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Stability of the New River Spit, and the Position of Oregon's Beach-Zone Line

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ABSTRACT

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The stability of the New River Spit, Oregon, has been investigated to determine whether the State's beach-zone line should be moved. The zone line approximately followed the edge of dune vegetation when it was established in 1967–69, so relevant to the decision are the subsequent changes in morphology of the Spit and movement of the vegetation line. There are several factors that have produced significant changes in the morphology and stability of the New River Spit. The Coquille River to its north mainly supplies sand to the beach, while sea-cliff erosion to the south yields granules and pebbles. The result is a pronounced longshore variation in beach sediment grain sizes and morphodynamics, with beaches at the north being dissipative while the coarse-grained beaches to the south are intermediate to reflective. This longshore variation in large part controls the stability of the Spit. Also important are the low elevations of the Spit at its north end, produced by the northward migration of the mouth of the New River by 4.7 km between 1967 and 1997. There has been insufficient time for dune growth, and the low elevations permit frequent overwash events. In contrast, over most of the length of the Spit the dunes have grown vertically since 1967, and the vegetation line has shifted seaward. There is a long history of breaching of the Spit at its south end where ranchers have cut channels to drain flooded pastures, or have occurred naturally when flood waters in the river eroded the back side of the Spit, aided by storm-wave erosion of the dunes. Analyses have been undertaken of the beach and dune erosion that might occur in the future, during extreme events when unusually high tides combine with the runup of storm waves. Those analyses reaffirm that the Spit is relatively stable along its central portion where high dunes have developed, but is unstable at its north and south ends where elevations are low. It was concluded that the State's beach-zone line can be shifted oceanward along the central part of the Spit, to the present location of the vegetation line, but needs to be moved landward along portions that are now more unstable than in 1967–69 when the line was first established.

ADDITIONAL INDEX WORDS: *Beaches, beach sediments, beach-zone line, coastal, Oregon, wave runup.*

INTRODUCTION

Locating the boundary between upland properties versus the state-owned or regulated beach can be complicated due to the dynamic nature of the coastal zone. MORTON and SPEED (1998) have reviewed these issues, with specific application to the coast of Texas where much of the problem stems from defining the boundary in terms of the MHHW tidal elevation, not recognizing that the horizontal position of the line formed by the intersection of this tide level with the coast would fluctuate widely, both in the short and long term. Their analysis demonstrated that the vegetation line, a biological indicator of the limits of inland erosion and flooding, provides a more reliable indicator of long-term shoreline movement and represents a more stable boundary between private versus state ownership.

When the beach-zone boundary was established by law in the State of Oregon, for the most part it corresponded with the line of vegetation where dunes back beaches, or extended along the base of sea cliffs. The beach-zone line or Statutory Vegetation Line (SVL) was surveyed in 1967, mainly using aerial-photo analysis techniques, and was established by law in 1969. The location of the SVL is important in that it denotes the active beach area over which the State has jurisdiction, affecting such things as access and recreational use of the beach by the general public, and decisions concerning the construction of shore-protection structures.

Although the morphology of the Oregon coast has changed during the 30 years since the establishment of the SVL, until recently there had been no request to change its position so that it better reflects present-day conditions. The first request to do so came in the area of the New River Spit, Figure 1, located on the south coast of Oregon, centered approximately 15 km south of the city of Bandon. The Spit consists of the stretch of beach and dunes that extends in the longshore direction and is partially isolated by the channel of the New River which forms its landward boundary. After flowing west from the Coast Range and coming within approximately a hundred meters from the ocean shore, the river takes a right turn and flows 15 km to the north parallel to the ocean beach, before it again turns to the west and finally flows into

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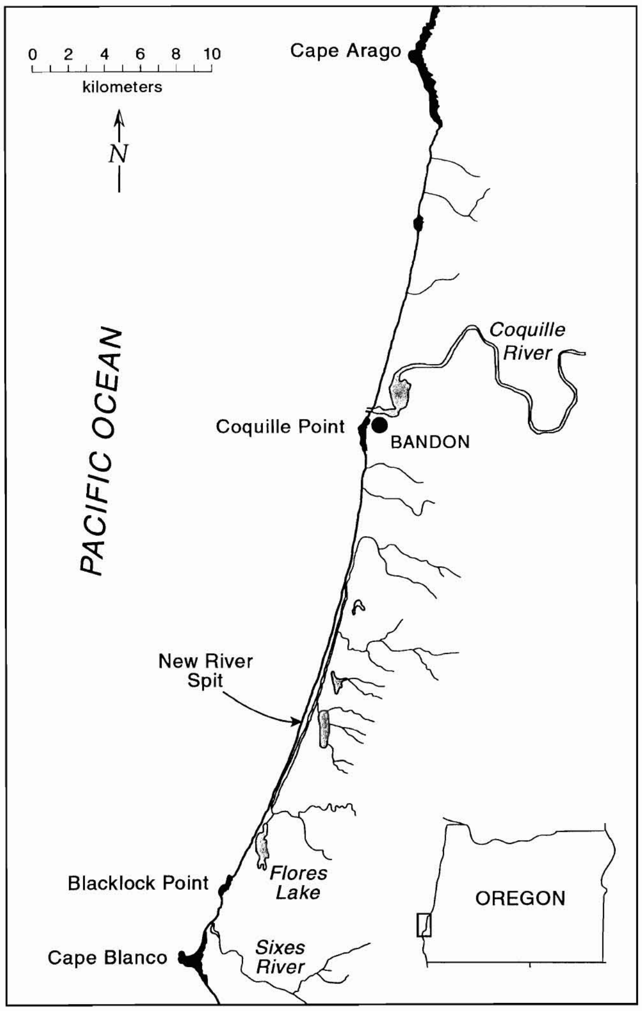

Figure 1: The New River and Spit, located within the Bandon Littoral Cell, Oregon.

the ocean. As the term is used, the "Spit" refers to this stretch of ocean beach and active foredunes that is parallel to and immediately west of the New River.

