OREGON GEOLOGY

published by the
Oregon Department of Geology and Mineral Industries

VOLUME 60, NUMBER 3 MAY/JUNE 1998

IN THIS ISSUE:

OREGON GEOLOGY

(ISSN 0164-3304)

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Published bimonthly in January, March, May, July, September, and November by the Oregon Department of Geology and Mineral Industries. (Volumes 1 through 40 were entitled *The Ore Bin*.)

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Periodicals postage paid at Portland, Oregon. Subscription rates: 1 year, $10; 3 years, $22. Single issues, $3. Address subscription orders, renewals, and changes of address to Oregon Geology, Suite 965, 800 NE Oregon Street # 28, Portland 97232.

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Cover photo

Nestucca Spit, projecting south from Cape Kiwanda, demonstrates the erosion power of storm waves in this picture of March 1978. Two articles in this issue describe the intensifying effect the El Niño and La Niña phenomena exert on coastal hazards in Oregon. Photo by Oregon Department of Transportation.

Chinese earthquake scientists visit to learn from Oregon

A 12-member delegation of seismologists and engineers from eastern China met with staff of the Department of Geology and Mineral Industries (DOGAMI) in April. The visit was organized by the Oregon Office of Emergency Management (OEM) as a means to exchange information on earthquake hazards and communication techniques

Each of the delegates was a director of a local branch of the Chinese National Earthquake Bureau. The function of the bureau is to disseminate earthquake-related information and to assist local government on earthquake issues. The visitors were especially interested in the methods used by DOGAMI to communicate information to various sectors of the public.

Dr. Zhenming Wang, a geotechnical specialist with DOGAMI, helped organize the trip and provided translation assistance. Dr. Wang previously worked for nine years at the Earthquake Bureau of Fujian Province before coming to the United States. Fujian Province is a sister state to Oregon and was one of the stops Governor John Kitzhaber made during his visit to China earlier this year.

State Geologist Don Hull and director of earthquake programs Yumei Wang explained Oregon's earthquake hazards and how Oregonians deal with them. They discussed ways of disseminating earthquake information and how state and local governments and the public are partners in earthquake hazard mitigation efforts. As in China, many Oregon areas are at risk from multiple hazards, where shaking is followed by such disasters as collapsed buildings, landslides, and tsunamis.

Although Chinese experts have predicted a few of the many large earthquakes that have occurred in China in this century, most earthquakes came without any warning. The Chinese government has adopted a new policy, Earthquake Prevention and Disaster Reduction, that places emphasis on mitigation rather than prediction.

The Chinese shared valuable lessons in preparedness, particularly from their public schools. On September 16, 1995, the city of Zhangzhou was shaken by an earthquake (M 7.3). The students in a middle school without earthquake education reacted in a panic, and several thousand suffered injuries. But students in a city primary school that had conducted earthquake education reacted correctly, and no one was hurt. Because of other experiences like this around the world, Oregon law requires schools to hold at least two earthquake drills a year. Coastal schools must hold three drills a year and include tsunami evacuation drills.

Delegates also visited OEM, Portland State University, the Portland area Metro office, the Emergency Management Center in Keizer, Marion County, and the Rural Fire Protection District of Cannon Beach, Clatsop County. □

Impacts of the El Niño Southern Oscillation on the Pacific Northwest

by George H. Taylor, State Climatologist, Oregon State University, Corvallis, Oregon 97331[1]

INTRODUCTION

The El Niño Southern Oscillation (ENSO) exerts a profound influence on global weather and climate patterns. A great deal of time and effort has been spent investigating the phenomenon, with good success. Increasingly, ENSO predictions and assessments are being used for decision-making, with benefits for the economy, public safety, and the environment. Oregon and the Pacific Northwest are strongly influenced by ENSO, and as ENSO information has improved and become more publicized it is being used more frequently in both the public and private sectors for everyday and long-term decisions. Below is a brief overview of ENSO effects in this region, followed by several examples of how such information is influencing decisions.

HISTORY OF ENSO

Residents of the west coast of South America have long been aware of occasional changes in weather patterns that dramatically change the landscape. Northern Chile and southern Peru are among the driest areas in the world, while cold offshore currents and strong upwelling produce some of the richest fishing grounds anywhere. Every few years, however, a warm, southward moving current flows along the coast that raises water temperatures significantly and abruptly ends upwelling. The warm current is accompanied by heavy rains that turn the desert into a lush garden and replace barren sand with green pastures. Such episodes were known as "años de abundancia" (years of abundance) to the locals (Philander, 1990). Unfortunately, the effects on the ocean conditions were just the opposite: the normal abundance of bird and marine life virtually disappeared, devastating a major portion of the local economy. These periods of warm offshore waters became known as "El Niño" (Christ Child) because they generally appeared immediately after Christmas. Later, they were often known as "warm events" or "warm episodes."

Early in the 20th century, Sir Gilbert Walker began to study large-scale weather patterns in the tropics in hopes that they could explain the occasional disastrous failures of Indian monsoons. Walker became Director-General of Observatories in India in 1904; a few years earlier, a poor monsoon had led to a widespread famine in that country. Walker discovered that interannual pressure changes over the Indian Ocean and the eastern tropical Pacific Ocean are out of phase: lower than average pressures over the Indian Ocean correspond with higher than average pressures over the east Pacific and vice versa. Walker named this phenomenon the "Southern Oscillation." It became clear that monsoons are part of a global climate system, and Walker undertook an effort to better understand the components and variables in hopes of producing better predictions for monsoon timing and intensity.

Between 1923 and 1937, Walker and his associates published many papers and reports and successfully found correlations between the Indian monsoon and weather in various parts of Africa, Asia, North America, and the Atlantic and Pacific Oceans. Unfortunately, the attempts to produce a prediction scheme failed. This lack of a prediction scheme and of a good physical explanation for the cause-effect relationship, caused Walker's contemporaries to be very skeptical of his work. As a result, interest in the Southern Oscillation faded during the mid-20th century (Philander, 1990).

If Walker had had better sea-surface data, his findings might have been much more significant (and better accepted). Unfortunately, the available data were quite inadequate. It was not until the International Geophysical Year of 1957–58 that thorough measurements were made during a period of significant ocean and atmosphere anomalies. A strong "warm event" occurred that year, and warm surface waters were found to extend nearly to the Date Line. For the first time the true extent of El Niño was revealed. Accompanying the large area of warm surface waters were weak trade winds and heavy rains throughout the eastern tropical Pacific. After many decades, Walker's theory had been observed and verified.

Nonetheless, El Niño events remained poorly understood and infrequently studied. In the 1960s and 1970s, Dr. William Quinn of Oregon State University, an oceanographer, became interested in the El Niño phenomenon and began making trips to South America to study it. Quinn taught himself Spanish and Portuguese so he could pore over explorers' log books, fishing records, and other Peruvian and Chilean documents in search of anecdotal information about El Niño occurrences. His published results (Quinn and Neal, 1987) list

[1] Oregon weather and climate are the subject of the internet home page of the Oregon Climate Service at http://www.ocs.orst.edu/

El Niño events back to A.D. 1525. At the time of his death in 1994, Quinn was working on an El Niño data set dating to A.D. 622. Quinn's conclusion was: The El Niño phenomenon has been with us for millennia.

In 1982–83, the strongest El Niño event of the century formed in the Pacific and began affecting the Pacific Rim and most of the rest of the world. Severe weather and climate effects were widespread and disastrous on almost every continent. Australia, Africa, and Indonesia suffered droughts, dust storms, and brush fires. Peru was hit with the heaviest rainfall in recorded history—11 ft in areas where 6 in. was the norm. Some rivers carried 1,000 times their normal flow. The United States, particularly California, was hit very hard. Worldwide, the event was blamed for between 1,300 and 2,000 deaths and more than $13 billion in damage to property.

The El Niño devastation of 1982–83 gave the world a wake-up call. Suddenly, the potential effects of a strong El Niño event were recognized and understood. Scientists began measuring and studying the tropical Pacific in hopes of being able to identify and forecast the conditions and help citizens of the world to prepare for trouble. In the past 15 years, El Niño has been thoroughly studied and discussed. Philander (1990) and Diaz and Markgraf (1992) provide excellent overviews of the ENSO phenomenon.

