A Geographic Information System and Remote Sensing to Support Community-based Coastal Hazards Planning in the Netarts Littoral Cell, Oregon

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ABSTRACT

A Geographic Information System and Remote Sensing to Support Community-based Coastal Hazards Planning in the Netarts Littoral Cell, Oregon

The 14-km long Netarts Littoral Cell, located on the northern Oregon coast, experienced episodic erosion as a result of the severe 1997-98 El Niño and 1998-99 La Niña. The erosion events led to the development of a unique partnership bridging scientists, stakeholders, and various planning agencies. To address these erosion issues, a regional demonstration project for littoral cell hazard planning was undertaken. To support the planning efforts a GIS inventory was created to spatially examine erosion hotspots and aid stakeholders in planning for future chronic and catastrophic erosion events. The GIS combines a physical, cultural, and hazards inventory, a shoreline change analysis, and coastal hazard risk assessment into a decision support tool to facilitate coastal hazards management. Shoreline change analysis examined historical aerial photos and new LIDAR remote sensing technologies, with results showing multiple scale patterns of erosion and accretion that have significant implications to both science and management. Hazard risk zones were generated using predictive erosion models and geological observations. The GIS and decision support system facilitates the examination of hazards to develop avoidance strategies. Through spatial queries, decision-makers can examine various data layers to guide future oceanfront development and redevelopment. The development of this GIS in conjunction with a stakeholder process facilitates community involvement from GIS design through implementation of identified hazard management recommendations. Implementing mechanisms will occur through adoption of local land use policies and changes to park master plans. The interdisciplinary nature of this project allows for the range of stakeholder opinions, thus creating a unique opportunity to address coastal hazards at a regional scale, the same scale at which coastal erosion processes operate.

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INTRODUCTION

Majestic coastal headlands, ancient forests, huge storm waves, and pristine estuaries characterize much of the Oregon coast. These headlands divide the coast into compartments, called littoral cells that constrain the seasonal flow of beach sands. Oregon's beaches and scenic ocean shorelines are among the most valued natural recreational resources in the state. Hundreds of thousands of visitors are attracted to Oregon's coastal parks and beaches year round, providing the basis for a mainstay of local coastal economies—tourism. Because of their recreational and aesthetic amenities, oceanfront areas also have attracted residential and commercial development. In recent decades, as the demand and price for ocean view and beachfront lands have escalated, large-scale, poorly sited development projects have become more common. One consequence of these practices is that winter storms and accompanying erosion and flooding place more and more oceanfront development at risk of loss, creating the demand for seawalls, revetments, and other shoreline stabilization structures that potentially threaten the physical integrity and aesthetics of the beach.

Oregon's coastal management program includes local comprehensive plans designed to regulate oceanfront development and shore protection in a manner that minimizes the risk of loss of life and property while protecting beach resources and amenities. However, in many cases, the controls and guidelines that have been put in place have been ineffective in anticipating exposure to hazards and loss.

Problems include: inadequate construction setbacks that have no basis in coastal process science; consulting geology and engineering reports that cater to the desire of developers to minimize the threat of hazards and maximize profits; lack of time and resources for adequate local or state peer review and criticism of such reports; and the chilling effect of the property rights movement on government's willingness to intervene in suspect development proposals. These issues often lead to parcel by parcel development and accompanying expanse of shore protection structures that threaten adjacent neighbors, rarely considering coastal hazards in a regional context, the scale at which these erosion processes operate.

These issues and problems along the Oregon coast have led to suggestions for regional, multi-hazards shoreline planning, where as much as possible development and shore protection decisions are made in advance for whole stretches of shoreline, and the best available science is incorporated to better understand risks and appropriate management strategies. Frameworks for such *littoral cell management planning* have been proposed (CNHPWG 1994; Marra 1995), risk zone assessment methodologies developed (Marra 1998; Komar et al. 1999, Priest 2000), and experiences from similar regional planning processes—those used to develop Oregon's estuary plans—incorporated.

The Netarts littoral cell, a 14 km long stretch of beach on the northern Oregon coast bounded by Cape Lookout and Cape Meares (Figure 1), was chosen in 1998 as a demonstration area for littoral cell management planning. For several reasons, the Netarts cell was a good choice. First, the 1997-98 El Niño and the La Niña that followed the next year resulted in costly beach and shoreline erosion in the cell—hazard impacts were recent and significant. Second, hazard mitigation proposals and governmental responses were highly controversial and publicized throughout the state and nation—visibility was high. Finally, although there were several lawsuits filed against The Capes developer, there seemed to be strong community interest in cooperative resolution of hazard issues and planning that would avoid similar problems in the future.

Recent erosion problems in the Netarts cell were associated with two strong El Niños (1982-83 and 1997-98) and subsequent erosion that continued in the years following those events. One area affected was Cape Lookout State Park, a popular day use and campground area on Netarts spit (Figure 1, Figure 2). Affected by both El Niño events, severe erosion all along the developed part of the park left State Parks with few options short of large-scale shore protection or park abandonment. Given their promotion of non-structural approaches to erosion control along the entire coast—they regulate beachfront alterations along the state's ocean shore—it would have seemed poor form for them to immediately resort to massive structural shore protection. Instead, the State Parks opted to treat the park as a natural laboratory to examine the potential for alternative shore protection structures. The second problem area within the cell was at The Capes, a gated development of condominiums and single family homes built in Oceanside, Oregon in 1994 (Figure 1, Figure 3). After several geotechnical assessments, The Capes developer received permission to construct an oceanfront row of condominiums just 10 feet from the edge of the high sandy bluff adjacent to the beach. During the 1997-98 El Niño, the northward migration of Netarts Bay's tidal inlet just to the south caused major toe erosion and over-steepening of the slope, leading to slumping and sliding at the top of the bluff. Eight oceanfront units had to be condemned. Unfortunately for the property owners, shoreline armoring to prevent additional loss was not an option because state policy prohibits hard structures on oceanfront areas developed after January 1, 1977, when Oregon adopted its coastal management program. However, few homeowners, if any, knew of this limitation prior to purchasing their homes.

Oregon State Parks contracted with Oregon State University Extension Sea Grant in spring 1998 to seek an assessment of shore protection options for the severely damaged Cape Lookout State Park. Extension Sea Grant suggested that an assessment of erosion problems and solutions for the entire littoral cell made more sense, given the interconnectedness of erosion problems in the cell and the likely need for a regional prescription. The regional planning methodology for littoral cells interested Tillamook County and the Oceanside-Netarts communities to develop a prototype plan for the area that could be applied to other littoral cells along the 80 km Tillamook County shoreline. A partnership was formed between the county, OSU Extension Sea Grant, the OSU College of Oceanic and Atmospheric Sciences (COAS), Oregon State Parks and Recreation Department (OPRD), the Department of Land Conservation and Development (DLCD), the Oregon Coastal Management Program (OCMP) and the Department of Geology and Mineral Industries (DOGAMI), who at the time was beginning to develop a county-wide inventory of natural hazards (Good 1998).

An important participant in this partnership has been a stakeholder group that has provided insight into community values of citizens that live and work in the immediate area. A 13 member stakeholder group was self selected and consisted of homeowners, members from the communities of Oceanside and Netarts, land managers, state and local planning agencies, representatives of homeowner associations, and watershed councils. The purpose for this local group was to identify avoidance strategies and build support for recommendations that arise from the coupling of science and community values. This group agreed to make decisions based on group consensus. Through a series of technical and public workshops, the stakeholders were educated about coastal processes and participated in several hazard analysis workshops. The stakeholders placed education of the community as a high priority. The education outreach program they have developed targets individuals and community groups who may play a role in facilitating or thwarting implementation.

Oregon State Parks and the OCMP provided funding to Oregon State University for development of a geographic information system (GIS)-based littoral cell inventory—the subject of this research paper—to support a stakeholder-based littoral cell planning process. The guiding goal is to design a GIS that will incorporate the best available science to address the range of issues raised by local and state coastal management agencies and local stakeholder concerns.

The Netarts littoral cell management planning process is by design a demonstration project, one where risk assessment methods incorporating the best available science are combined with local stakeholder and public preferences to reach management solutions. This process is adaptive and evolutionary, with the end products being both a local littoral cell plan *and* a "how-to" model or template for development of similar plans along other shorelines in the county, state, or other regions where development and coastal hazards have resulted in conflicts between public and private rights.

This report presents the process of GIS development for the Netarts littoral cell and is structured as follows. First, ***background*** on coastal hazards that affect the Oregon coast is presented, followed by a description of the Netarts littoral cell and how coastal hazards affect that area. Additional background is presented on the Oregon Coastal Management Program as it relates to erosion and oceanfront development management, the concept of littoral cell management planning and developmental work on risk assessment for dunes and bluffed shorelines, and the use of GIS for decision support and planning. Next, the ***objectives and methods*** for developing the GIS are presented. The next section, ***results and discussion***, describes the design and features of the GIS and its use in decision making. Finally, ***conclusions and recommendations*** detail lessons learned and suggestions for improving the use of GIS in support of littoral cell management planning.

BACKGROUND

Regional Setting and Coastal Hazards

Regional Tectonics and Geology

The regional tectonic setting of the Pacific Northwest is important to the patterns of erosion along the Oregon Coast as a whole and the Netarts littoral cell. Most significant is the presence of the Juan de Fuca Plate that extends along the coasts of Washington, Oregon, and Northern California approximately 12-40 miles offshore (Figure 4). The sea floor spreading center along the Juan de Fuca Ridge pushes the Juan de Fuca Plate toward the North American Plate. The Juan de Fuca Plate is subducted beneath the North American plate along the Cascadia Subduction Zone (CSZ), and is responsible for the volcanic activity found in the mountain ranges of the Pacific Northwest as well as very large, infrequent earthquakes of magnitude 8 to 9 or greater. Recurring on average about every 500 years, these earthquakes release the strain that has accumulated along the locked plate boundary (Atwater and Hemphill-Haley 1997). At the offshore plate boundary, rapid uplift occurs, generating large tsunami waves. Onshore, subsidence occurs, resulting in permanent flooding of lands along parts of the coast, including the Netarts area. Evidence for previous subduction earthquakes estimated to be of a magnitude 8.0 – 9.0, is widespread along this coast (Atwater 1987, Darienzo and Peterson 1990, Peterson and Priest 1995). Along the eastern bank of Netarts Bay, evidence for this last great earthquake exists in the form of submerged tsunami deposits overlying former marsh surfaces. Based on Japanese tsunami records, the last earthquake occurred on January 26, 1700 (Satake et al. 1996). The period following these subduction events is characterized by uplift of the land relative to sea level rise.

Through these tectonic processes, coastal mountain ranges have emerged fronting the Pacific Ocean. Most of the Pacific Northwest coastline is backed by high sea cliffs, long wide beaches and dune systems. Along the northern Oregon Coast, there is considerable diversity in the shoreline features. The most dominant features are massive basalt headlands that jut out into deep water. These basalt headlands are quite resilient to the onslaught of wave attack. As the land between the headlands eroded more rapidly, pocket beaches formed. The areas between these headlands are known as littoral cells Komar 1986). There are 21 such littoral cells in the Pacific Northwest. They have been identified by the sediment composition in each cell and provide evidence of historic sea level rise. The sediments on the beaches in the Pacific Northwest come from a variety of sources, and were transported to their current littoral cells during lower sea levels. The three major sources of sediments are the Klamath Mountains in Northern California, the rivers of the Coast Range, and the Columbia River. Distinct sediment composition differences around headlands indicate a closed sediment or littoral system boundary (Clemens and Komar 1988). Within each littoral cell, various sources (rivers, bluff erosion) and sinks (losses into estuaries, offshore deposition) of sediments can be quantified to determine a sediment budget. Sediment budgets can be used to better understand historic erosion and to better predict where future shorelines may be. Sediments grain sizes play an important role in erosion. Different sediment sizes control the beach, the coarser the sediment, the steeper the beach. The steeper the beach, the higher the run-up and the faster the beach responds to large wave events and other wave forcing mechanisms. The tectonic setting on the coast of the Pacific Northwest interacts with climatic changes occurring on geological time scales to control the distribution of littoral cells, sediments, and shoreline location.

Sea level rise occurs primarily as a result of the melting of the polar ice sheets, and enhances the erosion potential along the Oregon Coast. Global sea level rise is estimated to be about 2 mm / year. In the Pacific Northwest, the North American plate is rising as a result of the subduction of the Juan de Fuca Plate. Differences between rates of sea level rise and rates of tectonic uplift, known as relative sea level rise, vary on the Oregon Coast; in some areas the coast actually rises faster than sea level. In Netarts and the Tillamook area, relative sea level is rising at approximately 1 mm / year (Komar 1997, Vincent 1989) (Figure 6). Relative sea level rise effects erosion by decreasing the buffering width of the beach, allowing elevated water levels and waves to erode the shoreline as part of natural climatic and geological processes. Climatic variability effects erosion on time scales ranging from seasonal, to interannual, to interdecadal, to geologic scales.

Coastal Processes and Climate Variability

The Pacific Northwest, known for its extremely dynamic ocean environment, can be characterized by the seasonal fluctuations that continuously reshape the shoreline. These dynamic coastal processes are largely responsible for the patterns of erosion and accretion. Once humans get in the way of these coastal processes, they become known as coastal hazards. To understand coastal hazards, it is necessary to understand basic coastal processes, seasonal changes to these processes, and how these processes contribute to erosion. The erosion potential also increases as a result of longer term periodic climate fluctuations such as El Niño, La Niña, and the Pacific Decadal Oscillation.

The wave climate in the North Pacific is one of the most extreme in the world with strong seasonal changes (Figure 7). Long fetch areas and strong winds associated with storm systems in the North Pacific create large wave heights with long periods (Tillotson and Komar 1997). As these waves break on the beach, the wave energy is dissipated in the surf zone. When the wave energy hits the beach, the swash rushes up the beachface and then pours back into the ocean. The steeper the beach, the larger this swash excursion (Holman and Sallenger 1986, Ruggiero et al. 1996). As waves reach the coast and break on a sloping beach, they generate currents in the nearshore that are responsible for sediment transport (Basco 1983). These nearshore currents range between two types of circulation, rip current cells, and longshore currents. The first is a cell circulation system that consists of onshore wave energy and offshore rip currents. Rip currents tend to form when waves break mostly parallel to the beach. The second current circulation type is a longshore current that is generated by waves breaking at an oblique angle to the beach (Komar 1998c). Waves and currents are superimposed on varying water levels dominated by tidal influences. The tides along the Pacific Northwest Coast are moderate with an average tidal range of about 3.7 m (12 feet). The tides are mixed semi-diurnal, meaning that there are two high tides and two low tides of unequal height. By measuring tide levels, differences between measured and predicted water levels can be examined. Factors affecting changes in water level are important to understanding shoreline erosion.

Most causes of discrepancies between measured and predicted tides can be tied to seasonal meteorological factors such as strong winds, ocean currents, water temperature, and changes in atmospheric pressure. Strong winds, especially when accompanied by frequent storms, can result in a *storm surge* that piles water up on the coast raising nearshore water elevations. Ocean currents, driven by the prevailing winds, are effected by the Coriolis force. This force is caused by the rotation of the earth and serves to deflect currents to the right in the Northern Hemisphere and can also change water elevations. Atmospheric or barometric pressure differences also play a role in changing water levels. Low pressure systems result in an increase in elevation of sea water level, while high-pressure systems suppress water levels. Colder water is denser, also leading to a decrease in water levels. Conversely, warmer water is less dense and due to the thermal expansion of water takes up more volume leading to an elevation of water levels.

During the winter, storms generate large ocean waves and winds that approach the coast from the southwest. Wave attack results in longshore variability of erosion that can be attributed to the presence of rip embayments. Rip embayments are created by rip currents scouring out pockets of sediments and steepening the slope (Komar 1997). This channels wave run-up into a focal point and increases wave run-up with an increase in beach slope. Rip currents scour out a cross shore channel through offshore sand bars that enables waves to travel relatively unimpeded to the shoreline before breaking, without first dissipating much of the energy. These storm waves from the southwest drive longshore currents that pull sediments into offshore sand bars and transport sediments toward the northern end of the littoral cells (Komar 1986, Peterson et al. 1990). In effect, this winter transport lowers the beach profile and its ability to buffer extreme storm events. The same winds that drive the longshore currents also cause a seasonal reversal in ocean currents. The northward flowing California Current is deflected against the coast of Oregon by the Coriolis force and elevates water levels. Winter in the Pacific Northwest also means more low pressure storm systems that result in an increase in water heights due to lower barometric pressures. Frequent storms in the winter can pile water up along the coast, resulting in significant storm surges. In general, water levels are higher in the winter than in the summer (Huyer 1983, Komar et al., in review). Summer in the Pacific Northwest brings smaller significant wave heights and a wind reversal. Summer winds are typically from the northwest, causing upwelling that decreases the water temperature, increasing water density and lowering water levels. The net result of these winds is to generate longshore currents that transport sediments to the south and back onshore, building up the beach profile. Combining these seasonal changes in sediment transport yields the net littoral drift (Figure 9). It has been suggested that along the coast of Oregon the net drift is zero when averaged over a several year period (Clemens and Komar 1988, Komar 1997). Evidence for this includes the accretion of sediments on both sides of jetties as opposed to only one side, which would indicate uni-directional drift. This zero net drift process, however, breaks down during an El Niño event and has significant erosion consequences to the Pacific Northwest that will be discussed later.

Seasonal fluctuations contribute heavily to the amount of erosion that occurs. The two most important factors to erosion of beaches, dunes, and sea cliffs are measured tide levels, and the wave run-up. Erosion of dunes and beach occurs when the total water level (tide levels + wave run-up) reaches a higher elevation than the toe of the dune. Erosion of this toe creates an oversteepened scarp that eventually seeks to reach a stable angle of repose, causing erosion from the top of the scarp face. Bluff erosion has similar erosion catalysts, but with additional complications.

Bluff erosion depends primarily on the tide water level, wave attack, and bluff composition (Shih and Komar 1994, Benumof and Griggs 2000). Coastal bluff erosion generally occurs in a series of steps. During the first step, erosion of the bluff toe by waves and slope weathering by physical processes occurs, resulting in an over-steepening of the sea cliff face. At some point, slope failure occurs and blocks of various sizes may slide, fall, or topple. The final forcing event for bluff failure could be (a) exceeding some critical slope stability angle, (b) exposure of weak rock layers in the bluff face, (c) unusually high ground water table, (d) an earthquake, or (e) extreme wave attack. Talus debris is gradually removed by waves. Depending on how much debris accumulates, it can temporarily protect the bluff from wave erosion; where debris continues sliding seaward, additional block failures can occur, especially in soft soil bluffs (Priest 2000). This bluff erosion contributes sediment to the beaches and makes up an important component in sediment budget considerations.

Interannual Variability in Erosion Processes

El Niño: El Niño is a periodic phenomenon resulting from a breakdown of the equatorial trade winds. These trade winds normally elevates warm water in the western end of the equatorial Pacific. When these winds dissipate, the potential energy of this warm water is released, and a wave like bulge travels east toward South America. When this warm water wave reaches the coast of South America, it splits, part traveling north and part to the south. Both waves are held against the coast by the Coriolis effect, which increases in intensity and water elevations at higher latitudes. This phenomenon has a host of consequences. Most important to erosion is a temporary rise in sea level along the coast (Komar 1986, Komar *et al.* 1988, Komar and Good 1989, Komar 1997). The rise in sea level due largely to this warm water bulge significantly increases measured sea level heights 30 to 60 cm above seasonal averages (Komar *et al.* in review) (Figure 10). The elevated water levels move the shoreline further inland and allow waves to attack coastal properties more directly. For example, during the 1982-83 El Niño, sea levels on average were 35 cm above predicted tide levels, with extreme storm events elevating sea levels to 85 cm (Komar 1986). When considered on the beach in front of Cape Lookout with a slope of 2.5° this 85 cm would move the shoreline location 18 meters inland. Add on the effect of 10 meter wave heights, and it is no wonder that there has been major erosion at the State Park in recent years.

The other important El Niño consequence is the southerly shift in the storm track that results in southerly waves striking the coast at a more oblique angle causing greater than normal littoral drift to the north. This increased drift scours sediments from the south end of the cell lowering the buffering capacity of the beach and deposits the sediments in then north. Additionally, the unrestricted tidal inlets, such as Netarts Bay, tend to deflect to the north as another result of the increased northward currents (Figure 11).

In the Netarts littoral cell, the actual El Niño pattern resulted in a scouring of sand from the southern end of the cell along Cape Lookout State Park. The decreased beach levels provided little protection from large winter waves, causing overwashing and flooding into the park campground. The sediment transported to the north results in a decrease in the seasonal beach cut at the northern end of the cell, with minor accretion (Revell and Komar submitted 2000). The increased northward transport deflects the Netarts Bay tidal inlet, eroding the beach and toe of the sandy bluff underlying the Capes development. The deflection of the deep water channel acts like a rip current, allowing waves to attack the shoreline more directly without dissipating much of its energy. These general patterns of El Niño erosion have been seen in historical aerial photos at both The Capes and Cape Lookout State Park. For the first time, during the 1997-98 El Niño, application of a new remote sensing technology, LIDAR, enabled patterns of shoreline change at a variety of scales to be measured.

La Niña: La Niña is caused by an increase in the equatorial trade winds that increases upwelling off the coast of South America. These increases lead to a decrease in water temperature that again complicates the "normal" weather patterns. La Niña results in a convergence of the cold polar jet stream with warm humid subtropical air masses, increasing the storm intensities in the Pacific Northwest. These increased storm intensities results in increased precipitation and increased wave heights. Storms are more frequent and concentrated, elevating water levels due to storm surges. These surges can raise water levels 50-150 cm above predicted tide levels (Komar et al. in review)(Figure 10). With an increase in water levels, increased wave heights, and a depleted beach remaining from the previous El Niño year, substantial erosion in the Netarts littoral cell continues.

Interdecadal Variability - Pacific Decadal Oscillation

The discovery of the Pacific Decadal Climatic Oscillation (PDO) is relatively recent and not completely understood. In general it seems to be a climatic shift with a 20-30 year frequency. This shift involves the cycle between the dominance of El Niños and La Niñas. One of the distinguishing features is a pool of colder water that sets up in the North Pacific during the warm phase of the PDO (Mantua et al. 1997). During one phase, when La Niña dominates, the climate is exceedingly wet and cool, with increased precipitation and storm intensities (Allan and Komar 2000). The other phase favoring El Niño, is warm and dry spell when the weather tends to be hotter and drier (Mantua et al. 1997). The effect of this PDO phenomenon on wave heights has not been determined largely due to the lack of temporal wave statistics (personal communication Jonathan Allan 6/3/00).

Netarts Littoral Cell

Regional Overview

The Netarts littoral cell extends 14 km from the Cape Meares headland in the north to Cape Lookout headland in the south. The beaches in this littoral cell are considered "dissipative" with a low beach slope, up to three offshore bars and a wide surf zone present during large storm events. Cape Lookout State Park in the south is located on a 6.5 km sand spit that separates Netarts Bay from the Pacific Ocean (Figure 1). Netarts Bay is classified as a *Conservation Estuary* by the Oregon Coastal Management Program and is world famous for its oysters. Fed only by 12 small creeks, the health of these oysters attests to the health of the estuarine ecosystem and clean water quality. The unrestricted mouth of the tidal inlet has historically migrated north and south as a result of the El Niño. Much of the shoreline is backed a series of high bluffs composed of Pleistocene dune sands and basalt. To the immediate north of the inlet is The Capes Development that is situated on an ancient sand dune that has experience periodic landslides. Underlying the sand is a muddy, clay layer that rotates as it is squeezed out from underneath the ancient dune (Rich Rennie personal communication 8/12/98, Komar 1998). There is some disagreement over the composition of this layer. It could be equivalent to the 80,000 year old marine terrace, or could consist of mudstone-clast breccias and sandstone deposited as a combination of sheet wash and mass movements (George Priest personal communication 9/21/98).

Maxwell Point and a series of offshore sea stacks, known as Three Arch Rocks, form the remnants of an ancient headland attesting to the power of erosion on the Oregon Coast. To the north of Maxwell Point, Radar Beach Lost Boy Beach, and Short Beach, small pocket beaches underlain by cobbles, form the remaining stretch of coastline up to Cape Meares. The full extent of the study area encompasses the 34 km^2 watershed, and the littoral cell as described above that extends seaward out to the 15 meter depth. The 15 meter contour is estimated to be closure depth, the depth at which bedload sediment ceases to be transported by wave action (Clemens and Komar 1988), although this depth is somewhat arbitrary and varies with the significant wave heights. This littoral cell has been relatively stable throughout recorded history; it has only been effected more recently by significant erosion. (Table 1)

Natural Hazards History of the Netarts Littoral Cell

This littoral cell has experienced a lot of historic chronic erosion. The timeline shows the erosion history in the Netarts littoral cell.