A study has been undertaken of the physical processes, morphology and stability of the New River Spit with the objective of determining whether or not the SVL should be moved. In the area of the Spit, the SVL shifts inland and follows the east bank of the River, probably placed there because in 1967 the Spit was only sparsely covered with dune vegetation and experienced frequent overwash events during winter storms. Significant changes have occurred in this area since the 1960s, specifically in the morphology and degree of vegetation cover. As a result, local property owners requested that a review be undertaken to move the SVL from the east bank of the river out onto the Spit.

The investigations included in our study have been undertaken in order to provide data and analyses required by the State in making such a decision (KOMAR *et al.,* 1999a). These requirements include:

(a) A documentation of changes since 1967 when the SVL was surveyed;
(b) An assessment of the extent to which the vegetation line has moved;
(c) An examination of the perceived cause of the movement of the vegetation line and the likelihood that such movement is continuing and will be permanent;
(d) A consideration of the likelihood that the present location of the vegetation line will remain stable over a period of 25 years or more;
(e) A review of the stability of the site based on the physical conditions and expected processes.

Although these requirements are seemingly straight forward, the area of application proved to be of special interest due to unusual conditions in the area of the New River Spit that affect its stability. This includes a longshore variation in beach-sediment grain sizes that determines the morphology and stability of the Spit, and the progressive northward migration of the mouth of the New River and lengthening of the Spit, which has created an area that is less stable than in 1967 when the SVL was established. Finally, as noted above, significant to the determination of whether to move the SVL is a projection of the future stability of the site. We have evaluated this through assessments of the potential for episodes of dune erosion or Spit overwash, based on analyses of extreme events when high storm waves combine with elevated tides. The present application provides an example of the use of analysis techniques developed to evaluate the potential for major erosion, more commonly used to establish set-back lines.

LITTORAL CELL AND BEACH SEDIMENTS

The Oregon coast consists of a series of littoral cells, stretches of beach confined between headlands (KOMAR, 1997). The New River Spit is located in the southern half of the Bandon Littoral Cell, Figure 1, which extends for 45 km from Cape Arago at the north to Blacklock Point in the south. It is unclear whether Blacklock Point prevents bypassing of beach sediment; if not, there would be an exchange of sediment with the small pocket beach between Blacklock Point and Cape Blanco, Figure 1. This is only important with respect to whether the Sixes River, which supplies sand and gravel to the beach near Cape Blanco, is also a source of sediment to the New River Spit. The chief sources of sediment to the Bandon Littoral Cell are the Coquille River at the north and from sea cliff erosion to the immediate north of Blacklock Point. Sand is lost from the beach when it is blown inland to form dunes, a loss that has been particularly significant at the north end of the cell where a large field of sand dunes exists. Sand dunes also have formed to the south of Bandon and along the central part of the New River Spit.

It is not possible to develop a detailed sediment budget for the Bandon Littoral Cell, since little study has been made of sediment transport by the Coquille River and only rough estimates can be made of the amount of beach sediment derived from sea cliff erosion near Blacklock Point. The Coquille River drainage basin (1,985 km^2) is substantially larger than the other rivers of the littoral cell, and can be expected to be a significant source of sediment to the beach. Based on sediments in its estuary and on the adjacent beach, it is clear that the Coquille River mainly supplies sand, with only a scatter of pebbles being found in its deposits. The drainage area of the New River has increased with time as its mouth has migrated to the north, but its present drainage area (333 km^2) and discharges remain small, and can be expected to transport mainly fine-grained silt and clay, sediment that is too fine to remain on the beach.

The other important source of beach sediment is from erosion of the sea cliff extending from Blacklock Point north to just south of Floras Lake, a total longshore length of about 3 km. The height of the cliff is variable and includes a number of gullies; on average the height is approximately 25 m. The lower part of the cliff is composed of a Tertiary siltstone, which yields fine-grained sediment that will not remain on the beach. It is the upper portion of the cliff that is an important contributor of sediment, since it consists of Pleistocene marine terrace sediments, interpreted as being ancient (circa 80,000 years old) beach sediments. These terrace sediments are coarse grained, with abundant lenses of granules and pebbles. From measurements on aerial photographs it is estimated that the long-term average cliff erosion rate is about 9 cm/yr (KOMAR *et al.*, 1999a). With this rate and dimensions of the cliff, the calculated total volume of sediment eroded from the cliff is estimated to have been about 7,500 m^3/yr, but only about 25% of this sediment is coarse enough to remain on the beach, reducing the contribution to about 1,880 m^3/yr, most of which is granules and pebbles.

This coarse sediment contributed by sea-cliff erosion at the south end of the littoral cell is carried to the north where it mixes with sand contributed by the Coquille River. The overall pattern of sediment movement and mixing is diagrammed in Figure 2, distinguishing between "sand" and "coarse sediment" which includes granules (2 to 4 mm) through pebbles (4 to 64 mm). In varying proportions these two grain-size components account for the sediments found in the beach along the length of the Bandon Littoral Cell, representing a mixing of sand derived chiefly from the Coquille River and coarse sediment from sea-cliff erosion near Blacklock Point. The resulting longshore variation in beach sediment grain sizes is documented in Figure 3 by a series of histograms derived from sieving analyses. The longshore variation is particularly noteworthy along the 15-km length of the New River Spit, with pebbles being abundant at the south end of the Spit, while at its north end the beach is composed almost entirely of sand. There is a broad range of grain sizes and concentration of pebbles at the south end of the Spit (sample G in Figure 3), a local concentration that is due to the frequent breaching of the Spit at its south end, an event that tends to transport away the sand, leaving a concentration of pebbles. The decrease in sand toward the south along the length of the cell in part reflects the increasing distance from its primary source, the Coquille River, but also reflects its progressive loss from the beach as it is blown inland and accumulates in dunes. There is an overall trend of decreasing foredune heights and volumes with distance from the Coquille River, but with interruptions in the trend due to Spit breaching events and the migration of the mouth of the New River which has cut away the dunes.