This improved understanding paid off handsomely in 1997. Quite suddenly in the early spring, an El Niño event began to develop. It was immediately identified by scientists, who began to inform regulatory agencies and emergency response teams, as well as the media. Despite a great deal of hype (some have called this "the weather event of the century," which it certainly is not!), agencies have been able to prepare for this event like no other in history. When California and the Gulf Coast began to be pummeled by massive storms in early 1998, just as scientists had predicted, the advance warning was appreciated.

EL NIÑO AND LA NIÑA

Typical El Niño events begin with a decrease in easterly winds off South America, reducing upwelling and causing sea-surface temperatures to increase. This warms the atmosphere and lowers the pressure over the eastern Pacific, causing the trade winds to be further reduced. Gradually this process continues until El Niño develops. In strong El Niño situations, anomalously warm waters cover nearly all of the eastern and central tropical Pacific. The area of strong convection (large rain clouds) usually shifts eastward as waters in those areas warm.

El Niño has a counterpart, which happens approximately as often: it is known as "La Niña" or "cold event." During normal conditions, the sea-surface temperatures across the tropical Pacific increase steadily from east to west. El Niño conditions cause a reduction in this temperature gradient. La Niña events, on the other hand, see an increase in the east-west gradient, with western Pacific temperatures even warmer than average and eastern waters cooler. The result is an even stronger, more concentrated area of convection in the western Pacific with above-average precipitation and more tropical storms than usual.

The sequence of events that is thought to cause El Niño conditions (described above) may also apply to La Niña formation, except in reverse. In the latter case, increased easterly winds off South America would cause greater upwelling, cooler sea temperatures, higher air pressure, and hence still stronger winds. Bjerknes (1969) suggested "a never-ending succession of alternating trends by air-sea interaction in the equatorial belt." He added, "just how the turnabout between trends takes place is not yet quite clear." Bjerknes believed that investigations of ocean dynamics held the key to understanding these transitions.

EFFECTS OF ENSO IN THE PACIFIC NORTHWEST

The earliest systematic study of ENSO in the Northwest was conducted by Redmond and Koch (1991). They concluded that there are "a few dominant modes which account for most of the temporal variation in the surface climate." They determined that the Southern Oscillation Index (SOI) can be used as a predictor for climate, especially during winter. SOI, originally used by Walker to define and detect the Southern Oscillation, is based on pressure differences between Tahiti and Darwin, Australia. SOI values less than zero represent El Niño conditions, near zero values are "normal" or average, and positive values represent La Niña conditions. According to Redmond and Koch, the greatest correlations between SOI and winter climate patterns in the Northwest occurred with about a 4-month time lag, with summer average SOI correlating well with conditions in the Northwest during the following winter The results were sufficiently strong that the authors suggested a cause-effect relationship.

In recent years, the Oregon Climate Service (OCS) has studied various aspects of this SOI-climate relationship in the Northwest. We have also investigated use of other indices and correlations involving averages other than the summer SOI. Some general results are listed below.

Precipitation

For the most part, El Niño or warm events correlate with below-average precipitation the following winter in the Northwest. In southern Oregon, the correlation is fairly weak, but north of about Roseburg (and extending into Bristish Columbia) the correlation is fairly strong. The winter of 1982–83 was a notable exception in that it was a very wet winter throughout the Northwest, but the intensity and timing of that event was unprecedented, at least in the last 75 years.

Figure 1 is a plot showing the summer average SOI versus precipitation during the following winter at Bonneville Dam on the Columbia River. El Niño years (negative SOI values) are associated with average or lower than average winter precipitation, while La Niña conditions (positive SOIs) are likely to produce wetter than average winters. The horizontal lines denote the average for each SOI category.

Figure 2 shows the water-year (October-September) precipitation for the Oregon coast climate division compared with the previous summer's SOI (by categories), showing a similar relationship as Figure 1.

Temperature

Winter temperatures correlate well with SOI values. In general, negative-SOI (El Niño) conditions are associated with mild winter temperatures, while positive-SOI (La Niña) conditions have a greater likelihood of colder than average winter temperatures. These correlations apply for both long-term (monthly and seasonal averages) and short-term (individual days) periods.

Figure 3 shows mean monthly February temperatures at Astoria, Oregon, compared with the average SOI of the previous October-December period. El Niño years (negative values) generally result in mild conditions during late winter, while La Niña years are associated with colder temperatures. Figure 4 shows extreme low temperatures in Salem, Oregon, in February compared with the same October-December SOI average. Extreme cold events occur almost exclusively during La Niña years.

Snowfall

A consistent correlation throughout Oregon exists between SOI and total snowfall. At either end of the SOI distribution (strong El Niño or strong La Niña), total snowfall in valley locations is relatively low; this is true both east and west of the Cascades. Although years with moderate (near-zero) SOI values may also have low snowfall totals, the years with greatest snowfall occur in conjunction with these moderate values. Figure 5 shows a plot of total winter snowfall compared with the SOI of the previous summer for Hood River, Oregon.

EFFECTS OF ENSO NATIONWIDE

ENSO conditions cause greatly differing impacts in the northern and southern halves of the United States. In the southern tier of states (from California on the west to Florida on the east), the wettest winters occur during El Niño years, while La Niña years tend to produce dry winters. The northern states, on the other

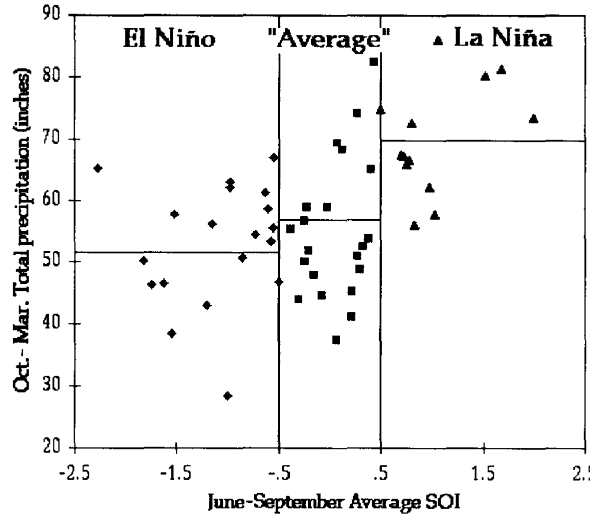

Figure 1. Bonneville Dam winter precipitation vs. previous summer's SOI. Data points show correlation of negative SOI values (El Niño, diamonds) with low precipitation and positive SOI values (La Niña, triangles) with high precipitation during the following winter months. Squares = average; horizontal lines = average of category.

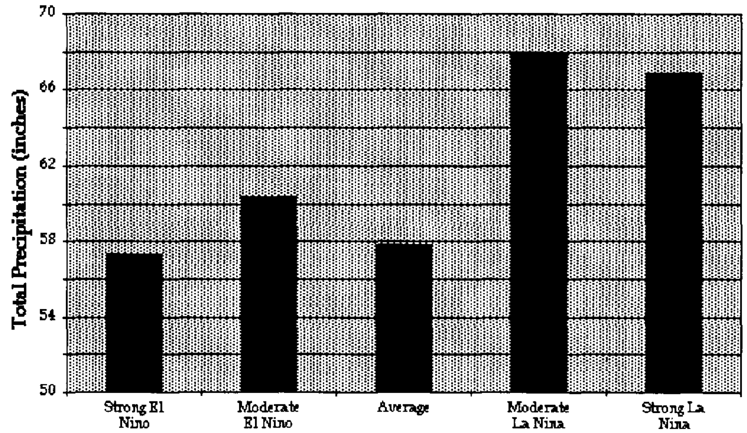

Figure 2. Water-year precipitation, Oregon coast, vs. previous summer SOI.

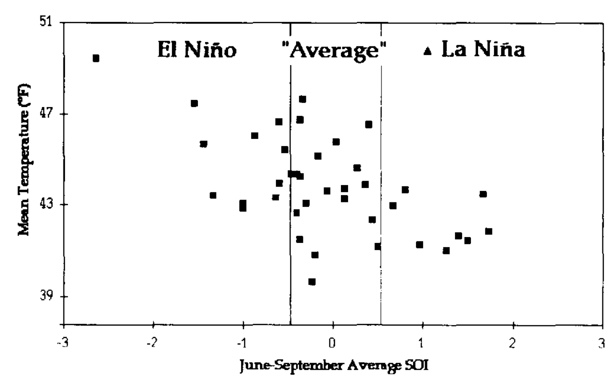

Figure 3. Mean January-March temperature in Astoria, Oregon, vs. preceding October-December average SOI.