Table 1: Erosion history in the Netarts Littoral Cell.

DATE	EVENT
Jan 26, 1700	Tsunami hits the Oregon Coast and Netarts Bay
1896	Tsunami hits Happy Camp
1899-00	Strong El Niño
1902	Moderate El Niño
1905	Moderate El Niño
1907	Three Arch Rock National Wildlife Refuge designated by President

	Taft.
1911-12	Strong El Niño
1914	Moderate El Niño
1918-19	Strong El Niño
1920's	Extensive logging on east slope of Netarts Bay
1925-26	Strong El Niño
1929-30	Moderate El Niño
1931	Air Photo taken showing overtopping of spit
1933	Tillamook Burn, large fires in the watershed
1939	Medium El Niño Sand Spit Overtopped (anecdotal evidence only)
1939	Trail to tip of Cape Lookout constructed by Civilian Conservation Corp.
1941	Strong El Niño
1943	World War II B-17 Bomber crashes on Cape Lookout, 1 survivor
1949	Jackson Creek diverted from ocean into the head of Netarts Bay
1951	European beach grass first planted
1951-1975	Extensive checkerboard logging in the South, Southeast and Northeast portions of Netarts Bay.
1952-	Bayocean spit breached
1952	Access Road to Jackson Creek and Cape Lookout State Park constructed
1953	Moderate El Niño
1953	Campground facilities constructed, topographic survey conducted
1957	Bathymetric Survey done on Netarts Bay
1957-58	Strong El Niño
	10% decrease in the volume of the bay
1957-1969	55% increase in mature marsh at head of bay (air photos)
1939-1962	9% decrease in the head of the spit (air photos)
1964	Alaska Earthquake and Tsunami
1965	Moderate El Niño
1967-1968	Seawall constructed along the base of the foredune to concentrate access points and minimize dune erosion.
	Air photos taken. Beach Zone line established
1972-73	Strong El Niño
1976	Moderate El Niño
Jan 1, 1977	Beach Bill established limiting shore protection structures to buildings constructed prior to this date.
1979	Rip Rap installed along southern beach access in day use area
1982-1983	Very Strong El Niño event damaged the seawall.
Jan 31, 1984	Air photos show overtopping of spit during El Niño winter
1987-1988	Rip embayment set up, seawall lost, dune erosion accelerated
1988	Additional 40 acres of land added to Cape Lookout
June 1988	Beach profile taken of Cape Lookout (Komar 1989)
1991-92	Moderate El Niño
1991-1994	Capes Development constructed

1997 –1998	Strong El Niño strikes again! Ocean restroom threatened, emergency rip rap installed. (largest storm 10.5 meters (34 feet)
1997-1998	Capes development erosion resulting in the condemning by the county of 27 homes to be reduced to 8.
Jan 20, 1998	Emergency Rip Rap placed to protect Cape Lookout Restroom
Jan – July 1998	I beams removed at bedrock level.
Summer 1998	Partnership for Netarts Littoral Cell Management Plan established
1998-99	La Niña Strikes! Two storms, Nov 17-18, and March 2-4 wave heights 10 m (33 feet) and 14 m 9 (46 feet). Cape Lookout amphitheater lost and ocean front restroom torn down.
Jan. 1999	Stakeholder group starts
Oct. 20, 1999	Overtopping occurred in State Park
March 2000	Day use restroom torn down.
April 2000	Dune restoration efforts Phase 1: dune restoration and flood wall complete.

Erosion History in the Netarts Littoral Cell

To more closely examine the erosion in the Netarts littoral cell, it is useful to step back to 1966 when the state parks installed a timber seawall in an effort to regulate public access and minimize erosion to the foredune caused by human trampling. Visitors recreating on the sand dunes disrupt vegetation and vital root systems that stabilize the dunes. Additionally, the habit of visitors to collect driftwood for firewood reduces the amount of driftwood on the beach that serves as a trap for blowing sand and is paramount in creating dunes on the Oregon Coast. During this time, the foredune extended roughly 175 feet to the west and 45 feet high from the access road (State Parks blueprints 1953, Aerial Surveys from 1953, 1967). (Figure 12) During the winter, the sand in front of the foredune was scoured by large waves, usually exposing a layer of cobbles that ran from Cape Lookout in the south to about a half mile north of the campground where the sand continued again (personal communication Pete Bond 8/10/98). In 1979, erosion occurred as the result of a severe storm event, and a small amount of rip rap was placed at the southern day use beach access to stop further erosion (Unpublished report to State Parks May 15, 1979; OPRD 1981). These events may be important due to the gap left between the seawall and the rip rap. Gaps in shore protection structures have enhanced erosion between the gaps and at the ends of structures in controlled laboratory conditions and in the field (Komar and McDougal 1988, Griggs and Fulton-Bennett 1986, 1988). It has been difficult to establish such evidence on the Oregon coast because any effects of structures are often masked by rip current embayments (Komar and McDougal 1988). It is important to note the construction of these structures because prior to the 1982-83 El Niño, little erosion of the Netarts Spit had occurred even through several strong El Niño events (Komar, Good, and Shih 1988, Komar 1997).

The El Niño event of 1982-83 was one of the strongest events on record. Several key factors resulted in extensive erosion to the seawall and foredune. The first was the abnormally high sea level. Water levels reached nearly 35 cm higher than the average winter water level, some 10-20 cm higher than previous recordings (Komar and Good 1989) (Figure 10). Coupled with these elevated sea levels were three occurrences of exceptionally high breakers, with significant wave heights of 25 feet. During these largest three storms, elevated sea levels and high spring tides raised water levels 58 cm, 85 cm, and 43 cm, respectively, above the predicted tide levels; thus, contributing heavily to the erosion (Komar 1986). The strength of this particular El Niño event pushed the jet stream farther south sending storm waves from a more southerly direction increasing beach scour and sediment transport from in front of the State Park. The set up of a large rip embayment just to the south of the campground in front of the day use area contributed heavily to the erosion that occurred (Komar et al. 1988, Komar and Good 1989). Some of the seawall was damaged and part of the foredune was destroyed. The strong northerly sediment transport pushed much of the beach sand into the tidal inlet at Netarts Bay and resulted in noticeable shoaling in the bay (Jim Mundell personal communication 7/14/98, Komar et al. 1988). Additionally, the mouth of the bay cut a much more northerly track than usual. Another observation from the 1984 aerial photos, and the interview with Jim Mundell was that during the 1982-83 El Niño, the beach in front of Maxwell Point and Oceanside saw no noticeable buildup. The predicted El Niño pattern of sediment buildup at the northern end of the littoral cell was not observed.

The loss of sediments from the beach at Netarts resulted in continued erosion to the foredune in front of Cape Lookout for several years. Missing sediments could have either been carried too far offshore to return to the beach, or could have been swept into the tidal inlet at Netarts Bay and contributed to the shoaling of the bay (Komar et al. 1988).

The next few years saw little buildup of the beach in front of the State Park. The winter of 1987-88 had a tremendous impact on the beach topography in front of the State Park. A large rip embayment set up in front of the campground, scouring sand, and reduced the beach to cobbles. This embayment lowered the already decreased buffering capability of the beach (Komar and Good 1989). The first storm of the season destroyed a major section of the seawall. The area of maximum erosion migrated northward as the rip embayment moved north (Komar and Good 1989). By the end of the spring and storm season much of the foredune had been lost. All that remained of the seawall were the I-beams that formerly supported the timber. The beach and foredune was reduced to 90-100 feet wide with about 15-20 feet of elevation (Pete Marvin personal communication 8/11/98). A beach profile done in June of 1988 showed the dune retreat to be 20 to 25 meters inland from the former seawall (Komar and Good 1989).

The depletion of the foredune had some additional effects. Previous to 1988, the campground was comprised of mature, mixed forest stands of hemlock, spruce, and shore pine, characterized by healthy green crowns indicating good tree health. The healthy trees were located in the leeward side of the foredune. Following the breakdown of the foredune, the wind buffer was lost and the winter of 1989-90 brought extensive blow downs (Al Tocchini personal communication 7/28/98, Pete Marvin 8/11/98). The forest health continues to deteriorate in the campground as evidenced by the spikiness of tree crowns (Al Tocchini 7/28/98). Wind intensification had the additional impact of blowing sand into the campground, covering campsites and access roads. Since the loss of the foredune, State Park personnel have engaged in a spring "cleaning" of the inundated sand by bulldozing 20-30 feet of sand back onto the beach (Pete Marvin 8/11/98). This management practice has contributed to the continued loss of sediments. Sand inundation is the natural processes at work trying to reconstruct a foredune farther inland. Fallen timber, drift wood, and vegetation provide wind breaks to collect sand. State Parks have attempted to utilize sand fencing to minimize the inundation with modest success. The sand fencing resulted in a berm buildup of 3-5 feet (Pete Marvin 8/11/98).

The 1997-98 El Niño has continued the erosion problems at the State Park. Since the 1982-83 El Niño, relatively little beach buildup has occurred. During the 1997-98 El Niño, remaining sand was scoured from the beach and transported northward, reducing the beach to cobbles and revealing ancient Sitka Spruce trees that are approximately 6,000 – 7,000 years old (George Priest personal communication 8/99). A rip current set up due west of the ocean front restroom, and created a channel for the extreme waves to attack the coast. The storm of January 17, 1998 resulted in wave heights of 10.5 meters resulting in breakers of 35-40 feet (Komar 1998). These wave heights were expected every ten to twenty years. Additionally, the wave setup caused by the El Niño oscillation raised sea level 14-16 inches above average winter level (Komar 1998). (Figure 10) The remnant foredune at the campground was wiped out, and extensive washovers occurred, depositing large amounts of sand and severely hindering access (Pete Marvin 8/11/98, Komar 1998). During one storm near the end of the storm season, with the foredune and beach drastically reduced, wave run-up would splash 12-15 feet over the restroom (Pete Marvin 8/11/98). The ocean front restroom sustained some damage and state parks in an emergency action placed rip rap in front of the facility for protection. In the places onshore of the rip embayment, in particular, the public restroom and amphitheater, the cobbles were gone.

Cape Lookout State Park was not the only place to experience erosion in this littoral cell. Between 1991 and 1994, a Portland developer, made their way through the development permitting process and was permitted to develop tract homes on the sandy bluff with a 10 foot setback. Regardless of the geological specifics, the final building permits issued only required a ten-foot setback from the bluff edge.

Part of the El Niño sediment transport process, results in the mouth of Netarts Bay shifting to the north (Komar 1986, Komar et al. 1988, Komar and Good 1989). This phenomenon has been documented in other cases along the Oregon Coast, in particular, along the Alsea Spit (Komar 1986, Komar and Good 1989, Komar, 1998). The migration of the tidal entrance moved the channel of deeper water in front of the Capes Development and had a similar effect as a rip embayment (Komar 1998). The deeper water enabled large waves to travel relatively unhindered to the shore before breaking, so wave energy on the beach was very high. This wave energy scoured the beach in front of the Capes exposing the toe of the clay-mud-sandstone layer. The resulting toe erosion made the Pleistocene sand dune unstable and caused some slumping; threatening the front row of homes (Komar 1998) To date, eight homes have been condemned by Tillamook County (Tom Ascher personal communication 7/14/98). The homeowners applied for a shore protection structure, but were turned down by the governor's office due to the Beach Bill. The Beach Bill does not allow shore protection structures to be placed on properties developed after January 1, 1977. Lawsuits were filed on all sides and in the final settlement the developer paid for damages to the homeowners association.

The erosion problems during the La Niña winter of 1998-99 continued since the beach had never recovered from the El Niño. Huge storms pounded the coast including a storm with significant wave heights of 14 meters (46'). The state park lost the amphitheater and was forced to close for nearly three months as high water levels and large storm waves deposited sediments over 150 meters back into the park. (Figure 13).

Natural Hazards Management in Oregon

Local, state, and federal agencies all have certain responsibilities related to coastal hazard management in Oregon. There are five main functions that are shared by all levels of government. These functions start with research and technical information usually summarized and illustrated on hazard maps that are distributed to local jurisdictions. These maps are then used to plan coastal areas and situate development away from hazardous areas. Once situated, construction and building standards attempt to avoid poor design and construction. Following periods of erosion, many oceanfront property owners will apply for shore protection structures to protect their real estate investments, Oregon permitting of shore protection is strict with regards to new developments that built too close to hazardous areas. The fifth government function regards emergency management of hazards particularly those catastrophic disasters such as earthquakes and flooding (Table 2).

Ocean front development in the Netarts littoral cell is regulated by Tillamook County through the local comprehensive plan (LCP) and zoning ordinance. This plan and ordinance has been certified by the State of Oregon to be consistent with all of the Statewide Land Use Planning Goals. Goals 7, 17, and 18 specifically address coastal issues and hazards that affect the beaches and dunes in the Netarts littoral cell. Goal 7, Natural Hazards, mandates that developments not be placed in areas of known natural hazards without appropriate safeguards. Goal 17, the Coastal Shorelands Goal, requires that LCP's consider geologic and hydrologic hazards along the ocean shoreline. Preference is given to land use management and practices that avoid non-structural solutions to erosion. Goal 18, Beaches and Dunes, prohibits development on hazardous dunes unless findings can be made that such developments are adequately protected from erosion and other hazards. Goal 18 also designated areas eligible for shore protection structures as those developed prior to January 1, 1977. Development was defined as houses, commercial and industrial buildings, and vacant subdivisions that were physically improved with street access and utilities to the lots.

Additionally, the Oregon Ocean Shores Law (the "Beach Bill") requires that a permit be obtained from the Oregon Department of Parks and Recreation (OPRD) prior to any beach "improvements" to be placed seaward of the statutory vegetation line adopted in 1967 (Beach Zone Line). This line, the 16 foot contour was mapped on the 1967 aerial photos as the most seaward line of vegetation in 1967, and serves as a benchmark on most of the coast for this historic shoreline. The beach zone line did not cover existing publicly owned lands, and as a result, Cape Lookout State Park did not have this line mapped. The Removal/Fill Law, administered by OPRD, regulates structures involving 50 cubic yards or more of material, and thus plays an important role in regulating shore protection structures.

Oregon's current hazards management program has several problems that have been identified in the Coastal Natural Hazards Policy Working Group. There were 23 Issue areas that were identified by the Policy Working group regarding current management of coastal hazards. Some issues that are particularly pertinent to planning in the Netarts Littoral cell are found in Table 2.

Table 2: Oregon Hazard Management Issues (CNHPWG 1994)

Hazard Assessment And Information Access Issue 1: Maps	Existing maps and information about coastal hazards are inadequate for planning and decision making
Issue 2: Geotechnical Reports	Geotechnical site reports are inadequate for making decisions on land development and shore protection projects.
Issue 3: Information availability	Information regarding coastal hazards is not readily available nor well understood and applied by decision makers.
Issue 4: Real Estate Disclosure	Hazard disclosure during property transactions is insufficient
Beach and Shore Protection Structures Issue 5: Outdated Goals and Policies	Goals and policies for shore protection are inconsistent and outdated, particularly with regard to hard shore protection structures.
Issue 7: Shore Protection Permitting	Permit process is poorly structured, has weak review standards and limited enforcement authority, and appeals process is antiquated.
Issue 8: Emergency Provisions	Emergency shore protection structures and procedures are lacking.
Issue 9: Ineffective Integration	Land Use Planning and site-specific land use decisions relating to coastal hazards suffer from ineffective integration of existing and new information, piecemeal decision making, and poor coordination between administrators of coastal hazard programs.
Issue 11: Unbuildable lots	There is no consistent way to determine what properties along the Oregon coast are "unbuildable" due to coastal hazards.
Issue 13: Oceanfront Setbacks	Oceanfront construction setbacks, as now implemented, have not proven to be an effective means for avoiding hazards.
Issue 14: Tsunami Inundation	Development continues to be sited in earthquake prone and tsunami high-hazard areas.
Issue 23: Disruption of infrastructure	Physical Infrastructure, lifelines, and utility systems will be severely disrupted in the event of a large Cascadia Subduction Zone earthquake.

Many of the identified issues result from a lack of information, integration, and mechanism to incorporate information into decision making. Additionally, the parcel by parcel approach of the existing natural hazards management program neglects the effect on adjacent neighbors. A more regional planning mechanism could remedy many of these problems (CNHPWG 1994). Littoral cell planning is a specific type of regional planning that could directly address issues 1, 2, 3, 9, 11, 13, 14, and 23. Issue 7 would also be partially addressed, by reviewing potential shore protection sites before they reach an emergency stage (avoiding issue 8: Emergency Provisions).

Littoral Cell Management Planning

Regional, consensus-based planning addressing a wide range of issues has been one of the principal management strategies employed by coastal states. Special area management plans, or SAMPs as they are called, have been used most often to address development-conservation conflicts in ports, harbors, and entire estuaries. In Oregon, a variant of the SAMP process was used to develop estuary-shoreland management plans for major estuaries (Cortright et al. 1987). Zoning within SAMP management units separates conflicting uses, preserves particularly valuable resources, provides for development opportunities, addresses cumulative impacts through mitigation, and creates a climate of predictability for shoreline landowners. Oceanfront beaches and shorelands, although a much different environment, have similar issues and conflicts that have led to recommendations for SAMP's to address hazards, sand supply issues, public access and recreation, and scenic resource conservation, among other things (Good 1992, CNHPWG 1994).

Littoral cell planning approaches coastal hazards on a regional scale providing several important benefits including:

- Incorporating the best available science, and standardizing the quality of hazard assessment;
- Addressing hazards at the same scale as the processes affecting shoreline stability;
- Reducing potential for adverse impacts due to risk assessments;

- Reducing cumulative impacts to adjacent sections of shoreline;
- Increasing efficiency in decision making due to enhanced interagency coordination.

These regional benefits improve protection of the natural resources and economic opportunities by educating both public and private interests regarding locations of future developments. In Netarts, most of the oceanfront property is developed and eligible for shore protection. This littoral cell management plan will guide redevelopment and the location of shore protection structures, as well as promoting interactions between neighbors who may be adversely affected by piecemeal shore protection.

Generally there are three steps in the littoral cell planning process, inventory, analysis and implementation (Marra 1995). The inventory creation and analysis for the Netarts littoral cell has been developed in a GIS framework to facilitate communication of the best available scientific information and integrate the information into the decision making support tool. This GIS inventories the littoral cell, examines shoreline changes, applies risk assessment methods to generate hazard zones, and serves as a decision support tool during the stakeholder process and facilitate land use planning.

Marra (1995) developed a guidebook for littoral cell hazards planning that outlines explicit, science-based risk assessment methods. Marra tested and refined these risk assessment techniques for areas within the Newport littoral cell along the central Oregon coast (Marra 1998). Similar methods are being employed in the Netarts littoral cell for dune hazard risk assessment and bluff hazard assessment (Priest 2000); these are described later. These risk assessment methodologies have identified hazardous areas that will enable local stakeholders and planning agencies to arrive at preferred management solutions that can be implemented through local ordinances, changes to state park master plans, and development standards.

GIS for Planning and Plan Implementation Decision Support

Scientists, land managers, planners and local citizens all speak somewhat different languages. GIS provides an opportunity to bridge the communication barriers that exist between all of the stakeholders. Included in these stakeholders are local and state planning agencies, all of whom play different roles in decision making at the county level. One limitation of existing coastal hazards planning is the lack of current shoreline data. Part of this limitation is due to the incredible effort needed to conduct large scale fieldwork necessary to understand coastal processes and episodic erosion events. Recent developments in remote sensing technologies are remedying this problem. LIDAR, standing for Light Detection and Ranging, applies airborne laser altimetry to generate high resolution topographic maps that capture current beach conditions and provide a means to quantify the erosion caused by the 1997-98 El Niño.

Spatial Decision Support Systems

Spatial Decision Support Systems (SDSS) have become an integral part of GIS evolution. SDSS is an interactive, computer based system designed to support a group of users in achieving a higher effectiveness of decision making while solving a semi-structured spatial problem. A semi-structured problem refers to a spatial issue, in this case coastal erosion, which can be programmed into a computer, but lacks the input of user perceptions and values (Malczewski 1999). The increased efficiency of decision making revolves around the rapid examination of diverse data, and the ability of the decision makers to incorporate their values and preferences by ranking various evaluation criteria. Criteria ranking determine which factors, such as landslide presence, elevation, or retreat distance, play the major role in identifying redevelopment locations. Most SDSS forms are based on GIS capabilities to identify alternatives based on spatial relationships such as connectivity, proximity, or overlay methods. Example operations include buffering, overlaying risk zones, and examining proximity of parcels to hazards.

GIS Development in Tillamook County

Initial GIS database development in Tillamook County grew out of the work program for the Tillamook Bay National Estuary Project (TBNEP). Subsequent technical GIS support involves the NOAA Coastal Service Center as part of a federal Performance Partnership. The Oregon Department of Land Conservation and Development (DLCD) has also invested money into GIS in Tillamook County to develop a Coastal Hazard Inventory, with technical expertise and mapping provided by the Oregon Department of Geology and Mineral Industries (DOGAMI). The Netarts Coastal Hazard GIS has developed as a demonstration project for the Coastal Hazard Inventory and to support the creation of the Netarts Littoral Cell Management Plan.

OBJECTIVES

Netarts Coastal Hazard GIS

The overall goal of the Netarts project is to prepare an all hazards focused littoral cell management plan for the eight mile long Netarts littoral cell. This management plan will address chronic and catastrophic hazards; and concerns over oceanfront land development, beach management, and shore protection. The Netarts Coastal Hazard GIS (NCHGIS) has been developed to support this planning effort.

The guiding goal of the GIS is to design a GIS that will incorporate the best available science to address the range of issues raised by local and state coastal management agencies and local stakeholder concerns. Components of the GIS include a coastal hazard inventory, risk hazard zones and analysis, and the creation of a GIS Decision Support System. Unique elements added to this project include input from a variety of stakeholders to design the inventory and incorporate community concerns and preferences. Another unique aspect is the use of GIS to educate stakeholders and promote more effective communication. To reach these ambitious goals, four objectives were identified.

Objective 1 - Represent the littoral cell with a series of digital maps

The Representation Model addresses the question, how can we describe the littoral cell? To completely answer this question, data had to be collected representing the physical, cultural, biological and socio-economic aspects of the littoral cell.

Objective 2 - Examine shoreline changes, trends, and major events

This objective addresses the questions; what are the historical shoreline changes, and how much erosion does El Niño cause? These questions lead to the management question, where will the future shoreline be? Understanding the coastal processes and historic erosion events is of paramount importance to begin to bracket these questions and accurately represent hazardous areas. The nature of erosion on the Oregon coast spans a range of time scales and is dominated by episodic erosion events often caused by climatic cycles. Superimposed over these events are seasonal fluctuations and changes in relative sea level (Figure 14). Historic changes were documented primarily by changes in shoreline locations using historic aerial photography. A new remote sensing technology, LIDAR enables a detailed examination of the 1997-98 El Niño leading to a better understanding of patterns of erosion including changes in sediment volumes caused by a large episodic event.

Objective 3 - Generate hazard zones to support risk analysis

This objective addresses the question, what areas are most susceptible to various hazards? Through this objective, coastal process science is used in risk assessment models to design hazard zones (Komar et al. 1999, Marra 1998, and Priest 2000). These models allow decision-makers to examine a variety of potential erosion events with different time recurrence intervals.

Objective 4 – Facilitate spatial decision-making

This objective elevates the GIS from being a map maker and data viewer to a spatial decision support tool. This objective focuses on questions like which areas should be avoided. This objective will facilitate decision making through the use of GIS queries to answer questions of particular concern to local stakeholders and planning agencies.

METHODOLOGY

Representation Model

This model identified informational needs, designed a data model, and collected or created needed data layers. Data layers representing the littoral cell include layers on physical, cultural, biological, and hazard characteristics. Public and stakeholder recommendations were gathered through surveys during public workshops and interactions with local stakeholders. These inputs regarded specific issues of community concern. Once needed data layers were identified, the collection of existing data occurred. Most of the existing data came from two sources, the Tillamook Coastal Watershed Resource Center and the Oregon State Service Center for GIS. A complete summary of the physical, cultural, hazard, and base data layers collected and created including information on the sources of the data, scale, and type of coverage are included in Table 3: GIS Data Layers. After collecting or generating the data, all of the coverages were projected to the Oregon North State Plane Coordinate System:

Projection:	*Lambert Conformal Conic*
Spheroid:	*GRS80*
Horiz. Datum:	*NAD83*
Vert. Datum:	*NGVD29*
Units of Meters	
Parameters	
Central Meridian:	*-120.5*
Reference Latitude:	*43.6667*
First Standard Parallel:	*44.3333*
Second Stnd. Parallel:	*46.0*
False Easting:	*2,500,000*
False Northing:	*0*

The next step was to develop a data model that incorporated the issues of concern containing spatially relevant components (Figure 15). Attribute tables were then constructed using attributes generated by the public and stakeholders during the educational workshops. Attributes proved critical for determining spatial relationships between the data sets.