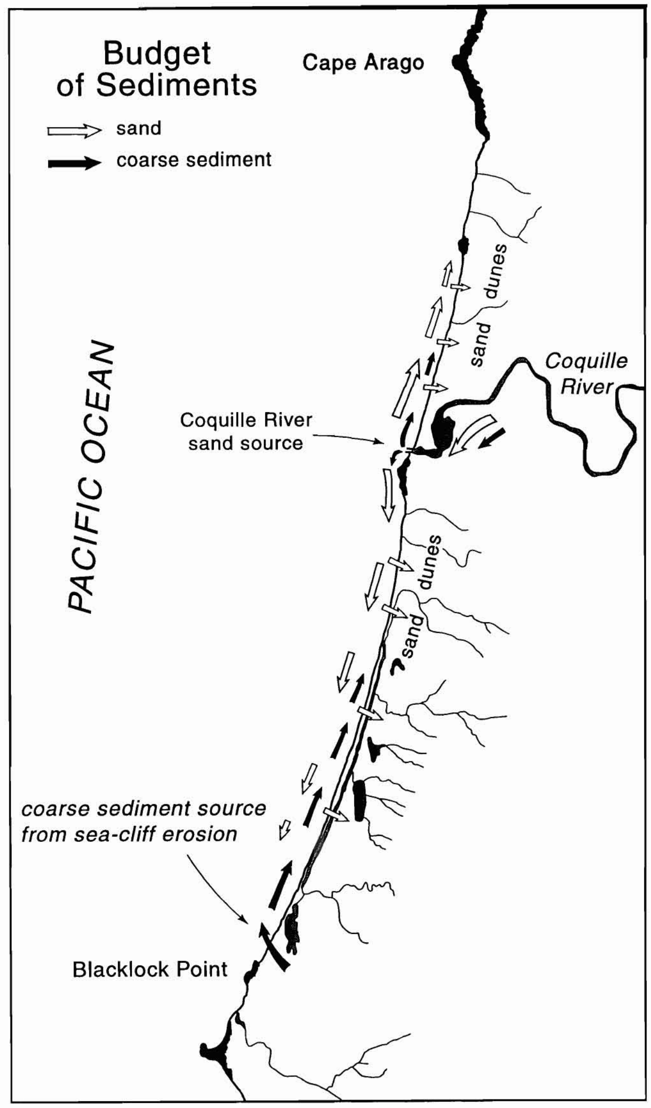

Figure 2: The movement of "sand" (open arrows) and "coarse sediment" (dark arrows) from their sources, respectively the Coquille River and from sea cliff erosion north of Blacklock Point. The sizes of the arrows qualitatively represent quantities of sediment.

The diagram of Figure 2 and the grain-size histograms of Figure 3 show that at any location along the shoreline, the beach sediment is made up of "sand" and/or "coarse sediment", with the proportions depending on the proximity of the location relative to the two sediment sources. A longshore mixing of sediment is underway, and this mixing is greatest along the New River Spit. The mixing must be progressing with time, in particular with the northward movement of coarse sediment. This does not represent a net longshore sediment transport toward the north, since within the "pocket-beach" littoral cells of the Oregon coast the net transport is effectively zero (KOMAR, 1997). This is seen specifically in the

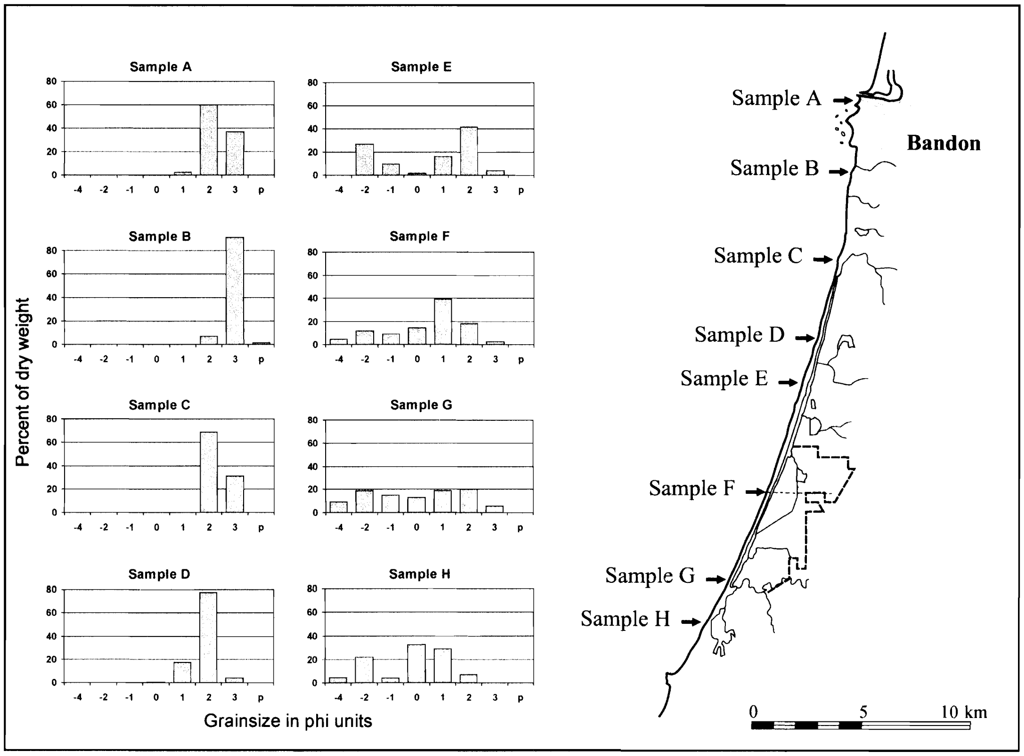

Figure 3: Grain-size histograms derived by sieving analyses of beach sediments. The −4 and −2 phi sieves represent pebbles, −1 phi is granules, and 0 through 3 phi are respectively very coarse through fine sand.

