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Coastal Accretion and Erosion in Southwest Washington

1977 - 1987

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Coastal Accretion and Erosion in Southwest Washington: 1977 - 1987

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for

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PREFACE

Coastal accretion and erosion in southwest Washington: 1977 - 1987 is a study that was undertaken by Ecology's Shorelands and Coastal Zone Management Program in support of a number of initiatives and responsibilities. When we last visited the issue of coastal accretion in 1976 and 1977, the beaches of southwest Washington were accreting rapidly. This is a relatively rare phenomenon in the United States -- most beaches are erosional. By 1987 there was reason to suspect that the rate of accretion had slowed, but there was no good evidence.

In 1987 the Pacific County Commissioners and Planning Department chose to use part of their annual Coastal Zone Management grant to conduct a planning study of ocean beach dunes management. A citizen advisory committee was appointed in early 1988. It was soon apparent that the committee required up to date information about coastal accretion and erosion patterns and rates to carry out their repsonsibilities. By mid-year, Shorelands Program had contracted with the principal researcher who had carried out the original 1977 study, James Phipps, for an update study.

Simulataneously, the issue of global climate change and sea level rise had passed from the "exotic" to the generally accepted in most coastal management circles, and the Washington Shorelands and Coastal Zone Management Program initiated a Sea Level Rise project. Increased coastal erosion is just one of the anticipated effects of accelerated sea level rise. The accretion/erosion up date study was completed, and an interim printing of the report was issued in April, 1989. Since then, additional information and new perspectives on the issue have been developed. Where appropriate, editorial footnotes have been added to Dr. Phipps' 1989 report.

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April, 1990

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INTRODUCTION

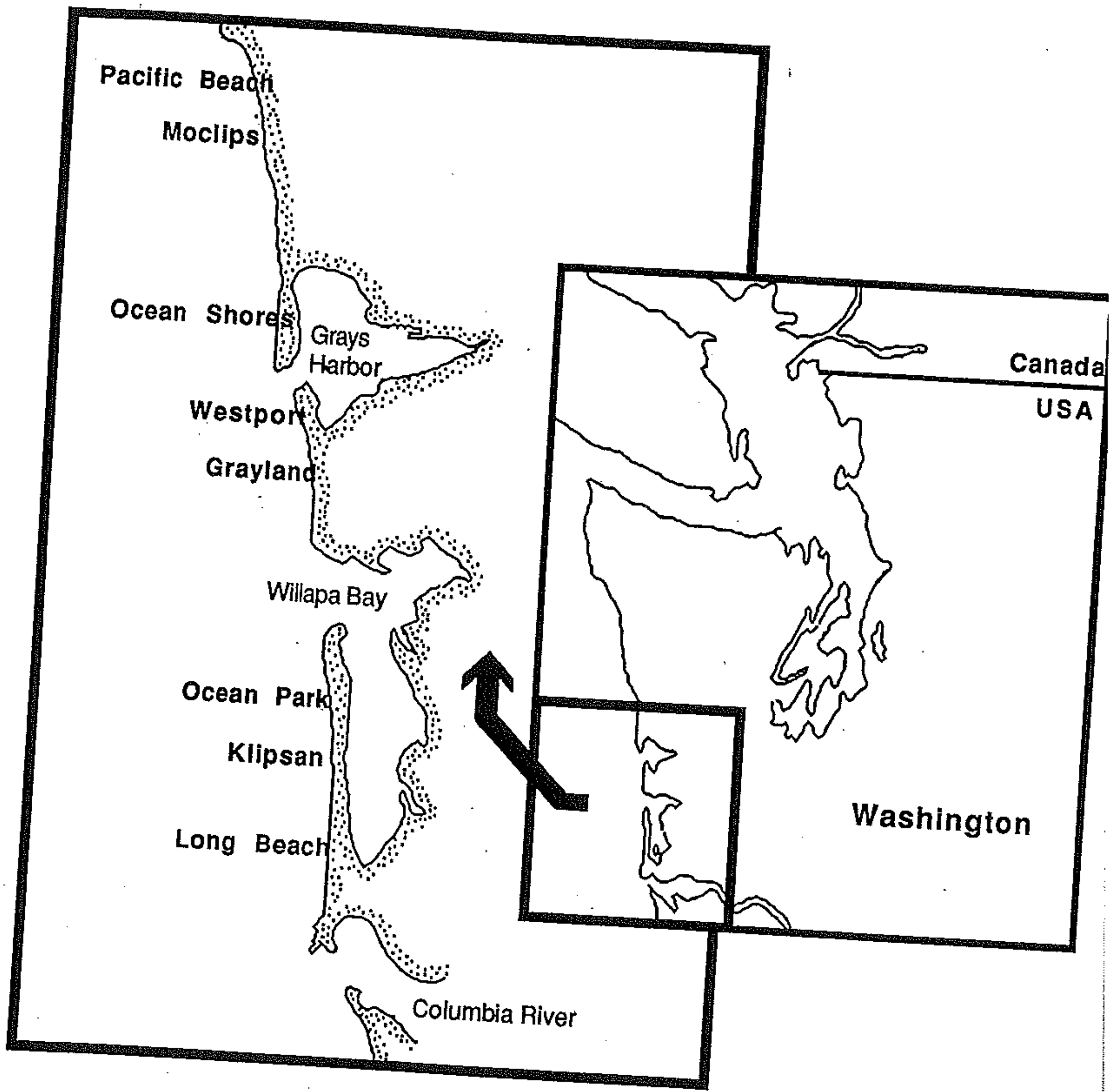
The beaches of southwestern Washington (Figure 1) are characterized by wide expanses of sand, the eastern edges of which have been formed into sand dunes. The surf that pounds this sand is some of the heaviest in the world and a continuous source of fascination for wave watchers. The winter waves, which may thirty feet high, are born in local storms that regularly buffet the coast. Winter waves crash on the sand, carrying it off the beach into deeper waters. The summer waves are created in storms of the austral winter in the south Pacific and travel more than 10,000 miles to break upon the beaches of Grays Harbor and Pacific counties. By the time the waves reach Washington they are low rounded swells that gently return sand to the beach. Thus, there is a seasonality to the southwestern Washington beaches. During the winter the sand is removed, making the beaches narrower, steeper, and rockier. In the summer the sand is returned and the beaches become wider, flatter, and the rocks exposed in the winter are recovered with sand.

In addition to this seasonal cycle there is another process, longshore drift. Because the waves seldom strike the beaches obliquely, rather than straight on, there is always a small component of motion directed along the beaches. In the summer the wind and waves move the sand to the south and in the winter the "sou'westers" drive the sand to the north. The amount of sand transported along the beaches by these currents is considerable, and any disruption of this sand flow can result in rapid accretion or erosion.

Paul Komar, at Oregon State University, and his students have studied longshore drift along the Oregon and Washington coast for several years and have concluded that the amount of sand moved northward in the winter is generally the same as the amount moved southward in the summer. The one exception to this is in southwestern Washington where net northward movement of sand from the Columbia River forms the unusually wide beaches of the Long Beach and North Beach peninsulas. Studies of the diagnostic mineralogy of the beach sands show that the of Columbia River sands can be traced as far north as Ocean Shores. North of Ocean Shores the wide beaches disappear and active sea cliff erosion begins. This marks the end of the river of sand. From there northward the sands for the beaches are furnished by sea cliff erosion and local rivers.

The "river of sand" which pours out of the Columbia is encouraged northward by seasonly reversing currents. On its northward journey its volume is slowly diminished by withdrawls to the beaches, bays, and ocean deeps, until at Copalis Rocks the "river" is gone. The width of the beach is a rough measure of the amount of sand in the system: if there is a lot of sand the beaches are wide and and accreting; if there is little sand the beaches are narrow and eroding.

Figure 1. The location of the study area. The portion of the Washington coast described in this study area lies between Pacific Beach and the Columbia River as shown on the expanded inset.