The final task was the creation of Federal Geospatial Data Commission (FGDC) compliant metadata. Metadata provides data about the data, so that future users can understand where the data came from, and how and why it was created. Most of the metadata was collected using the Metadata Collector Tool 1.0 Extension available from the NOAA Coastal Service Center. Data layers obtained for the Representation Model are in Table 4.

Table 4: Representation Model Layers

Layer	Type	Comments
1994 USGS Orthoquad	.tiff image	1m^2 pixel resolution
Geology	Polygon	DOGAMI data layers
Bluff Top Crest Line	Line	
Soil Maps	Polygon	Soil Conservation Service
10 m Digital Elevation Model	Elevation grid	USGS
Contours	Line	3 m , 10 m derived from DEM
Slopes	Grid	High, Moderate, Risk slopes
Creeks	Line	Netarts Watershed Assessment
GPS Points	Point	< 1 m accuracy
Beach Access	Point	DLCD

Shoreline Change Model

This GIS objective addresses the questions; what are the historical shoreline changes, and how much erosion was caused by the 1997-1998 El Niño? In the Netarts Coastal Hazard GIS, analyses examined the location of historic shorelines, shoreline reorientation and erosional hotspots. The first task was to obtain historic aerial photography in a digital form. Processing steps in ARCINFO included registering the images using the REGISTER command, then rectifying the images using the GRIDWARP command. Both of these processing steps depended on the GPS Points Layer. Two features were digitized including the wet sand line that estimates mean high water, and the most westward vegetation line that gives an estimate for the toe of the dune and bluff.

The second shoreline change task examined new LIDAR data to examine erosion occurring during the 1997-98 El Niño. LIDAR (Light Detection and Ranging) applies laser altimetry to generate high resolution topographic maps. In a cooperative program, USGS, NOAA, and NASA acquired LIDAR data for 1200 km of the West Coast before and after the El Niño of 1997-98. A mounted laser was flown from a Twin Otter DHC-6 airplane with an onboard inertial navigation system, and a survey grade GPS receiver. An onboard rotating elliptical scanner with a 15° off nadir angle that collected first return point data covering ~700 - 900 meters of the shoreline. Consequently there is a lot of noise within the data especially around vegetated areas. The horizontal accuracy of this data is considered to be 1 m^2 in the horizontal and 15 cm in the vertical (Sallenger et al. 1999) (Figure 16). Data collected on October 15^{th} was determined to be faulty by USGS, NOAA, and NASA, so it was removed from the analysis (Abby Sallenger personal communication 4/27/00).

During each data flight two passes were made over each site. Flights taken for the Netarts littoral cell were flown on October 15^{th} & October 17^{th}, 1997 and April 26^{th} & 28^{th}, 1998. It is important to note that this sampling design captures two phenomena, a seasonal cut in the beach and an El Niño effect. During each data flight, digital videography was recorded with a time stamp enabling accurate measurements of tide levels. (Table 5) Data analysis included subtracting the DEM's, making it possible to quantify the patterns of erosion at a variety of scales.

Table 5: LIDAR Tide levels from the Garibaldi tide station

	October 17^{th}, 1997	April 26^{th}, 1998	April 28^{th}, 1998
Tide Level (MLLW)	1.74 m (ebbing)	-.58 m (low tide)	-.46 m (flooding)
NGVD29	.49 m	-1.83 m	-1.71 m

After differencing the grids from both years, a series of cross shore transects were extracted at 100 meter alongshore intervals along the length of the cell. By interpreting the profiles, a 40 meter stretch of the crosshore profile was selected to isolate the backshore. Creating a polygon connecting these 40 meter sections with each adjacent cross shore profile isolated the sand on the beach and served to filter the raw data from vegetation and other noise. Histograms of shoreline change were generated for each of the 4000 m^2 polygons. Plotting the mean differences for each of these 4000 m^2 polygons gives us a representation of the littoral cell from North to South that shows both the trends of shoreline change and some of the rythmicities of evolving beach morphology. It also shows the areas of overall erosion and accretion. (Figure 17). From this first plot it became obvious that there was considerable noise resulting from changes in the inlet and spit end, so this data was removed from further cell wide analysis. To isolate the El Niño signal from the seasonal fluctuations in the beach, the mean difference for the entire cell was averaged and then subtracted from each of the polygons. When multiplied by the 4000 m^2 polygons this plot shows areas of net erosion and accretion caused by the El Niño (Figure 18). A trendline was fit to this data to examine the shoreline reorientation. The next step was to examine the beach slope at each of these transects along the 40 m sections. (Figure 19). The next step in the cell wide analysis was to examine the horizontal retreat of certain contour intervals across the cell. (Figure 20). The final step in the LIDAR analysis was to break up the littoral cell into three sections, the developed areas of Cape Lookout State Park, the sand spit, and the shoreline from the tidal inlet to Maxwell Point. For each of these sections, a trend line was fitted to the section to assess the mean volume transport across the littoral cell (Figure 21).

Table 6: Shoreline Change Model Data Layers

Layer	Type	Comments
1955 Shoreline	Lines	Mean High Water
1967 Shoreline	Lines	Wet sand, Vegetation Line
1984 Shoreline	Lines	Wet Sand, Vegetation Line
1994 Shoreline	Lines	Wet Sand, Vegetation Line
1997 Shoreline	Lines	LIDAR
1998 Shoreline	Lines	LIDAR
LIDAR97	Grid	2 m^2
LIDAR98	Grid	2 m^2
DIF97-98	Grid	Subtraction of LIDAR97-98
1957 Bathymetry	Point	TBNEP

Hazard Impact Model

The Hazard Impact model will improve the ability of decision-makers to analyze the risks of coastal hazards on oceanfront properties. The Netarts littoral cell can be divided into bluff backed and dune backed shorelines. For both bluff backed and dune backed shoreline types, erosion models have been developed to predict the potential extent of erosion based on independent probabilities of extreme storm events (Table 7) (Priest 2000, Komar et al. 1999, Marra 1998). Science enters into the decision making process twice, once during the creation of these models, and again when the necessary parameters are inputted. Proper application of the models can assist decision-makers in realizing potential hazards giving them a baseline inventory of resources from which future technical reports can expand.

For Dune-backed shorelines, a geometric dune erosion model was run to generate the High, Moderate, and Low Risk Hazard zones (Komar et al. 1999) (Figure 22). Physical beach parameters were collected during profile fieldwork and extracted from the LIDAR data set. Water level data was collected from measurements taken by the Yaquina Bay tide gauges and wave height data was taken from the National Data Buoy Center buoy 46050 offshore from Newport.

The Active, High, and Moderate risk zones for bluffs were calculated by George Priest of DOGAMI using site specific geological observations (Figure 23). Due to limited resources, these characteristics were confined to maximum block failure width, general angles of repose, angles of long term stability, field observations and estimated average annual recession rates. Average annual recession rates for similar material bluffs in Lincoln Country were used to provide (.27 ft/year +/- .34 ft. "one standard deviation") estimates of Netarts bluff retreat.

Table 7: Hazard Impact Model Data Layers

Layer	Type	Comments
Active Bluff Hazard Zone	Polygon	DOGAMI
High Bluff hazard Zone	Polygon	DOGAMI
Moderate Bluff Hazard Zone	Polygon	DOGAMI
High Dune Hazard Zone	Polygon	Geometric Dune Erosion Model
Moderate Dune Hazard Zone	Polygon	Geometric Dune Erosion Model
Low Dune Hazard Zone	Polygon	Geometric Dune Erosion Model

Facilitating spatial decision-making

This objective elevates the GIS from being a map maker and data viewer to a spatial decision support tool. One method to do this includes the use of a well-attributed Tax Parcel layer coupled with several Tillamook County planning databases (Table 12). These databases include the Tax Assessors database, and the community planning databases for Oceanside and Netarts. To couple the polygon layer and the database, the parcel identification number (PIN number) for each parcel was attributed to each polygon creating a common joinable field. The attribute table was then constructed using attributes identified during the data model formulation (Figure 15). The other method to put science into the hands of decision makers is the use of two AML scripts to calculate the hazard risk zones. One script was written by Jeff Foisy working for Shoreland Solutions (John Marra personal communication 1999), and the other by the NOAA Coastal Service Center. There were two data layers generated to implement the decision support system. (Table 8)

Table 8: Decision Support Data Layers

Layer	Type	Comments
Tax Parcel Layer	Polygon	Digitized by Dept. of Corrections
Tax Parcel database	Database	Tillamook County

RESULTS AND DISCUSSION

Representation Model

The representation model pulls together the basic GIS data layers that begins to enhance decision making by consolidating and coupling a variety of diverse data sets. This inventory design process provided an opportunity to educate the stakeholders and public on some of the benefits and limitations of the GIS.

Several problems arose during the initial phase of GIS development. The first involved reprojecting all of the diverse data sets from their wide variety of projections into the same projection. Data providers had a wide range of GIS competency so transferring data was always an issue. Additionally, the GIS Research Lab at Oregon State in the College of Oceanic and Atmospheric Sciences was not set up to promote data transfers. Just changing data between computers within the lab required FTP. Any data transfer had to be handled by the UNIX operating system, which was not always compatible with the PC desktop environment. The GIS facilities at OSU lack a system administrator who is familiar with GIS software. As a result, building the GIS with input from hundreds of people was a crash course in GIS development.

Shoreline Change Model

Shorelines change on hourly, weekly, seasonally, yearly, decadal, and geological time scales. These changes occur at a variety of space scales, ranging from turbulence in the nearshore to littoral cell wide reorientations. All of the factors influencing shoreline changes are seen in Figure 14. The scales most useful to decision makers fall under the category of Large Scale Coastal Behavior, with time scales of months to years, and spatial extents of meters to kilometers. Decision-makers and land managers want to understand the annual average recession rates to give them an idea of where the shoreline will be in the future. Average annual recession rates are very suspect due to the episodic nature of erosion on the Oregon coast and the limited historic data.

The primary objective of the large-scale shoreline change analysis is to examine the change of the shoreline in the Netarts cell. The longer the temporal coverage of the aerial photos, the more likely to notice significant changes. The layers used in the analysis begin with a 1955 MHW shoreline digitized from a NOS Nautical Chart, a 1967 shoreline, 1984 shoreline, 1991 shoreline, 1994 shoreline, and 1997 and 1998 shoreline.

Before discussing any of analysis results it is important to understand the errors associated with shoreline mapping.

Shoreline Mapping

Mapping shorelines has been a difficult proposition, primarily due to the natural dynamics of the ocean-land interface. This dynamic nature has a varied temporal component that includes seasonal fluctuations, intra-annual variability, decadal oscillations, and long term sea level rise. In order to determine historic changes, it is important to compile as long of an historic record as possible (Ewing 1993). The longer the photo record, the more accurate the analysis. For example, certain extreme El Niños have caused significant shoreline alterations in the Netarts cell. If the span of air photos examined was only several years and encompassed an ENSO event, then any calculated average recession rate would be too high. It may, however, be useful in predicting short-term shoreline positions following strong El Niño events. If seeking long term historical change, it is important to insure that all shoreline data sets are approximately consistent with respect to season, water levels, and short term history of coastal processes (Anders et al. 1991). This is an important part to shoreline mapping as evidenced by the work of Smith and Zarillo (1990) that estimated potential errors of up to 40 meters in shoreline positions when comparing photo sets taken during different seasons. The best approach is preferably to use summer conditions for all photo and avoid post storm photo sets (Crowell et al. 1991).

Uncertainties in Shoreline Mapping

There are several primary sources of error associated with historic shoreline mapping using aerial photography. The first problem arises from identifying and interpreting the shoreline. The second type of error occurs from photogrammetric distortion. A third problem is associated with digitizing errors combined with photo interpretation. Even the line width and location of lines can provide additional errors depending on scale.

Shoreline Identification

The shoreline reference feature problem arises from difficulties in identifying different features. The three reference features used in this analysis include:

- *Mean High Water – used to examine spit tip changes*
- *Wet-sand inundation lines – proxy for MHW, used to examine spit tip changes*
- *Beach Morphological Features – examine episodic erosion*

Mean High Water: The MHW level is probably the longest historically used shoreline determinator. The primary use of the MHW datum is for navigational purposes. The National Ocean Survey, commissioned in part to map the navigational channels in the United States has historic bathymetric maps dating back to the early 1800's. This shoreline determination is filled with errors. The charts illustrate depth based on Mean Lower Low Water (MLLW) so as to err on the side of navigational safety. The MHW is based on an average of the predicted high tides for that region, and a value above MLLW. MHW also fails to take into account changes in atmospheric pressure, storm surges, significant wave heights, El Niño oscillations, or wind vectors. The MHW shoreline was used to examine the fluctuations in the spit tip primarily because of the lack of vegetation available to map.

Wet-Sand Shoreline: The second method of determining a shoreline is one of the most commonly used in aerial photographic interpretation. This line is usually identifiable on air photos by the sharp contrast between the bright dry sand and the saturated wet sand (Shalowitz 1964, Crowell et al. 1991). On the Oregon coast, the semi diurnal tide cycle leaves two lines of wet sand that may not even be visible on adjacent photos due to poor contrast in the photos (Crowell et al. 1991). Rain can also obscure this contrasting line by wetting the entire beach. Another of the disadvantages of using this method is that the wet sand saturation is dependent on the water table, the tide level, and the porosity (grain size) of the sediments comprising the beach. As the tide drops, the water table drops slowly with some lag period. The more porous the sediments, the faster the water table drops. This dropping water table causes the wet-sand "shoreline" to retreat. The time of day of the photo may be estimated by assessing shadow lengths and direction. By estimating the time of photo, a tidal estimate can be made by looking up the historic predicted tides. Additional errors arise from the difference between the actual and predicted tides. This wet sand line can give a rough approximation for the MHW shoreline, and was digitized to compare with MHW shorelines in examining fluctuations to the spit tip where there is a lack of vegetation or other morphological feature.

Beach Morphology: The final type of shoreline delineation is to use a beach morphological feature. The leading edge of upland vegetation can be a more reliable indicator of long-term shoreline movement than the high water line because it is not affected by short-term variations in ocean conditions or climatic processes (Crowell et al. 1991, Morton and Speed 1998). However, two factors keep the vegetation line from being the perfect boundary determinant. First, the vegetation line is a biological feature that responds to terrestrial impacts. Plants can move independently and in opposite directions to the beach. Secondly, the vegetation line is not always readily identifiable. There often exists a distinct line of older vegetation that stretches inland, as well as younger vegetation that backs the bare beach. Depending on the season and the type of vegetation, and photo resolution and contrast, the plant vigor may be weak and hard to detect as well (Morton and Speed 1998). The shoreline is also susceptible to anthropogenic effects and artificial shore stabilization. In the Netarts cell, the vegetation line is relatively stable, especially away from Cape Lookout State Park. Historic oblique photos show that the community of Oceanside has changed little since the early 1800's (Figures 33,34,35). This shoreline was used to assess the episodic nature of erosion at the south end of the littoral cell where the dune has historically been abundantly vegetated.

Photogrammetric distortion

Unfortunately, shoreline identification isn't the only means of introducing error into the change analysis. There are also photogrammetric distortions caused by aerial photographic techniques. These distortions can be broken down to the tilt, crab, and pitch of the aircraft; the radial distortion of representing topographic relief (3D) on a two dimensional plane; and scale variation caused by fluctuations in the platform height above ground level. Additionally, uneven shrinkage of historic photos and other early photographic shortcomings limit the accuracy of aerial photos (Anders et al. 1991, Fulton 1981).

The first photogrammetric errors arise from simple air photo techniques. Aerial photos are supposed to be taken vertically (90 degrees). This results in the nadir equaling the principal point (nadir = point directly under the plane at 90 degrees; principal point = center point of the photo). When this occurs (rarely) the tilt of the platform is equal to 0. However, 1-3 degrees of tilt from vertical is acceptable, but results in distortion on the photo. For example, photography taken at 1:20,000 scale with a 1 degree tilt may displace a shoreline feature by 20 meters. If the tilt is 3 degrees, the tilt displacement may be closer to 60 meters. Orthorectifying processes of these historic photos used at least five control points per photo in an effort to reduce some of these errors. This orthorectification was done using the GPS Points Layer and the GRIDWARP command in ARC/INFO. Errors arose in regions with a lack of geodetic reference points.

Radial distortion caused by the representation of a 3D world on a 2D paper can displace shoreline features away from the photo isocenter (Crowell et al. 1991). Fortunately in over Netarts spit, the topographic relief is relatively low. Additionally, most shorelines occur near the center of the historic photos and therefore avoid some of this distortion. In order to rectify this radial distortion, control points must be at the same elevation as the height of the cliffs (Crowell et al. 1991)

The third distortion issue involves scale changes caused by fluctuations in the flying height of the aircraft. These height changes come as a result of small changes in light aircraft altitude from wind and weather patterns (Sometimes as much as 10-15 m from start of flight to the end). For example if the focal length of the camera and the flying height create a scale of 1:20,000, then a 10 m decrease in the aircraft altitude would result in a scale of 19,934. When these variable scales are used to measure the distance from a known point to a shoreline, then this subtle difference could result in a 6.6 meter shoreline offset. This type of error is difficult to correct creating additional uncertainties in determining shoreline locations.

All of these potential errors can negate measuring shoreline changes when we are only talking about 5-10 m of erosion. It was difficult to determine significant changes from non-significant changes in historic shoreline positions.

Improvements to Shoreline Change

A better method is needed to quantify the changes of the spit tip, an area that is susceptible to pronounced shoreline reorientation and extreme fluctuations. The best method to quantify these changes may be to create a polygon that represents the surface area of the tip at some set reference line. By doing a surface area calculation on the polygon, long term changes to the spit could be assessed. Another means would be to identify a set point through triangulation (via COGO) from known benchmarks. Relative distances of features from this point could then assess changes in spit location.

Results of the Large Scale Shoreline Change Analysis

The shoreline change analysis met with modest success. Limitations arose primarily due to the lack of geodetic control in the undeveloped portions of the spit, the lack of long temporal photographic record (<45 years), and the relatively stable nature of much of the shoreline in the littoral cell. Two results provided modest successes; the identification of the spit end deflection and the scouring of the vegetation line as evidence for episodic erosion events at Cape Lookout. The shorelines do illustrate general patterns of change where episodic events have moved the location of the shoreline, primarily at the erosion hot spots.

Generally, the shoreline change analysis illustrates the predicted El Niño pattern with the deflection of the tidal inlet. During "normal years" (1967 & 1994), the spit tip maintains a linear shape on both sides of the inlet, and the channel extends in a perpendicular direction to the tidal inlet. As the inlet channel deflects northward during an El Niño, sediment transport hooks the end of the spit into the bay. This hooking is visible in the 1955 and 1984 shorelines that followed immediately after strong El Niños (Figure 24). Aerial photos and LIDAR illustrate the hooking of the inlet during the 1997-98 El Niño.

The 1991 shoreline was taken during an El Nino year, but prior to the onset (Table 1). The other successful result comes from analyses of the Cape Lookout erosion hot spots. The vegetated shorelines illustrate the large dune erosion that occurred at the park between 1967 and 1994. (Figure 25). Attempting to identify the MHW or wet-sand shoreline on the LIDAR data has proved troublesome, so the effects from the 1997-98 El Niño were quantified using the LIDAR data without comparing the results to the historic shoreline change

LIDAR

LIDAR provides an incredible opportunity to closely examine the effects of a single El Niño storm season and to document Large Scale Coastal Behavior in the Netarts Littoral Cell. It is important to note that the sampling design of data collected before and after El Niño captured two phenomena, a seasonal cut in the beach and an El Niño effect. This data set has the potential to greatly improve large scale high resolution shoreline mapping and shoreline change analysis. The following discussion addresses the results of LIDAR analyses and the measurements of shoreline change across the littoral cell. Trends of large scale coastal behavior on the scales of meters to kilometers, periodic fluctuations of erosion and accretion emerge from this analysis. This data set and analysis has both scientific and management implications.

Multiple-scale Erosion Patterns in the Netarts Littoral Cell

In general, the expected large scale patterns of El Niño erosion were found. Two erosional hotspots developed, one in the south at Cape Lookout State Park, and the second just north of the tidal inlet at The Capes Development. To describe the scales of change measured by LIDAR, the discussion will begin at the south in Cape Lookout and move northward along the spit, past the tidal inlet, and up to Maxwell Point.

Cape Lookout State Park

Cape Lookout developed into an erosion hot spot that eventually resulted in emergency rip rap being placed to protect an oceanfront restroom. At Cape Lookout State Park there is strong evidence of the El Niño pattern increasing beach scour at the south end of the littoral cell. The average scouring in the southern end was -1.25 meters. There are some rythmic patterns in the erosion in the south associated with rip embayments and surface water flow coming out onto the beach. On a whole, the beach in front of Cape Lookout lost a total of 70,800 m^3 of sand.

Interestingly, at the base of the Cape Lookout headland, the beach response was less than areas just 200 meters to the north. Storm waves approaching from the southwest diffract around Cape Lookout, dissipating some of the wave energy and create a shadowing effect. (Figure 17) Additional evidence for this shadowing effect can be seen in the volume change from each 4000 m^2 polygon. The two polygons to the farthest south lost 965 m^3 and 1857 m^3 of sand. Moving 200 m northward from the Cape Lookout headland, there is a loss of over 3000 m^3 of sand (Figure 18).

Near the south end of the cell, there was a steepening of the beach slope (Figure 19). This implies that there is a coarser sediment grain size. Steeper beaches promote higher swash run-up, which may have potentially led to increased erosion at Cape Lookout State Park. Beach slopes in Cape Lookout were overall steeper after the El Niño event by an average of .0025. Slopes in the southern end range from about .06 in 1997 to .09 in 1998. The El Niño storm season played a major role in changing the variability of slopes.

This area suffered significant erosion with horizontal retreats of the .5, 1.0, 1.5, and 2.0 meter elevation contours. The average horizontal retreat for each contour is found in Table 9. The lower contours eroded more than the upper contours. This indicates that more sediment is transported from lower on the beach face. Comparing the shoreline retreat with the volume of sediment change shows the relation between loss of sediment volumes and shoreline retreat (Figure 26).

Table 9: Contour Retreat

	.5m Contour	1.0m Contour	1.5m Contour	2.0m Contour
Avg. Retreat CLSP	29.7 m	24.3 m	20.3 m	12.1 m
Spit	3.6 m	4.1 m	5.8 m	5.1 m
North end of the cell	9.8 m	5.7 m	6.7 m	2.4 m

The area of greatest erosion in the state park occurred on the foredune to the north of the oceanfront restroom (Figures 27 & 28). Cross shore reduction in sand volumes enabled wave attack to impact the toe of the dune, scarping the foredune and causing slumping until it reached an equilibrium angle of repose. The change in vertical distance on average at this location of maximum dune erosion was –1.30 meters. The total amount of sand volume eroded from the sand dune was ~7500 m^3 (Figure 29). This volume is above and beyond the 70,800 m^3 that was scoured from the beachface in front of the State Park. The erosion of the toe of the dune at the hotspot site resulted in erosion across the profile. Erosion of the 1 m, 1.5 m, 2 m, and 3.2 m (toe) contours were 36 m, 30 m, 19 m, and 10.4 m respectively. (Figure 30).

Netarts Spit

Moving north on the spit away from the developed part of the park, the amount of beach scour decreased. The southern half of the spit shows an average cut of -.43 meters, the northern half -.23 meters excluding the rip embayment and tidal inlet impacts. The average cutting of the beach on the entire spit in the cross shore profile is only -.4 meters, but this section shows a lot of spatial and volumetric variability at different scales. Several interesting rythmic features appear along the spit including three rip embayments and four pockets of accretion. These features can be seen both in the differencing, and in the contour retreat (Figures 17, 20). Rip embayments lower the beach profile approximately -.6 to -.9 meters, and occur in pairs about 500 meters apart. Initially it was thought that these pairs of erosion were an artifact of the LIDAR sampling of only two snapshots in time. Review of the videotape data illustrates the presence of pairs of rip embayments bracketed by pockets of accretion. These accreted areas show deposition of approximately .2 to .4 meters for 300 meters and are located between 1,200 - 1,700 meters apart. The volumes of accreted sediments from south to north are 14,200 m^3, 16,150 m^3, and 11,600 m^3. The contour retreat for these pockets of accretion are negative, showing the migration of the shoreline was seaward (Figure 20). These accretion and erosion pockets are also accounted for in Table 9, with the average contour retreat interval for the spit section having been relatively small. Beach slopes for these features vary but do not seem to have any significant correlation with contour retreat, mean difference, or El Niño sediment changes (Figure 31). On the other hand, accretion does show up quite well with the horizontal shoreline advance (Figure 26).