Bandon Littoral Cell by the shoreline changes that occurred following jetty construction at the mouth of the Coquille River early in the century (KOMAR *et al.,* 1976). An interesting question is why the coarse sediment derived from the south has not had time to move further to the north, so that it is found along the entire length of the littoral cell. Our interpretation is the same as that of SHIH and KOMAR (1994) who documented a similar longshore variation of beach sediment grain sizes within a littoral cell on the northern Oregon coast; the interpretation is that sea-cliff erosion and the introduction of the coarse sediment to the beach only began in the year 1700 when a major subduction earthquake caused many areas of the coast to subside by 1 to 2 m, initiating the erosion (ATWATER, 1987; DARIENZO *et al.,* 1994). This interpretation also accounts for the inception of sea cliff erosion at Bandon, with the erosion progressively decreasing with time due in part to the aseismic uplift of the area that has occurred subsequent to the 1700 earthquake (KOMAR *et al.,* 1991).

Although we have been unable to accurately evaluate the quantities of sand and coarse sediment contributed to the beach within the Bandon Littoral Cell by the Coquille River and from sea cliff erosion, it is clear that these contributions exceed the losses as sand is blown inland to form dunes or possibly lost offshore to deep water. Thus, the budget of sediments should have a positive balance, and one would expect to see this balance reflected in the long-term growth of the beach and dunes within the littoral cell. This is, in fact, what we have found in our analyses of aerial photographs.

AERIAL PHOTO ANALYSES OF LONG-TERM CHANGES

Of importance to deciding whether the SVL should be moved was a documentation of the physiographic changes that have occurred along the New River Spit since the survey of the SVL in 1967. Such analyses have been undertaken using seven sets of aerial photographs ranging in dates from 1939 to 1997, including the 1967 set that served as the basis for establishing the SVL. Maps of the area also have been used, with the oldest (1851, 1882 and 1903) being useful in providing a documentation of the physiography of the area prior to the availability of aerial photos. The summary here will be brief; more detailed accounts can be found in our State report and in a conference paper (KOMAR *et al.,* 1999a; DIAZ MENDEZ *et al.,* 1999).

The maps and aerial photos show that there have been major changes in the physiography of the area. The oldest maps show that in the late 1800s and throughout the early 20th century, there generally were multiple stream mouths so it is difficult to define the actual extent of the New River and Spit at that time. The southern-most mouth was that of Floras Creek and the drainage from Floras Lake, Figure 1. The early history of Spit growth involved the northward migration of the Floras Creek mouth so that it progressively captured a series of small drainages, making jumps to the north when these linkages occurred. Since the middle of the 20th century and the existence of a well defined New River, there

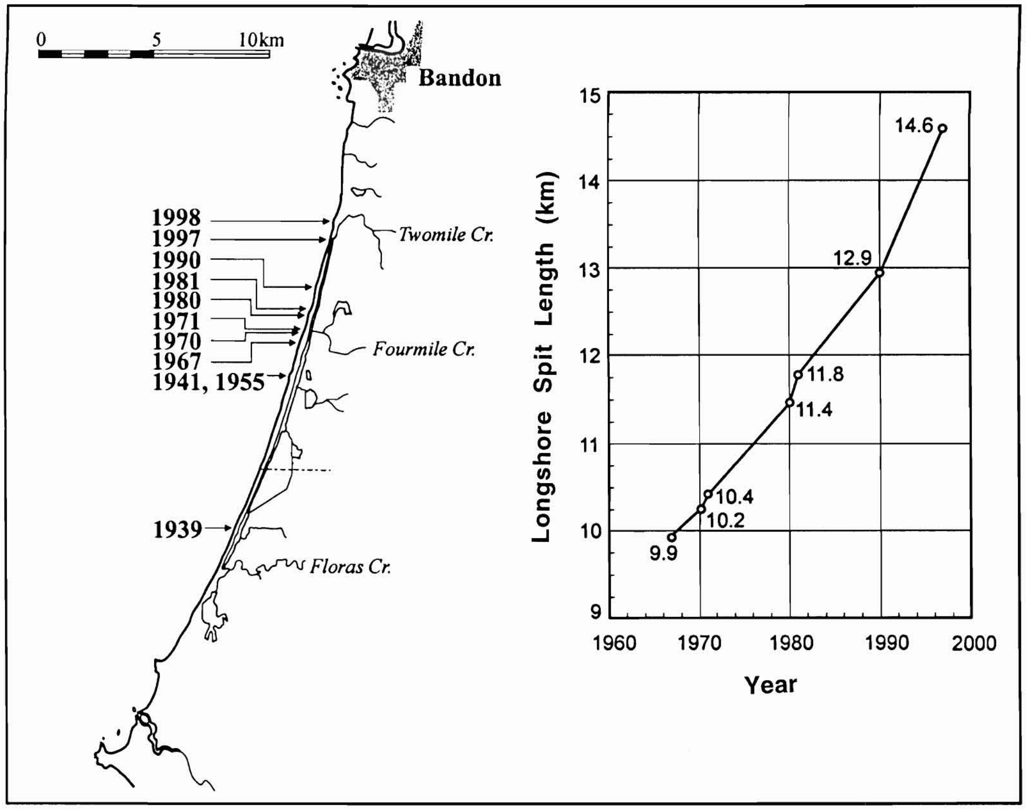

Figure 4: Locations of the mouth of the New River as it migrated to the north. The graph shows the increase in Spit length as measured on aerial photographs.

has been a single dominant river mouth at the north. The most profound change observed in the series of aerial photographs from 1967 to the present is the progressive northward migration of the river's mouth. The positions established by the series of aerial photos are indicated by the arrows in Figure 4, which demonstrate that the mouth has shifted to the north by some 4.7 km in 30 years.