In 1978 we undertook a study of erosional and accretional changes along the beaches (Phipps and Smith, 1978). The 1978 study utilized the first mapping ever done along the Washington coast (done in the late 1800's) and followed the changes as subsequently recorded on U.S. Army topographic mapping, U.S. Geological Survey maps, and by the 1950's, aerial photography. The 1978 study also used the annual Razor Clam Beach surveys done by the Washington Department of Fisheries. The 1978 study presented several conclusions:

1. *The beaches were characterized by a general pattern of accretion since the late 1800's.*
    a. *The portion of the Long Beach Peninsula protected by North Head has accreted continuously since the earliest maps (1871), but the northern part of the peninsula, starting near Klipsan, has been subjected to various episodes of erosion. These seem to intensify northward so that the 1977 shoreline is well east of the 1926 shoreline near the latitude of Oysterville. Interestingly, the fisheries data collected since the middle 50's show accretion for the entire Long Beach Peninsula.*
    b. *There have been few changes on the Grayland beaches since the 1926 mapping, except in the very southern tip. While the portion south of the county line shows several hundred feet of accretion most of the Grayland area would seem to fit Komar's description of equilibrium. The fisheries data confirm this analysis of the Grayland beaches.*
    c. *The North Beach has enjoyed an accretionary history, much like Long Beach, Similarly, most of the accretion has occurred along the southern portion where the beach is protected by the north jetty of Grays Harbor. The fisheries data confirm high accretion rates in the Ocean Shores and Oyehut areas, while to the north along the sea cliffs, the shoreline has been stable.*
2. *The net northerly long shore drift causes the northward movement of the mouths of Willapa Bay and Grays Harbor estuaries. This movement ceased at the mouth of Grays Harbor when the jetties were constructed, but is continuing today at the mouth of Willapa Harbor. This produced the highest erosion rates in the study, up to 250 feet per year at North Cove.*
3. *The areas adjacent to the jetties experience accretion and or erosion dependent upon the condition of the jetties. When the jetties were built, or when they were refurbished, the adjacent beaches accreted and as these structures wear down the lands next to them erode.*

One of the major questions that initiated the 1978 study was "Have the dams on the Columbia River, (which stop the passage of sand downstream to the beaches), had an effect on the beaches of southwestern Washington." The answer in 1978 was "not yet."

Methods

Since 1978 our understanding of beach processes has increased, as has our awareness of hazards of the beach environment. Better information is also now available. The current study utilizes aerial photography taken in 1977 and in 1987 and the available Department of Fisheries data. The 1987 photos were enlarged to a scale of 1"= 400' and the 1977 shoreline was plotted on them. The shoreline was the approximate high tide line as marked by either the line where the sand becomes wet or by a line of flotsam along the beach. The approximate location of the seaward edge of the vegetation in 1977 was also plotted, as this is of some interest, particularly in Pacific County. Information on storm surges, El Nino events, tsunamis, greenhouse generated sea level rise and geodetic measurements of the land rising was not generally available in the late 1970s and was not included in that report. Finally, we note that in comparing the aerial photographs from 1977 and 1987, one has to be impressed that there are many more houses along the beaches and "at risk" in 1987 than there were in 1977.

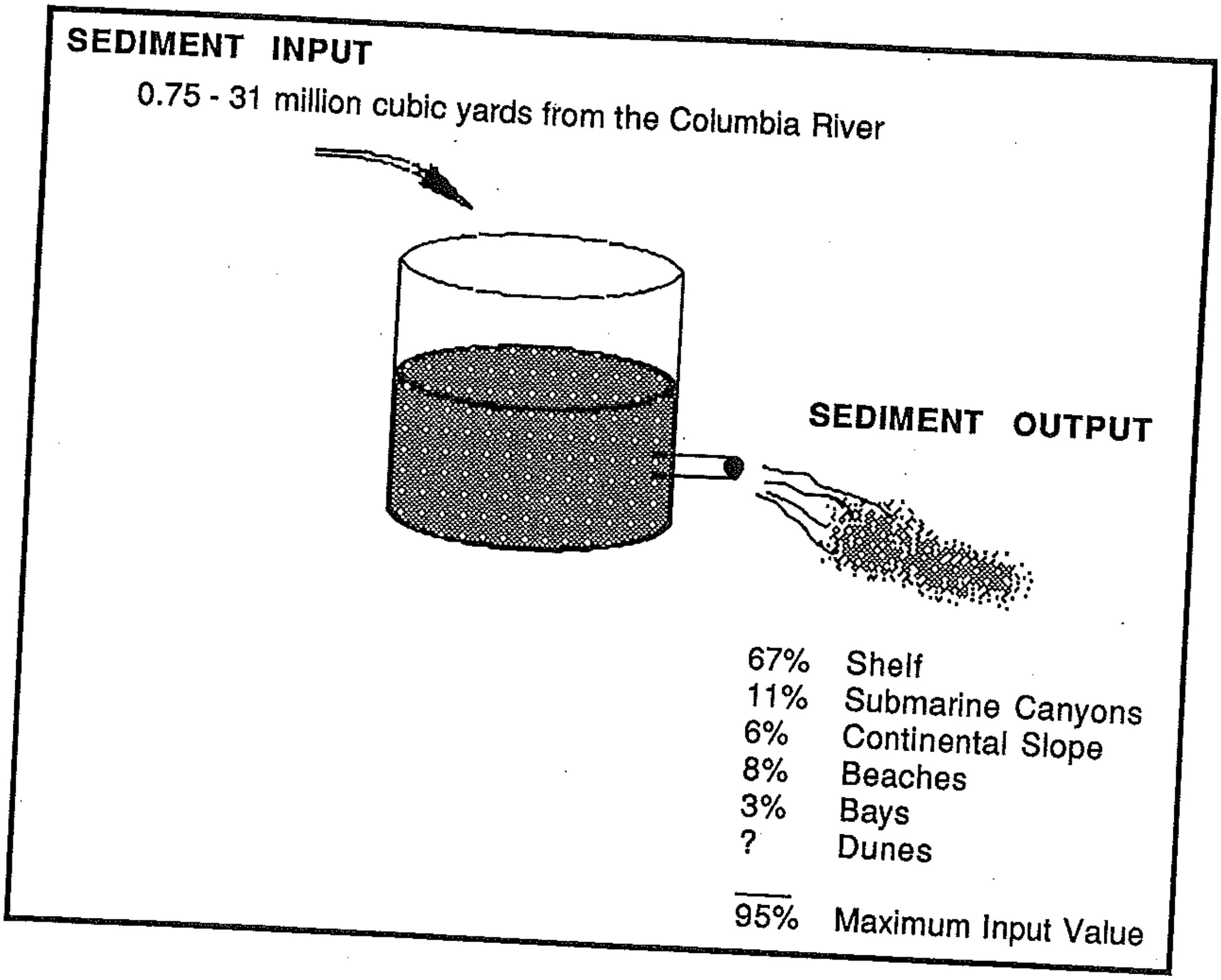
THE SAND BUDGET

The concern over the possibility of a diminished supply of sand to the southwest Washington beaches was one of the major factors in initiating the 1978 study. One of the conclusions of that study was that the the construction of the dams on the Columbia River had not yet affected the sand supply to the beaches. It was hard to believe that these massive dams had caused the third largest river in the United States to virtually cease flowing, yet there was "no effect". In the middle 1980s, the U.S. Army Corps of Engineers published a series of maps on historical changes in the bathymetry at the mouth of the Columbia river. This series of maps indicated that the probable source of sand for beach accretion northward in Washington State was Peacock Spit. Created by sand jetted out of the mouth of the Columbia by the construction of the jetties, Peacock Spit became a notorious graveyard of ships during the early part of the 20th century. The shoal had slowly yielded its sands to the longshore drift until today Peacock spit is merely a label on a map and not the huge shoal it once was. There is essentially no more sand available for accretion from this source. The mapping done by the Portland Division of the Army Corps of Engineers shows that Peacock Spit diminished from 1935 to 1982 by approximately 97 million cubic yards of sand, or about 2.0 million cubic yards per year.

For comparison, in our 1978 study, it was estimated that all the accretion along all the beaches from the mouth of the Columbia to Copalis Rocks accounted for about 2.5 million cubic yards of sand. The sand from Peacock Spit could account for 80% of the observed accretion of the beaches.

What is the fate of the sand presently coming from the Columbia River? Some of the best numbers concerning a sand budget (Figure 2) were compiled in a Ph.D. thesis, at the University of Washington, by Charles Nittrouer (1978), and later updated by his professor, Richard Sternberg (1986). Although their figures were in metric tons they are presented here in cubic yards, which may be a more familiar unit (the conversion, assumes 30% porosity and a density of 1.75 g/cm^3 and is 1.5 yds^3 / metric ton). Estimates of the total sediment input to the system from the Columbia River range from 3/4 million to 31 million cubic yards of material and are directly related to the discharge of the river. The relationship is exponential so that if, for example, the discharge increases by 10 times the sediment load will increase by approximately 100 times. The estimates of total sediment input are further complicated by the determination of the fraction of sand in the total sediment load.

Figure 2. A sediment budget for the shelf, slope, and beaches off western Washington. Data from Sternberg (1986) and Phipps and Smith (1978).