The Tidal Inlet

The LIDAR reveals evidence of a northward inlet deflection in the last several hundred meters of the spit. At the end of the vegetation near the inlet, there was a severe erosion pocket of ~4700 m^3 (~ -1.7 m) that caused a retreat of over 40 meters at each of the contour intervals. The sediments scoured from this pocket seemed to have been deposited eastward into the inlet mouth, resulting in accretion of ~ 10 meters in the bay. This erosion and accretion served to hook the end of the spit. Missing data in the 1997 flight prevent a complete picture of this hooking by LIDAR alone. To bolster the inlet migration analysis, historical air photos were rectified and shorelines digitized from El Niño and non – El Niño years. The observed patterns confirm this hooking and inlet deflection. (Figure 24) On the other side of the inlet, this northern deflection of the channel moved deeper water offshore from The Capes. This allowed wave energy to travel relatively unimpeded to the shoreline and attack the toe of the sandy bluff under The Capes development.

North end of the littoral cell

The beachface immediately north of the channel shows some accretion that ranges from .3 to 1.0 meters (average .35 m). This accretion is possibly due to the flood tide transport of the sand from the Capes landslide into Netarts Bay. The LIDAR data from the 1997 flight does not extend into the tidal inlet far enough to determine the full extent of this accretion. The sandy beach in front of The Capes experienced an average scour of –.45

meters, which is less than the average seasonal fluctuation of -.56 m. Two rip embayments immediately under the main slide block reduced the beach by -.9 meters. The previously discussed accretion immediately north of the inlet is about 1,200 meters away from another accreted area that together bracket the two rip embayments.

The bluff erosion below The Capes was the largest erosion volumetric event in the littoral cell during the 1997-98 El Niño. The 1.5 meter contour eroded back some 35 meters, and the 1.0 meter contour eroded 27 meters. The Capes landslide resulted in greater than 5 meters of vertical loss from the bluff itself (Figure 32). However, the 1997 LIDAR survey did not fly over the headwall of the slide block, so LIDAR cannot show volumetric changes, but does show toe scour, areas of slumping and depositional areas lower on the slope. The beach in front of the Capes landslide showed some variability of volume changes. After subtracting out the estimated seasonal fluctuation, the beach in front of The Capes accreted about 3300 m^3. Historical oblique photo examination shows landslides of varying degrees following El Niño years (Figures 33,34,35). These episodic landslides may be part of the reason that Oceanside has experienced relatively little erosion since the 1880's. As the landslides occur, sand is released onto the beach where it is affected by northward sediment transport nourishing the beach at Oceanside. At the southern end of The Capes section, overall accretion may be indicative of the beach nourishment coming from The Capes landslide and transported into Netarts Bay on the flood tidal currents (Figures 18, 26).

Moving north toward Maxwell Point, the average beach scour decreases to an average of -.26 meters. After subtracting out the seasonal estimate (-.56 m), this northern section shows accretion relative to seasonal fluctuations (Figure 18). Some minor rythmic features about 200 meters apart appear to be small rip embayments. At the far north end adjacent to Maxwell Point, there is a significant rip embayment (~.9 meters). This feature is probably created each winter as the southerly wave attack forces water into the corner of this southwest oriented headland. This may be enhanced during an El Niño. Photographic evidence show that there is a recurring summer ridge and runnel system that develops at this site that may be evidence for the recurrence of this rip current in recent years. The ridge and runnel may be formed during the onshore summer migration of sand choking off the rip embayment, creating a depression in the beach behind the summer berm (Wright and Short 1983).

The most northern portion of the cell between Maxwell Point and Cape Meares was very difficult to conduct similar change analysis since the twisting shoreline was almost completely missed during the 1997 flight. This prevented the shoreline difference layer from being created for this stretch of shoreline.

Sectional trends

In an effort to examine the trends associated with the large scale coastal behavior, four trend lines were examined. The first examines the volume changes to the cell after subtracting out the seasonal fluctuation estimate shows a steep trend of erosion. This trend for the overall cell wide change is given by the equation y = -37.891x + 2214.4. (Figure 18) This trend shows the overall shoreline reorientation from south to north.

The second trend examined the erosion volumes on the beach in front of the developed portion of Cape Lookout State Park. This southern end trend yields the equation of y = -43.203x – 2269.9. Without the entire cell being considered, the slope of this trend line steepens considerably. (Figure 21a). The sand spit section continues to show an erosion trend, but the slope of this line reduces significantly to y = -25.771x + 1608.4. (Figure 21b) This trend shows the continued longshore transport of sediment to the north. The northern section from the tidal inlet to Maxwell Point shows a reversal in the erosion trend line to a positive slope. This trend line is given by the equation y = 3.5078 + 743.52. (Figure 21c) The reversal of the trend line shows that after the seasonal fluctuation has been subtracted out, there is net accretion on the beaches to the north of the tidal inlet. How much of this accretion is caused by contributions from the landslide at The Capes versus longshore transport overall is an area for future research.

LIDAR Conclusions

LIDAR provides the first opportunity to quantify Large Scale Coastal Behavior. This data set as more is collected may form a bridge between LCSB and nearshore processes that operate on spatial scales of meters. To do so, more systematic and regular sampling needs to occur. LIDAR provided good data to quantify the littoral cell wide erosion – accretion trend in the Netarts littoral cell. The migration of the tidal inlet was also detected using both historic shorelines and volumetric measurements. Significant erosion in the south end and accretion in the north end was quantified using horizontal shoreline retreat, and volumetric changes after subtracting out the seasonal mean. This seasonal mean that was filtered out is a simplistic assumption, but is the only potential filtering mechanism to isolate the El Niño signal considering there are only two data points in time.

While LSCB focuses on the trends of shoreline change, LIDAR also provides the data to examine the fluctuations around those mean trends. The periodic nature of the shoreline change enables various scales of patterns to be detected. Some of these features include paired rip embayments and pockets of accretion that formed most likely as a result of an infragravity band frequency. One outcome of the analysis illustrated the relationship between the horizontal retreat and the longshore volume transport. Areas of large horizontal retreat correlated well with areas of large volume losses (Figure 26).

Attempts were made to correlate the periodic rip embayments and the shoreline retreat with changes in beach slopes, but these proved inconclusive. Comparing the slope distributions with the horizontal shoreline retreat at .5, 1.0, 1.5, and 2.0 meter contours showed no correlation between changing beach slopes and horizontal retreat (Figure 31). This is somewhat surprising but could be explained by the time scale constraints of LIDAR. Daily changes to beach morphology including beach slopes are not picked up by two data points collected before and after a storm season. Another possible explanation for the changes in beach slopes from 1997- 98 could be the different tide levels picked up by LIDAR. (Table 5). These difficulties may have risen as an artifact of the LIDAR data with the sampling of only two points in time compared with beach slopes that change with each tide. This indicates a shortcoming of the LIDAR in that it does not address changes on short time scales. Another potential error may have come from an artifact of deriving the slope at 100 m spacings instead of a tighter or nested sampling design. It may assist future users of LIDAR to examine various sampling designs to study the various scales of patterns.

Examining the littoral cell in three different sections showed that there were several trends underlying the main trend. The southern end definitely eroded, while the erosion on the sand spit eroded at a lesser rate and decreased significantly as one moved northward toward the tidal inlet. The northern section of the cell showed minor accretion as one moved north toward the tidal inlet. In general, this fits the predicted patterns for El Niño. Source for these accreted sediments could be from longshore sediment transport, or from the release of new sediments from the Capes landslide. The LIDAR did not provide enough data to distinguish between the two sources, but identifies the need for a more in depth sediment budget to determine the sources and sinks of the sediments in the littoral cell.

The shoreline change analysis demonstrates that El Niño causes much of the episodic erosion in this littoral cell. It appears that the nearshore transport in the dissipative Netarts Littoral cell is characterized during normal years by the rip cell circulation. Episodic El Niño events redistribute the sediments and result in significant erosional hotspots. La Niña has played an important role in erosion due to the decreased buffering capacity of the beach following an El Niño event. Most of the normal sediment transport can be characterized by a relatively simple cross shore sediment transport, offshore in the winter and onshore in the summer.

Management Implications of LIDAR

On the management side of this issue, the incorporation of this LIDAR data into the Netarts Coastal Hazard GIS enables decision-makers to understand the scales of changes that can happen as a result of a single El Niño. Most notably is the ability to examine specific erosion hot spots. The utility for this data set in a decision support capacity extends to providing high resolution elevation data that can be used to examine bluff heights, dune heights, elevation of parcels, and provide physical beach parameters that can be incorporated into the development of hazard assessment models. Other useful information to land managers is information regarding the volume of sediments transported across the cell. Understanding the seasonal fluctuations and the loss of sand from the cell gives some evidence for the loss of sediments to the system during an El Niño year and may help assess future shoreline locations. Knowledge of these transport mechanisms can help state parks assess the appropriate amount of sand and cobbles that they could back pass to protect the park during episodic erosion events.

Scientific Implications of LIDAR

The scientific opportunities for such data are immense especially in the realm of Large Scale Coastal Behavior. The rapid collection of high resolution topographic data can facilitate LCSB studies on larger scales than the Netarts Littoral cell. The three dimensional nature of the LIDAR data enables longshore sediment transport to be quantified and volumes of sediment changes examined. Geologists can get detailed elevation changes related to landslides features. This may help in the long run to quantify sediment budgets. The limitations of LIDAR to scales of meters and time of storm event could be reduced by more frequent sampling. This would be especially useful in better determining the normal seasonal fluctuation.

Sediment Budget Considerations

The Shoreline change model explores various methods to understand historic erosion in the Netarts Littoral cell. In recent history there has been a significant amount of sediment lost from the nearshore system that has reduced the buffering capacity of the beach to protect upland development from erosion especially as it relates to Cape Lookout State Park. The littoral cell is a system that involves sources and sinks of sediments. In order to fully appreciate the future potential for erosion, a sediment budget should be conducted, quantifying the sources and sinks of sediment for the cell (Figure 36) Several potential sinks have already been identified. Netarts Bay may be the sink for the sediments that are scoured from the beach (Komar et al. 1988). Another sink possibility could be that the sediments are deposited too far offshore to return to the beach (Komar and Good 1989, Komar 1998b). Other potential sinks could include offshore deposition or transport around Cape Meares, which extends offshore to between the 12 and 15 meter bathymetric contour.

Many of the uncertainties that have developed out of the future location of the shoreline revolves around several key features of the sediment budget. For example, what is the normal cross shore transport? How much sediment do various El Niños transport? Is there some minimal loss expected? The key to these answers here revolve around Netarts Bay and the changes to the tidal prism as the bay fills up and its effect on the tidal inlet dynamics. In effect these components of the littoral system control the future shoreline. Understanding the bathymetric change over time will help quantify the entire sediment budget. In 1957, there was a National Ocean Survey navigational survey conducted that recorded the bathymetry in Netarts Bay and north to Tillamook Bay. In 1969, Thomas Glanzman conducted his masters research on the Tidal Hydraulics and Flushing Characteristics of Netarts Bay. In that time, Glanzman determined a 10% decrease in the volume of the bay (Glanzman 1971). Thirty-one years later, the opportunity to understand the sediment budget in this small littoral cell is within reach. The critical piece of missing information is a current bathymetry of the cell.

Hazard Impact Model

The Hazard Impact model is the coupling of the "best available science" (accurate and efficient) with risk assessment and incorporating both into a decision support system. The Netarts Coastal Hazard GIS incorporates science into the decision making process during the creation of these predictive models, and again when the necessary parameters are inputted. Understanding the limitations and input parameters is important to properly apply these models. These limitations and parameters will be discussed below. Education of local coastal planners needs to promote a better understanding of coastal processes.

To input all of the physical beach parameters, data was collected using various beach profiling techniques and extracted from the 1998 LIDAR grid layer. Storm scenarios, based on independent probabilities of extreme water and wave levels were used to calculate the High, Moderate, and Low risk zones (Table 10). The High and Moderate storm parameters were taken during the largest storms of the 1997-98 El Niño and 1998-99 La Niña winters. Water level data was collected from measurements taken at the Yaquina Bay tide station and wave height data was taken from the National Data Buoy Center buoy 46050 west of Newport. The Low Risk Zone was based on predicted storm statistics of independent water levels and independent wave heights.

Geometric Model of Foredune Erosion

A geometric erosion model for dune backed shorelines has been developed and calibrated for the Oregon Coast (Marra 1998, Komar et al.1999). It assumes that dune erosion is a simple geometric cut into the dune based on a beach slope and a combination of extreme water levels and wave attack (Figure 37). The erosion of the foredune is projected landward from an accreted shoreline position. This is one of the fundamental assumptions when applying the model to the Oregon coast, is that the beach eventually will build back out (Komar et al. 1999). In most cases the Beach Zone line provides a good starting point on the Oregon coast. This line was not identified for public lands, so the Vegshore67 layer was used as the reference line to project the hazard zones.

There are two forms of this formula. The one by Komar et al. 1999 below focuses primarily on the consequence of a single storm event and is given by the equation given in Figure 37. The formula by Marra 1998, includes a trend parameter that accounts for both individual storm events, and a trend parameter that can take into account sea level rise, and sediment budget constraints.

Necessary input parameters into the equations include:
Significant wave height (H_s),
Wave period (T),
Predicted tide level (E_t),
Wave run-up ($R2_{\%}$),
Beach slope (β),
Elevation of the dune toe (H_j)
Dune crest elevation
optional parameters include:
Sea level rise,
Shoreline retreat,
Decreased beach level (ΔBL, e.g. from a rip embayment).

Table 10: Dune Hazard parameters

Beach Slope = .05	**High**	**Moderate**	**Low**
Wave Height H_s	12.0 m (39.4')	14.0 m (46')	16.0 m (52.5')
Wave Period T	15 sec	17 sec	20 sec
Wave Runup $R_{2\%}$	4.4 m (14.4')	4.8 m (15.7')	6.0 m (19.7')
Water Level WL	2.4 m (7.8')	2.2 m (7.2')	2.5 m (8.2')
HAZARD ZONE	72 m (236')	80 m (262')	108 m (354')

Calibration and Limitations of the Geometric Dune Erosion model

Calibration of this model to the Oregon Coast has been conducted using a series of beach profiles taken over several storm seasons by Komar et al. 1999. Comparing model predictions using 1997-98 El Niño storm parameters with erosion measured by the LIDAR are illustrated below. (Figure 38)

Comparison of foredune model predictions, using storm parameters from the largest El Niño and La Niña storms, with measured erosion indicated some of the limitations of the model. (Table 11) Erosion measurements for El Niño were extracted from the LIDAR data, while the La Niña measurements were taken using GPS equipment.

Table 11: Erosion Results Predicted Vs. Measured

	El Niño	La Niña
Measured Erosion	10.4 m	7.5 – 140 m
Predicted Erosion	18.9 m	64.4 m

- Assumes an instantaneous cut into the dune regardless of storm duration.
- Assumes net littoral drift is zero (hence 1967 starting line)
- No method for dealing with a foredune breach and flooding into the deflation plain (explains discrepancies between La Niña measured and predicted)
- Does not address the mixed sand and cobble beach with different slopes and erosion coefficients.

Merits to the model include:

- Single storm parameters provides good estimate of cumulative erosion.
- Overestimation of storm cuts increase the safety factor into risk zones
- Separate trend for sea level rise

Bluff Hazard Zones

Bluff erosion can be examined for both trends and episodic events. Bluff erosion trends relate more closely with sea level rise and annual recession rates, while episodic block failures are generally catalyst by unusual events such as an earthquake, large storm wave attack, or sustained rainfall. Other factors affecting bluff erosion include bluff composition, wave attack, and bluff height. Most bluffs in the Netarts littoral cell are Pleistocene dune bluffs with varying levels of material consolidation. Some bluffs, such as Cape Lookout and Cape Meares contain large volumes of basalt that are quite resilient to wave attack. Block failures are associated with all types of bluffs, with the larger block failures involved with deeply penetrating bedrock landslides (Priest 2000).

The Active, High, and Moderate risk zones were created by George Priest at DOGAMI using site specific geological observations. (Figure 23) Due to limited resources, these characteristics were confined to maximum block failure width, general angles of repose, angles of long term stability, field observations and estimated average annual recession rates. Estimated annual average recession rates of .27 ft/year +/- .34 ft (one standard deviation) were taken from data collected in Lincoln County and applied to Netarts bluffs.

Priest defined his hazard zones as:

Active Erosion Zone: Currently active erosion area (rapid soil creep, active or potentially active landslides, active beach processes).

High Hazard Zone: High probability that the area could be affected by active erosion in the near future (~100 years).

Moderate Hazard Zone: Moderate probability that the area could be affected by active erosion in the near future (~100 years).

In general, the Active zone was generated by delineating the crest of the current bluff and extending the zone seaward of this line. The High Hazard Zone estimates an equilibrium angle of repose between 1:1 and 1:1.5 varying with actual bluff type and composition then added the annual recession rates x a 100 year planning horizon. The Moderate

Hazard Zone was calculated using a 2:1 angle of repose and adding the annual recession rates x the 100 year planning horizon. (Figure 39)

The delineation of geological units resulted in application of different hazard zone calculations. The geological units can be broken down into seven categories, based on bluff composition, angles of repose, bluff height, and landslide presence. These bluffs like those found on the headlands of Cape Meares and Cape Lookout require different hazard zone calculations due to steeper equilibrium angles of repose and increased bluff strength that make them less susceptible to wave attack. Additional considerations of prehistoric slides or susceptibility to wave attack may alter the extent Moderate Hazard Zone and require geological judgment based on field observations. The Crab Avenue area in Netarts illustrates this alteration based on field observations, and professional geological judgement (Figure 40).

Automating the Bluff Hazard Calculation

In the event that the stakeholders decide on a different set of risk zones assuming less risk or a smaller planning horizon, then an automated technique based on various angles of repose would be employed. This automated method can be derived using angles of repose and average recession rates derived via the AML script developed by Foisy for Shoreland Solutions. This method would lack site specific field observations regarding block failure widths, and bluff composition. Improvements to this automation could occur if the bluff type and material strength were determined so that a dynamically segmented line could be generated containing the bluff attributes. Variations in the bluffs could then be reflected in the automated hazard calculations by coupling the segmented line with the hazard calculations.

Following the creation of each of these hazard zones, the attribute tables for each of these zones were populated with the appropriate geological unit, and assumptions made in the creation of each zone. Eventually the proposed management recommendations from the stakeholder process would be attributed as well to show the recommended hazard avoidance strategies.

Decision Support System

Spatial Decision Support Systems can be viewed as an effort to integrate diverse spatial data to inform and facilitate decision-making. The decision support system uses two methods to facilitate decision-making. The most important method involves queries to a Tax Parcel layer that has been joined with several county databases. Additionally, two AML scripts have been developed; the first developed by Jeff Foisy working with Shoreland Solutions and the second by the NOAA Coastal Service Center. These scripts enable calculation of the hazard zones to be interactive facilitating the incorporation of decision-maker and stakeholder preferences.

The public input survey and the Technical Advisory committee helped identify the important management issues and generated a list of management questions that ideally, the GIS would answer. Sample management questions that have driven the inventory and attribute design include:

- *What areas may be susceptible to various types of hazards?*
- *What are safe development setbacks?*
- *What areas are eligible for shore protection structures?*
- *How much damage would a tsunami cause?*
- *Where are the different backshore beach types located?*
- *What is the vegetation coverage for the cell?*
- *Where are the sensitive biological species located?*
- *What types of geology are present along the shoreline?*
- *Where are existing shore protection structures?*
- *Where are the public access points?*

Specific attributes needed to answer GIS queries were thus driven by the Technical Advisory Group, stakeholders and members of the public. Many of these attributes were populated to the Tax Parcel Data Layer (Table 12).

The tax parcel map was digitized by the Department of Corrections under contract with OPRD. Differences between constructed and planned maps create some errors regarding absolute locations of tax lots. This layer should not be used to resolve property line disputes or take the place of land surveying. Discrepancies between the digitized maps and actual lot location gets worse as one moves inland away from the shoreline. This layer does however show the relative location of properties, enabling hazard assessment and facilitating decision making.

Table 12: Tax Parcel Attributes

Parcel Identification Number (PIN number)
Street Address
Common name of subdivision
Landowner contact information
Owner type (Private, Public, Utility, Corporation, Parks)
Primary residence of current owner
Year round resident? (Y/N)
Value
Assessed Value of the House
Assessed Property Value
Cell Data
Sub-cell (Spit, Bay, Mouth of Bay to Three Arch Rocks, Radar Beach)
Proximity to nearest beach access
Physical Characteristics of Parcel
Elevation of the parcel
Ocean frontage length
Landform – Backshore type (Dune, Bluff)
Bluffs
Slope of sea cliff landform
Site specific erosion history
Average annual recession rate?
Length of time for calculating AARR
Beach Conditions
Width of winter beach at low tide
Width of winter beach at high tide
Vegetation cover on backshore (% coverage)
Vegetation type
Driftwood Present (Y/N)
Cobbles Present (Y/N)
Developed versus Undeveloped prior to January 1, 1977? (Y/N)
Year Unit Built
Shore Protection Structure existing (Y/N)
Hazards
Calculated Risk Hazard Zone
Principal hazards affecting property owner
Existing setback from crest of dune or bluff
Setback from eastern most portion of the site
Adjacent parcel setback

Flood Zone	
Insurance Zone	
Tsunami Inundation	

These attributes enable GIS queries to answer of most of the management questions that were raised by the public, stakeholders, and planning agencies. Several will be given below demonstrating the results of queries that can be used to answer some of these questions that were designed into the GIS. Some example management questions that can be answered with the Netarts Coastal Hazard GIS follow.

What areas are eligible for shore protection structures?
Where are the public access points?

To answer some questions that a decision maker in Tillamook County may ask, the GIS is zoomed into Oceanside to show the tax parcel map. After selecting the Tax Parcel Layer in the Views Table of Contents, the query builder in ArcView selects all private lands built after 1977 adds them to a new set. The next part of the query identifies the public recreation management zoning and adds those lands to the existing set. A management decision in this example could be to forbid shore protection structures that are highlighted by that set so that a) Goal 18 – Beaches and Dunes is not violated with regards to shore protection structures, and b) public access to the beach from upland recreation areas is not blocked. The results of this query are found in Figure 41.

What areas may be susceptible to various types of hazards?
What are safe development setbacks?

To provide answers to these questions, first turn on the Orthoquads, DOGAMI_Geology layer, landslides, the tax parcel layer, and the Active, High, and Moderate bluff hazard zones. Then zoom the GIS into the unbuilt area just north of the Capes. Using the select by themes option to select all parcels that intersect landslides and create a new set. From this set query the parcels that are intersected by the active bluff hazard zone and add this to the set. Assuming that the decision maker wants to require the maximum appropriate setbacks examine the parcels in the set for distances outside of the hazard zones. This would be an appropriate area for development (Figure 42).

How much damage would a tsunami cause?

To answer this question, turn on the Orthoquads, tax parcel layers, and tsunami inundation contour. Select by theme all parcels that are interested by the Tsunami Inundation line and add them to a new set. The next step is to summarize the statistics for these selected parcels based on the Assessed Property Value attribute in the Tax Parcel layer. Assuming total loss of the property as a result of the tsunami, then the Sum field after the Statistics query will be the total investment lost. (Figure 43).

Another example of the use of GIS during the stakeholder workshops occurred during the January 29th Dune Hazard Workshop. One of the stakeholders asked whether Netarts Spit could be breached at its narrowest point. Using the geometric dune erosion model and a 100 year water level and 100 year wave height, a hazard zone was generated which did not extend into Netarts Bay indicating that the probability of the spit breaching was less than a 1 in 1000 year storm event. These interactions during workshops enabled many opportunities to educate the public and stakeholders about the benefits and limitations of GIS.

CONCLUSIONS AND RECOMMENDATIONS

Littoral Cell Planning

In conclusion, littoral cell planning addresses coastal hazards by collecting pertinent information in a display friendly environment that provides a rapid assessment tool of regional coastal hazards based on a scientific baseline. Littoral cell planning has three steps, inventory, risk analysis, and implementation; the focus of this project has been to develop the GIS inventory and to conduct a preliminary risk assessment. Regional approaches to coastal hazards insure that hazard alleviation techniques are chosen based on the same scale that coastal processes operate in the Pacific Northwest, littoral cells. The consolidation of diverse data into a GIS enables better communication between agencies and individuals regarding factors affecting coastal hazards. Littoral cell planning has the potential to minimize adverse impacts from these regional hazards and promote the use of science into the decision-making process. This type of proactive planning has implications to urbanizing coastlines and developing coastal nations that can address many of these erosion concerns before they become a hazardous issue.