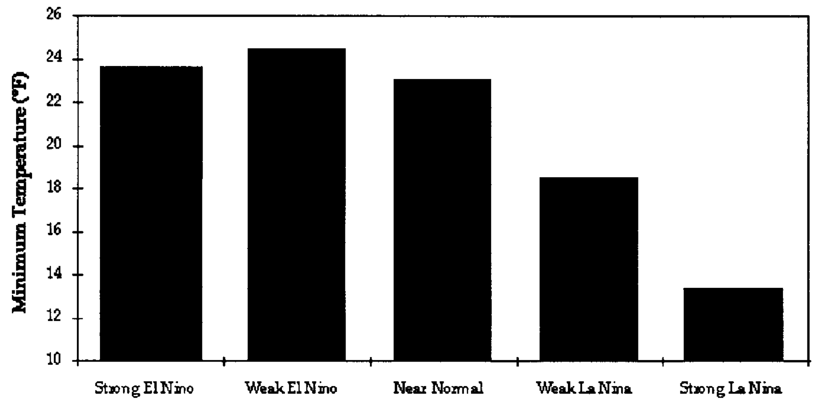

Figure 4. Extreme low temperature, Salem, Oregon, February, vs. preceding October-December average SOI.

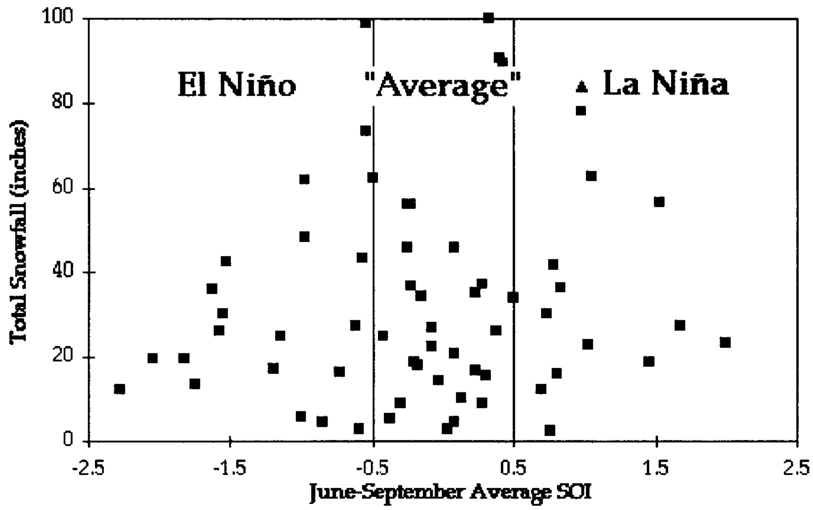

Figure 5. Total winter snowfall, Hood River, Oregon, vs. SOI values of previous summer.

hand, experience their driest winters during El Niño periods and the wettest during La Niña periods. Figure 6 is a chart of precipitation extremes during El Niño events for the months of December through February.

In the case of temperatures, El Niño events generally bring mild winters to the entire West Coast and the northern tier of states as far east as the Great Lakes. Figure 7 shows December-February temperature extremes during El Niño periods and indicates that only in the western Gulf Coast and western Great Plains are cold winters likely during El Niño periods. For the past winter (1997–98), observed temperature patterns have closely paralleled those in Figure 7. Oregon and Washington have been unusually mild all winter, as have the northern central states. In Minnesota, where the ice-fishing season generally begins in November, most lakes did not freeze until early January.

IMPLICATIONS FOR DISASTER POTENTIAL AND EMERGENCY RESPONSE

As the 1997 El Niño began to unfold, emergency response personnel were warned to take preventive action to mitigate the disasters that were expected to occur. In many cases, this was justified and was borne out by the very severe weather that affected California and other parts of the United States. On the other hand, many areas were not adversely affected, including Oregon. Yet, this should not surprise us, for El Niño winters are generally quite benign here, milder than normal, and with average or below-average precipitation.

Nonetheless, many stern warnings were given Oregonians this year. In August, 1997, a "Watch Out For El Niño" article appeared in the Los Angeles Times. It warned of potentially serious weather during winter and suggested that readers prepare their homes and property for heavy rains, mudslides, and flooding. The abundant rains of January and February 1998 are testimonies to accurate forecasts of El Niño effects. In Oregon, the same article, without modification, ran in the Salem *Statesman-Journal* with the headline "Prepare for a Wild Winter." What is true for California is sometimes completely untrue for Oregon, as in this case.

What Oregonians should fear, however, is La Niña. Severe flooding during the winters of 1995–96 and 1996–97 was attributable largely to the combination of heavy snows and warm, intense tropical rain. The tropical moisture arrived in Oregon from the western tropical Pacific, where ocean temperatures were well above normal (La Niña conditions), causing greater evaporation, more extensive clouds, and a greater push of clouds across the Pacific toward the northeast. During such conditions Oregon is on the receiving end. Severe flooding, the worst in the state since 1964, killed several people and caused widespread property damage. Mudslides and landslides were numerous. The Oregon coast was lashed with strong winds, violent surf, and heavy rains. Nearly every river in Oregon reached or exceeded flood stage, some setting all-time records.

Looking back over similar damaging winters in the past, we see them coinciding frequently with La Niña events. There is now evidence that El Niño and La Niña

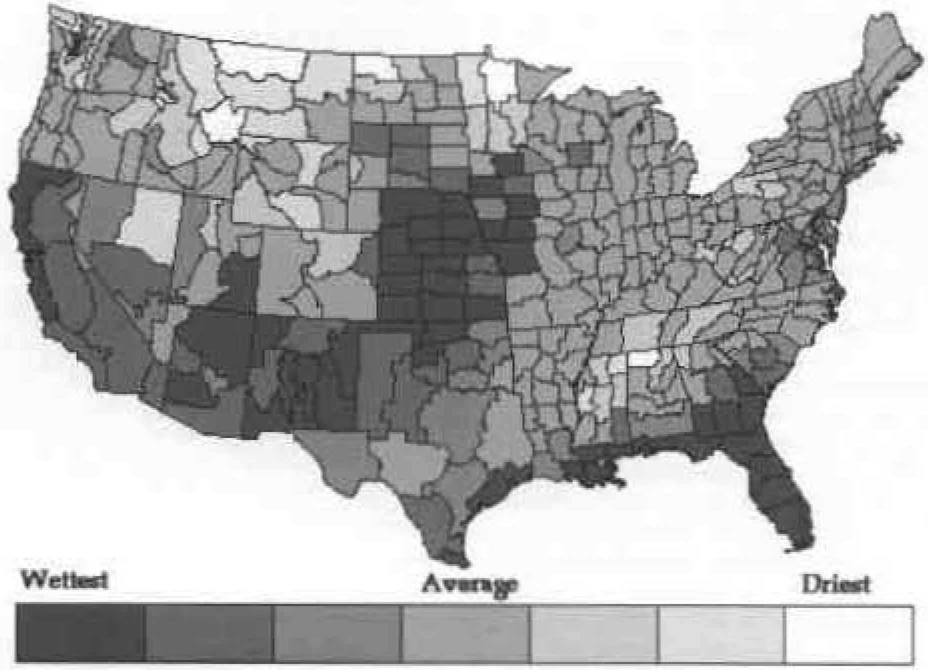

Figure 6. Precipitation extremes between December and February during El Niño years in climate divisions of the conterminous United States. Darkest = most likely rather wet winters. Lightest = most likely rather dry winters. Graphic from NOAA Climate Diagnostics Center.