The interesting part about the sediment budget is that Sternberg can account for 84% of the of the larger value, 31 million cubic yards, (deposits on the continental shelf (67%) the continental slope (6%) and in the submarine canyons (11%). If the Columbia River sediment input is less that the highest value, the total amount accounted for is even higher. This does not leave much for the beaches.

Looking at the sediment budget from a slightly different perspective, Nittrouer (1978) states that 15 million cubic yards of sand are deposited on the shelf, annually. The sand fraction of the sediment load (the other fractions are silt and mud) is important because that is the component that makes up the beaches and the dunes. Historically, the sand fraction has been estimated at 10% of the total sediment load, which would be 3 million cubic yards in this case (31 million cubic yards total input). This means that there is 5 times more sand being deposited on the shelf than is being supplied by the river, suggesting that there are some lags in the system. Nittrouer's values were averages over the last several hundred years, so the sand he is describing was deposited before the Columbia was dammed. The shelf he describes is probably not in equilibrium with the modern sediment input from the Columbia. Finally, the 10% estimate of the sand fraction may be low.

What do these numbers tell us? It would seem that there is not enough sand coming out of the river to even replenish the losses from Peacock spit much less to nourish the beaches or provide the shelf with its historical quota of sediment. Even with the help of the Army Corps of Engineers who dump between 3.0 and 3.5 million cubic yards of dredged sand adjacent to Peacock Spit every year, it is still losing. While the ultimate fate of that dredged material is not clear, some of that sand undoubtedly ends up on the beaches of the Long Beach Peninsula.

The conclusion drawn from considerations of the sediment budget is that in the case of the Washington beaches and adjacent shelf there are more withdrawls than deposits. While contributions from Peacock Spit supported growth of the beaches during most of the twentieth century, that source is now depleted.

EROSION AND ACCRETION PATTERNS SINCE 1977

Long Beach Peninsula

The area between the North Jetty on the Columbia River and North Head is eroding as rapidly as any area along the coast. The aerial photos show about 300 feet of erosion during the period 1977-1988. This sand was rapidly accreted into this area when the North Jetty was rehabilitated and as that structure wears down, its ability to hold the sand also decreases. Erosion at this site is a localized event related to the jetty condition[1].

Northward of North Head for approximately two miles the beach is slightly erosional, but from Seaview north along the entire length of the peninsula, the beaches are accreting gradually. The accretion is between 50 and 100 feet for the entire ten year period, a rate much reduced from the previous fifty years.

There are two available Washington State Department of Fisheries razor clam survey beach profiles for the Long Beach Peninsula, one at Joe John Road and the other at Klipsan. The average accretion rate for each of these profiles during the last thirty years is 14 feet per year, but for the most recent data available (1977 to 1983), the rates averaged 3 and 12 feet per year *erosion* (see appendix).

Why do the photos show accretion, while the clam surveys show erosion? Remember that the photography has an accuracy of plus or minus fifty feet at best, and the photos only record two brief moments in the life of beach whose size fluctuates much more than 50 feet seasonally. The survey data, on the other hand, are measured every year, during the same season. Within the variance in the data, both the photos and beach surveys are consistent with one another. They indicate that the Long Beach Peninsula did not behave during the past decade as it had for the previous century.

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[1] Relatively high rates of accretion and erosion, as well as rapid shifts between accretion and erosion patterns are common in the vicinity of jetties. This is caused by the jetties themselves, which form a disruption in the normal wave energy patterns in their vicinity. Since 1988 when this study was begun, it has become apparent that the rapid erosion between the North Jetty and North Head has slowed or ceased. It is difficult if not impossible to predict accretion/erosion patterns or rates in areas such as this.

Grayland Area

In the Grayland area, on the north side of Willapa Harbor, the spectacular erosion of "Wash-a-Way" Beach continues. About 900 feet has eroded in the last ten years, an average rate of 90 feet per year. This value is down a bit from the high rates mentioned in the 1978 study, but may still be the highest on the Pacific coast. The decrease in erosion may be related to the growth of the large shoal off Cape Shoalwater as described by the Army Corps of Engineers.

Just north of "Wash-a-Way" Beach where the shore swings northward to meet the open ocean, the beach is accreting. For the first 1 3/4 miles the accretion is as great as 200 feet during the last ten years. Farther north the beach becomes erosional, having retreated as much as 200 feet, and it remains so to about 1 1/2 miles north of the Pacific- Grays Harbor county line. From this point northward, the beach is static, neither accreting nor eroding, until one nears the South Jetty of Grays Harbor. Next to the jetty the beach is continuing to erode, as it was in 1978. However, during the past two years, 1987 and 1988, this erosion has accelerated substantially[2].

The Department of Fisheries data for the Grayland area tend to corroborate the photo observations. The survey lines, called "Grayland" and "Twin Harbors", both show a thirty-year accretion rate of 5 feet per year. Data collected from 1978 to 1983 show a 2 feet per year *erosion* rate for "Twin Harbors" and a 14 feet per year erosion rate for "Grayland". The correlation coefficient for these data is very low since the data are scattered and thus should be interpreted as "low or no change" values. The photos show about 200 feet of erosion along the beach near the "Grayland" survey line and show essentially no change in the region of the "Twin Harbors" line.

North Beach Area

Across the throat of Grays Harbor, the North Beaches stretch from the North Jetty to the limit of the study area. The area adjacent (within 3500 feet) to the North Jetty is eroding as shown in the 1978 study. The beach north of this small erosional area shows the highest accretion rates of anywhere in southwestern Washington. Since 1977 much of the North Beach area has accreted 500 to 600 feet. There is so much sand in this area that it has extended northward past the historical accretional-beach terminus at Copalis Rocks and is building out from the sea cliffs at Iron

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[2] Here too, in the vicinity of the Grays Harbor South Jetty, complex and strong accretion/erosion patterns are found. Near the jetty at Westhaven State Park, erosion at a rate of 5 to 10 feet per year has been occurring since the mid-1960s. The Washington Parks and Recreation Commission has established a policy of periodic retreat with temporary buildings.

Springs, Pacific Beach, and Moclips. These areas now have about 150 feet of dry sand in front of the sea cliffs, where in 1977 there was none. Furthermore, sedges and pioneer grasses are starting to colonize this new sand.

There are eight available razor clam survey lines along the North Beach: the northerly six show accretion rates during the last ten years that are significantly higher than the thirty-year trend (see appendix).

VEGETATION

Incidental to the main thrust of this study, the approximate location of the western edge of continuous vegetation was plotted. This was delineated on the air photos by choosing the line between the grassy dunes and the clumps of pioneer plants the spring up to the west.

The relationship between the position of the vegetation and the position of the high tide line varies *on the average,* as follows: along the North Beach in 1977 the distance from the vegetation to the water was about 330 feet, but by 1987 it had increased to about 530 as the accretion outpaced dune building. The accretion during this time was about 420 feet. In the Grayland sector the distance from the grass to the water in 1977 was 290 feet and in 1987 it was 220 feet. During the same time the beach eroded an average of 50 feet. At Long Beach the vegetation to water distances were 390 feet in 1977 and 280 feet in 1987 whereas the entire beach accreted roughly 20 feet.

It is possible for a shoreline to be erosional for several years while the vegetation line continues to move west. Under these conditions, arguments can be expected as to whether the beach is eroding or accreting. Clearly, the beach and shoreline are erosional, while the dunes may be accreting slightly as the new vegetation traps wind-blown sand.

WATER LEVEL CHANGES

Erosion of the seashore does not necessarily occur in the measured grain-by-grain removal of sand from the beaches, but most often during severe winter storms and high surf. Ultimately such erosion narrows the beach and threatens dwellings with destruction by flooding. But what about those times when the sea level rises, even if briefly, and floods dwellings by the sea. The result is the same. It does not matter if a residence is filled with sea water for three hours or three days as the structure will probably be destroyed in either case. Such events are described below, beginning with the rarest and the most severe, tsunamis, to the more mundane tidal changes.

