon coast are an important source of sand supply to the littoral system (Jim Good photo).

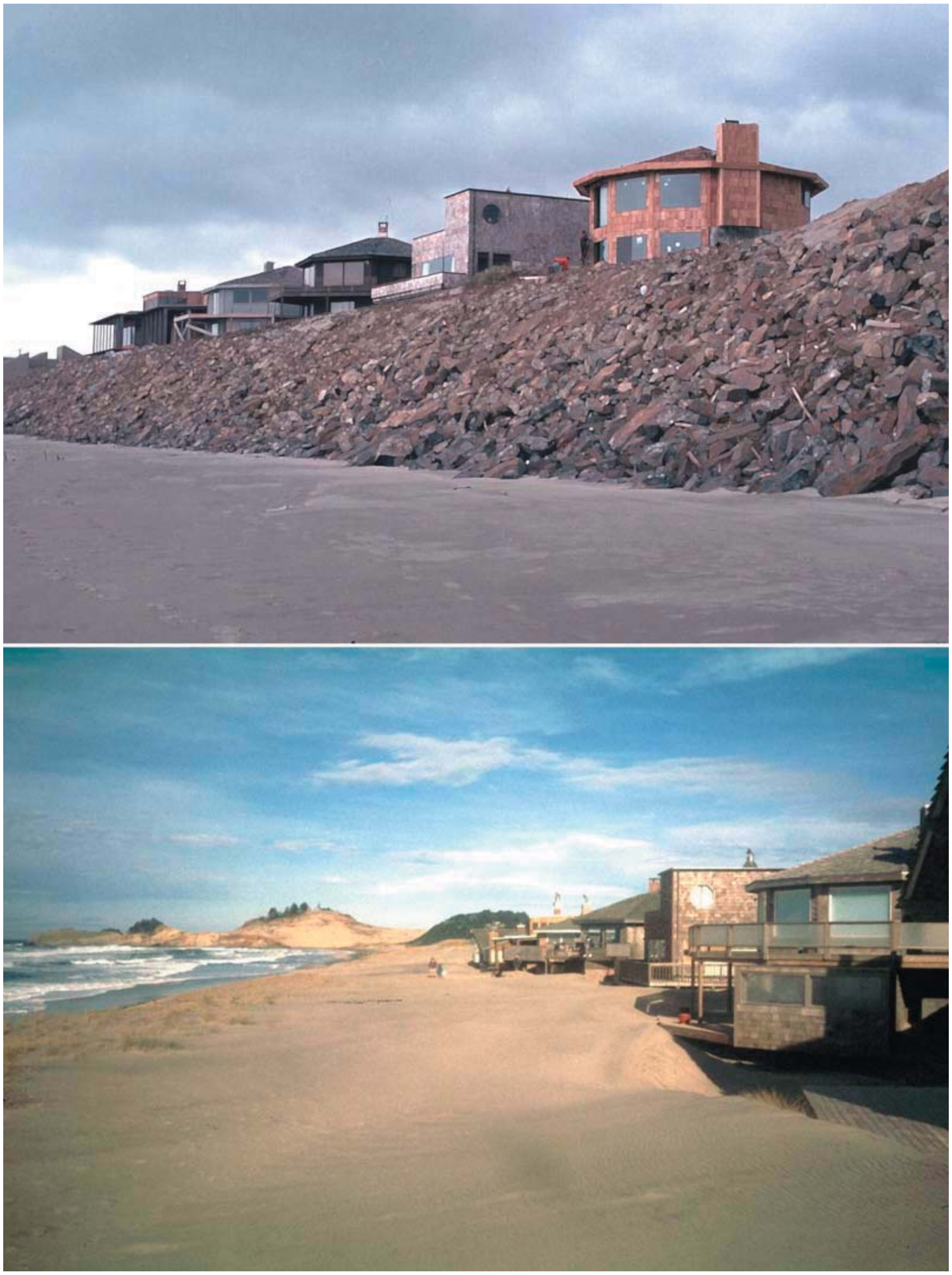


Figure 12. (upper): The massive riprap revetment constructed in 1978 to protect the newly built homes in the Kiwanda Beach development following erosion during a February storm. (lower): The accumulation of dune sand that has covered the revetment and now threatens to bury the homes [Komar (1997)].

during an extreme (e.g. 100-year) storm. The horizontal displacement of the triangle follows the slope of the beach such that it shifts inland until the total water level is reached, thereby yielding the extent of dune retreat. Also included is the potential for a change in the beach elevation, ΔBL, caused by general storm erosion or perhaps by local erosion of an embayment by a rip current.