Shoreline change

From the shoreline change analysis, several conclusions can be made regarding coastal response to episodic erosion and trends. The Netarts littoral cell seems dominated largely by seasonal cross shore sediment fluctuations, offshore in the winter and onshore in the summer. This pattern seems caused primarily by rip current cell circulation in the nearshore. Slight deflections in these rip currents coincide with prevailing current directions. Episodic erosion, particularly El Niño is generally responsible for the redistribution of sand and sediments in the Netarts littoral cell. The observed pattern response results in a scouring of sediments from in front of Cape Lookout promoting erosion of the dune in front of the State Park. A northward deflection of the tidal inlet hooks the end of the spit tip into the bay and scours away the toe of the sandy bluff under the Capes, causing slumping of sand onto the beach. This sand may be the primary source of beach sands and nourishment to the northern end of the littoral cell. On a trend scale, there seems to be a slow loss of sediment over time. The primary sink of these sediments is probably Netarts Bay, but other potential sinks could include transport out of the littoral cell around Cape Meares, or offshore deposition near Three Arch Rocks. The role of the ebb and flood tidal deltas is not completely understood. These potential sinks illustrate the need for a more quantitative sediment budget. The most critical data currently missing is a current bathymetry layer.

LIDAR

LIDAR provides detailed topographic data that facilitates change detection of both large and small scale spatial patterns. This data provides a lot of information regarding morphological changes, horizontal shoreline retreat, and sediment volume transport that has never been available at such a large scale with such detail. For example, from historic photos, it is apparent that the sandy bluff underneath The Capes has experienced historic periodic slumping. This has always been attributed to toe scour from deflection of the tidal inlet. Air photos, though, lack elevation data especially on the beach. LIDAR not only provides information on sand volumes moved as a result of this toe scour, but with the high level of detail, enables detection of smaller rip embayment features immediately underneath the landslide.

The good spatial detail to the data has implications for both scientists and managers. Scientists can examine large scale (meters to kilometers) seasonal and storm related beach responses. Sediment volumes can be measured to aid in sediment budget analysis. Managers can use LIDAR data to examine the extent of episodic erosion and begin to bracket hazard zones by examining erosion hotspots. Large scale detailed elevation data can be used by both scientists attempting to measure landslides and bluff erosion; and managers who may attempt to apply erosion models to delineate hazard avoidance setbacks. The ease of viewing LIDAR data in a GIS enables many people of varying GIS and scientific competence to explore various erosion and elevation features.

The primary limitation to LIDAR is the lack of temporal data. This hinders the understanding of "normal" seasonal fluctuations. Removing this normal fluctuation would better isolate the El Niño signal and enable a more in depth analysis of El Niño responses. This could be remedied partly by subsequent surveys during both "normal" and El Niño years. The vast utility of LIDAR will come ten to twenty years down the road as future surveys are completed. These first flights will provide the initial baseline for long term, large scale monitoring of beaches. Improvements of LIDAR technology would ideally include some water penetrating capabilities that could be used to study bathymetric differences as well as beach morphology.

GIS

The purpose of this GIS was to inventory the littoral cell and conduct a preliminary risk assessment. GIS facilitates the examination and communication of diverse data sets in a manor that promotes interactions among stakeholders of varying background and computer literacy, as well as across disciplines. It facilitated meetings and the regional examination of littoral cells. In general it was received favorably by stakeholders and public citizens who came forward with a variety of questions unrelated to hazards during the educational public workshops. This GIS database provides local coastal planners with a sound scientific inventory of the littoral cell. This will enable them to better assess complicated geotechnical reports. It will also improve the quality of the site specific geotechnical report by standardizing the baseline and enabling consultant efforts to focus on more detailed analysis of each site.

The dune erosion model proves an efficient method to generate risk hazard zones on the Oregon Coast for dune backed shorelines, but limitations must be understood to avoid misapplication. To expedite future bluff hazard calculations, an automated technique based on angles of repose, bluff composition, and average annual recession rates should be agreed upon, but it is acknowledged that more research into annual average recession rates is needed. An automated method will admittedly lack site specific field observations regarding block failure widths and susceptibility to wave attack.

To design the GIS inventory, it was beneficial to have specific management questions in mind, so specific queries could be designed ahead of time. These queries helped shape the data model, data structure, and attribute field design. Attempting to incorporate the variety of community values, scientific information, and planning data was complicated by a rigorous stakeholder workshop schedule. The use of the stakeholders to design the inventory was important, but there was a need to slow the process, to insure time for quality control before using the data in a public forum.

Education of stakeholders regarding the benefits and limitations of GIS must be part of this process for two reasons. Many people are skeptical of technological advances until they are familiar with them, so being up front with stakeholders about GIS is important so that in the future the work product may be used. Conversely, issues arise from becoming too technologically dependent on GIS. GIS is a tool, not a substitute for good planning, as such, there should be some time for GIS and coastal processes education designed into future littoral cell projects. Expectations that the GIS will do everything and answer all the questions were prevalent both in the Technical Advisory Group and the Stakeholders. Education can remedy these preconceptions. Tillamook County needs more GIS courses to promote increase in usage of county GIS facilities and build capacity for use of spatial decision support tools by both the citizens and planners.

Recommendations for the future use of GIS in littoral cell planning would be to develop a standard set of base layers and basic inventory before holding any public or stakeholder workshops. The GIS could then incorporate stakeholder needs and additional concerns through expanded the criteria ranking and adding more data into the decision support system. One of the limitations in the GIS development was the slow development of the tax parcel layer. Providing planning agencies with a list of necessary parcel attributes up front would expedite parcel layer creation. The attribute list could also provide a mechanism to involve stakeholders more directly in research and involve them more in the littoral cell planning process. The final recommendation especially in high turn over positions such as watershed coordinators and state agencies would be to standardize a digital library structure so that the transition time for new GIS personnel is reduced due to prior knowledge of data locations.

Overall, GIS provides an effective means to blend coastal process science with coastal hazard management and community preferences to assess coastal hazards and support littoral cell management planning.

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APPENDIX 1

Netarts Coastal Hazard Geographic Information System
Data Dictionary

The Netarts Coastal Hazards Geographic Information System is an inventory and decision support system developed to assist local and state planners, citizen groups, concerned members of the public, and land use managers in facilitating decision making in the Netarts Littoral cell. This document accompanies a CD-ROM of the entire GIS database containing maps, and attributes (Table 1). A variety of sources have provided data. All of the data was then projected into:

Projection:	*Lambert Conformal Conic*
Spheroid:	*GRS80*
Horiz. Datum:	*NAD83*
Vert. Datum:	*NGVD29*
Units of Meters	
Parameters	
Central Meridian:	*-120.5*
Reference Latitude:	*43.6667*
First Standard Parallel:	*44.3333*
Second Stnd. Parallel:	*46.0*
False Easting:	*2,500,000*
False Northing:	*0*

The majority of existing digital data for this GIS inventory comes from either the United States Geological Survey (USGS) or the Tillamook Bay National Estuary Program (TBNEP). TBNEP has turned the spatial data portion of the project over to the Tillamook Coastal Watershed Resource Center (TCWRC) which has a GIS lab. This center is open to the public and is a source of information for the numerous watershed councils in the area. The Netarts Watershed Council has used this data to compile the first watershed assessment available on the internet. The assessment is the source for much of the biological data in this inventory.

http://www.tbcc.cc.or.us/~tcwrc/netarts/index.html

THE DATA LAYERS

The Base Layers

The basemap layers provide the backdrop to illustrate and graphically represent the littoral cell.

Orthoquads – North, South, East, West

Attributes: none

The photos were taken on Sept 4, 1994. These orthorectified air photos were created by USGS to remove some of the photogrammetric distortion associated with aerial photography. The resolution is 1 m^2 pixels. It is possible to get approximate latitude and longitude.

The tidal stage on September 4 was

High Tide 12:22pm	7.56 feet.
Low Tide 6:31 pm	-0.56 feet

Metadata for this data can be downloaded at:

http://mapping.usgs.gov/standards/

10 Meter Digital Elevation Models (DEM) – netarts.dem, sand.dem

Attributes: Elevation (NGVD29)

These USGS elevation terrain models parcel the landscape into 10 m^2 pixels and assign one elevation value to each pixel. The vertical datum that this is tied to is NGVD29. From these DEM's the following layers have been generated in ArcView.

- Contour maps at 3 meter and 10 meter intervals
- Slope maps –classified based on Tillamook County determination of 0-19°, 19-29°, and >29° slopes.
- Hillshade (solar incident angle)

Further metadata can be downloaded at the aforementioned USGS site.

http://mapping.usgs.gov/standards/

Creeks

This clipped line coverage comes from the Tillamook Bay National Estuary Project. It was created by Earth Design Insitute (website) by chosing the lowest elevational points along the contours and connecting those points with a creek line. The data was edited by Sean Allen, a GIS specialist at the TCWRC. His edits corrected mistakes based on an overlay with the digital orthoquads. It was clipped by the CLIP polygon function to fit it to the Netarts Littoral Cell boundaries. Additional creeks outside the Netarts Watershed boundary were added from the initial TBNEP layer and edited based on the Digital orthoquad.

GPS_PTS

Attributes: X,Y, Elevation (NAVD88), Description

This point coverage was created as a result of the Partnership. All of the points were collected using differential kinematic Global Positioning Systems (GPS). Differential kinematic indicates that it is a roaming capable (kinematic) unit, and the differential indicates that a basestation can be placed on a known elevation and broadcast a radio signal to the roaming unit providing differential elevation corrections that remove the dithering of the satellite signals. The Department of Transportation (ODOT) donated GPS survey time during a highway survey in Tillamook. Rapid communication allowed time to have a benchmark Billy set in concrete above Cape Lookout. Using a Leica xxx.... ODOT tied two of the HARN stations (High Accuracy R Network??) into the study site and occupied 7 benchmarks. The vertical accuracy of the control points is +/- 7 cm.

Part two of the GPS saga was to collect various points that would fill two needs. The first was to get control points from which to tie in the Tax Parcel maps that were digitized by the Oregon Department of Corrections. The second was to get points that were identifiable throughout the historic photo record. These points will be used to orthorectify future shorelines. These points were collected using a Trimble 4600 Pro XR. The accuracy of these second points is .5 meters.

LIDAR (LIght Detection And Ranging)

Attributes: X,Y, Elevation (NGVD29)

This gridded binary raster data set is a DEM on the order of 2 m^2 pixels. LIDAR is laser altimetry that provides vertical resolution on the order of 15 cm (Sallenger *et. al* 1999). The rotating scanning swath is 30 degrees giving an approximately 700 m – 900 m swath on the beach. Two flights were flown that bracketed the 1997-98 El Niño on October 17^{th} 1997 and April 27^{th} & 28^{th} 1998. During the flight, data was recorded that included time stamps, and GPS coordinates. From these time stamps, exact tide levels can be determined. The tide cycles at these times were

	October 17^{th}, 1997	April 26^{th}, 1998	April 28^{th}, 1998
Tide Level (NGVD29)	5.7 feet (ebbing)	-1.9 feet (low tide)	-1.5 feet (flooding)

It is possible with this data source to extract profiles and to subtract the grid to give the difference between the beach morphology following the El Niño. A series of 100 meter spaced beach profiles were generated to examine the changes in local features.

PHYSICAL LAYERS

These layers are important to represent the various aspects of the physical environment that effect shoreline hazards.

Slopes

Attributes: slope percentages, Risk zones (Low, Medium, High)

This layer was derived from the 10 m DEM. The slopes were broken down to be compatible with Tillamook County hazardous slopes classification.

Low = slopes of 0-19%

Moderate = slopes of 19-29%

High = slopes >29%

Geology

Attributes: Soil type, Ptype

This polygon coverage from Ray Wells at USGS is relatively accurate.

The layer includes the following geological (Ptype)formations:

Symbol	Description
Qf	Holocene fluvial and estuarine deposits
Qb	Holocene beach deposits
Qt	Pleistocene fluvial and estuarine deposits
Qls	Landslides
Twfs	Frenchman Springs Member of the Wanapum Basalt
Tcm	Cape Meares Sandstone
Tgr	Grande Ronde Basalt
Tacs	Sandstone unit of Cannon Beach Member of the Astoria Formation
Tac	Cannon Beach Member of the Astoria Formation
Tan	Netarts Bay Member of the Astoria Formation
Taa	Angora Peak Member of the Astoria Formation
Tms	Mudstone of Sutton Creek

Priest_Geology

Attributes: Geological Symbol, Description

This layer was generated by George Priest at DOGAMI following field reconnaissance surveys during the summer of 1999. Using the 1994 air photos, geological polygons were digitized and attributed with the appropriate Geological Symbol (see table below). Initially all of the different geological formations were sent individually. After reprojecting the various polygon layers in ARCINFO using the PROJECT command and examining the individual layers for accuracy, all of the layers were merged using the Geoprocessing Wizard in ARCVIEW.

The layer includes the following geological formations:

Symbol	Description
Qf	Holocene fluvial and estuarine deposits
Qb	Holocene beach deposits
Qt	Pleistocene fluvial and estuarine deposits
Qls	Landslides
Twfs	Frenchman Springs Member of the Wanapum Basalt
Tcm	Cape Meares Sandstone
Tgr	Grande Ronde Basalt
Tacs	Sandstone unit of Cannon Beach Member of the Astoria Formation
Tac	Cannon Beach Member of the Astoria Formation

Landslides

Attribute: description, classification (active, potentially active, prehistoric)

This layer maps the landslides in the Netarts Littoral cell and watershed. This polygon layer was created by George Priest during his summer field work in August of 1999. Each description describes the individual landslides

SHORELINE CHANGE ANALYSIS

This series of layers will enable some understanding of the trends and episodic events that characterize erosion and coastal hazards on the Oregon Coast.

Shore55
This line coverage was digitized by Randy Dana at DLCD from a NOS T sheet. The shoreline reference feature was MHW. Scale was 1:5,000 (1 cm. =50 m.) This map. The original map was created from photo interpretation of October 1955 air photos and field checked from December 1955 - May 1956.

Shore67
This shoreline was digitized by John Marra of Shoreland Solutions off of the 1967 ODOT air photos. The shoreline reference feature for this coverage was the wet sand beach, a proxy for the MHW. This photo set is the one that the Oregon Department of Parks and Recreation have mapped the Beach Zone Line.

Vegshore67
This shoreline was digitized by John Marra of Shoreland Solutions off of the 1967 ODOT air photos. The shoreline reference feature for this coverage was the toe of the vegetated shoreline. This photo set is the one that the Oregon Department of Parks and Recreation have mapped the Beach Zone Line.

Shore84 and Vegshore84
This line coverage was digitized off of airphotos that were taken on ***June 29, 1984.*** The first part of the processing for this coverage was done in ARC/INFO. Using the REGISTER command and the GPS POINTS layer, the scanned .tiff images were georeferenced. Using a series of GPS points, and obvious locations on the 1994 Orthoquad, the georeferenced image was orthorectified using the GRIDWARP command. This was done using a least squares geometric transformation, with a threshold set for 5 meters. For each image, at least 7 reference points were used in the orthorectification process. Problems with identifying reference points in the undeveloped portion of the spit required this region to be ignored. These 1984 shoreline layers, therefore, only contain the developed portion of the state park, and the end of the spit where good positional data was available.

Shore91
This MHW shoreline was identified by Ray Welles during the geological mapping that occurred in 1991.

Shore94
This line coverage was heads up digitized off of the orthoquads. The shoreline reference feature is the wet sand beach (a proxy for the MHW). Tides during the day of September 4: High Tide 1:39 pm PDT 6.92 feet
Low Tide 6:52 pm PDT 1.39 feet

Vegshore94
This line coverage was heads up digitized off of the USGS orthoquads. The shoreline reference feature was the vegetation line.

Bathy57
This layer provides the foundation for bathymetric differencing which would be the key to understanding and quantifying the sediment budget for this littoral cell.
Attribute: Depth,
This point layer created during the TBNEP by Earth Design Consultants. It was originally digitized off of an NOS T sheet. Estimated vertical accuracy is

Bathy2000
Attribute: Depth, X, Y
This point layer will be created using the Coastal Profiling System.

Cultural layers
These layers represent the cultural and the socio economic features in the littoral cell.

Roads
Attributes: Road and Road Type
This line coverage comes from the Tillamook Bay National Estuary Project. It was created by Earth Design Consultants by digitizing the roads off of the 7.5 minute USGS quads.

Shor_prot
Attributes: *Shore Protection Structures,*
Type of Structure,
Erosion at Flanks (Y/N)
If yes then
-Which side of structure?
Distance
Parcel ID's protected
Permit numbers and contact information
Contiguous properties
Year Built
Builder/Contractor/Geologist
Estimated Cost
Comments on the condition of the structure

This line layer shows the presence and location of existing shore protection structures in the littoral cell. This layer was generated by George Priest at DOGAMI during his 1999 summer field season and drafted digitally in MapINFO.

Access
Attributes:

This layer currently is under construction by DLCD as part of a public access inventory update.

Tax Parcels

This layer forms the basis for the decision support system to facilitate local planning. This layer was the most difficult to create and attribute, but exemplifies the interdisciplinary partnership that collaborated to create this layer.

The first task was to digitize the Assessors Tax Parcel Maps. Digitizing was done by the Department of Corrections under contract with the Oregon Department of Parks and Recreation. This digitization was done using two methods. The first method used the coordinate survey information on the maps and the COGO (coordinate geometry) extension of ARCINFO to generate the tax parcels. Not all of the parcels had detailed COGO information, so the large format paper maps were scanned and the remaining parcels heads up digitized. The digitized polygons were then registered using high resolution GPS points created during the summer field season of 1999 (see GPS_PTS layer) Very accurate metadata regarding methods of creation, hours spent, who did the digitizing was attributed to the polygon layer and can be examined under the Parcel Layer Theme Properties menu. More importantly, the Parcel Identification Number was attributed providing a nexus to link the planning databases with the polygon layer.

Phase two of the Tax Parcel Layer was to join and link several Tillamook County planning databases with the polygon layer. The first database came from the Tillamook County Assessors Database. Certain attributes from the Assessors database were found to be faulty, so additional databases from the Tillamook County Office of Community Development particular for the communities of Netarts and Oceanside were used to edit the database. Each of the databases was linked and joined to the Tax parcel polygon layer based on the PIN number. These databases provided most of the attributes to the layer. Additional attribute fields including the Private versus Public, the Shore Protection Structures, and some of the physical characteristics of the site were created using GIS queries and overlay methods. Additional attributes will require fieldwork to populate the rest of the attributes and to ground truth the parcel layer.

Attributes:

Parcel ID

Street Address

Common name of subdivision

Landowner contact information

- *Owner type (Private, Public, Utility, Corporation, Parks)*
- *Length of residence of current owner*
- *Year round resident? (Y/N)*

Value

- *Assessed Value of the House*
- *Assessed Property Value*

Cell Data

- *Sub-cell (Spit, Bay, Mouth of Bay to Three Arch Rocks, Radar Beach)*
- *Proximity to nearest beach access*

Principal hazards affecting property owner

Physical

Elevation of the parcel
Ocean frontage length
Slope of sea cliff landform
Site specific erosion history
Stream proximity

Developed versus Undeveloped

Developed prior to January 1, 1977? (Y/N)
Year Unit Built
Shore Protection Structure existing
Eligible for shore protection structure?

Average annual recession rate?

Length of time for calculating AARR

Setbacks

Existing setback from crest of dune or bluff
Required setback from County
Calculated Risk Hazard Zone
Setback from eastern most portion of the site
Adjacent parcel setback

Flood

Base flood elevation
Insurance Zone
Tsunami Elevation

Beach Conditions

Width of winter beach at low tide
Width of winter beach at high tide
Landform – Backshore type (Dune, Bluff)
Vegetation cover on backshore (% coverage)
Vegetation type
Driftwood Present (Y/N)
Cobbles Present (Y/N)

Zoning

Attributes: Zoning classification

This layer was created by David Revell at Oregon State. First, cross referencing the three Tillamook County databases enabled the majority of zoning to be determine. Queries to the parcel layer were then converted to a shapefile of each zoning designation. The next step was to examine the parcel layer and zoning shapefiles for missing parcels. These parcels without zoning were identified and in most cases attributed based on the surrounding parcel zoning. The shapefiles were then edited to include these parcels in their appropriate zoning. The final quality check was to reference the hardcopy zoning maps with the digital zoning map. After this quality control, each individual zoning shapefile was merged into a single coverage using the ARCVIEW Geoprocessing Wizard.

Owners

Attribute: owner classification (Private, Public, Forest Industry)

This layer was retrieved from the TBNEP website. This polygon layer showing land ownership was created by Interrain Pacific and Dr. Phil Sollins at Oregon State University using Department of Forestry ownership information.

Beach Zone Line

Attribute:

This line represents the statutory vegetation line or the leading edge of vegetation in 1967. This layer was generated by Michele Dailey at Ecotrust. For information contact Ecotrust at 503-226-8108.

HAZARD ZONES

The hazard zones generated as a part of the Netarts Littoral Cell Hazard Assessment were dependent on a variety of field observations as well as modeling.

High, Moderate, and Low Dune Hazard Zone

Attributes: Active, High, and Moderate

These layers were generated using a calibrated geometric foredune erosion model created by Komar *et. al* 1999. The hazard zone used storm parameters based on independent probabilities of water level and wave heights. Storm parameters were coupled with physical parameters taken from LIDAR and from field measurements. The following parameters were used to calculate the risk zones:

Beach Slope = .05	High Risk	Moderate Risk	Low Risk
Wave Height Hs	12.0 m (39.4')	14.0 m (46')	16.0 m (52.5')
Wave Period T	15 sec	17 sec	20 sec
Wave Runup R2%	4.4 m (14.4')	4.8 m (15.7')	6.0 m (19.7')
Water Level WL	2.4 m (7.8')	2.2 m (7.2')	2.5 m (8.2')
HAZARD ZONE	72 m (236')	80 m (262')	108 m (354')

Bluff Hazard Zones

Attributes: Active, High,and Moderate

These hazard zones were derived using a variety of techniques based on geological field observations by George Priest. He broke the littoral cell into seven different bluff types to which he applied different setback calculations based on many factors. The factors considered were the angle of repose, the bluff composition, the angle of stability, susceptibility to wave attack, and average annual recession rates. For more detail on the derivation of each hazard zone, please see appendix 2:DOGAMI Hazard Zone Calculations).