Tsunamis

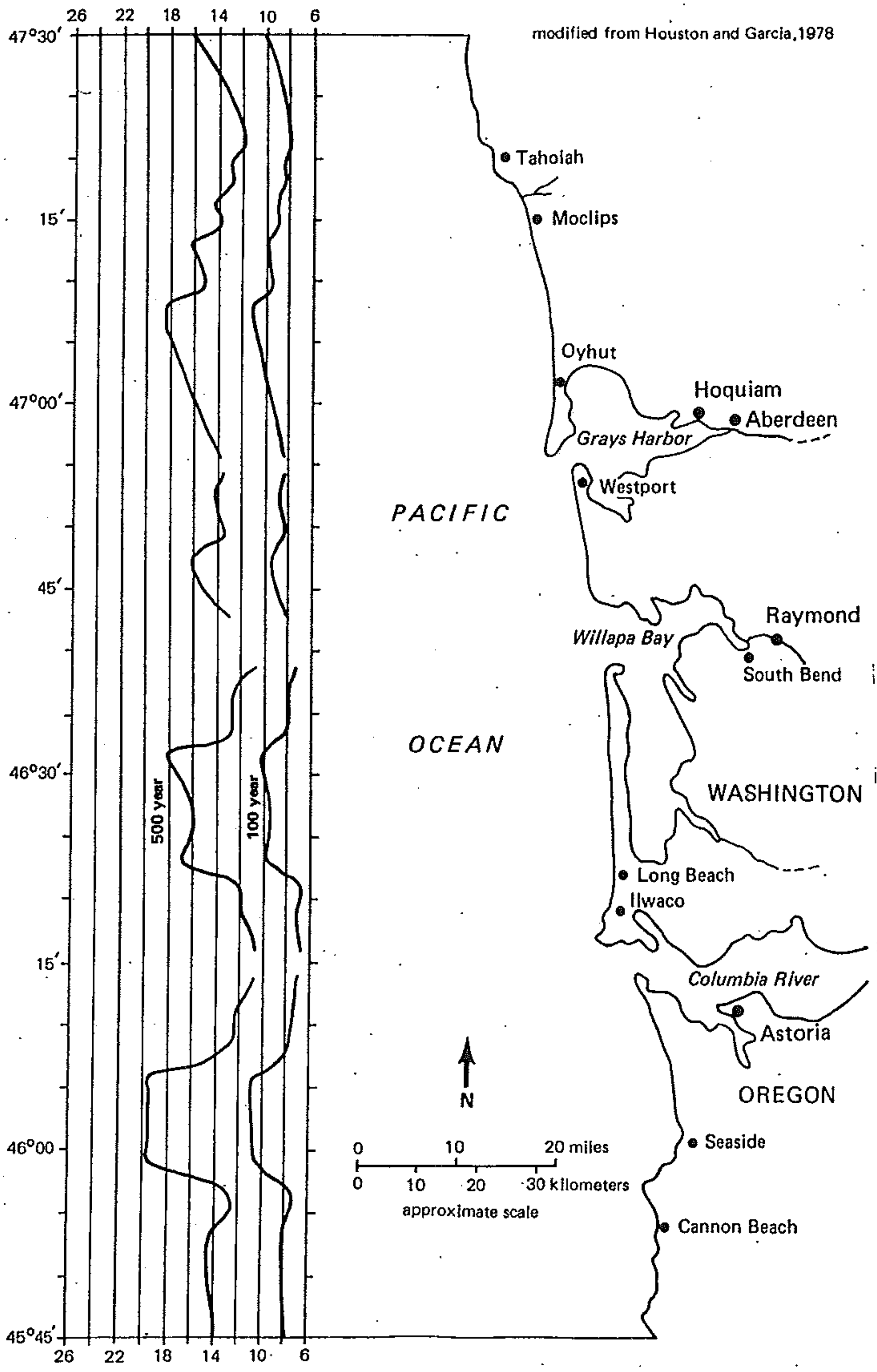
Tsunamis are large waves generated by submarine earthquakes and/or landslides. In the open ocean these large waves travel at speeds of about 470 miles per hour requiring 3 to 5 hours to reach the Washington coast from their most frequent source, the Aleutian Islands. Indeed seismologists are presently (fall of 1988) concerned about an area in the Aleutian Islands they call the Shumagin Gap as ripe for just such an earthquake.

Tsunamis have deep water heights that are generally undetectable - only one to two feet - and periods (the time between successive crests) of 15 to 20 minutes. When they reach the shore, however, they are transformed, in much the same fashion as wind waves, into waves that are much higher although their periods remain the same. The height of wave run-up onto the beach is determined by the shape of the near shore and of the beach.

Far-Source Tsunamis. Far-source tsunamis are defined as those generated by earthquakes occurring several hundred miles from the Washington coast. In such instances, residents might have some warning and be able to evacuate. The height of wave run-up from such an event has been modeled for the Washington coast (see Figure 3).

The Good Friday earthquake of 1964 in Alaska generated a tsunami that provides the only record of a tsunami striking the Washington coastline in modern times. Because the wave moved down the coast at night it was not observed by most of the population. Investigations on the following day showed damaged bridges at Wreck Creek and Copalis, debris filled yards in the Ocean Shores area, and one house moved 40 feet off its foundation in the Moclips area. Investigations by the Army Corps of Engineers in the following week showed that the "dwellings along most of the coast were protected by the large foredune, and damage only occurred where the foredune was missing" (at Moclips) or where it had been breached for road cuts (at Oyehut).

Figure 3. Predicted tsunami wave run-up elevations for the Washington coast. Modified from Houston and Garcia (1978) by Thorsen (1988).



The actual measured heights of the waves above predicted tidal levels at three spots along the Washington coast were: 11.1 feet at Moclips, 9.7 feet at Ocean Shores, and 12.5 feet at Seaview.

The 1964 tsunami also revealed that such an event could also cause problems along the estuaries and tidal streams. These problems were two fold: first, the rise in the water level created flooding and second, the strong currents generated by the rapid changes in water levels moved oysters about, ripped boats loose from their moorings, and severely battered bridge abutments with floating logs and debris. Such was the case with the Wreck Creek and Copalis River bridges described above.

Near-Source Tsunamis. Near-source tsunamis are those events that occur so near the shoreline that little or no warning is possible. Although Washington has never, in recorded history, experienced such an event, there is a large (and growing) group of researchers that say this is only due to the very short length of the record (less than 200 years). The situation is similar in some regards to the 1980 eruption of Mt. St. Helens, which was predicted on a geological basis, despite limited historical evidence. There is mounting geological evidence, in the form of buried peat layers, suggesting that such large earthquakes are rather common over geological time along the Washington coast (Atwater, 1987). Not only might such an event create large waves that would wreak havoc, it might likely be accompanied by ground subsidence of several feet. For example, during the 1964 earthquake in Alaska, the motel at the end of Homer spit sank with the ground so that the subsequent normal high tides filled the rooms on the lower floors with sea water.

There are no forecasts as to the run-up heights of near source tsunamis, but it generally agreed that their effects would be more severe than similar waves generated from a distant source. The record wave height for such an event, often mentioned in oceanography textbooks, is just over 100 feet, measured at Scotch Cap, Alaska.

Storm Surges

Storm surges are large waves that are associated with high winds and very low pressure weather systems. They commonly have periods of several hours and observed heights along the Washington coast are 4 to 5 feet. They usually occur as a single crest or surge, thus the name. On the Gulf Coast such surges are associated with hurricanes and cause the water level to rise several feet flooding low-lying coastal areas.

In the U.S., the classic case of storm surge damage is the flooding of Galveston, Texas, around the turn of the century. A storm surge associated with a hurricane swept across the entire barrier island upon which Galveston was built and ultimately was responsible for 5000 deaths.

While very large storms, like hurricanes, don't frequent the Washington coast, we do have some relatively severe weather. It was a storm surge arriving coincidentally with high tide that put sea water over the top of the pool tables in Ugly Ed's Tavern in Raymond in 1981 (see Figure 4). Another surge occurred on Thanksgiving Day, 1983, when a severe storm swept the Washington coastline, but did little damage. The surge arrived at low tide and was only noticed by the tide gauge observations at the Chehalis River bridge (see Figure 4). Had it arrived several hours earlier, or later, coincident with high tide, there might have been several feet of water in downtown Aberdeen. NOAA now routinely monitors the conditions that would generate such storm surges.

