Report to the
Oregon Department of Land Conservation and Development

CONTENTS OF GEOTECHNICAL REPORTS RELATED TO THE IMPACTS OF COASTAL EROSION AND RELATED HAZARDS

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September 1993

INTRODUCTION

Properties along coastlines are prone to geologic and oceanographic hazards, and this is particularly the case for the Oregon coast. These hazards include the erosional attack of waves and related processes during extreme storms, often resulting in substantial losses of the seaward fronting portions of properties together with the destruction of homes and other structures. Many properties on the Oregon coast also suffer from instability problems, at times leading to massive landsliding. In addition to these "normal" hazards, evidence has come to light that every few hundred years the Northwest coast experiences a major subduction earthquake and accompanying tsunami, a truly extreme hazard, the recurrence of which would result in the massive destruction of properties along the coast.

The recognition of such hazards and their potentially destructive impacts has resulted in requirements that geotechnical investigations and reports be undertaken of property sites that are susceptible to these hazards, and be completed prior to their development or modification. Such investigations vary widely in their contents, depending in large part on the potential hazards, and have been undertaken by individuals with diverse backgrounds — geologists, engineering geologists, civil or ocean engineers, geographers, and oceanographers. In the State of Oregon, the specific requirements that a coastal site be investigated and a geotechnical report completed prior to development vary from county to county, and also differ for the various incorporated communities. These government entities variously define the expertise of the individuals who will undertake the site inspections, and the contents of the resulting reports. However, on the whole there is a unity of purpose in undertaking geotechnical investigations, so in the present analysis the problem is addressed on a coast-wide basis with no attempt made to be specific to individual counties and communities. Indeed, one of the objectives is to achieve a greater uniformity in the contents of geotechnical reports.

The present analysis was initiated in response to concerns regarding the contents of the geotechnical reports, and in part due to questions concerning the quality of the site inspections. The quality issue in large part resulted from instances where inadequate reports led to the development of properties that were subsequently impacted by erosion and/or landsliding. Furthermore, considerable advances have been made in recent years in our understanding of the coastal processes of waves, nearshore currents and beach morphology changes, the processes ultimately responsible for episodic beach and property erosion. The question is whether this new information has found its way into the geotechnical site studies, and if not, what measures can be made to improve the reports in this area. Finally, uncertainty exists regarding the response to the new evidence of extreme hazards from a potential subduction earthquake and tsunami. How can the geotechnical reports address this extreme hazard, the recurrence of which is so uncertain?

In analyzing the contents of geotechnical reports, the first order of business is obviously to read a large number of reports that have been written investigating various sites along the Oregon coast. Unfortunately, this was only possible to a limited extent as there are no permanent repositories of reports within the various governmental entities. Therefore, my review of past reports was limited, although fortunately the few I did examine covered a range of site inspections dealing with all types of hazards, and were written by both geologists and engineers. Most of these reports were judged to be typical of those being completed for site inspections along the coast. Some reports represented failures of the system (e.g., Jump-Off Joe in Newport), where the hazards were inadequately accounted for, leading to extensive property losses. In addition to reading past reports, much information important to the present analysis was derived from two meetings, one with coastal planners representing the various government entities, and a meeting with geologists and engineers who have been involved in site inspections and the preparation of geotechnical reports.

The present analysis will focus on four areas that were deemed to be of particular concern regarding the contents of geotechnical reports: (1) the assessment of coastal erosion rates; (2) analyses of the susceptibility of properties to future erosion during unusually severe storms; (3) assessments of the land stability and potential for landsliding; and (4) a consideration of extreme events such as subduction earthquakes and tsunami.

