APPRAISAL
OF
CHRONIC HAZARD ALLEVIATION TECHNIQUES

WITH SPECIAL REFERENCE TO THE OREGON COAST

REPORT

to the

OREGON DEPARTMENT OF LAND CONSERVATION AND DEVELOPMENT

Shoreland Solutions

for

OREGON COASTAL ZONE MANAGEMENT ASSOCIATION

December 1994

Funding for this work was provided by the Office of Coastal Zone Management, National Oceanic and Atmospheric Administration, under Section 309 of the Coastal Zone Management Act through the Oregon Department of Land Conservation and Development.

PREFACE

The Oregon Department of Land Conservation and Development (DLCD), in cooperation with other state agencies, has developed a five year '309 strategy' to improve coastal natural hazards policy, assessment, and awareness in Oregon. In addition to supporting the efforts of the Coastal Natural Hazards Policy Working Group, last year's efforts under the 309 strategy focused on improved hazard identification. Specifically, a model chronic hazards mapping methodology was developed and implemented along a portion of the central Oregon coast. Detailed report content standards were also developed as a means of enhancing the quality of site-specific hazard reports.

Again in addition to supporting the efforts of the Coastal Natural Hazards Policy Working Group, this year's efforts under the 309 strategy focus on hazard mitigation. In this regard, the 'Appraisal of Coastal Hazards Alleviation Techniques (ACHAT) Project' was conducted by DLCD through the Oregon Coastal Zone Management Association (OCZMA) in an effort to identify what techniques are available to alleviate the risks resulting from identified chronic coastal natural hazards and to evaluate the applicability of individual hazard alleviation techniques taking into account the physical and social diversity of the Oregon coast. The report that follows is the culmination of this project. It was prepared through a process involving project advisory committee deliberations on, as well as external review of drafts of this document. This report is intended to serve as a guide that can be used by decision-makers at all levels to assess chronic coastal natural hazard alleviation options. It is also intended to serve as a basis for improvements in chronic coastal natural hazards management in Oregon.

Appraisal of Chronic Hazard Alleviation Techniques
with special reference to the Oregon Coast

REPORT OVERVIEW

● Chronic coastal natural hazards arise from ocean flooding, beach and dune erosion, dune accretion, bluff recession, landsliding, and human activities. The identification and evaluation of chronic hazard alleviation techniques is the focus of this report. Earthquakes, tsunamis, and other so-called catastrophic hazards are beyond the scope of this work.

● A wide range of techniques are available to lessen the risks associated with chronic coastal natural hazards. Owing to the diversity of physical and social settings along the Oregon coast, and as a result differences in hazard alleviation needs, there is no universally applicable hazard alleviation technique (HAT).

● Factors affecting shoreline stability occur over a broad range of spatial and temporal scales. They are the fundamental consideration in choosing a HAT.

- Along the Oregon coast, processes operating over time scales of hundreds to hundreds of thousands of years have resulted in the formation of a series of quasi-discrete headland-bounded segments of dune-backed and bluff-backed shoreline, commonly referred to as littoral cells. The combination of tectonic and eustatic processes, in the form of relative sea level rise, represent a first order control on shoreline stability. However, over time scales of years to hundreds of years the extent to which relative sea level rise is a factor affecting chronic shoreline stability along the Oregon coast is limited. Sand supply also is also a first order control on shoreline stability. Expressed in terms of littoral cell sediment budgets, sand supply is a particularly important, but not well understood, consideration along the Oregon coast.

- In terms of processes operating over time scales of days to years, a distinction is made here between processes of wave attack, mass wasting, and human activities.

  Along dune-backed shorelines processes of wave attack are the primary factor affecting shoreline stability. With no long-term trend for increasing susceptibility to wave attack, it is flooding and erosion associated with episodic storm events that present the greatest hazard potential along dune-backed shorelines. Also, because limited areas of shoreline are affected by storms and because these areas tend to recover, hazard alleviation needs along dune-backed shorelines are for the most part localized and temporary.

Along bluff-backed shorelines both processes of mass wasting and wave attack affect shoreline stability. Even where landsliding/slumping does not present the greatest hazard potential locally, large segments of bluff-backed shoreline experience bluff recession. Because large areas of shoreline may be affected by mass wasting and because its effects tend to be irreversible, hazard alleviation needs along bluff-backed shorelines are more regionalized and permanent.

Human activities such as jetty construction, maintenance dredging, site development, shoreline stabilization, pedestrian/vehicular traffic, and even graffiti carving, may affect the stability of both dune-backed and bluff-backed shorelines.

- Social settings are also an important consideration in choosing a HAT. In this regard distinctions between levels and types of development (e.g. rural versus urban, new versus existing) are important as they may influence hazard alleviation needs. Further, as hazard alleviation is only one of a number of competing interests, a broad range of economic, social, and environmental factors come into play in choosing a HAT. Cost-benefit analysis is a means whereby the full range of positive and negative consequences of employing alternative HATs can be evaluated.

- HATs may be considered individually, and in some cases can be implemented on a site-specific basis. For a variety of reasons however, it is when considered together and implemented on an area-wide basis that they are most effective.

- Siting, Design, and Construction Standards; Construction Setbacks; and Relocation and Land Acquisition Incentives fall under the category of Hazard Avoidance Options.

  - **Siting, Design, and Construction Standards** have the greatest potential to alleviate hazards when applied to new development. The applicability of different techniques is specific to particular settings.

  - **Construction Setbacks** have great potential as a HAT. Further work on the development and testing of construction setbacks in a range of shoreline settings is warranted. Also, while directly applicable to new development, they may have a role to play in assessing hazard alleviation needs in settings with high levels of existing development.

  - **Relocation and Land Acquisition Incentives** have limited applicability as a HAT. Their greatest potential is in the form of either small scale on-site relocation or acquisition of undeveloped land suitable for recreational use. The ability to generate funding needed to subsidize large scale relocation/acquisition efforts severely constrains their potential applicability.

- Foredune Enhancement, Beach Nourishment, and Boulder Berms fall under the category of Soft Stabilization Options.

  • **Foredune Enhancement** has great potential as a HAT. There is a degree of uncertainty associated with this HAT. However, among other considerations, its low cost and the moderate level of flood, erosion, and inundation protection afforded by this area-wide technique make it an attractive HAT along dune-backed shorelines. Its applicability along bluff-backed shorelines is more limited, but should not be overlooked. Also, it may not be appropriate where critical facilities or significant resources warrant high levels of protection.

  • **Beach Nourishment** is a HAT whose potential applicability is very specific to its setting. The potential applicability of large scale nourishment in the form of shallow-water disposal of material dredged from navigation channels is believed to be high and needs to be more fully explored. Along dune-backed shorelines, the potential of small scale nourishment schemes involving sand banking and sediment budget management is also believed to be high. This too needs to be more fully explored. In settings where maintenance or enhancement of recreational uses associated with a sandy beach are considered important, beach nourishment is likely to be the preferred HAT. It may not be appropriate where critical facilities or significant resources warrant high levels of protection however.

  • **Boulder Berms** have moderate applicability as a HAT. On a large scale, their potential for applicability along bluff-backed shorelines as toe protection to be used in conjunction with other slope management measures warrants further consideration. On a small scale, their potential to serve as a temporary hazard alleviation measure along both dune-backed and bluff-backed shorelines should be given greater attention.

- Groins, Breakwaters, and Seawalls/Revetments fall under the category of Hard Stabilization Options.

  • **Groins** have low potential for applicability, as their effectiveness is limited by the existence of wide surf zones and the occurrence of seasonal reversals of littoral drift that are characteristic of the Oregon coast.

  • **Breakwaters** have limited applicability as HAT. Potentially they are applicable as an alternative to seawalls/revetments along highly developed shorelines. However, design and other considerations need to be more fully evaluated before a firm conclusion can be made as to their applicability along the high energy Oregon coast.

- **Seawalls/Revetments** have moderate applicability as a HAT. While they have been shown to be effective, they have also been shown to have a high potential for adverse impacts. Where critical facilities or significant resources warrant high levels of protection, hard stabilization may be necessary. Properly designed revetments may be an appropriate means of achieving permanent toe protection along highly developed bluff-backed shorelines. Along dune-backed shorelines modified forms of seawalls/revetments (e.g. sand bags and gabions) may be an appropriate hazard alleviation measure. There is a need to develop seawall/revetment designs suitable for such purposes.

● Vegetation Enhancement, Surface Fixing, Drainage Controls, Slope Regrading, and Reinforcing Structures fall under the category of Options for processes of Mass Wasting.

- **Vegetation Enhancement, Drainage Controls, Slope Regrading** are techniques that when used in combination and in conjunction with toe protection have a high potential applicability along bluff-backed shorelines. Such measures can be carried out on an area-wide basis, in the form of bluff management plans - the corollary of existing foredune management plans. Greater attention needs to be given to the applicability of such measures.

- **Surface Fixing** has limited applicability as a HAT. The applicability of different techniques (e.g. gunite, fabric matting) is specific to particular settings.

- **Reinforcing Structures** have moderate applicability as a HAT. Much like seawalls/ revetments, they may be warranted in some settings.

● Public Education Programs, Natural Resource Protection Laws, and Zoning and Infrastructure Planning fall under the category of Indirect Approaches. As they are integral components of a comprehensive, area-wide hazard alleviation strategy, the potential of these indirect approaches should not be overlooked.

● Among other actions, the development and implementation of cooperative state and local demonstration projects will lead to a better understanding of the positive and negative attributes of the various hazard alleviation techniques and to improvements in chronic coastal natural hazards management in Oregon.

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1 INTRODUCTION

Chronic coastal natural hazards are a concern along much of the Oregon coast. They arise from ocean flooding, beach and dune erosion, dune accretion, bluff recession, landsliding, and human alterations. Although generally manifest as damage to or loss of property, they may also result in the loss of recreational, resource, and other values.

Recent advances in our understanding of chronic coastal natural hazards have highlighted the diverse and dynamic nature of sandy shorelines along the Oregon coast. Further, as tourists, retirees, and second home buyers are drawn to the Oregon coast in increasing numbers and development expands to meet the increased demand for facilities and services, the potential for property damage or loss is more likely. Over time the potential for chronic coastal natural hazards to be a concern to existing development is also likely to increase. For these, among other reasons, there is a need to identify and evaluate hazard alleviation techniques potentially applicable along the Oregon coast. In this regard, a wide range of techniques are available to lessen the risks associated with chronic coastal natural hazards. Choosing among these hazard alleviation techniques (HATs) is the focus of this document.

The first two sections of this document outline the elements of a decision-making framework (Figure 1.1). In section 2, physical settings along the Oregon coast are described in terms of factors affecting shoreline stability, the fundamental consideration in choosing a HAT. Here, emphasis is placed on the distinction between dune-backed and bluff-backed littoral cell shorelines in terms of processes of wave attack, mass wasting, and to a lesser extent human activities. Although longer term, more regionalized processes are briefly considered, the identification and evaluation of so-called catastrophic hazards (e.g. earthquakes and tsunamis) and hazard alleviation techniques is beyond the scope of this work.

Social settings along the Oregon coast are considered in section 3. Here, distinctions are made between levels and types of development (e.g. rural versus urban; new versus existing). Recognizing that hazard alleviation is only one of a number of competing interests, the broad range of economic, social, and environmental factors that come into play in choosing a HAT are also considered in this section.

In section 4, which makes up the bulk of this document, the decision-making framework outlined in the two previous sections is applied to a wide range of HATs potentially applicable along the Oregon coast. Here, identified HATs are categorized and each of the identified HATs is evaluated generally in

Hazard Alleviation Technique (HAT) IDENTIFICATION AND EVALUATION FRAMEWORK

H A T s

↓

PHYSICAL SETTING

Dune-Backed Shorelines

- Wave Attack
- Human Activities

Bluff-Backed Shorelines

- Wave Attack
- Mass Wasting
- Human Activities

↓

SOCIAL SETTING

Rural

- New (low density residential, recreational) Low Intensity Development
- Existing (low density residential, recreational) Low Intensity Development

Urban

- New (high density residential,commercial, and industrial) High Intensity Development
- Existing (high density residential,commercial, and industrial) High Intensity Development

↓

APPRAISAL CRITERIA

Economic Factors

Social Factors

Environmental Factors

↓

preferred HAT

Figure 1.1 Hazard Alleviation Technique (HAT) IDENTIFICATION AND EVALUATION FRAMEWORK terms of their function, design, impacts, and applicability. It is important to note in this regard that the information presented in this document provides only general guidance on choosing an appropriate HAT. Individual HATs are not evaluated to the level of detail required in specific situations. Before attempting to implement any of the HATs described, individuals are advised to seek qualified professionals to conduct detailed site-specific investigations.

Finally, section 5 identifies actions that can be taken to improve our understanding of the positive and negative attributes of the various hazard alleviation techniques and to improve chronic coastal natural hazards management in Oregon.

2 FACTORS AFFECTING SHORELINE STABILITY

Factors affecting shoreline stability occur across a broad range of spatial and temporal scales (Figure 2.1). They involve a complex combination of interactions between geologic, oceanographic, and, to a lesser extent, biologic processes.

2.1 LONG TERM, REGIONAL CONTROLS

Deposition and tectonic deformation that has occurred along the Cascadia subduction zone over the last sixty million years has shaped the morphology of the Pacific Northwest coast. In this regard, a body of recent evidence indicates that a cycle of tectonic activity occurs along the convergent plate boundary that fronts the Pacific Northwest coast. During one part of the tectonic cycle, an extended period of gradual aseismic uplift of the coastal margin occurs in response to the accumulation of strain within the subduction zone. Gradual variations in mean water level, and hence shoreline position, accompany this part of the tectonic cycle. In contrast, the other part of the tectonic cycle is characterized by a major seismic event which occurs as the strain that has accumulated within the subduction zone is suddenly and dramatically released. Rapid variations in mean water level due to subsidence of the margin are associated with this part of the tectonic cycle. Superimposed upon these tectonically-induced variations in shoreline position are variations in global eustatic sea level due to the alternating growth and melting of glaciers. These repeated marine transgressions and regressions have also shaped regional coastal morphology.

One result of these processes operating over time scales of hundreds to thousands of years is that basalts deposited some 15 to 45 million years ago are today resistant headlands, prominent morphologic features along the Oregon coast. For the most part, the prominence of these features is such that over time scales of tens to hundreds of years they restrict longshore transport and thereby define discrete segments of shoreline. Viewing the Oregon coast in terms of headland-bounded segments of shoreline, or littoral cells, is a concept that is useful for both scientific and management purposes (Figure 2.2).

Another result of these processes is that sands and muds deposited some 2 to 40 million years ago, carried upward by tectonic activity, and eroded by waves of ancient seas, today form a series of marine terraces that back much of the Oregon coast. Because this uplift and erosion is differentially distributed along the coast, bluff-backed shorelines along some segments of the Oregon coast stand in

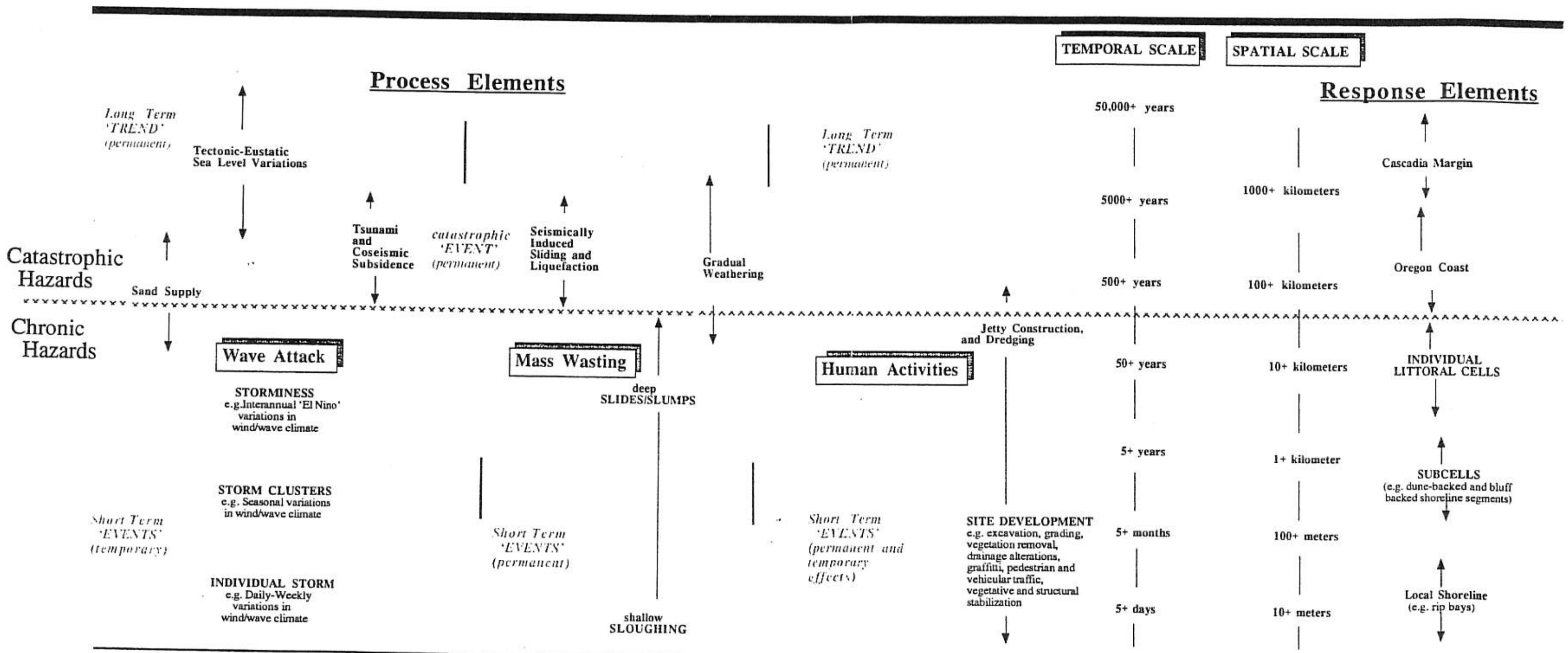


Figure 2.1. FACTORS AFFECTING SHORELINE STABILITY along the OREGON COAST

marked contrast to dune-backed shorelines found elsewhere along the Oregon coast (Figure 2.3).*

*Inlets represent another type of sandy shoreline setting. Although inlets exist within many Oregon coast littoral cells, are important elements of littoral cell dynamics, and may be the principal factor affecting shoreline stability along some segments of shoreline, here they are not directly addressed in the context of HATs.

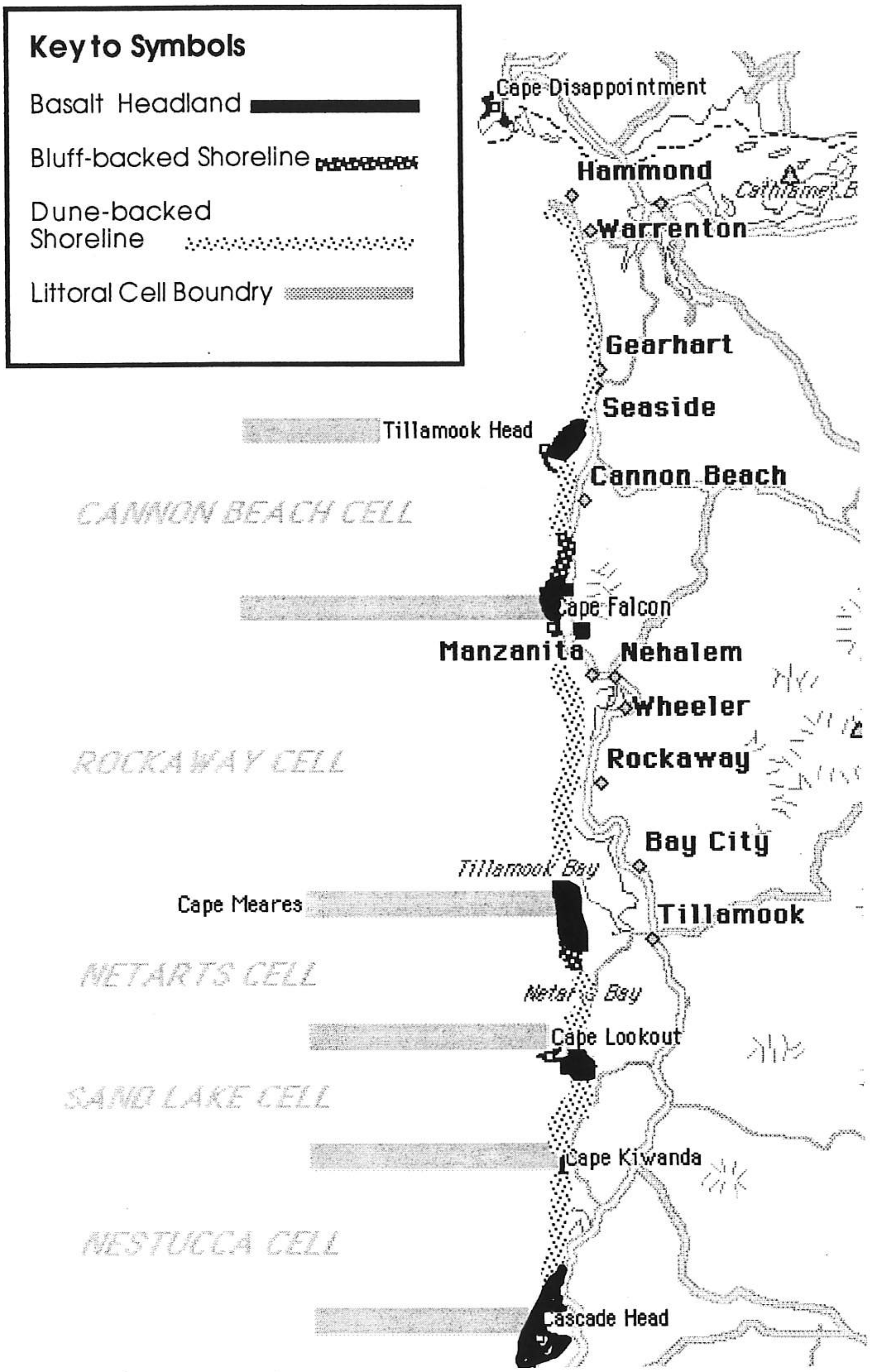


Figure 2.2. Oregon Coast Littoral Cells a) North Oregon Coast

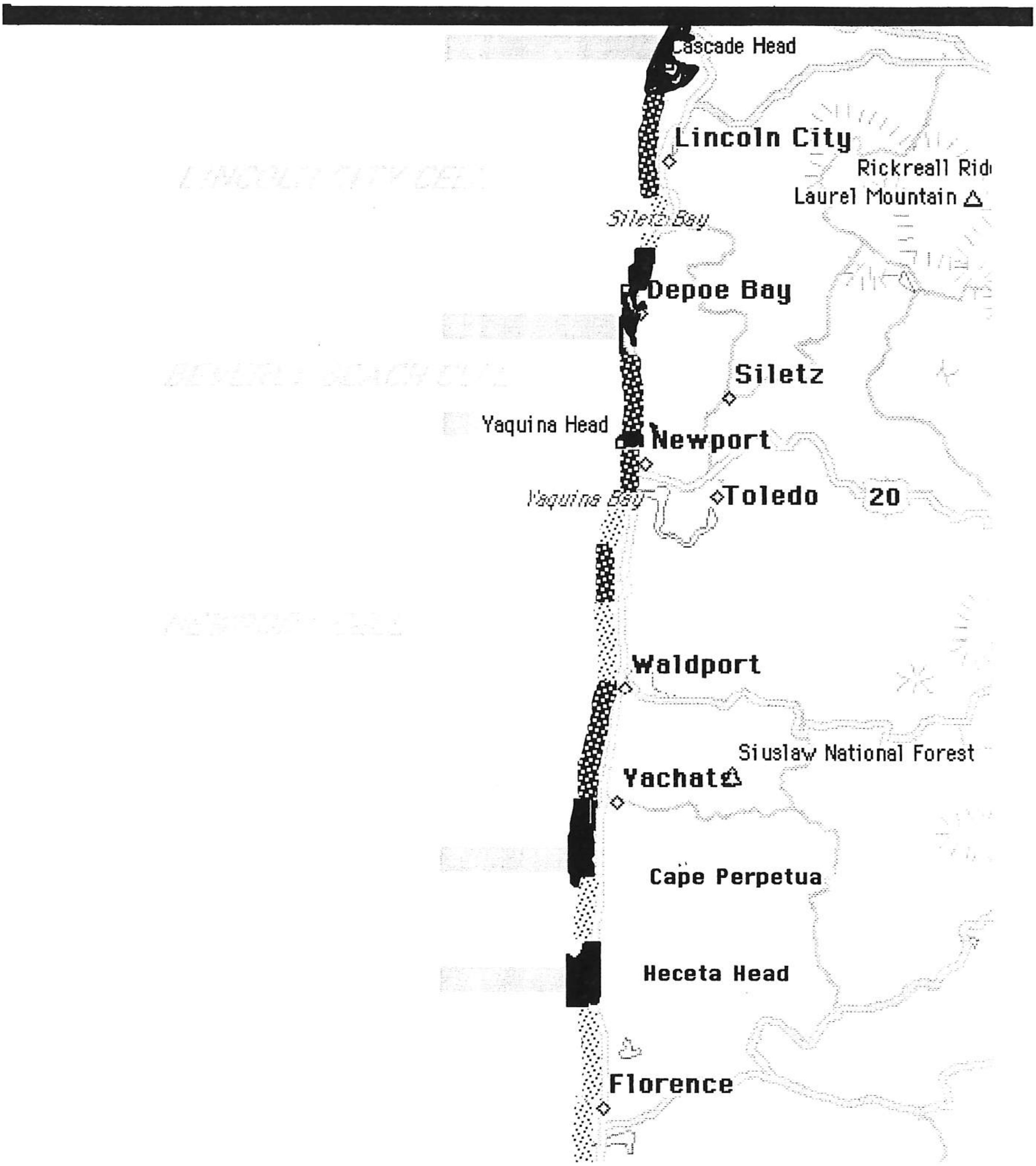
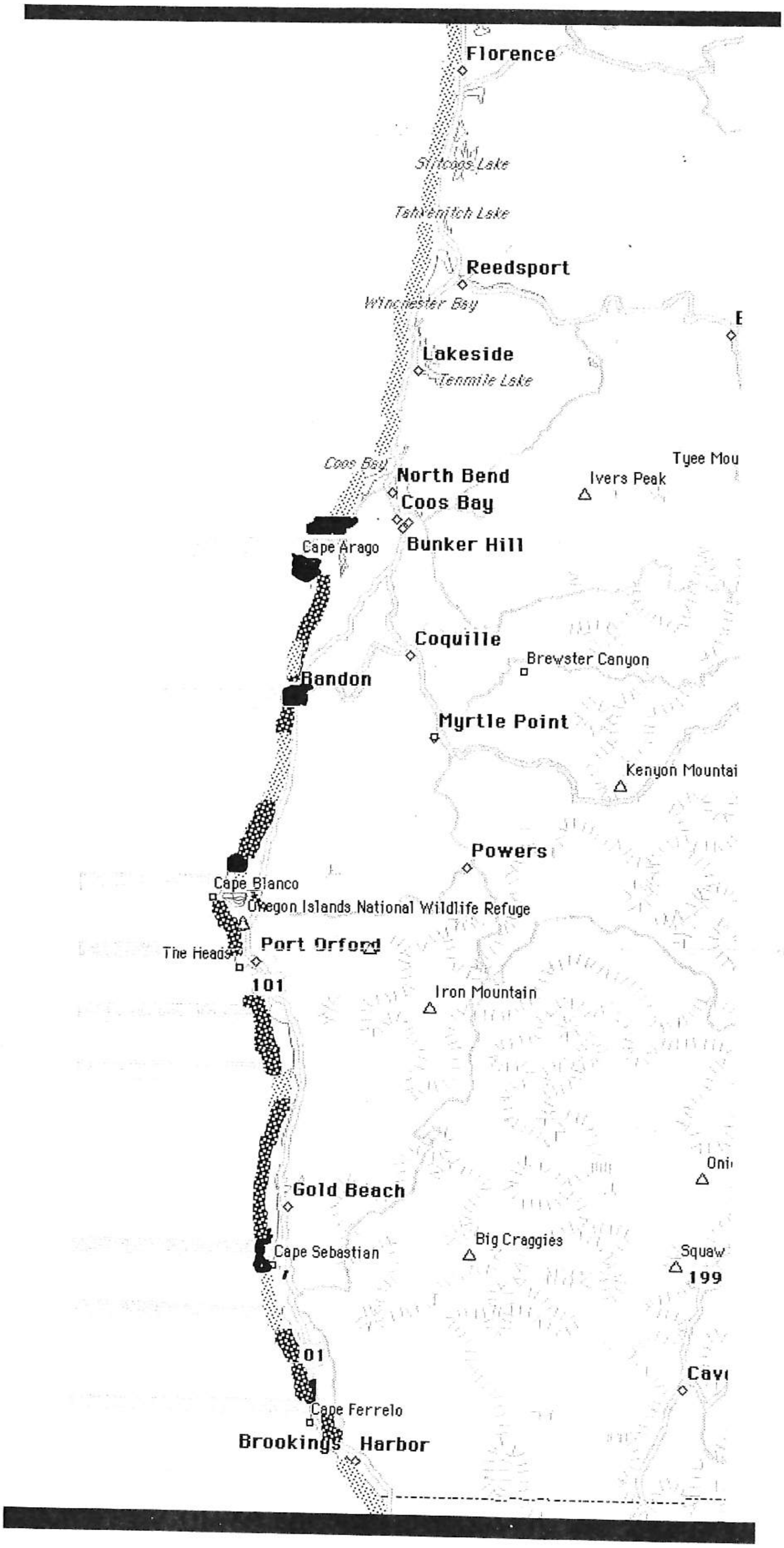


Figure 2.2. Oregon Coast Littoral Cells b) Central Oregon Coast

Figure 2.2. Oregon Coast Littoral Cells c) South Oregon Coast



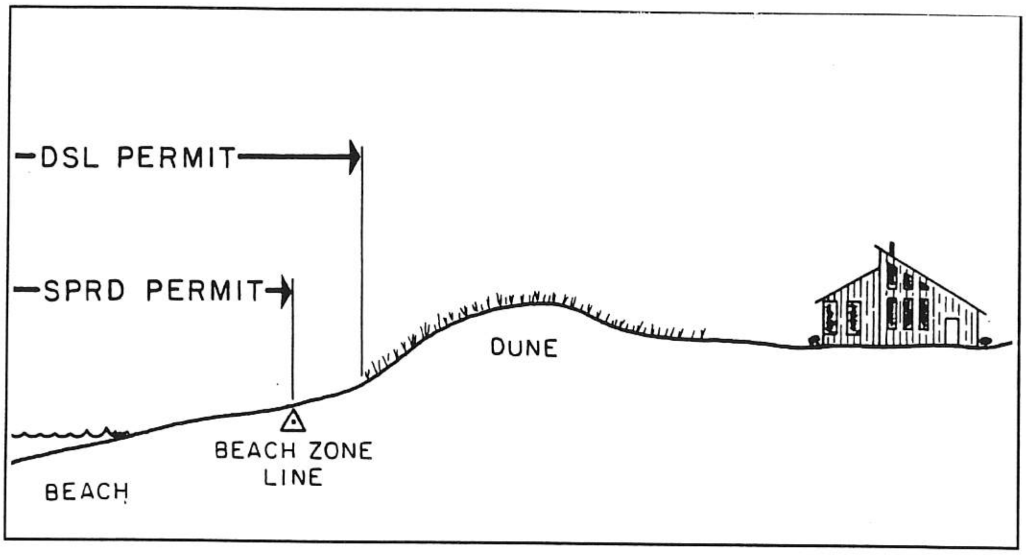


Figure 2.3a. Schematic of Dune-Backed Shoreline (after Good and Ridlington, 1994).

As much as 45% of the Oregon coast consists of dune-backed shorelines. The littoral cell that extends from Heceta Head on the north to Cape Arago on the south, for example, contains the Coos Bay dune sheet. This approximately 150 mile long coastal dune accumulation is the largest in the United States. Other littoral cells characterized by dune-backed shorelines include the southern portion of the littoral cell that contains the Columbia River and Clatsop Plains, the Rockaway Littoral Cell, and the Nestucca Littoral Cell, on the north Oregon coast, as well as the littoral cells south of Cape Arago, south of Coquille Point, and in the vicinity of Gold Beach on the south Oregon coast.

Bluff-backed shorelines also makeup large segments of the Oregon coast. Much of the central Oregon coast, from Cascade Head on the north to Cape Perpetua on the south consists of bluff-backed shoreline for example. Similarly, portions of the south coast, north of Coquille Point and north of Blacklock Point for example, can also be characterized as bluff-backed shoreline. As will be seen further below, the distinction between segments of shoreline where a sandy beach and dune are the major morphologic elements, and those where a sandy beach and bluff are the major morphologic elements, is another a concept that is useful for both scientific and management purposes.

It was noted above that uplift and erosion is differentially distributed along the Oregon coast. In this regard, along coast differences in rates of aseismic uplift of the coastal margin approach, and in some cases slightly out pace, current rates of global eustatic sea level rise. Specifically, these net changes in mean water level, or relative sea level rise, are such that along northern and southern portions of the Oregon coast the mean water level is estimated to be decreasing at a rate that is currently on the

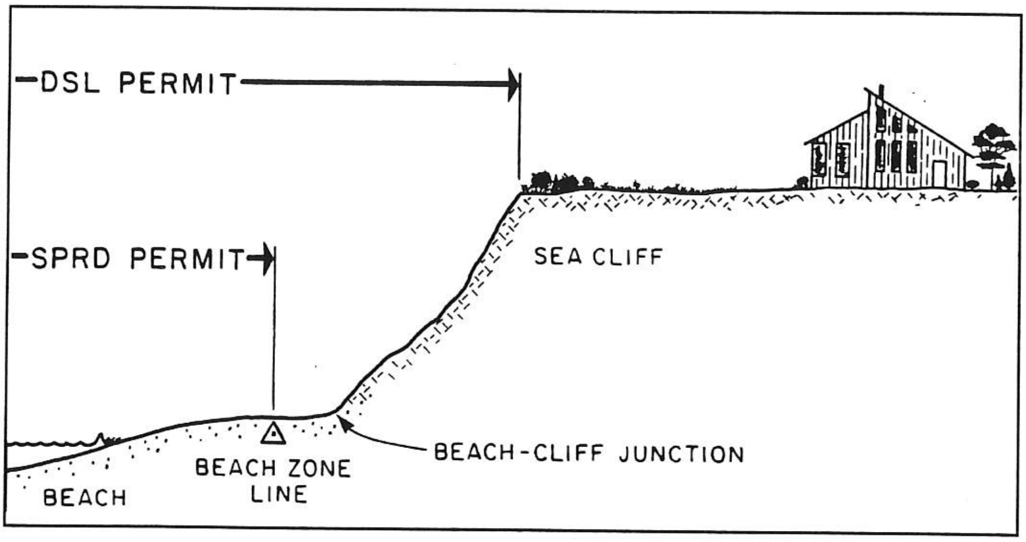


Figure 2.3b. Schematic of Bluff-Backed Shoreline (after Good and Ridlington, 1994).

order of 4 to 8 inches per century. In contrast, along the central Oregon coast the mean water level is estimated to be increasing at a rate that is currently on the order of 4 to 8 inches per century.

Observations have been made which point towards a first order correspondence between rates of relative sea level rise and shoreline stability. Along bluff-backed shorelines of the the south coast, the presence of talus at the toe of the slope and of heavy vegetation along the bluff face suggests that processes of wave attack have been relatively inactive since the occurrence of the last catastrophic subduction zone earthquake some 350 years ago: Along bluff-backed shorelines of the central Oregon coast, the absence of talus and at the toe of the slope and of vegetation on the bluff face suggests that processes of wave attack continue to be active.

However, when net rates of change of mean water level along the Oregon coast are compared with those observed elsewhere, the extent to which relative sea level rise is a factor affecting shoreline stability within Oregon coast littoral cells is relatively limited. Rates of relative sea level rise along the Atlantic and Gulf coast, for example, are estimated to be on the order of 2-6 times as high as those observed along the Oregon coast. This is because along the Atlantic and Gulf coasts, unlike the Oregon coast, rising global sea levels are coupled with a continuously subsiding coastal margin, and as a result, an ever increasing mean water level. Still, consideration of the extent to which relative sea level rise may be a factor affecting shoreline stability within individual Oregon coast littoral cells is warranted, particularly if rates of relative sea level rise increase as envisioned under scenarios of global warming in response to the greenhouse effect.