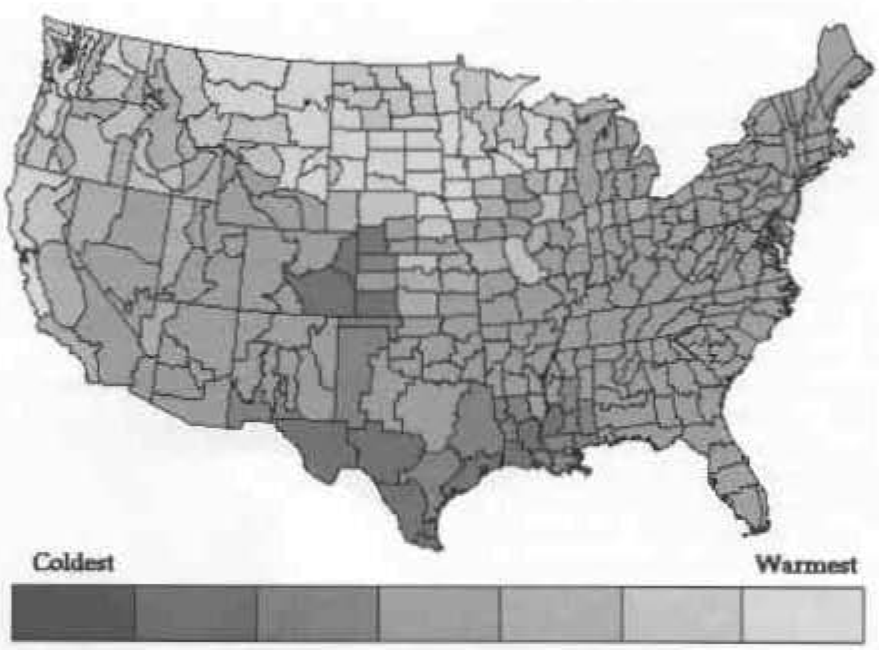

Figure 7. Temperature extremes between December and February during El Niño years in climate divisions of the conterminous United States. Darkest = most likely rather cold winters. Lightest=most likely rather warm winters. Graphic from NOAA Climate Diagnostics Center.

events, which historically occur with about the same frequency, are bunched into periods of 20–25 years, some of those years dominated by El Niño, others by La Niña. There is also evidence that a regime shift has occurred and that we have moved from an El Niño period (1975–1994) to one with many more La Niña events. The latter regime would resemble that which occurred here from about 1948 through 1973, a period dominated by cool, wet weather, abundant snows, and floods. Based on what has been observed in such periods in the past, it is likely that about 75 percent of the years will be wetter than normal in the next 20 years.

This year's rather dull winter (mild temperatures, lower than average snow pack, and only average precipitation) may be merely a brief respite in what may be an exciting and perhaps very damaging period between now and 2020. Watch for La Niña, and be prepared!

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Oregonians need more information about tsunamis to save lives

Do you know how to save your life if a tsunami strikes the Oregon coast? Poll results recently released by the Oregon Department of Geology and Mineral Industries (DOGAMI) suggest Oregon coastal residents need more information to protect themselves from these giant waves. Tsunamis are waves that are generally up to 25 ft high, but can be 50 ft high, and are generated by undersea earthquakes.

Tsunamis can be generated by earthquakes off the Oregon coast, or they can be triggered by undersea earthquakes elsewhere in the Pacific Ocean. When asked, "If you feel an earthquake at the Oregon coast, how much time do you have to evacuate to a safe place before the first tsunami wave hits?", only 31 percent of coastal residents correctly answered 30 minutes or less. Almost half (49 percent) said they didn't know.

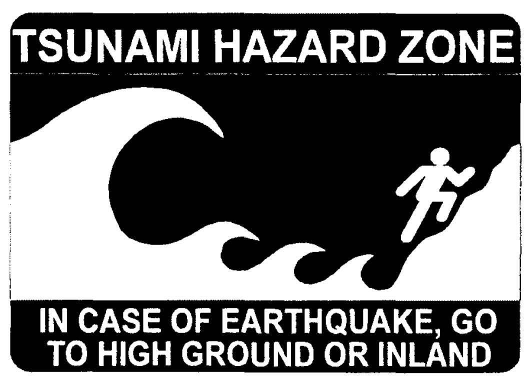
Only 27 percent knew that after a distant earthquake, they would have 1 to 8 hours before the first tsunami wave hit the Oregon coast.

When asked, "After a tsunami has struck, when is it safe to return to low-lying areas?", nearly one-fourth (22 percent) of the respondents incorrectly said it was safe to return when the wave receded. "Tsunamis are a series of waves," explained Lou Clark, Earth Science Information Officer for DOGAMI. "If you go back to the areas that were flooded by the first wave, you might get trapped by a second, third, or later wave." About a third of respondents (31 percent) gave the correct answer: "Return only when given approval by appropriate authorities."

On the positive side, 80 percent of coastal residents understood that a tsunami is a huge amount of water, and two-thirds (69 percent) understood that an earthquake along the Oregon coast could cause a tsunami. Only 3 percent incorrectly said an offshore earthquake would definitely not cause a tsunami.

To better prepare school children, coastal schools are required to participate in three earthquake and tsunami drills a year. One-fourth of respondents (24 percent) knew schools were holding drop, cover, and hold drills. About the same number (27 percent) knew schools were conducting tsunami evacuation drills.

Residents in 18 coastal cities (Astoria, Bandon, Brookings, Cannon Beach, Coos Bay, Florence, Gold Beach, Lincoln City, Newport, North Bend, Pacific City, Port Orford, Reedsport, Rockaway, Seaside, Tillamook, Waldport, and Yachats) were polled. The survey has a margin of error of plus or minus 5 percent. □



El Niño and coastal erosion in the Pacific Northwest

by Paul D. Komar, College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, Oregon 97403

INTRODUCTION

El Niño Southern Oscillation (ENSO) has a profound effect on the Earth's weather and climate and on ocean processes including water temperatures, currents, mean sea level and wave generation. The paper by Taylor on the preceding pages of this issue focused on changes in weather and climate in the Pacific Northwest, while the present paper deals with the oceanic processes that are important in causing beach and property erosion.

We became particularly aware of the importance of El Niño to coastal erosion in the Northwest during the extreme 1982–83 event (Komar 1986, 1997; Komar and others, 1988; Komar and Good, 1989), and this awareness has been reinforced by the 1997–98 El Niño event. We have seen much news coverage of the erosion El Niño produced along the coast of California (with accounts of floods and landslides). Beach and property erosion also has been severe in the Pacific Northwest, having occurred at numerous sites along the coast.

The main objective of this paper is to examine the atmospheric and oceanic processes produced by El Niño that are important in causing erosion. Most of the discussion of the processes will center on the 1982–83 event, since data collected from that period have been thoroughly analyzed. While measurements of the processes during the ongoing 1997–98 event are still being collected, it is evident that the processes important to coastal erosion are very similar to those experienced in 1982–83. The paper will end with a brief account of erosional "hot spots" experienced during the 1997–98 El Niño event along the Oregon coast, which serve to illustrate how these processes combine to produce beach erosion and property losses.

PROCESSES OF COASTAL EROSION

Most occurrences of coastal erosion involve one or more of the following processes or factors:

- *storm-generated waves;
- high predicted tides;
- *elevated water levels above the predicted tidal elevation;
- an increase in relative sea level due to glacial melting plus land-level change;
- *erosion of embayments by rip currents;
- *alongshore movement of beach sediment;
- *jetty or breakwater disruption of beach sand movement;
- *migrations of tidal inlets and river mouths.

The processes and factors that are enhanced during an El Niño event are designated by an asterisk (*). The greatly increased erosional impacts along the west coast of the United States during an El Niño event are accounted for by the increased intensities of these processes and by the fact that they generally reinforce one another to maximize their impacts. These important processes and factors are briefly recounted here.

Enhanced sea levels

Particularly unusual during an El Niño occurrence are the processes that locally alter mean water levels in the ocean. They become readily apparent when we compare predicted tides, those found in tide tables, with the measured tides that are actually experienced. During both the 1982–83 and 1997–98 El Niño years, tides were typically on the order of 1.5 ft higher than predicted. The elevated water levels tended to drown out the beaches and were extremely important at times of high tides, since the water was able to reach sea cliffs and foredunes, allowing waves to attack and erode coastal properties.