In general the dune-erosion model is expected to predict the maximum extent of the potential dune retreat, with the actual retreat tending to be smaller due to the delayed responses of the erosion behind the causative processes and because the total water level is reached for only a relatively short time when the tide is at its highest. However, we found in tests of the model that it yields reasonable results when the coast is impacted

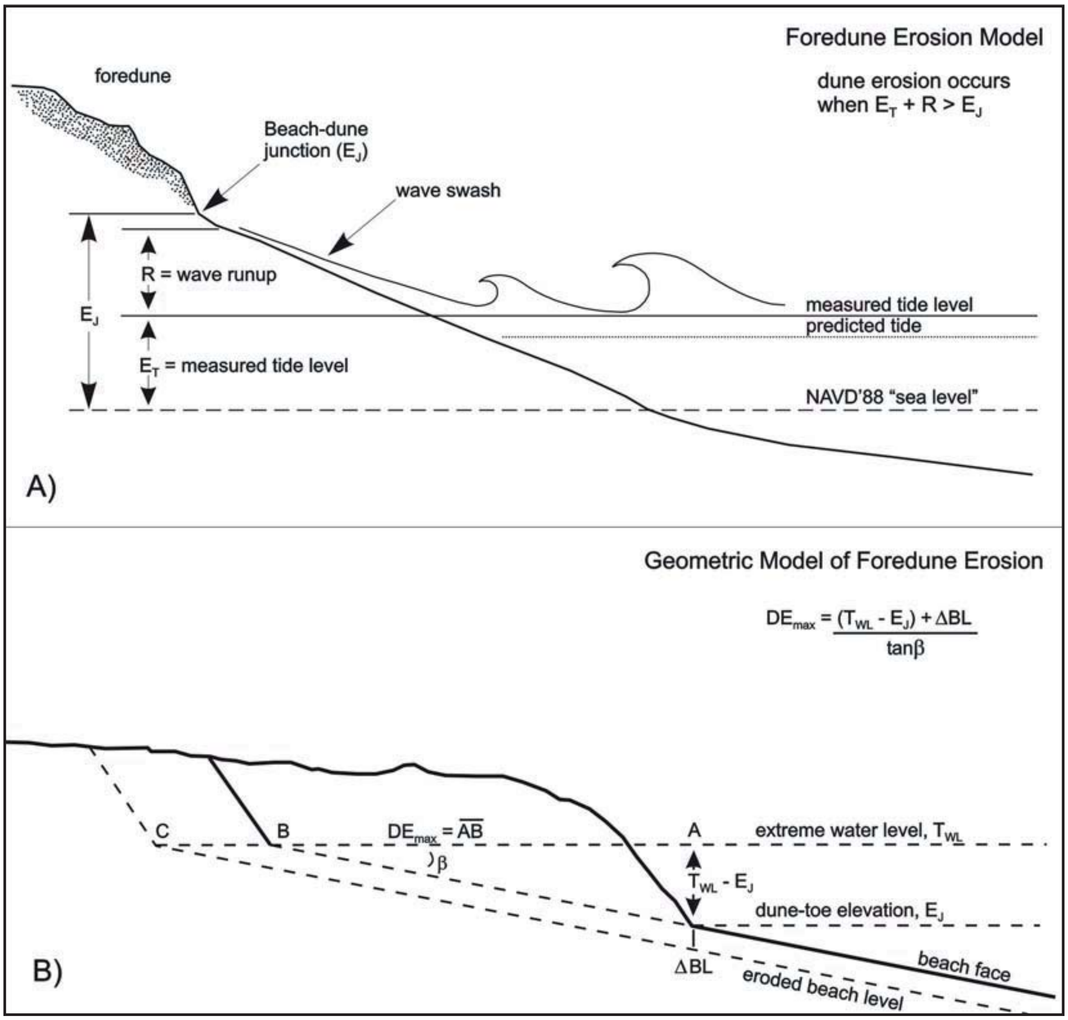


Figure 13. A model for the assessment of extreme water levels at the shore (Ruggiero and others, 2001) and the geometric model that has been developed to predict the resulting potential extent of dune retreat (Komar and others, 1999a).

by a series of storms, like it was during the winter of 1998-99, with the final extent of dune retreat governed by the largest of the storms in March 1999. Accordingly, this model is now being recommended for use by cities and counties to establish the inland extent of hazard zones or setbacks in foredune areas along the Oregon coast, in order to avoid the problems like those experienced in the Kiwanda Beach development of Pacific City.

In July 2000, the Coastal Field Office of the Oregon Dept. of Geology and Mineral Industries (DOGAMI) was established on the central Oregon coast in Newport. The directive of the Coastal Field Office is to undertake fundamental research on beach processes and coastal hazards, including those associated with extreme storm erosion, tsunamis, and landslides, and to map out the locations and likely impacts of these hazards along the coast for the safe establishment of properties and infrastructure. In June 2001, we completed our first major study of coastal geologic hazards in Tillamook County (Allan and Priest, 2001a). An important outcome of the study was the establishment of a variety of hazard zones along the counties dune- and bluff-backed shorelines that could be used by the counties planners to guide existing and future developments. Mapping of the hazard zones along the dune-backed shorelines was accomplished using the geometric model described previously.