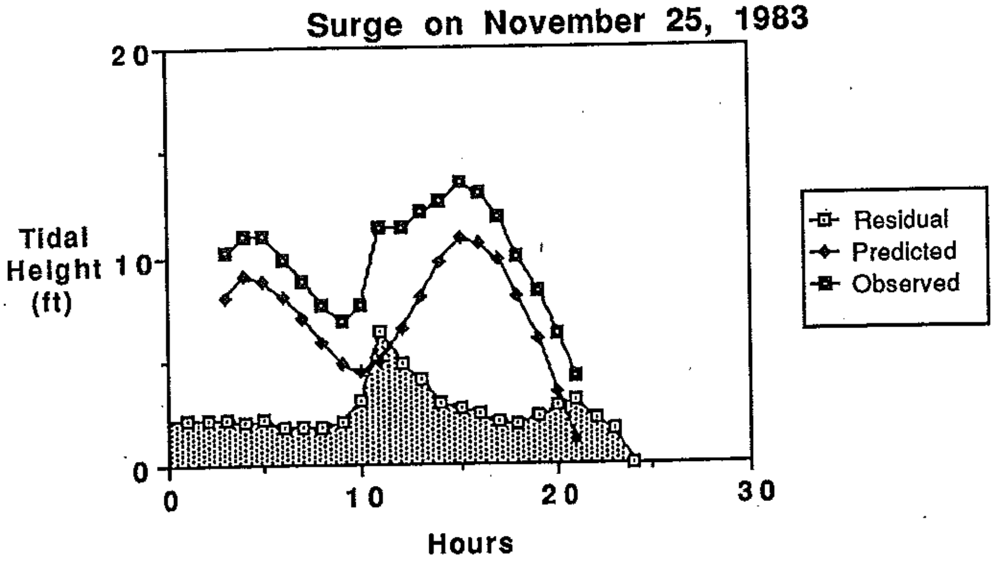
El Niño

El Niño is a global, weather-generated oceanographic event that occurs at irregular intervals spanning many years (see Table 1). It is marked by the intrusion of warm equatorial water into the normally cold waters of the Peruvian coast. The event gets its name because it often occurred near Christmas and "El Niño" means "the Christ child". While such events are most commonly noted by severe disruption of Peruvian coastal ecosystems, the more severe events reach into the North Pacific.

The severe El Niño that occurred during the winter of 1982-83 was studied intensely by Paul Komar and researchers at Oregon State University. Those studies showed a rise in sea level along the Oregon-Washington coast of about a foot above the normal winter tides. During this same period there were several winter storms, creating unusually high waves (22 foot breakers) and storm conditions resulting in water levels about 3 feet above the predicted high tides in January of 1983 Komar reported that this high energy situation upset the equilibria in long shore transport that normally exists along the Oregon coast line, driving far more sand northward than could return in the summer. This consequently created an erosion episode for some portions of the beach that lasted several years.

One of the responses of this El Niño along the Washington coast was also rather extensive erosion of the foredunes along much of the coast. For example, during this time period the foredune on the southern stretch of the Grayland beach was eroded until only about one-third of it remained.

Figure 4. The tidal records of two storm surges. The records for the 1981 surge are from Grays Harbor, while the 1983 surge is from a Willapa Harbor tide gauge. The data is from Lyles et al. (1988).



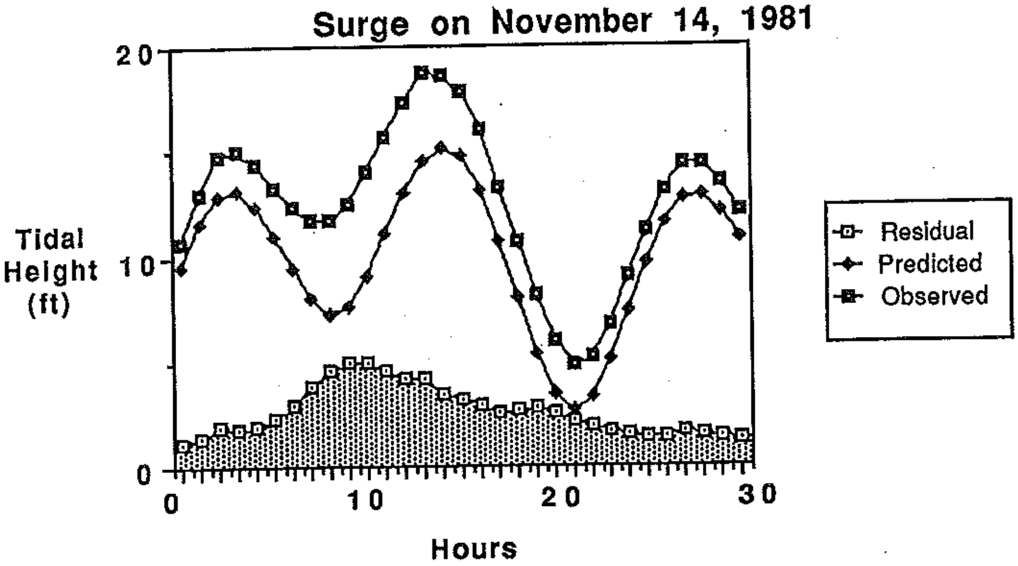
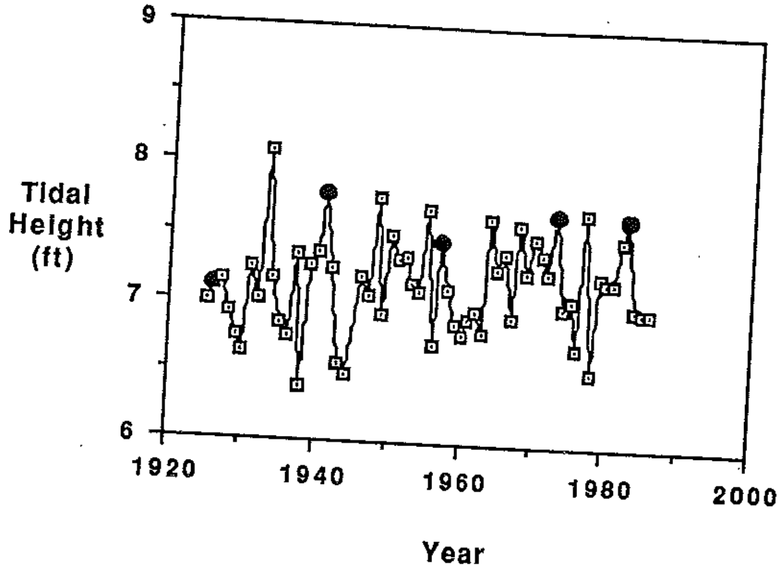


Table 1. A list of El Nino events during the 20th century. Ranked as medium or strong, only the strong (in bold)events are likely to have affected oceanographic conditions in the North Pacific. Data from Komar (1986).

El Ninos

1982-83	**strong**
1976	medium
1972-73	**strong**
1965	medium
1957-58	**strong**
1953	medium
1941	**strong**
1939	medium
1929-30	medium
1925-26	**strong**
1918-19	**strong**
1914	medium
1911-12	**strong**
1905	medium
1902	medium
1899-1900	**strong**

Figure 5. Variations in the average December tidal heights from 1925 to 1986. The years of the strong El Ninos (see Table 1) are enlarged and shaded. The figure shows that El Nino events were always associated with above average tidal heights, but that the converse is not true.

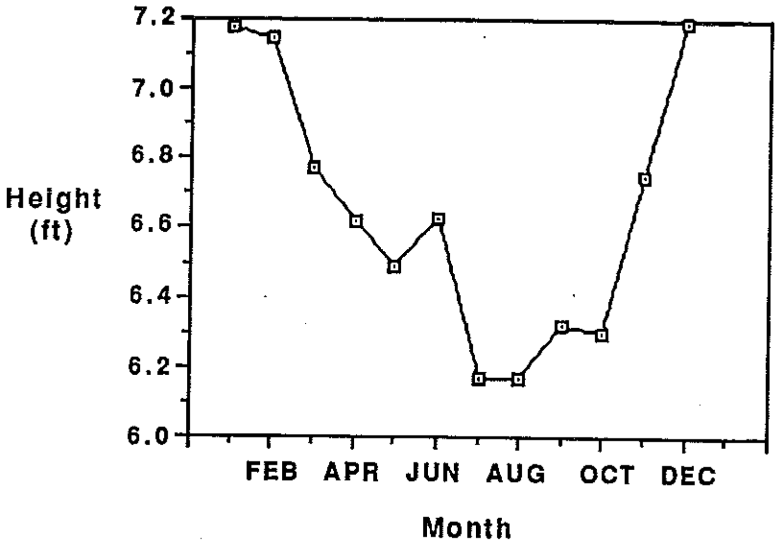


Do the El Niño conditions cause the December tides to be higher? Figure 5 shows that this is not always the case. The winter tides are not exclusively controlled by these events, but they are very often affected by it.

Tidal Changes

The monthly averages of tidal measurements take at Astoria since 1925 show about a 1 foot seasonal variation, with the summer average at about 6.2 feet and the winter average at about 7.2 feet (Figure 6). These changes are mostly due to weather changes, and barometric pressure variations in particular. The lower pressure during the winter raises sea level, a phenomenon called the inverse barometer effect. In the summer, cold upwelled water appears off our coast. This water is denser and thus lowers sea level. Fresh water contributions from the Columbia and coastal streams tend to make sea level rise as the fresh water floats on top of the saline ocean water. The winter on-shore winds tend to blow the water toward the shore causing a sea level rise, while off-shore winds in the summer tend to blow the water away from the shoreline causing a lower sea level. The list of causes is lengthy, and only a few are mentioned here. The point is to illustrate that tidal variation is influenced by many more factors that just the relative positions of the sun and the moon.