Figure 4 presents this northward migration of the mouth as a graph of the length of the New River Spit versus time. The nearly uniform slope of the curve implies that the migration of the mouth has been at a fairly constant rate of 0.16 km/yr; the position in 1997 compared with 1990 suggests a somewhat greater rate (0.26 km/yr) during recent years. Actually, it is likely that the migration has always been somewhat episodic, not nearly so steady as implied by the graph. In particular, during major El Niño years such as 1982–83 and 1997–98, strong waves approached the coast from the southwest, and this can be expected to have caused a more rapid northward shift in the river's mouth and lengthening of the Spit (KOMAR, 1998). The El Niño periods of rapid migration of the river's mouth would have been separated by years of slower migration or even stability in its position.

With the northward migration of the river's mouth, the northern most portion of the accreting Spit is younger than the more southerly portions. The Spit to the immediate south of the river's mouth has had little time for the accumulation of sand dunes. Over roughly the most northerly 1.5 km of Spit length, there are only intermittent clumps of low dunes, separated by zones where winter storms actively wash over low elevations of the Spit. Each of these overwash channels ends in a "delta" composed of beach and dune sand that has been carried into the river channel. High winter discharges in the river act to erode these deltas and transport the sand back to the beach. With increasing distance southward from the mouth of the river, the dunes become progressively higher and more effective in preventing overwash during storms. The heights of the dunes reach a maximum approximately midway along the length of the Spit, first growing in size further to the south due to the longer time available for development, but then decreasing in size further to the south because of the reduced availability of sand on the beach, sand derived mainly from the Coquille River to the north.

The elevations of the dunes, and even their existence, are also affected by breaching events that have occurred at the south end of the Spit. There has been a complex history of breaching, in each instance forming a temporary inlet connecting the river with the ocean at a more southerly position than its "stable" mouth at the north. Breaching has occurred mainly at the south end of the Spit where the New River turns to the north. Natural breaches in this area have occurred when meandering on the river cuts away at the back side of the spit, perhaps aided by storm wave erosion of the

Figure 5: The 1997 aerial photo of the breach area at the south end of the New River Spit.

beach. More often, breaching has resulted from the ranchers cutting channels through the Spit to drain flooded pastures or to permit the entry of salmon into the river.

The main area of breaching at the south end of the Spit is shown in Figure 5, from the 1997 aerial photos. The accreting point bar on the inside of the bend in the river is apparent; erosion on the outside of the bend cuts a high scarp into the dunes and in the sand deposited within the channel by previous overwash events. Figure 5 shows that breaching has completely cut away the dunes over a 1.5 km stretch, while the dunes had been partially eroded for an additional 0.8 km to the north. Although breaching is initiated in a narrow zone at the south end of the Spit, river flow and storm waves rapidly widen the opening and generally cause its expansion toward the north because the winter storm waves predominantly arrive from the southwest, causing a northward migration of the opening. Breaching most recently occurred during December 1998, caused by heavy rains and a flood in the New River. This recent occurrence illustrates the continued instability along the base of the Spit.

Although the New River Spit has repeatedly breached at its south end, the breach always closes during the following summer when beach sand is carried into the gap by waves and currents. The mouth of the river then returns to its "stable" location far to the north. One might expect that the breached inlet in the south would be more efficient in dis-

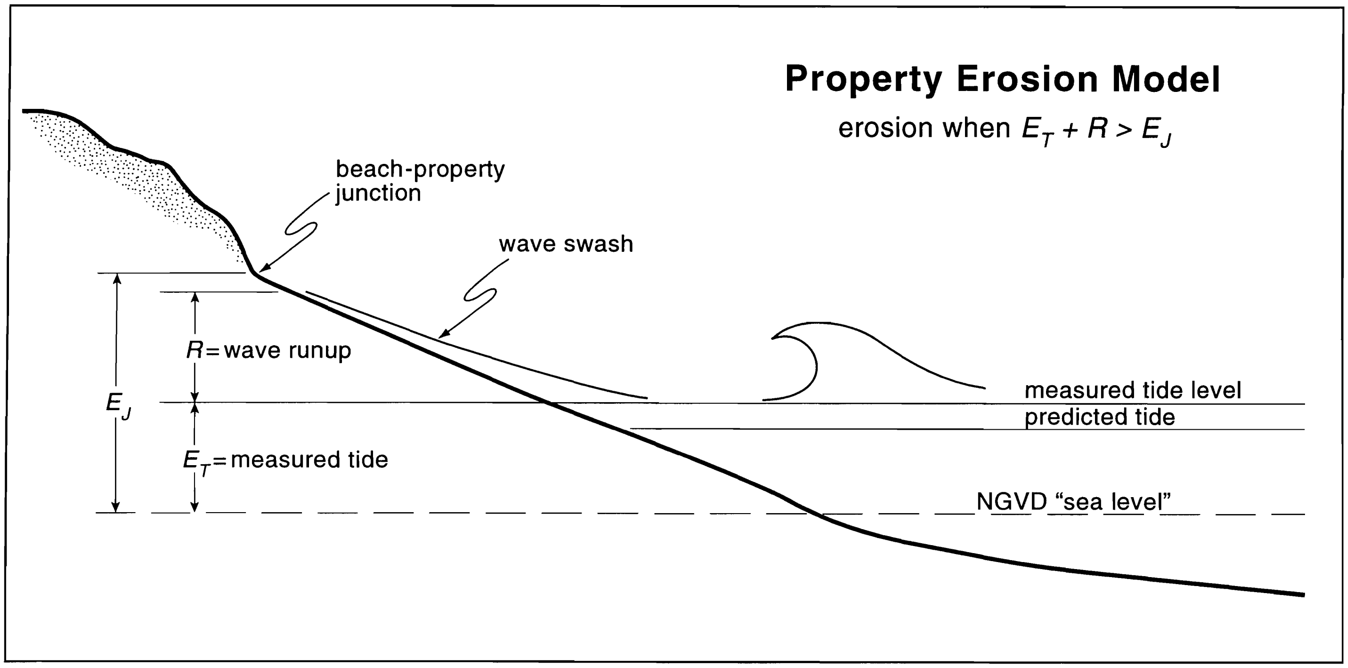

Figure 6: The model used to compare the measured tide, E_T, plus the runup of waves, R, with the elevation E_J of the toe of the foredunes.

charging the river water into the ocean than transporting it along the coast for some 15 km over a very low gradient. The likely explanation has to do with the variation in beach sediment grain sizes along the length of the Spit. Coarse grained beaches are particularly dynamic in responding to changing wave conditions, and undergo large changes in elevations from summer to winter as wave energy levels are altered (WRIGHT and SHORT, 1983; SHIH and KOMAR, 1994). The presence of a coarse sediment beach in the area of breaching therefore permits the filling of the gap as part of the overall beach recovery during the summer. In contrast, at the north end of the Spit the beach is composed of sand, and such a fine-grained dissipative beach undergoes only minor changes in elevations from summer to winter, always remaining relatively low. The river flow, even at low discharges, finds it easier to maintain a mouth through this sand beach at the north.