ASSESSMENTS OF COASTAL EROSION RATES

It is important to evaluate the past and on-going rates of erosion at the property site, the long-term retreat of the sea cliff or foredunes separating the property from the adjacent beach. This assessment is far more difficult than commonly realized, due in part to its spatial variability and episodic occurrence, and the limited data upon which to base such assessments for the Oregon coast. The rates of sea cliff erosion are highly variable along the coast, resulting from the changing patterns of tectonic uplift versus sea-level rise, as well as local factors governed by the compositions of the sea cliffs and buffering ability of the fronting beach which separates the cliff from the attacking waves. The many factors responsible for sea cliff erosion along the Oregon coast have been the focus of our recent research programs and resulting publications (Shih, 1992; Komar and Shih, in press; Shih and Komar, in press). There is a coast-wide tectonic imprint due to the variable rates of aseismic uplift of the land as determined by Vincent (1989). The rate of rise of the land presently exceeds the global rise in sea level along the coast south of about Coos Bay and in the far north near Astoria, and this has reduced the impacts of sea cliff erosion in those areas. In contrast, there apparently is minimal tectonic uplift of the land along the north-central coast, so that the global rise in sea level (1 to 2 mm/year) has resulted in the slow but progressive transgression of the water over the land and the continued erosion of sea cliffs. In that area, the more local factors of cliff resistance and buffering ability of the fronting beach become particularly important, and account for the high variability in cliff recession.

The erosional retreat of properties consisting in part of foredunes is still more complex due to its extremely episodic occurrence. All of the completed studies of sand-spit erosion on the Oregon coast [e.g., the studies of Komar and Rea (1976) and Komar (1983) on Siletz Spit] have emphasized its episodic nature, wherein the foredunes undergo a rapid retreat of 10's of meters during a storm, only to build back out during the subsequent months to years as sand is blown into the eroded area and the foredunes are reestablished. Thus, it is not satisfactory, nor generally possible, to simply determine a long-term net erosion rate of the foredunes; more important is the maximum, short-term incursions of the erosion as this has commonly resulted in the loss of homes and other structures.

The importance of obtaining a truly long-term assessment of the erosion, spanning many decades, is illustrated by the unusual impacts of the 1982-83 El Niño. That event was characterized by a series of extreme storms, an unusual rise in monthly-averaged sea levels, and a northward shift of beach sand within the "pocket beach" littoral cells of the Oregon coast, processes which combined to yield unusual patterns of coastal erosion (Komar, 1986; Komar et al., 1988). Specifically, the maximum erosion tended to be to the immediate north of headlands, and to the north of tidal inlets [e.g., the Alsea Bay inlet] due to the northward movement of beach sand during the 1982-83 El Niño.

It is important that geotechnical reports of a specific coastal property include considerations of the full spatial variability and episodic nature of the erosion processes. This is necessary for both properties on sea cliffs and in foredune areas. Failure to account for this variability has in a few cases resulted in geotechnical reports that inadequately account for this hazard, resulting in the subsequent loss of structures.

The general approach in geotechnical reports to evaluate rates of sea cliff erosion has been to use sequences of aerial photographs. The oldest set of aerial photographs of the Oregon coast dates back to 1939, potentially providing more than 50 years for basing a net rate of erosion. However, the coverage of this set of photos is limited, and they are of relatively poor quality. Therefore, most analyses have relied on the 1967 aerial photographs available from the Department of Transportation or other sets dating from the 1970s for the earliest coverage, making the comparison with a more recently obtained set of photos. The time frame of comparison is therefore generally on the order of 25 years or less. This is often inadequate as erosion rates along the Oregon coast are generally low, so there is little recession of sea cliffs within that time frame, amounting to distances that are below the accuracy of aerial-photo analyses as generally undertaken by those involved in the preparation of geotechnical reports.

Priest (1993) has completed a pilot study for FEMA of erosion along the central Oregon coast (Seal Rock to Cascade Head), an area that is representative of the many coastal environments of Oregon but is within the north-central stretch of coast where erosion is greatest due to minimal tectonic uplift. The analyses were based on the 1939, 1967 and 1991 aerial photographs, on an 1868 topographic map of the Newport area, and on field measurements of the present distances from houses to bluff edges. Even in this area of greater sea cliff erosion, rates of bluff retreat were found to be quite low [e.g., on the order of 0.17 ft/yr in Lincoln City; a mean rate of 0.75 ± 0.86 ft/yr for house-to-bluff measurements in Gleneden Beach]. The results of this detailed study by Priest (1993) indicate that in site-specific studies undertaken for the preparation of geotechnical reports, the best approach is to compare field measurements of house-to-bluff distances with comparable measurements obtained from old aerial photographs. The uncertainties in such measurements are still considerable, so time frames of 25 to 50 years at minimum are necessary, and it is preferable to have a series of such comparisons to demonstrate a uniformity of the measured results. Even then, the results are expected to be satisfactory only in areas that have undergone substantial bluff retreat over the decades. There are considerable stretches of the Oregon coast where the rates of erosion are too low to be accurately measured by any such techniques.