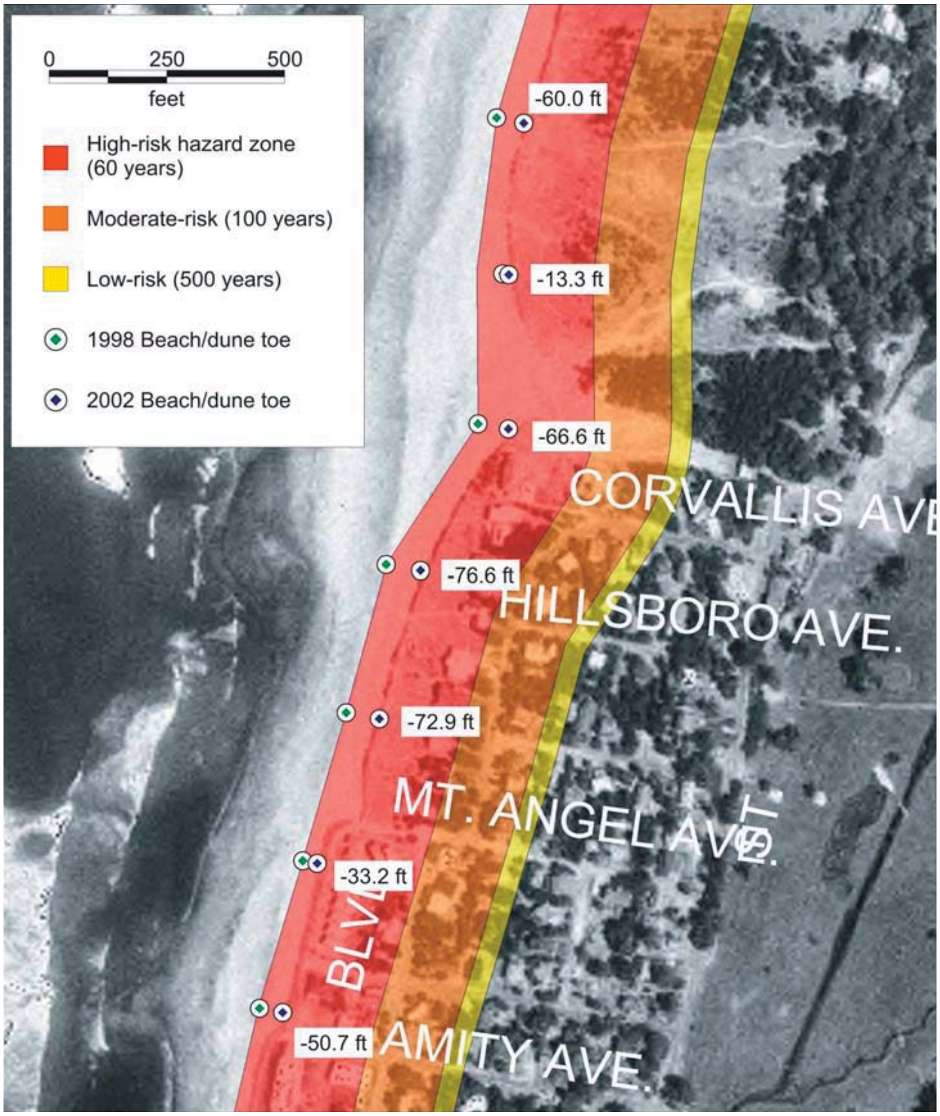


Figure 14. Coastal hazard mapping along the town of Neskowin in Tillamook County. Included in the figure is the change in position of the beach/dune toe (EJ) between 1998 and 2002. The high (red) hazard has a width of 250 ft.