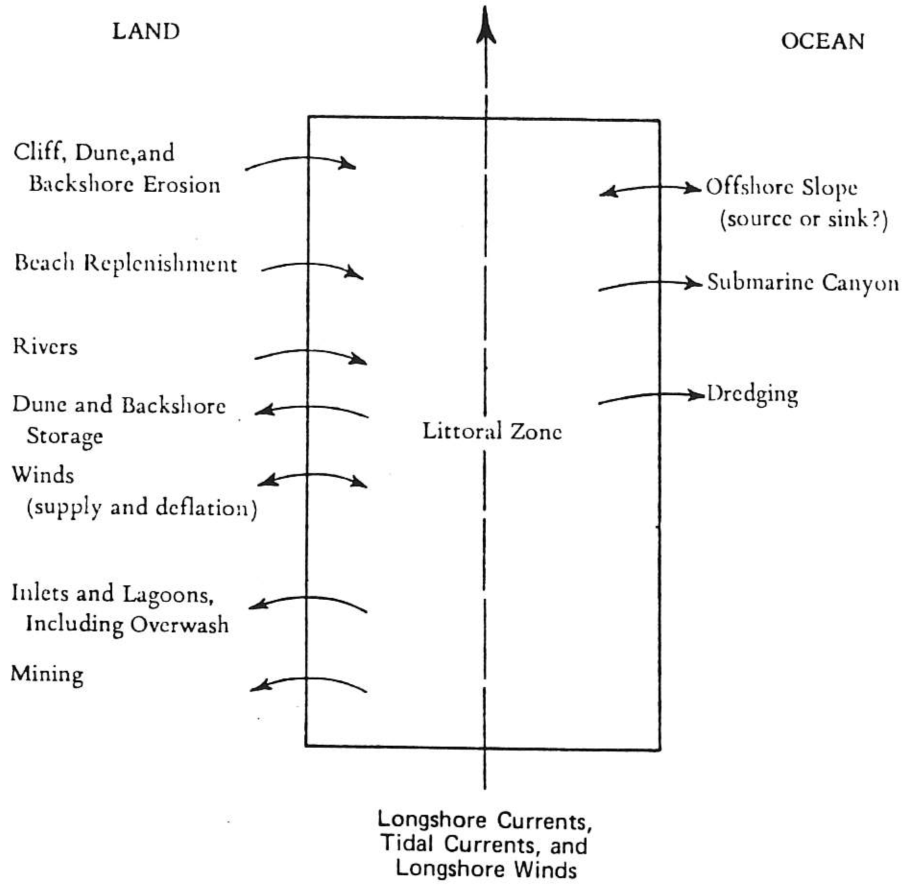


Figure 2.4. The Sediment Budget (from ACOE, 1984).

In addition to tectonically and eustatically-induced variations in mean water level, sand supply also represents a first order control on shoreline stability within Oregon coast littoral cells. In this regard, the sediment budget concept is relevant (Figure 2.4). This concept involves viewing a given segment of shoreline in terms of the positive or negative transfers of sediment that occur within it. The resultant balance of the sediment budget is determined by comparing the volume of sediment gained from sources (positive transfers) to the volume lost to sinks (negative transfers). A negative balance means that more sand is leaving than is arriving and, that as a result, that segment of shoreline is eroding. Conversely, a positive balance means that more sand is arriving than is leaving so that the segment of shoreline is accreting.

Whether intentionally or unintentionally, most HATs modify the sediment budget along a segment of shoreline in some manner (Figure 2.5). Beach nourishment, for example, results in augmentation of the sediment budget. By blocking contributions of sediment to the shoreline, seawalls may result in diminution of the sediment budget. Thus, efforts to alleviate hazards along one segment of shoreline have the potential to impact other segments of shoreline. Because of the compartmentalized nature of the Oregon coast, where transfers of sediment are limited principally to exchanges within individual littoral cells, sediment budget considerations are particularly relevant in this regard.

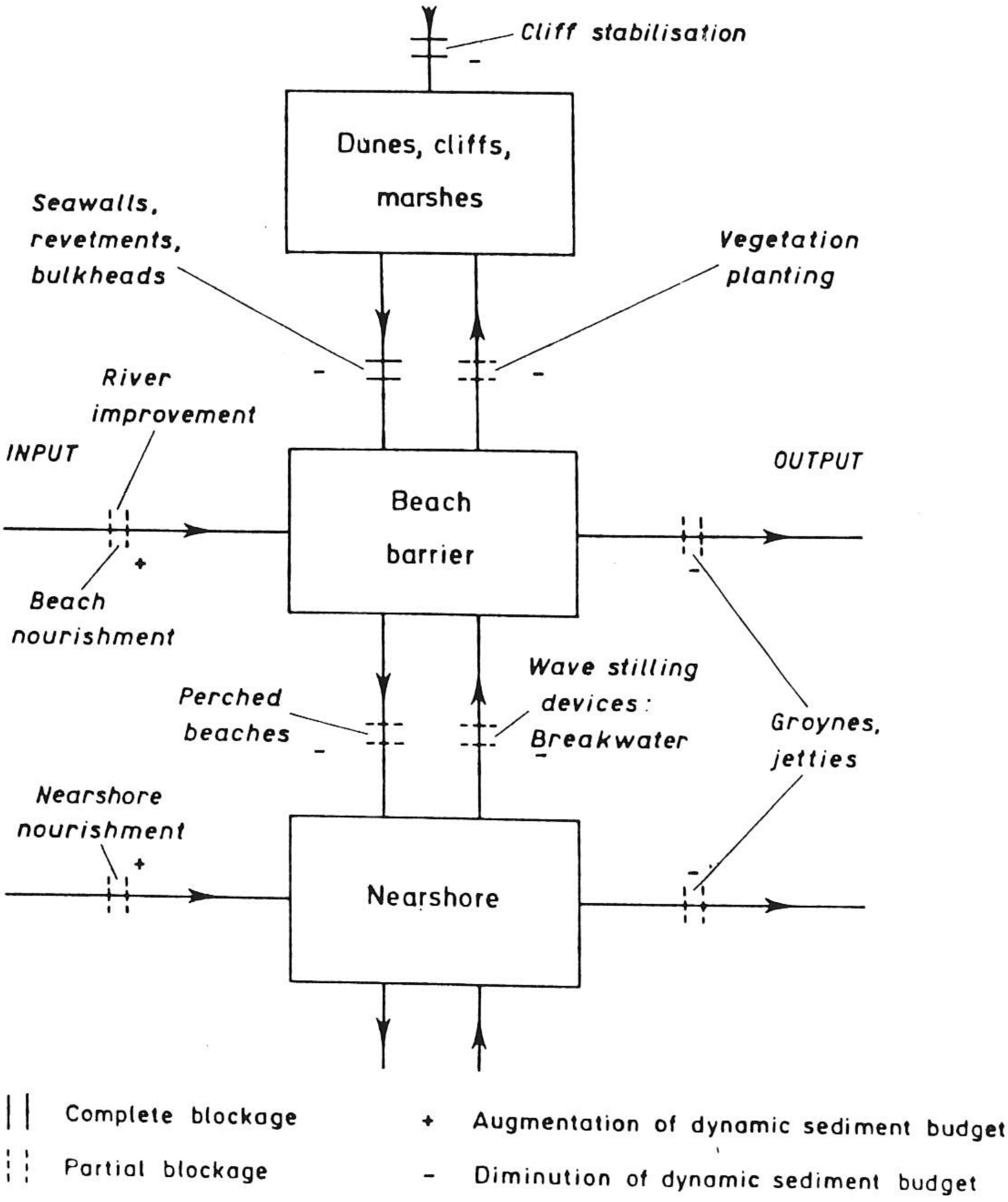


Figure 2.5. Impacts of Various Hazard Alleviation Techniques on the Sediment Budget (from Carter, 1988).

Along the Oregon coast, potential sources of sand include rivers, bluffs, dunes, and the inner shelf. Potential sinks include, bays, dunes, offshore, dredging, and mining. Detailed sediment budgets of Oregon coast littoral cells are generally lacking. However, it is know that combinations of sources and sinks, as well as absolute budget balances, differ markedly between Oregon coast littoral cells. For example, in the littoral cell that extends from Yaquina Head south to Cape Perpetua, rivers, bluffs, and the inner shelf are likely sand sources. Here active sand volumes per meter of shoreline are estimated at 627 cubic meters. In contrast, active sand volumes per meter of shoreline are estimated at 77 cubic meters in the adjacent Beverly Beach Littoral Cell, where potential sand sources are limited to bluffs and the inner shelf.

2.2 SHORT TERM, LOCAL CONTROLS

Up to this point in the discussion of factors affecting shoreline stability, the focus has been on processes that operate over relatively large temporal and spatial scales. From the standpoint of chronic hazard alleviation, these processes are for the most part manifest as long term trends whose effects are permanent/irreversible (Figure 2.1). Superimposed on these long term regional controls, are processes that operate over relatively small temporal and spatial scales. It is these short term local controls, whose effects are both permanent/irreversible and temporary/reversible, that are the focus of the remainder of the discussion.

2.2.1 DUNE-BACKED SHORELINES AND PROCESSES OF WAVE ATTACK

Along dune-backed shorelines processes of wave attack are the primary control on shoreline stability (Figure 2.1). From the standpoint of ocean flooding it is primarily the magnitude of an extreme runup event that is of particular interest. In this regard, tides, storm surges, barometric pressure effects, temperature effects, and baroclinic currents all affect mean water level. Superimposed upon these longer term elevations in mean water level are short-term variations associated with the passage of waves. Extreme water surface elevations achieved during storms, and expressed at the shoreline as wave runup, result from the simultaneous occurrence of individual maxima within this range of forcing events.

The magnitude of wave runup is influenced not only by water levels and wave heights, but also by beach morphology. On wide, gently-sloping, dissipative beaches runup is weak because much of the incoming wave energy is expended in breaking before it reaches the shoreline (Figure 2.6a). On narrow, steeply-sloping, reflective beaches runup is strong because incoming waves break right at the shoreline with little prior loss of energy (Figure 2.6b).

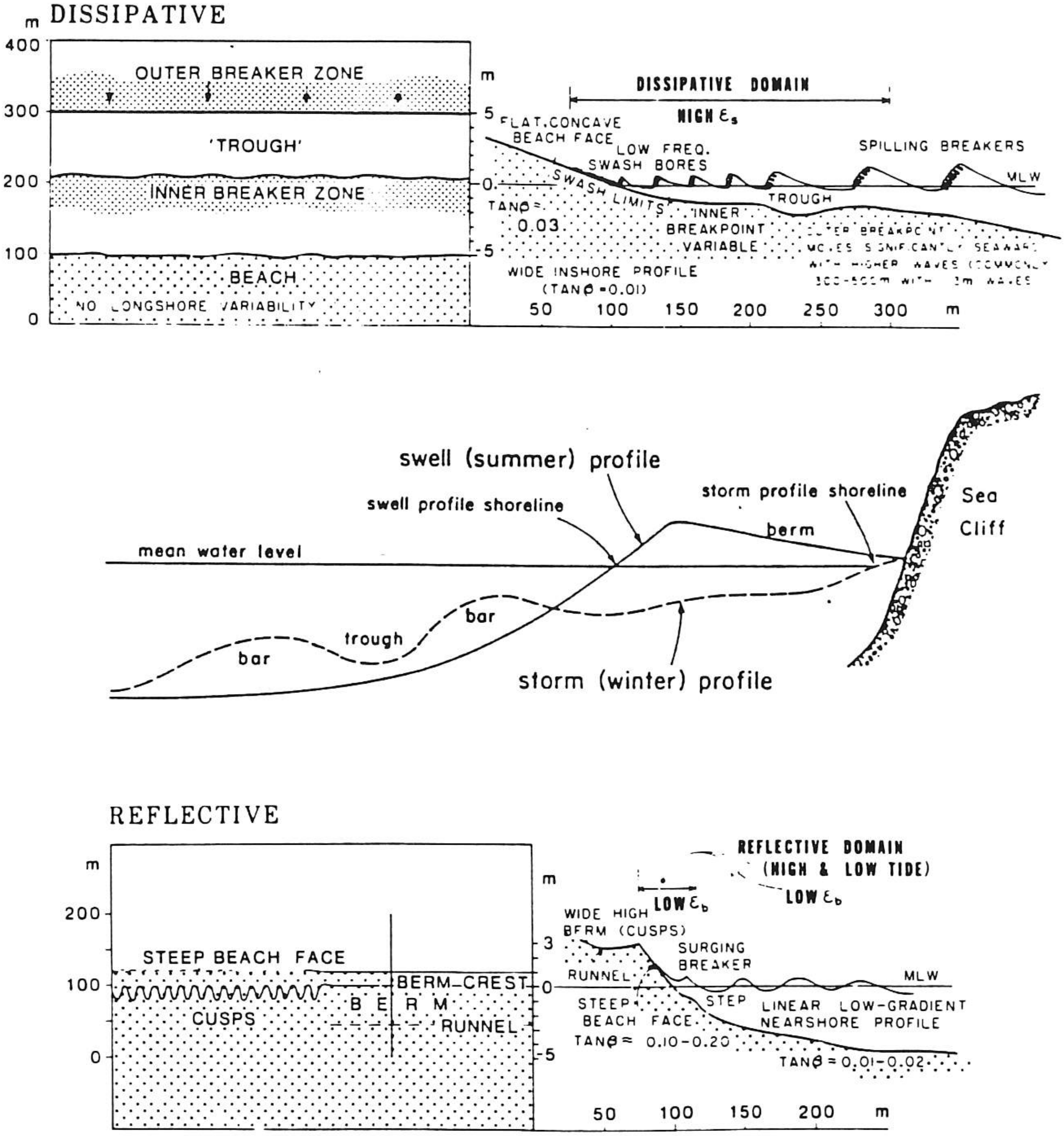


Figure 2.6. Dissipative (a) and Reflective (b) Beach Morphologies (from Wright and Short, 1983).

Note affinities to storm/winter and swell/summer profiles in center of figure (from Komar, 1976).

From the standpoint of wave erosion it is not only the magnitude of runup but its frequency of occurrence that is of interest. In this regard, flooding and erosion along the Oregon coast are confined mainly to the stormy winter months. During this season, regional atmospheric circulation is dominated by the Aleutian Low, a series of low pressure centers that move over the coast at intervals of several days to a week or two and bring heavy rains, high velocity south to southwesterly winds, and high waves. Breaking wave heights of 25-30 feet are not uncommon during winter storms. The shoreline system responds to such high winter waves by transferring sand offshore and storing it in subaqueous bars (Figure 2.6 a). As a result of this erosion, the profile takes on a more concave form (i.e. it becomes more dissipative).

In the summer, the regional atmospheric circulation is dominated by the North Pacific High which brings fair weather, moderate velocity north-north westerly winds, and low waves. During this season, the shoreline system responds to the low waves by transferring sand onshore and storing it in the subaerial beach and dune (Figure 2.6 b). As a result of this accretion, the profile takes on a more convex form (i.e. it becomes more reflective). Profile changes in response to seasonal variations in wave height can be dramatic (Figure 2.7). Such seasonal beach cycles are a characteristic feature of Oregon coast littoral cell dynamics.

During winter storms, rip currents are an important element of nearshore circulation in Oregon coast littoral cells. Rip currents are wave-generated, seaward-flowing currents that develop as part of a larger pattern of horizontal cell circulation (Figure 2.8). In the process of eroding crescent-shaped embayments and moving sand offshore, they act as the locus of storm wave attack. A major episode of erosion that occurred at Siletz Spit in 1972-73 has been clearly associated with rip currents. Similarly, rip currents are likely to have contributed to erosion that occurred at Nedonna Beach in 1977-78 and at Netarts Spit since 1982-83. Erosion in the lee of rip currents can be dramatic, reaching inland as much as 150 feet. However, such erosion tends to be limited in longshore extent, generally affecting only several hundred feet of shoreline.

Besides rip currents, longshore currents are also an important element of nearshore circulation in Oregon coast littoral cells. Generated by waves approaching at an angle to the shore, longshore currents flow parallel to the shoreline (Figure 2.9). Thus, unlike rip currents whose effects on shoreline stability tend to be relatively local, longshore currents affect shoreline stability across the entire length of the littoral cell. Because winds and waves tend to arrive from the southwest during the winter and from the northwest during the summer, Oregon coast littoral cells generally exhibit a seasonal reversal in the direction of longshore as well as cross-shore transport (i.e.net transport is offshore and to north in winter, net transport is onshore and to the south during the summer). The tendency for bay spits to be oriented both to the north and south, and for deposition on opposite sides of harbor jetties to be relatively symmetrical, suggests that in general there is a long term balance between northerly versus southerly sand transport in Oregon coast littoral cells.

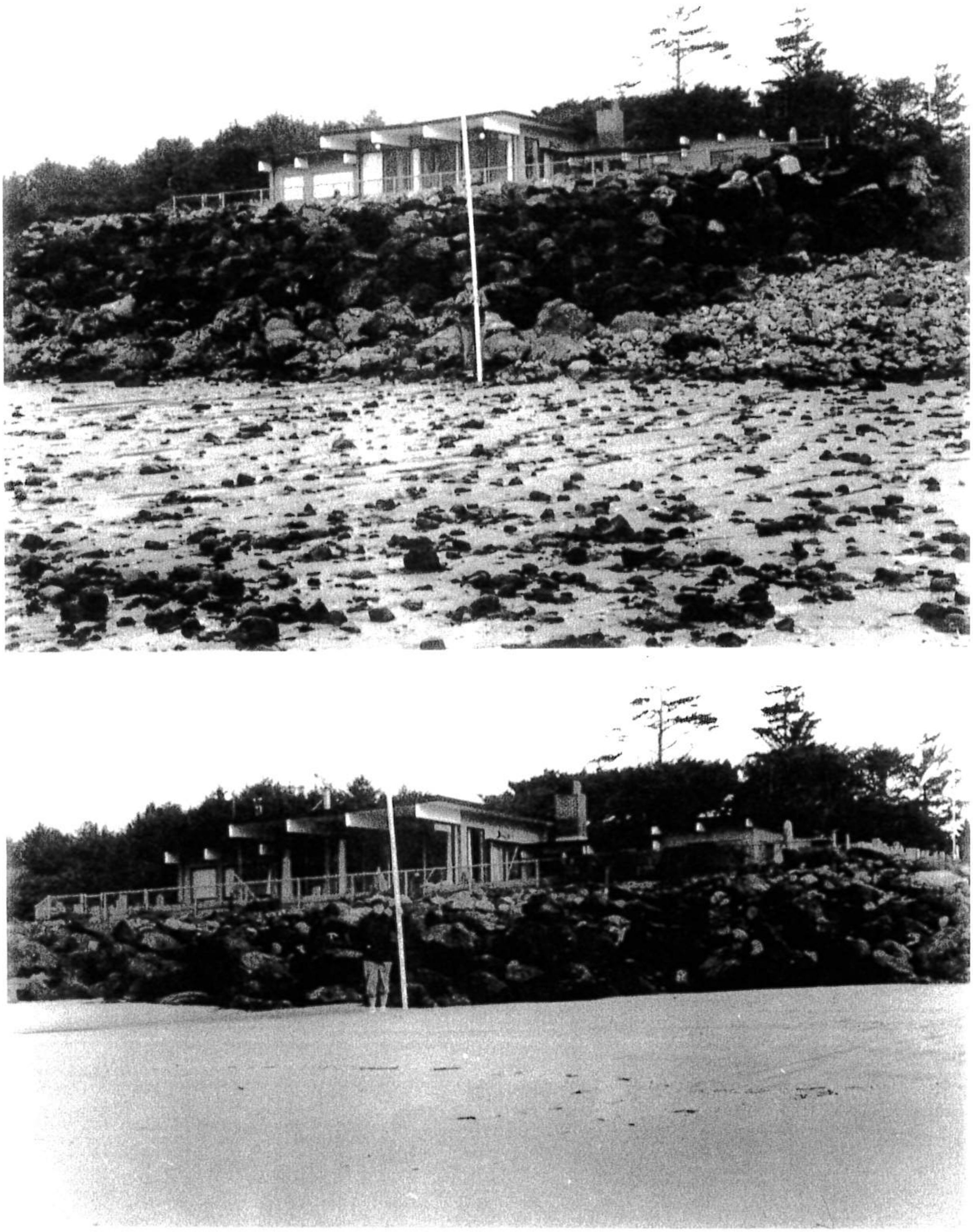


Figure 2.7. Comparison of Winter (top) versus Summer (bottom) beach near Yachats (from Peterson et al., 1990). Note elevation change.

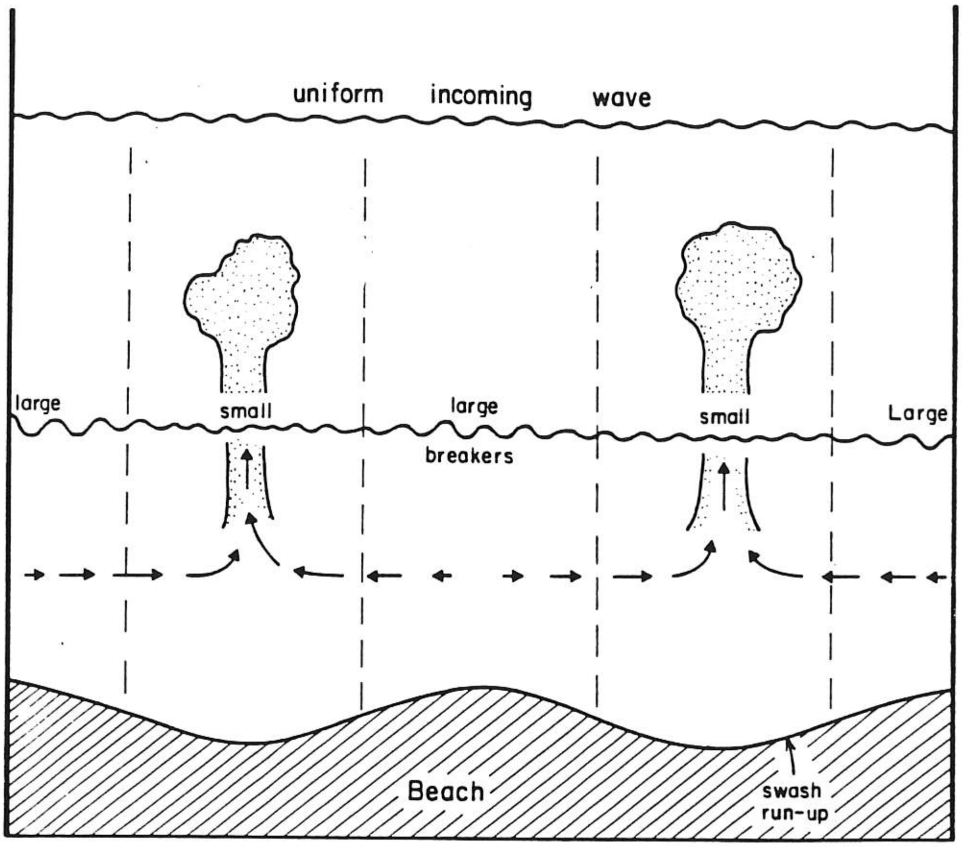


Figure 2.8. Schematic Illustration of Horizontal Cell Circulation (from Komar, 1976).

Although the concept of long term zero net longshore transport may apply to most Oregon coast littoral cells, it is clear that it does not apply to all Oregon coast littoral cells. A case in point is the littoral cell that encompasses the Columbia River cell, where there is a net northerly direction of longshore sediment transport. Also, the concept of zero net longshore transport does not apply to short term shoreline change. In this regard, significant short term variation in shoreline position has been associated with the 1982-83 El Nino event. During this event, due to the southward displacement of winter storm tracks, waves approached the coast from a more southwesterly direction than normal. An increased frequency of large storms, and in turn more frequent high waves also occurred during this event. Wave heights in the Coquille-Newport area exceeded the average wave height by 2 standard deviations on 22 days for example. Finally, anomalously high values of mean sea level, values as much as 2 feet above the average, were also reported during this event.

In many Oregon coast littoral cells the response to these conditions appears to have been a short-term net displacement of sand from the southern to the northern ends of littoral cells (Figure 2.10). More precisely, the southern ends of littoral cells experienced major erosion during and in the years immediately following an El Nino. At the northern ends of littoral cells, accretion occurred in

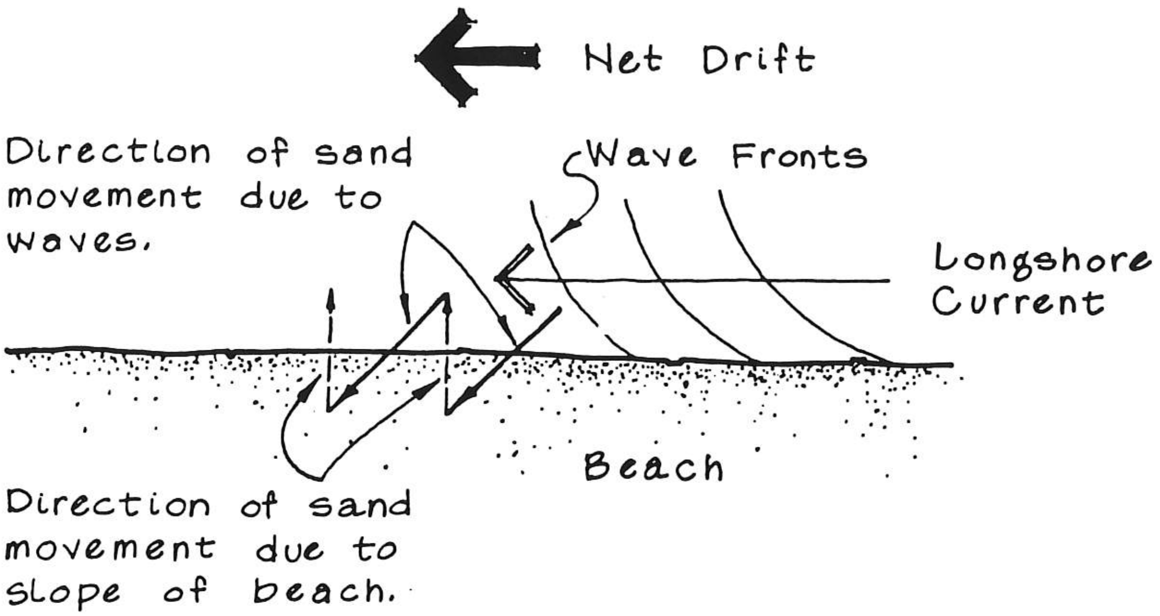


Figure 2.9. Schematic Illustration of Longshore Drift (from Katz and Gabriel, 1982).

conjunction with and over the years following an El Nino. Such is the case in the Cannon Beach Cell where, at Arch Cape, located on the southern end of the cell, erosion that occurred in association with the 1982-83 El Nino resulted in the loss of a home to the sea. In contrast, dwellings in Cannon Beach, located at the northern end of the cell, have been experiencing accretion verging on inundation since the 1982-83 El Nino. Similarly, in Neskowin, at the southern end of the Nestucca Cell, erosion occurred in association with the 1982-83 El Nino: Sand accretion in Pacific City, at the northern end of the Nestucca Cell, has resulted in the loss of a home to sand inundation (Figure 2.11). Similar patterns of shoreline change were observed in along portions of the central Oregon coast, near Newport. Alsea Spit and Netarts Spit are also specific locations on the Oregon coast where erosion problems have been attributed to the northward displacement of sand during the 1982-83 El Nino event. Thus, interannual variations in the direction of longshore transport should be viewed as a particularly important factor affecting shoreline stability within Oregon coast littoral cells, although specific effects in any given littoral cell are expected to vary.

Before considering factors affecting the stability of bluff-backed shorelines, the significant role wind-driven sediment transport plays in controlling shoreline stability along some segments of dune-backed shoreline should not be overlooked. As noted above in the context of the 1982-83 El Nino event, excessive accumulation of wind blown sand is a concern along northern portions of several north Oregon coast littoral cells. Excessive accumulation of wind blown sand has also been observed locally within other littoral cells along the Oregon coast (e.g. Bayshore, north of Waldport). Like

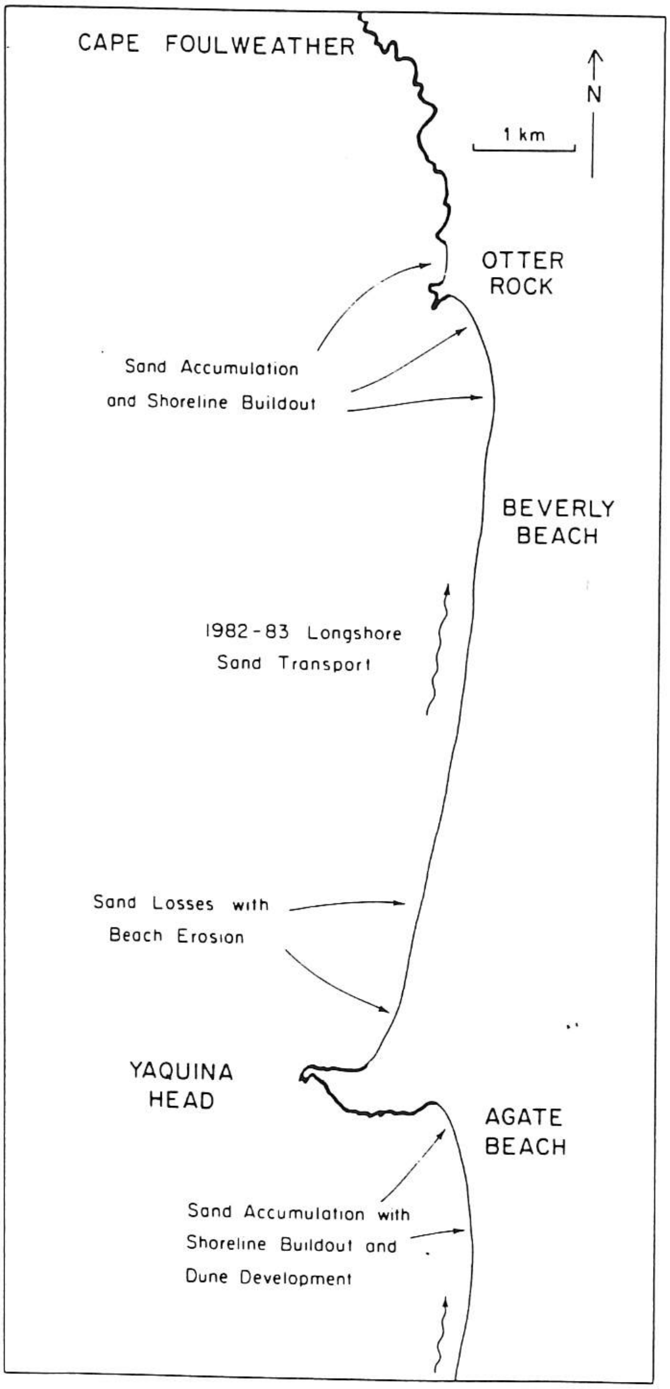


Figure 2.10. Pattern of Beach Erosion and Accretion along a segment of Central Oregon Coast shoreline associated with 1982-1983 El Nino event (from Komar, 1986).

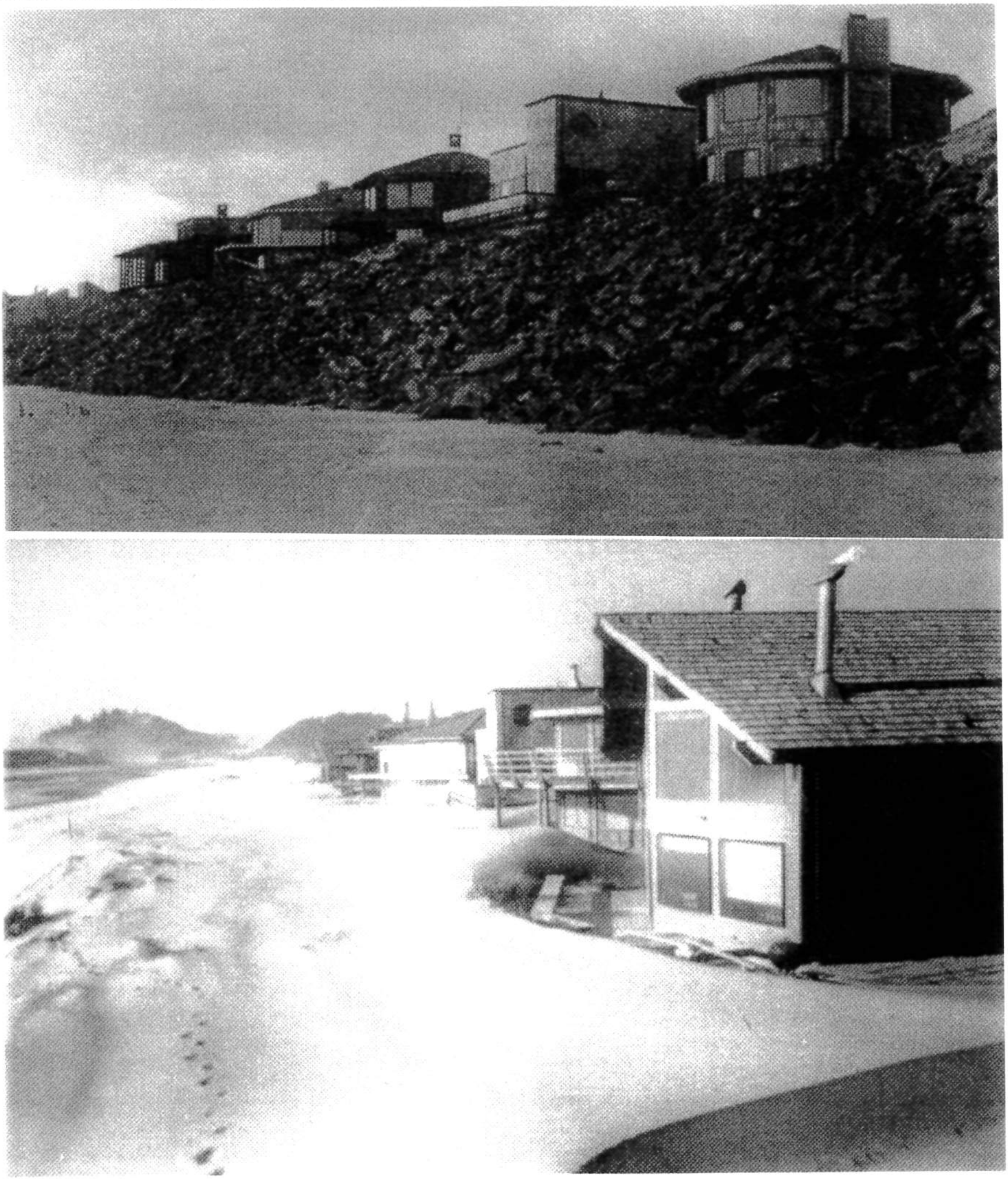


Figure 2.11. Interannual Variation in Beach Elevation at Pacific City (from Komar, 1988): upper photo taken in 1978 and lower photo taken in 1988

wave-driven sediment transport, Oregon coast littoral cells generally exhibit a seasonal reversal in the direction of wind-driven sediment transport, with south-southwesterly winds dominating in the summer and north-northwesterly in the summer. Although it has been suggested that along the north coast south-southwesterly winds are the effective winds and along the south coast north-northwesterly winds are the effective winds, the relative dominance of south-southwesterly versus north-northwesterly in individual littoral cells is not well understood.

2.2.2 BLUFF-BACKED SHORELINES AND PROCESSES OF MASS WASTING

Along bluff-backed shorelines processes of wave attack and processes of mass wasting both control shoreline stability (Figure 2.1). Mass wasting includes gradual weathering processes that result in long term trends of bluff recession, such as direct wind and rain impact, as well as episodic landsliding or slumping. The term landsliding is generally applied to translational mass movements, or motions that occur along a more or less planar surface. The term slumping is generally applied to rotational mass movements, or motions that occur about an axis. As most mass movements posses both translational and rotational components of motion however, the terms landsliding or slumping are taken here to represent a broad range of gravity-driven rock, soil, or sediment mass movements (Figure 2.12).