There are qualitative indicators of the presence or absence of sea-cliff erosion that should not be ignored in site inspections. These range from ground and oblique-aerial photographs taken over the years (some back into the late 1800s) to the extent and age of vegetation cover. These are most effectively used to establish the absence of erosion or minimal extent of bluff retreat. These qualitative indicators should be used as a ground-truth evaluation even where the analyses of aerial photographs have supposedly yielded quantitative measurements of erosion rates. There have been instances where rates of bluff retreat of 1 to 2 ft/yr derived from aerial photographs are directly refuted by dense vegetation and old trees growing on the supposedly eroding bluff.

The measurement of long-term erosion rates of sea cliffs and foredunes of the Oregon coast will remain a problem. Only in the case of major developments will it be possible to undertake detailed analyses as in the pilot study of Priest (1993), and even then the results may not be definitive. When erosion-rate data are a part of the geotechnical report, there must be a full account of the difficulties involved in such measurements and of the inherent uncertainties in the resulting measurements. Due to these uncertainties and the extreme spatial variability and episodic nature of the erosion processes, wide margins of safety must be established for developments where long-term erosion might represent a hazard.

SUSCEPTIBILITY TO WAVE EROSION

The occurrence of erosion at a specific site is determined by the processes of waves and nearshore currents, versus the capacity of the fronting beach to serve as a buffer between these oceanic processes and the coastal properties. In spite of the importance of the beach processes and morphology in determining whether or not property erosion occurs, and in governing the extent of any resulting erosion, there has been minimal consideration of these factors in site inspections and geotechnical reports. This probably results from the lack of familiarity with the available techniques that have been developed to quantitatively predict run-up elevations of waves on beaches during storm conditions, and of the models of cross-shore sediment transport that modify the beach profile and can result in the erosion of properties backing the beach. It also reflects the fact that many of these analysis techniques are still in the developmental stage, and have not been adequately tested under the conditions specific to the Oregon coast. These later limitations will hopefully be reduced or eliminated in the near future as this is the focus of our on-going research. The overall purpose of that research is to develop and implement models that relate the extreme elevations of wave run-up, superimposed on tides and storm surge that determine mean water elevations, to the level of the junction between the beach face and coastal properties (the sea cliff or foredune edge). These are the two critical factors in the occurrence of property erosion, which develops only if the extreme run-up elevations exceed the elevation of the beach/property junction. One expected product of our research will be analysis techniques that permit quantitative predictions of the susceptibility of erosion of a property due to attack by ocean waves and currents. This will be expressed in terms of the probabilities of the extreme run-up actually reaching the property, the base of the sea cliff or foredunes, with perhaps some estimation of the forces of wave attack. Assessments of the resulting erosion would be site specific as this depends on the competence of the material being eroded, ranging from loose dune sands to resistant sea cliffs.

In the case of the erosion of foredunes, models have already been developed that relate the horizontal extent of dune retreat to the factors governing the elevation of the water level and the intensity of wave attack. SBEACH is a numerical model developed by the Corps of Engineers (Larson and Kraus, 1989; Larson et al., 1988) to simulate beach profile changes due to varying wave conditions, including the movement of offshore bars and the growth or erosion of the beach berm. It can be utilized to evaluate the erosion of foredunes under extreme water elevations and wave attack. Although SBEACH was calibrated with data from near-prototype scale wave tanks and tested on east-coast beaches, with some recalibration the model is likely to be applicable to the Oregon coast. Similar models to analyze beach-profile variations and dune erosion have been developed by Kriebel and Dean (1985) and Kriebel (1986), with later modifications of the analyses having been made by Kriebel (1990). Their models have successfully been applied to analyses of beach and dune erosion on the coast of Florida experienced during hurricanes.