In contrast to the continued instability of the New River Spit at its north and south ends, the central stretch of the Spit has become more stable since 1967 with the growth of higher dunes. Important during this century has been the explosive growth of European beach grass along the Oregon coast, having first been introduced to limited areas in 1915 to control dunes, but then rapidly spreading to other areas (COOPER, 1958). During the 1930s it became established in the New River area (BLM, 1995), and it has had a significant effect on the stability of the Spit by raising the heights of foredunes.

The main use of the aerial photographs was to quantitatively investigate the changing position of the dune vegetation line since 1967 when the SVL was surveyed. Measurements of positions of the vegetation line along the central portion of the Spit show a number of reversals, with periods of erosion cutting back the vegetation line, followed by longer intervals of dune rebuilding with a seaward shift of the vegetation line. Such cycles of erosion and dune rebuilding are typical of the Oregon coast, and are observed in most areas of foredunes backing beaches (KOMAR, 1997). For the most part, within this cycle of erosion and rebuilding, the net effect along the central New River Spit has been a 15 to 30-m seaward shift in the position of the dune vegetation line during the 30-year period between 1967 to 1997.

SPIT STABILITY DURING EXTREME STORMS

The analysis of the long-term stability of the New River Spit, required to move the SVL, was based on our research on the Oregon coast that has focused on the erosion processes and projections of extreme events (SHIH *et al.,* 1994; RUGGIERO *et al.,* 1996, 2001). As diagrammed in Figure 6, of interest is the total water level produced by a high tide (elevation E_T) plus the runup level of the waves (R), which must reach or exceed the elevation of the beach/dune junction (E_J) for dune erosion to occur. In the analysis these processes are combined to evaluate the potentially extreme total water elevations that could occur within a 25- to 100-year time frame. Based on those evaluations, an analysis is then undertaken to estimate the maximum foredune erosion that might occur, using a geometric model of dune erosion (KOMAR *et al.,* 1999b).

Most occurrences of major erosion along the Oregon coast have taken place during high Spring tides when E_T in Figure

6 represents an exceptional water level (KOMAR, 1997). Predicted astronomical Spring tides typically range up to about 3 m MLLW (about 1.8 m above the 1929 NGVD datum); however, extreme measured tides can reach 3.5 m MLLW or greater. These highest tides tend to occur during the winter, when their role in bringing about coastal erosion is most significant. The increase in the levels of the measured tides above predicted is due to a number of atmospheric and oceanic processes, the most important involving the effects of ocean currents and water temperatures. Upwelling during the summer produces colder water over the continental shelf than in the winter, and this cold, dense water depresses the mean level of the sea along the coast, while the warmer water in the winter produces a thermal expansion and raises the mean water level. Furthermore, the effects of northward flowing shelf currents in the winter also raise sea levels along the shore, while the predominant southward currents of the summer lower sea level. As a result, during the winter the monthly averaged sea levels are generally about 30 cm higher than in the summer, causing the measured tides to be systematically higher than predicted. This becomes even more extreme in an El Ninño, when the processes are intensified. During the El Niño winters of 1982–83 and 1997–98, measured high tides along the Oregon coast were on the order of 50 to 60 cm higher than predicted (KOMAR, 1998; KOMAR *et al.,* 2000).

Storm surges produced by strong onshore winds and low atmospheric pressures are generally not a major process on the Oregon coast, usually elevating the water level by less than 25 cm (RUGGIERO *et al.,* 1996). However, a major storm on 2–4 March 1999 produced a measured storm surge of about 1.5 m on the Washington coast (KOMAR *et al.,* 2000), demonstrating that under the right conditions this process could also raise the measured tide, contributing to the erosion.

The Oregon coast is characterized by severe wave conditions, and this is the primary process responsible for episodes of erosion and property losses. Measurements of waves off the Northwest coast have been collected by offshore buoys since the mid 1970s. The data have been analyzed by TILLOTSON and KOMAR (1997), with a re-evaluation of the wave climate by ALLAN and KOMAR (in review) undertaken in light of substantially stronger storms and higher waves since 1997. Important in the application of the model diagrammed in Figure 6 are the runup levels, *R,* achieved by the storm waves when they reach the beaches. Part of our research has been to obtain measurements of runup under a range of deep-water wave conditions and beach slopes (RUGGIERO *et al.,* 1996; 2001). Our data from the Oregon coast, combined with those obtained by HOLMAN (1986) at the Field Research Facility, Duck, North Carolina, yield the relationship

$$R_{2\%} = 0.27(SH_{S0}L_0)^{1/2} \quad (1)$$

for the runup elevation $R_{2\%}$ (the 2% exceedence elevation), where S is the slope of the beach, H_{S0} is the deep-water significant wave height, and L_0 is the deep-water wave length [$L_0 = (g/2\pi)T^2$ where T is the wave period].