Along bluff-backed shorelines, shoreline stability is pretty much synonymous with slope stability. In this regard, a number of factors affect slope stability, basically by acting to increase driving forces and/or reduce resisting forces (Table 2.1). Bluff material composition is a primary control on slope stability. Hard headland-forming basalts for example, while not immune to mass wasting, do not readily give way. In contrast, soft bluff-forming sandstones and mudstone are highly susceptible to mass wasting. Prolonged winter rains saturate these porous bluff materials, both loading the the slope and lowering cohesive strength, to further decrease slope stability. The geometry and structure of bluff materials also affects slope stability (e.g. bedding and fractures constitute lines of weakness). Further, and together with differences in the permeability of layers, they can control surface as well as subsurface drainage. The slope of bedding may also be relevant in this regard.

With reference to the Oregon coast, much of the shoreline along the central coast consists of seaward-dipping relatively impermeable Tertiary mudstones overlain by permeable Tertiary sand and siltstones. These units are in turn overlain unconformably by Pleistocene marine terrace sands. This sequence of rock units is known to be prone to deep-seated landsliding/slumping, particularly along the segment of shoreline between Yaquina Head and Otter Rock. Where bluffs consists entirely of Plesitocene terrace sands, small, shallow, surficial sloughing rather than than large, deep-seated massive landslides are the primary concern. This distinction between deep-seated slides and shallow surficial sloughs, and a corresponding distinction between long term trends and short term events

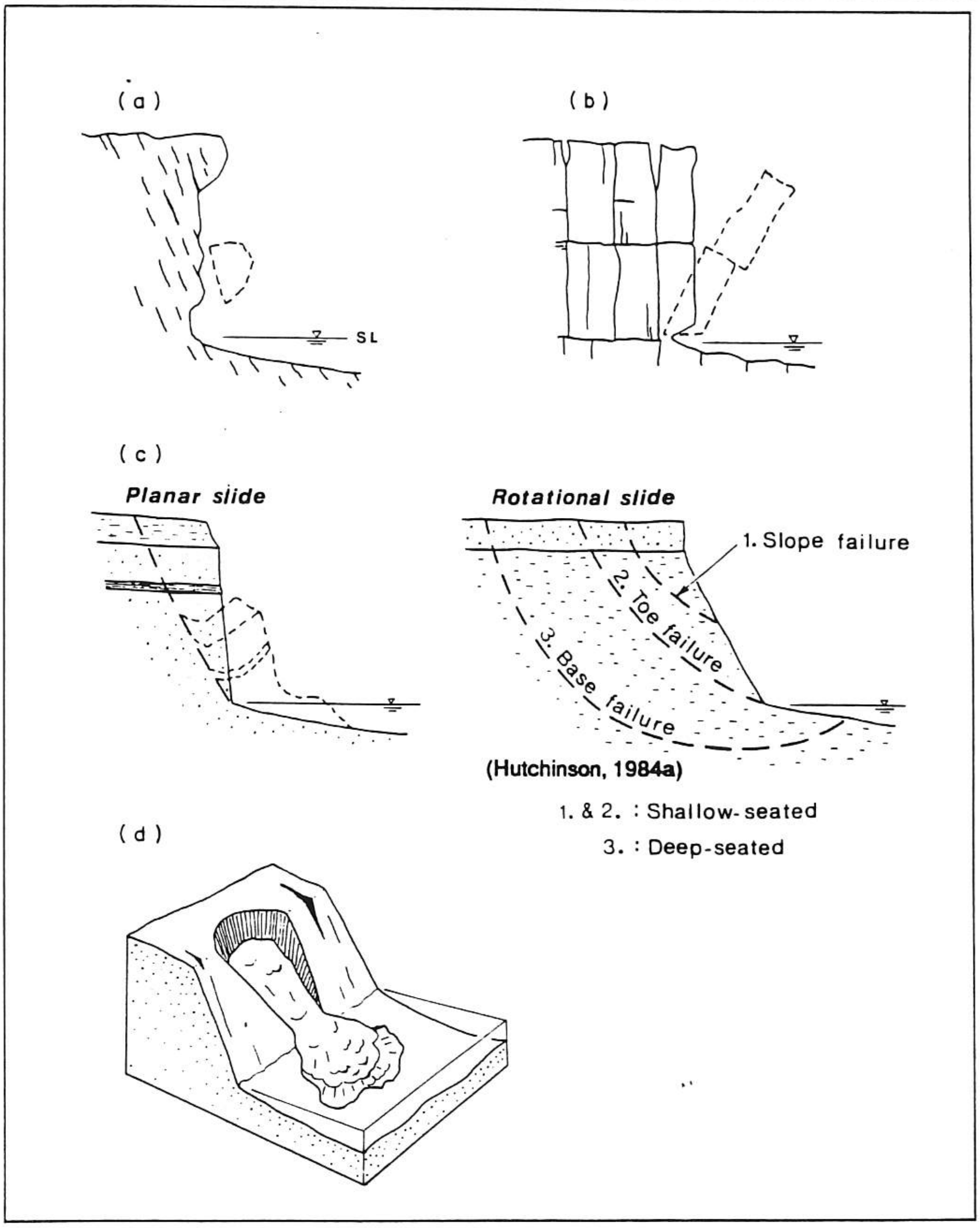


Figure 2.12. Four Primary Types of Mass Movement: a) fall; b) topple; c) slide; and d) flow (from Sunamura, 1992).

respectively, is more conceptual than it is real. It is however, useful for scientific and management purposes.

By removing sediment from the base of bluffs and by cutting into the bluffs themselves, processes of wave attack may also affect slope stability. The extent to which the beach fronting the bluff acts as a buffer is important in this regard. For example, in the actively eroding Beverly Beach cell, where

TABLE 2.1. FACTORS CONTRIBUTING TO THE INSTABILITY OF EARTH SLOPES (from Gray and Leiser, 1982).

Factors that Contribute to *High Shear Stress*	Factors that Contribute to *Low Shear Strength*
A. Removal of lateral support	**A.** Initial state
1. Erosion—bank cutting by streams and rivers	1. Composition—inherently weak materials
2. Human agencies—cuts, canals, pits, etc.	2. Texture—loose soils, metastable grain structures
	3. Gross structure—faults, jointing, bedding, planes, varving, etc.
B. Surcharge	**B.** Changes due to weathering and other physico-Chemical reactions
1. Natural agencies—weight of snow, ice, and rainwater	1. Frost action and thermal expansion
2. Human agencies, fills, buildings, etc.	2. Hydration of clay minerals
C. Transitory earth stresses—earthquakes	3. Drying and cracking
D. Regional tilting	4. Leaching
E. Removal of underlying support	**C.** Changes in intergrannular forces due to pore water
1. Subaerial weathering—solutioning by groundwater	1. Buoyancy in saturated state
2. Subterranean erosion—piping	2. Loss in capillary tension upon saturation
3. Human agencies—mining	3. Seepage pressure of percolating groundwater
F. Lateral pressures	**D.** Changes in structure
1. Water in vertical cracks	1. Fissuring of preconsolidated clays due to release of lateral restraint
2. Freezing water in cracks	2. Grain structure collapse upon disturbance
3. Swelling	
4. Root wedging	

sand volumes are low and as a result the fronting beach is narrow, it has been observed that wave runup reaches the toe of the bluff more frequently than it does in adjacent cells. Similarly, in the Lincoln City cell it has been observed that wave runup reaches the toe of the bluff more frequently at the southern end of the cell, along Gleneden Beach where the beach is coarser-grained, steeper-sloping, and narrower(i.e. more reflective), than it does at the northern end of the cell along Road's End Beach, where the beach is finer-grained, gentler, and wider (i.e. more dissipative). Correspondingly, bluff recession has been shown to occur at a higher rate at Gleneden Beach than it does at Road's End.

With respect to actual rates of bluff recession in response to mass wasting and wave attack, high long term rates have been observed along some segments of shoreline. In the vicinity of the Jump Off Joe (Newport) for example, long term rates of bluff recession are as high as 5 feet per year. Along much of the bluff-backed shoreline of the Oregon coast however, long term rates of bluff recession are typically less than 1 foot per year. Still, owing to its spatial variability and episodic nature, together with the permanence of its effects, mass wasting should be viewed as a particularly important factor affecting shoreline stability within Oregon coast littoral cells.

2.2.3 HUMAN ACTIVITIES

Human activities affect the stability of both dune-backed and bluff-backed shorelines (Figure 2.1). At longer time and larger space scales jetty construction and maintenance dredging are factors that can affect shoreline stability (Figure 2.13a). This is particularly true along dune-backed shorelines. The Columbia River and Tillamook Bay jetties, for example, have both been shown to have had a significant impact on patterns of erosion and accretion observed within their respective littoral cells. With respect to maintenance dredging, it has been estimated that one million cubic meters of sand is dredged from Yaquina Bay annually. The entire Newport Cell is estimated to have about 11 million cubic meters of sand. Thus, each year roughly 10 % of the littoral cell sand volume is placed offshore. How much of this sand gets back onshore is unknown.

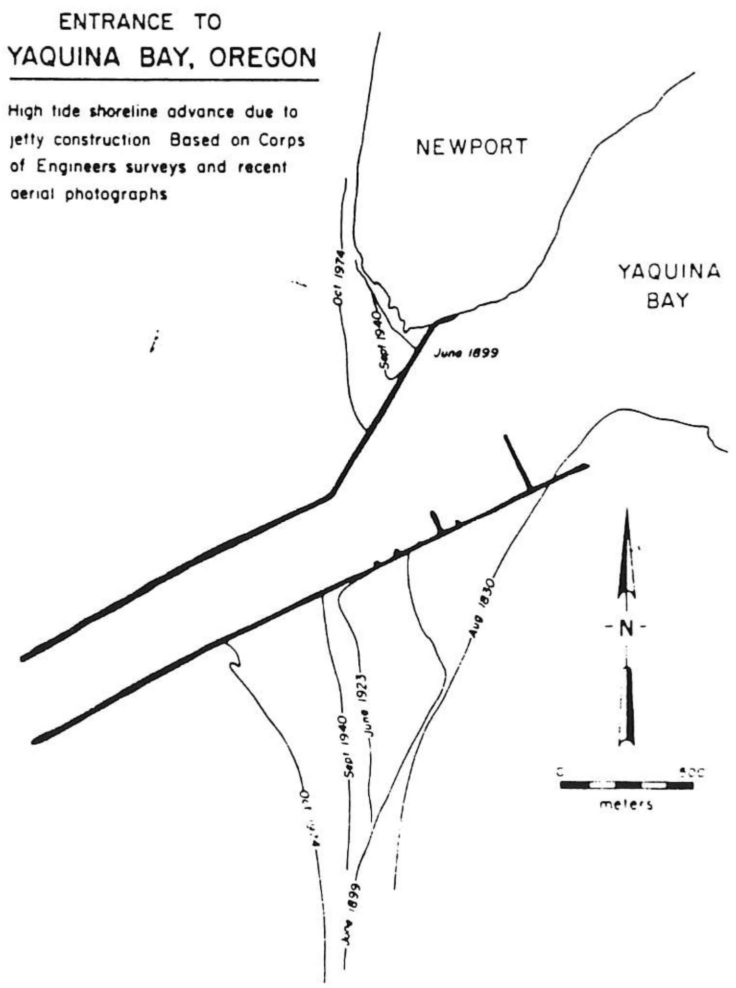


Figure 2.13 Human Alterations a) shoreline change due to jetty construction off Yaquina River Inlet, Newport (from Komar, 1992).

Figure 2.13 Human Alterations b) residential development at Pacific City (ODOT photo from Good and Ridlington, 1994).

Cumulative effects of shoreline hardening and the planting of European Beachgrass can also be considered in this context. The latter of these two activities has had a particularly marked affect on the morphology of the Oregon coast. Prior to the introduction of European Beachgrass, generally open unvegetated sand along the shoreline was associated with the presence of large expanses of active dunes that extended considerable distances inland in some areas. With the spread of European Beach grass, the vegetated foredunes that today characterize much of the shoreline of the Oregon coast formed as major portions of these active dune areas were stabilized.

Figure 2.13 Human Alterations c) residential and commercial development at Seaside (ODOT photo from Good and Ridlington, 1994).

There are a variety of human activities that can affect shoreline stability over shorter time and smaller space scales. Examples of activities typically associated with residential and commercial development include grading and excavation, surface and subsurface drainage alterations, vegetation removal, and vegetative as well as structural shoreline stabilization (Figure 2.13b, 2.13c). With the exception of the latter two, these activities tend to be a particular concern along bluff-backed shorelines where they affect slope stability. With respect to the latter two activities, Nedonna Beach, Manzanita, Pacific City, and Bayshore, are examples of localities where vegetative stabilization has had an effect on shoreline stability; Pacific City and Bayshore are also examples where structural stabilization has had an effect on shoreline stability. Human activities typically associated with recreational use and that are particularly relevant along dune-backed shorelines include pedestrian and vehicular traffic. These activities may result in the loss of fragile vegetation cover (e.g. Coos Bay Dune Sheet.). Human activities associated with recreational use and that are particularly relevant along bluff-backed shorelines include not only pedestrian and vehicular traffic, but also graffiti carving. For example, along Gleneden Beach naturally occurring bluff recession is likely to have been accelerated by graffiti carving.

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3 ECONOMIC, SOCIAL, AND ENVIRONMENTAL FACTORS

Like physical characteristics, social characteristics of shorelines vary along the Oregon coast. High density residential and/or commercial development are prevalent along some segments of littoral cell shoreline. Much of the Cannon Beach Cell and major portions of the Siletz cell are highly developed, for example. Along others, such as the Nestucca Cell, low density residential use is prevalent. Yet other segments of shoreline, are mostly undeveloped, and recreational uses are predominant (e.g. The Dune National Recreation Area between Florence and Coos Bay). In this regard a distinction is made here between rural and urban uses (Table 3.1). Rural refers to low density residential, recreational, and other low intensity uses and activities. Urban refers to high density residential, commercial, industrial, and other high intensity uses and activities. A distinction is also made here between new and existing development. Such differences in levels and types of use are likely to generate different hazard alleviation needs. For example, higher design levels and longer design lives may be warranted along shorelines characterized by high intensity use (e.g. mostly developed, commercial use) than along shorelines characterized by low intensity use (e.g. mostly undeveloped, single-family residential use). Because not all HATs afford the same degree and duration of protection, such differences in hazard alleviation needs may be a determining factor in choosing a HAT.

A combination of city, county, state, and federal jurisdictions apply along the coast (Table 3.2). In this regard, the siting of new development in potentially hazardous areas is principally regulated at the local level through elements of Local Comprehensive Plans and Ordinances acknowledged to be consistent with Statewide Planning Goals 7, 17, and 18. Hazard alleviation for existing development in potentially hazardous areas is principally regulated at the state level through the Ocean Shore Law and the Removal/Fill Law. Such differences in jurisdictional function also influence the choice of HATs, albeit indirectly. Together with the fact that multiple jurisdictions may exist within a single cell, the current management framework favors isolated, site-specific as opposed to integrated, areawide approaches to chronic coastal natural hazards management.

Finally, hazard alleviation is only one of a number of competing shoreline interests. Other factors need to be taken into consideration in choosing a HAT. A list of economic, social, and environmental factors that may need to be considered are listed in Table 3.3 and described briefly below.

TABLE 3.1. SOCIAL SETTINGS OF OREGON COAST LITTORAL CELLS.

TYPES AND LEVELS OF DEVELOPMENT		
	Rural	**Urban**
New or Existing	Low Density Residential Recreationall	High Density Residential Commercial Industrial

JURISDICTION
City
County
State
Federal

ECONOMIC FACTORS

• **Costs.** Here, costs refer to the real monetary expense involved in the development and implementation of a given HAT. Development costs are the full range of short-term expenditures associated with concept formulation and construction. Implementation costs are the full range of long-term expenditures associated with maintenance and monitoring.

Clearly, costs will vary with the areal extent of application of a HAT. Costs will also vary as a function of design level and design life.

• **Protected Property Use Value** - the value associated with the temporary extension of property uses attributable to the implementation of a given HAT. Property refers to land as well as structures. Thus, protected property use value can be regarded in many, but clearly not all situations as a benefit to be weighed against costs. Like cost, use value will vary as a function of

TABLE 3.2. Governmental Functions and Agencies or Authorities for Coastal Natural Hazard Management in Oregon (from Good and Ridlington, 1992).

GOVERNMENTAL FUNCTION	FEDERAL GOVERNMENT	STATE GOVERNMENT	LOCAL GOVERNMENT
Research, technical information, and mapping	■ US Geological Survey (USGS)—hazards ■ Federal Emergency Management Agency (FEMA)—flood and erosion hazards ■ Corps of Engineers (COE)—erosion hazards	■ Dept. of Geology and Mineral Industries (DOGAMI)—hazards info and mapping ■ Dept. of Land Conservation and Development (DLCD)—hazards inventory standards ■ Universities/Sea Grant—research	■ Local Comprehensive Plan (LCP)—hazards inventory and maps
Planning and siting of development	■ FEMA—National Flood Insurance Program (NFIP)	■ DLCD statewide planning standards— Goal 7: Natural Hazards Goal 17: Coastal Shorelands Goal 18: Beaches and Dunes	■ State-approved LCP with natural hazards, shorelands, beaches, and dunes elements; local subdivision, zoning, and flood damage prevention ordinances
Design and building criteria	■ FEMA coastal and flood construction standards	■ State Building Code Agency—building standards	■ Local building code administration—city and county
Shore protection	■ COE Nationwide Permit No. 13—bank stabilization	■ State Parks and Recreation Department (SPRD): Beach Law—regulates shore protection structures ■ Division of State Lands (DSL): Removal/Fill Law—regulates revetments and fill	■ LCP and development ordinances (provisions vary)
Emergency planning and response	■ FEMA	■ Emergency Management Division (EMD)—disaster response and planning	■ County emergency services

the degree of alleviation, the duration of alleviation, and the areal extent of hazard alleviation. Several distinctions can be made in terms of protected property use value. Protected uses can be categorized by type and level (e.g. residential, commercial, industrial). They can be identified

TABLE 3.3. H.A.T. APPRAISAL CRITERIA.

ECONOMIC FACTORS

- COSTS
  - Development
  - Implementation
- PROTECTED PROPERTY USE VALUE
  - Beach (types and levels)
  - Upland (types and levels)
  - Adjacent Shoreline (types and levels)
- PROTECTED INFRASTRUCTURE USE VALUE
  - Critical (e.g. highways, water/sewer mains)
  - Non-Critical (e.g. streets, water/sewer lines)
- PROTECTED INDIRECT USE VALUE (e.g. tourism, tax base)

SOCIAL FACTORS

- SAFETY (e.g. life, health)
- RECREATIONAL USE VALUE
  - (types and levels)
- SCENIC and OTHER SUCH USE VALUE
  - (e.g. cultural, historic, scientific, educational, etc.)

ENVIRONMENTAL FACTORS

- RESOURCE USE VALUE (e.g. commercial fish habitat)
  - Subaerial
  - Subaqueous
- CONSERVATION USE VALUE (e.g. T and E species habitat)
  - Subaerial
  - Subaqueous

as either public or private. A distinction between beach, upland, and adjacent shoreline uses may be particularly pertinent.

Figure 3.1. Recreational Use (from Komar, 1976).

◦ **Protected Infrastructure Use Value** - the value associated with the temporary extension of infrastructure uses attributable to the implementation of a given HAT. Infrastructure may be regarded as critical (e.g highways and water/sewer mains) or non-critical (e.g. streets and water/sewer lines).

◦ **Protected Indirect Use Value** - the value associated with the indirect economic impact that occurs as a result of the implementation of a given HAT. Impacts to tourism and to the tax base are good examples of uses that may be indirectly impacted by the implementation of a given HAT.

SOCIAL FACTORS

◦ **Safety.** In the context of HATs, concerns about safety (e.g. risks to life or health) are generally minimal. In some instances, however, when beach access is blocked or when circulation patterns are altered to an extent that they pose a risk to swimmers for example, consideration of safety as a factor affecting the choice of HATs may be warranted.

◦ **Recreational Use Value** - the value associated with the degradation, maintenance, or enhancement of recreational uses attributable to the implementation of a given HAT. Thus, recreational use values may be either positive or negative. A wide variety of types and levels of recreational use fall into this category (e.g. walking, kite flying, picnicking, surfing, etc.: Figure 3.1) The distinction between beach, upland, and adjacent shoreline uses may also be

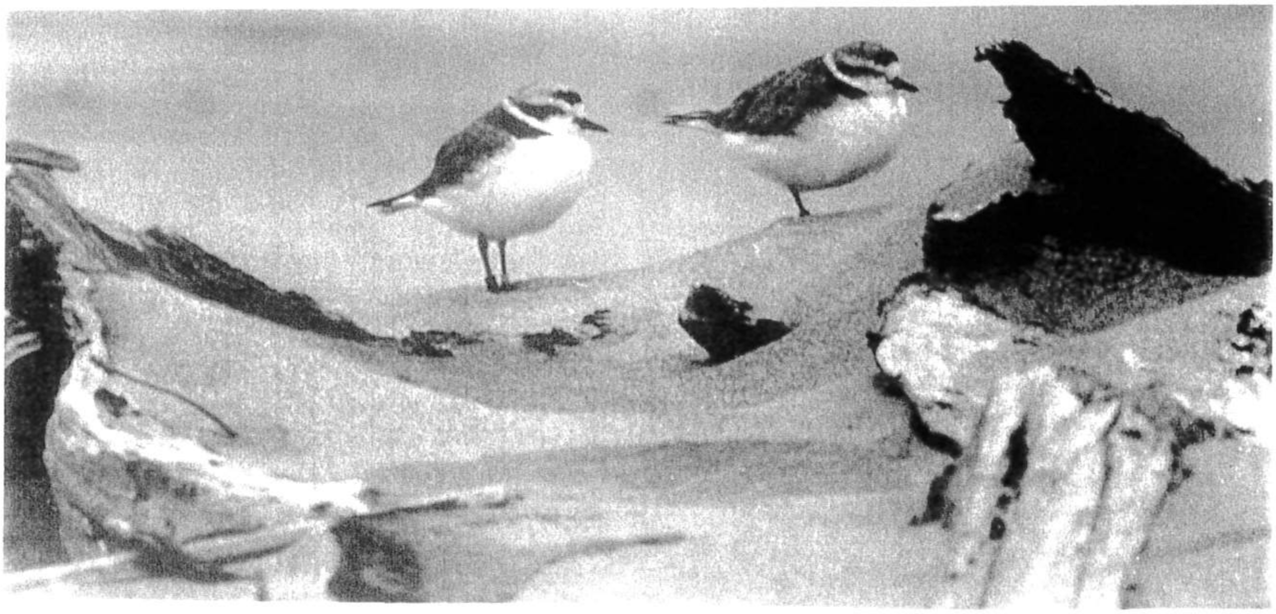

Figure 3.2. Snowy Plover (from Wiedemann, 1984).

relevant in this context. Recreational use values may be a particularly important, if not an over-riding concern in some settings.

◦ **Scenic and Other Such Use Values** - the value associated with the degradation, maintenance, or enhancement of scenic, historic, scientific, educational, cultural and other such uses attributable to the implementation of a given HAT. In this regard, the concept of significance is often relevant. Namely, while all settings have some such use value, in relative terms some settings are particularly significant.

ENVIRONMENTAL FACTORS

◦ **Resource Use Value** - the value associated with the degradation, maintenance, or enhancement of natural resources attributable to the implementation of a given HAT. In this instance the natural resources are assumed to have some known or measurable resource value. Commercial fish species and their habitat is an example of such a natural resource. Air and water quality might also be included in this category. A further distinction between subaerial (land) and subaqueous (water) resources can be made in this regard.

◦ **Conservation Use Value** - the value associated with the degradation, maintenance, or enhancement of natural resources that is attributable to the implementation of a given HAT. In this instance, however, the natural resources have an intrinsic use value. Threatened and endangered species, such as the Snowy Plover, and their habitat is an example of such a natural resource (Figure 3.2). The distinction between subaerial and subaqueous resources can also be made in this regard. The concept of significance may also be relevant in this regard.

Generally the economic, social, and environmental factors identified above are manifest as negative (costs) and positive (benefits) consequences of employing a given HAT. Cost-benefit analysis is the formal means whereby the positive and negative consequences of employing a given HAT can be compared with those of an alternative. Expressed as a ratio, costs outweigh benefits if the value of the ratio is less than 1 and benefits outweigh costs if the ratio is greater than 1. The results of a particular cost-benefit analysis is given in Table 3.4. In this Table, cost-benefit ratios are provided for a combination of HATs and social settings. This particular cost-benefit analysis reveals that acquisition/relocation is most attractive in areas with the lowest intensity of development. In areas with the highest intensity of development, structural approaches with high design levels and long design lives are most attractive. An interesting result of this particular analysis is that in areas with moderate levels of development, structural approaches with moderate design levels and short design lives are far and away the most attractive option.

TABLE 3.4. Example of Formal Cost-Benefit Analysis (from Carter, 1988).

Shoreline type[a]	Strategy option	Durability (years)	Effectiveness (%)	Benefit[b] – cost[c] ratio
Underdeveloped	Structural[d] I	10	15	0·105
	II	15	20	0·150
	III	25	50	0·182
	IV	40	95	0·187
	Acquisition/ relocation	–	–	0·573
Partly developed	Structural[d] I	15	50	2·210
	II	40	95	0·748
	III	40	95	0·397
	Acquisition/ relocation	–	–	0·187
Developed	Structural[d] I	40	95	1·058
	II	40	95	0·528
	Acquisition/ relocation	–	–	0·372

[a] Shoreline reach = 100 feet (31 m).
[b] Benefits include those accruing to both private owners and to the public.
[c] Costs discounted at 8% per annum include legal and technical assistance, construction and maintenance, land acquisition, and removal or rebuilding.
[d] Structural options include a variety of control measures – groynes, revetments, beach fill, etc.

Because it is only upon a consideration of its full set of positive and negative consequences that the attractiveness of any given HAT is truly revealed, cost-benefit analysis is a conceptually appealing HAT evaluation methodology. In many instances simply structuring an evaluation of HATs in the cost-benefit context and conducting an informal analysis is sufficient to reveal an attractive HAT. Only rarely is an elaborate formal analysis likely to be necessary. It is essential to keep in mind however, that the value judgments and tradeoffs encompassed within cost-benefit analysis, which may at first glance appear fairly straight forward, are upon close inspection not at all clear-cut. Placing values on resources at risk (e.g. land, structures, infrastructure) may not be too difficult. However, placing values on other coastal resources (e.g. recreational use, scenic attraction, endangered species habitat) possibly impacted by hazard alleviation may be extremely difficult, if not impossible. For one reason, such resources by their very nature are invaluable. Also, comparative values are to a great extent a matter of perspective. For example, in considering tradeoffs between upland property protection and recreational use of the beach, ocean-front property owners are likely to have a different perspective than that of the beach-using public. In this regard, Oregon law suggests that the balance be weighted towards the preservation of public interests and natural resources over private interests.

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4 H.A.T. OPTION IDENTIFICATION & EVALUATION

This section identifies a wide range of HATs and evaluates their potential applicability to shoreline settings along the Oregon coast (Table 4.1). HATs are grouped into four basic categories: Hazard Avoidance Options, Options for Wave Attack: Soft Stabilization, Options for Wave Attack: Hard Stabilization, and Options for Mass Wasting. The function, design, impacts, and applicability of individual HATs within these categories is considered below. At the end of this section, education and other indirect approaches are also briefly considered.

Although HATs are treated separately in the preceding discussion, it is important to note that they are often applied combination. Beach nourishment, for example is commonly employed in conjunction with hard stabilization. Similarly, vegetation management, slope regrading, and drainage controls are commonly used together. Another of the more common of such combinations or, hybrids, is the use of vegetation management in conjunction with hard stabilization/reinforcing structures. A variety of other possible combinations of avoidance options, wave attack options, mass wasting options, and indirect approaches are imaginable.

Besides hybrids, another type of integrated approach involves phasing. The term phasing can be applied to a planned transition to 'softer' approaches to hazard alleviation. Typically however, phasing refers to the planned transition to progressively 'harder' approaches to hazard alleviation. Preference is given first to the application of 'softer' approaches. Only after it has been demonstrated, through application, that specific HATs are not effective in meeting hazard alleviation needs are other, lower priority, hard HATs allowed. In reality, a form of phasing often occurs unintentionally as part of ongoing efforts to meet hazard alleviation needs. Segments of shoreline are subjected to the application of various HATs, in part as preferred techniques change over time, and in part as new HATs are sought to remedy artificially accelerated problems that result from application or misapplication of the originally applied HATs. Along Miami Beach for example, extensive shoreline development in the 1920's followed by a hurricane in 1926 led individual property owners to employ hard stabilization. The result was that by the early 1960's the Miami Beach shoreline was a jumble of different types of structures and little natural sandy beach-backed shoreline remained. Since that time, beach nourishment has been employed to maintain a sandy beach for recreational as well as hazard alleviation purposes. The Miami Beach example is not dissimilar to that afforded by the shoreline segment that makes up the Lincoln City Cell.

TABLE 4.1. LIST OF HAZARD ALLEVIATION TECHNIQUES (HATs)

HAZARD AVOIDANCE OPTIONS
- Siting, Design, and Construction Standards
- Construction Setbacks
- Relocation Incentives and Land Acquisition Programs

OPTIONS FOR WAVE ATTACK: SOFT STABILIZATION
- Foredune Enhancement
- Beach Nourishment
- Boulder Berm/Beach

OPTIONS FOR WAVE ATTACK: HARD STABILIZATION
- Groins
- Breakwaters
- Revetments and Seawalls

OPTIONS FOR MASS WASTING
- Vegetation Management
- Drainage Controls
- Slope Regrading
- Reinforcing Structures
- Surface Fixing

INDIRECT APPROACHES
- Public Education Programs
- Natural Resource Protection Laws
- Zoning Controls and Infrastructure Planning

The costs of employing such integrated approaches to hazard alleviation vary with the techniques employed. In many instances the existence of multiple hazards may require the application of multiple HATs. However, integrated approaches are effective even when not dictated by the physical setting. Integrated approaches assure that hazard alleviation is not dependent on the success of a single approach. Also integrated approaches provide a means of minimizing adverse impacts. Finally, planned sequential selection of HATs provides a means whereby advances in technical knowledge, both about the nature and cause of shoreline problems as well as of the effectiveness and impacts of HAT options, can be incorporated into HAT selection.

Integrated approaches to hazard alleviation typically require area-wide hazard management. Such an integrated, areawide approaches allow comprehensive hazard management strategies to be developed which are unique to their physical and social setting. For example, discrete shoreline segments could be identified using littoral cells boundaries. Within a given shoreline segment, factors affecting shoreline stability as well social and environmental characteristics could be inventoried. Based on this inventory, natural resources protection laws could be applied to significant resources areas along the given segment of shoreline. Inventory information would also be used to establish management units, accompanying management objectives, and in turn management strategies along the given segment of shoreline (e.g. design levels and lives, value weighting). Priority would be given to land use and nonstructural solutions to hazard alleviation. In this regard, existing zoning and infrastructure planning in identified hazard areas would be reviewed. Construction setbacks would be applied to undeveloped lots and to developed lots in the form of an imminent collapse criteria which could be used to determine eligibility for relocation incentives and/or land acquisition programs, as well as other methods of hazard alleviation. Depending on the physical setting, different combinations of non-structural HATs would then be applied. For example, along dune-backed shorelines hazard alleviation might initially focus on foredune enhancement in combination with soft structures (e.g. sand bag walls). Along bluff-backed shorelines hazard alleviation might initially focus on foredune enhancement and/or boulder berms at the toe of the bluff in combination with vegetation management, drainage controls, and slope regrading along the upper portions of the bluff. Consideration would then be given to structural stabilization in areas where high design levels and long design lives are warranted. Critical facilities could be considered in this regard. Consideration might also be given to structural stabilization in areas where it has been shown that non-structural solutions have failed to provide adequate hazard alleviation. With respect to structural stabilization, structures could continue to be built on a lot by lot basis, but according to a structural design consistent with that used elsewhere along the given segment of shoreline. In this regard, attention might even be given to compensatory mitigation to make up for anticipated losses to the sediment budget, the subaerial beach, and recreational, scenic, or other such use values. Finally, educational programs would also be carried out in conjunction with such an integrated areawide approach to hazard management.

4.1 HAZARD AVOIDANCE OPTIONS

Broadly, hazard avoidance refers to techniques which reduce potential risk by influencing the location, elevation, and design of existing as well as new structures and infrastructure. Hazard avoidance techniques are passive in that they are not intended to prevent or retard the processes of wave attack or mass wasting, rather these processes continue to occur. Specific HATs included within this category are: siting, design and construction standards; construction setbacks; and relocation

TABLE 4.2 AVOIDANCE OPTIONS and APPLICABILITY MATRIX

SITING, DESIGN, and CONSTRUCTION STANDARDS (S/D) generally take the form of standard engineering and construction practices intended to increase structure survivability, applied to all new and/or remodeled development, implemented through state and/or local building codes, and certified by registered engineers or architects.

The NFIP V-zone construction requirement, for the lower horizontal structural member of new structures to be elevated above the 100-year "base-flood" elevation, is a specific example of such measures. Other examples include standards governing the removal of existing vegetation, site excavation, drainage controls, as well as foundation, frame, and roof design details and construction materials.

COSTS/BENEFITS
- Low Costs
- Low Technical Uncertainty.
- Moderate Design Level and Life
- Minimal Adverse Impact on Adjacent Shoreline
- Positive Impact on Recreation, Scenic, Resource, and Conservation Use Values.

CONSTRUCTION SETBACKS (CS) include a variety of requirements to locate new development some minimum horizontal distance landward of an identified hazard.

Setback distance is projected landward from an identified reference feature. Reference features may be 'fixed' or 'floating'. Setback distance is commonly determined through a formula which multiplies the projected annual average recession rate by the anticipated years of protection. Annual average recession rate values may be site-specific, but are typically grouped values. Anticipated years of protection commonly varies with the type and level of development.

COSTS/BENEFITS
- Low Costs
- Moderate Technical Uncertainty.
- Moderate Design Level and Life
- Minimal Adverse Impact on Adjacent Shoreline
- Positive Impact on Recreation, Scenic, Resource, and Conservation Use Values.

RELOCATION INCENTIVES and LAND ACQUISITION PROGRAMS (R/A). Relocation involves moving existing development sufficiently landward from the hazard while staying on the same site. In other instances, development may need to be moved off the site, or perhaps demolished, and be reestablished elsewhere. Because relocation efforts are generally subsidized and in some instances the most viable option may be to buy the entire parcel, land acquisition programs are a closely related HAT.

COSTS/BENEFITS
- High Costs
- Low Technical Uncertainty.
- High Design Level and Life
- Positive Impact on Recreation, Scenic, Resource, and Conservation Use Values.

H.A.T. \ SETTING	DUNE-BACKED SHORELINE				BLUFF-BACKED SHORELINE			
	Rural		Urban		Rural		Urban	
AVOIDANCE	New	Existing	New	Existing	New	Existing	New	Existing
S/D	High	Moderate	High	Moderate	High	Moderate	High	Moderate
CS	High	Moderate	Moderate	Moderate	High	Moderate	Moderate	Moderate
R/A	Moderate	High	Moderate	Moderate	Moderate	High	Moderate	Moderate

APPLICABILITY
- ● High
- ◍ Moderate
- ○ Low

incentives and land acquisition programs (Table 4.2). Hazard avoidance techniques are potentially applicable along both dune-backed and bluff-backed shorelines. Hazard avoidance techniques are potentially applicable to new and existing development along shorelines with rural and urban levels of use.

4.1.1 SITING, DESIGN, and CONSTRUCTION STANDARDS

This option encompasses standards which govern aspects of development in an identified hazard area ranging from site preparation to building design and construction. With respect to site preparation, examples include standards governing the removal of existing vegetation, excavation, and drainage controls. With respect to building design and construction, examples include standards governing foundation, frame, and roof design details as well as construction materials. Although generally applied to new or remodeled structures, existing structures may be retrofitted.

A specific and well known example of standards of this type are those encompassed within the National Flood Insurance Program (NFIP). Established in 1968 by the National Flood Insurance Act, the NFIP requires the adoption of local land use ordinances that meet minimum flood plain management standards as a means of reducing potential flood damage and as a precondition to the availability of federal flood insurance.

Along the coast, the 'V-zone' construction requirements are a central element of the NFIP. The Federal Emergency Management Agency (FEMA) forecasts a 100 year ocean "base-flood" elevation and, based on this elevation, identifies a zone of velocity flooding. A FEMA V-zone elevation is essentially a forecasted maximum wave crest/runup elevation superimposed upon a forecasted maximum still water level. Still water level maxima are derived from analysis of observed and/or predicted tide and surge levels. Wave crest/runup maxima are also derived from analysis of observed and/or predicted water surface wave data. Depending upon the volume of sand in the the foredune area, the effect of dune removal may or may not be factored into such analyses. A V-zone elevation is thus a prediction of the area that is likely to be submerged and, as a result, subject in varying degrees to the forces of breaking and runup of a **single wave** over a given slope.