It is important that considerations of ocean processes and the buffering ability of the fronting beach be included in site investigations and geotechnical reports documenting the hazards associated with coastal erosion. At present this can be undertaken on a semi-quantitative basis by providing information as to the widths and slopes of the fronting beach during the summer and winter, and the frequency of occurrence of rip currents that further cut back the beach and allow the waves to reach the properties. It has been observed that coarse-sand beaches (reflective beaches) respond much more rapidly than fine-sand beaches (dissipative beaches) to individual storms and to the annual variations in wave energy level, and also develop larger rip-current embayments (Shih, 1992; Shih and Komar, in press). This in itself makes properties backing coarse-sand beaches more susceptible to episodic attack by ocean waves and currents, with greater rates of erosion. This accounts for the significant occurrences of erosion of the foredunes on Siletz Spit (Komar and Rea, 1976) and of the sea cliffs along Gleneden Beach (Komar, 1992; Komar and Shih, in press). It the next few years it should be possible to undertake more sophisticated analyses of the susceptibility to erosion of specific sites using the models of wave run-up as discussed above, together with models such as SBEACH to evaluate the cross-shore sediment transport and resulting dune erosion.

LAND STABILITY

The instability of the land leading to sliding has been a major hazard along the Oregon coast. In the extreme are the large, massive landslides in the Newport area, the slide at Jump-Off Joe being the prime example. That particular landslide first developed during the 1940s, leading to the destruction of a number of homes (Stembridge, 1976; Sayre and Komar, 1988). A further attempt to develop the site during the 1980s resulted in the destruction of a condominium, with financial losses to a number of individuals and institutions, including the city of Newport. This episode undoubtedly represents the most extreme case of failure in requiring a geotechnical report in order to avoid property losses due to coastal hazards. In this case the failure resulted more from a lapse in ethical standards on the part of the geologist undertaking the study, than in any lack of understanding or recognition of instability hazards. Although it is not difficult to recognize the hazards associated with an existent landslide such as Jump-Off Joe, more of a problem is the recognition of instabilities that involve the slow movement of rocks and soil, and especially of the susceptibility for the occurrence of mass movement should a property be developed.

Most site inspections and geotechnical reports base their assessments of land instability on the measured topography, particularly the extreme slopes, and on determinations of the soil and rock compositions. Borings are sometimes obtained to assist these analyses, especially on sites believed to be particularly susceptible to instabilities. Obvious evidence for land movement is of course noted — fractures in the earth, slip planes, tilted trees, etc. To my knowledge, there have been no attempts to analyze the mechanics of instability and sliding, through the use of the Culmann theory for planar failure or for rotational slides [see Sunamura (1992, pages 107-116) for a review]. There are many uncertainties in such analyses, and they are recommended only for major developments such as a large structure whose weight might initiate slope failure.

Further research is required that focuses on land instabilities along the Oregon coast in order to improve the geotechnical investigations. For example, in his report on the Newport area and the stretch of coast north to Otter Rock, Priest (1993) suggested that in addition to the dip angles of the seaward sloping beds being an important factor, the slope instability depends on the orientation of the eroding sea cliff compared with the strike of the rocks being eroded. Additional research could also focus on the use of the mechanical models to analyze the extent of potential landsliding, and on practical measures that could be implemented to reduce this hazard.

EXTREME EVENTS

The hazards considered thus far can be viewed as those "normally" encountered when developing the coast. In addition, there are "extreme" hazards particular to the Northwest coast, the ocean shores of Washington, Oregon and northern California. These extreme hazards are associated with the rare occurrence of major subduction earthquakes, estimated to be of magnitude 8 to 9. Accompanying such earthquakes are the generation of tsunami and the abrupt subsidence of major portions of the coast.