Part of this elevated water level on the Northwest coast owes its inception to changes in processes acting along the Earth's equator during an El Niño event. Historically, the first recognized impacts of El Niño were dramatic changes in water temperatures and effects on fisheries off the coast of Peru. Upwelling normally brings deep ocean water to the surface, much as it does off Oregon and Washington. The cold water, high in nutrients, has made the Peruvian fisheries one of the richest in the world. However, during an El Niño occurrence this system breaks down: the water becomes warm and fish and sea birds die en masse. Such an event usually develops during the Christmas season—hence its name, El Niño, Spanish for "The Child."

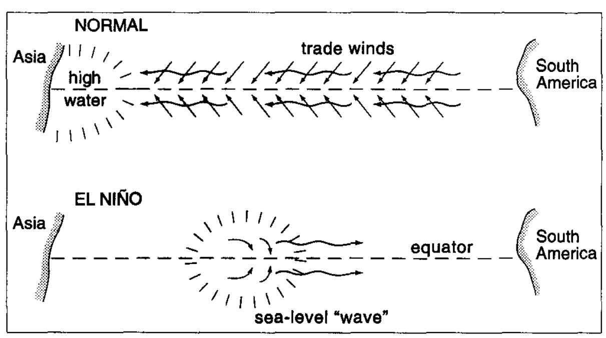


Figure 1. Schematic diagram of the shift in trade winds and ocean currents along the equator in the Pacific Ocean during a normal year (upper part) versus an El Niño year (lower part). The cessation of the trade winds during El Niño produces a sea-level "wave" that travels eastward along the equator.

It once was thought that the onset of El Niño off Peru was caused by the cessation of local coastal winds that produce upwelling. This view changed when the physical oceanographer Klaus Wyrtki demonstrated that these local winds do not necessarily diminish during an El Niño event (Wyrtki, 1975). Instead, he found that the breakdown of the equatorial trade winds in the central and western Pacific trigger El Niño, far away from the Peruvian coastal waters where its chief impact is felt. The process is illustrated schematically in Figure 1, contrasting a normal period with an El Niño year. During normal years, the trade winds blow toward the equator, but with a component directed toward the west, and generate ocean currents that flow toward the west parallel to the equator. The stress of the wind on the water and the westward flow of currents combine to produce an elevated water level in the western Pacific, centered in the area where the equator intersects the coast of Asia. The same effect is obtained when you blow steadily across a cup of coffee: the surface of the coffee becomes highest on the side of the cup away from you. If you stop blowing, the coffee surges back and runs up your side of the cup. The process is similar in the ocean, when the trade winds stop blowing during an El Niño year. This condition is depicted in the lower half of Figure 1. The potential energy of the sloping water surface is released, and it is this release that produces the eastward flow of warm water along the equator toward the coast of Peru, where it kills fish not adapted to warm temperatures.

Associated with this warm-water movement eastward along the equator is a wavelike bulge in sea level, also depicted in the lower diagram of Figure 1. The eastward progress of the sea-level wave has been monitored at tide gauges located on islands near the equator. Data from a tide gauge can be averaged to remove the tidal fluctuations, yielding a measure of the mean level of the sea during that time interval. Such analyses were undertaken by Wyrtki to demonstrate the eastward movement of sea-level waves during El Niño events (Wyrtki, 1977, 1984). Figure 2 shows the results for the 1982–83 El Niño. From this series one can easily see the passage of the released sea-level wave as it traveled eastward across the Pacific, affecting in turn tide gauges on a series of equatorial islands. Sea level at Rabaul in the western Pacific reached a peak in March or April 1982 and then began to drop. The crest passed Fanning Island south of Hawaii in late August, Santa Cruz in the Galapagos at the end of the year, and reached Callao on the coast of Peru in January 1983.

Upon its arrival on the coast of South America, the sea-level wave splits, and the separated parts respectively move north and south along the coast. Analyses of tide-gauge records along the full length of the west coasts of North and South America have demonstrated that the sea-level waves can travel as far north as Alaska (Enfield and Allen, 1980). The wave travels at a rate of about 50 mi per day, so it quickly reaches California and Oregon. The passage of the sea-level wave along the Oregon coast is depicted in Figure 3, which also shows the locations of tide gauges used to monitor its movement. Figure 4 gives the monthly mean sea levels measured by the tide gauge in Yaquina Bay, Oregon, during the 1982–83 El Niño year, contrasting the levels with more normal years (Huyer and others, 1983). As in the analyses of Wyrtki, the tide-gauge record was averaged

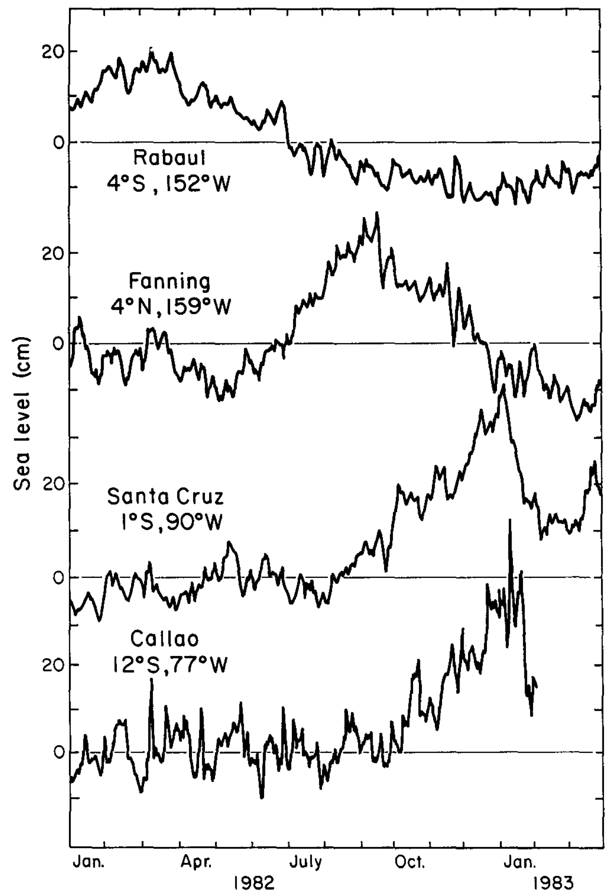


Figure 2. Sea-level waves measured on tide gauges of islands located along the length of the equator during the 1982–83 El Niño event (after Wyrtki, 1984).

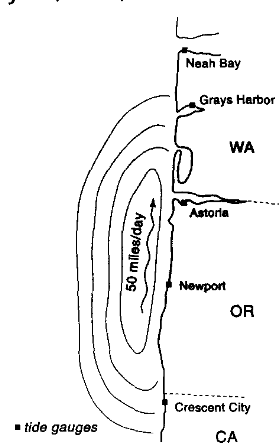


Figure 3. Schematic depiction of the sea-level wave moving northward along the Oregon coast as measured by the series of tide gauges also indicated.

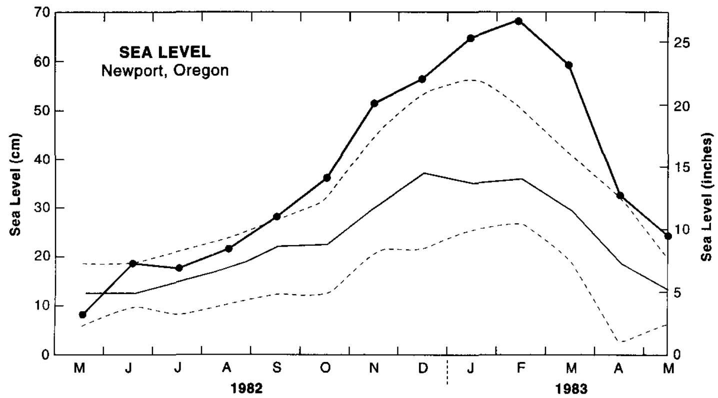


Figure 4. Monthly averaged sea levels measured on the tide gauge in Yaquina Bay, with the 1982–83 El Niño extreme levels (heavy solid line) compared with previous years. The thin solid line in the figure follows the ten-year averages for the seasonal variations, and the dashed lines give the previous maxima and minima measured at Newport (after Huyer and others, 1983).

to remove the tides, leaving the net difference between the predicted and measured tides for the month. During the 1982–83 El Niño year, sea level reached a maximum during February 1983, nearly 24 in. higher than the mean water surface in May 1982, nine months earlier.