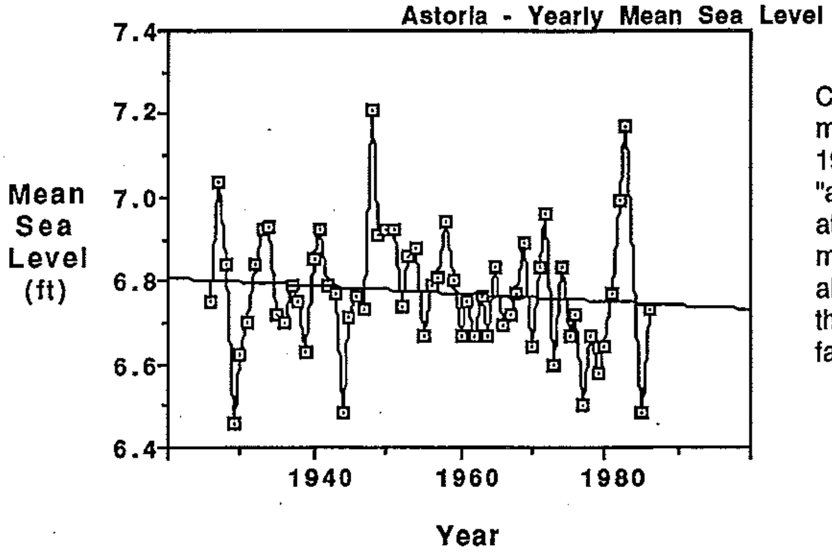
Figure 6. The monthly variation in sea level at Astroria. These data from 1980 show about a one foot difference between summer and winter.



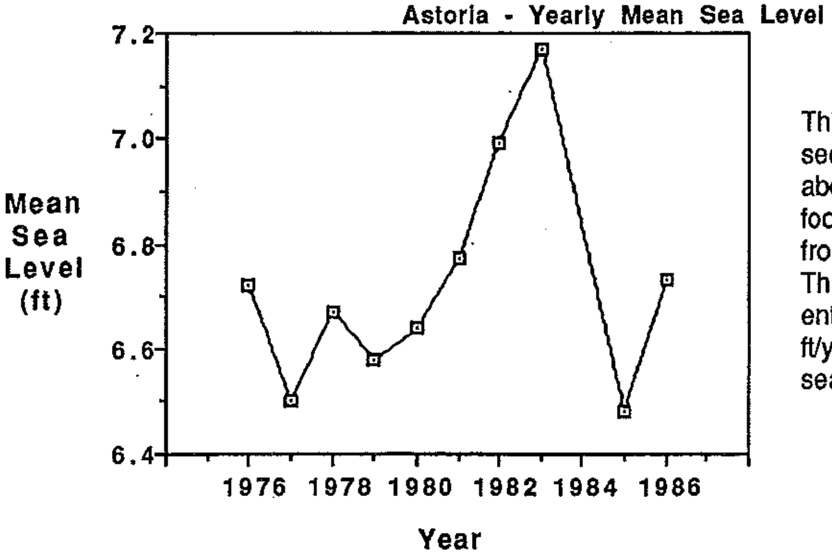
In addition to factors listed above there are non-periodic variations in sea level that persist over many years. Such variations are called "secular" and are used to show the relative vertical movements of the land and the sea. For example, it will be the study of the secular tidal variations that will tell us, eventually, how much sea level has risen due the greenhouse effect.

The secular variation, measured at Astoria, for the period from 1925 to 1980 shows a 0.5 mm per year drop in sea level and a greater (1.3 mm per year) drop in sea level for the period from 1940 to 1980 (see Figure 7). Because there is a general global sea level rise, this means that at Astoria the land is rising more rapidly than the sea is rising. The most probable reason for this is the uplifting of the land by forces deep within the earth.

Figure 7. The long term "average" sea level appears to falling by a small amount (a) if the entire tidal record is considered. However, if one considers only the last ten years (b), sea level has been rising 30 times faster than the long term average. Furthermore, during the 7 years from 1977 to 1983 sea level rose 0.7 feet. Data from Hicks et al. (1983) and Lyles et al. (1988).



Changes in the yearly mean sea level from 1925 to 1986. The "average line" slopes at 0.0009 ft/yr (0.27 mm/yr). This graph allows the conclusion that sea level is slightly falling.



This is an expanded section of the graph above. It shows a 0.7 foot rise in sea level from 1977 to 1983. The average for the entire period is 0.022 ft/yr (6.7 mm/yr) rise in sea level.

Averages from tide stations around the world indicate that global sea level is rising about 1.2 mm per year. This is referred to as eustatic sea level rise and is the result of glacial melting and other changes in the total volume of the oceans. This rate of eustatic sea level rise, combined with the 1.3 mm per year fall in sea level observed at Astoria, implies tectonic uplift of at least 2.3 mm per year. Thus both the land and sea are rising, but the land is rising faster.

Although these rates seem very slow (for example, your finger nails grow about ten times faster than this), they are important in affecting long-term changes of the shoreline. On the Atlantic Coast, where the land surface is falling, the rate of relative sea level rise is as much as 2.6 mm per year[3].

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[3] Since 1988, Shorelands Program has completed a study of vertical land movements in western Washington and adjacent areas. That report, *Vertical land movements in coastal Washington: Implications for relative sea level change*, is available from the Sea Level Rise Project, Shorelands and Coastal Zone Management Program, Department of Ecology, Olympia, Washington. It is certain that uplift occurs in the vicinity of Astoria (1.7 mm/yr; 6.7 inches/century) and Neah Bay (2.5 mm/yr; 9.8 inches/century) at rates greater than the eustatic sea level rise, producing a relative sea level decrease in those areas. The Grays Harbor area near Aberdeen is subsiding slightly (0.3 mm/yr; 1.2 inches/century). Uplift and subsidence patterns and rates are not yet certain along the Pacific Ocean coast between Astoria and Neah Bay.

FUTURE SEA LEVEL RISE DUE TO GLOBAL WARMING

It is now rather widely accepted that changes in the composition of our atmosphere may result in the overall warming of the planet. This warming will have a wide range of effects, one of which would be a possible acceleration of the existing rise in sea level. This sea level rise would be due primarily to the melting of ice in Greenland and Antarctica, and the thermal expansion of the sea as it warms up (warm water has a larger volume than cold water). One should note that we are not talking about melting all the ice, which might raise sea level about 200 feet, but the melting a small amount of ice, enough to raise sea level about 3 feet.

At this point the general agreement ceases, and there is a great deal of discussion about how soon this rapid rise will begin and how high sea level will rise? The answers to these questions are highly uncertain (Table 2).

Table 2. Estimates of sea level rise, from several sources.

ESTIMATES OF FUTURE SEA LEVEL RISE
feet
centimeters

	2000	2025	2050	2075	2100
EPA (1983)					
low	**.16**	**.42**	**.75**	**1.2**	**1.8**
	4.8	13	23	38	56
mid-range low	.29	**.85**	**1.7**	**2.9**	**4.7**
	8.8	26	53	91	144
mid-range high	**.43**	**1.3**	**2.6**	**4.5**	**7.1**
	13.2	39	79	137	217
high	.56	**1.8**	**3.8**	**6.9**	**11.3**
	17.2	55	117	212	345
Hoffman *et al* (1986)					
low	**.11**	.32	**.65**	**1.2**	**1.9**
	3.5	10	20	36	57
high	**.18**	**.68**	**1.8**	**6.3**	**12.1**
	5.5	21	55	191	368
Thomas (1986)					
low		**1.3**			**2.9**
		40			90
best					**3.6**
					110
high		**2.0**			**5.6**
		60			170

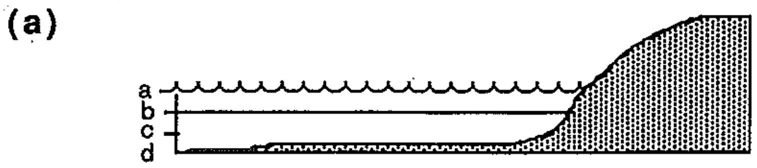
Paleoclimatologists describe the predicted climate-sea level conditions as a "super interglacial", an abnormal extension of the interglacial climate we have experienced for the last few thousand years. This may be an appropriate way to view the next hundred years, for sea level has certainly been rising for the last several thousand years. However, the predictions require that the rate of sea level rise will have to increase by at least tenfold. Tidal data discussed earlier in this report suggested a present global or eustatic sea level rise of 1.2 mm per year. In order to reach the "best" estimates of a 1 meter rise by the year 2100 the rate must increase to 10 mm per year, and to reach the maximum estimates, 30 mm per year.