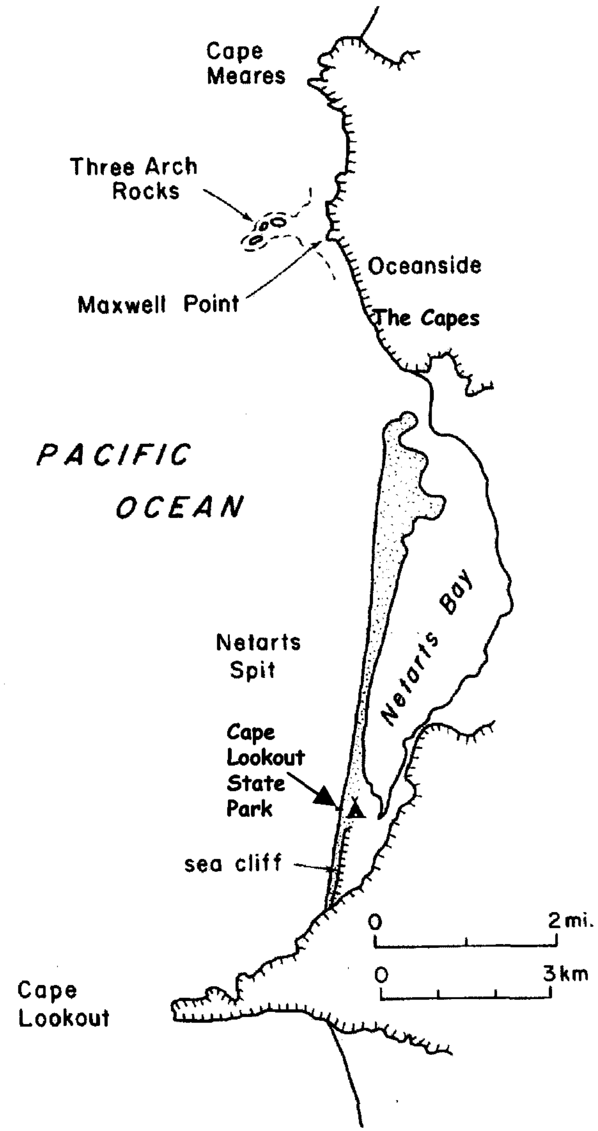


Figure 1: Netarts Littoral Cell

Figure 2: Cape Lookout State Park
Photo taken 11/98

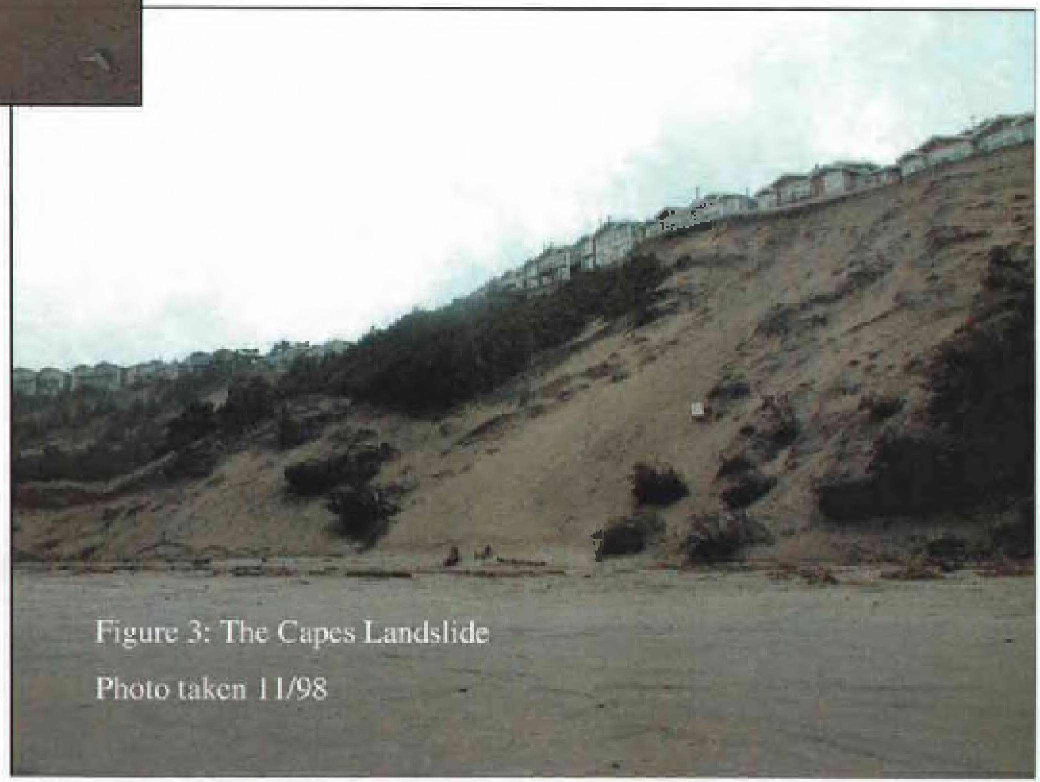


Figure 3: The Capes Landslide
Photo taken 11/98

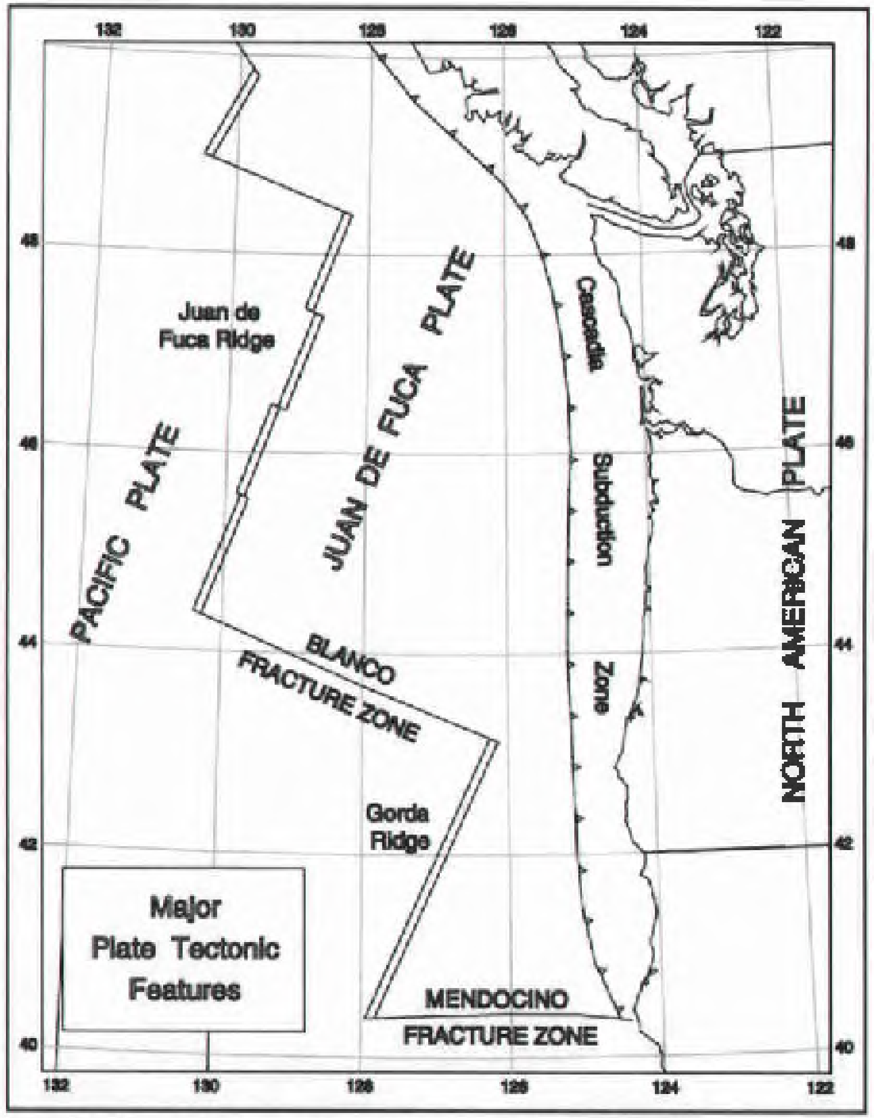


Figure 4: Tectonic Overview of the Cascadia Subduction Zone and the Pacific Northwest

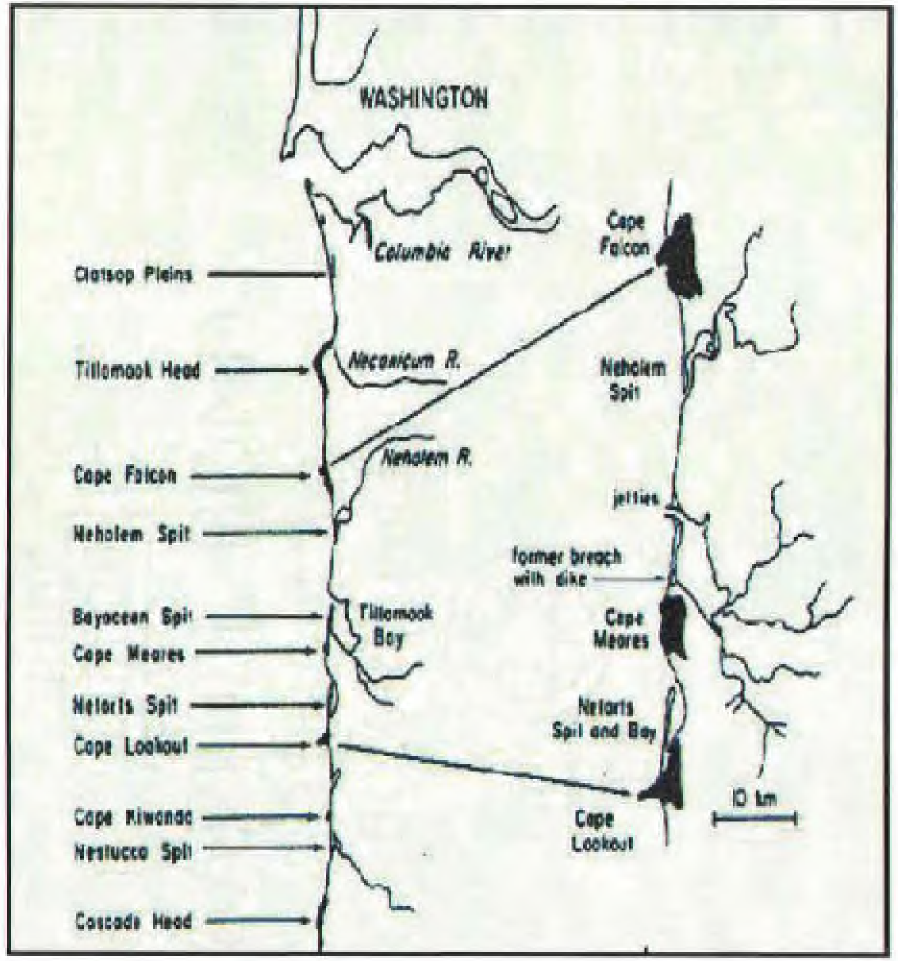
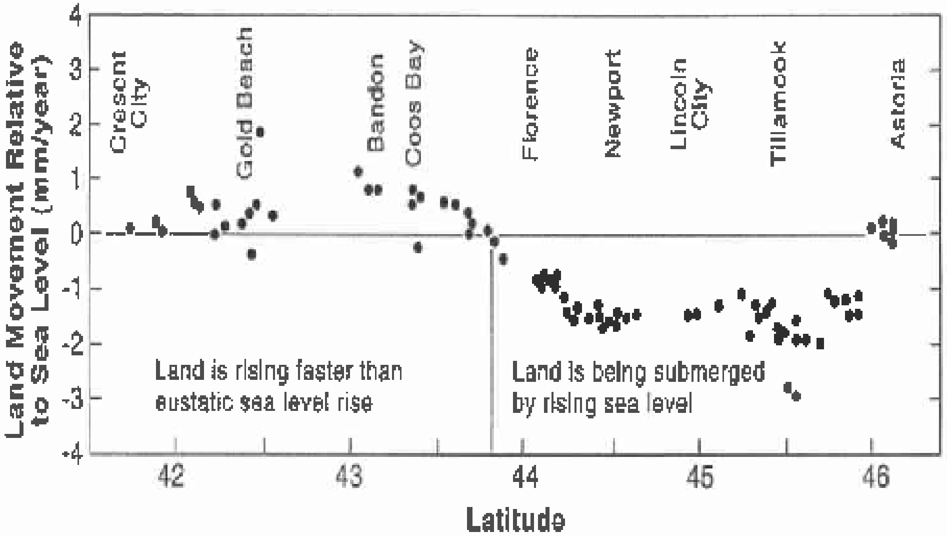


Figure 5: Littoral Cells of the Pacific Northwest

Figure 6: Relative Sea Level Rise along the Oregon Coast



Data from Vincent (1989) and Komar (1997)

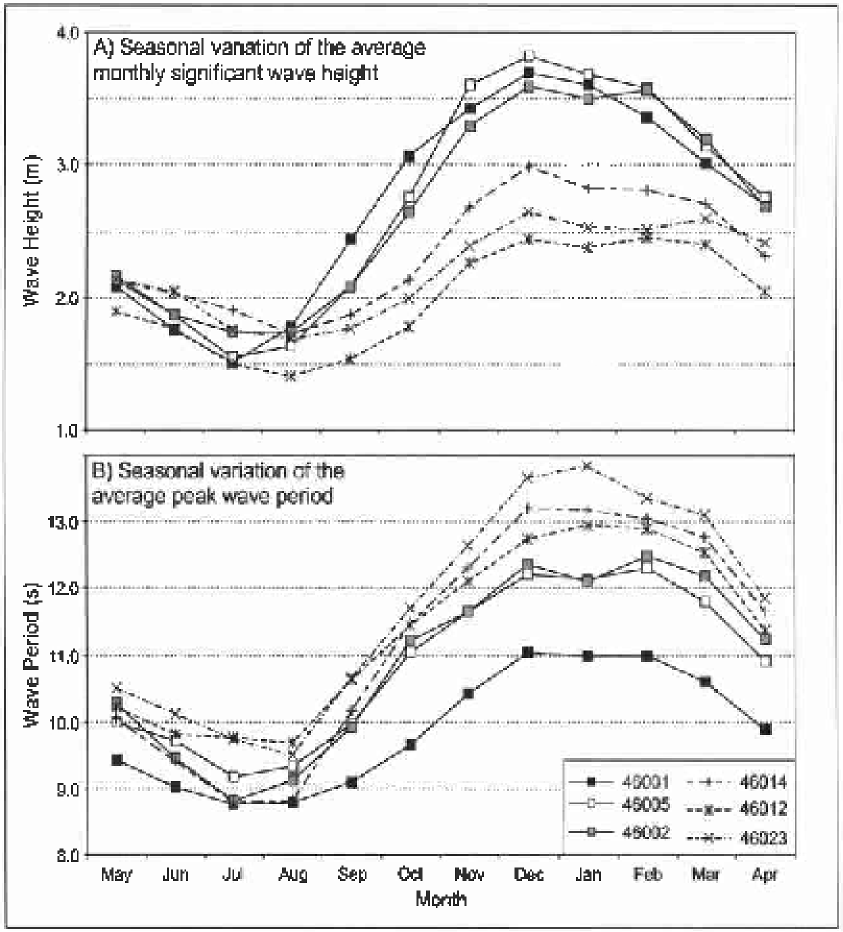


Figure 7: Seasonal Variations in Wave Heights and Periods

(Allan and Komar 2000)

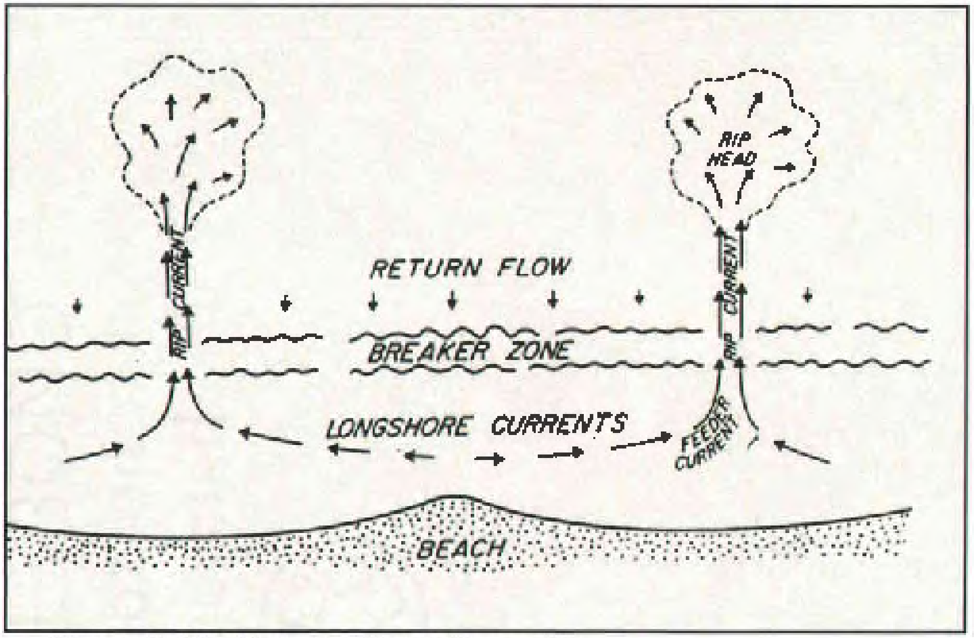


Figure 8: Rip Currents (*From Komar 92*)

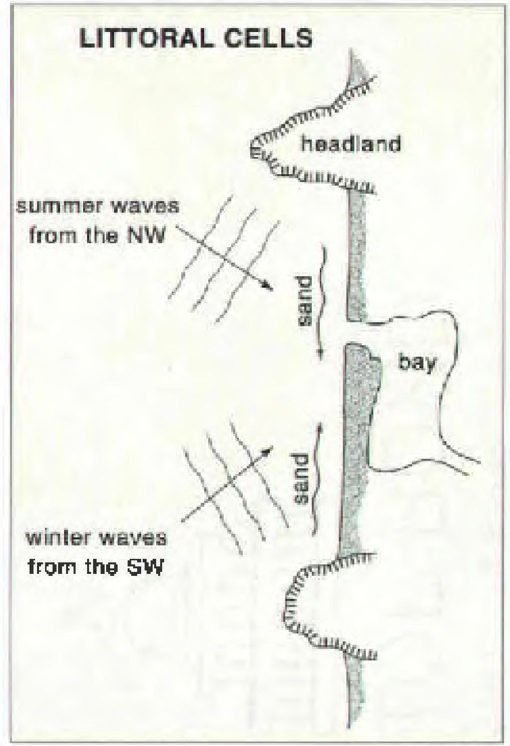


Figure 9: Normal Sediment Fluxes

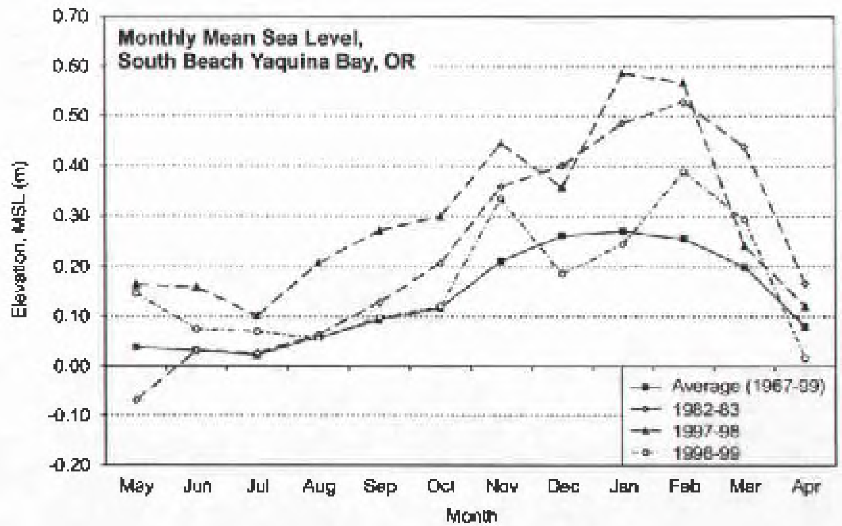


Figure 10: Mean monthly water levels (*Komar et al., in review*).

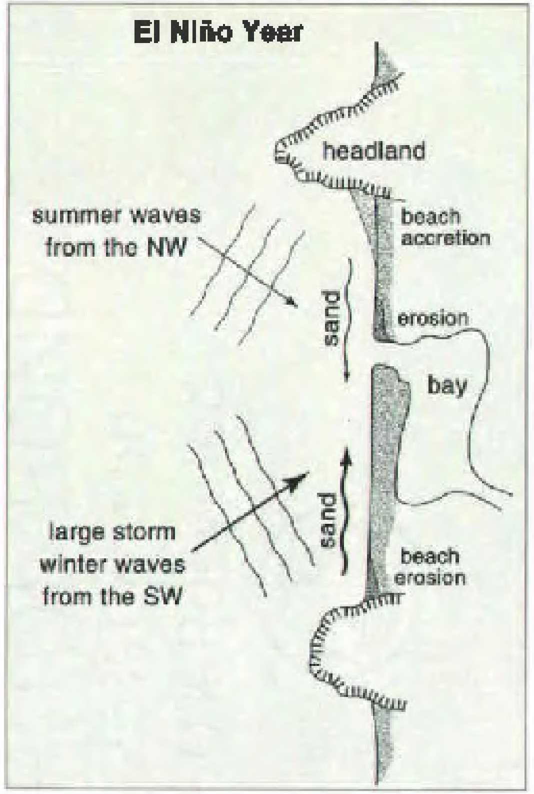


Figure 11: El Niño Sediment Fluxes

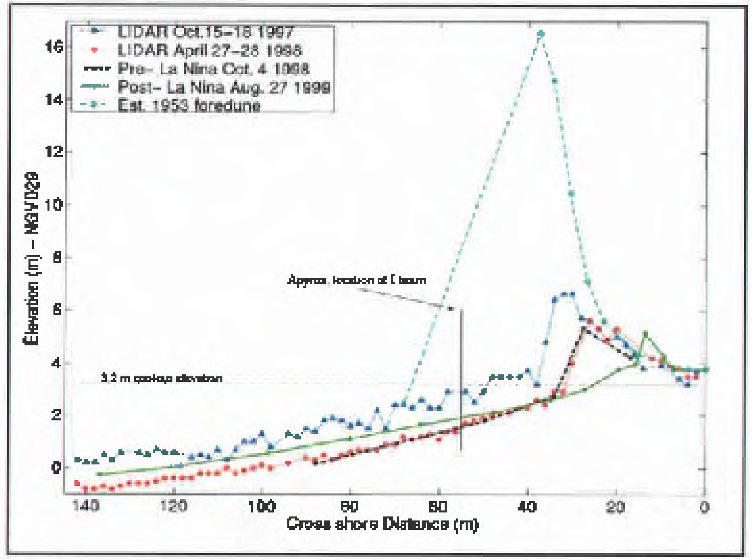


Figure 12: Historical Beach Profiles At Cape Lookout


Figure 13: La Niña Erosion at Cape Lookout

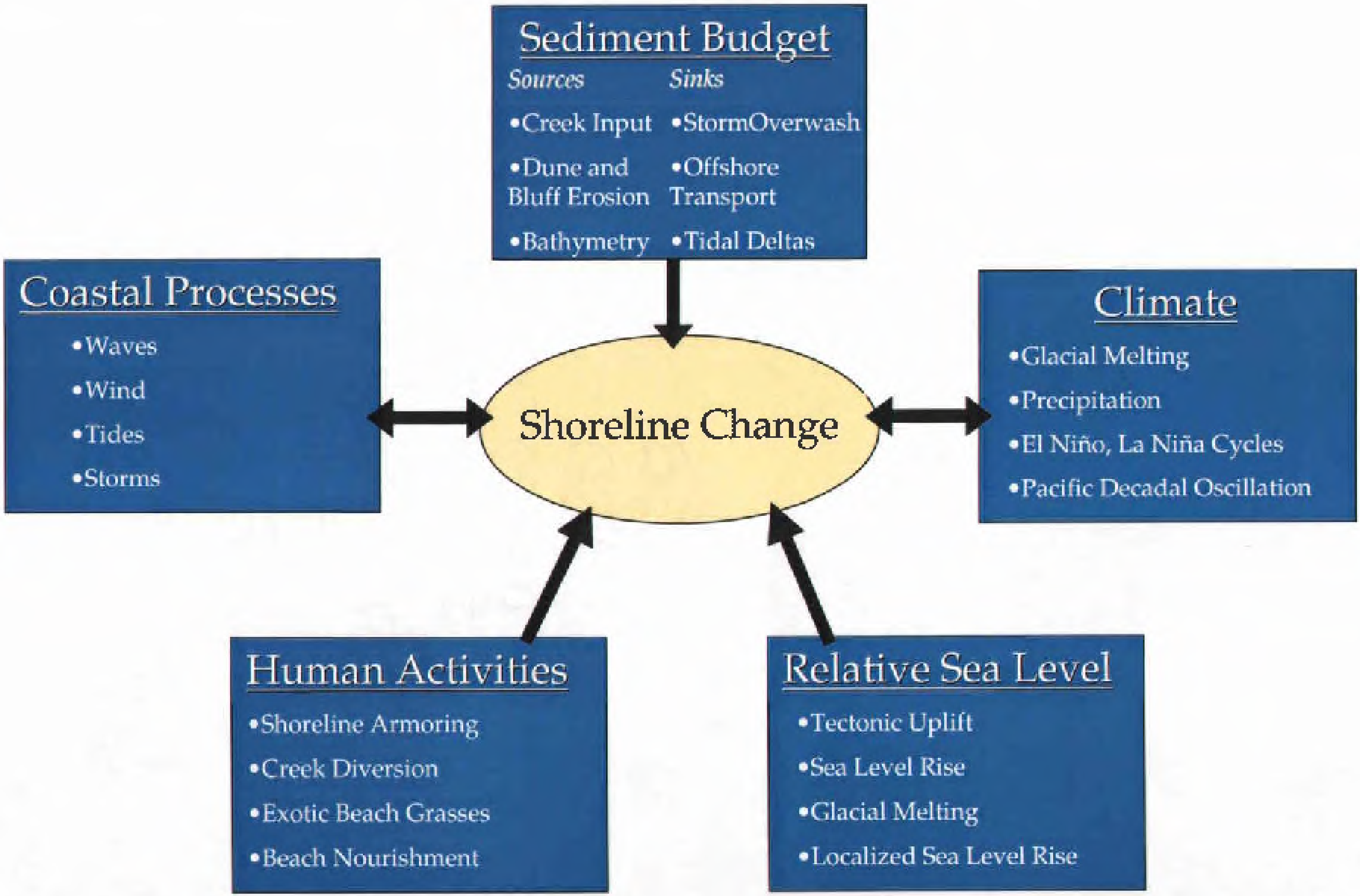
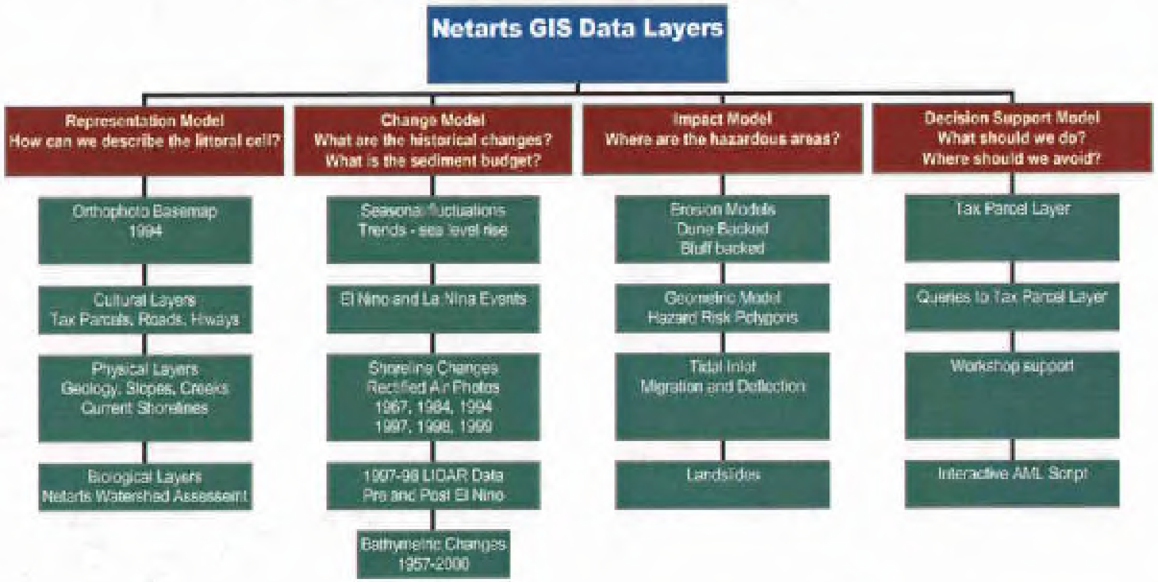