The increased elevations in mean sea level along the Northwest coast during El Niño are only in part due to a sea-level wave originating at the equator. Other factors include changes in water temperatures along the coast and the development of a northward-flowing current. The curves in Figure 4 in part reflect the normal seasonal cycle of sea level that is produced by parallel variations in water temperatures—colder during the summer than during the winter, due to the occurrence of upwelling in the summer. The thermal expansion of the warm water of the winter raises the water level along the coast, while the cold, dense water of the summer depresses the level. There is also a reversal in current directions from winter to summer. During the winter, the current flows toward the north, and the rotation of the Earth (the Coriolis effect) deflects the current toward the right, that is, toward the coast, elevating the level of the sea along the shoreline. These processes tend to occur every year, causing sea levels along the Northwest coast to be higher during the winter than the summer. But in an El Niño year, these processes are more intense: the water during the winter is warmer than usual and the northward current stronger. So these factors add to the sea-level wave moving northward from the equator to produce the observed extreme water levels during an El Niño winter.

It is seen in Figure 4 that the 1982–83 sea levels were truly exceptional, reaching some 8–16 in. higher than previous winter maxima, about 14 in. above the average winter level. Similar analyses are underway for the 1997–98 El Niño. During January and February 1998, the measured sea levels were again 14–16 in. above the average winter level, indicating that water levels during this El Niño event reached higher elevations than during the 1982–83 event.

The water-level increase during an El Niño year along the Northwest coast is seen to be substantial, making the measured tides significantly higher than predicted (both high and low tides are elevated). For example, in the 1982–83 El Niño year, during a January 1983 storm, the highest spring tides of the month reached +12.4 ft MLLW (Mean Lower Low Water, the standard reference), 34 in. higher than the predicted tide (elevated by both the El Niño processes and the strong onshore winds of the storm). During a February storm, high tides of +10.3 ft were measured, 17 in. above the predicted level. All of these tides were exceptional for the Oregon coast, where a spring tide level of +9.0 ft MLLW is fairly representative (Komar, 1997). This elevated water level is extremely important in producing coastal erosion during an El Niño event. Beaches along the Oregon coast typically have a slope of about 1-in-50, so an increase in water level of 17–34 in., as experienced during the 1982–83 El Niño winter, shifts the shoreline landward by about 70–140 ft, drowning out most beaches at high tide. This moves the shoreline to the base of the sea cliffs or foredunes, and permits the direct attack of waves against coastal properties, in large part accounting for the extreme erosion during El Niño winters.

El Niño storm waves

Coastal property erosion usually occurs when storm waves combine with elevated water levels, and this is especially true during an El Niño event, when these processes are intensified and act to reinforce one another. During El Niño, the high-altitude jet stream in the atmosphere becomes narrow and strong and spins off cyclonic storms over the Pacific that are more intense than usual. The jet stream is also shifted further south than normal, so the storms cross the North American coast in southern California rather than in the Northwest. These storm system are important to the generation of high-energy waves, and in an El Niño year, with the shift of storms to the south, communities such as Malibu Beach in southern California have a taste of wave energies to which they are not accustomed.

Wave conditions along the Northwest coast are also intensified during an El Niño year (Komar, 1986). Daily measurements obtained during the 1982–83 event demonstrated the occurrence of several storms that generated high-energy waves, three having produced deep-water significant wave heights on the order of 20–25 ft ("significant wave height" is the average of the highest one-third of the waves). The strongest storms occurred during January and February 1983, simultaneous with the occurrence of the highest water levels (Figure 4). Given this combination, it is understandable that extensive erosion took place during the El Niño winter of 1982–83.

An intensification of wave conditions along the Northwest coast also occurred during the 1997–98 El Niño. The first major storm of the winter arrived on November 14, 1997, when deep-water significant wave heights reached 16 ft. The first substantial property erosion of the El Niño winter occurred during a storm on December 13–14. Although the wave conditions were comparable to those on November 14, the tides were higher, and the beaches had been cut back during the preceding month, allowing the waves to attack sea cliffs and dunes. Storm wave activity increased significantly in January and continued through February. During those two months, 12 storms generated waves having deep-water significant wave heights in excess of 20 ft. Far and away the largest storm occurred on January 17, when the deep-water significant wave height reached 30 ft—the waves often growing to some 35 to 40 ft in height as they traveled to the nearshore and broke on Northwest beaches.

While we observed an overall intensification of wave energies along the Northwest coast during both the 1982–83 and 1997–98 El Niño years, compared with normal years, this intensification is significant more in the frequency of storm-wave occurrences than in the absolute extreme sizes of the generated waves. The 30-ft waves of January 17, 1998, have an expected return interval of about 10–20 years and so are exceptional, while the 20- to 25-ft storm waves have return periods of roughly one year, which means that we experience waves with those heights essentially every winter. The decisive difference is that we saw more storm wave occurrences having 20- to 25-ft heights during the El Niño winters than during normal years. Higher waves can occur along the Northwest coast even during normal years, in part because the paths of storms cut directly across our shores. While extreme waves are generated by El Niño storms (Seymour and others, 1985), their impacts are felt more directly in southern California than on the Northwest coast.

Longshore movement of beach sand

An important aspect of coastal erosion in the Northwest caused by El Niño storms and the waves they generate is the southerly shift of the storm systems. The result of this shift is that the storm waves approach the Northwest coast more frequently from the far southwest quadrant, compared with normal years. This results in the northward movement of sand along Northwest beaches, which exerts a strong control on the alongshore centers of "hot spot" erosion.

Important to this control is the fact that the Oregon coast is divided naturally into a series of littoral cells, stretches of beach isolated by large rocky headlands (Komar, 1997). The stretches of beach may range from only a couple of miles to as long as 50 mi (in the case of the Coos Bay littoral cell that extends from Cape Arago in the south to Cape Perpetua in the north). There is little or no exchange of beach sand around the bounding headlands (shown by differences in beach sand grain sizes and mineralogies), so the stretch of beach within a littoral cell is largely isolated and self contained.

A schematic diagram of a littoral cell is depicted in Figure 5, contrasting the wave directions and alongshore sand movements during normal years (left) with El Niño years (right). In a normal year the summer waves dominantly approach the coast from the northwest, causing sand to move southward along the beaches, while the winter waves arrive from the south-

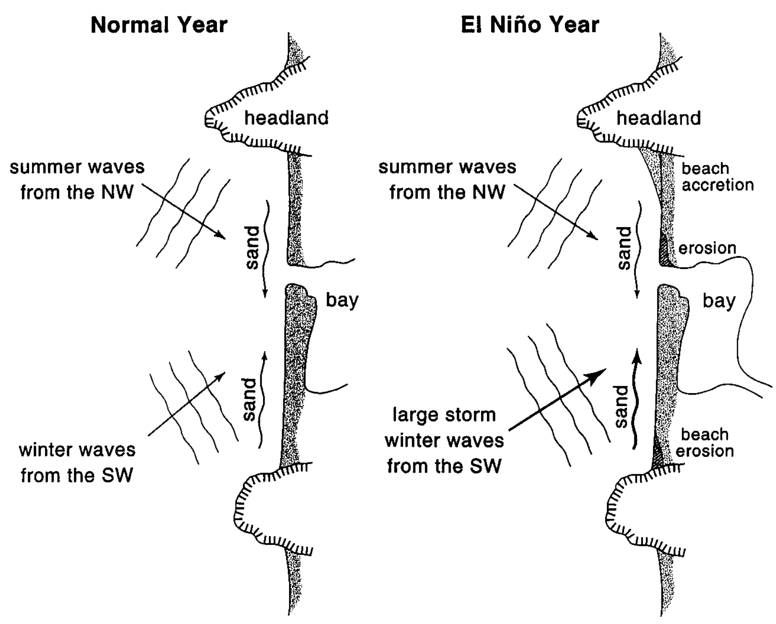


Figure 5. Schematic depiction of alongshore movement of beach sand within a littoral cell on the Oregon coast due to the seasonal shift in directions of waves approaching the coast. During normal years, there is an approximate balance of north and south sand movements, but in an El Niño year the strong storm waves from the southwest move large amounts of sand to the north, causing "hot spot" erosion as shown.

west and move sand back toward the north. Over the span of several normal years we observe an equilibrium, with approximately equal amounts of sand moving north and south. This equilibrium was seen in the shoreline changes that occurred when jetties were constructed along the coast early in the century (Komar, 1997), with a symmetrical pattern of shoreline change north and south of the jetties. In contrast to the equal north and south movements of sand in a normal year, during an El Niño event (Figure 5, right) more sand moves toward the north under the more frequent storm waves arriving from the southwest. One effect is that sand is systematically moved away from the south ends of the littoral cells, producing erosion there, while sand accumulates at the north ends, where the beaches widen.