lineates 3 hazard zones; the high-risk (red) zone is the projected erosion from a 60-year storm or from storms-in-series, the moderate-risk (orange) zone is the projected erosion based on a 100-year event and sea level rise, while the low-risk (yellow) zone is the projected erosion associated with a 100-year event and a major subduction earthquake. Included in the figure is the change in position of the beach/dune toe (described above) from 1998 to 2002, further highlighting theerosional effects of recent winter storms on the foredune at Neskowin. Given that the high-risk zone is calculated to be 250 ft wide, it is apparent from **Figure 14** that the recent dune erosion has already encroached well into the high-risk zone, further reducing the safety margin afforded to this shoreline segment. Similar studies of coastal hazard studies have now been completed for the Clatsop Plains (Allan and Priest, 2001b) and for northern Lincoln County (Priest and Allan, in press). It is unclear at this stage how effective these maps have been for mitigating coastal hazards, since few counties have integrated such information in their county ordinances, while most local governments already have state-approved comprehensive plans. Each jurisdiction uses its own, often ineffective approach for establishing construction setbacks. Mandating the new approach would require a change in statutes or administrative law, neither of which is likely in the immediate future. Landslides are another prominent coastal hazard along the Oregon shore. On our way to our next stop, we will pass around a major landslide just north of Pacific City on the Three Capes Loop **(Figure 15)**. This complex translational/rotational landslide occurred in June 1999 and consists of Holocene dune sands overlying the Tertiary seaward-dipping sandstone and mudstone deposits of the Astoria formation. The slide was subsequently stabilized by Landslide Technology, Inc. using a shear key buttressing system, with dewatering. We will pass other landslides as we move along the coast, but this is the most recent and visible.

STOP #3 — CAPE LOOKOUT STATE PARK

The increased erosion in recent years along the Oregon coast has affected public lands and infrastructure, as well as private properties. This is particularly illustrated by Cape Lookout State Park, where like Neskowin the erosion was initiated by the strong El Niños of 1982-83 and 1997-98, culminating with the series of unusually severe storms during the winter of 1998-99.

Cape Lookout State Park (CLSP) is located at the south end of the Netarts Littoral Cell **(Figure 16)**, one of the smallest littoral cells on the Oregon coast, with a shoreline length of 13 km between Cape Lookout to the south and Cape Mears in the north. Being small, the northward displacement of beach sand during El Niños has been particularly dramatic, and the localized erosion in the park during the 1982-83 event was important to our first recognition of the hot-spot nature of El Niño erosion (Komar, 1986; 1998); the renewed erosion during the 1997-98 El Niño reaffirmed the important role of that pattern (Komar, 1998). Looking ahead, the other hot-spot area of erosion is to the north of the inlet leading into Netarts Bay, produced by the migration of the inlet due to the northward drift of beach sand; this is the site of the erosion that threatened the multimillion dollar Capes development following the end of the 1997-98 El Niño. The northward displacement of sand within this littoral cell during the 1997-98 El Niño has been documented by LIDAR surveys, the first obtained in October 1997 prior to the impact and the second during April 1998. The change in beach elevations between the surveys shows a clear pattern of "hot spot" erosion and sand displacement from the southern half of the littoral cell to the northern half **(Figure 4A)** (Allan and others, 2003). We suspect that a considerable amount of the sand eroded from the spit has been moved into Netarts Bay on flood tides.

Figure 15 Complex oceanfront landslide on Three Capes Loop Road between Pacific City and Sand Lake.

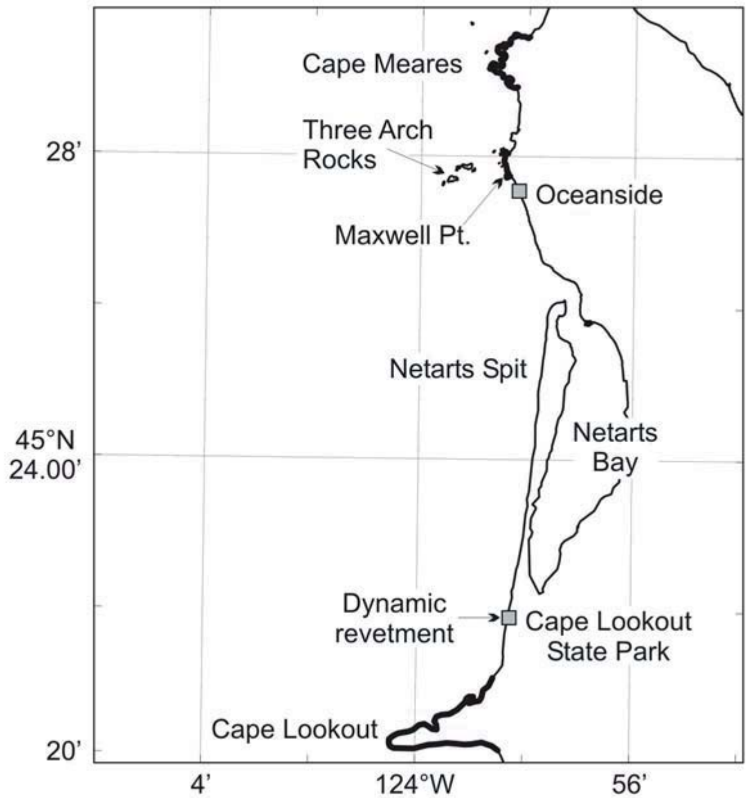


Figure 16. The Netarts Littoral Cell, with the main infrastructure of Cape Lookout State Park being near the south end where it was affected by El Niño hot-spot erosion.