Figure 14: Factors Effecting Shoreline Change in The Netarts Littoral Cell



ะ 15: GIS Data Model

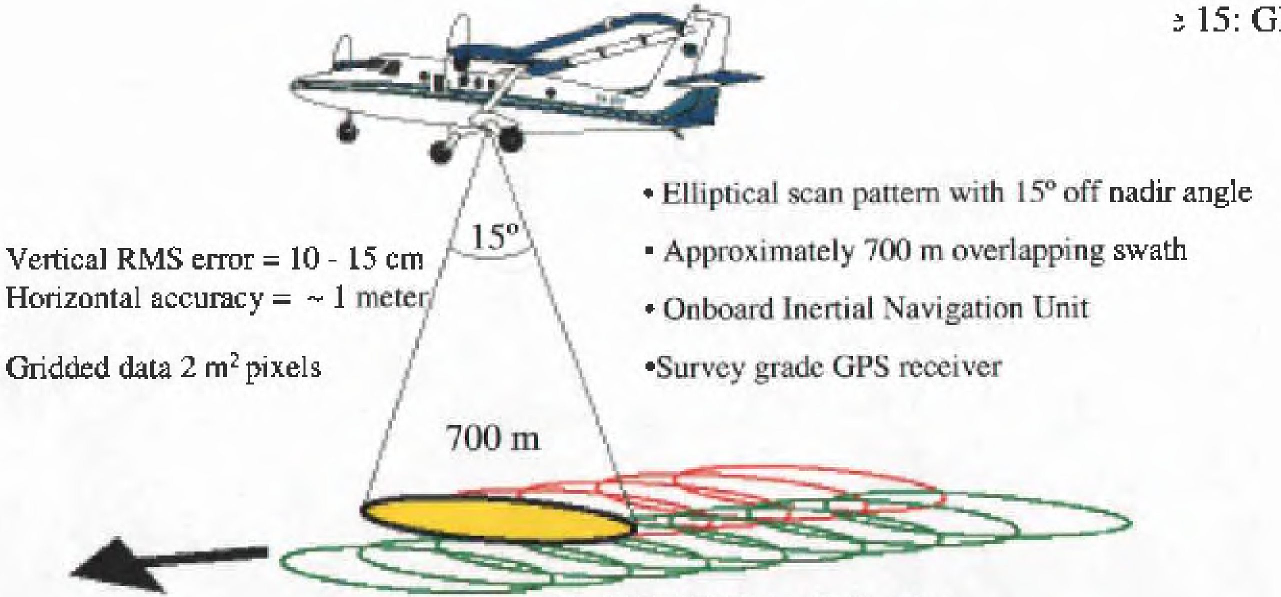


Figure 16: LIDAR Data Collection

Figure 17: Mean Vertical Erosion - Seasonal & El Niño

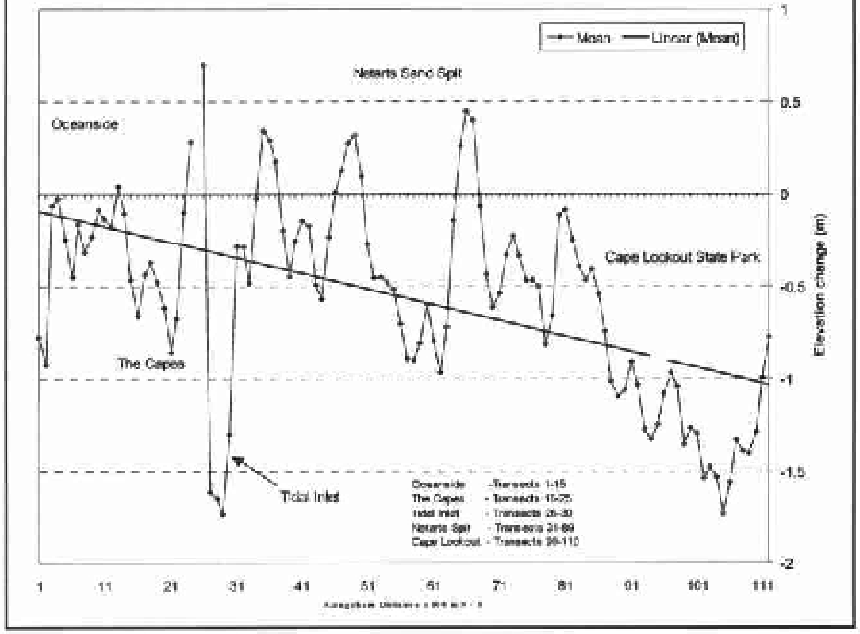


Figure 18: El Niño Component of Sediment Volume Changes

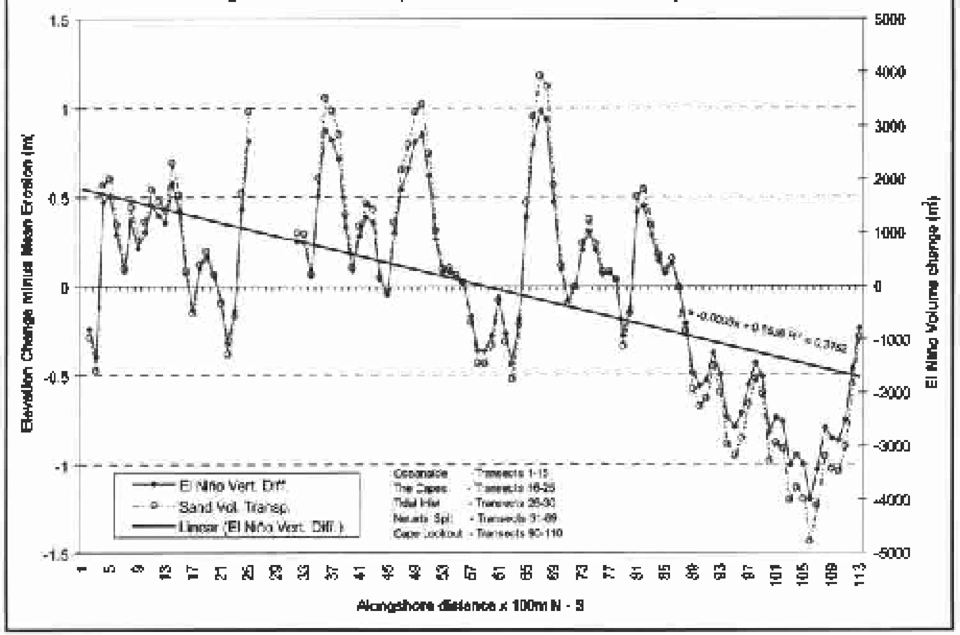


Figure 19: Distribution of Beach Slopes

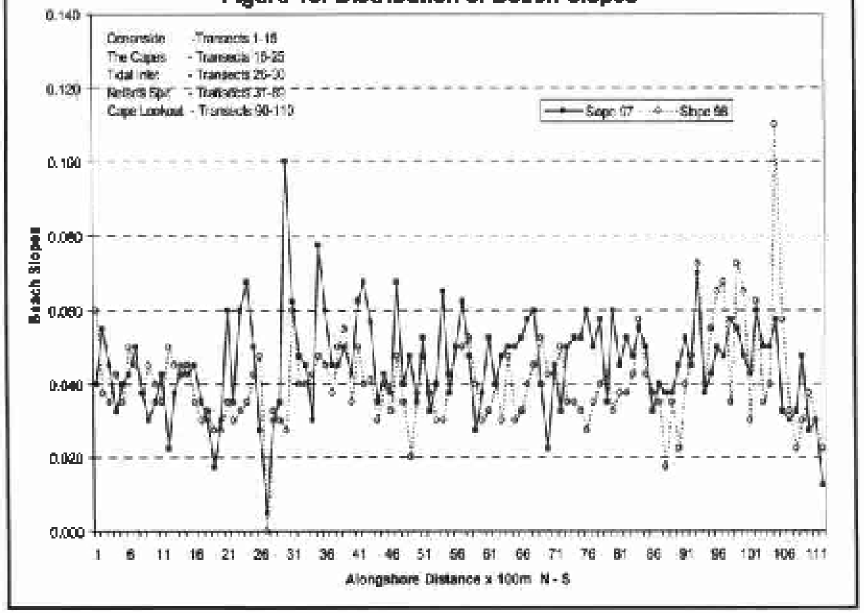


Figure 20: Shoreline Retreat of Different Contours

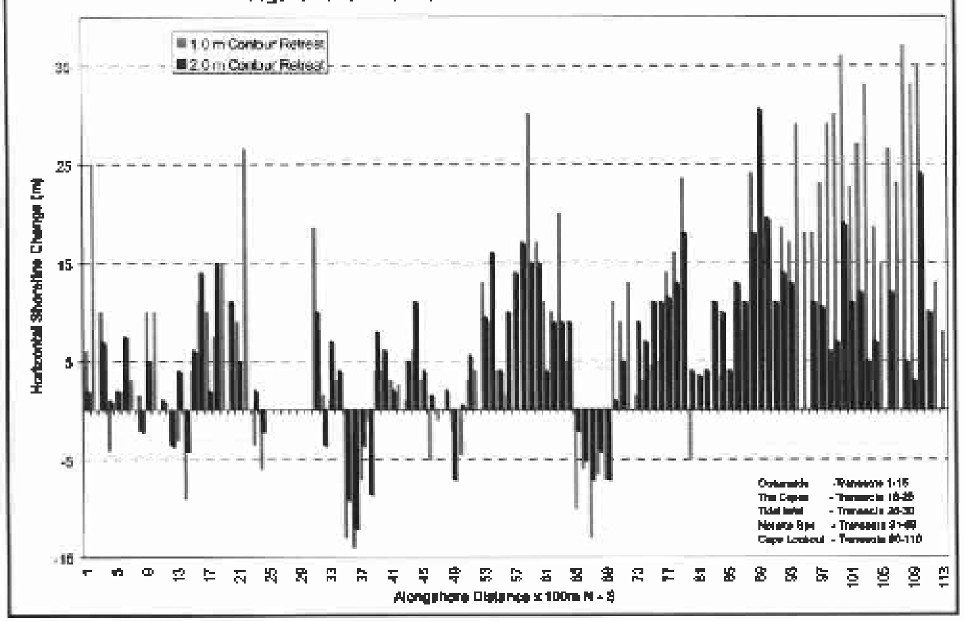
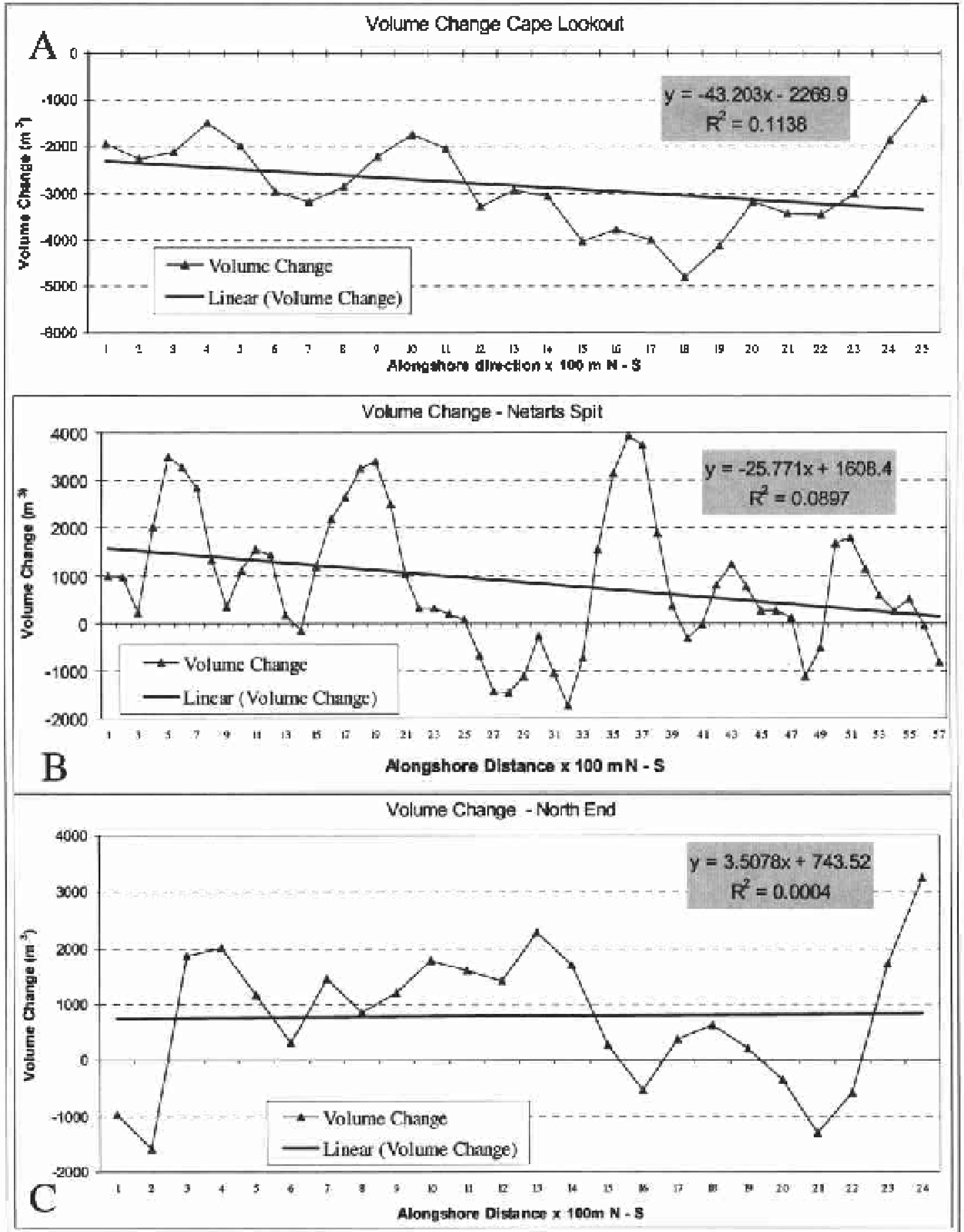


Figure 21: Sectional Trends in Volume Change

A: Cape Lookout

B: Netarts Spit

C: North End



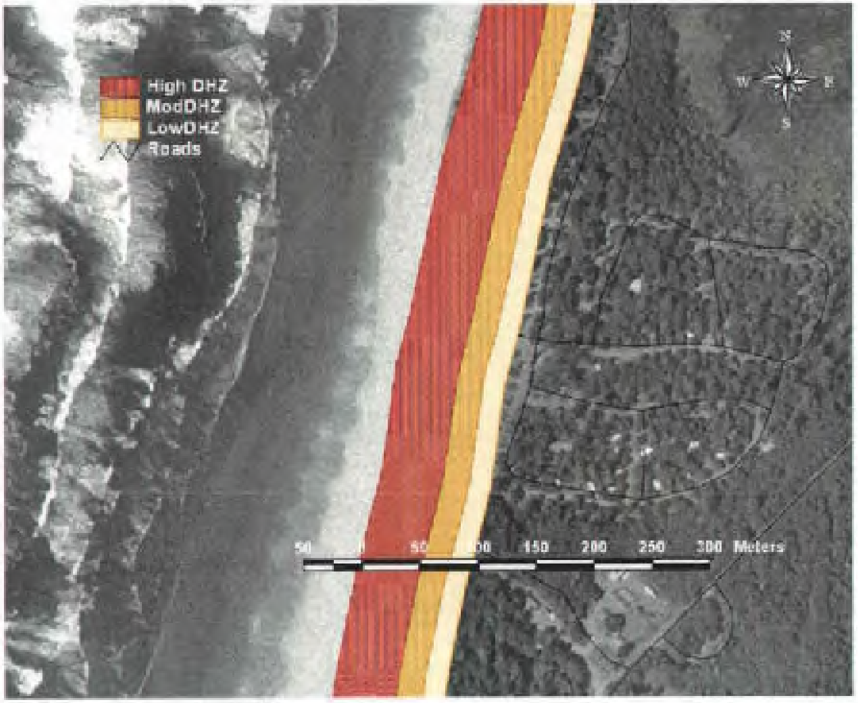


Figure 22: Dune Hazard Zones

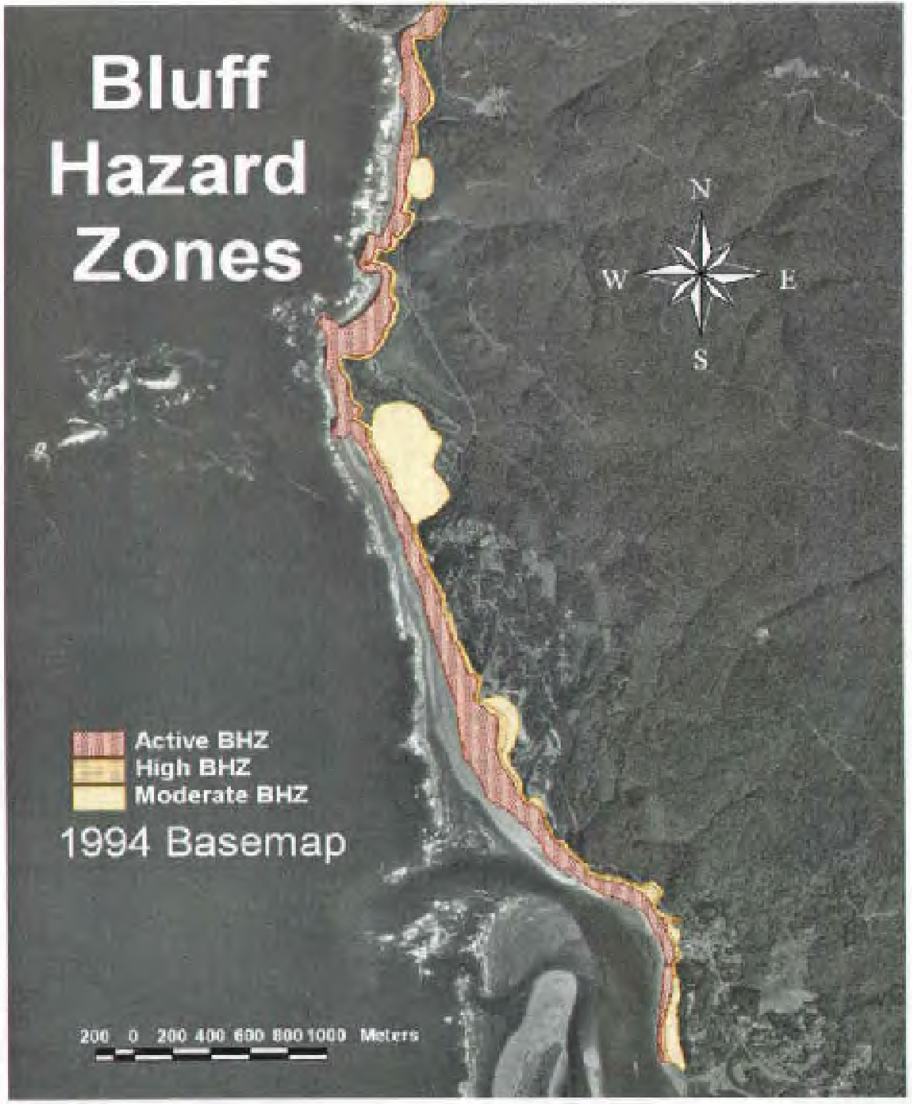


Figure 23: Bluff Hazard Zones

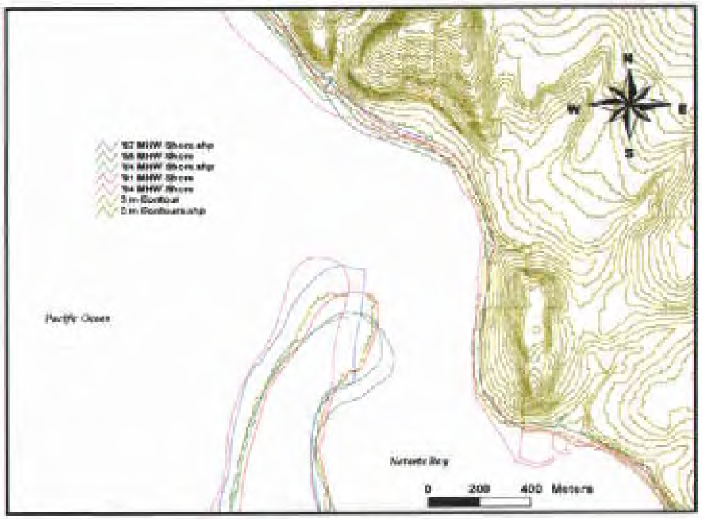
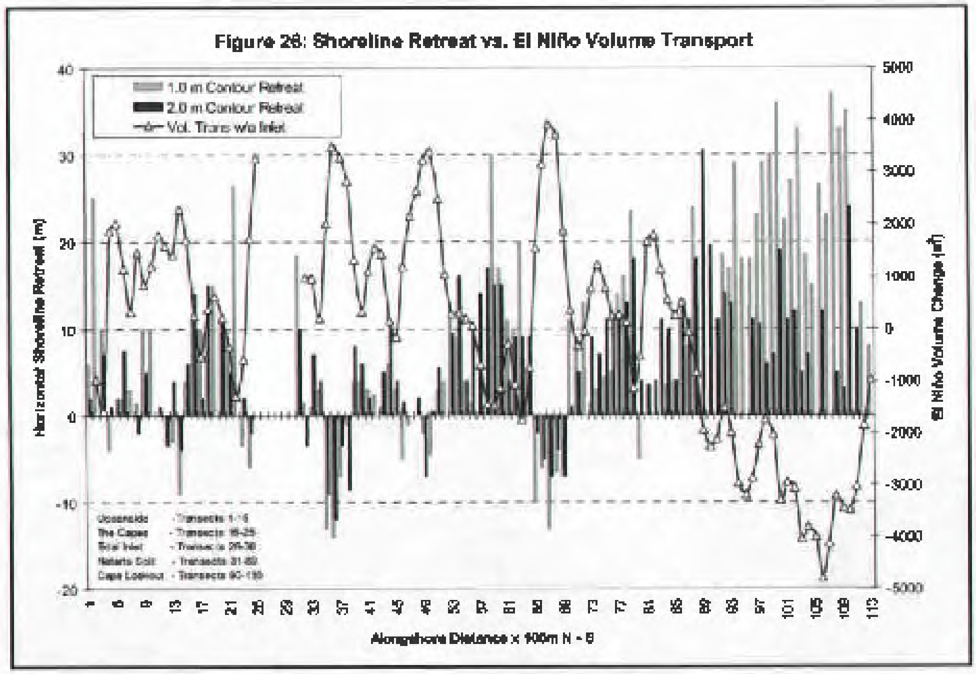