Jetties on inlets can have much the same effect as a headland. During an El Niño year with the enhanced sand movement toward the north, the jetties block this drift, causing beach accretion to the south of the jetties, while erosion occurs to the immediate north. This pattern may be obscured in part by the seasonal cross-shore movement of sand along the beach profile: During the winter, the high waves erode sand from the dry part of the beach and transport it to offshore bars, while low waves of the summer reverse this process (Komar, 1998). Thus the actual response of the beach (net erosion or accretion) at a specific site depends on the combined effects of the alongshore movement of sand related to El Niño and the cross-shore movement associated with the seasonal cycle of beach profile change.

Natural inlets to bays and estuaries on the Northwest coast, that is, inlets not controlled by jetties, tend to migrate toward the north during an El Niño event, due to the stronger northward movement of beach sand. This can result in beach and property erosion to the immediate north of inlets, as depicted in Figure 5. The shift is temporary—during subsequent normal years, the inlets tend to migrate back toward the south.

OCCURRENCES OF EROSION DURING THE 1997–98 EL NIÑO EVENT

In the preceding section it was seen that a number of processes are involved in producing enhanced coastal erosion during an El Niño. In this section we will examine several erosional "hot spots" that occurred along the Oregon coast during the 1997–98 El Niño and attempt to understand their development in light of the processes described above.

Port Orford

The erosion at Port Orford during the 1997–98 winter illustrates several factors that are important in an El Niño year. Port Orford is a small community on the southern Oregon coast, with the center of the city situated immediately south of a headland known as The Heads. However, the community extends to the north of The Heads, and it is this area that has been experiencing severe erosion. This stretch of beach comprises a littoral cell that extends north to Cape Blanco, a distance of about 8 mi. The erosion occurred at the south end of the littoral cell and fits the normal pattern of El Niño impacts with storm waves arriving from the southwest, moving the beach sand alongshore toward the north.

The shore erosion is centered on the narrow beach/dune barrier that separates the ocean from Garrison Lake. The beach is composed of coarse sand with some gravel, is steep, and has a narrow surf zone. This type of beach erodes very rapidly when attacked by storm waves that break directly on the beach face close to shore (Komar, 1997). Prior to the El Niño erosion, extensive dunes had accumulated in this area, and the City of Port Orford had installed the drainage field for its sewage treatment system within the dunes. Erosion this winter has all but eliminated the dune field and destroyed most of the drain field (Figure 6). The threat now is that continued erosion may break through the beach/dune barrier into Garrison Lake. This lake is the principal source of fresh water for the community, and a several homes have been built along its shore and may be adversely affected by a breach. The combined elevated mean water levels and runup of storm waves from El Niño have frequently washed over the barrier into the lake. This overwash process has eroded sand from the beach and carried it over the top of the barrier and into the lake. This has had a positive effect of building up the elevation of the barrier, making it less likely that the erosion will break through and create an

Figure 6: Erosion at Port Orford, north of The Heads, during the 1997–98 El Niño event. The erosion of sand dunes has destroyed the drain field of the sewage treatment plant.

Figure 7. Erosion at Port Orford, north of The Heads, during the 1997–98 El Niño event. View is to the south from the location of Figure 6. The erosion is now threatening to break through the beach/dune barrier and wash into Garrison Lake, which is being prevented by the placement of a gravel ridge.

inlet connecting the ocean with Garrison Lake. There is still a critical area at the south end of the barrier, where the erosion is cutting back the dunes and forming a nearly vertical scarp. Although washovers of ocean water have occurred frequently in this area, they did not carry sand to build up the elevation of the barrier, as has occurred further to the north. The barrier at the south end is now very narrow, so there is the possibility that the ocean could break through into the lake. The City of Port Orford has placed a ridge of gravel and cobbles along the top of the barrier (Figure 7) to prevent further washover that, at this stage, could develop into a breach of the barrier and form an inlet. If dune erosion continues, the mass of gravel and cobbles will slough off onto the eroding dune scarp and upper beach, where its presence should provide some temporary protection from continued wave attack. It is hoped that this is a sufficient defense until the impacts of the 1997–98 El Niño end.

Alsea Spit

One of the main areas of erosion during the 1982–83 El Niño event took place along Alsea Spit on the central Oregon coast (Komar, 1986, 1997; Komar and Good, 1989). The primary factor important to erosion was the northward migration of the inlet to Alsea Bay. This inlet migration combined with elevated water levels and storm waves and completely eroded away the beach along nearly the full length of the spit. The waves and currents then began to cut back the foredunes, where a number of homes had been constructed. One house was lost, while the others were saved by the placement of riprap at the base of the eroding dunes.

In the years subsequent to the 1982–83 El Niño event, the return of lower water levels and less severe wave conditions has allowed the beach to recover along Alsea Spit. The beach has become very wide, and onshore winds have blown sand into the dunes so they had fully recovered from the El Niño erosion. Eventually the riprap revetment was covered by the accumulating dune sand, and apparently forgotten. Development began once again, and a number of new homes were build on the spit. Unfortunately, some were constructed atop and across the now buried revetment, seaward of this line of defense, in the area where erosion had occurred only a decade earlier.

The return of El Niño during the winter of 1997–98 has brought about a recurrence of erosion processes and problems on Alsea Spit. Older homes landward from the line of riprap placed in 1982–83 are likely safe from the renewed attack, but the newly constructed homes that extend seaward from the riprap line are now in danger. It is possible that another line of riprap will have to be installed to protect those homes.

Cape Lookout State Park

Another area of significant erosion during the 1982–83 El Niño event occurred at Cape Lookout State Park on Netarts Spit (Komar, 1997; Komar and others, 1988; Komar and Good, 1989). This park is located at the south end of the Oceanside littoral cell, so again much of its erosion can be attributed to the northward transport of sand by the approach of high storm waves from the southwest during El Niño, moving sand toward the north. Much of this sand has disappeared from the beach, apparently carried into Netarts Bay. The reduction of sand volumes on the beach along this littoral cell now makes the beach more susceptible to attack by waves, during normal years as well as in an El Niño event. Another factor in the erosion during the 1982–83 El Niño event was the presence of a large rip current flowing seaward from the area of the park, carrying sand offshore, and contributing to the local erosion. Erosion in the park partially destroyed an old log seawall and then eroded away the high ridge of dune sand that had sheltered the park development.

Erosion of Cape Lookout State Park during the 1997–98 El Niño year has essentially picked up where the 1982–83 event left off (Figure 8). The last remnants of the log seawall are rapidly disappearing, leaving the tall iron beams that had supported the logs sticking up from the beach—the beams remaining after the 1982–83 erosion were cut off by the Parks and Recreation Department. Additional dune erosion has occurred, and

Figure 8. Recent erosion at Cape Lookout State Park on Netarts Spit has cut back the large coastal dunes and is now eroding the campground.

the public bathrooms were in danger of being undermined by waves until a line of riprap was placed for protection. High water elevations have combined with storm wave runup to wash over into the park lands, depositing a large amount of beach sand in the campground. Such extensive washovers did not occur during the 1982–83 El Niño event.

The Capes

Most dramatic and newsworthy during the 1997–98 El Niño year has been the erosion at The Capes, a development consisting of expensive condominiums recently built on the high bluff to the immediate north of the inlet to Netarts Bay (Figure 9). The site is centered within the Oceanside littoral cell, about 6 mi north of Cape Lookout State Park. Erosion at The Capes is dramatic not only in its potential economic impact for the home owners, but also with regard to the number of coastal hazards involved.