V-zone construction standards require that the the lower horizontal structural members of new structures be elevated above the 100-year "base-flood" elevation. No horizontal setback is required inland of mean high tide. New construction or substantial improvements in V-zones are not prohibited. Thus, the V-zone construction standards currently emphasize vertical over horizontal displacement.

Other standards of this type are also commonly employed. To protect against damage from floating or wind-born debris, for example, structures are designed to allow for the relatively undisturbed passage of water and wind. In addition, joists and beams are anchored, braced or strengthened; windows and doors shuttered from direct winds. Many of these types of measures are accepted as standard engineering and construction practices, are implemented through state and/or local building codes and local zoning ordinances, and are certified by registered engineers or architects. Other examples of standards of this type are those commonly related to aspects of site preparation (e.g. vegetation removal, excavation, drainage). These types of measures are discussed later in the context of options for mass wasting as they tend to be particularly relevant in that regard.

COSTS/BENEFITS

The application of siting, design, and construction standards can add on the order of 5-10% to the cost of a home. When averaged over the lifetime of the structure, these costs are low. When compared to the increase in structure survivability that is achieved, siting, design, and construction standards are a cost-effective HAT. Because many of these measures are standard practices, technical uncertainty is low.

Siting, design, and construction standards do not prohibit new construction or substantial improvements in an identified hazard area. For example, development may occur in V-zones, despite the high level of hazard potentially present. Also, code requirements are often minimums. Design and construction needs for specific structures may exceed code minimums. Further, because there are several potential sources of structural risk associated with a hazard, it may not only be difficult but expensive to provide effective protection against all of them. Thus, it is generally only a measure of hazard alleviation that is achieved through the implementation of siting, design, and construction standards.

Because the application of siting, design, and construction standards is specific to a site, they generally have no adverse impact on adjacent properties. Also, because the application of these standards generally does not impact the natural state of the shoreline, they can be regarded as beneficial from the standpoint of preservation of recreation, scenic, resource, and conservation use values.

APPLICABILITY TO OREGON

Overall applicability of siting, design, and construction standards is high. Potential applicability of particular standards is specific to physical setting. For example, V-zone requirements are primarily applicable along dune-backed shorelines. Similarly, measures pertaining to the vegetation removal tend to be particularly applicable along bluff-backed shorelines. Siting, design, and construction standards are applicable along dune-backed and bluff-backed shorelines. They are applicable along shorelines with high and low levels of development. Clearly, their greatest potential applicability is undeveloped areas. However, their potential applicability to areas with existing development should not be overlooked.

4.1.2 CONSTRUCTION SETBACKS

This option encompasses requirements to locate new development (i.e. structures and infrastructure) some minimum horizontal distance landward of an identified hazard. Although construction setbacks are typically applied to new development, they may also be applied to remodeling or repair of existing development. They are applicable along both dune-backed and bluff-backed shorelines.

Construction setbacks are employed worldwide as a HAT. On a national basis, the NFIP has attempted to embrace construction setbacks as a HAT. As early as 1976 the National Flood Insurance Act was amended to include a definition of "areas of special flood-related erosion hazards" as a separate and distinct hazard area category to be designated as "Zone E" on flood hazard maps. Although the recommended E-zone designations summarized in Figure 4.1 are yet to be implemented, they serve as a good example of construction setback requirements.

Construction setbacks are currently in place along much of the Atlantic and Gulf coasts (Table 4.3). In Florida, for example, where the concept was first promoted in the late 1960's, single family dwellings are required to be setback a distance of 30 times the annual average recession rate from the seasonal high water line elevation contour. In North Carolina all new development is required to be located the farthest landward of these four points: 1) the erosion rate (equal to 30 or 60 times the annual average recession rate as measured from the vegetation line; 2) the minimum setback (60 or 120 feet from the vegetation line); 3) the landward toe of the frontal dune; or 4) the crest of the primary dune, which is taken as the the first dune with an elevation equal to the 100 year V-zone plus six feet elevation.

The state of Oregon currently does not require setbacks for new development along the ocean shore. However, construction setbacks are required by some local jurisdictions. Clatsop County employs a fixed setback that prohibits development seaward of an identified "active dune line". Lincoln County, the City of Newport, and the City of Lincoln City all employ a floating setback (i.e. setback distances vary with the rate of erosion and the bluff elevation). Lane County and Tillamook County also have coastal construction setback requirements. In the case of Tillamook County, however, the setback distance is determined on an equity rather than a hazard basis.

ZONE	DESCRIPTION	REQUIREMENTS
E-10	The are of "imminent collapse" located between the water line and the projected 10-year erosion line.	No new habitable structures are permitted within this area.
E-30	The area located between the projected 10-year and 30-year erosion lines.	Only readily moveable 'low intensity' structures (e.g. single and multiple family dwellings < 5,000 sq.ft.), are permitted, and only if they can not be located further shoreward.
E-60	The area located between the projected 30-year and 60-year erosion lines.	Any readily moveable structures are permitted. Fixed structures of 'low intensity' are permitted. Fixed structures of 'high intensity' (e.g. residential, commercial, or industrial buildings > 5,000 sq. ft.) are not permitted.

Any structure is permitted landward of the E-60 line.

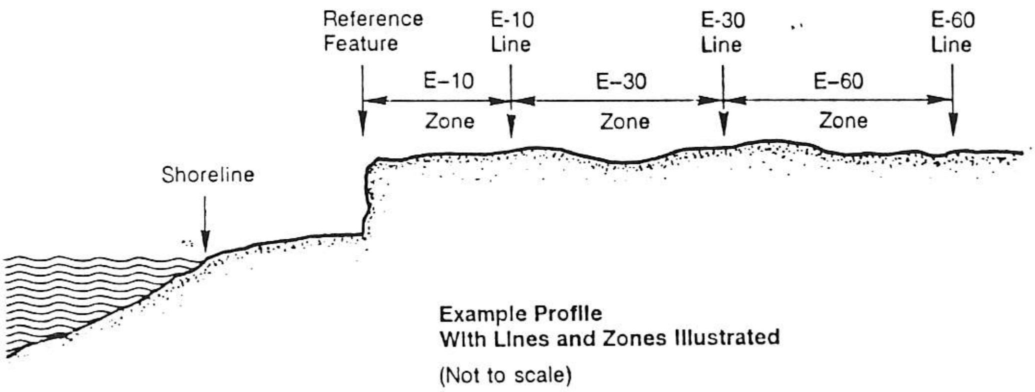

Figure 4.1. Recommended E-zone Designations (after NRC, 1990)

TABLE 4.3. Summary of State Coastal Construction Setback Programs (from NRC, 1990).

State/Territory	Recession Rates from Aerial Photos	Recession Rates from Charts	Recession Rates from Ground Surveys	Erosion Setbacks Established*	Reference Feature	Years of Setback	Local Admin-istration	One Foot per Year Standard	Fixed Setback	Floating Setback
Alabama	Y	Y	N	Y	MHW	NA	N	Y	N	
Alaska	Y	Y		N	NA	NA	NA	NA	NA	NA
American Samoa	N	N	N	N	NA	NA	NA	NA	NA	NA
California	Y	Y	Y	N	NA	NA	Y	NA	NA	NA
Connecticut	Y	Y		N	NA	NA	NA	NA	NA	NA
Delaware	Y	Y		Y4	TD	NA	Y	N	Y	N
Florida	Y	Y		Y5	NA	30	Y	N	Y	N
Georgia	Y	Y		N	NA	NA	NA	NA	NA	NA
Hawaii	N	N	N	Y	6	N	Y	N	Y	N
Indiana	Y	N	Y	N	NA	NA	NA	Y	NA	NA
Illinois	Y	Y	Y	N	NA	NA	NA		NA	NA
Louisiana	Y	Y	N	N	NA	NA	NA	NA	NA	NA
Maine	N	N	Y	N7	NA	NA	NA	NA	NA	NA
Maryland	Y	Y		N	NA	NA	NA	NA	NA	NA
Massachusetts	Y	Y	N	N	NA	NA	NA	NA	NA	NA
Michigan	Y	N	N	Y	BC2	30	Y	Y	N	Y
Minnesota	Y	N	N	N	NA	NA	NA	Y	NA	NA
Mississippi	N	N	N	N	NA	NA	NA	NA	NA	NA
New Hampshire	N	N	N	N	NA	NA	NA	NA	NA	NA
New Jersey	Y	Y	Y	Y	MHW	50				
New York	Y	Y	N	Y	BC	30-40	Y	Y	Y	N
North Carolina	Y	N		Y	DC	30-60	Y	N	N	Y
N. Mariana's	N	N	N	N	NA	NA	NA	NA	NA	NA
Ohio	Y	Y	N	N1	BC	30	NA	Y	Y	N
Oregon				N		NA	NA	NA	NA	NA
Pennsylvania	Y	N	Y	Y	BC	50+	Y	Y	N	Y
Puerto Rico	N	N	N	N	NA	NA	NA	NA		
Rhode Island	N	N	Y	Y	DC	30	N	N7	Y	N
South Carolina			Y	Y		40	BL		Y	N
Texas	Y	Y	Y	N	NA	NA	NA	NA	NA	NA
Virgin Islands	N	N	N	N	NA	NA	NA	NA	NA	NA
Virginia	Y	Y		N	MHW	NA	Y			
Washington				N	NA	NA	NA	NA	NA	NA
Wisconsin	Y	Y	N	N3	NA	NA	NA		N	Y

NOTE: 1 = setbacks may be established within 2 years; 2 = bluff crest or edge of active erosion; 3 = some counties have setbacks; 4 = has 100 foot setback regulation over new subdivisions and parcels where sufficient room exists landward of setback; 5 = not all counties have coastal construction control lines established; 6 = storm debris line or vegetation line; 7 = 2 feet per year standard. Y, yes; N, no; NA, not applicable; BC, bluff crest; MHW, mean high water; TD, toe of dune; DC, dune crest, toe of frontal dune or vegetation line; BL, base line. A blank means no information was available.

*Most states have setbacks from water line but not based on an erosion hazard.

DESIGN ELEMENTS

Probably the most common method of determining a construction setback involves multiplying the annual average recession rate by the anticipated years of protection to yield a projected distance of retreat landward from an identified reference feature. Broadly, a reference feature is the seaward-most point from which a setback distance is projected landward. Oregon's 'Beach Zone Line' is an example of a fixed reference feature. Examples of floating reference features include the line of vegetation, the primary dune toe or crest, or the bluff toe or crest. The geomorphology of the shoreline area may determine which feature is appropriate to use as a reference feature (e.g. the dune crest along dune-backed shorelines or bluff crest along bluff-backed shorelines). Like construction setback requirements, the choice of reference features vary from state to state (Table 4.3).

The annual average recession rate (R) is typically determined through an analysis of shoreline or bluff line positions on consecutive sets of aerial photographs. Some states such as Florida determine and apply annual average recession rates on a site-specific basis. Many other states, however, employ various types of grouping procedures. For example, in some states annual average recession rates are averaged across a length of shoreline, and the entire length of shoreline is assigned the average value. In other states, observed recession rates along a given length of shoreline that are similar in magnitude are grouped according to their relationship to the average rate of recession along the length of shoreline (e.g. assigned annual average recession rate values corresponding to standard deviations about the mean). In yet others, the highest annual average recession rate observed along a length of shoreline is assigned to the entire length of shoreline.

Anticipated years of protection (T) is generally represented as a time span associated with the useful life of a structure (e.g. home, motel). To be fully effective a setback should afford protection for the entire useful life of the structure. In this regard, several states and the NFIP have recognized that it is appropriate to assign different useful lifetimes to different classes of structures. In North Carolina for example, a 30-year setback applies to smaller structures (e.g. < 5,000 square feet) and a 60-year setback to larger ones (e.g. > 5,000 square feet). Although 30 and 60 year time spans are those most commonly applied, it has been argued by some that these time frames are too short. Since the useful lifetime of a wood-frame house is 70 or more years, it has been suggested that 50 and 100 year time spans are more realistic estimates of the useful life of small and large structures respectively.

Arguably, shoreline change attributable to relative sea level rise (r) is accounted for in the annual average recession rate term. However in some instances it may be appropriate to treat relative sea level rise as a separate term. Predicted rates of relative sea level rise vary among the different sea level rise scenarios. Further, it is well recognized that the prediction of shoreline change using Bruun rule type models (a standard methodology) is of questionable accuracy. This is true even along dune-backed shorelines, where the Bruun rule is intended to apply. Fortunately, these concerns may not need to be addressed in Oregon because relative sea level rise along the Oregon coast is likely to be negligible over the next few decades.

Arguably, the annual average recession rate term also accounts for short term events (S), such as wave-induced dune erosion or surficial sloughing of bluff tops, as it represents the cumulative effect of these individual events. However, there are clearly instances where short term events need to be taken into account in determining a construction setback. This is the case along dune-backed shorelines of the Oregon coast, where over the long term shoreline change is more an oscillation about a mean position than it is a gradual shoreward migration of that position. Thus, in terms of construction setbacks along dune-backed shorelines of the Oregon coast, S, which represents the projected maximum range in short term fluctuations in shoreline position attributable to individual or clusters of storm events, is likely to be the primary consideration. Along dune-backed shorelines, S might also be taken to represent projected shoreline change due to inlet migration. Short term events may also need to be taken into account in determining construction setbacks along bluff-backed shorelines. In this setting, S might be taken to represent the areal extent of individual active slides (e.g. the distance from the toe of the bluff landward to the location of the head scarp).

The angle of repose (H) is another term that is sometimes used in the determination of construction setbacks. An angle of 33-34 degrees (H:V = 1.5:1) is the theoretical angle of repose for unconsolidated sediments. Measured from the beach-dune or beach-bluff junction, angles in the range of 22-27 degrees (H:V > 2:1) are common along dune-backed shorelines and angles in the range of 27-45 degrees (H:V = 1:1) are common along bluff-backed shorelines. Even higher angles are typically associated with hard rock bluffs.

In some instances safety factors (F) are also incorporated into construction setbacks. In Michigan, for example, an additional 15 feet of setback is added to areas where recession rates exceed a set value. New York identifies the bluff face and crest as a special protective feature. The setback is measured from the landward side of this area. This has the effect of increasing the setback by 25 feet. Such considerations may be particularly warranted in Oregon, where the first set of accurate aerial photographs were flown as late as 1967. Thus, for the most part, accurate aerial photographs cover only slightly more than a 25 year period.

Finally, a number of refinements to the basic setback concept have developed over time. Rather than establish setback requirements along all erodible shorelines, some states have established a threshold recession rate that must be exceeded before the application of a construction setback is required (e.g. R > 1 foot per year in Michigan). In Michigan, if a lot is found to lack sufficient depth to meet the setback and the lot was established before the effective date of the setback provisions, then the property is designated as a substandard lot and a special exception to the setback requirement may be granted. This permits a structure to be built on the substandard lot provided it can be moved before suffering damage. Florida and North Carolina have similar sorts of of provisions allowing minor exceptions to setback requirements.

COSTS/BENEFITS

Development and implementation costs of coastal construction setback requirements are low, particularly when compared to other HATs. When technically sound and where socially practicable, setbacks are an extremely effective means of hazard avoidance. Coastal construction setbacks are not without limitations, however.

There is an inherent element of technical uncertainty involved in the application of coastal construction setbacks. For example, it is well recognized that shoreline change rates from aerial photographs can be of questionable accuracy. Sources of error in annual average recession rates are attributable to photo quality, distortion related to tilt and pitch, measurement and interpretation errors, and the time span of photo coverage, among others. It is essential that limitations of this type be clearly recognized. Also, because shoreline stability and our understanding of factors affecting shoreline stability change over time, annual average recession rates must be modified periodically. Florida, Michigan, and Texas, for example, update annual average recession rate values approximately every 10 years.

Even when technically sound, social factors may influence the effectiveness of coastal construction setbacks. It was noted above that 50 and 100 year time spans are generally regarded as more realistic estimates of the useful life of small and large structure respectively. While such time spans may more accurately reflect the useful life of a structure, states have found that some oceanfront lots lack the depth that would allow such setbacks to be applied. Even using 30 and 60 year time spans states have had to provide for exceptions to the setback requirements. This suggests that in some instances the potential to locate structures far enough enough away from a hazard to truly avoid the hazard for their entire useful life may be low. It also suggests in these instances that, even with setbacks, development will eventually be threatened and may even be lost. Such anticipated eventual losses are an issue that needs to be considered in the application of coastal construction setbacks. Another issue that needs to be considered if setbacks are to be applied is the tendency for the required minimum distance to become the preferred setback distance, even when there is sufficient lot depth for a larger setback.

Irrespective of the concerns identified above, coastal construction setbacks are generally regarded as an attractive HAT. Beside being effective from a hazard alleviation standpoint, they have generally positive consequences from both a social and an environmental point of view. Allowing erosion to continue contributes sediment to the shoreline system and thereby minimizes potential erosion losses in adjacent areas. Maintaining the shoreline in a natural state, in general, preserves recreation, scenic, resource, and conservation use values.

APPLICABILITY TO OREGON

Coastal construction setbacks have high potential for applicability along the Oregon coast. Their greatest potential as a HAT is along dune-backed shorelines with low levels of existing development. This is because it is flooding and erosion associated with episodic storm events that presents the greatest hazard potential along dune-backed shorelines. Because the shoreline tends to eventually recover from the effects of storm events, there is generally no long-term trend of shoreline retreat in this setting. Thus, along dune-backed shorelines, setbacks do have the potential to result in the location of structures far enough away from a hazard to truly avoid the hazard for their entire useful life. Anticipated eventual loss is unlikely to be a concern.

The potential applicability of coastal construction setbacks is also high along bluff-backed shorelines with low levels of existing development. However, owing to the existence of long-term trends of shoreline retreat along many bluff-backed shorelines, the potential for setbacks to result in the location of structures far enough away to truly avoid the hazard for their entire useful life is not as great. Anticipated eventual loss may be a concern in this shoreline setting. Still, in most cases bluff recession rates are so low that, even in this shoreline setting, setbacks are likely to result in an extended period of hazard avoidance.

If coastal construction setbacks are to be applied in the two settings identified above, there are a number of outstanding issues that need to be addressed. What is the appropriate methodology for determining setback distances? What are appropriate structure classes, if any? What are appropriate values for anticipated structure lives (e.g. 30 and 60-year versus 50 and 100-year)? What uses and activities would be prohibited or allowed within different setback areas? In what situations might exceptions be justified?

With respect to the question of methodology, possible setback formulas for dune-backed shorelines and for bluff-backed shorelines are outlined below and illustrated schematically in Figure 4.3. Following from the consideration of design elements, possible terms in a construction setback formula are: r, relative sea level rise; R, annual average recession rate; T, anticipated years of protection; S, magnitude of short term event; H, angle of repose; and F, a safety factor.

Along dune-backed shorelines, where processes of wave attack are the primary control on shoreline stability, S, H, and F are the relevant terms (Figure 4.2 a). As noted above, in this setting S is the projected maximum range in short term fluctuations in shoreline position attributable to individual or clusters of storm events, or the projected *storm event response.* The value of this term will vary with the nature of the design event (i.e. the magnitude of the storm, the duration of the storm, the number of storms during the year, the direction from which the waves approach the shore) and the beach type (i.e the beach slope and/or grain size). The nature of the design event will in turn vary with the class of structure. For example, smaller structures might be required to adhere to a construction setback based upon a projected 100-year storm event response, larger structures to a projected 500-year storm event response. Note that T, the anticipated years of protection, is implicitly accounted for.

Actual numerical values of S in feet from the identified reference feature, with the accreted foredune

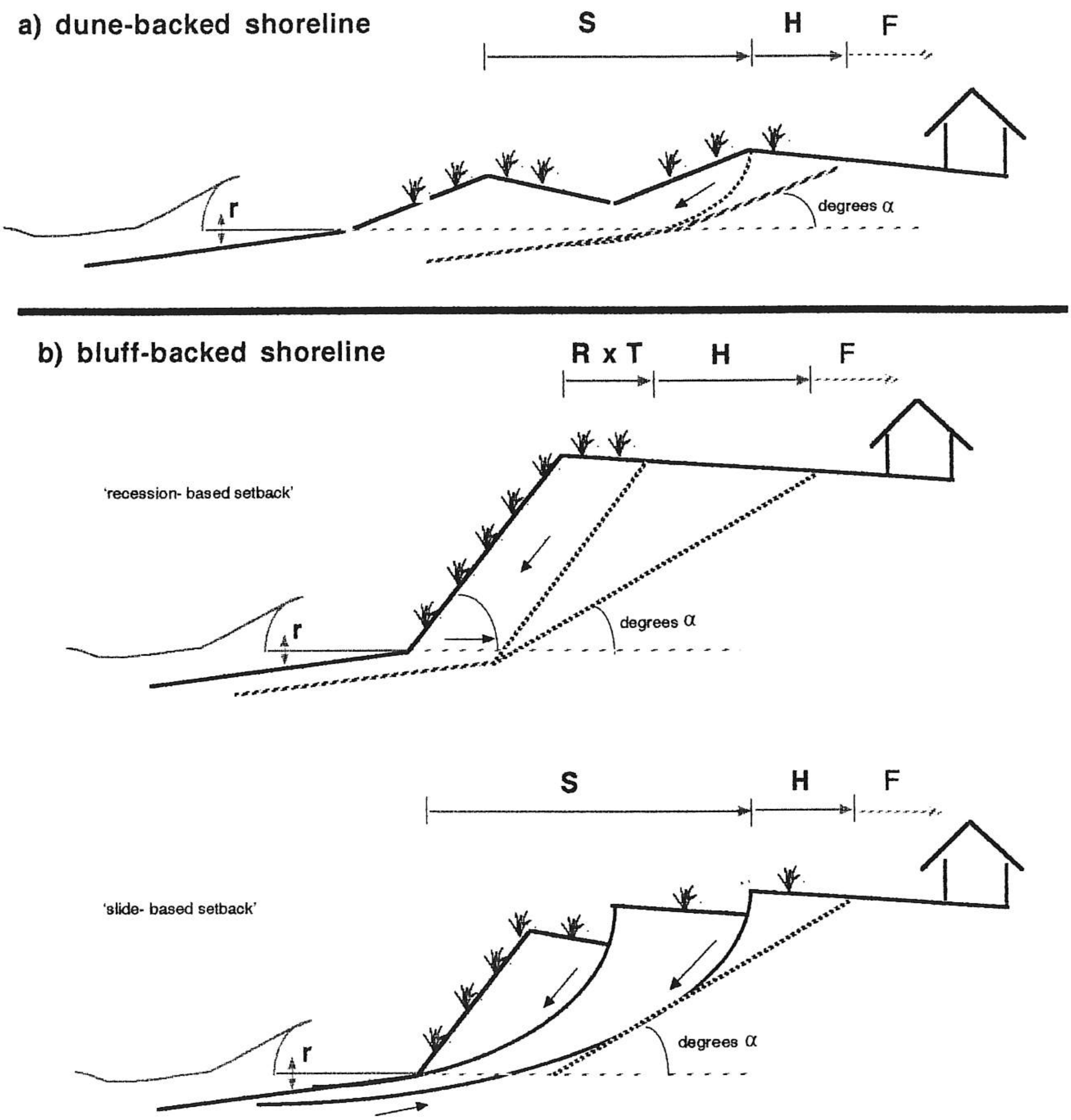

Figure 4.2. Schematic Illustration of Possible Construction Setbacks for a) Dune-backed Shorelines and b) Bluff-backed Shorelines.

R= average annual recession rate, T= anticipated years of protection, H= angle of repose, S=short term event, F= safety factor, and r = relative sea level rise (see text for details).

crest or scarp being an appropriate reference feature in this setting, could be determined empirically and/or through numerical modeling. In the former, analysis of aerial photographs and field reconnaissance mapping could be used to determine the landward extent of dune erosion that has occurred in response to storm events along various dune-backed shorelines. Although such analysis may prove difficult it is believed that a valid data set can be generated. Grouping procedures would be applied to the data set to determine projected distances of dune retreat for representative classes of storm events and beach types.

Numerical models of wave runup, cross-shore sediment transport, and resulting beach and dune erosion (e.g. SBEACH) afford an opportunity to simulate different design events and as a result better identify worst case scenarios. For example, a comparison might be made between the projected storm event response to a single 100-year storm event and the projected storm event response to a succession of two or three 50 year events. Numerical modeling would not eliminate the need to carry out empirical analysis. Comparing model predictions with observations provides a means to fine tune the generic models to local conditions and as a result increase the likelihood of achieving more accurate results.

Based on the assumption that the storm event would result in a scarped foredune morphology, H, where H is equal to 22 to 27 degrees from the beach-dune junction, could be used to determine a distance that would be added to S. This distance corresponds to the shoreward translation of an accreted foredune morphology. With regards to the safety factor, F, this term might be accounted for by taking an S value that is the mean plus one standard deviation from the mean rather than the mean S value.

Along bluff-backed shorelines, where processes of mass wasting and wave attack both control shoreline stability, R, T, S, H, and F are the relevant terms (Figure 4.2 b). Thus, in this setting coastal construction setbacks need to account for shoreline response to long-term trends as well as short term events. In this regard, R, the projected annual average recession rate could be determined from aerial photographs. The value of R that is applied to the construction setback should be a grouped value, where the grouping is based on bluff characteristics (composition, structure, geometry, etc.) and beach type. Once a projected annual average recession rate has been determined, then as with typical setback formulas, it would be multiplied by the anticipated years of protection, T, to determine a basic setback distance, where the anticipated years of protection varies with the class of structure and where the setback distance is measured from the crest of the bluff.

The angle of repose, H, where H varies with bluff composition, structure, geometry, etc., (generally in the range of 27 to 45 degrees from the beach-bluff junction) could be used to determine a distance that would be added to the basic setback distance. This distance corresponds to the shoreward translation of a stable bluff slope morphology. It is intended to account for the fact that the basic setback distance described above is a simple translation of the existing bluff profile shoreward, and therefore may not account for the existence of an over steepened bluff profile. With regards to the safety factor, F, this term might be accounted for by taking an R value that is the mean plus one standard deviation from the mean rather than the mean R value. Such a recession-based setback may be applicable along major portions of the Lincoln City littoral cell.

Finally, along some segments of bluff-backed shoreline, active sliding/slumping may be the dominant factor affecting shoreline stability. In such instances construction setbacks need to account for the landward extent of active sliding. This distance would be represented by the S term, which here could represent the distance from the toe of the bluff landward to the location of the head scarp for example. Again, the angle of repose, H, could be used to determine a distance that would be added to the basic setback distance. Similarly a safety factor, F, may also be warranted. Such a slide-based setback may be applicable to the Beverly Beach littoral cell.

The slide-based setback distance may well be greater than the recession-based distance. Whichever is the greater of the two setback distances (recession or slide-based) is the one that should be applied.

4.1.3 RELOCATION INCENTIVES and LAND ACQUISITION PROGRAMS

This option encompasses incentives to relocate existing development away from an identified hazard. In some instances development is relocated on-site. In other instances it is necessary to move development off the site, or perhaps demolish it, and reestablish it elsewhere at a new safer location. Generally, some sort of subsidy is required to encourage relocation. In some instances, rather than partially subsidizing relocation, the most viable option may be to buy the entire parcel at market value. For this reason, land acquisition programs are included with relocation incentives as a HAT. Land acquisition programs do however, have broader applicability than relocation incentives in that they may apply to undeveloped areas as well as to areas with existing development. These areas can be acquired and preserved for recreation, open space, or other appropriate public purposes. Such programs generally include specific criteria establishing priorities for acquisition.

Most states currently give little attention to the relocation of existing development and land acquisition. States have generally relied on the federal government to take the lead in this area. The state of North Carolina does require plans for redevelopment and relocation of damaged and threatened structures. Land acquisition is also an element of North Carolina's hazard management program. Under the state's beach access program, explicit statutory priority is given to the acquisition of those lands that are unsuitable for permanent structures but that could be useful for beach access, and to natural areas containing undeveloped beaches. The state has also adopted an income tax credit to encourage the donation of beach access and natural areas. A few other states provide low-interest loans or small grants to encourage relocation of houses away from identified hazard areas.

At a national level the NFIP, specifically the Upton-Jones Amendment, encourages but does not require the relocation of threatened development. Adopted in 1987, the Upton-Jones amendment takes an anticipatory approach to hazard management by allowing for the payment of insurance claims prior to actual damage for the purpose of relocating or demolishing a structure as a means of reducing public and private costs of development in hazardous areas.

To be eligible for claim payments under the Upton-Jones Amendment, a structure must be subject to *imminent collapse* as a result of undermining by waves or currents of water exceeding anticipated cyclical levels. Specifically, the structure must be located within a zone defined as an area seaward of a line that is 10 feet plus five times the local annual average recession rate as measured from a prominent physical reference feature (i.e. ~ E-5 plus 10 foot setback). For structures that fall outside this zone of imminent collapse, a claim may be based on technical or scientific data demonstrating the presence of a unique or highly unstable condition. It has been suggested that if the intent of the Upton-Jones amendment is to encourage anticipatory action to remove structures threatened by flooding and erosion, than the interim definition of imminent collapse is too narrow to accomplish this. For example, in an area with a 2 foot per year annual average recession rate the structure would have to be within 20 feet of the reference feature to be eligible for Upton-Jones benefits. As a result, it has been suggested that the definition of the zone of imminent collapse be expanded, at least to a distance of 10 times the long term annual average recession rate (i.e. ~ E-10 setback).

Once a determination has been made that a structure is subject to imminent collapse, then owners of the structure are eligible to receive full claim payments for the purpose of moving the threatened structure to a safer location. These payments may include not only payments equal in value to that of a comparable structure, the price paid for the structure, or the value of the structure identified in the flood insurance contract, but also payments of up to 40 percent of the costs incurred in removing the structure from the site, including demolition, site cleanup, debris removal, moving to the new site, and new site preparation. Owners of structures that are not relocated or demolished within a reasonable amount of time following a determination of imminent collapse are eligible to recover only 40 percent of their covered losses should the structure be damaged subsequently by a flood.

Relocation provisions of the Upton Jones Upton-Jones amendment are currently not in place in Oregon, nor are any other type of relocation incentives. Small scale land acquisition programs do exist at the state level.

COSTS/BENEFITS

The choice of on site or off site relocation is a fundamental determinant of economic feasibility. On site relocation is the most cost-effective, and as a result most attractive of the two alternatives. The cost of on-site relocation of a single-family residential dwelling is typically on the order of $25,000. This is relatively expensive in comparison to the costs of some HATs, such as foredune enhancement. However, it is relatively inexpensive in comparison to the costs of hard stabilization, which over the long run may cost several to as much as 10 times this amount. In terms of costs, off site relocation is generally a less attractive alternative. However, if sufficient space is not available on the same lot, it is the only alternative. The need to acquire and prepare an alternative site increases the cost of relocation substantially, particularly if the alternative site possess the view and/or access of the vacated site. For both on-site and off-site relocation, costs can be reduced by incorporating ease of mobility into structure design and construction.

The technical feasibility of relocation, particularly with respect to small or medium-sized structures, is well established. However, social considerations can be a problem. With respect to on-site relocation, the loss of view and/or access resulting from relocation may be unacceptable to oceanfront property owners. Similarly, oceanfront property owners are unlikely to consider off-site relocation as an option unless the alternative site possess the view and/or access of the vacated site.

Still, it should be noted that a structure threatened by imminent collapse is essentially valueless and poses substantial potential costs to the community in terms of lost tax revenue, deterioration related to abandonment, clearance of wreckage, and flood insurance loss payments. Thus, even when costs are high, relocation is often a desirable public goal when the only other option is abandonment or hard stabilization. Further, like other HATs in the avoidance category, relocation is generally regarded as having positive consequences in terms of recreation, scenic, resource, and conservation use values.

APPLICABILITY TO OREGON

Overall, relocation incentives and land acquisition programs are believed to have moderate potential applicability. This is confirmed by recent observations made in the Lincoln City Littoral Cell, the most highly-developed littoral cell along the Oregon coast, which suggest that as much as 50% of the oceanfront lots have a sufficient depth to accommodate on-site relocation. Along highly developed shorelines, the ability of local jurisdictions or the state to subsidize relocation on such a scale represents a major constraint. In such settings, low-interest loans or income tax credits might be considered as an alternative to direct payments as a means of encouraging relocation. Along less developed shorelines, where subsidization of relocation would be on a smaller scale, on-site relocation is likely to have its greatest potential applicability. Still, local jurisdictions and the state will likely need to rely on federal funding sources such as Section 1362 of the National Flood

Insurance Act, the Land and Water Conservation Fund, and Section 306A of the Federal Coastal Zone Management Act to augment the limited state and local resources that can be devoted to these types of programs. From a physical standpoint, on-site relocation is likely to be more effective along dune-backed than along bluff-backed shorelines for the same reasons identified in the discussion of construction setbacks.

For the most part, similar arguments apply with respect to the potential applicability of off-site relocation and correspondingly land acquisition. Costs to subsidize such programs are likely to be even higher than those associated with on-site relocation. Still, a program focusing on acquisition of undeveloped lots suitable for use as beach access and/or natural areas on a limited basis has high potential applicability.

If relocation incentives and land acquisition programs are to be applied as a HAT in Oregon, some type of eligibility criterion, such as the NFIP imminent collapse criteria, will need to be established. It is in this regard that the coastal construction setback methodologies described in the previous section are relevant even in areas of existing development, as they provide the basis for such an eligibility criterion. Such an eligibility criterion has an even broader range of applicability than that pertaining to relocation incentives and land acquisition programs. An imminent collapse criterion based on setbacks could be used to determine eligibility for structural shoreline stabilization as well. For example, in order for a site-specifc application for structural stabilization to be considered, it would first be necessary to make a determination that a structure is subject to imminent collapse. Perhaps a tiered need criterion could even be developed as a means of encouraging alternatives to structural stabilization. For example, structural stabilization would be eligible under a narrow-sized need window, soft stabilization under a moderate-sized need window, and relocation eligible under a wide-sized need window.

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4.2 OPTIONS FOR WAVE ATTACK: SOFT STABILIZATION

Soft stabilization refers to techniques which reduce potential risk by enhancing the inherent buffering capabilities of the natural shoreline system as a means of retarding the effects of wave attack. Although the shoreline is stabilized in a relative sense through the application of these techniques, it is still expected to experience displacements during storm events. Specific HATs included within this category are: foredune enhancement; beach nourishment; and boulder berms (Table 4.4). Soft stabilization techniques are potentially applicable along both dune-backed and bluff-backed shorelines with both high intensity and low intensity use.

4.2.1 FOREDUNE ENHANCEMENT

This option encompasses the application of techniques intended to encourage the accumulation of sediment in the foredune area as a means of maintaining a subaerial sediment volume sufficient to effectively dissipate the forces of wave runup. Foredune enhancement has been likened to a savings account, where a series of small but regular deposits build a sizable amount of security available for withdrawal on special occasions. Foredune enhancement is also intended to encourage the stabilization of wind-blown sand. As a result, it is an applicable technique when sand inundation has been identified as a potential hazard.

Ages-old foredune enhancement techniques, typically involving the planting of sand-stilling grasses, are used world-wide. The Dutch, for example, have practiced foredune enhancement for the purpose of increasing flood/erosion protection and decreasing sand inundation for at least six hundred years. Today, the Dutch practice state of the art foredune enhancement for a variety of purposes including water abstraction, agriculture and forestry, recreation, and nature conservation, as well as hazard alleviation. Foredune enhancement has also been carried out extensively in the United States. The East Coast, for example, is characterized by long stretches of artificial dunes.

In Oregon, planting of sand-stilling grasses commenced just after the turn of the century. These plantings were more for the purpose of preventing sand inundation than providing flood/erosion protection. In the 1930's work began on the Warrenton Dune Control Project. Under this project, the most extensive effort of its type along the west coast of the United States, twenty three miles of sand fences were installed and over 3000 acres of active sand were planted with sand-stilling grasses and other types of stabilizing vegetation. From that time up until 1960's planting, principally of European beach grass, was carried out all along the Oregon coast. Recent efforts in the area of foredune enhancement in Oregon have focused on the development of areawide foredune management

TABLE 4.4 OPTIONS for WAVE ATTACK - SOFT STABILIZATION and APPLICABILITY MATRIX

FOREDUNE ENHANCEMENT (FE). The application of foredune construction and stabilization techniques as a means of holding and/or capturing sediment in the foredune area and thereby maintaining a subaerial sediment volume sufficient to effectively dissipate wave energy (runup).