These major coastal earthquakes in the Northwest result from the subduction of the oceanic Juan de Fuca plate beneath the continental North American plate. The cause of these earthquakes is the scraping together of the two plates as the ocean crust slides beneath the continent. The subduction of the similar ocean plate beneath South America has caused major earthquakes within historic times that have resulted in catastrophic destruction along the coasts of Peru and Chile. Until recently, we had been puzzled by the absence of such subduction earthquakes in the Northwest. However, there is growing evidence that such earthquakes have occurred, but at intervals of hundreds to thousands of years, with none having taken place within the last 200 years since Europeans came to the Northwest. Apparently the lack of subduction earthquakes within historic times means that the oceanic Juan de Fuca plate and the North American plate are temporarily locked together, and if so, they must be accumulating energy. The longer the plates remain locked, the greater the amount of stored energy, and the more catastrophic the resulting earthquake when the plates finally do break apart along the subduction zone.

The principal evidence for major prehistoric earthquakes associated with subduction has come from investigations of estuarine marsh sediments buried by anomalous sand layers, deposits which suggest that portions of the coast have abruptly subsided, followed by an extreme tsunami that swept over the area to deposit the sand [Atwater, 1984; Atwater and Yamaguchi, 1991; Darienzo and Peterson, 1990]. Based on the numbers of such layers found in bays along the coast and from carbon-14 dates of the sediments, it has been estimated that catastrophic earthquakes have occurred at least six times in the past 7,000 years, at intervals ranging from 300 to 1,000 years. The last recorded earthquake/tsunami event took place about 300 years ago. Therefore, the evidence is strong that major subduction earthquakes have indeed taken place along the Northwest coast. Given the frequency of occurrence suggested by the estuarine sediments, there is a reasonable probability that a major earthquake and tsunami will occur in the not-too-distant future [recent estimates place the probability at 20 to 30% in the next 50 years]. The drilling of cores in the area that is now Cannon Beach demonstrates the existence of tsunami derived sand layers that cover the area inland to at least Highway 101 (C. Peterson, pers. communication), illustrating the extreme run-up that could be associated with any future event. Analyses of the mechanics of tsunami generation indicate that individual waves could have heights of 8 to 10 meters, there being a series of such waves with the first reaching the land about 30 minutes following the earthquake (A. Babtista, pers. communication).

Taken together — a major earthquake, tsunami, and land-level change — the impact any future event can be expected to lead to the nearly complete devastation of the Oregon coast. The question is, how can geotechnical reports address this extreme hazard, the recurrence of which is so uncertain and long term? The answer to this question remains uncertain, as few coastal-zone management decisions have been made with respect to these extreme hazards. Given their rare occurrence, it is not possible to preclude any development on the coast. Instead, the more likely decision is to keep developments such as schools and hospitals out of low-lying areas that would receive the greatest impact from tsunami, as well as requiring building codes that would reduce destruction by the earthquake itself. It is not likely that limits will be placed on the siting of single-family homes, so they could be in the immediate path of tsunami associated with a subduction earthquake.

Although basic management decisions remain regarding coastal development in the face of these extreme hazards, it is not too soon to incorporate our growing evidence of these hazards into the geotechnical reports. These include treatments of the land stability under the shocks of an 8 to 9 magnitude earthquake, the susceptibility of the property to tsunami run-up, the possibility that the site will be affected by major landslides, and probable conditions of the property after subsidence, including the expected enhanced erosion associated with such an abrupt lowering of the site. At minimum, the property owner should be educated by the geotechnical report as to the immanent danger of the site during a subduction earthquake and possible evacuation routes.

SUMMARY AND DISCUSSION

For the most part, requirements to have site inspections and geotechnical reports have served the intended purpose of establishing the nature of the hazards endangering the property. The failures in the system have resulted mainly due to ethical lapses, cases where the hazards are evident but the developer "shops around" for a malleable investigator. Other failures have resulted from an over reliance on aerial photo techniques in establishing erosion rates without recognizing that the results are bogus.

There is room for improvement in the geotechnical reports, and this has been the principal focus of the present analysis. First, we noted the difficulty in establishing long-term erosion rates for the Oregon coast. This will remain a fundamental problem, particularly in that many investigators are not trained in the interpretation of aerial photographs and do not have the needed equipment for a detailed analysis. It would be preferable to have a coast-wide study along the lines of the pilot investigation completed by Priest (1993). The quality of the results would thus be assured, and they would be directly available to planners and developers, and easily incorporated into geotechnical reports for specific sites.