Prior to the El Niño of 1982-83 a wide sandy beach had existed along the length of CLSP, and there had been no record of significant erosion of the park's high protective dunes. A log seawall supported by vertical I-beams had been constructed along a portion of the dunes in the 1960s, but it was placed there mainly to prevent people from crossing the dunes between the beach and campground. The northward shift of sand during the El Niños greatly reduced the extent of the beach fronting CLSP, allowing storm waves to attack the high dunes. The log seawall quickly failed at its south end during the 1982-83 El Niño, with the failure progressing toward the north in subsequent years, and then continuing during the 1997-98 El Niño when the wall was entirely eliminated. Its loss allowed the waves to reach the dunes, even during normal (non-El Niño) winters, so they too have been lost progressively from south to north, **Figure 17 (upper)**. This loss placed the campground and park facilities at the mercy of winter storms.

As discussed earlier, the La Niña winter of 1998-99 saw four storm events when deep-water significant wave heights exceeded 10 meters, including the most severe on 2-4 March 1999 that generated deep-water significant wave heights of 14.1 meters. That storm in particular washed into the campground, **Figure 17** (lower), carrying sand, cobbles and drift logs some 125 meters inland and resulting in considerable damage. Clean-up costs were considerable. It was clear that the park could expect further damage each winter, and that expenses would mount. Either the park had to be abandoned, or some form of shore protection would be required. In 1998 the Oregon State Parks and Recreation Department (OPRD) had constructed a revetment of large quarry stones to protect the public bathrooms **(Figure 17 (upper))**, and the structure was successful in accomplishing this but the bathrooms were subsequently torn down due to frequent flooding. OPRD was severely criticized for using this structure at a time when they were denying permits (e.g. The Capes development to the north) to citizens who felt that they also needed structures to protect their homes. In light of this criticism and due to their desire to maintain the park in as much a natural state as possible, it was decided to construct a "dynamic revetment" or "cobble berm", one that in essence would be like a natural cobble beach (Allan and Komar, 2002a; 2004). This shore-protection structure would be "dynamic" because the movement of individual stones is expected, contrasting with conventional "static" riprap revetments like those seen at Neskowin where displacement of individual armor stones is not supposed to occur and can result in the failure of the structure. There are a number of other advantages in using a cobble revetment: stone size is smaller than required for traditional armor, and placement does not require special care so its construction is simpler than that of a conventional revetment. Although more material may be needed, its construction is generally less expensive. Furthermore, a cobble revetment is not much different from a natural cobble beach, representing something of a "design with nature" approach to shore protection. A primary objective in designing the cobble revetment for Cape Lookout State Park was to make it as similar as possible in appearance to natural cobble beaches found in the park and common along the Oregon coast, and in its response to ocean processes (Komar and others, 1999b). There has been comparatively little research into their design, and few examples have been constructed, particularly on the scale of that at CLSP and in such a high-energy environment. The design of the cobble revetment for shore protection in CLSP was based mainly on comparisons with natural cobble beaches on the Oregon coast, particularly those along Netarts Spit to the north of the eroded park lands. A cobble beach already existed in the erosion area, but was too low in elevations and widths to provide adequate protection to the park facilities. Considering the pre-existence of this cobble beach, the project could be considered as being one of renourishment rather than the construction of a dynamic revetment, but its design focusing on structure elevations relative to projected extreme water levels is more akin to the design of revetments. The main design elements were the slope and elevations of the structure required to reduce the degree of storm overwash penetration into the park (Komar and others, 1999b). Analyses of potential extreme events yielded swash runup levels of 7 to 8 m (23 – 26 ft), which when added to a Spring tide yielded total water elevations ranging from about 9 to 10.5 m (29 – 34 ft) NAVD88. The surveys of the cobble beach along the north portion of Netarts Spit supported these estimates in that the cobble beach was backed by dunes, with elevations of the junction between the cobble beach and dune being in the range 7 to 8.5 m NAVD88. It was recommended that the constructed dynamic revetment be backed by a re-established dune to provide further protection from