Ages-old foredune enhancement techniques typically involve the selective planting of sand-stilling grasses. The use of earth-moving equipment to reconfigure the foredune is also a common practice. Mechanical aids such as sand fences and brush matting are also commonly employed.

COSTS/BENEFITS
- Low Costs
- Moderate Technical Uncertainty.
- Low Design Level and Short Design Life
- Potential Adverse Impact on Adjacent Shoreline
- Generally Positive Impact on Recreation, Scenic, Resource, and Conservation Use Values.

BEACH NOURISHMENT (BN). Augmentation of the natural supply of sediment to a segment of shoreline as a means of maintaining a volume of sediment in the shoreline system sufficient to effectively dissipate the forces of wave breaking and runup.

A common method of beach nourishment involves dredging sand from offshore or harbor entrances and placing it in shallow subaqueous bar and beach areas. Typically beach nourishment involves an initial major placement of sediment (restoration) followed by subsequent minor placements of sediment (replenishment). Beach nourishment commonly involves sand, rarely gravel. Nourishment is commonly employed in conjunction with other HATs.

COSTS/BENEFITS
- Variable Costs
- High Technical Uncertainty.
- Low Design Level and Short Design Life
- Minimal Adverse Impact on Adjacent Shoreline
- Positive Impact on Recreation, Scenic, Resource, and Conservation Use Values.

BOULDER BERMS (BB). Emplacement of an apron of boulder to cobble-sized materials along the shoreline as a means of dissipating the forces of runup. Basically, this HAT is an attempt to mimic the behavior of naturally occurring cobble-boulder beaches, which remain for the most part static under normal conditions but behave dynamically under extreme conditions. Being therefore transitional between soft stabilization and hard stabilization, this HAT has also been referred to as a dynamic revetment.

While conceptually appealing, this HAT has had limited application.

COSTS/BENEFITS
- Moderate Costs
- High Technical Uncertainty.
- Moderate Design Level and Life
- Generally Positive Impact on Recreation, Scenic, Resource, and Conservation use values.

H.A.T. \ SETTING		DUNE-BACKED SHORELINE				BLUFF-BACKED SHORELINE			
		Rural		Urban		Rural		Urban	
		New	Existing	New	Existing	New	Existing	New	Existing
SOFT STABILIZATION	FE	High	High	High	High	Moderate	Moderate	Moderate	Moderate
	BN	Moderate	High	Moderate	High	Moderate	High	Moderate	High
	BB	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate

APPLICABILITY
- ● High
- ◍ Moderate
- ○ Low

plans as provided for under Statewide Planning Goal 18 Implementation Requirement 7. Specifically, a foredune grading plan shall include the following elements based on consideration of factors affecting the stability of the shoreline to be managed including sources of sand, ocean flooding, and patterns of accretion and erosion (including wind erosion), and effects of beachfront protective structures and jetties. The plan shall: a) Cover an entire beach and foredune area subject to an accretion problem, including adjacent areas potentially affected by changes in flooding, erosion, or accretion as a result of dune grading; b) Specify minimum dune height and width requirements to be maintained for protection from flooding and erosion. The minimum height for flood protection is 4 feet above the 100 year flood elevation; c) Identify and set priorities for low and narrow dune areas which need to be built up; d) Prescribe standards for redistribution of sand and temporary and permanent stabilization measures including the timing of these activities; and e) Prohibit removal of sand from the beach foredune system. A foredune management plan is currently in place at Nedonna Beach. A foredune management plan has recently been adopted in Seaside. Foredune management plans are currently being developed for Manzanita and Pacific City.

DESIGN ELEMENTS

Fill Volume. Determining what constitutes a foredune volume sufficient to survive a design storm event is a primary consideration in foredune enhancement. As was the case with construction setbacks, empirical observations and/or numerical modeling can be used to predict runup elevations, cross-shore sediment transport, and resulting beach and dune erosion for a given design event. This information provides the basis for establishing design foredune elevations and widths.

Once foredune design specifications have been established, the next step is to construct a foredune area that meets these specifications. Wind-driven, as opposed to wave-driven, sediment transport becomes a primary consideration at this stage. Also, because foredune construction typically involves the use of vegetation to capture and hold sediment, biologic as well as geologic and oceanographic processes need to be taken into account. Techniques commonly used to construct foredunes are described briefly below.

Vegetation. Foredunes can be constructed naturally through the planting of sand-stilling grasses. Sand-stilling grasses disrupt wind flow and as a result encourage sand deposition. Vertical growth rates and volume increases induced by sand-stilling grasses are not normally as spectacular as those due to fencing, but once established, most planted dunes will grow steadily in areas with a sufficient sand supply.

The three types of sand-stilling grasses commonly associated with foredune construction in the Pacific Northwest are European beachgrass, American beachgrass, and American dunegrass.

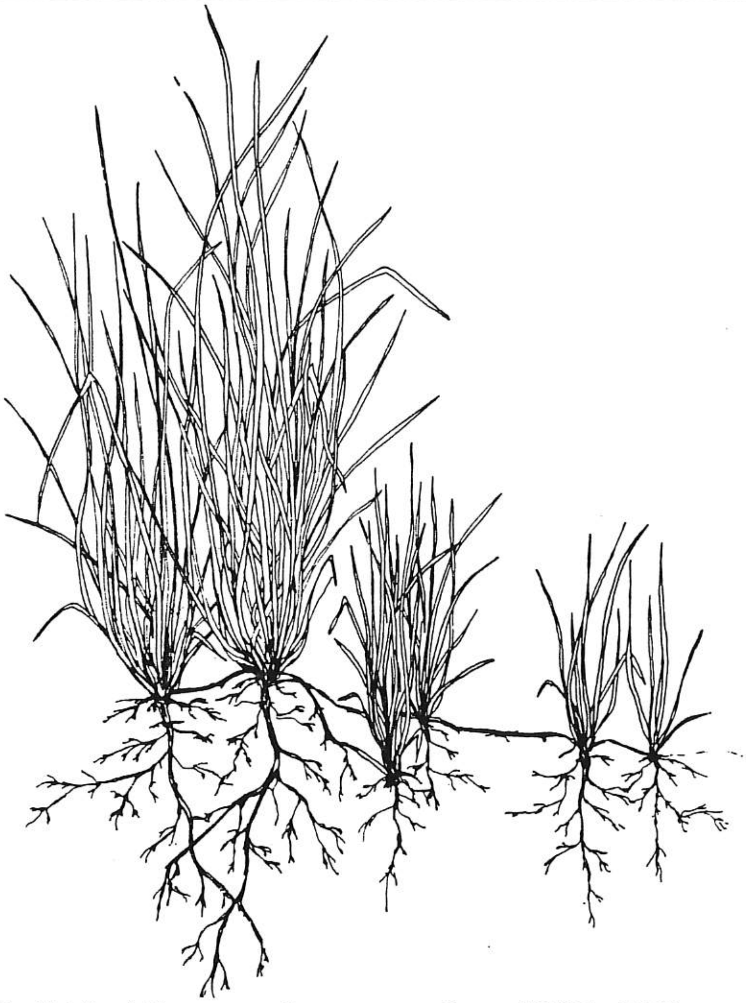


Figure 4.3. Growth Habit of European Beachgrass (from ACOE, 1978).

• **European beachgrass** (Ammophila arenaria) forms dense stands that are very effective at trapping sand. A continuous sand supply promotes vigorous vertical growth (Figure 4.3). Lateral spread is slow. As a result, European beachgrass forms foredunes characterized by high, steep windward slopes. European beachgrass can tolerate burial up to three feet deep and there are no known serious animal feeders or plant parasites. However, as sand supply is cut off behind the foredune crest, growth declines, the grass looses vigor, and eventually it dies out. This makes it essential either to carry out regular maintenance or introduce other species that can take over. Because this introduced species is easily propagated and correspondingly its production costs are low, European beachgrass is far and away the most commonly planted species.

• **American beachgrass** (Ammophila brevigulata) is a species closely related to European beachgrass. Compared to European beachgrass, American beachgrass grows slower and is more

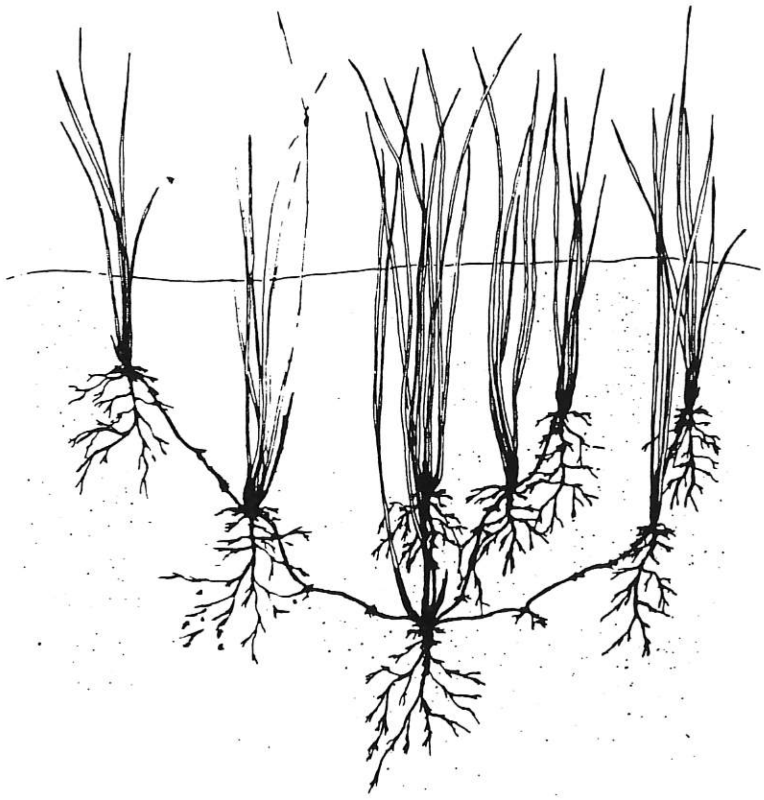


Figure 4.4. Growth Habit of American Beachgrass (from ACOE, 1978).

dependent upon a continuous sand supply for survival. However, lateral spread of American beachgrass is better than that of European beachgrass (Figure 4.4). As a result, American beachgrass forms foredunes characterized by lower, gentler windward slopes than those associated with European beachgrass. There are arguments both for and against the planting of American beachgrass over European beachgrass. However, because it is not as easily propagated and correspondingly its production costs are higher (as much as four times more), the use of this introduced species is usually limited to the planting of small areas, or in small amounts in conjunction with the planting of European beachgrass.

• **American dunegrass** (Elymus mollis) is the only species native to the Oregon coast. Like the non-native species, it too requires a continuous sand supply for growth. It possesses an open spreading growth habit. As a result, foredune areas with American dunegrass tend to be characterized by a loosely aggregated collection of relatively low hummocks. American dunegrass is much more difficult to propagate and correspondingly its production costs much higher than either of the non-native species. Despite such limitations, there is continued interest in the use of American dunegrass, particularly in foredune areas where it is found naturally and in small amounts in conjunction with the planting of European beachgrass.

Planting of European and American beachgrass needs to be carried out during the cool wet months of November through April. Because of the potential for winter storm damage, planting is probably best carried out in early spring. American dunegrass must be planted while dormant. Planting density varies with needs. Typically, the foreslope and crests of foredunes, and other more exposed areas need to be planted at high densities (e.g. 12" hill spacing and 5 culms per hill). The backslope of foredunes and other less exposed areas can be planted at lower densities (e.g. 18" hill spacing and 3 culms per hill). All planted areas need to be fertilized immediately after planting. Initial plantings need to be maintained through follow up fertilization and repair planting until vegetative cover is well established (generally in about two years).

Besides facilitating foredune volume building, planting of sand-stilling grasses is useful for securing bare sand surfaces against deflation. In this regard, there are a variety of grass, shrub, and tree species that can be used to accelerate foredune stabilization and establish permanent cover. Examples of secondary plantings include seashore lupine, seashore bluegrass, purple beach pea, creeping red fescue, and shore pine. Generally such species are planted about two years after initial planting of sand-stilling grasses. Like the sand-stilling grasses, secondary plantings require maintenance in the form of follow up fertilization and repair planting

Foredune Grading. Commonly, foredune construction involves reconfiguration of existing foredune areas using earth-moving equipment. Foredune grading facilitates rapid molding of the foredune area to desired design specifications. It is perhaps the only means of restoring badly dissected, and highly irregular foredune areas. Also, it may be the only way of constructing foredunes where sand supplies are limited. The Dutch, for example, employ a practice that involves moving offshore sands or remnant foredunes landward as a means of conserving and/or enlarging the volume of the foredune area.

Sand Fencing. Foredune construction can also be accomplished by mechanically disrupting wind flow so as to encourage sand deposition through the use of fencing, brush, straw bales, or similar materials. Of these methods, sand fences are the most common mechanical sand trapping aid.

- **Fence Height.** Sand fences are usually about four-five feet high. As a general rule, all significant deposition will occur within a distance eight times the fence height. An ideal sequence of sand deposition around a single sand fence is illustrated in Figure 4.5.

- **Fence Positioning.** Fence spacing is a function of sand grain size, specific gravity, and wind velocity, among other considerations. Proper positioning and spacing of fencing is critical. However, as desired effects and environmental conditions vary, so too do fence configurations. Common configurations include a single fence oriented perpendicular to the wind and lifted episodically as sand accumulates, two parallel rows oriented perpendicular to

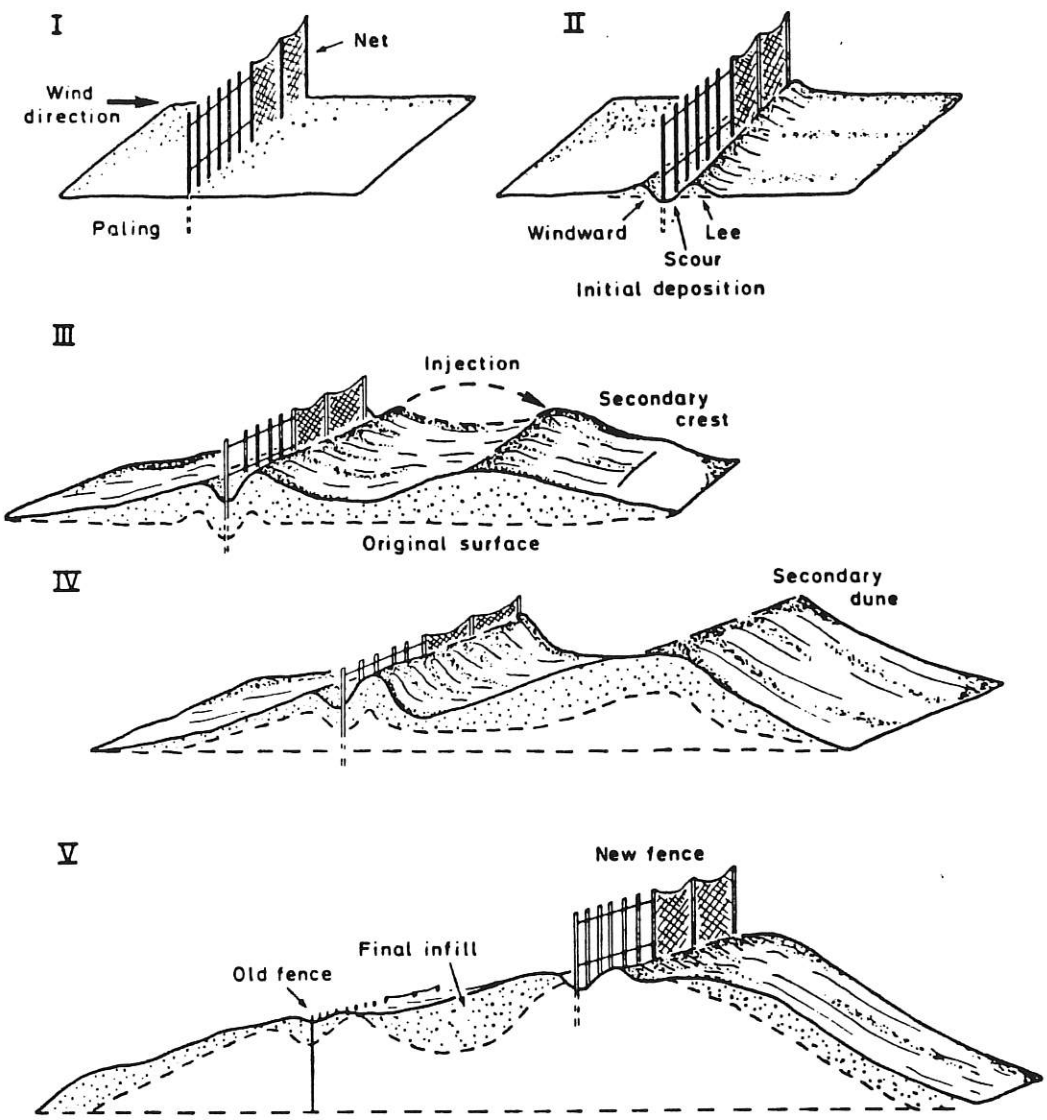


Figure 4.5. Sequence of Sand Deposition Around a Single Sand Fence (from Carter, 1988).

the wind and spaced about 30-40 feet apart, and multiple fences placed in zig-zagged patterns so as to be oriented towards variable winds.

• **Fence Porosity.** It is essential that the fencing be porous so as to impede but not halt the air flow. A fence porosity of 40 - 50% is generally regarded as being most effective.

Temporary Stabilization. Surface fixing can be achieved through means other than the use of vegetation. Brush matting is commonly used as a temporary stabilization measure. Oil-based mulches may also used as a temporary stabilization measure, however they are generally considered as unacceptable. In situations where stabilization needs are particularly acute and/or where stabilization needs are limited in areal extent synthetic compounds may be appropriate. Commonly sprayed on and drying to a hard surface, such compounds have a broader application than foredune stabilization because in addition to binding the sand surface they reduce the effects of weathering. Synthetic compounds however are essentially untested along the Oregon coast and, as they prevent vegetation reestablishment, may have limited applicability.

COSTS/BENEFITS

Costs of employing foredune enhancement techniques are on the order of $300 a year for a single-family residential dwelling. This is low, particularly when compared to hard stabilization. Such low costs are attributable in part to their ease of applicability, and in part to the practice of these techniques on an area-wide basis. It needs to be kept in mind however, that the shoreline is still expected to experience displacements during storm events. As a result, foredune enhancement offers relatively lower design levels and shorter design lives than those afforded by hard stabilization.

There are several elements of technical uncertainty associated with the application of foredune enhancement techniques that suggest limits to their overall effectiveness as a HAT. They may have adverse impacts on the stability of adjacent segments of shoreline. Improper placement of sand fences, for example, may rapidly generate a large dune form that can migrate into adjacent foredune areas. At a more fundamental level, our ability to accurately estimate design levels and design lives is limited by our basic inability to accurately predict shoreline response to storm events. Even if appropriate design specifications could be identified, the foredune area is constructed to these specifications, and the foredune area does withstand a design event, following the event there will be a window of vulnerability that will exist before the foredune area can be reestablished to design specifications.

Other elements of technical uncertainty are associated with foredune enhancement when it is viewed in the context of the sediment budget, where accumulation of sediment in the foredune area is carried out at the expense of depletion of sediment in other shoreline areas. With respect to cross-shore sediment exchange, it has been shown that encouraging the buildup of high artificial dunes can actually increase susceptibility to wave attack. As sediment accumulates in the dunes, it is depleted in the surf zone. This results in a steeper, more reflective beach where larger waves break closer to shore. Similar types of sediment budget considerations apply to longshore sediment exchange as well. Capture of sand, and correspondingly an increase in flood/erosion protection potential, in one foredune area can result in the starvation, and correspondingly a decrease in flood/erosion protection potential, along adjacent foredune areas. These concerns suggest that it is essential to address application of foredune enhance techniques in an areawide management context.

Irrespective of the concerns identified above, foredune enhancement is generally regarded as an attractive HAT. In addition to buffering landward development from the effects of wave attack, foredune enhancement shelters landward development from the effects of sand inundation. While this added benefit is likely to be appreciated by ocean-front property owners, growth in the height of the foredune to the point where it results in the loss of ocean views may not be looked upon so favorably.

Foredune enhancement is also generally regarded as having positive consequences from both a social and environmental point of view. Because foredune enhancement promotes the existence of a sandy beach it has generally positive impacts on recreational use value. Foredune enhancement is not always compatible with recreational use however. In this regard, beach grass covered dunes are probably less preferable than open sand beach. Also, plant species used for foredune enhancement are particularly vulnerable to destruction by pedestrian and vehicular traffic. Only rarely might it be practical to completely exclude people from foredune areas a means of protecting vegetation. As a result, it is most likely that foredune enhancement will need to occur while simultaneously providing for recreational use.

Because foredune enhancement maintains the shoreline in a relatively natural state, in general it preserves scenic, resource, and conservation use values. There are instances however, where the application of foredune enhancement techniques may negatively impact such values. Specifically, Snowy Plover nest in areas above the high tide line with loose sand and sparse foredune vegetation. Thus, the application of foredune enhancement techniques may not be compatible with restoration of Snowy Plover habitat.

APPLICABILITY TO OREGON

Foredune enhancement has high potential applicability along the Oregon coast. Its greatest potential as a HAT is along dune-backed shorelines that are not highly developed. In such settings foredune enhancement can inhibit the landward migration of dune sands, can increase the elevation of the foredune to diminish storm-surge flooding, and provide a moderate level of hazard alleviation by locally slowing down short-term beach erosion -- all at a low cost. It is important to note however, that foredune enhancement is not a cure for long-term, areawide retreat under conditions of marine transgression and limited sand supply. Thus, the potential applicability of foredune enhancement as a HAT along bluff-backed shorelines is more limited. Still, foredune enhancement can provide some measure of hazard alleviation in such a setting. When used in conjunction with other HATs foredune enhancement may represent an effective alternative to hard stabilization.

Along highly developed shorelines the potential applicability of foredune enhancement is moderate to low. In such a setting, and in terms of wave attack, foredune enhancement may not afford high enough levels of protection to the resources at risk. Similar arguments are likely to apply to the applicability of foredune enhancement as a HAT when critical facilities or significant natural resources are at risk. In such a setting, foredune enhancement is however the appropriate means of minimizing potential for sand inundation.

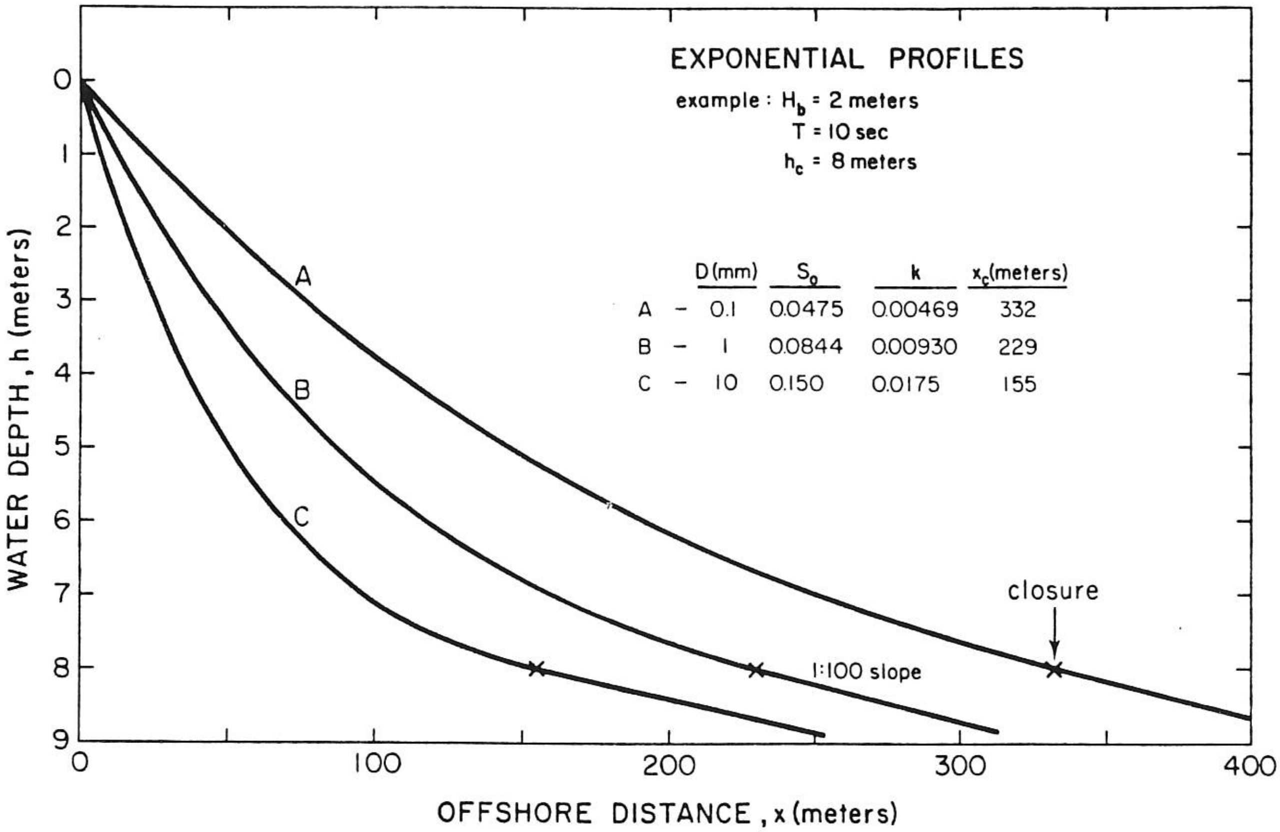
To be successful in any setting foredune enhancement needs to be carried-out in the context of areawide sand management. It is in this context that potentially conflicting management objectives can be balanced against each other in a way that provides not only for effective hazard alleviation, but also allows for multiple use of shoreline resources. As noted above, areawide management of foredune areas is currently provided for along dune-backed shorelines under Goal 18. As will be suggested again later, areawide management of foredune areas along bluff-backed shorelines needs to be provided for as well.

4.2.2 BEACH NOURISHMENT

This option encompasses augmentation of the natural sediment supply along a segment of shoreline as a means of maintaining a volume of sediment in the shoreline system that is sufficient to effectively dissipate the forces of wave breaking and runup through sediment transport.

A common method of beach nourishment involves trucking sand from upland areas or pumping sand through a pipeline from an inlet/navigation channel or back bay and placing it in subaerial beach and dune areas (onshore nourishment). Another common method of beach nourishment involves dredging sand from offshore, from harbor entrances, and from inshore regions and placing it in shallow subaqueous bar and beach areas (offshore nourishment). The terms bypassing (moved down drift) and backpassing (moved up drift) may apply in these instances. Beach nourishment is commonly employed in conjunction with the construction of groins, jetties, breakwaters, seawalls, etc. Typically sand is the material used in nourishment. However, nourishment has been carried out successfully in instances where gravel has been used. Because permanent retention of augmented shoreline sediment is not an expectation, nourishment typically involves an initial major placement of sediment (restoration) followed by subsequent minor placements of sediment (replenishment).

Beach nourishment is increasingly identified worldwide as a preferred HAT. Becoming popular in the United States in 1950's, beach nourishment is responsible for the existence of the wide sand beaches of southern California and is widely used along the Atlantic and Gulf coasts (e.g. Florida, New Jersey). Other than minor projects at Port Orford and Gold Beach involving the placement of dredged material on the subaerial beach, beach nourishment has not been carried out as HAT in Oregon .



Example exponential beach profiles
S_c = 0.010 at the closure depth h_c = 8 meters.

Figure 4.6 Example Illustrating Predicted Equilibrium Profiles and Closure Depths (from Komar and McDougal, 1994).

DESIGN ELEMENTS

Fill Volume/Form. Determining the volume and form of fill sufficient to survive a design storm event is a primary consideration in beach nourishment. Common practice with respect to determining the cross-sectional volume and form of fill is simply to translate a 'profile of equilibrium' seaward to achieve the desired design level. The difference between the dimensions of the existing and design profiles determines the minimum quantity of material needed for nourishment. The profile of equilibrium is the configuration of the beach that is expected to prevail under average environmental conditions. Relationships used to determine the profile of equilibrium are given in the coastal literature (Figure 4.6). Care needs to be taken to ensure that the profile extends to the 'closure depth', the seaward limit of significant sediment transport.

It has been suggested that these concepts, based on geometric models of shoreline response to sea level rise, greatly over-simplify reality and are of questionable use as design parameters. Physical

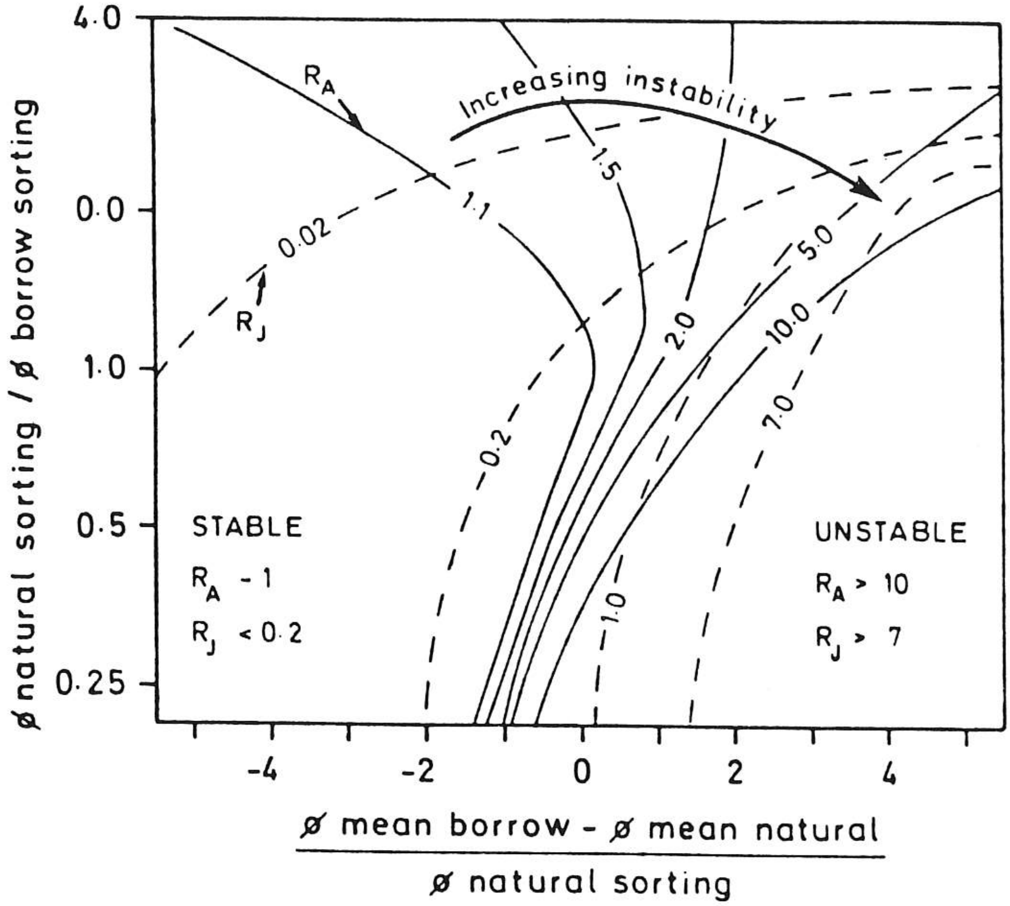


Figure 4.7. Example of Relationship Used to Predict Fill Volume and Replenishment Interval in Terms of the Grain Size and Sorting of 'Native' versus 'Foreign' Sediment (from Carter, 1988).

models, that involve sediment transport and include sediment budget terms, may more accurately predict the shoreline response to storm events and, as result, are more likely to generate appropriate design specifications.

Fill Texture. The textural characteristics (e.g. size, density, sorting, etc.) of the sediment used as fill are a fundamental design element of a beach nourishment project. It is important that the 'foreign' sediment used for fill be compatible with the 'native' sediment, as this is a determinant of how much fill is needed and how often the fill will need to be replenished (Figure 4.7). Ideally the grain size of the foreign sediment should be the same or slightly coarser than that of the native sediment. If the sediment is too fine it is easily lost offshore and as a result either a greater amount of material or more frequent filling will be required. Less material may be needed if the sediment is coarse, but if it is too coarse there is a possibility that the native materials will be displaced offshore.

Fill Compartmentalization. The potential for end losses is another element that needs to be addressed in the design of a beach nourishment project. The extent of end losses are highly variable from site to site, commonly depending not only on the longshore length of the fill area but also on the degree of geographical or structural compartmentalization. Although there are undoubtedly exceptions, as a general rule, as fill length is increased so to is fill stability. Along these same lines, it is generally agreed that the most successful beach nourishment projects are those that encompass an entire closed compartment or littoral cell. In this regard, it has been suggested that the greater longevity of Pacific Coast nourishment projects as compared to Atlantic and Gulf Coast nourishment projects is at least in part attributable to the relatively high degree of natural and structural compartmentalization of the Pacific Coast.

Fill Replenishment. As permanent retention of augmented shoreline sediment is clearly not an expectation, the need for replenishment is to be anticipated. With respect to the determination of a replenishment interval, two basic approaches can be identified. Replenishment may be carried out on as needed, or crisis, basis. However, the preferred approach is to replenish on a regular, or maintenance, basis.

COSTS/BENEFITS

Because design considerations of beach nourishment projects are so site dependent, costs vary widely from project to project. Factors that influence project costs include the type of nourishment technique employed, the amount of material required, the frequency of nourishment activities, and the proximity to source material. Compared with other HATs, nourishment is generally regarded as being particularly cost-effective when it occurs in association with maintenance dredging of navigation channels. Other ways of increasing cost-effectiveness include the use of sediment sources near to the project area, maximizing placement volumes, and cost-sharing in part through areawide management. Although costs may be higher, the use of external sediment is likely to result in better performance because in this way the sediment supply is truly augmented rather than simply recycled. Finally, with respect to costs, to be successfully employed beach nourishment requires a commitment to long-term funding.

A relatively high level of technical uncertainty is inherent in beach nourishment projects. As noted in the context of foredune enhancement, our current understanding of coastal processes and beach dynamics limits our ability to accurately estimate design levels and design lives. In this regard, it has been suggested that past performance estimates of beach nourishment projects have tended to be overly optimistic: Nourished beaches typically disappear more rapidly than predicted. Further, even with regularly scheduled replenishment, a long time may be required for a segment of shoreline to recover from a major storm event. During this time a window of vulnerability may exist when a project is expected to provide less than the design level of protection. Provisions for interim protection and for expediting replenishment can keep this risk to a minimum. Finally, when beach nourishment is viewed in the context of the sediment budget the possibility of adverse impacts on the stability of adjacent segments of shoreline also potentially limits the overall effectiveness of beach nourishment. Such elements of technical uncertainty inherent in beach nourishment projects can be minimized, however, by ensuring that baseline studies of coastal processes and beach dynamics in the project area are sufficiently detailed, that comprehensive projecting monitoring follows initial nourishment, and that nourishment is carried out in the context of areawide management.

Irrespective of the concerns identified above, foredune enhancement is generally regarded as an attractive HAT. While it provides relatively lower design levels and shorter design lives than those afforded by hard stabilization, its has a generally positive impact on adjacent property because the hazard alleviation benefits extend past the immediate area of fill as the fill spreads out laterally. Some potential does exist for negative impacts related to changes in inlet dynamics, wave refraction patterns, and possible increases in subaerial sand accumulation.

The generally positive impacts of beach nourishment on recreational use values is a particularly appealing aspect of beach nourishment. Not only does promoting the existence of a sandy beach provide a flood/erosion buffer for backshore development and protect hard coastal structures such as seawalls, but it maintains valuable recreational benefits that can in turn result in indirect economic benefits to coastal communities through increased tourism. In some instances maintenance of a sandy beach for recreational purposes may be the primary reason for beach nourishment.

Because beach nourishment maintains the shoreline in a relatively natural state, it preserves scenic, resource, and conservation use values. While its impact on such use values is generally positive, there are instances where beach nourishment may negatively impact such values. Beach nourishment may have some permanent negative environmental impacts on rocky intertidal habitats, for example. For the most part however, adverse environmental impacts associated with nourishment (e.g. disturbance of source area sessile benthic habitat) are believed to be temporary.