Sea level rise is relative, however, because the land also moves up and down in response to tectonic forces acting from deep within the earth. These movements lend a regional character to sea level rise as measured on tidal gauges and indeed, as "seen" by the shoreline. The uplifted terraces along the edges of Willapa Harbor, Grays Harbor (Grays Harbor College is built on such a terrace), Point Grenville, and Destruction Island were all surfaces formed at (or very close) to sea level that have been uplifted by these forces. Although these uplifting forces have been active for millions of years, they also affect measurements on the existing tidal gauges. The tectonic history of coastal Washington is still being worked out and there is a puzzling 10,000 year period in which sea level rise overwhelmed the uplift rate in Grays Harbor. Perhaps our interests should be directed to some recent estimates of uplift rates, for they are the same order of magnitude as present sea level rise rates.

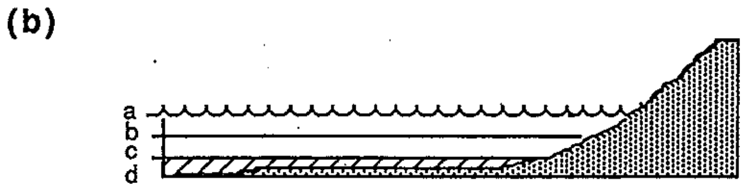
Lyles *et al.* (1988) describe the long term trends of sea level rise (or fall) as determined from tidal data. The coastal stations of interest are: Astoria -0.5 mm/yr, Neah Bay -1.3 mm/yr, Seattle 1.9 mm/yr, and Friday Harbor 0.9 mm/yr. Negative values imply falling sea level. Holdahl et al. (1987) presented uplift rates based on surveying data. Their work shows uplift rates of -2 mm/year (using the same sign convention as with the tidal data) on the Upper Olympic Peninsula beaches, dropping to zero north of Aberdeen and zero at Aberdeen and then rising south toward Oregon. They also shows positive (land sinking) values for the Puget Sound region from 0 to +2 mm/yr. The two data sets, tidal and land survey, generally tend to agree.

Although global sea level is rising, uplift rates on the Pacific Coast of Washington are sufficiently high to produce a fall in relative sea level. The uplift rates are variable, so at Neah Bay relative sea level is dropping, but at Grays Harbor the net change is zero. Although Holdahl's data do not extend to Astoria, the tidal data implies a positive uplift there also. In the Puget trough the tectonic movements are downward, resulting in a rise of relative sea level. The global warming predictions suggest that rates of sea level rise may increase significantly, overwhelming the tectonic uplift rates along the entire coast, and exacerbating the present sea level rise conditions in the Puget Sound.

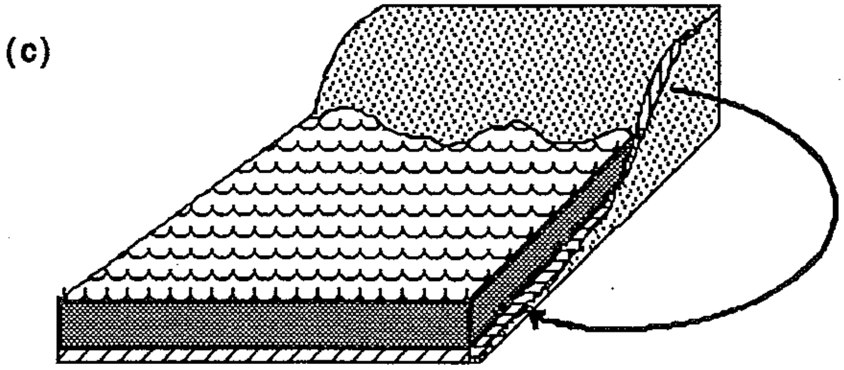
Figure 8. Per Brunn's ideas on beach erosion caused by rising sea level.



If sea level rises from a to b the bottom of the sea floor would rise by the same amount (c to d). The material for this comes from the shoreline.



Thus the shoreline erosion is far greater than that accounted for by the lapping of the sea onto the land



The block diagram shows the process in three dimensions. The sand (shown by hachures) required to move the sea floor up to the new equilibrium level is supplied by the beach.

The theory of erosion caused by a rise in sea level

Per Brunn (1962, 1986) is generally given credit for quantifying the the relationship between sea level rise and shoreline erosion rates.. The idea, simply stated, is that the beach and nearshore shallows are in equilibrium with the water such that changes in water depth are reflected in movements of the water-sand interface. If the sea level rises 2 mm the sediment on the bottom of the ocean must rise 2 mm also, and the sediment needed to raise the bottom that distance must come from the adjacent beach. Because this sediment is taken from a short section of beach and spread over a rather long section of the nearshore, a small rise in sea level results in proportionately greater recession of the shoreline (see Figure 8). Since Per Brunn's article in 1962 there have been many papers written about this idea, almost all of them describing conditions on the Atlantic Coast. Brunn's model of shoreline recession is a useful device as long as the nearshore and shoreface profiles represent equilibrium conditions and as long as there is no signicant net flux of sediment along the beach.

Can the concepts of Brunn be applied to the beaches of southwestern Washington? It does appear that at times of higher sea level the primary dunes erode and the beaches recede. This occurred during the 1982-83 El Niño, and generally occurs every winter when the spring tides are higher than they are in the summer. However, both of these cases are also accompanied by high surf conditions which certainly add to the erosive conditions. Regardless of what happens in the nearshore, it is likely that if the sea rises against the dunes, the dunes will recede.

The coast of southwest Washington is not very much like the Atlantic coastlines that Per Brunn decribed. Unlike the coast of the Carolinas, southwest Washington is a high energy coastline, with the longshore drift moving millions of cubic yards of material each year. Along the coastline of the Carolinas the long shore drift moves two or three orders of magnitude less sediment. The large amount of sediment moving along the high energy Washington coastline creates two problems with the application of Per Brunn's ideas: first, the material required to bring the sea floor up to match the sea level rise would be brought along the beach from river sources rather than from the immediately adjacent dunes, and second, the erosion rates would initially be much lower than the rates caused by a lack of sediment. Representative figures published by Brunn (1986) suggest that a 3 centimeter (1.25 inch) rise in sea level would cause 3 to 4.5 meter (10-15 feet) of shoreline recession. At the projected rates of sea level rise such an event would take several years and the Washington beaches commonly have that much erosion and/or accretion in a single year. However, the sea level rise will be progressive and continuous, and ultimately a 1 meter rise could result in 330 to 500 feet of recession. Additionally, the diminished sediment supply from the Columbia River may exacerbate the erosion problems caused by rising sea levels.

Very Long Term Changes -- The Last 10,000 Years

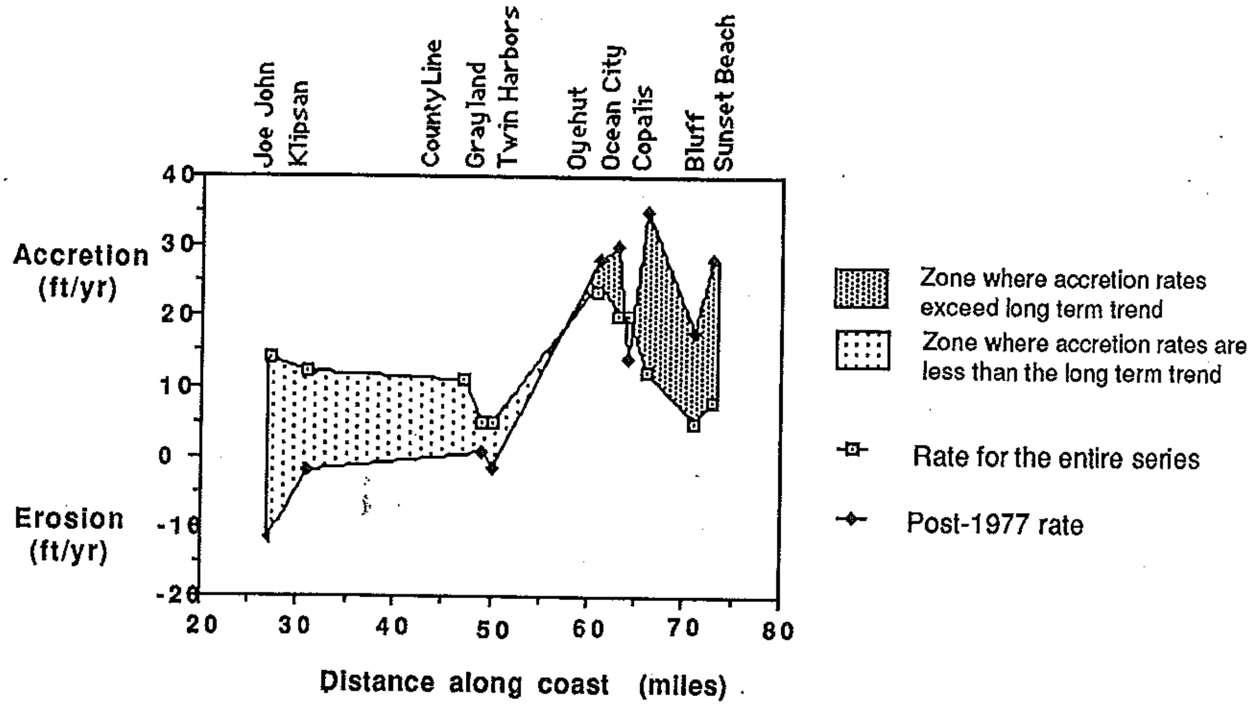
In the recent geological past there has been enough sediment available and moving along the southern Washington coastline to overwhelm eustatic changes in sea level. Studies at Grays Harbor, for example, show that throughout the last 10,000 years, as post-glacial sea level rose 60 meters, Grays Harbor remained an estuary. This means that the peninsulas of Ocean Shores and Westport existed in some form during this time. The beaches, instead of migrating landward across the continental shelf, simply built upwards with the sea and consequently remained in about their same relative locations. If that process were continuing today, we would see the beach areas growing higher and higher, while the bogs and swamps behind them became flooded. By taming the mighty Columbia, and turning the river's energy into kilowatts, we have greatly diminished the supply of sand to the beaches. The sand-starved beaches will be little match for the rising sea and so will respond by eroding, much as the rest of the world's shorelines.