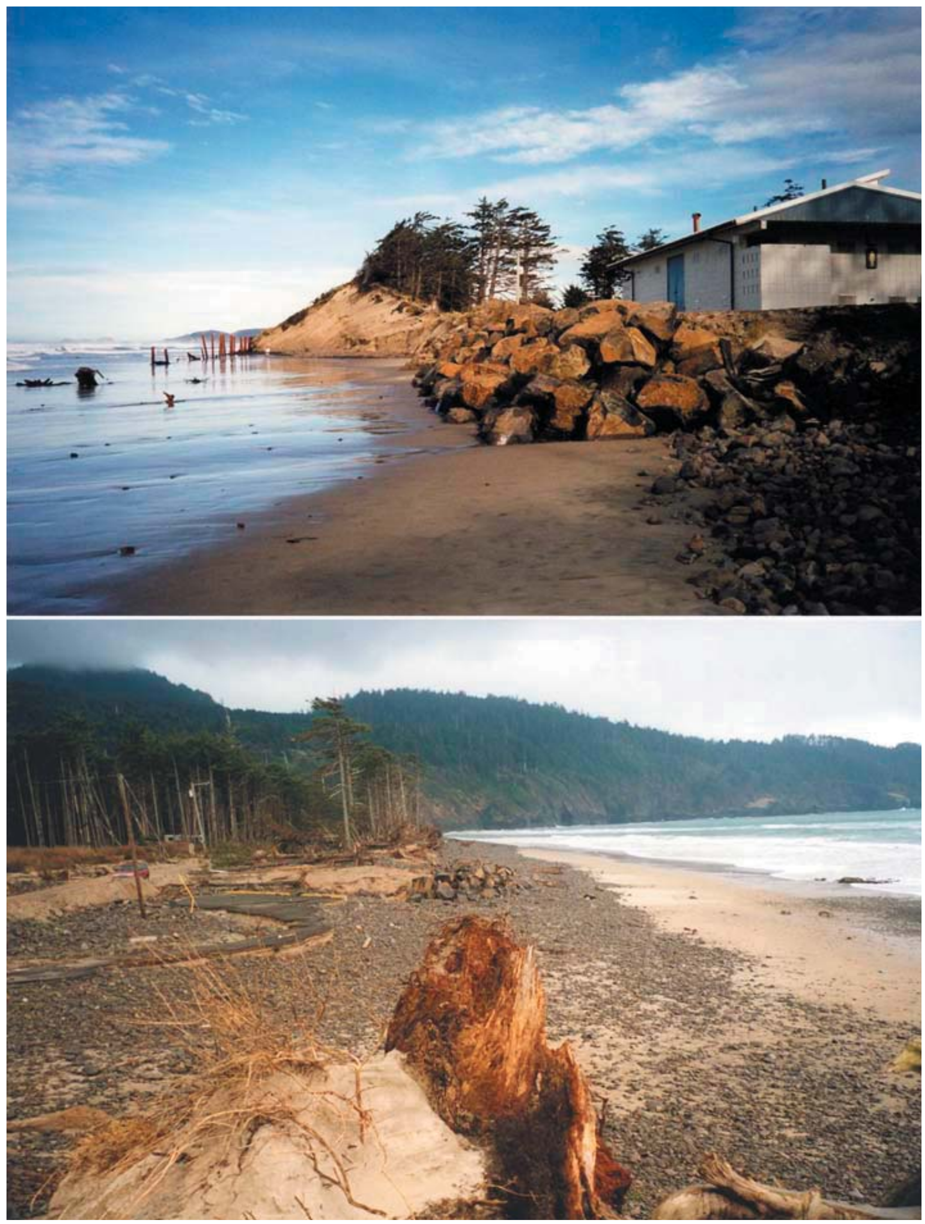


Figure 17. Erosion in CLSP owing to the occurrence of El Niños throughout the 1980s that eroded the 10 to 15 m high dunes (upper), and eventual storm wave penetration into the campground during the La Niña winter of 1998-99 (lower) (Paul D. Komar photo).

storms and to restore the former appearance of the park (Komar and others, 1999b). OPRD decided to have this re-constructed dune become an integral part of their shore protection strategy, thereby constructing the dynamic revetment at a lesser scale than was recommended. The core of the artificial dune consists of 2,750 geotextile bags, each filled with approximately 1 cubic meter of sand, **Figure 18 (upper)**. The mound of bags was then buried under 15 to 30 cm (0.5 – 1 ft) of sand, covered with a biodegradable jute-coconut fiber mat, in turn covered by another layer of loose sand that was eventually planted with dune grass native to the Oregon coast, **Figure 18 (lower)**.