APPLICABILITY TO OREGON

Overall, beach nourishment is believed to have moderate potential applicability along the Oregon coast. In specific situations, such as large scale nourishment projects in the form of shallow-water disposal of material dredged from navigation channels, potential applicability as a HAT is high. As a case in point, one million cubic meters of sand is dredged from Yaquina Bay annually. The entire associated littoral cell has about 11 million cubic meters of sand. Each year then, about 10 % of the littoral cell sand supply could be replenished. In this instance, costs are low because of the federal subsidization of dredging activities. Also, by reducing haul distance shallow-water disposal may in turn reduce dredging costs. Thus, the viability of large scale beach nourishment as a HAT in littoral cells with navigation channels and correspondingly maintenance dredging needs to be explored.

Along dune-backed shorelines, where hazard alleviation needs are for the most part localized and temporary, there may be a real opportunity for the the development and implementation of small sand nourishment schemes involving sediment budget management and sand banking. For example, in some littoral cells artificial balancing of the sediment budget could be carried out by backpassing to the southern extremes of a cell, sand that has collected at the northern extremes of the cell. This would have the advantage of providing hazard alleviation not only to segments of shoreline where flooding/erosion potential is greatest, but also to segments of shoreline where sand accumulations is itself a potential hazard. Thus, the potential applicability of small sand nourishment schemes also needs to be explored.

Along bluff-backed shorelines, where hazard alleviation needs tend to be more regional and permanent, beach nourishment is a less attractive option. In this setting it has the potential to provide some measure of hazard alleviation, primarily in the form of toe protection. Compared to hard stabilization, its appeal in this setting is that it provides for continued existence of a sandy beach. In this regard, it may be appropriate to use in conjunction with hard stabilization.

When the maintenance of a sandy beach for public recreational use is identified as a priority, beach nourishment is likely to be the preferred HAT. In contrast, when critical facilities or significant natural resources are at risk, beach nourishment may not be an appropriate HAT.

Although some broad generalizations have been made as to the potential applicability of beach nourishment as a HAT along the Oregon coast, the need to evaluate the applicability of beach nourishment as a HAT on a case-by-case basis can not be over emphasized. Also, the need for beach nourishment to be carried-out in the context of areawide sand management can not be over emphasized. Before the applicability of beach nourishment can be evaluated in any setting along the Oregon coast, a more detailed understanding of individual littoral cell sediment budgets is needed than currently exists.

4.2.3 BOULDER BERMS

This option encompasses the emplacement of an apron of boulder to cobble-sized materials along the shoreline as a means of dissipating the forces of runup (Figure 4.8). Basically, this HAT is an attempt to mimic the behavior of naturally occurring cobble-boulder beaches, which remain for the

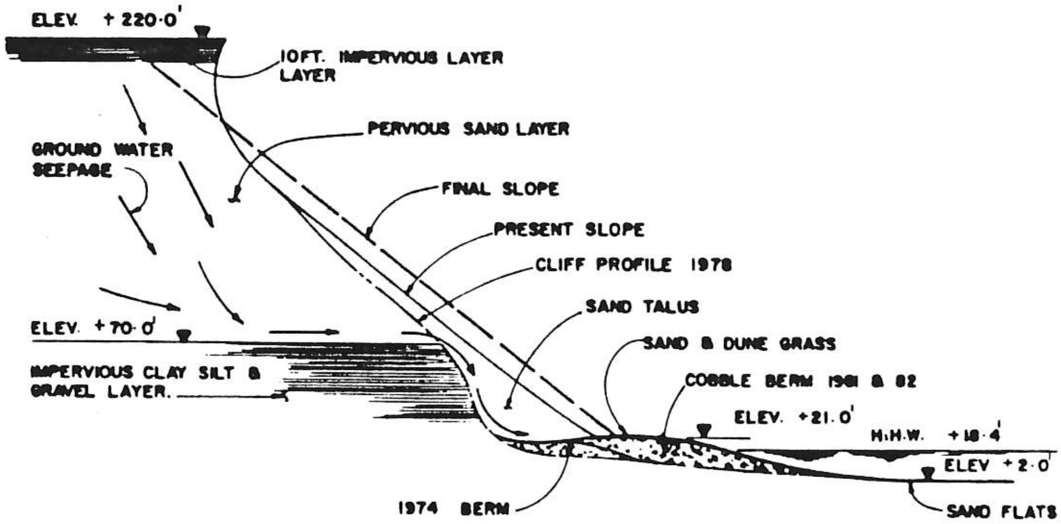


Figure 4.8. Schematic of Cobble Berm Deployed along Bluff-Backed Shoreline in British Columbia, Canada (from Downie and Saaltink, 1983).

most part static under normal conditions but behave dynamically under extreme conditions. This HAT, which is in effect transitional between soft stabilization and hard stabilization, has also been referred to as a dynamic revetment.

While conceptually appealing, this HAT has had limited application. In instances where they have been applied, primarily in conjunction with other HATs, boulder berms have been effective. Boulder berms have not been employed as a HAT along the Oregon cost.

DESIGN ELEMENTS

Textural Characteristics. The size, density, sorting, etc. of the fill material are a key element in the design of boulder berms. This is because the design of boulder berms is to a great extent centered around identifying material that will only just begin to behave dynamically under the design event condition (i.e. just beyond the entrainment threshold). Equations relating stone weight to incident wave conditions are given in the coastal literature (Figure 4.9). However, because they are generally intended to ensure that structures remain static, these equations will tend to result in overestimates of the weight, and hence size of material needed for the construction of boulder berms.

Other ways that textural characteristics affect the stability of boulder berms, such as through their

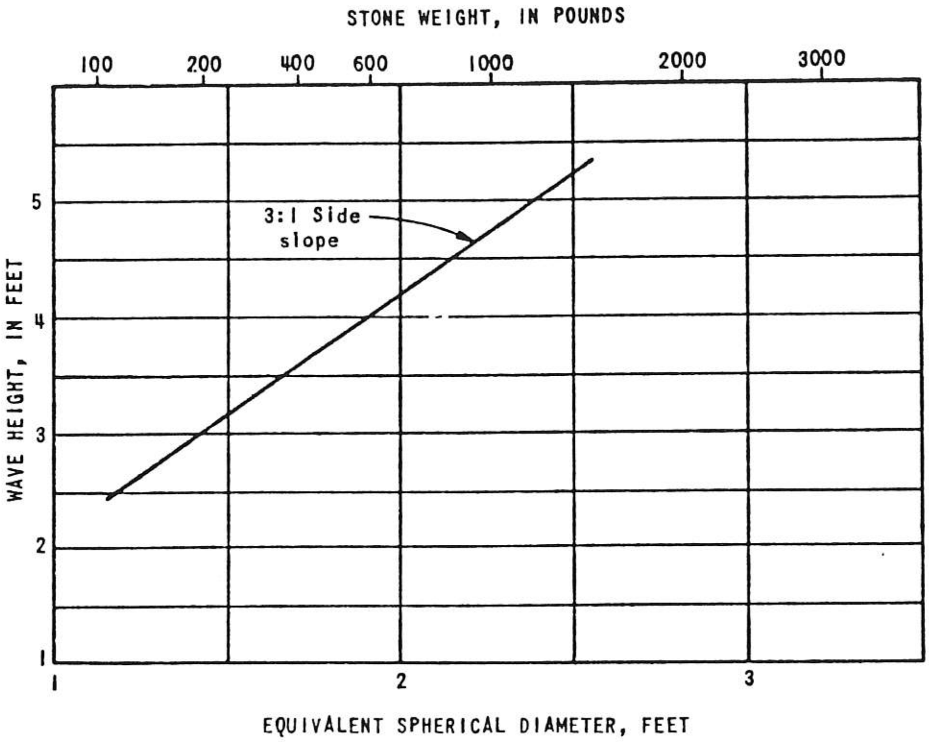


Figure 4.9. Example of Relationship Used in Revetment Design to Predict Stone Size in Terms of Wave Height (from Gray and Leiser, 1982).

influence on porosity, also need to be taken into account.

Fill Form/Volume. The inherent stability of the volume of fill materials is another concern in the design of boulder berms. In much the same manner as for beach nourishment, the volume and form of fill sufficient to survive a design storm event is determined by identifying an 'equilibrium profile' and translating it shoreward of the existing and profile. As is the case for beach nourishment, relationships used to determine the profile of equilibrium are given in the coastal literature. In this instance, care needs to be taken to ensure that the crest height of the profile is sufficient to avoid overtopping.

COSTS/BENEFITS

Costs in deploying boulder berms as a HAT will vary with the type and amount of material needed. When compared with other HATs, particularly hard stabilization, the costs of deploying boulder berms is believed to be low. However, when compared to hard stabilization their design life is relatively low. Further, the ability to obtain suitable types and quantities of fill material is a major constraint to the widespread application of boulder/cobble berms. Rounded boulders/cobbles are scarce. Unless used as a core to be covered by sand and vegetation, angular quarry stone is unacceptable in most instances. This lack of suitable source material problem is exacerbated when the need for regular replenishment is taken into account.

A relatively high level of technical uncertainty is inherent in the deployment of boulder berms as a HAT. Aside from inherent uncertainty related to our level of understanding of coastal processes and beach dynamics, design and performance of flexible structures are particularly poorly understood. While there is an element of uncertainty associated with this HAT, it does afford higher design levels and longer design lives than those afforded by other types of soft stabilization. Also, because the fill material is easily tapered into the adjacent shoreline, impacts on adjacent property are likely to be minimal.

Boulder berms may be an attractive HAT for other reasons. While they are not as valued as a broad sandy beach, boulder-cobble beaches do provide some degree of recreational use. There may, however, be reason for concern that increased shoreline roughness will flush sand out into the surf zone and result in some loss of subaerial sandy beach. In this regard, boulder berms can be covered with sand and planted. It is important to note that naturally occurring boulder berms are common at the the base of bluffs and around creek outlets. Thus, artificial boulder berms maintain the shoreline in a relatively natural state thereby preserving scenic, resource, and conservation use values. Adverse environmental impacts associated with boulder berms are believed to be minimal.

APPLICABILITY TO OREGON

Overall, the potential applicability of boulder berms in Oregon is believed to be moderate. On a large scale their greatest potential applicability is along bluff-backed shorelines where, in conjunction with the application of slope stabilization measures, they can be used as bluff toe protection. In this setting they may represent a lower cost, more easily deployed and maintained, more aesthetically pleasing alternative to more massive rip rap revetments or seawalls. Along both dune-backed and bluff-backed shorelines, in the form of localized berm construction in areas experiencing active erosion (e.g. the toe of the foredune scarp) their is high potential for boulder berms to serve as a temporary hazard alleviation measure. Boulder berms are likely to be equally applicable along highly developed and less developed segments of shoreline.

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4.3 OPTIONS FOR WAVE ATTACK: HARD STABILIZATION

Hard stabilization refers to techniques which reduce potential risk by attempting to fix the position of the shoreline so as to prevent the effects of wave attack. Thus, in most instances the shoreline is stabilized in a real sense through the application of these techniques and does not experience displacements during storm events. Specific HATs included within this category are: groins; breakwaters; and revetments/seawalls (Table 4.2). Hard stabilization techniques are potentially applicable along both dune-backed and bluff-backed shorelines. They are potentially applicable along shorelines with high as well as low levels of development.

4.3.1 GROINS

This option encompasses the deployment of wall-like structures aligned normal to the shoreline, attached to the shore, and extending into the surf zone for the purpose of intercepting a portion of material drifting along shore and thereby creating and/or maintaining a protective beach.

Typically groins are impermeable rubble mound structures that are linear in form. Through the addition of lateral appendages plan form can be modified into a range of T-shaped, L-shaped, inverted Y-shaped, and C-shaped structures. Modification of the typical groin may also involve variations in permeability as well as alignment. Besides quarry stone, other materials such as concrete, steel, wood, and even sand bags can be used to construct groins. In some cases only one groin is installed along a section of shoreline. More commonly however, two or more groins are installed in a series that tapers off in length down drift (i.e. a groin field). Groins exhibit affinities to jetties. However, the latter are larger structures located at entrance channels, rather than along the shoreline, and are intended primarily for navigation-related purposes, not hazard alleviation.

Groins are used worldwide as a HAT. They are common along the East, Gulf, Southern California, and Great Lakes coasts. Recognition of the adverse impacts of groins on adjacent shorelines has resulted in less extensive use of groins over the last few decades. Groins have not been employed as a HAT along the Oregon coast.

DESIGN ELEMENTS

Structural and Material Stability. Because a groin extends out into the surf zone it must be capable of withstanding continuous direct wave attack. Thus both structural and material stability

TABLE 4.5 OPTIONS for WAVE ATTACK - HARD STABILIZATION and APPLICABILITY MATRIX

GROINS (G). Wall-like structures aligned normal to the shoreline, attached to the shore and extending into the surf zone as a means of trapping material drifting alongshore and thereby widening and/or building a protective beach.

Typically groins are linear, impermeable, rubble mound structures. However, they may take a range of T-shaped, L-shaped, inverted Y-shaped, and C-shaped forms, may be permeable, and may be composed of concrete, steel, wood, or even sand bags. Groins are commonly deployed alongshore in a series, rarely in isolation.

COSTS/BENEFITS
- High Costs
- Moderate Technical Uncertainty
- High Design Level and Long Design Life
- Adverse Impacts on Adjacent Shoreline
- Negative Impact on Recreation, Scenic, Resource, and Conservation Use Values.

BREAKWATERS (BW). Wall-like structures aligned parallel to the shoreline, detached from the shore and located in the surf zone as a means of dissipating (breaking) and/or redirecting wave energy and thereby sheltering and/or widening the protective beach along the shoreline area behind the structure.

Typically breakwaters are fixed, rubble mound structures. However, they may be prefabricated structures composed of various patented types of concrete armor units. Breakwaters are commonly deployed alongshore in a series, rarely in isolation.

COSTS/BENEFITS
- High Costs
- High Technical Uncertainty
- High Design Level and Long Design Life
- Adverse Impacts on Adjacent Shoreline
- Generally Positive Impact on Recreation, Scenic, Resource, and Conservation Use Values.

REVETMENTS AND SEAWALLS (R/W). Wall-like structures aligned parallel to the shoreline and attached to the shore as a means of dissipating wave energy (runup) and thereby sheltering the upland area behind the structure.

Typically revetments are seaward-sloping rubble mound (rip rap) structures. Patented types of concrete armor units are also used to construct revetments. Typically seawalls are vertical concrete structures. Steel and timber are also used to construct seawalls. Both revetments and seawalls may also be constructed with stacked sand-filled synthetic fiber bags or with loose materials secured in cages (gabions).

COSTS/BENEFITS
- High Costs
- Moderate Technical Uncertainty
- High Design Level and Long Design Life
- Adverse Impacts on Adjacent Shoreline
- Negative Impact on Recreation, Scenic, Resource, and Conservation Use Values.

H.A.T. \ SETTING	DUNE-BACKED SHORELINE				BLUFF-BACKED SHORELINE			
	Rural		Urban		Rural		Urban	
HARD STABILIZATION	New	Existing	New	Existing	New	Existing	New	Existing
G	Low	Low	Low	Low	Low	Low	Low	Low
BW	Low	Low	Low	Moderate	Low	Low	Low	Moderate
R/W	Low	Low	Low	Moderate	Moderate	Moderate	Moderate	High

APPLICABILITY

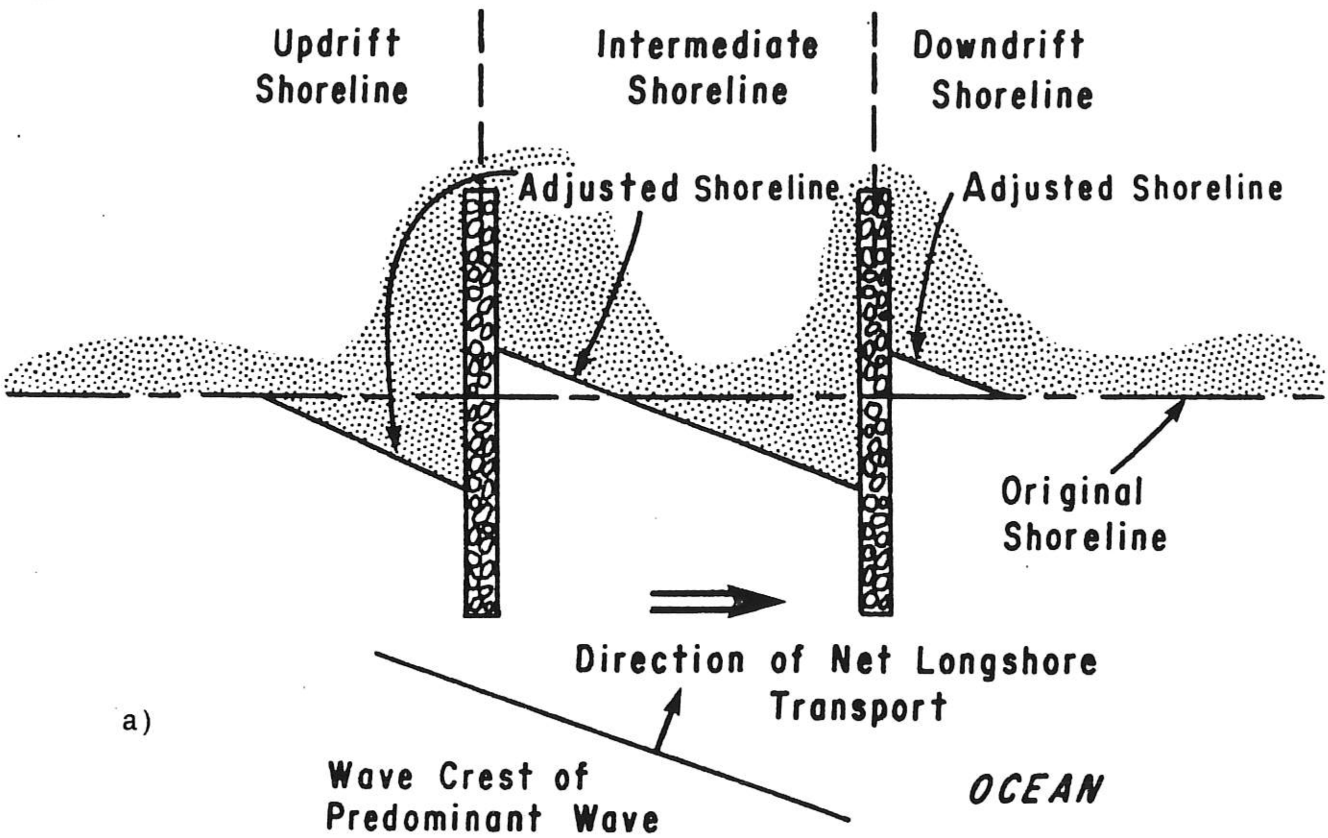
- ● High
- ◍ Moderate
- ○ Low

are a primary design consideration. Structural stability here refers to the overall stability of the structure, that is, the ability of the structure to remain in place. Stability in this sense is basically determined by stone weight and stone placement. Wave scour around the base of the structure is a particular concern with respect to structural stability. Also, periodic repair is generally needed to maintain structural stability. With respect to material stability, the materials that makeup the structure need to durable enough not to break-up in response to continuous wave attack.

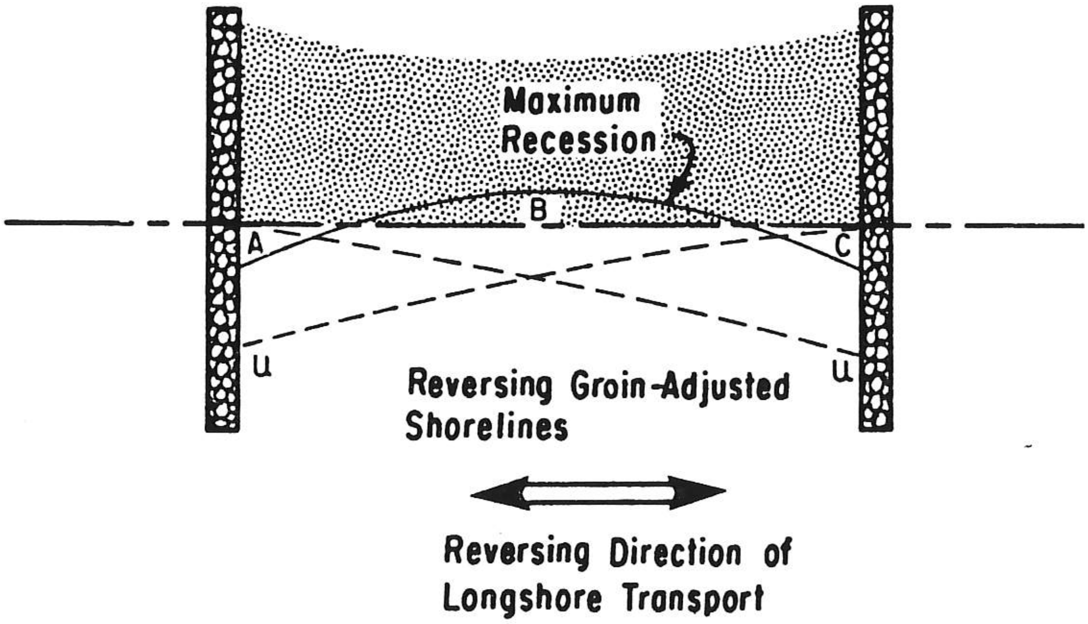
Trapping Efficiency. As noted above, a groin functions by intercepting a portion of the littoral sand supply. In areas with strong net littoral drift augmentation of the up drift beach is accompanied by depletion of the down drift beach. Typically, this results in a local realignment of the shoreline characterized by what is recognized as the classic up-drift fill and down-drift scour signature associated with drift interruption (Figure 4.10a). A different shoreline signature, characterized by scour in the central area between the two groins and fill in the areas in proximity to the groins, is associated with areas with reversing directions of littoral drift (Figure 4.10b). Groin design, then, to a great extent centers around determining the degree of drift interruption or, trapping efficiency, and in turn the anticipated nature and extent of shoreline realignment to be expected under design wave climate conditions. Groin length, height, and spacing are the design elements commonly used to control trapping efficiency. These design elements determine the extent to which material is allowed to pass around seaward or pass over the groin. Another way of controlling trapping efficiency and fine-tuning groin performance is to control the extent to which materials area allowed to pass through a groin (i.e. permeability). Groin design needs to be considered on a on case-by-case basis and involve numerical modeling. However, assuming that the design wave climate (e.g. direction and magnitude of longshore drift) is known, rules of thumb are briefly described below.

- **Groin Length**. 'Effective groin length', the length of groin in the active surf zone, has a major impact on trapping efficiency: The greater the length of the structure in the surf zone, the greater the amount of material intercepted. Correspondingly, the longer the groin, the greater the extent of accreted up drift and eroded down drift areas. As a general rule, effective groin length is approximately 40 to 60 percent of the width of the average surf zone. Thus, on reflective beaches, or more specifically on gravel beaches where sediment transport is confined primarily to the swash zone, short groins can be very effective. On dissipative beaches, with their broad sandy beaches and wide multiple-barred surf zones, groins need to be very long to be effective. Longshore drift volumes also enter into the consideration of groin length. For example, a lower than normal trapping efficiency (groin length) may be acceptable along segments of shoreline where longshore drift volumes are high .

- **Groin Height**. What might be referred to as 'effective groin height', the elevation of the groin relative to that of the water level, also has a major impact on trapping efficiency: The greater the height of groin, the greater the amount of material intercepted. Correspondingly,



a)



b)

Figure 4.10. Shoreline Realignment Associated with Groins. a) Conditions of Strong Net Littoral Drift; and b) Conditions of No Net Littoral Drift (from ACOE, 1984).

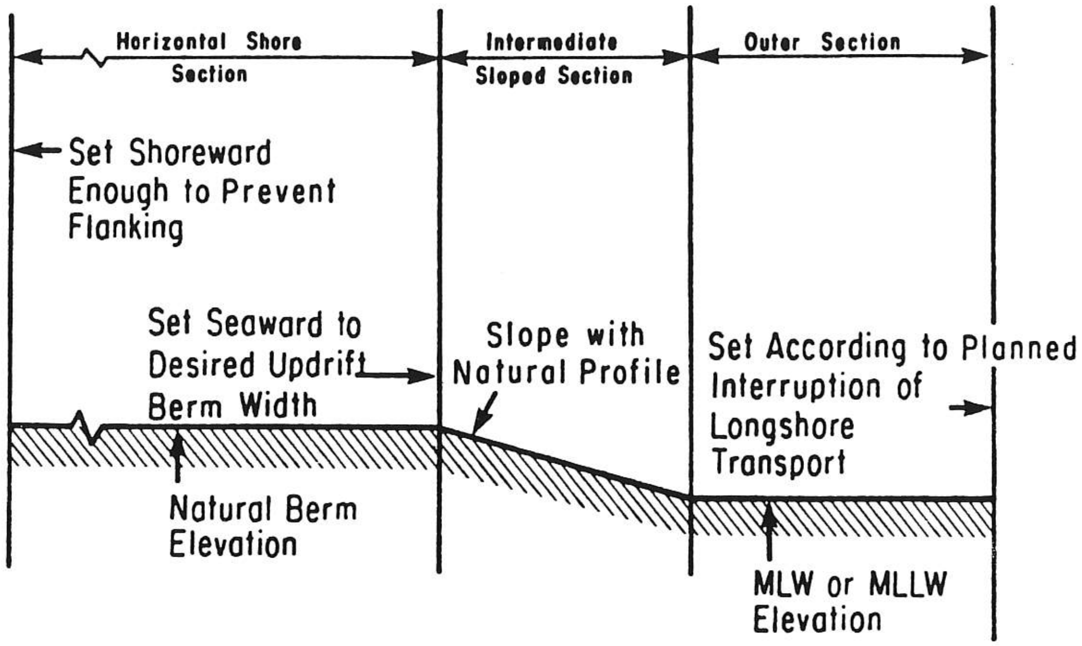


Figure 4.11. Schematic of Groin Design in Profile (from ACOE, 1984).

the higher the groin, the greater the drift interruption signature. For design purposes three sections can be identified: a horizontal shore section, an intermediate sloped section, and an outer section (Figure 4.11). To prevent regular overtopping and avoid potential for flanking, the elevation of the horizontal shore section, the section anchoring the groin to the land, usually corresponds closely to that of HHW. From here, elevation decreases seaward, with the intermediate sloped section paralleling the slope of the natural foreshore and connecting to the outer section at an elevation usually corresponding to that of LLW. This configuration allows for the groin to be overtopped at the seaward end and as a result for some material to move alongshore.

• **Groin Spacing.** Groins fields are used to provide hazard alleviation along a stretch of shoreline. In this regard, spacing between groins can be critical to groin performance (Figure 4.12). When spaced too close together trapping is ineffective: When spaced too far apart shoreward flanking may result. As a general rule, on sandy beaches the spacing between groins should be roughly two to four times the length of the groins. Groin fields are also used to minimize the expression of the fill and scour signature associated with this HAT. Standard practice is to gradually reduce the effective length of groins in a down drift direction. In areas with reversing directions of longshore transport, groins are tapered along shore in both directions.

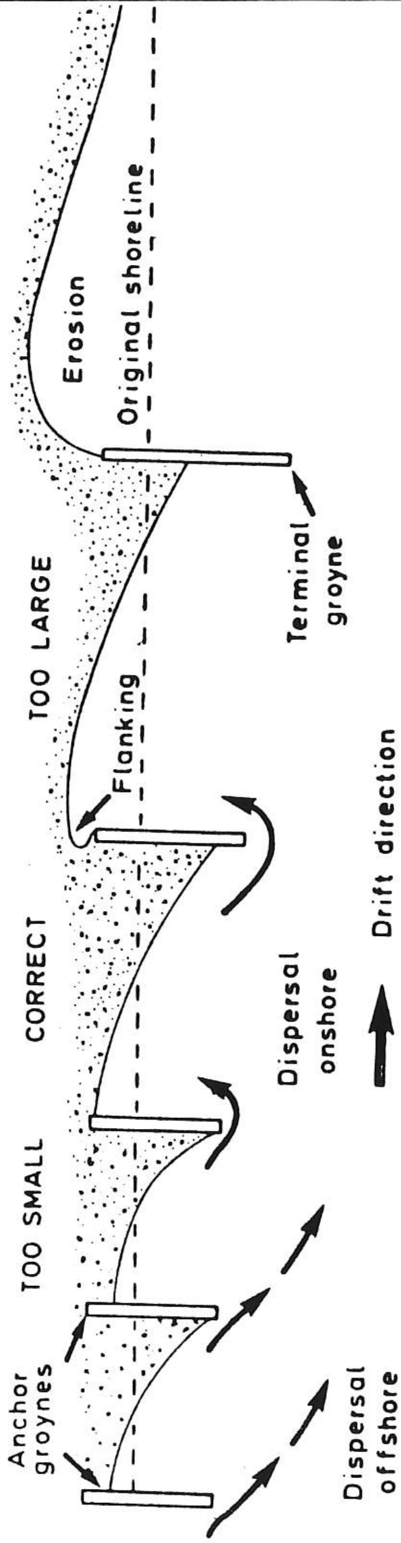


Figure 4.12 Effect of Groin Spacing on Trapping Efficiency and in turn Shoreline Signature (from, Carter, 1988).

Beach Nourishment. Another standard practice intended to minimize the effects of drift interruption is to nourish the groin field. Starting with the ungroined down drift beach, down drift compartments are progressively filled in an up drift direction.

COSTS/BENEFITS

Construction and maintenance costs of groins vary depending on types and amounts of materials used. Cost can be reduced somewhat through the use of prefabricated structures. Still, when compared to other HATs, the cost of groins are high. As a result, groins tend to be cost-effective only when the value of the uses being protected are themselves high.

A moderate to high level of technical uncertainty is associated with the deployment of groins as a HAT. Interactions between coastal processes and groins are poorly understood. As a result, the ability to control trapping efficiency with any degree of certainty and in turn accurately predict the anticipated nature and extent of shoreline realignment is limited. In this regard, it has been suggested that only about half the time can groins be said to have performed satisfactorily. When performing satisfactorily however, groins do afford relatively high design levels and long design lives.

Realignment of the shoreline that occurs in response to groins has high potential to adversely affect stability of the adjacent shoreline. As noted above, in areas with strong net littoral drift accumulation along the up drift shoreline occurs in conjunction with depletion along the down drift shoreline. As a result of this effect, the placement of one groin often leads to the need for another. In this way depletion progresses down drift. Only after compartments have filled will bypassing occur and drift cease to be interrupted. Adverse affects associated with groin-induced shoreline realignment are not limited to areas with strong net littoral drift. As noted above, in areas with reversing directions of littoral drift groins also result in a realignment of the shoreline. Also, because groins tend to enhance horizontal 'rip' cell circulation, which in turn tends to flush material offshore and out of the system, they may enhance shoreline erosion locally. The potential for such adverse impacts can be reduced through careful monitoring.

In terms of social factors, groins have both positive and negative impacts on recreational use values. Up drift the of the groin, where beach width is increased, recreational opportunities are enhanced. However, down drift of the groin, where beach width is decreased, recreational opportunities are diminished. Groins may benefit recreational activities such as fishing through increased access. However, groins may present a safety hazard to swimmers because of the complex circulation patterns that develop around them. They are generally regarded as unsightly and obtrusive, and as a result have a negative impact on scenic use values. By placing the groins below summer beach level such impacts can be minimized however.

In terms of environmental factors, adverse impacts of groins on resource and conservation use values are primarily temporary effects associated with bottom disturbance. There is some potential for groins to interfere with fish spawning areas or migratory routes. The increase in rocky intertidal habitat however, has a generally a beneficial impact on resource and conservation use values.

APPLICABILITY TO OREGON

Along the Oregon coast the potential applicability of groins is low. At a fundamental level, their effectiveness as a HAT is limited by the existence of wide surf zones and the occurrence of seasonal reversals of littoral drift that are characteristic of the Oregon coast. Along highly developed shorelines, groins might be used in conjunction with beach nourishment for the purpose of compartmentalizing the shoreline. In such settings, the use of groins to maintain a protective beach along shoreline areas immediately down drift of headlands (which are in effect groins) might also be considered. Groins are unlikely to be an attractive HAT along shorelines with low levels of development.

Differences in the nature of hazard alleviation needs (temporary versus permanent respectively), suggest that the potential applicability of groins as a HAT is lower along dune-backed than along bluff-backed shorelines of the Oregon coast.

4.3.2 BREAKWATERS

This option encompasses the deployment of wall-like structures aligned parallel to the shoreline and detached from the shore for the purpose of dissipating and/or redirecting incoming wave energy, thereby sheltering the shoreline area behind the breakwater and promoting the existence of a protective beach in this area. A breakwater is basically an attempt to mimic the effects of a naturally occurring offshore sandbar or rock reef.

In terms of the water depth at the base of the structure (and correspondingly the location of the structure relative to to the location of the shoreline), breakwaters and seawalls/revetments can be viewed as end members in a continuum of types of shore parallel structures. Here, the term breakwater refers generally to a structure whose base is always below water and as a result is continuously subjected to the full force of wave impacts, principally in the form of wave breaking.

Typically breakwaters are fixed rubble mound structures with a core of smaller more loosely packed materials covered by a layer of larger more tightly packed materials (Figure 4.13a). Besides quarry stone, various patented types of concrete blocks are commonly used to construct breakwaters. A variety of prefabricated structures are also employed. To provide hazard alleviation along a

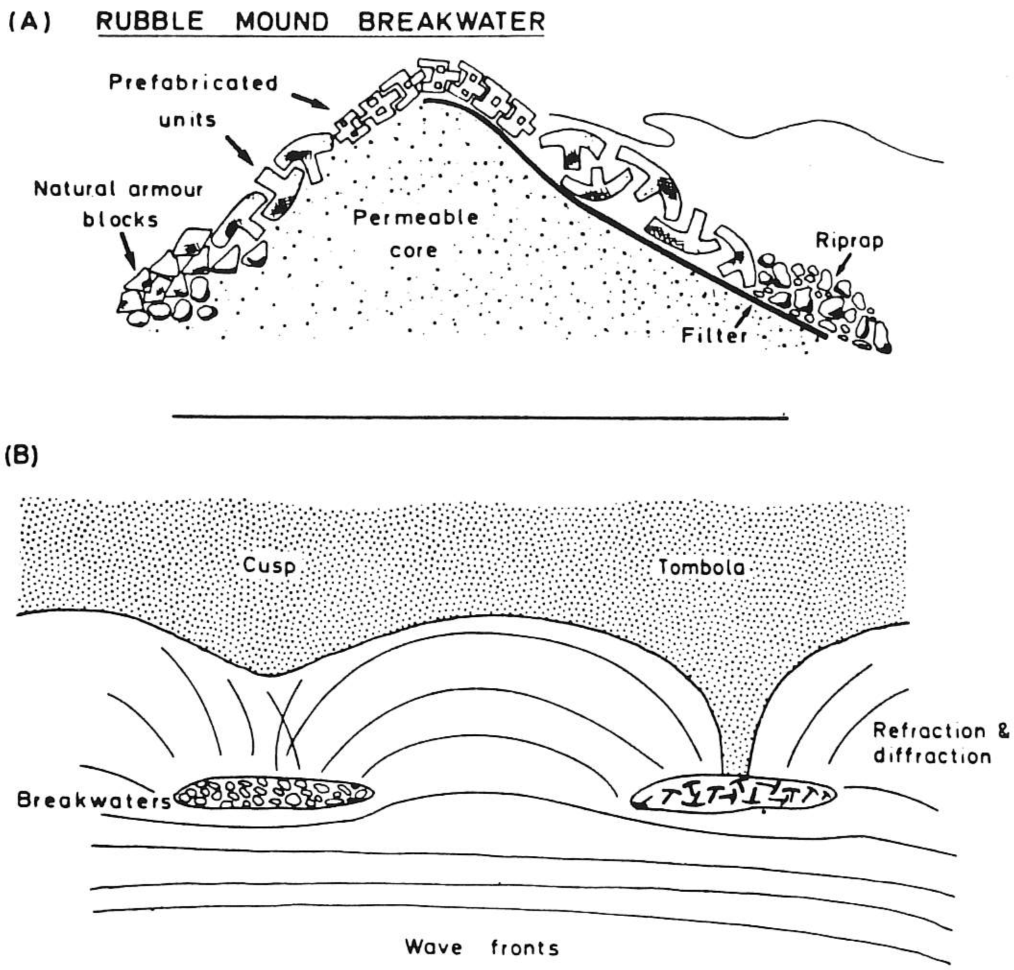


Figure 4.13 Schematic of Breakwater Design. a) Profile; and b) Plan (from Carter, 1988).

stretch of shoreline breakwaters are generally deployed in a series alongshore (i.e. segmented breakwaters). Breakwaters may be floating as well as fixed, however floating breakwaters are not considered here.