Perhaps the greatest area of potential improvement in the coverage by geotechnical reports is in considerations of oceanic and beach processes that are directly responsible for episodes of property erosion. As discussed above, much general information is already available in this area, but models to specifically assess the susceptibility to erosion of a specific property are still in the developmental stage. It is hoped that significant advances will be made here in the next few years, both in better establishing the science behind these analysis techniques and in their increased use in geotechnical reports.

The instability of the land leading to sliding has been a major problem on the Oregon coast, and there have been substantial losses in attempts to develop such areas. The principal problem is the derive to develop these unstable areas in spite of the obvious hazard. Further research into slope stability specific to the Oregon coast is recommended, as outlined in this report. Finally, we are faced with the extreme hazards of subduction earthquakes and accompanying tsunami. Those responsible for site inspections and the writing of geotechnical reports must keep themselves informed of the rapidly accumulating information regarding these extreme hazards, and must progressively incorporate more analyses into their reports that reflect these hazards.

Depending on the nature of the property, we have seen that the potential hazards range from land instabilities, to processes of wave attack, to subduction earthquakes and tsunami. This range stretches the capability of any one investigator to adequately undertake a site inspection and to complete a satisfactory report. With the future inclusion of new techniques [e.g., SBEACH and related models], additional training may be required for those undertaking geotechnical investigations, and there will probably be the need for cooperative undertakings by investigators trained separately in geology, engineering and oceanography.

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GUIDELINES FOR THE PREPARATION OF TECHNICAL REPORTS RELATED TO THE IMPACTS OF COASTAL EROSION

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September 1993

INTRODUCTION

An important control on the development of coastal properties is the requirement of site investigation reports. In beach and dune areas these reports have the objective of providing information on geological hazards and environmental factors that may impact the proposed development, or may be affected by the development. The intent is to provide the developer with information regarding the potential hazards, and to inform governmental agencies and planning staffs that have jurisdiction over approval of the development plans.

In order for the site-inspection reports to meet this intended objective, it is important that the field work at the site include the careful collection of data and observations relevant to potential hazards. Based on those field observations, additional analyses may be required ranging from the study of past aerial photographs of the site, calculations of expected water levels due to tides, etc., and wave run-up which may impact the ocean front of the property. Each property will be unique as to its potential hazards, and the level of the report will also depend on the expected degree of development, whether it be a single-family dwelling versus a large hotel complex. Reports may also be required for proposed shore-protection structures to defend established developments, and may require somewhat different types of field measurements and analyses to justify the structure.

Guidelines are already available to assist investigators responsible for undertaking the site inspections and writing the required reports. The California Division of Mines and Geology has published *Guidelines to Geologic/Seismic Reports* and also *Recommended Guidelines for Preparing Engineering Geological Reports*, both of which contain outlines for the proposed contents of such reports. The State Board of Geologist Examiners in Oregon has prepared a slightly modified version, *Guidelines for Preparing Engineering Geologic Reports in Oregon.* These reports are very generally, equally applicable to conditions in eastern Oregon as on the coast, and hence to not adequately account for the special hazards faced in the coastal zone.

More relevant is the report written by Wilbur Ternyik and published by the Oregon Coastal Zone Management Association (1979), *Beach & Dune Implementation Techniques: Site Investigation Reports.* Two phases or levels of reports are recommended. The Phase 1 report consists of four pages containing a series of simple "yes" or "no" checklist questions that provide the basic information about the site, the proposed development, and evidence of potential hazards. If significant hazards are identified or if there are possible compliance problems with state or local land-use regulations, then a Phase 2 report would be required. A detailed discussion is provided, in outline form, of the possible content of this Phase 2 report and questions that should be addressed. The hazards considered include: (a) wind erosion, (b) water erosion, and (c) slide areas. For the most part, the coverage of these hazards is good, with suggestions as to what evidence to look for during the inspection of the site and adjacent properties. There are fewer suggestions as to follow-up analyses. For example, in the case of water erosion, the only recommendation for additional analyses is the inspection of aerial photographs — "Historical aerial photographs with scale and date will provide evidence of past erosion rates and cycles."