The cobble revetment was constructed following the completion of the artificial dune. It was decided that cobble accumulations elsewhere in the park, in places more than sufficient to protect the park from erosion, would serve as the source of cobbles for the construction of the revetment in the eroded area. The cobbles were carried to the construction site on a front loader, and placed evenly across the pre-existing profile. The volume added along the length of the constructed dynamic revetment was not consistent, and everywhere was typically less than 0.5 meters. Construction of the artificial dune was begun in November 1999 and completed in April 2000, while the dynamic revetment was completed in December 2000. The work was undertaken by State Parks with the employment of work-released labor from the State penitentiary, which helped to keep the cost of the project to approximately $125,000, contrasting with a $500,000 - $600,000 estimated cost for a conventional static riprap revetment having the same length. Growth of the planted vegetation quickly covered the dune, so that as seen in **Figure 19** the completed project had the desired appearance of natural cobble beaches and dunes found along the Oregon coast. Unfortunately, in terms of the expected runup elevations of storm waves combined with high tides, the completed project did not achieve the recommended design specifications along its full length **(Figure 20)**; the northern portion of the artifi-

Figure 18. The completed cobble revetment in July 2001, backed by a line of reconstructed artificial dunes containing a core of sand-filled geotextile bags. Recent storms have deposited drift logs atop the dunes, while sand carried by summer winds has also begun to accumulate and cover the cobble berm (Jonathan Allan photo).

Figure 19. Construction of the artificial dune (upper) followed by planting with American dune grass at CLSP (lower). (Oregon Parks and Recreation Department photos).

cial dune has an elevation of 7 – 8 m and is typically 1 – 2 m lower when compared with the southern half of the structure, while the top of the dynamic revetment has a crest elevation of 6 m and is about 1 m lower in the north compared with the south. As such, the cobble revetment alone cannot provide sufficient protection to the park, and the line of artificial dunes yields a variable level of defense with the expectation of fairly frequent overtopping.

This expectation of overtopping has been confirmed by our monitoring study of the completed structures (Komar and others, 2003; Allan and others, in press). This study was initiated in order to document the effectiveness of these structures, and includes a program of periodic surveys, analyses of tides and wave runup compared with structure elevations, and an examination of the progressive changes in the structures wherein they evolve to become more like their natural counterparts on the coast. To date the structures have survived five winters, including several major storms that produced some overtopping in the area where the cobble revetment and artificial dunes have their lowest elevations. While some dune sand and planted

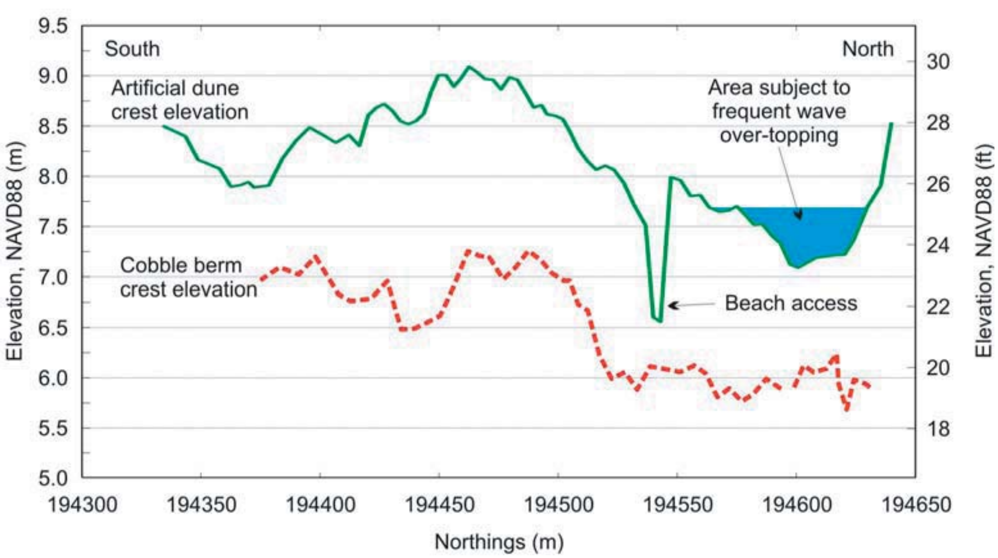


Figure 20. Variations in the crest elevations of the artificial dune and dynamic revetment at Cape Lookout State Park.

grass has been lost, the integrity of the artificial dunes remains, and there was little change to the fronting cobble revetment. It needs to be recognized that had these structures not been constructed in 1999, those recent storms would have washed into the park grounds, resulting in considerable clean-up costs. The structures at Cape Lookout State Park are therefore paying for themselves.

It remains to be seen whether the cobble revetment and artificial dune can survive future storms, which are expected to produce still higher total water levels and wave forces. Our monitoring program of the structure is continuing, and has been expanded thanks to a grant from the U.S. Army Corps of Engineers through their Innovative Structures research program. This expansion will include further comparisons with adjacent natural cobble beaches and dunes in the Netarts Cell, the collection of video records of wave swash on the cobble revetment and natural beaches, and the documentation of cobble movement during extreme events. The goal of our study is the improved design of such “natural” structures, and to demonstrate their effectiveness in shore protection.