Breakwaters have been used worldwide as a HAT. In Japan for example, where they are a preferred HAT, numerous detached breakwaters have been built since the 1960's. A limited number of breakwaters were built in the U.S. as early as the 1930's. However, only recently has interest in the use of breakwaters as a HAT increased in the U.S., particularly on low wave energy coasts (e.g. Gulf Coast, Great Lakes), where submerged offshore breakwaters are preferred. Breakwaters have not been employed as a HAT in Oregon.

DESIGN ELEMENTS

Structure and Material Stability. Breakwaters are continuously subjected to the full force of wave impacts. Ensuring that breakwaters have the structural and material stability needed to withstand repeated direct wave attack is thus a primary design consideration. Breakwaters need to possess overall stability, that is the structure in whole and in part needs to remain in place even during episodes of extreme wave attack. Stability in this sense is basically determined by stone weight and stone placement. In this regard, relationships which predict stone weight as a function of incident wave conditions are given in the coastal literature. In terms of structural stability, collapse and failure as a result of scour around the base of the structure is a particular concern in the construction of breakwaters. Permeability is also a factor affecting structural stability: Increasing permeability decreases wave forces on the structure. With respect to material stability, the materials that makeup the structure need to durable enough not to break-up in response to continuous wave attack.

Trapping Efficiency. As noted above, a breakwater functions by dissipating incoming wave energy through breaking and/or redirecting wave energy through diffraction. Typically this results in some degree of accumulation of sediment in the lee of the structure and depletion of sediment along the adjacent beach (Figure 4.13b). Breakwater design, then, to a great extent centers around determining the degree transmission and transformation or, trapping efficiency, and in turn the anticipated nature and extent of shoreline realignment to be expected under design wave climate conditions. Rules of thumb associated with the basic elements of breakwater design are described briefly below. However, because a number of variables affect breakwater performance, designs need to be considered on a case-by-case basis and involve numerical modeling.

- **Structure Height/Offshore Distance.** Transmission refers to the amount of wave energy passing over or through the structure. Determined to a great extent by the height of the structure (and correspondingly its location relative to the location of the shoreline), transmission is a primary control on trapping efficiency and in turn shoreline realignment. Typically, the height of the breakwater relative to the depth of water at the structure (i.e. effective height) is such that some wave energy is allowed to pass over the structure. This allows for some sediment to be deposited in the lee of the breakwater while at the same time providing for the continued movement of some sediment alongshore. With respect to offshore distance, this means that breakwaters are usually placed somewhat farther offshore than the average width of the surf zone. If the structure is so high or so close to shore as to severely limit wave overtopping, then the potential for insufficient circulation and in turn excessive deposition in the lee of the breakwater is high. If the structure is so low or so far from shore as to allow regular wave overtopping, then the potential for excessive circulation and in turn insufficient deposition in the lee of the breakwater is high. As might be expected, lower structures possessing low transmission coefficients experience less wave force and tend to last longer (i.e. are more stable).

The suggestions made above with respect to structure height apply to structure permeability as well: Typically, the permeability of the breakwater is such that some wave energy is allowed to pass through the structure.

• **Structure and Gap Length.** Transformation refers to the amount of wave energy passing around the ends of the structure. Determined to a great extent by the length of the structure relative to the length of the average waves at the structure (i.e. effective length) and the length of the gaps between breakwater segments, transformation also controls trapping efficiency and in turn shoreline realignment. Typically, the length of the structure relative to the length of the average waves at the structure is such that some wave energy is allowed to diffract around the ends of the structure or through the gaps between structures. This allows for some sediment to be deposited in the lee of the breakwater while at the same time providing for the continued movement of some sediment alongshore. If the structure is too long or the gaps too narrow, then the potential for insufficient circulation and in turn excessive deposition in the lee of the breakwater is high. If the structure structure is too short or the gaps too wide, then the potential for excessive circulation and in turn insufficient deposition in the lee of the breakwater is high. A standard practice is to gradually increase the structure length/reduce the gap length until the desired balance between circulation and sedimentation is achieved. This commonly results in breakwaters that are on the order of 100-300 feet long.

Beach Nourishment. A standard practice in the construction of breakwaters is to place fill on the beach behind the structure so as to minimize impacts on the adjacent shoreline.

COSTS/BENEFITS

Costs of breakwater construction are high. In high energy environments, breakwaters are not only very expensive because large amounts of durable material are needed, but because construction, usually done from a barge or trestle, is difficult. Also, the need for regular maintenance is to be expected. As a result breakwaters tend to be cost-effective only when the uses that they are to protect are of high value. In low energy environments, breakwaters may be particularly cost-effective, because smaller structures can be used and as a result material costs are lower. Also, the need for maintenance is likely to be less frequent.

Although breakwaters may possess a relatively high design level and long design life, a high degree of technical uncertainty is associated with this HAT. Our current understanding of coastal processes and beach dynamics limits our ability to accurately predict breakwater performance. Even when extensive theoretical and experimental testing has been employed in breakwater design, breakwaters have suffered serious and costly damage in the form of collapse and breaching during storms.

In terms of potential adverse impacts on adjacent shoreline, our present ability to accurately predict shoreline response to offshore breakwaters is also limited. In this regard, there is a real concern that accumulation of material behind the breakwater will occur at the expense of depletion of material along the adjacent shoreline. This may result in the need for construction of additional structures along the shore.

In terms of social factors, breakwaters have generally positive impacts on recreational use values. This is because they promote the existence of a wide, sandy beach and therefore increase recreational opportunities associated with this resource. However, because complex circulation patterns tend to develop around breakwaters they may present a safety hazard to swimmers. Also, breakwaters may be regarded as unsightly and obtrusive, and thus as having a negative impact scenic use values. The reduction in scenic attraction associated with breakwaters is low, however, when compared to groins.

In terms of environmental factors, impacts of breakwaters on resource and conservation use values are not well known. They have the potential to adversely impact water quality, to interfere with fish spawning areas or migratory routes, and decrease benthic habitat. However, they do result in an increase in rocky intertidal and subtidal habitat.

APPLICABILITY TO OREGON

Breakwaters have moderate to low potential applicability. The hostile nature of the Oregon coast places a real limit on their use as a HAT: Not only would structures have to be large and therefore expensive, but their design life would be uncertain. Along shorelines where high intensity uses need to coexist with recreational use breakwaters may represent an alternative to revetments and seawalls because breakwaters do promote the existence of a sandy beach. Breakwaters are unlikely to be an attractive HAT along shorelines with low levels of development.

Differences in the nature of hazard alleviation needs between dune-backed and bluff-backed shorelines of the Oregon coast (temporary versus permanent respectively), suggest that the potential applicability of breakwaters as a HAT is lower along the former than the latter. In this regard, although breakwaters are most commonly employed along dune-backed shorelines, they have been shown to also be an effective HAT along bluff-backed shorelines.

4.3.3 REVETMENTS and SEAWALLS

This option encompasses the deployment of wall-like structures aligned parallel to the shoreline and attached to the shore for the purpose of dissipating incoming wave energy, thereby directly sheltering the area behind the structure. Revetments and seawalls prevent landward retreat of the shoreline by fixing the position of the shoreline. They are not intended to protect the fronting beach.

In terms of the water depth at the base of the structure (and correspondingly the location of the structure relative to to the location of the shoreline), revetments/seawalls and breakwaters can be viewed as end members in a continuum of types of shore parallel structures. Here, the terms revetment or seawall refers generally to a structure whose base is seldom below water and as a result is only rarely subjected to the full force of wave impacts, principally in the form of wave runup.

In terms of other types of wall-like structures, revetment and seawall are the terms given to structures intended to provide stability only against wave forces. Bulkhead is the term given to structures that provide stability against both gravity and wave forces. Retaining wall is the term given to structures that provide only slope stability. These ideal distinctions do not always hold along the Oregon coast, where revetments and seawalls commonly provide stability against gravity as well as wave forces.

Typically, revetments are fixed, sloping, rubble mound structures (Figure 4.14). They consist of several key components: filter fabric or bedding layer, armor stones, toe trench, sand topping, beach grass, and backshore drainage. The most conspicuous of these components is the armor layer which is commonly constructed from large stones. A variety of precast armoring is also available (e.g. T-shaped Dolos and four-legged Tetrapods). Occasionally, revetments are composed of loose materials secured in cages or wire frame gabions, which in turn allows smaller blocks to be used.

Typically, seawalls are fixed near-vertical concrete structures (Figure 4.15). Where the likelihood of direct or sustained wave attack is limited, geotextiles bags filled with sand or gravel may be stacked to form a gravity type seawall. Cantilevered type seawalls are constructed using timber, concrete, or steel.

Revetments and seawalls are used worldwide as a HAT. Prior to World War II, revetments and seawalls were the most common choice of hazard alleviation employed in the U.S. Unquestionably many buildings owe their continued existence to the presences of a seawall or revetment. However, increased understanding of the dynamic nature of shorelines, and of the potential adverse impacts and cumulative effects of hard stabilization over the last 20 to 30 years, has led virtually every state coastal management program to enact regulations limiting the proliferation of revetments and

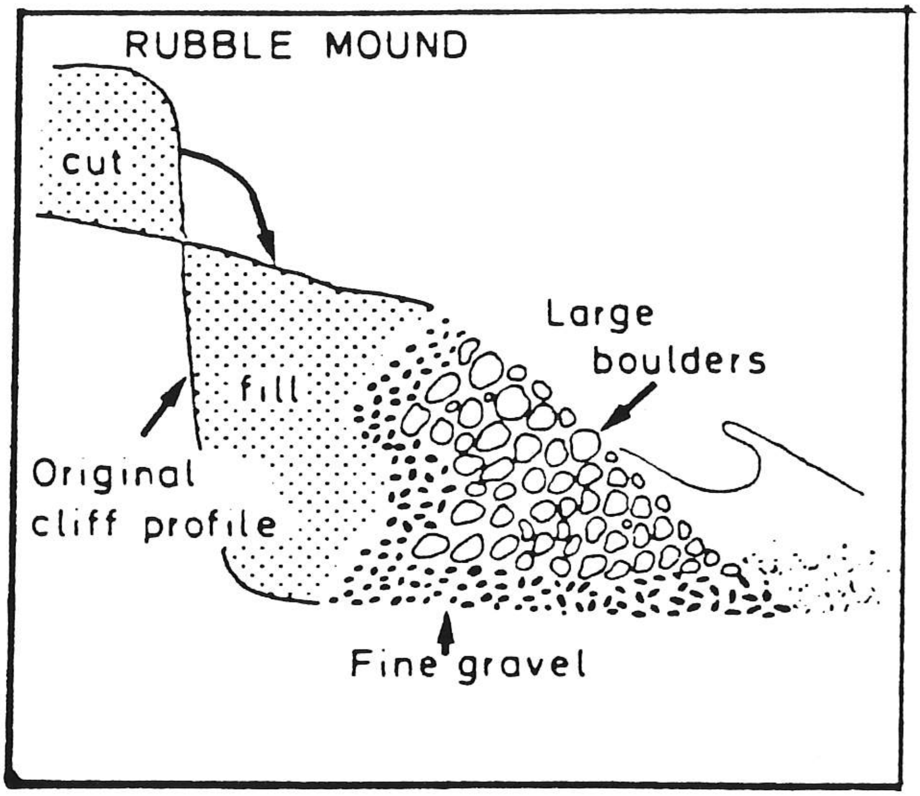


Figure 4.14. Schematic of Revetment Design in Profile (from Carter, 1988).

seawalls.

In this regard, Statewide Planning Goal 17: Coastal Shorelands (Implementation Requirement 5) requires that land use management practices and nonstructural solutions to problems of erosion and flooding be preferred to structural solutions. In addition to the Statewide Planning Goals, the Ocean Shore Law and the Removal/Fill Law contain standards including those requiring that alternatives to structural shore protection methods be considered. Still, rip rap revetments are the most commonly used method of hazard alleviation along the Oregon coast. In the Lincoln City littoral cell, for example, nearly half of the sandy shoreline is backed by revetments or seawalls.

DESIGN ELEMENTS

Structural Stability. The primary concern in the design of revetments and seawalls is the ability of the structure to stay in place when exposed to direct wave attack. The focus below is on factors affecting the structural stability of revetments, although many of the same considerations

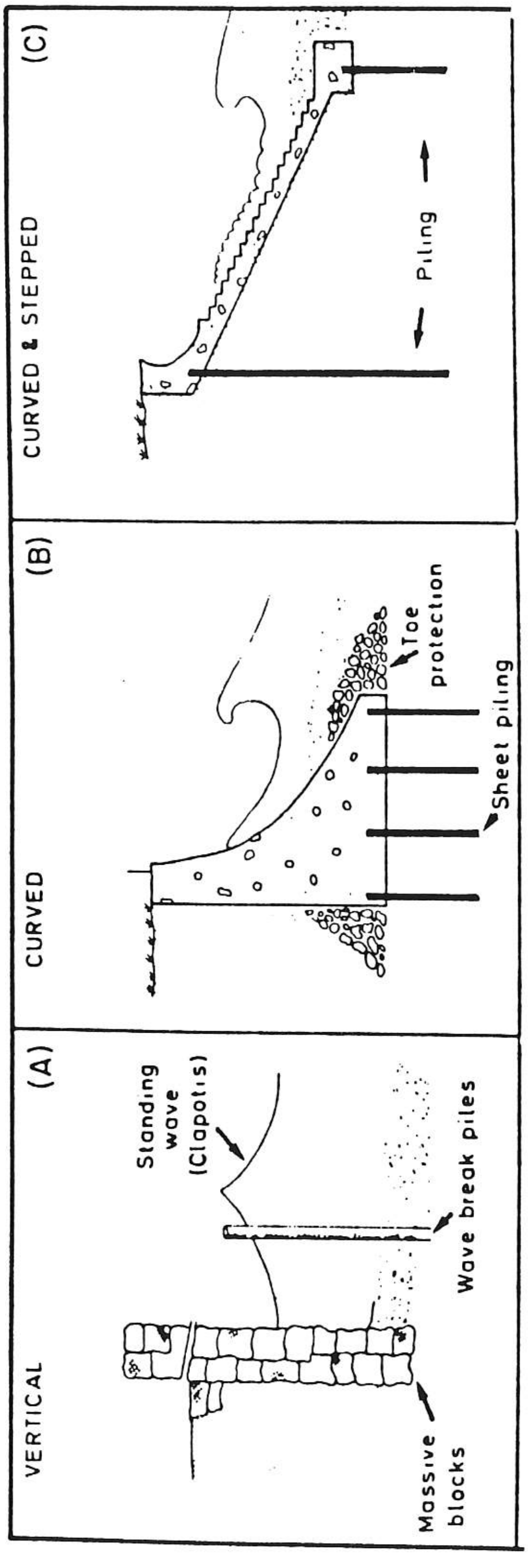


Figure 4.15. Various Types of Seawalls Designs in Profile (from Carter, 1988).

apply to seawalls as well.

• **Stone Weight.** Stated simply, an individual armor stone is immobile when its weight force exceeds those of the waves. Equations relating stone weight to wave forces can be found in the coastal literature (Figure 4.9). These relationships show that required stone weight is roughly proportional to the cube of the water depth. As a result, the further landward the structure is located the smaller the stone size is needed.

• **Stone Placement.** Armor stones can either be stacked so as to be self-supporting or stacked against and supported by the material landward of them. In both cases, to avoid structural failure care must be exercised in the selection and placement of armor stones. Rounded stones and stones with one very short or one very long axis should be avoided (i.e. spheres, plates, rods). The revetment is started in the toe trench. From there, armor stones are typically stacked in a two stone thick interlocking layer. Stones should be stacked at a slope of 1.5:1 (35 degrees) or less. Not only are gentler slopes more stable, but by dissipating a greater amount of wave energy they decrease the likelihood of wave overtopping. In this regard, curved or stepped seawalls are preferable to to vertical seawalls which cause near-perfect reflection of wave energy.

A particular concern with respect to structural stability of revetments and seawalls is scour around the base of the structure. It is common for a beach backed by a revetment or seawall to suffer a drop in level when the toe of the structure is exposed to wave forces. Toe scour may occur to the extent that the wall is undermined and requires repair. To prevent this from occurring it is necessary excavate the toe trench down to the maximum scour depth, roughly proportional to the significant deep water wave height. Because of their influence on the degree of reflection of wave energy, structure slope and roughness affect scour depth: The more reflective the structure the greater the scour depth. Similarly, the morphology of the fronting beach also influences scour depth: The more reflective the fronting beach the greater the scour depth.

Scour around the ends of the structure is also a concern with respect to structural stability of revetments and seawalls. If structures are not tied-in to the adjacent shoreline, waves may erode the junction between protected and unprotected sections of shoreline. Terminal scour may occur to the extent that the rear of the structure is exposed and vulnerable to wave attack. Repair will then be required to maintain structural stability.

• **Drainage.** Inadequate drainage may impede ground water flow from behind the structure, ultimately causing the structure to fail by bursting forward. Inadequate drainage of ground water may also contribute to collapse caused by undermining of the structure. Although revetments typically do not require special drainage systems, filter fabric or bedding layers are commonly employed in their design. They allow ground water to be released as well as prevent armor stones from sinking into the sand.

Material Stability. The materials that makeup the structure need to durable enough not to break-up in response to episodic wave attack.

COSTS/BENEFITS

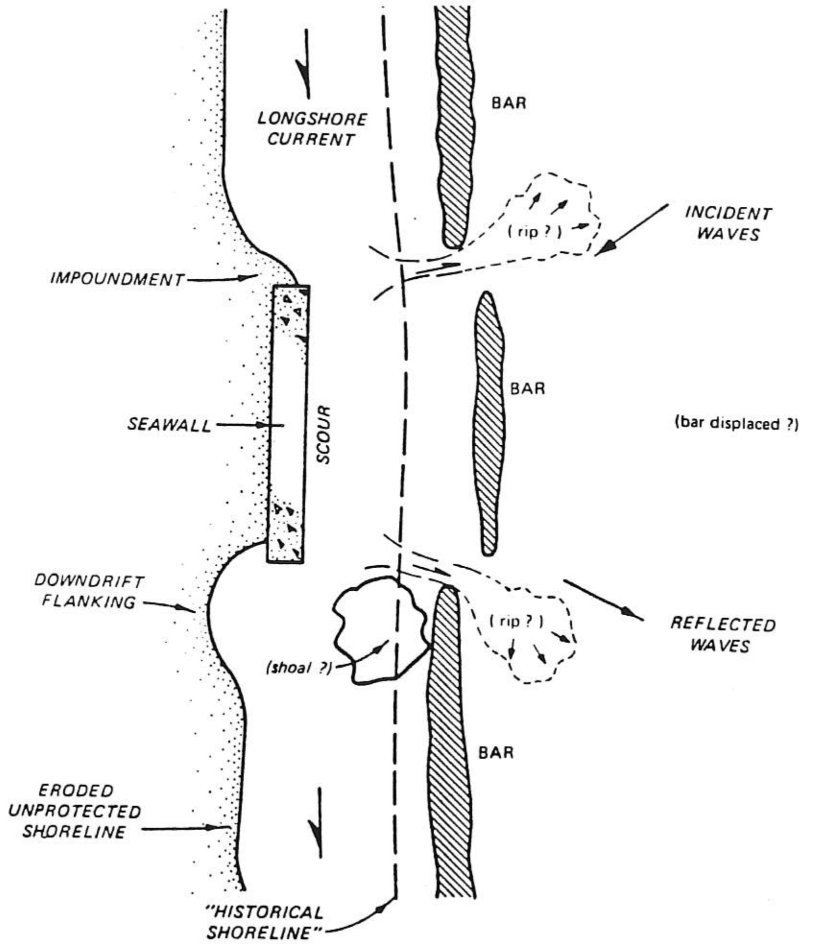
Costs of this HAT vary widely depending on the type of structure and the materials used. In comparison to other HATs, the cost of employing revetments and seawalls as a HAT are high. Rip rap revetments generally cost less than concrete seawalls. Also they are more easily maintained and modified. As a result, rip rap revetments tend to be more cost-effective than seawalls. Along the Oregon coast rip rap revetments typically cost on the order of $500 per linear foot of shoreline.

Revetments and seawalls afford relatively high design levels and long design lives. They can be very effective in providing hazard alleviation for the property backing the structure. They do fail on occasion however, and should not be regarded as permanent solutions. When compared to soft stabilization, technical uncertainty associated with revetments and seawalls is low. In part, this is because determining if material will move is a simpler design than determining the magnitude and rate at which material will move.

One major concern about the application of revetments and seawalls as a HAT is their potential to adversely impact adjacent shoreline (Figure 4.16a). On this topic there has been a great deal of debate. Although the response of the adjacent shoreline to the presence of revetments and seawalls is highly variable, it is generally agreed that the potential for adverse impacts both over the short and the long term does exist.

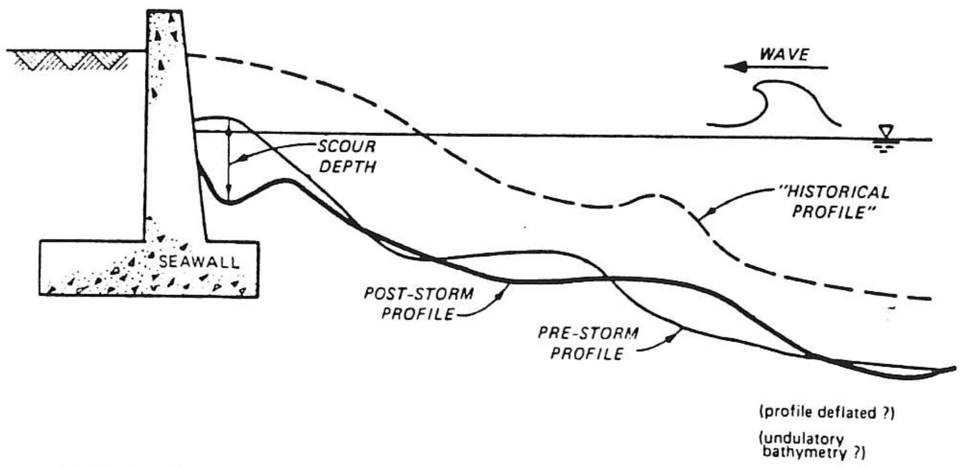
Over the short term, local erosion at the ends of the structure was noted above in the context of terminal scour. Another effect they may lead to flanking erosion is if the structure projects seaward enough that it functions like a groin, gaining sand on the up drift side of the structure and loosing sand on the down drift side of the structure. In this regard, the extent of down drift erosion has been shown to have a strong dependence on the length of structure. It is principally these effects, which lead adjacent property owners to also deploy structures, that lead to the proliferation of structures and hardening of long stretches of shoreline.

Over the long term, adverse impacts on adjacent shoreline may result from the retention behind the structure of sediment which would otherwise be released to the littoral system. To make up for the a)



Plan view of potential impacts of seawalls.

b)



Profile view of potential impacts of seawalls.

Figure 4.16. Potential Impacts of Seawalls. a) Plan; and b) Profile (from Kraus, 1988).

deficit in the sediment budget, sediment may come from unprotected adjacent shoreline. Excess erosion along the shoreline may manifest. Clearly the length of the structure will determine how much sediment is held behind the wall and thus removed from the littoral system. Because of the compartmentalized nature of the Oregon coast, where transfers of sediment are limited principally to exchanges within individual littoral cells, potential depletion of the sediment budget in response to shoreline hardening is a particular concern.

Similar concerns have arisen regarding the potential for revetments and seawalls to adversely impact the fronting beach (Figure 4.16b). Local erosion at the base of the structure was noted above in the context of toe scour. In terms of larger scale effects, loss of the summer berm does tend to occur sooner in front of structures than it does on adjacent unprotected beach. Also, loss of the berm tends to occur sooner in front of a seawall than it does in front of a revetment. However, with an adequate sand supply beaches with and without revetments or seawalls tend to exhibit similar behavior and variation with regard to storm and post-storm recovery. It is the response of the shoreline in areas experiencing net erosion, such as the Atlantic and Gulf coasts, that is of particular concern. In these areas narrowing of the beach in front of the seawall does occur over the long-term. Obviously, if the shoreline is moving landward than the beach will narrow relative to a fixed point. Such narrowing is not evident on a natural shoreline, where as the shoreline recedes it maintains a fronting beach in the process. Thus, owing to the loss of sandy beach, in areas experiencing net erosion the deployment of revetments or seawalls as a HAT is likely to have a negative impact on recreational use values. In this regard they may also limit beach access and as a result pose a safety hazard.

In terms of scenic use values, revetments and seawalls are typically regarded as unsightly and obtrusive, and thus as having a negative impact on scenic use values. At least for revetments, such impacts can be greatly reduced, however, by topping the structure with sand and planting beachgrass.

In terms of environmental factors, impacts of revetments and seawalls on resource and conservation use values are mostly temporary effects related to site disturbance during construction. Revetments and seawalls do have the potential to result in permanent loss of subaerial habitat. However, they may also be the only means of adequately protecting significant upland resources.

APPLICABILITY TO OREGON

Overall revetments and seawalls have moderate potential applicability. Their greatest potential as a HAT is along highly developed, bluff-backed shorelines. In this setting, where hazard alleviation needs tend to be regional and permanent, reasonable sized structures can protect the toe of the bluff from wave attack. They may also play a role in reducing the effects of weathering and increasing slope stability. The presence of the structure will do little to prevent the recession of the bluff top however. As a result, in most situations revetments and seawalls will need to be deployed in conjunction with options for mass wasting. Also, if maintaining a subaerial beach is a concern, then consideration will need to be given to beach nourishment in conjunction with the deployment of revetments or seawalls. Where critical facilities or significant resources warrant high levels of protection, hard stabilization may be necessary: The high values of the uses being protected may justify the relatively high economic as well as other costs of deploying revetments or seawalls.

Along dune-backed shorelines the potential applicability of revetments and seawalls is more limited. Owing to the nature of hazard alleviation needs in this setting, which are for the most part localized and temporary, the relative permanency of revetments and seawalls is likely to be unwarranted and may even be detrimental to shoreline stability over the long term. There may well be a use for relatively soft types of structures along dune-backed shorelines however (e.g. sand bags, gabions). Such structures are low cost, are easy to deploy and remove, and are effective against a moderate degree of wave attack occurring over a short duration. In other words, they may be well suited to meeting the hazard alleviation needs that exist along dune-backed shorelines.

If revetments and seawalls are to be applied as HATs along the Oregon coast, then there are several suggestions to consider. First of all, in most instances rip rap revetments will be preferable to seawalls: The availability of armor stone makes them particularly cost-effective and they tend to result in less adverse impacts. When there is insufficient space to install a sloping revetment, then a seawall may be the preferred alternative. Secondly, with respect to rip rap revetments, there should clearly be different designs for different types of shorelines. For example, relatively large structures may be warranted along reflective shorelines. Whereas along dissipative shorelines, adequate levels of protection may be afforded by relatively small structures. Finally, if rip rap revetments and seawalls are to be employed, they need to be done so in a manner that views hazard alleviation in an areawide context. For example, to understand the long-term effects of a structure on shoreline stability, sediment budget analysis should be carried out. To understand the short-term effects of a structure shoreline stability, numerical modeling of coastal processes in the vicinity of walls should be carried out. It may well be that potential adverse impacts are minimized when a single structure design is consistently applied along an entire segment of shoreline, not when a variety of structural types are applied ad-hoc on a lot by lot basis.

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4.4 OPTIONS FOR MASS WASTING

Options for mass wasting include a variety of techniques which reduce potential risk by improving slope stability and retarding weathering of the slope surface. Specific HATs included within this category are: vegetation management; drainage controls; slope regrading, reinforcing structures, and surface fixing (Table 4.6). Although they are treated separately here, these techniques are typically applied in combination. Options for mass wasting are principally applicable along bluff-backed shorelines with both high and low levels of use.

4.4.1 VEGETATION MANAGEMENT

This option encompasses the maintenance and/or enhancement of vegetation as a means of minimizing potential risk attributable to processes of mass wasting. The existence of vegetation generally improves slope stability (Table 4.7). It soaks up moisture, which unloads the slope and reduces driving forces. It also binds slope materials, which raises cohesive strength and increases resisting forces. Besides improving slope stability, vegetation retards weathering by protecting the slope surface from direct wind and rain impact.

Unless it presents a hazard of some sort (e.g. a tree on the verge of falling over), existing vegetation should be maintained. Establishing a green belt along the crest of the slope is a good practice, for example, as it provides a protective buffer for the slope face. This is particularly important in areas with very steep slopes. When vegetation has to be cleared, scattered selective removal is preferable to complete clearing. For example, it may be possible to simply thin out branches (e.g. windowing, interlimbing, or skirting up) rather than removing or topping trees, the latter of which should be discouraged (Figure 4.17). In this regard, it is preferable to wait until construction is complete to more accurately determine the need for vegetation removal.

Even when existing vegetation is maintained, vegetation enhancement is warranted in many instances. If absent, a band of vegetation along the crest of the slope should be reestablished. Vegetation should also be reestablished on patchy or barren slope faces. In this regard, a slope of 1.5:1 horizontal to vertical (33 degrees) or less should be considered manageable for the purpose of vegetation enhancement. Various species of grass, legumes, shrubs, minor trees, and mixtures of these species can be planted on slope faces and be expected to survive. Planting techniques commonly practiced in this regard include seeding, bare root planting, live staking, contour wattling, brush

TABLE 4.6 OPTIONS for MASS WASTING and APPLICABILITY MATRIX

VEGETATION MANAGEMENT (VM). Maintenance and/or enhancement of vegetation as a means of improving slope stability. Vegetation soaks up moisture, which unloads the slope. It also binds slope materials, which raises cohesive strength. Vegetation retards weathering by protecting the slope surface from direct wind and rain impact. Planting techniques commonly practiced include seeding, bare root planting, live staking, contour wattling, brush layering, and, mulching.

COSTS/BENEFITS
- Low Costs
- Low Technical Uncertainty
- Moderate Design Level and Life
- Minimal Adverse Impact on Adjacent Shoreline
- Positive Impact on Recreation, Scenic, Resource, and Conservation Use Values.

DRAINAGE CONTROLS (DC). Proper surface and subsurface drainage reduces the mass of the slope and improves cohesion of the slope materials. Typically drainage is controlled by diversion ditches and interceptor drains that carry water away from a slope and by horizontal drains, vertical drainage wells, and drainage tunnels to remove water from a slope.

COSTS/BENEFITS
- Variable Costs
- Moderate Technical Uncertainty
- High Design Level and Long Design Life
- Potential Adverse Impacts on Adjacent Shoreline
- Minimal Impact on Recreation, Scenic, Resource, and Conservation Use Values.

SLOPE REGRADING (SR). Complete or partial removal of unstable materials at the head of the slope reduces driving forces. Reconfiguration of over steepened slope profiles can also improve slope stability. Techniques typically employed include slope flattening and slope benching.

COSTS/BENEFITS
- Variable Costs
- Moderate Technical Uncertainty
- High Design Level and Long Design Life
- Minimal Adverse Impact on Adjacent Shoreline
- Minimal Impact on Recreation, Scenic, Resource, and Conservation Use Values.

REINFORCING STRUCTURES(RS). Application of external forces at the toe of the slope. Typical structures include buttress systems (walls and revetments), pile systems, and anchor systems. Reinforcing structures can be built from a variety of natural and artificial materials, including earth, rock, stone, timber, steel, and cement.

COSTS/BENEFITS
- High Costs
- Moderate Technical Uncertainty
- High Design Level and Long Design Life
- Potential Adverse Impacts on Adjacent Shoreline
- Negative Impact on Recreation, Scenic, Resource, and Conservation Use Values.

SURFACE FIXING (SF). Application of artificial surface fixing techniques to reduce physical weathering. Included among a variety surface fixing techniques is gunite or shotcrete, as well as masonry, slope paving, and a variety of rubber, asphalt, and synthetic compounds.

COSTS/BENEFITS
- Variable Costs
- Variable Technical Uncertainty
- Moderate Design Level and Life
- Minimal Adverse Impact on Adjacent Shoreline
- Negative Impact on Recreation, Scenic, Resource, and Conservation Use Values.

APPLICABILITY
- ● High
- ◍ Moderate
- ○ Low

SETTING — BLUFF-BACKED SHORELINE

H.A.T. (MASS WASTING)	Rural New	Rural Existing	Urban New	Urban Existing
VM	High	High	High	Moderate
DC	High	High	High	Moderate
SR	High	Moderate	High	Moderate
RS	Low	Moderate	Low	High
SF	Low	Moderate	Low	Moderate

TABLE 4.7 Positive and Negative Impacts of Vegetation on Slope Stability (from WSDE, 1993).

VEGETATION AND SLOPE STABILITY

Legend: (+) Beneficial to stability (–) Adverse to stability

MECHANISM	INFLUENCE
Hydrological Mechanisms	
Foliage intercepts rainfall, causing absorptive and evaporative losses that reduce rainfall available for infiltration.	(+)
Roots and stems increase the roughness of the ground surface and the permeability of the soil, leading to increased infiltration capacity.	(–)
Roots extract moisture from the soil which is lost to the atmosphere via transpiration, leading to lower pore-water pressure.	(+)
Depletion of soil moisture may accentuate desiccation cracking in the soil resulting in higher infiltration capacity (uncommon around Puget Sound).	(–)
Mechanical Mechanisms	
Roots reinforce the soil, increasing soil shear strength.	(+)
Tree roots may anchor into firm strata, providing support to the upslope soil mainly through buttressing and arching.	(+)
Weight of trees surcharges the slope, increasing normal and downhill force components.*	(+)/(–)
Vegetation exposed to the wind which transmits forces into the slope. (Degree of adverse effect is dependent upon exposure and health of vegetation. Typically a minor consideration for Puget Sound Inland Waterways.)	(–)
Roots bind soil particles at the ground surface, reducing their susceptibility to erosion.	(+)

layering, and, mulching (Figure 4.18). Mulches, which include hay or straw, wood fiber, jute netting, or fiber matting, have the additional use of protecting against rain and wind impact. Finally, vegetation should also be planted at the toe of the slope. Here, besides increasing slope stability, vegetation may reduce the effects of wave attack.

COSTS/BENEFITS

Costs of implementing vegetation management as a HAT are low. Clearly, maintaining existing vegetation is likely to be more cost-effective, and as a result more attractive than reestablishing vegetation. Although design levels and lives are low when compared to hard stabilization, vegetation management may afford a moderate design level and design life. Technical uncertainty is also relatively low, as many of these techniques are well established. Plantings are likely to be difficult

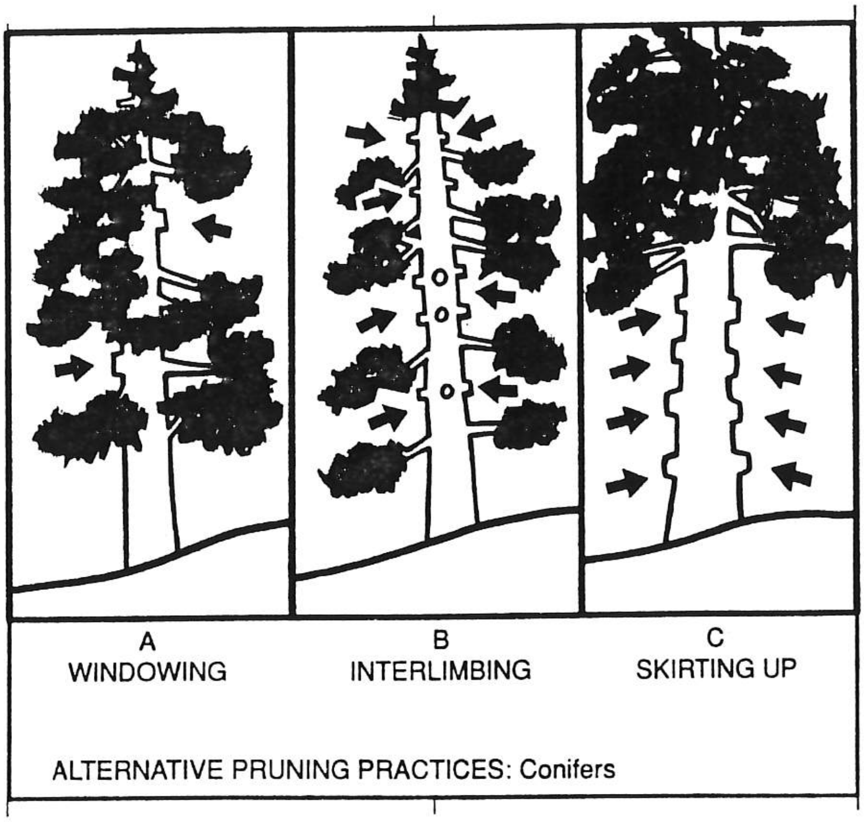

Figure 4.17. Pruning Techniques for Conifers (from WSDE, 1993).

to establish on severe slopes however. As a result, they may neither be technically nor economically desirable in such settings.