Application of the analysis involves comparisons between calculated total water levels, and the elevation of the beach

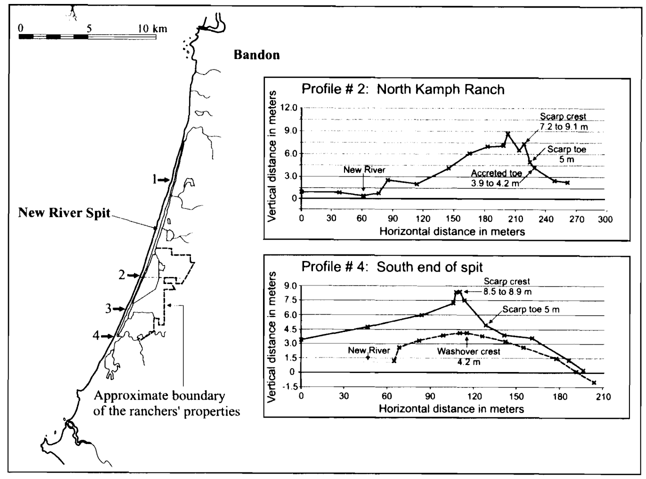

Figure 7: Surveyed beach and dune profiles from the New River Spit. Vertical elevations are relative to the NGVD29 datum, and horizontal distances are from the western shore of the New River. Profile #2 is from the central Spit where foredune growth has increased the stability of the Spit, while Profile #4 is from the breach area at the south end of the Spit, with the dashed profile being from the low-lying area within the breach and the solid profile is to the immediate south where dunes have not been directly affected by breaching.

and dunes, specifically with the beach/dune junction level, E_J (Fig. 6). This required accurate surveys at sites of interest along the Spit. In total, there were four survey sites on the Spit, and three further to the north to provide coverage along the length of the littoral cell (KOMAR *et al.,* 1999a). Locations of surveys on the Spit are shown in Figure 7, and include one profile at its north end where the elevations are still low and overwash events are frequent, two in the mid-Spit area where dune accretion has increased the Spit's stability, and profiles from the breach area at the south end of the Spit. Bench marks were established at each site, including GPS determinations of elevations relative to the NGVD29 vertical datum, important so that the elevations of the land surveys could be compared with the calculated water levels. Details of the survey techniques and all of the profiles can be found in KOMAR *et al.* (1999a). Two examples are included in Figure 7, Profile #2 from the stable mid-area of the spit, and Profile #4 from the breach area at the south end of the Spit.

The Spit surveys were obtained on 21-22 October 1998, which is prior to the first major storms of the winter season, so the profiles were still in their accreted summer conditions. For each profile the elevations of the dune toe and their average crest level were determined, and the results are given in Table 1. The dune toe also represents the elevation of the vegetation line as of October 1998. Of interest, it is seen in the sequence of profiles #1 through #3, north to south along the Spit, that there is a regular increase in the elevations of the dunes, both in the toe elevation/vegetation line, and in the average elevations of the dunes; these trends are interrupted at Profile #4 due to the occurrence of Spit breaching. Also listed in Table 1 are the average beach slopes, which increase from north to south. All of these characteristics re-

Table 1. *Analysis based on the model in Figure 6 for the profile locations in Figure 7, comparing the elevation of the dunes with water levels due to tides plus the runup of waves.*

Profile Number	Dune Toe Elev., E_J (m)	Dune Elev. (m)	Beach Slope, S	Event	Tides H_T (m)	Waves H_s (m)	Runup R (m)	Total $E_T + R$
1	2.8	1.8–6.8	0.02	El Niño	2.5	7.2	1.5	4.0
				Normal	2.1	8.9	2.1	4.2
2	3.9–4.2	7.2–9.1	0.04	El Niño	2.5	7.2	2.2	4.7
				Normal	2.1	8.9	3.0	5.1
3	6.5–6.9	9.5–11.3	0.10	El Niño	2.5	7.2	3.4	5.9
				Normal	2.1	8.9	4.8	6.9
4	5.0	8.5–8.9	0.10	El Niño	2.5	7.2	3.4	5.9
				Normal	2.1	8.9	4.8	6.9

* Elevations of dunes, tides and total water levels ($E_T + R$) are all relative to the 1929 NGVD datum.

late to the north-to-south increase in beach sediment grain size, documented in Figure 3, produced by the longshore mixing of Coquille River sand and granules and pebbled derived from sea-cliff erosion to the south. The runup of the waves given by equation (1) is greater with the steeper beach slope, S, and under otherwise uniform wave conditions along the length of the Spit, the greater wave runup toward the south accounts for the systematically higher dune-toe elevations.

Analysis results for the processes at each profile site are included in Table 1. Details of the analyses can be found in our unpublished report (KOMAR *et al.,* 1999a). A contrast is made between El Niño climate events, when measured tides are higher than normal while storm-wave energies are reduced due to the more southerly tracks of the storm systems, crossing central California, versus "Normal" winters when tides are closer to their predicted levels and storms cross the Pacific Northwest, bring higher wave conditions. The actual values of tides and wave heights and periods are derived from the analyses of RUGGIERO *et al.* (1996), having selected combinations that were thought to represent essentially 100-year events leading to high total water levels and the likelihood of Spit erosion. As noted above, the increase in beach slopes toward the south results in a parallel increase in the calculated runup levels, $R_{2\%}$, and in turn for the total water levels, $E_T + R_{2\%}$. At Profile #1 the total water levels exceed the elevations of the dunes, Table 1, accounting for the frequent occurrence of overwash events toward the north end of the Spit. At the mid-Spit locations, Profiles #2 and #3, the elevations of the calculated total water levels are similar to, or slightly greater than the surveyed dune toe/vegetation lines, demonstrating that combinations of high tides and storm-wave runup are controlling this elevation. With the total elevations of the dunes being substantially higher than the calculated water levels, there is little chance for dune overwash, and the field evidence indicates that toe erosion is the principal impact during storms. Applications of a geometric dune-erosion model developed by KOMAR *et al.* (1999b) to be used in conjunction with the model diagrammed in Figure 6, indicate that at maximum some 20 to 40 m of dune retreat might be expected in this mid-Spit area, the higher end of the estimated range occurring when a rip-current embayment also contributes to the erosion.