Aside from the area protected by the dynamic revetment and artificial dune at Cape Lookout State Park, significant erosion has continued to occur along much of Netarts Cell **(Figure 21)**. The largest changes are observed along the northern 4.5 km (2.9 miles) of Netarts Spit, with the beach/dune toe having eroded landward by some 15 – 27 m (49 – 88 ft). Given that the dunes have an average height of 15.1 m (49 ft) and the beach/dune toe has eroded landward on average by 15.6 m (51.2 ft), erosion of the spit has released approximately 1.1 million m3 (1.5 million yard3) of sand in four years! Of particular interest is the dune erosion occurring midway along the spit (around 10 kilometers in **Figure 21**). At current rates, it can be expected that ocean waves will breach the foredune sometime in the one to two decades, creating a southern tidal entrance to Netarts Spit. In the south, erosion continues to plague the day-use area operated by State Parks. Our monitoring of this area indicates that the bluff there is eroding landward at a rate of 3.5 m/year (11.5 ft/year). The cause of this erosion is due to the large ocean waves observed in recent years, the ongoing depletion of sand along the spit, and a net loss of protective cobbles from the south due to their along shore movement to the north. Given the success of the

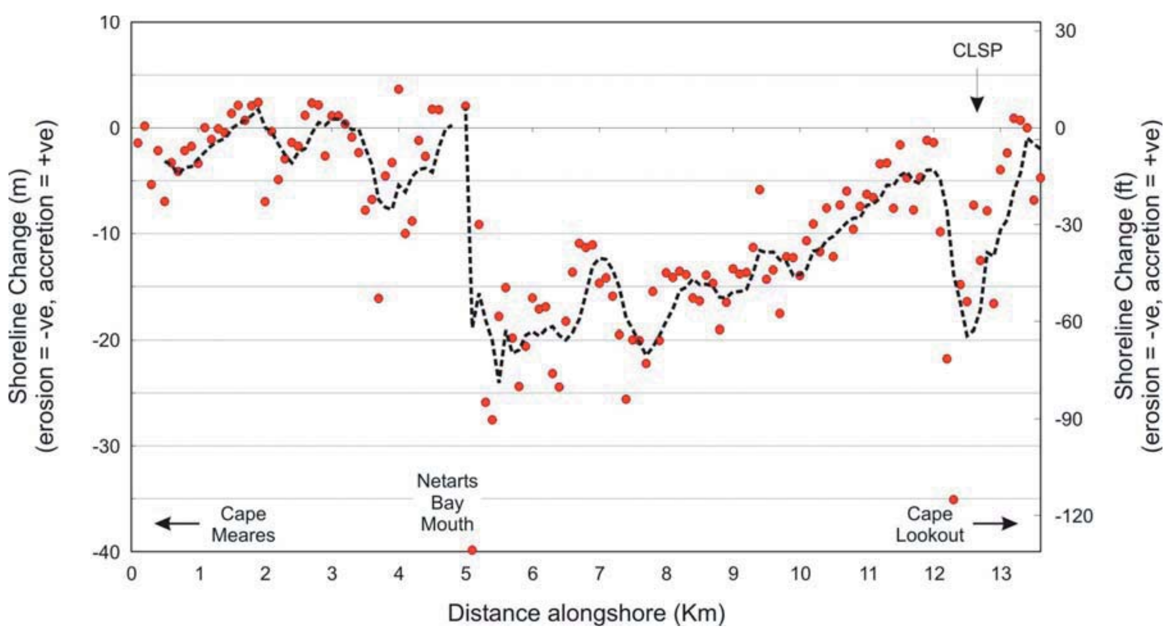


Figure 21. Positional changes in the beach/dune toe along the Netarts Cell between 1998 and 2002. The dashed line is a 500 m moving average fitted to the data.

dynamic revetment and artificial dune at Cape Lookout State Park, our analyses suggest that such a structure may be used effectively to mitigate the impacts of wave energy elsewhere in the park.

TOWARD IMPROVED NATURAL HAZARDS MANAGEMENT

Oregon has made significant strides toward improved management and mitigation of coastal natural hazards in the last decade. Much of that work was part of a state coastal management initiative that is continuing today with the development of littoral cell management plans, improved setback methods, and updated local comprehensive plans. These and other management efforts were first identified in a policy assessment initiative that involved coastal officials, citizens, and state agencies with hazard assessment, planning, or mitigation responsibilities. They formed the Oregon Coastal Natural Hazard Policy Working Group in 1992. Facilitated by Oregon Sea Grant, they developed 79 recommendations addressing hazard assessment, beach and shoreline management, land use planning for hazards, and earthquake and tsunami mitigation (CNHPWG, 1994). Many of the group's recommendations have been implemented through revised or new statutes, changes in administrative law, special studies by OSU and DOGAMI scientists, and other efforts. Further, some of the applied science projects discussed today were an outgrowth of the policy group's recommendations.

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