With respect to potential adverse impacts on adjacent shoreline, those associated with the application of vegetation management techniques are minimal Rather, they have generally positive impacts in this regard. Vegetation management also has generally positive impacts in terms of recreation, scenic, resource, and conservation use values. From the standpoint of the beach using public, vegetation management is likely to improve appearance and increase scenic use value. From the standpoint of the oceanfront property owner however, ocean views and hence value attributable to scenic attraction may be diminished to an unacceptable level.

APPLICABILITY TO OREGON

Vegetation management has high potential applicability. As noted in the context of siting, design, and construction standards, maintenance of existing vegetation has great potential applicability as a HAT along all shoreline types where new development is being considered. With respect to existing

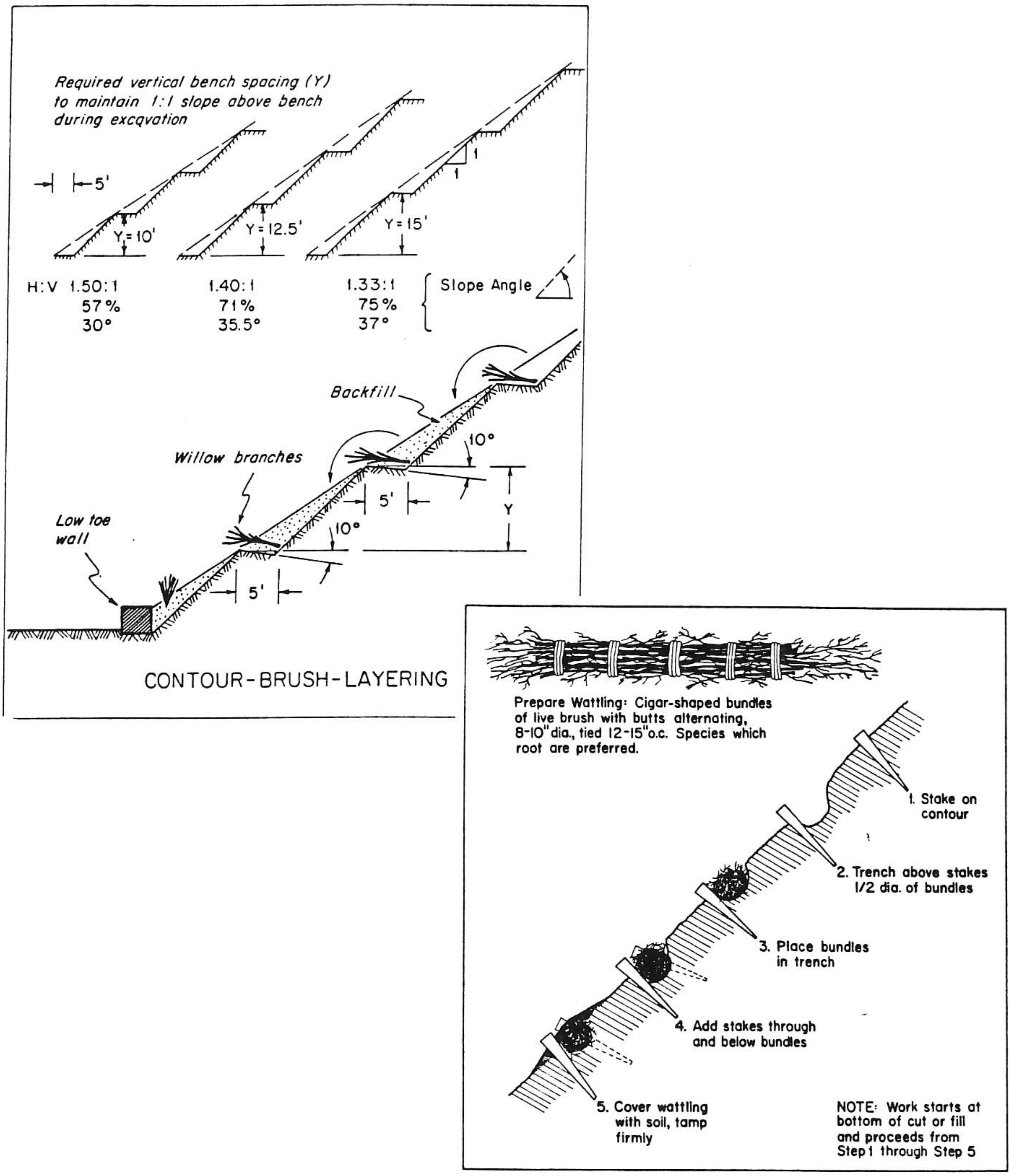

Figure 4.18 Contour Wattling and Brush Layering (from Gray and Leiser, 1982).

development along bluff-backed shorelines, potential applicability of vegetation enhancement is clearly greatest on slopes that are conducive to application of planting techniques (e.g. low bluffs and/or deep lots). In such situations, together with drainage controls and slope regrading, planting vegetation along the top and on the upper face of the slope and placing reasonably sized revetments at the toe of the slope may be an attractive alternative to large scale shoreline hardening. Even in areas with steep slopes vegetation enhancement has the potential to be an effective HAT.

The potential applicability of vegetation enhancement along dune-backed shorelines is considered in the context of foredune enhancement.

For a variety of technical, economic, and other reasons, it is suggested that together with drainage controls and slope regrading, vegetation management is most effective when carried out on an area-wide basis. In this regard, an area-wide management framework, as is currently provided for along dune-backed shorelines under Goal 18 (i.e. foredune management plans), needs to be developed for bluff-backed shorelines (i.e. bluff management plans).

4.4.2 DRAINAGE CONTROLS

This option encompasses the control of drainage as a means of minimizing potential risk attributable to processes of mass wasting. Surface and subsurface drainage is often a fundamental control on slope stability. Proper drainage, by reducing the mass of the slope materials will reduce driving forces. Also, by improving cohesion of the slope materials through a reduction in pore pressure, proper drainage will increase resisting forces. Drainage controls are often carried out in association with vegetation management and slope regrading.

Reduction of surface water flowing across the face of the slope and surface water that infiltrates the slope is typically controlled by diversion ditches and interceptor drains that carry water away from a slope. In this regard, drainage controls are often carried out in conjunction with slope regrading and may involve drainage of water filled areas (e.g. sag ponds) or conversely creation of storm water control ponds. In the context of site development, routing of storm water runoff and the location of drainage outlets need to be considered.

Compared to the control of surface water, lowering of the ground water level so as to lower water pressure and thereby improve slope stability is a more complex exercise generally involving formal slope stability analysis. Methods frequently used to improve subsurface drainage include the installation of horizontal drains, vertical drainage wells, and drainage tunnels. The effectiveness of these different types of drains, which may only flow under extreme conditions, varies depending on their size and permeability, among other considerations. The location of on-site sewage disposal systems, which inject water into ground water through the drain field, needs to be considered in this regard.

COSTS/BENEFITS

Costs of implementing drainage controls as a HAT are variable. Costs can be relatively low when pertaining to surface drainage prior to construction, but may be quite high when pertaining to subsurface drainage subsequent to construction, particularly with respect to treatment of deep-seated landslides. Having the potential to afford high design levels and long design lives, drainage controls can be an extremely effective means of improving slope stability.

Although many of these techniques are well established, technical uncertainty is moderate owing to potential technical complexity. The level of technical uncertainty is generally lower with respect to improving surface drainage than it is with respect to improving subsurface drainage: A detailed understanding of subsurface conditions may be difficult to achieve.

The potential for adverse impacts on adjacent shoreline to occur as a result of alteration of natural drainage patterns is high. Similarly, alteration of natural drainage patterns may negatively impact resource and conservation use values by negatively impacting habitat. Overall however, drainage controls are believed to have minimal adverse impacts in terms of recreation, scenic, resource, and conservation use values.

APPLICABILITY TO OREGON

The potential applicability of drainage controls is high. The greatest potential application of measures to improve either the surface or subsurface drainage is along bluff-backed shorelines. In this setting, potential applicability of drainage controls is likely to increase from the application of subsurface drainage controls in areas of existing development, to the application of surface drainage controls in areas of existing development, to the application of subsurface drainage controls in areas of new development, and finally to the application of surface drainage controls in areas of new development. Although more limited, the potential applicability of drainage controls along dune-backed shorelines may warrant consideration.

For a variety of technical, economic, and other reasons, it is suggested that together with vegetation management and slope regrading, drainage controls are most effective when carried out on an area-wide basis. In this regard, an area-wide management framework, as is currently provided for along dune-backed shorelines under Goal 18 (i.e. foredune management plans), needs to be developed for bluff-backed shorelines (i.e. bluff management plans).

4.4.3 SLOPE REGRADING

This option encompasses the complete or partial removal of unstable materials as a means of minimizing potential risk attributable to processes of mass wasting. Through a reduction in mass, selective removal of materials at the head of the slope reduces driving forces and improves slope stability. Reconfiguration of over steepened slope profiles can also improve slope stability. Besides reducing driving forces directly, slope regrading seals cracks which can carry water into the failure zone and thus indirectly reduces driving forces to improve slope stability. Slope regrading is often carried out in conjunction with drainage controls and vegetation management. A technique typically employed is slope flattening, which has been used successfully. Slope benching, which can present problems when misused, is also a technique that has been used successfully.

Replacement of unstable materials can also reduce risk attributable to processes of mass wasting. The use of light fill materials may be considered in this regard (e.g. wood product waste).

COSTS/BENEFITS

Costs of implementing removal or reconfiguration techniques are variable. The simple stripping of a near-surface layer can be fairly inexpensive, whereas high expense may be incurred in more complicated operation involving selective removal of large volumes of slope material based on formal slope stability analysis. Similarly, when carried out during initial site development these techniques can be fairly inexpensive, whereas high expenses may be incurred if they are carried out after structures are in place. Difficulty in employing these techniques increases along these same lines. Therefore, while these techniques have the potential to provide high design levels and long design lives, they also involve a moderate to high degree of technical uncertainty. In this regard, potential exists for adverse impacts on adjacent shoreline. For example, unloading the head of a small slide mass may also be unloading the toe of a larger slide mass. Social factors such as insufficient lot depth, may also limit the potential effectiveness of slope regrading techniques. Finally, slope regrading has the potential to both positively and negatively impact recreation, scenic, resource, and conservation use values.

APPLICABILITY TO OREGON

The potential applicability of slope regrading is high. The greatest potential is along bluff backed shorelines with low levels of existing development. Where sufficient lot depths exist, there is also a high potential applicability along bluff-backed shorelines with high levels of existing development, particularly in combination with other HATs. In such settings, for example, slope regrading in a manner that does not alter the underlying substrate, together with vegetation enhancement, drainage controls, and reasonably sized revetments may be an attractive alternative to large scale shoreline hardening. Along dune-backed shorelines, slope regrading is considered in the context of foredune enhancement.

For a variety of technical, economic, and other reasons, it is suggested that together with vegetation management and drainage controls, slope regrading is most effective when carried out on an area-wide basis. In this regard, an area-wide management framework, as is currently provided for along dune-backed shorelines under Goal 18 (i.e. foredune management plans), needs to be developed for bluff-backed shorelines (i.e. bluff management plans).

4.4.4 REINFORCING STRUCTURES

This option encompasses the use of slope stabilization structures as a means of minimizing potential risk attributable to processes of mass wasting. Through application of external forces at the toe of the slope, resisting forces are increased and slope stability is improved. Properly designed structures not only help to stabilize a slope by diverting and conveying water away from critical areas, but they protect the toe or face of a slope against scour by running water. Toe protection also affords protection from processes of wave attack. In this regard stabilization structures are also considered in the context of revetments and seawalls.

Typical structures include buttress systems (walls and revetments), pier and pile systems, and anchor systems (Figure 4.19). The latter two types are less likely to be applicable along shoreline settings than the former. Soil replacement (stone column replacement), and geotextile enforced slopes also qualify as reinforcing systems. Slope stabilization structures can be built from a variety of natural and artificial materials, including earth, rock, stone, timber, steel, and cement. Drainage control elements are usually incorporated into the structure. Slope regrading and vegetation management may also be incorporated into the design of a wall or revetment. As noted in the context of seawalls and revetments, structural stability is a primary concern in the design of slope stabilization structures. In this regard, the tendency in shoreline settings for the the lack of a firm foundation and active wave attack serves to complicate the stability analysis needed to establish wall and revetment designs.

COSTS/BENEFITS

Costs of deploying reinforcing structures are high. However, this HAT is generally capable of providing high design levels and long design lives. As a result high initial costs may be justified over the long term. Natural structures normally costs less but generally afford lower design levels and shorter design lives than artificial structures.

A moderate degree of technical uncertainty does exists in the application of this HAT. In this regard,

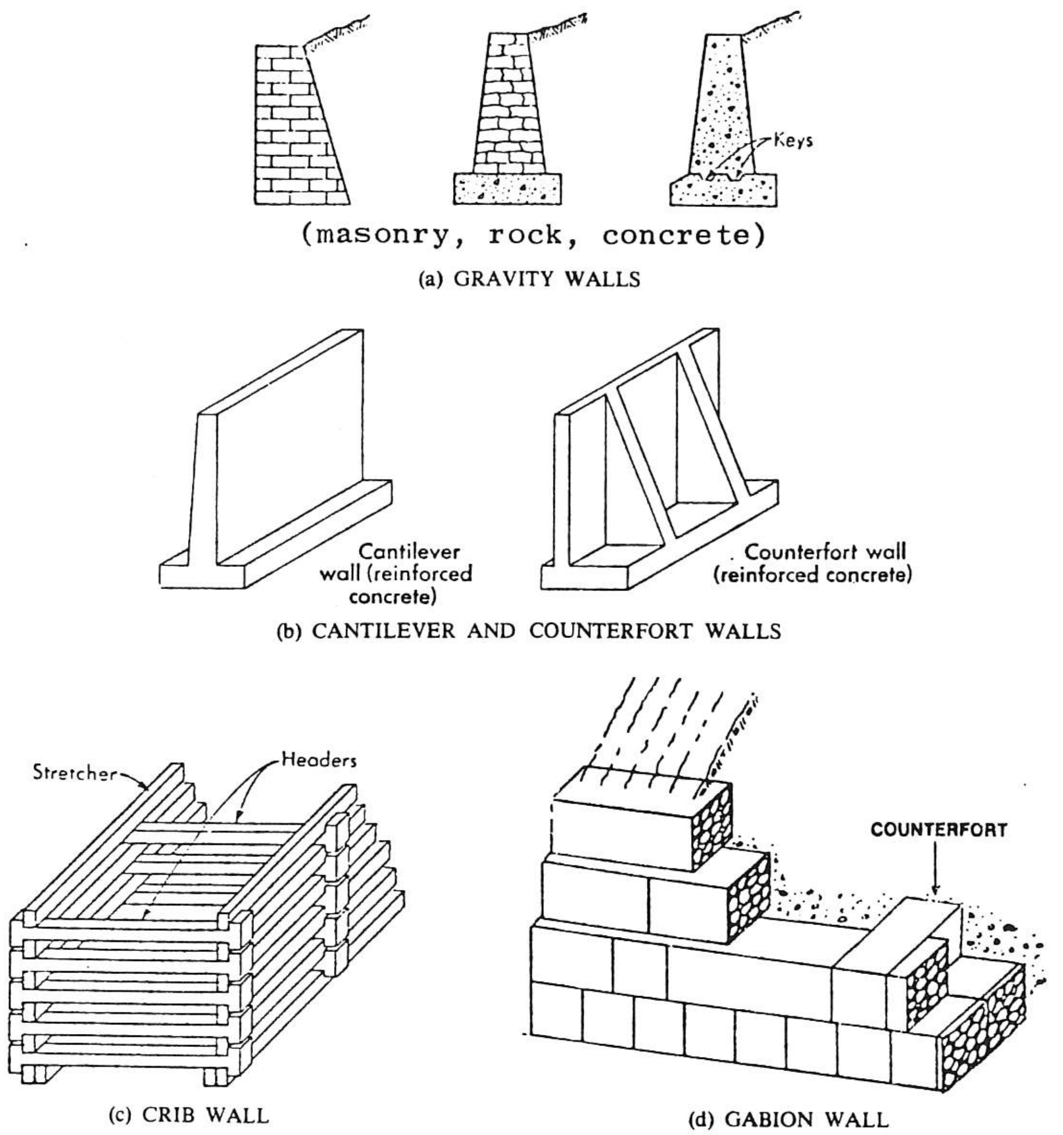

Figure 4.19. Various Types of Reinforing Structures (from Gray and Leiser, 1982).

potential for adverse impacts on adjacent shoreline exists (as noted previously in the context of shore protection structures). Also structures may have negative impacts on recreation and scenic use values. Because they are are better suited to vegetative treatment or modification, natural structures tend to have more positive impacts on recreation, scenic, resource, and conservation use values than do artificial structures.

APPLICABILITY TO OREGON

Reinforcing structures have moderate potential applicability. Many of the comments made earlier in reference to the applicability of revetments and seawalls apply to this HAT as well. Their greatest potential as a HAT is along highly developed bluff-backed shorelines. In this setting reasonable sized structures can reduce the effects of weathering and increase slope stability, as well as protecting the toe of the bluff from wave attack. In most situations reinforcing structures will need to be deployed in conjunction with other options for mass wasting (e.g. vegetation enhancement, drainage controls, slope regrading). Also, if maintaining a subaerial beach is a concern, then consideration needs to be given to the use of beach nourishment in conjunction with the deployment of reinforcing structures.

Because of the relatively high cost of deploying reinforcing structures, their potential applicability along shorelines with low levels of existing development is less than along highly developed shorelines. However, because of the relatively high levels of protection they afford, reinforcing structures may be warranted along shorelines where critical facilities or significant natural resources require protection.

4.4.5 SURFACE FIXING

This option encompasses the application of artificial surface fixing techniques as a means of minimizing potential risk attributable to processes of mass wasting. In many respects these techniques are intended to mimic natural effects of vegetation. Their role is to reduce the direct impacts of wind and rain on the slope surface and thereby reduce physical weathering. Also, these techniques may be used to seal cracks which can carry water into the failure zone and to increase material strength, both in turn increasing slope stability.

Included among a variety of surface fixing techniques is tieing down slope faces with posts and fencing. The application of gunite or shotcrete (i.e. concrete that consists of mortar with aggregate that is projected by air directly onto the slope surface), as well as masonry, slope paving, or even a variety of rubber, asphalt, and synthetic compounds are also examples of surface fixing techniques. Measures designed to increase internal cohesion may also be considered in this regard (e.g. chemical treatment, electrosmosis, thermal treatment).

COSTS/BENEFITS

Costs of implementing surface fixing techniques vary depending upon the technique. Some techniques are inexpensive while others are very expensive. In specific situations, particular techniques may afford moderate design levels and design lives. Similarly, particular techniques have a high degree of technical uncertainty, while others are well established. Measures designed to increase internal cohesion tend to be highly experimental, for example. In general, the greatest advantage afforded by these techniques is their ability to offer a rapid, relatively uncomplicated solution to slope surface degradation and shallow-seated slope stability problems.

Although their social and environmental impacts are variable, many of these techniques are generally regarded as having negative impacts on scenic, resource, and conservation use values.

APPLICABILITY TO OREGON

Overall, surface fixing techniques have moderate applicability potential. Potential applicability of specific techniques varies depending upon the technique and therefore needs to be evaluated on a case-by-case basis. The greatest potential for use of these techniques is along highly developed bluff-backed shorelines. Along less developed bluff-backed shorelines, the application of many of these techniques is unlikely to be cost-effective. The potential applicability of surface fixing techniques along dune-backed shoreline is considered in the context of foredune enhancement.

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4.5 INDIRECT APPROACHES

Like hazard avoidance, this group of HATs includes techniques which reduce potential risk by influencing, in this case indirectly, the location and design of new as well as existing structures (residential, commercial, industrial buildings) and infrastructure (roads, water, sewer). Also like hazard avoidance techniques, these indirect approaches are passive in that they are not intended to prevent or retard the processes of wave attack or mass wasting. Specific HATs included within this category are: educational programs; natural resource protection laws; and zoning controls and infrastructure planning. Indirect approaches to hazard alleviation are potentially applicable along all types of shoreline.

4.5.1 EDUCATIONAL PROGRAMS

Although educational programs are not a hazard alleviation technique in a strict sense, they may play a pivotal role in hazard alleviation. The range of hazard alleviation techniques taken into consideration by an individual is primarily a function of their level of awareness. Similarly, individuals perceptions of the potential risk from chronic coastal natural hazards and/or the perceived benefits of a given hazard alleviation technique influence their choice among alternatives. In regards to new development for example, the existence of realistic perceptions can minimize potential risk by influencing siting and design decisions. In regards to existing development, realistic perceptions can assist in ensuring that hazard alleviation is not achieved at expense of other values. Thus, more informed decision makers have a greater the likelihood of making better decisions about which HATs are most appropriate in given situations.

COSTS/BENEFITS

Development and implementation costs of educational programs are low. The non-regulatory nature of educational programs give them generally high political acceptability. Educational programs have the added benefit of building public support for regulatory approaches to chronic coastal natural hazards management. Further, educational programs, in the form of posting of signs and distribution of brochures for example, are particularly cost-effective when it comes to addressing public safety risks associated with coastal natural hazards (e.g. drowning).

Not all individuals in a community may see increased awareness about hazards as being beneficial, however. Rather, some may view the dissemination of information about hazard potential as bad publicity. In this regard, attention has to be given to the accuracy of the information being

TABLE 4.8 AUDIENCES, INFORMATION TYPES and LEVELS, and MODES of INFORMATION DISSEMINATION

TARGET AUDIENCE	TYPE/LEVEL OF INFORMATION	MODE OF INFORMATION DISEMMINATION
General Public (residents and visitors) *A 1*		
	CNH Identification and Mitigation *T1*	**Written Word**
	basic *L1*	Sign Posting *W1*
Private Landowners, Developers/Contractors, Realtors, Lenders/Insurers, Lawyers *A 2*	intermediate *L2*	Brochures and Displays *W2*
	advanced *L3*	Training Manuals *W3*
Local Officials (planning commission, city council, county board of commissioners) *A 3*	**CNH Management Program** *T2*	**A/V Presentation**
	basic *L1*	Lectures *P1*
Planners, Managers, Regulators *A 4*	intermediate *L2*	Workshops *P2*
Conslutants, Engineers and other 'experts' *A 5*	advanced *L3*	Short Courses *P3*

PREFERRED COMBINATIONS		
	A1, T1/L1 , T2/L1, W1-2, P1	*A2 ,T1/L1-2 , T2/L1-2, W2, P1-2*
A3, T1/L1-2 , T2/L1-2, W2, P1-2	*A4, T1/L2 , T2/L3, W3, P2-3*	*A5, T1/L3, T2/L2, W3, P2-3*

disseminated. No information is probably better than incorrect or exaggerated information, as the latter have the potential to result in a lack of credibility when more accurate information is obtained in the future. Also, attention has to be given to avoiding information saturation as this can lead to complacency. Further, because hazard alleviation is voluntary in nature, educational programs do not guarantee responsible actions.

APPLICABILITY TO OREGON

The potential applicability of educational programs is high. They have great appeal as an adjunct to direct methods of hazard alleviation along both bluff-backed and dune-backed shorelines. Their potential applicability may be somewhat greater with respect to new development where key decisions regarding siting and design have not been made. However, even with respect to existing development educational programs have the potential to influence and in turn improve HAT decision making.

Educational programs are most effective when specific types and levels of information are targeted to meet specific audiences needs. Table 4.8 summarizes different audiences, different types and levels of information, and different modes of information dissemination. Table 4.8 also identifies audience - information combinations that are likely to be applicable in Oregon. For example, it suggests that local officials can benefit from having a general knowledge of potential risks posed by hazards, alternative methods of hazard alleviation, and an understanding of the value tradeoffs to consider in the context of hazard alleviation. It also suggests that planners and regulators can benefit from basic technical knowledge about hazard identification and hazard alleviation alternatives. Finally, it suggests that consultants require a high level of technical knowledge about hazard identification and hazard alleviation alternatives.

4.5.2 NATURAL RESOURCE PROTECTION LAWS

This option encompasses laws generally designed to protect significant resource areas, but which in the process commonly result in some degree of hazard alleviation. When viewed as a HAT, natural resource protection laws are closely related to construction setbacks in that both attempt to reduce potential risk by influencing the location of development.

Natural resource protection laws are in place throughout the United States. Oregon's Statewide Planning Goal 17's requirements to protect "major marshes, significant wildlife habitat, coastal headlands, and exceptional aesthetic resources" as well as its requirement to maintain riparian vegetation are a form of natural resource protection law. With respect to dune-backed shorelines, Statewide Planning Goal 18's requirement that local governments and state and federal agencies "prohibit residential developments and commercial and industrial buildings on beaches, active foredunes, on other foredunes which are conditionally stable and that are subject to ocean undercutting or wave overtopping, and on interdune areas (deflation plains) that are subject to ocean flooding" also qualifies as a natural resource protection law. This particular requirement addresses hazard alleviation directly.

COSTS/BENEFITS

Development and implementation costs of natural resource protection laws are low. By prohibiting non-resource uses in protected areas, natural resource protection laws can be very effective in providing hazard alleviation. However, because they tend to apply to very specific areas, the overall effectiveness of natural resource protection laws is limited. By their very nature such laws generally have positive impacts on recreational, scenic, resource, and conservation use values. The regulatory nature of these programs gives them a moderate degree of political acceptability. In this regard, the complete prohibition of non-resource uses in a protected area is unlikely to be acceptable to most ocean front property owners.

APPLICABILITY TO OREGON

The potential applicability of natural resource protection laws is high. However, as noted above their applicability is likely to be limited to very specific shoreline segments, arguably ones where hazard alleviation needs are not acute.

In regards to the natural resource protection laws currently in place in Oregon, it is important to note that the Goal 18 prohibition on development in identified hazard areas only applies to dune-backed shorelines. There is no comparable prohibition on development and in turn protection of the bluff face and crest along bluff-backed shorelines. Further, because of its lack of specificity, the effectiveness of the Goal 18 prohibition on development in identified hazard areas is known to be questionable. Consideration of amendments to Goal 18 to make it applicable to bluff-backed as well as dune-backed shorelines, and to add greater specificity to some of its provisions are warranted.

4.5.3 ZONING CONTROLS and INFRASTRUCTURE PLANNING

This option encompasses the application of land use planning techniques to accomplish some degree of hazard alleviation by reducing the level of exposure to risks. Zoning controls can be used to encourage low development densities in identified hazard areas (e.g. down-zoning, clustering). Infrastructure planning can also be used to encourage low development densities in identified hazard areas (e.g. limiting the level of services).

All jurisdictions along the Oregon coast implement land use planning techniques through local comprehensive plans and zoning ordinances that are acknowledged to be consist with the Statewide Land Use Planning Goals.

COSTS/BENEFITS

Development and implementation costs of zoning controls and infrastructure planning are low. Land use planning techniques can be a very effective means of decreasing the need for hazard alleviation. Unfortunately, political acceptability tends to be low because indirect reduction in development density through the limitation of services capabilities or direct reduction in development density through down-zoning lowers expected property values. Still, because they generally allow some development to occur, land use planning techniques are not as severe in their impact on property values as natural resource protection laws. There may even be instances where the extension of services facilitates hazard alleviation. In terms of impacts on recreational, scenic, resource, and conservation use values, zoning controls and infrastructure planning are generally positive.

APPLICABILITY TO OREGON

The potential applicability of zoning controls and infrastructure planning is high. As noted above, local comprehensive plans and zoning ordinances are currently in place all along the Oregon coast. Reviewing these plans and ordinances in the context of hazard alleviation and amending them accordingly has the potential to result in a significant degree of hazard alleviation through a reduction in the level of exposure to risks along all shorelines.

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5 IMPLICATIONS FOR CHRONIC COASTAL NATURAL HAZARDS MANAGEMENT IN OREGON

This report outlines a decision-making framework in which a broad range of physical, social, economic, and environmental factors are taken into account in choosing a chronic coastal natural hazard alleviation technique (HAT). This framework is then applied generally to a wide range of HATs as a means of evaluating their potential applicability along the Oregon coast. Areas where improvements to chronic coastal hazards management in Oregon might be made have been identified through this process. A number of these is summarized below.

● This report suggests that integrated, area-wide approaches to hazard alleviation are attractive for a variety of reasons. Actions can be taken by decision-makers at all levels to encourage the development and implementation of comprehensive approaches to hazards management. Two specific actions are:

- Development of a planning framework specific to chronic hazards management at the scale of individual littoral cells; and

- Implementation of littoral cell management plans at the local level, on a voluntary basis, and in the form of cooperative state and local demonstration projects.

The decision-making framework outlined in this report, together with existing models of special area management plans (such as estuary management plans, wetland conservation plans, waterfront development plans, and foredune management plans) provide a basis for the development of 'littoral cell management plans'. While revisions to goals, statutes, or rules may be needed to facilitate implementation of littoral cell management plans, these revisions should not take the form of mandates.

● A variety of individual HATs are identified as having high potential applicability along the Oregon coast. In most instances the positive and negative attributes of the various hazard alleviation techniques need to be more fully evaluated. With respect to specific HATs:

- Construction setback formulas that take into account the full range of factors affecting shoreline stability in various Oregon coast shoreline settings warrant development and field testing.

- Beach nourishment, on a large scale within littoral cells where maintenance dredging occurs and on a smaller scale along dune-backed segments of shoreline, warrants attention. In this regard, a more detailed understanding of littoral cell sediment budgets is needed.

- Boulder berms and rip rap revetments, principally in the form of toe protection along bluff-backed shorelines and as temporary stabilization along dune-backed shorelines, warrant attention. Designs that are specific to conditions found along the Oregon coast need to be developed and field tested. The potential for adverse impacts and cumulative effects specific to the Oregon coast also need to be evaluated within the context of the littoral cell sediment budget.

- Vegetation management along dune-backed shorelines, and in conjunction with drainage controls and slope regrading along bluff-backed shorelines, warrants attention.

● Actions that might be taken over the short-term to encourage a more thorough evaluation of hazard alleviation needs and alternatives by decision makers at all levels include:

- Using the decision-making framework and the information in this report formally. In this regard, the decision-making framework outlined in this report can be used as a basis for making improvements to the existing permit application process pertaining to hazard alleviation in areas of existing development (see Appendix).

- Using the decision-making framework and the information in this report informally. For example, when applications for new development in potentially hazardous areas are received at the local level, planners might make information on potential chronic hazard alleviation alternatives available to the applicants.

- Provide opportunities for decision makers at all levels to become more informed about chronic coastal natural hazards and hazard alleviation alternatives. For example, regular workshops might be held for local planners, officials, state agency resource managers, realtors, developers, contractors, geologists, engineers, or the general public.

- Development of citizen volunteer and/or student networks might also be encouraged. Working at the scale of individual littoral cells, and in cooperation with the management and scientific communities, such groups could contribute to baseline data collection and analysis or to project monitoring.

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APPENDIX: MODEL H.A.T. ALTERNATIVES/IMPACTS ANALYSIS

This 'alternatives/impacts analysis' is an example of how ideas discussed in the accompanying report can be used by decision makers at local and state level. It details information to be provided by an applicant in order to establish that a need for hazard alleviation exists and that the technique they have chosen is the most appropriate means of meeting the identified need. Thus, it is basically an improvement upon what is currently in place. Like the existing procedure, the applicant has the burden of providing substantial evidence to support conclusions that the following standards have been met. In one form or another, these review standards can be found in local comprehensive plans and zoning ordinances, Statewide Planning Goals 7, 17, and 18, the Beach Bill, and the Removal/Fill Law. This site-specific format could readily be adapted into a procedure to identify comprehensive, area-wide hazard management strategies as part of a Littoral Cell Management Plan.

JUSTIFICATION. The application must set forth the facts and assumptions used as the basis for determining that there is a demonstrated need for hazard alleviation and how the proposed method of hazard alleviation meets this need. The types of information to be provided in this regard are identified below.

Social Setting. Indicate on a map and/or otherwise describe the level of improvements on the specific site where hazard alleviation is proposed, including any existing or proposed structures, their location and size. Indicate on a map and/or otherwise describe existing patterns and trends in land use along the segment of shoreline where hazard alleviation is proposed, including the types and levels of use (e.g. single family residential, commercial, recreational). Information on economic factors, such as property values in the area, may be included in this regard. If hard stabilization exists along this segment of shoreline, indicate on a map and/or otherwise describe its type and location relative to the specific site where hazard alleviation is proposed .

Physical Setting. Indicate on a map and/or otherwise describe the physical characteristics along the segment of shoreline where hazard alleviation is proposed, including key natural features (e.g. beaches, bluffs, headlands, inlets, etc.) and resources (e.g. fish and wildlife habitat). Identify the factors affecting the stability of the shoreline segment where hazard alleviation is proposed (e.g. wave attack, mass wasting, human activities) and indicate to what extent these factors, acting in isolation or in combination, constitute an active threat to existing uses or structures at the specific site where hazard alleviation is proposed.
For example:

If wave attack is identified as a threat, then present evidence which indicates the potential magnitude and frequency of overtopping (e.g. projected 100-year flood elevation) and/or undercutting (e.g. projected distance of dune retreat during a 100-year storm event);

If mass wasting is identified as a threat, then present evidence which indicates the potential magnitude and frequency of bluff recession due to weathering (e.g. projected average annual recession rate) and/or likelihood of ground movement due to landsliding (e.g. projected slope stability factor); and

If human activities are identified as a threat, then present evidence indicating the types and levels of human impact (e.g. graffiti, trampling) along the shoreline segment where hazard alleviation is proposed.

Proposed Hazard Alleviation Technique. Indicate through illustrations and/or otherwise describe the design of the proposed method of hazard alleviation, including how this design is appropriate at this location considering the factors affecting shoreline stability and to what extent this design is intended to minimize identified active threats (e.g. design level and life).

COMPATIBILITY. The application must list and/or otherwise describe the positive and negative consequences of employing the proposed method of hazard alleviation and indicate how the proposed method of hazard alleviation is compatible with existing uses and activities along the given segment of shoreline or will be rendered so through measures designed to reduce adverse impacts and cumulative effects The types of information to be provided in this regard are identified below.

Economic Consequences to be considered include projected development and implementation costs associated with the proposed hazard alleviation technique, projected direct and indirect value associated with the extension of property, infrastructure, and other uses attributable to implementation the proposed hazard alleviation technique, projected local, short-term adverse impacts attributable to implementation of the proposed hazard alleviation technique (e.g erosion of adjacent properties) , and projected regional, long-term cumulative effects attributable to implementation the proposed hazard alleviation technique (e.g. starvation of sand supply) .

Social Consequences to be considered include safety hazards attributable to implementation of the proposed hazard alleviation technique (e.g. generation of dangerous currents), positive and negative impacts on recreational uses and facilities as well as access to these uses and facilities attributable to implementation of the proposed hazard alleviation technique (e.g. gain or loss of subaerial beach, degraded or improved beach access), positive and negative impacts on scenic attraction of key natural features along the given segment of shoreline attributable to implementation of the proposed hazard alleviation technique (e.g obstruction of view, removal of vegetation), and positive and negative impacts on historic, scientific, educational or other such uses along the given segment of shoreline attributable to implementation of the proposed hazard alleviation technique.

Environmental Consequences to be considered include positive and negative impacts on natural resources along the given segment of shoreline attributable to implementation of the proposed hazard alleviation technique (e.g degraded or improved fish and wildlife habitat, air and water quality).

ALTERNATIVES. The application must list and/or otherwise describe alternatives to the proposed method of hazard alleviation either attempted or considered, and in the context of the two previous two standards provide facts to support the assertion that higher priority methods of hazard alleviation are not feasible. One or more of the following reasons may be used to demonstrate that higher priority methods of hazard alleviation are not feasible:

- Appropriately employed alternatives to the proposed method of hazard alleviation that have been attempted have failed to adequately address hazard alleviation needs;

- Alternatives to the proposed method of hazard alleviation will not address identified threats;

- Alternatives to the proposed method of hazard alleviation will result in a greater amount of negative consequences than would otherwise result from implementation of a higher priority alternative.

N.B. To increase the likelihood that the above standards are adequately addressed by applicants for hazard alleviation, it is recommended that a handbook along the lines of the accompanying staff report and a completed model application be made available to them.