EPILOGUE

Have the dams on the Columbia River had an effect on the beaches of southwestern Washington? The erosion-accretion pattern exhibited by the beaches in past decade is significantly different than the patterns for previous decades. Long Beach has not accreted as rapidly and most of the Grayland beaches show "no change" or erosion. While the North Beaches are still accreting, one could argue that they are at the end of the line and would be the last to "see" the effects of sediment starvation (see Figure 9).

Assuming that natural processes "slow down" before they stop, it appears that the accretional history of the beaches is at an end. Are the dams on the Columbia starting to affect the beaches of southwestern Washington? The answer is clearly "yes".

Figure 9. A comparison of the accretion rates for the last decade with those for the last 25 years. The recent rates exceed those of the long term on the northern beaches and are considerably less than the long term trend at Long Beach.



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APPENDIX

Department of Fisheries Data Description

Data collected by the Washington State Department of Fisheries in conjunction with their razor clam mangement program are probably the best available for the beaches of Southwest Washington. There are several reasons for the high quality: first, beach profiles are measured annually, during the same season, to remove the large seasonal variations that occur in such profiles; and secondly, surveying methods are used that allow precision to a few feet (laterally) as compared with air photos that allow precision of only plus or minus 50 feet.

Unfortunately the data presented here are somewhat irregular, with values for the most recent years not reported. Although the data have been collected, they have not been completely reduced. The data presented in Tables A1 and A2 are what was available in September of 1988.

Regression analyses of the total series of measurements show that the entire beach area of southwestern Washington has, on the average, been accreting since the measurements were instituted in the early 1950's (see Table A3). Interestingly, if the same statistical analysis is applied to the most recent data (which in most cases extends only from '77 to '83), we find that the beaches of Grayland and Long Beach are, for the first time, erosional. The North Beach area continues to be accretional.

Table A1. Fisheries survey data for the northern part of the area.

WASHINGTON STATE DEPARTMENT OF FISHERIES RAZOR CLAM BEACH SURVEY DATA

Date	Sunset Beach (MP)	Bluff (CP)	Copalis (GS)	Ocean City (M)	Ocean City (XL)	Oyehut (L)
1951						
52				550		480
53				560		480
54				540		440
55				540		460
56				580		520
57				590	560	550
58				650	560	590
59				690	680	610
60	230	250		700	690	650
61	270	220		680	690	680
62	300	230		750	720	680
63	300	230		670	-	670
64	340	260		740	770	760
65	300	260	690	800	790	800
66	330	240	690	820	760	870
67	-	280	710	780	870	860
68	260	250	730	800	900	870
69	290	260	670	870	900	930
70	300	230	-	900	890	900
71	300	240	680	930	900	-
72	350	290	760	940	930	890
73	350	300	750	980	1000	1000
74	-	280		-	990	970
75	310	300		1000	1050	1000
76	320	300	780	1020	-	980
77	370	-	-	1050	1000	1040
78	-	310	-	-	-	1080
79	420	280	760	1070	980	1120
80	400	300	840	1080	1040	1130
81	400	320	880	1110	1070	1230
82	464	330	890	1140	1040	1120
83	580	375		1170	1170	1240
84		400	910	1180	1180	1270
85				1130	1160	1250
86				1180	1190	1340
87						

The numbers are feet measured westward of a fixed monument to a beach elevation of +8 feet (approximately high tide).

1977-1987

Table A2. Fisheries survey data for the southern part of the area.

WASHINGTON STATE DEPARTMENT OF FISHERIES RAZOR CLAM BEACH SURVEY DATA

Date	Ocean Shores (XK)	Ocean Shores (K)	Twin Harbors (I)	Grayland (XH)	County Line (H)	Joe John (XB)	Klipsan (XA)
1951		450	350		490		
52		520	330		480		
53		490	260		440		
54		550	320		480		
55		620	300		500		
56		-	300		530		
57		730	360		610	500	400
58	670	800	400	460	620	570	440
59	680	820	350	470	590	600	490
60	700	800	-	-	-	580	460
61	810	860	340	530	650	600	510
62	-	810	350	500	640	580	480
63	880	960	400	540	680	-	500
64	890	1030	410	520	750	620	580
65	930	1100	430	520	750	640	580
66	980	1130	370	540	710	-	550
67	1000	1090	410	610	690	600	620
68	940	1120	380	540	730	640	620
69	-	1140	390	540	700	590	690
70	-	-	440	520	740	650	700
71	1030	1140	-	-	-	630	670
72	1140	1210	370	570	740	680	670
73	-	1280	350	550	740	730	720
74	1170	1220	410	530	700	640	680
75	1140	1280	400	520	680	670	650
76	1190	1320	460	530	780	760	790
77	1170	-	-	-	-	-	806
78	1280	-	490	625	-	-	825
79	1300	1410	460	630	780	760	670
80	1260	1420	470	700	770	925	760
81	1020	1500	480	550		954	790
82	1140	1400	450	610		740	670
83	1180	1410	480	570			
84	-						
85	1180						
86							
87							

The numbers are feet measured westward of a fixed monument to a beach elevation of +8 feet (approximately high tide).

Table A3. Linear regression analyses of the accretion rates.

RAZOR CLAM BEACH SURVEY STATISTICAL SUMMARY

	TOTAL SERIES		SINCE 1977	
	Accretion Rate (feet/year)	Corr. Coeff (R =)	Accretion Rate (feet/ year)	Corr. Coeff (R =)
Sunset Beach	10	0.8	28	0.8
Bluff	5.5	0.86	17	0.89
Copalis	18	0.91	27	0.88
Ocean City (M)	22	0.99	15	0.86
Ocean City (XL)	23	0.98	30	0.92
Oyehut	26	0.99	29	0.89
Ocean Shores (XK)	20	0.89	-12	0.35
Ocean Shores (K)	31	0.98	-2	0.08
Twin Harbors	6	0.84	-2	0.25
Grayland	5	0.67	-14	0.49
County Line	12	0.89	*	*
Joe John	14	0.83	-3	0.04
Klipsan	14	0.91	-12	0.36

Since 1977 the southern portion of the study area is erosional, while the northern portion is experiencing accelerated accretion rates. Note where the rates are negative (eroding beaches) the correlation coefficients are very low, showing the data are scattered.

Aerial Photography

Mapping of shoreline changes was done based on the photography used in the preceding study (Phipps and Smith, 1978) and additional photography flown in 1987. The 1987 and 1977 shorelines were marked on the black and white photos at a scale of 1 inch to 400 feet (1:4800).

These photos have been reproduced in this report at approximately 1 inch to 1000 feet (1:12000). The locations of the photos are indicated in the figure below. The general orientation of the photographs is north-south, but note that photos 10 and 15, at the mouths of Willapa Bay and Grays Harbor, are oriented perpindicular to this trend.

Index Map for Aerial Photos