Figure 24: Spit End Changes

Figure 25: Cape Lookout Shoreline Change



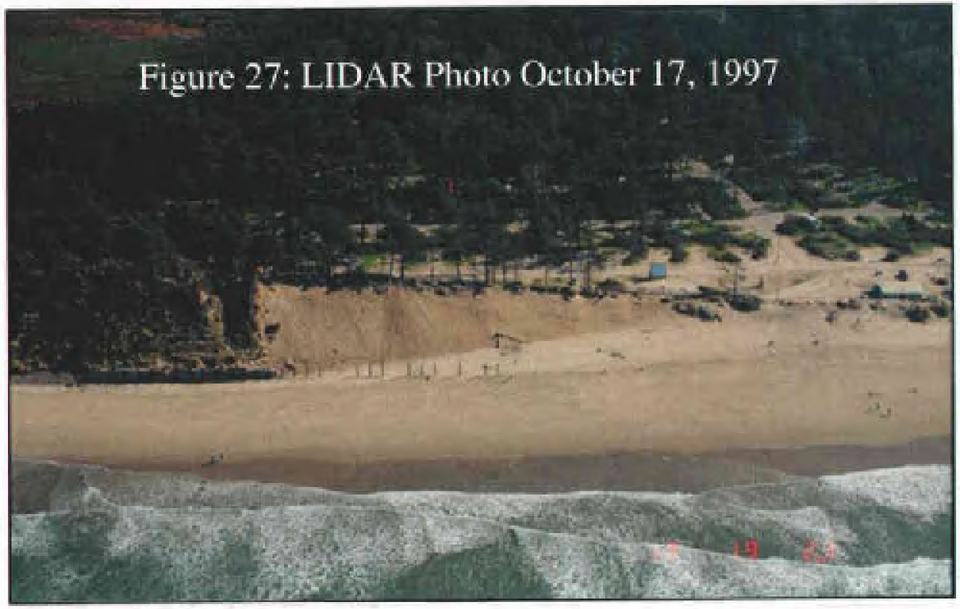


Figure 27: LIDAR Photo October 17, 1997

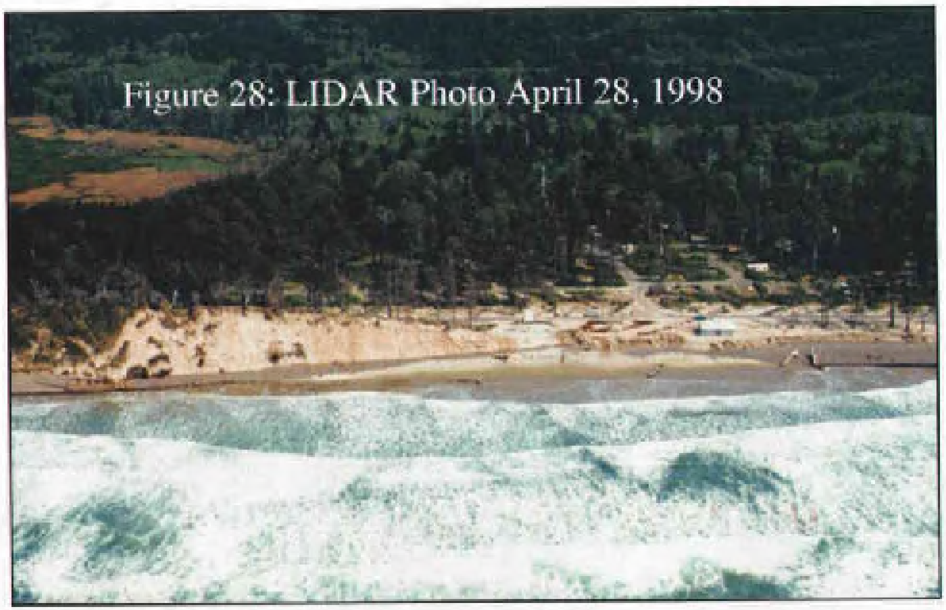


Figure 28: LIDAR Photo April 28, 1998

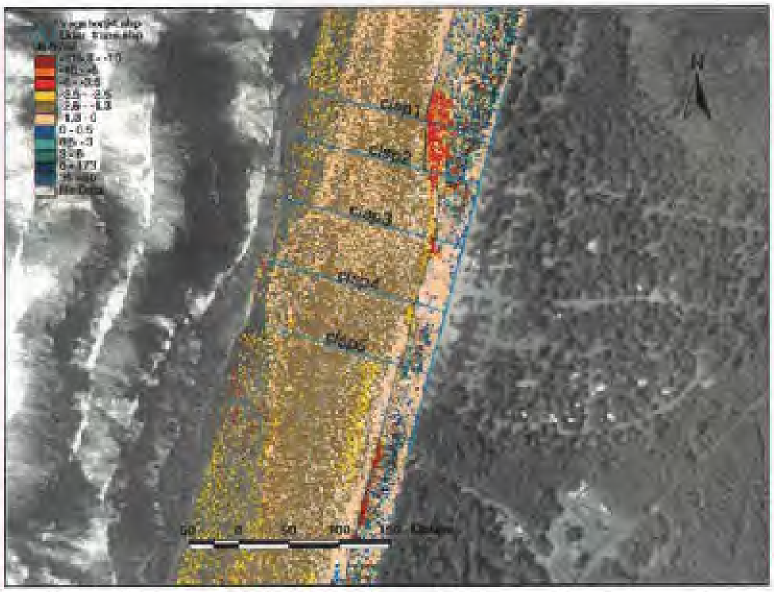


Figure 29: LIDAR Cape Lookout Hotspot Erosion

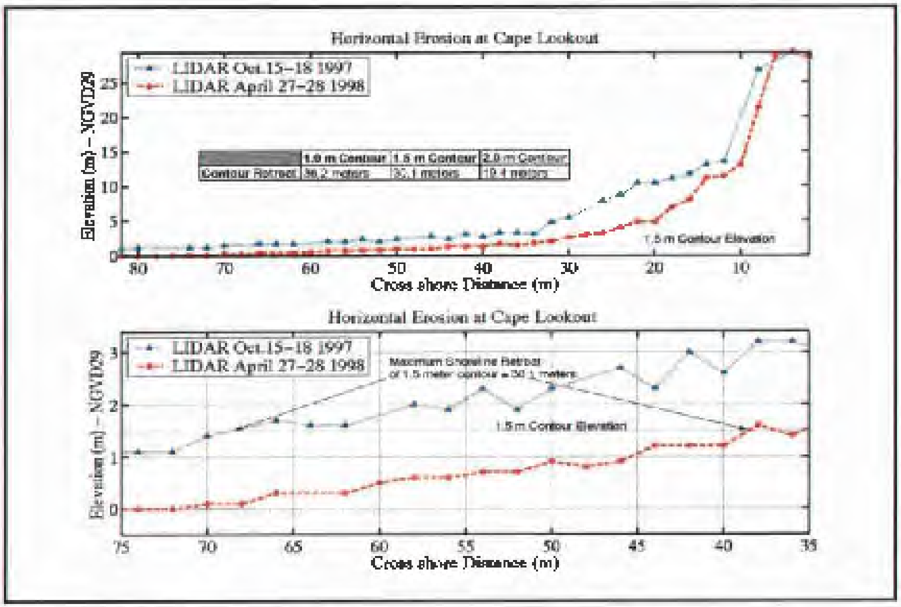


Figure 30: Profile of Maximum Erosion at Cape Lookout

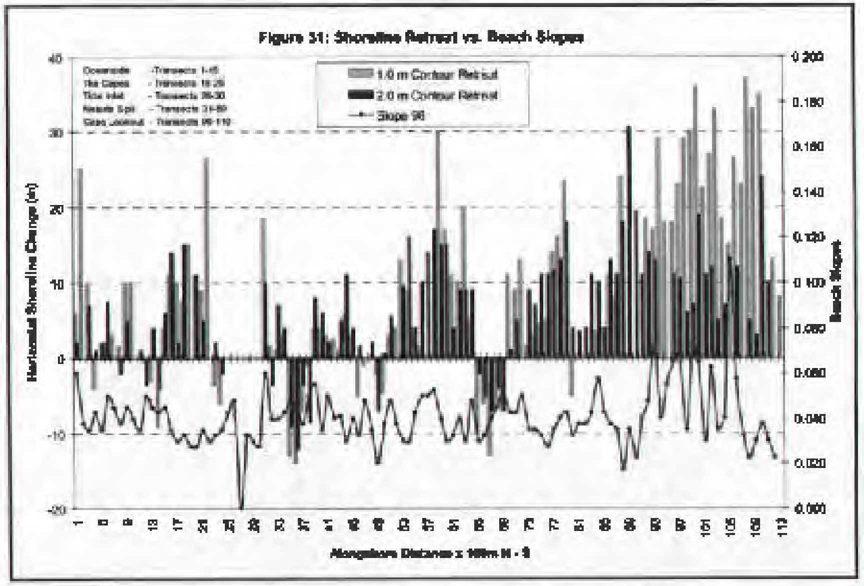


Figure 31: Shoreline Retreat vs. Beach Slopes

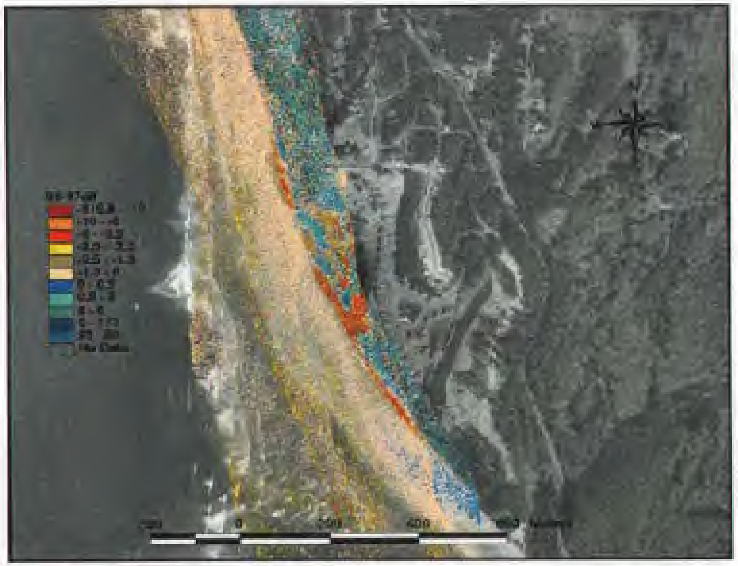


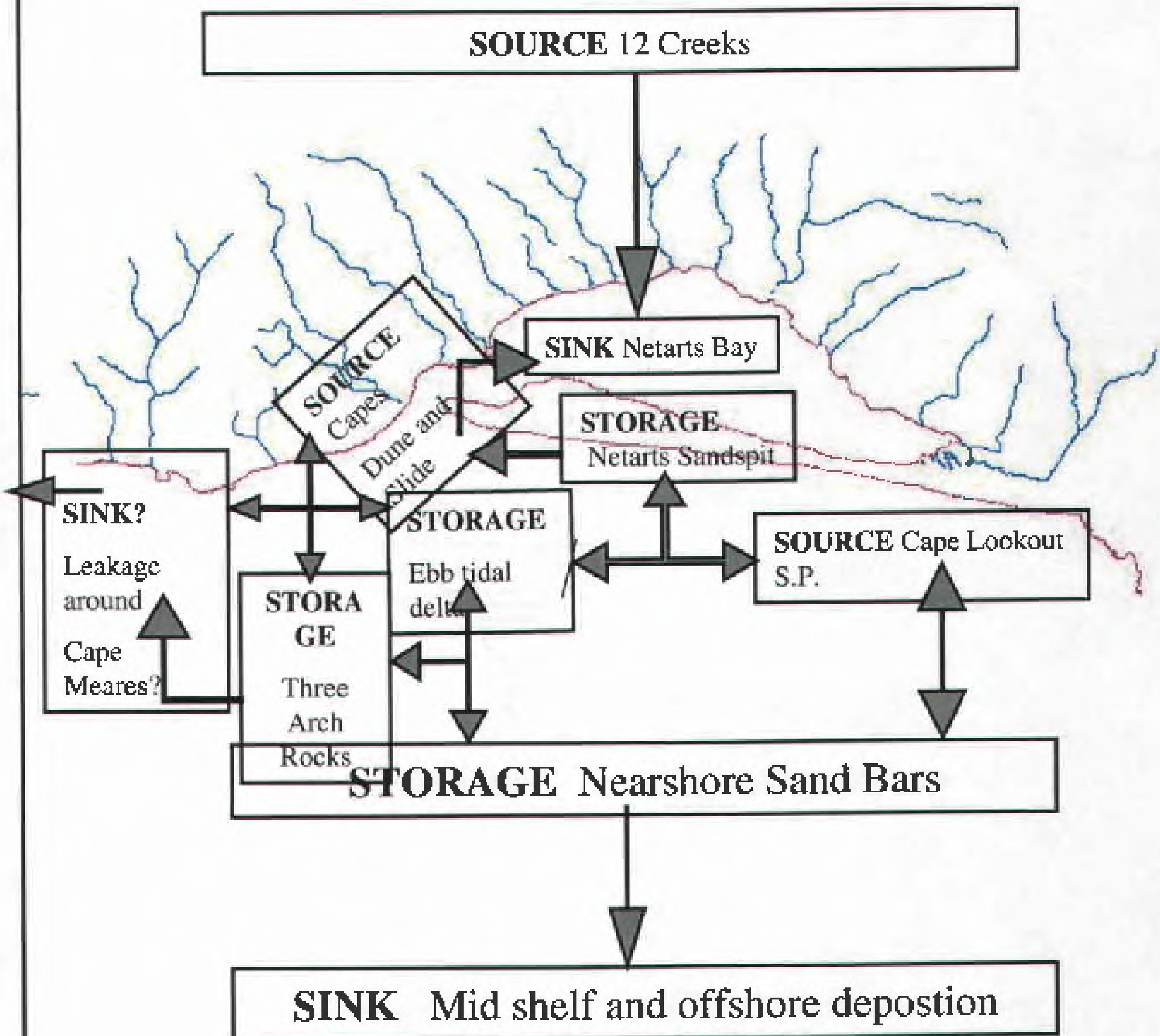
Figure 32: LIDAR Capes Erosion Hotspot

Figures 33, 34, 35:

Historic Oceanside Photos of The Capes Landslide

(Photos: Oregon Historical Society)

Figure 36: Sediment Budget Overview



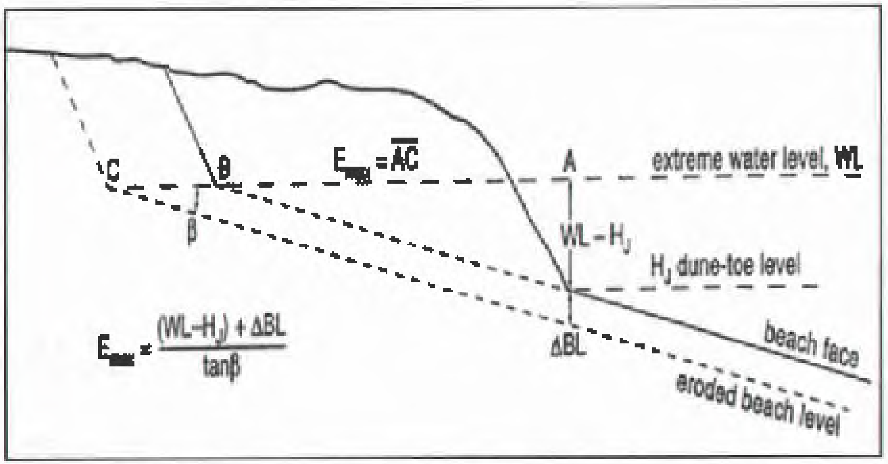


Figure 37: Dune Erosion Model From Komar et al. 1999

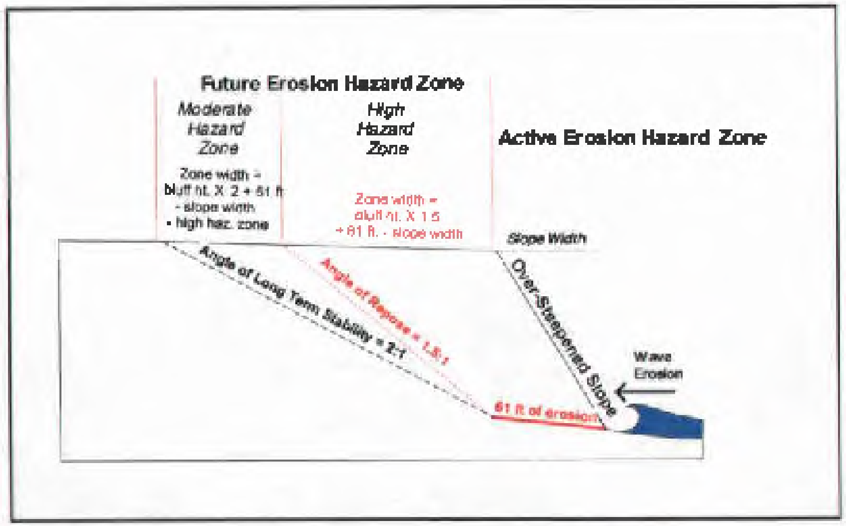


Figure 39: Calculation of Bluff Hazard Zones

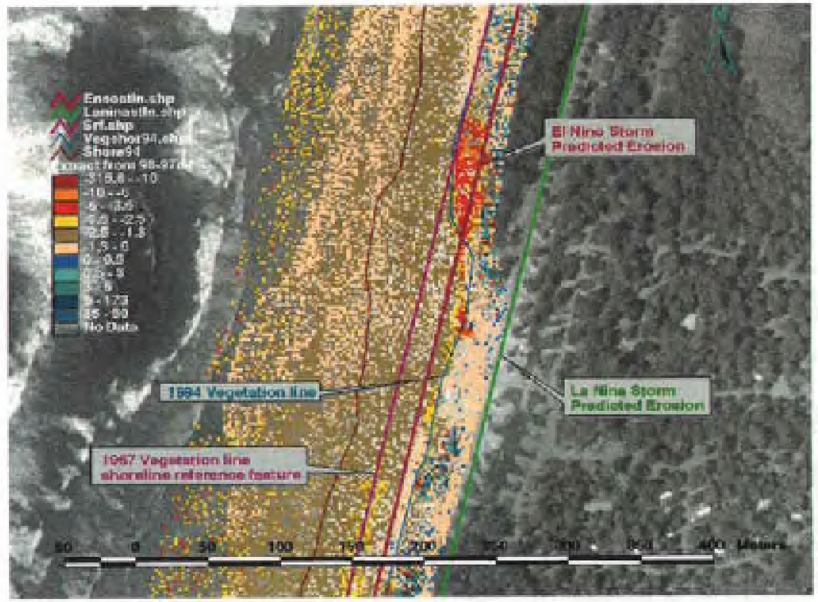


Figure 38: Results of the Geometric Model

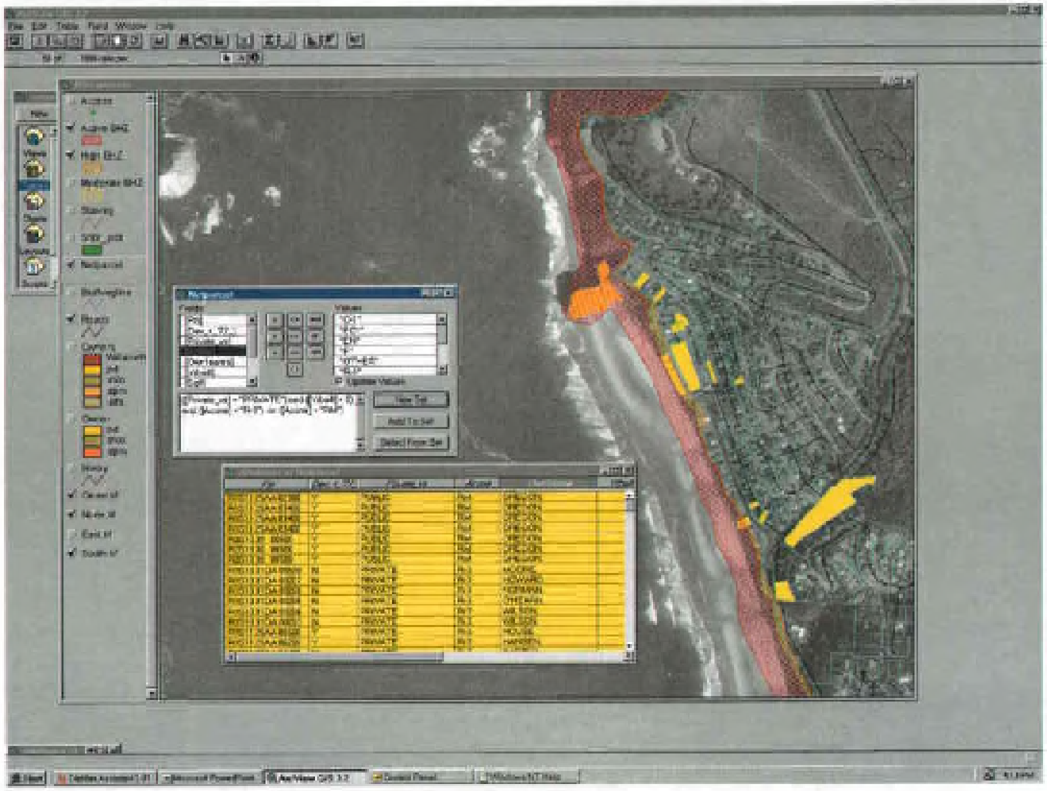


Figure 40: Frame Grab of Oceanside Query

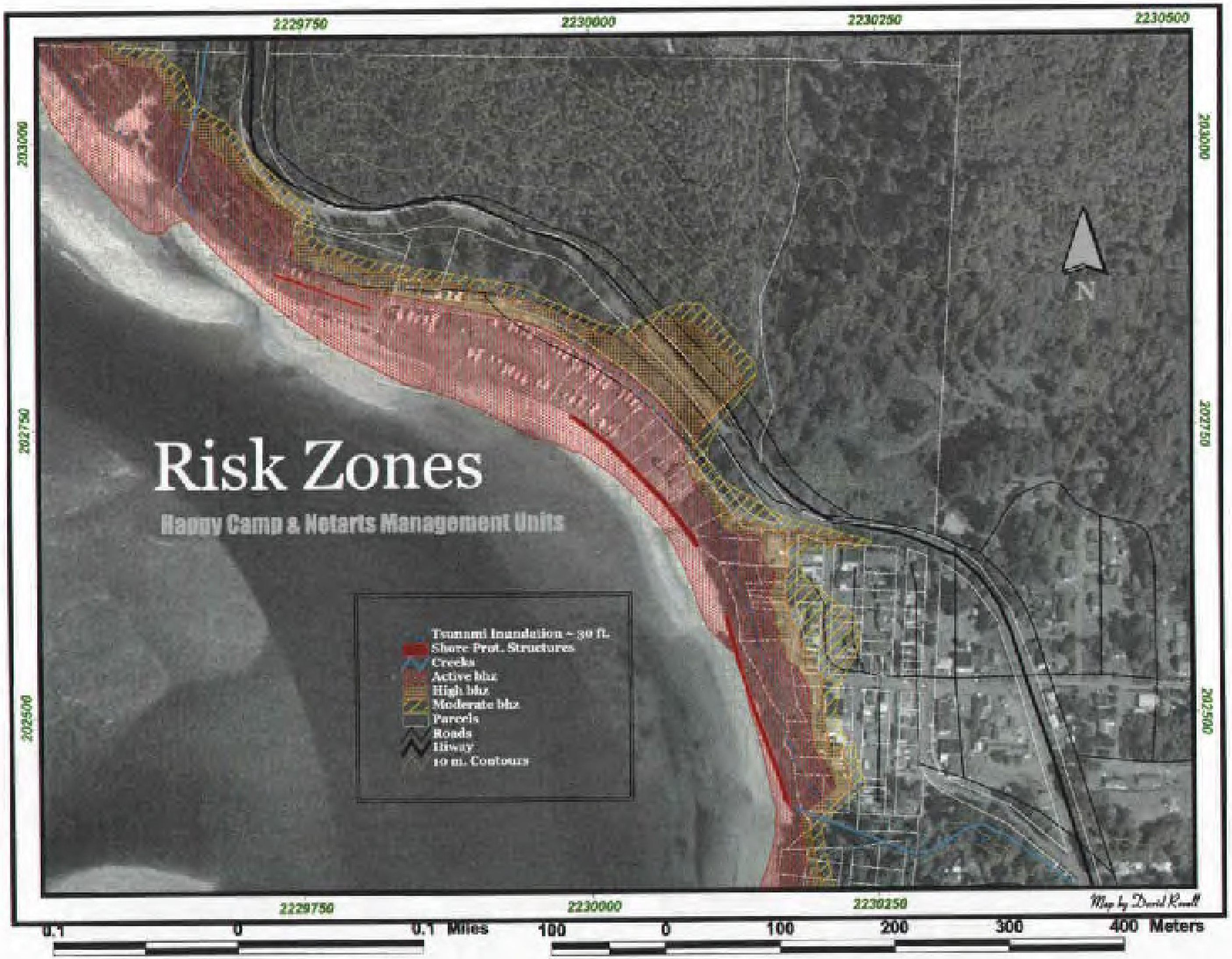

Risk Zones
Happy Camp & Netarts Management Units
Tsunami Inundation ~ 30 ft.
Shore Prot. Structures
Creeks
Active bhz
High bhz
Moderate bhz
Parcels
Roads
Hiway
10 m. Contours
N
2229750
2230000
2230250
2230500
203000
202750
202500
0.1
0
0.1 Miles
100
0
100
200
300
400 Meters
Map by David Rovell

Figure 42: Frame Grab of Query Results for Hazardous Area Setbacks

Figure 43: Frame Grab showing Parcels Effected by a Tsunami