Profile #4, Figure 7, is from the south end of the Spit in the area of frequent breaching. Two profiles were surveyed, one from the breach area and another to the immediate south where the dunes are intact. The analysis given in Table 1 is of the latter profile, with the toe of the dune being at an elevation $E_J = 5.0$ m NGVD29. Due to the steep beach slope caused by the coarse sediment, the calculated values of runup are large, and the total water levels reach 5.9 and 6.9 m NGVD29 respectively for the El Niño and Normal events. These extreme water levels are 0.9 to 1.9 m higher than the toe of the dunes, so one could expect significant dune erosion during such an extreme event; according to the geometric dune-erosion model, the estimated maximum erosion would again be on the order of 20 to 40 m. At the time of the survey in October 1998, the highest point within the breach area at the Profile #4 site had an elevation of only 4.2 m NGVD29 (Figure 7). Therefore, with the calculated water levels of 5.9 to 6.9 m (Table 1), there would be substantial overwash, possibly causing a breach from the ocean side. Actually, calculations indicate that this area can experience overwash events virtually every winter when a storm occurs at a time of reasonably high tides. It is apparent that this low-lying area at the base of the Spit remains highly unstable, both because storm-wave runup can easily wash over the Spit, but also because, as discussed earlier, the marked bend in the River results in erosion along the landward side of the Spit.

The analyses of tides and storm waves in Table 1 were based on evaluations of those processes up through 1996, and were meant to represent approximately the 100-year projected extremes (KOMAR *et al.,* 1999a). Soon after the completion of our report to the State concerning the stability of the New River Spit, a series of storms struck the Northwest coast in February and March 1999, which exceeded what had been projected for the 100-year deep-water significant wave height. Later analyses established that this seemingly recent increase in storm-wave conditions is part of a progressive, 25-year increase in wave heights and periods measured on the Northwest coast (ALLAN and KOMAR, in review). Although those recent storms had their greatest impacts along the shores of northern Oregon and Washington, with substantially less effect in southern Oregon, including the New River area, their occurrence has resulted in revised estimates of the projected extreme wave conditions for the Pacific Northwest (KOMAR *et al.,* 2000). Had those projections been used in our assessments of the stability of the New River Spit, they would have predicted potentially greater erosion during extreme storms, but our overall conclusions would have been much the same.

CONCLUSIONS AND DISCUSSION

Investigations have been undertaken related to evaluations of the morphological changes and stability of the New River Spit, in order to decide whether the Statutory Vegetation Line (SVL) should be relocated from its position as enacted in 1969. Substantial changes have occurred in the area throughout this century and in the 30 years since the establishment of the SVL. Most noteworthy has been the migration of the mouth of the New River to the north by nearly 4.7 km since 1967, with the area added to the Spit being low in elevation and experiencing frequent overwash events, thereby having become less stable than in 1967–69. Another area of Spit instability exists at its south end, where the New River makes a sharp bend to the north and tends to erode the backside of the Spit, contributing to frequent breaching occurrences. In contrast to the instability at the north and south ends of the Spit, its central portion has become relatively stable due to the growth of dunes aided by the introduction of European beach grass.

Based on the results of this study, it was proposed that the SVL be relocated (KOMAR *et al.,* 1999a). Along the central stretch of the Spit which had become more stable, it was proposed to move the SVL from its position on the east bank of the New River, to the beach/dune vegetation line along the Spit. On the other hand, in the area of frequent breaching at the south end of the Spit, the decision was to leave the SVL in its existing position on the east bank of the river. At the north end of the Spit where the area has become less stable since 1969, it was proposed to move the SVL inland, off from the Spit to the east bank of the river. Although there was generally a favorable response to these proposed changes in the SVL, during its 1998–99 session the Oregon State Legislature failed to act on the bill that would have legally changed the position.

Beyond such management issues, the New River area proved to be of scientific interest and provided the opportunity to apply analysis techniques developed to evaluate the potential for extreme occurrences of foredune erosion. An unusual feature of the littoral cell is the pronounced longshore variation in the coarseness of the beach sediment, produced by the mixing of sand derived from the Coquille River in the north with granules and pebble from sea-cliff erosion in the south. This variation in grain sizes has produced a parallel change in the morphodynamics of the beach, ranging from dissipative in the north to intermediate beach types toward the south, according to the classification of WRIGHT and SHORT (1983). This factor has been a primary control on the stability of the New River Spit, and may also account for the return of the mouth of the New River to its northerly position following Spit-breaching occurrences in the south.

Important to the long-term stability of the New River Spit are projected extreme combinations of high tides and storm-wave runup, the analysis of which is possible through application of the model diagrammed in Figure 6. This application to the New River Spit provided the first major use of the model on the Oregon coast, and the results have been encouraging. Of general interest is the observation of how the runup of the waves, calculated using equation (1), increases from north to south along the length of the Spit due to the increasing slope of the beach, and how the runup combined with high tides has controlled the elevations and positions of the dune toe/vegetation line. When the SVL was surveyed State-wide in 1967, it was noted that on average the elevation of the dune-vegetation line was at about 4.9 m MLLW (3.7 m NGVD29), which agrees approximately with the values found on the New River Spit (Table 1), particularly towards its north end where the beach is primarily sand, the typical composition of Oregon beaches. Toward the south end of the Spit where the beach is coarser grained and steeper, the greater elevation of wave runup has placed the vegetation line at elevations between 6.5 and 6.9 m NGVD29 (Table 1). This observation supports the conclusion by MORTON and SPEED (1998) concerning the process controls of the position of the vegetation line, that both tides and storm-wave runup are important. On the Oregon coast, it is seen in Table 1 that the wave runup has values up to 4.8 m, which are generally greater than the contribution by the tides, 2.1 to 2.5 m, in governing the elevation of the total water level and thus the position of the vegetation line. Had Oregon base its beach-zone line on the MHHW tidal elevation, as does Texas (MORTON and SPEED, 1998), rather than on the vegetation line, more than half of the sandy beach area would have been lost to private ownership.

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