The outline in the following section is provided as a supplement to the OCZMA report by Wilbur Ternyik. It involves assessments of expected water elevations and wave run-up on the property or on the beach fronting the property. Included is the collection of field data during the site inspection, and the techniques for analyses of that data. The collection of the field data and its analyses may in some instances require the combined talents of a geologist, oceanographer and engineer, with an awareness as to the availability of data on waves, tides and other ocean and beach processes for the Oregon coast. A partial discussion is presented of such analyses in the accompanying reports (Komar, 1993a, 1993b), where it is noted that additional research is still needed to yield analyses that have a higher degree of predictive accuracy. However, these models can already be implemented with results that will in most cases quantitatively document the susceptibilities of properties to erosion by wave undercutting or overwash.

OUTLINE OF ANALYSES OF WAVE RUN-UP AND THE SUSCEPTIBILITY OF PROPERTIES TO EROSION

A. Site Description

1. Topography, including elevations and slopes on the property itself.
2. Vegetation cover.
3 Subsurface materials — the nature of the rocks and soils.
4. Conditions of the seaward front of the property, particularly for sites having a sea cliff.
5. Presence of drift logs or other flotsam on or within the property.
6. Proximity of nearby streams that might locally reduce the level of the beach.
7. Proximity of nearby headlands which might block the longshore movement of beach sediments, thereby lowering the level of the beach in front of the property.

8. Description of any shore protection structures that may be existent on the property or on nearby properties.
9. Presence of pathways or stairs from the property to the beach.
10. Existing human impacts on the site, particularly that might effect the resistance of sea cliffs or foredunes to wave attack.
11. Expected modifications of the site during development that might alter the resistance to wave attack.

B. Description of the Fronting Beach

1. Average widths of the beach during the summer and winter.
2. Median grain size of beach sediment.
3. Average beach slopes during the summer and winter.
4. Elevations above mean sea level of the beach at the seaward edge of the property during summer and winter.
5. Presence of rip currents and their eroded embayments that can locally reduce the elevation of the fronting beach.
6. Presence of rock outcrops as stacks in the offshore or within the beach zone.
7. Information regarding the depth of beach sand down to bedrock at the seaward edge of the property.

C. Analyses of the Erosion History of the Site and Area

Documentation of any past erosion that has occurred on the property or in adjacent areas of comparable setting. In areas of sea cliffs, establish long-term recession rates using aerial photographs and/or ground surveys. Make qualitative assessment of the recent erosion from vegetation cover of the cliff. For sites on sand spits or within coastal dunes, use the same techniques to establish past occurrences of episodic erosion followed by longer periods of dune reformation, as well as determining any long term net accretion or erosion. Note the presence of old drift logs on or within the spit or dune sands.

D. Analyses of Erosion and Flooding Potential

Calculations of mean water elevations due to tides and other sea-level components, and wave run–up beyond that mean-water level that might result in the water reaching the base of the sea cliff or foredunes, with the potential of causing erosion [see Komar (1993a) for techniques required in these computations]. Evaluate the frequency with which such combinations of erosion-inducing processes could occur. Particularly consider the most extreme potential conditions of unusually high water levels together with severe storm wave energies. In the case of sites located on sand spits or within dunes, use established models to assess the potential distance of property erosion, and compare the results with direct evidence obtained during the site visit or in analyses of aerial photographs. Use the results to establish a set-back distance for the site.

Evaluate the potential run-up resulting from tsunami.

E. Assessment of Potential Reactions to Erosion Episodes

Full assessment of potential reactions should erosion occur at the site. These considerations should include an evaluation of the possibility of moving structures landward out of the path of the erosion, the use of vegetation to reduce the erosion, to the possible placement of a sea wall or riprap revetment.

REFERENCES

Komar, P.D. (1993) *Analyses of the Susceptibility of Coastal Properties to Wave Erosion*: Report to the Oregon Department of Land Conservation and Development.

Komar, P.D. (1993) *Analyses of the Susceptibility and Magnitudes of Foredune Erosion on the Oregon Coast*: Report to the Oregon Department of Land Conservation and Development.