Since the condominiums are situated immediately north of the inlet to Netarts Bay, the northward migration of the inlet during the 1997–98 El Niño winter has acted to erode the fronting beach and has created deepened water directly offshore. Normally, the low-sloping beaches in this littoral cell cause the waves to break well offshore, so that most of their energy is dissipated before they run up on the beach face at the shore (Komar, 1997). With the creation of deeper water due to the migration of the inlet, the waves can now travel closer to shore before breaking and lose less energy in the process. The runup of the stronger waves now combines with the elevated mean water levels associated with El Niño, allowing the runup to reach the toe of the high bluff below The Capes. The resulting toe erosion has made the bluff unstable, and slippage of the land now poses the immediate threat to the front line of condominiums (Figure 10). Unfortunately, the condominiums had been constructed with only a 10-ft setback distance—insufficient, considering the potential for erosion and instability of the site. So now many of the homes have immediately been placed in danger.

The development site is located atop an old massive landslide. The lower portion, now exposed by the toe erosion, consists of a layer of mud that is extremely mobile. Rather than participating in the rotational slippage typical of many landslides, this mud appears to be squeezed out like toothpaste by the weight of the overlying material. This overlying material is sand of old dunes deposited atop the bluff—sand that has minimal internal strength, so that it tends to cascade downslope, much like the loose sand of an active modern dune. Thus, only part of the problems at The Capes can be attributed to the occurrence of El Niño and its erosion processes. The preexisting hazardous conditions are that the development was constructed on a landslide, the upper part of which consists of dune sand. The present instability and movement of the landslide can, however, be attributed to the 1997–98 El Niño occurrence and its erosional impact, which has cut away the toe of the landslide.

Figure 9. The Capes, north of Netarts Bay, is a recent development of condominiums, located on the edge of an old massive landslide.

Figure 10. Homes at The Capes. Erosion of the toe of the landslide during the 1997–98 El Niño winter has caused the slide to become unstable, and slippage is threatening the first line of homes.

CONCLUSION

The Northwest coast now has experienced two major El Niño events, in 1982–83 and again in 1997–98. Both have resulted in substantial beach erosion and damage to or loss of coastal properties. Although data from the recent event are still being collected and analyzed, the evidence thus far is that the processes are very similar to those which occurred during the 1982–83 El Niño event. Important to coastal erosion are the elevated water levels that cause tides to be 1–1.5 ft higher than predicted, the generation of high energy waves by more frequent storms, and the fact that the waves approach the coast more from the southwest, causing a northward movement of sand that redistributes beach sand volumes along the coast and causes inlets to migrate toward the north. It is the combination of these processes and the fact that they reinforce one another that accounts for "hot spot" erosion areas along the Oregon coast such as at The Capes.

At the time of this writing (April 1998), El Niño is continuing but it looks as if it is decreasing and will likely soon come to an end. Water temperatures and sea levels in the equatorial Pacific are returning to more normal levels. The same can be expected off the Northwest coast. As discussed above, wave energies along the coast abruptly declined at the end of February, following the usual pattern of decreasing wave conditions in the summer (Komar, 1997). The eroded beaches have noticeably begun to rebuild. So additional property erosion is unlikely, at least through the summer. But we may not have seen the last of the impacts that can be attributed to El Niño of 1997–98. Following the 1982–83 event, significant erosion took place during subsequent winters, returning to the areas that had eroded during the El Niño winter. The processes directly associated with El Niño had ceased (unusually high water levels, etc.), but the beaches were unable to fully recover during the following summer. Sand that had been shifted far offshore to deep water did not completely return to the dry beach, and sand moved alongshore to the north within the littoral cells did not all shift back to the south. So when the next winter returned with its high storm waves, the beaches still depleted of sand were not able to adequately buffer coastal properties, so that erosion began once more. It took two to three years before the beaches finally recovered and the lingering impacts of the 1982–83 El Niño event finally ended. It remains to be seen whether history repeats itself and whether or not we have seen the last of El Niño 1997–98.

ACKNOWLEDGMENTS

I wish to thank Dr. John Marra, Prof. William McDougal, Dr. Peter Ruggiero, and Mr. John Stanley, who are involved in investigations of El Niño erosion problems with me, or have provided me with wave and water-level data. I am grateful for their assistance.

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(Continued on page 70)

Slope stability at aggregate mines in Oregon: Regulatory requirements and selected case histories

by E. Frank Schnitzer, Reclamationist, Oregon Department of Geology and Mineral Industries

This paper is a contribution to *Environmental, Groundwater, and Engineering Geology: Applications from Oregon*, edited by Scott Burns, Portland State University, and published 1998 in coordination with the Association of Engineering Geologists (AEG) as AEG Special Publication 11 by Star Publishing Company, Belmont, California (available from the Nature of the Northwest Information Center). We are printing it here by permission, with minor editorial changes, and apologize for the low quality of the figures for which the originals were unavailable due to circumstances beyond our control. —*ed.*

I.

The Oregon Department of Geology and Mineral Industries (DOGAMI) administers the Mined Land Reclamation Act passed in 1971 by the Oregon Legislature (ORS 517.750–517.992). In the policy statement enacted by the legislature, mineral extraction was recognized as making an essential contribution to the economic well-being of the state. Policy directs DOGAMI to allow mining and to protect natural resources during and after mining through reclamation of undesirable conditions. DOGAMI's authority exists for all types of surface and underground mining on lands under private, state, and federal ownership. The following discussion pertains exclusively to aggregate mines and includes all commodities except coal and precious metals. Federal law requirements for waterways and other federally protected lands such as the Columbia River Gorge Scenic Area are not discussed.

The Reclamation Act is implemented through the issuing of an operating permit that requires an approved mining and reclamation plan plus financial security based on the actual cost of reclamation. An application for a mine requires an on-site inspection by a reclamationist who is to evaluate the environmental conditions at the site and the adequacy of the proposal. A draft permit is then prepared and is circulated with the application to appropriate local, state, and federal agencies. Comments from these agencies are reviewed, and revisions are incorporated into the final permit as attached conditions.

Certain activities require state and local agencies to issue separate permit approvals. All necessary approvals are listed in Table 1 below. Permits or approvals are not required by the Oregon Department of Fish and Wildlife (ODFW). However, ODFW provides expertise and participates in the permit decisions at the time the siting decision is made by the county or city and also when the individual state agency approvals are issued.

The DOGAMI-issued operating permit requires approval of a reclamation plan submitted by the mine operator. Reclamation plans determined to be complete can be further modified or restricted by conditions of approval attached to the operating permit issued by DOGAMI. Reclamation plan requirements also include mine development issues such as soil salvage and storage, storage of mine waste, mine sequence, mine dewatering, maximum depth, backfilling and slope reconstruction, and interim and final slope angles.

After mineral extraction is completed (or concurrently with mining if practicable), reclamation of the disturbed areas is required and must be compatible with local zoning. In most cases, the site is reclaimed to upland or aquatic habitats. Minimum reclamation requirements include stable revegetated uplands and gently sloping pond banks.

II.

Unloading and loading slopes are two common mining activities that often lead to instability problems. Regulation of these activities is handled on a case-by-case basis during the permit approval process. For an application for an operating permit, ORS 517.790 (1) allows DOGAMI to customize information requirements on an application for an operating permit by requiring that the applicant submit specific information considered pertinent by the department.

The DOGAMI permits are not static approvals. If field inspections indicate that a potential or existing

Table 1. *Agency permits for aggregate mines in Oregon*

Permit type	Regulatory agency
Water rights	Water Resources Department
Air quality	Department of Environmental Quality
Water quality—process wastewater/storm water	Department of Environmental Quality
Fill/removal—in wetlands or streams	Division of State Lands
Mine zone designation or conditional use	County or local zoning authority
Scenic waterway	State Parks and Recreation Department
Operating	DOGAMI

slope stability problem is present, the permit can be modified by attached new requirements. These new requirements can be attached to preexisting permit approvals for protection of natural resources and reclamation during the life of the mine. This is frequently the case with many of the more than 800 commercial aggregate mines in the state.

Regulations provide general requirements on the angle of slopes left after mining (ratio of 1½ horizontal [H] to 1 vertical [V] = 1½H:1V on cut slopes and ratio of 2H:1V on fill slopes). DOGAMI has authority to allow steeper or require flatter final slopes. If a natural resource protection or reclamation concern exists, DOGAMI may attach conditions to the permit to regulate slopes, both those cut during mining and final slopes.

For new sites or boundary expansions of existing sites, the requirements for a slope stability evaluation or engineered design and construction for a mine cut or disposal area are determined through permit application review or field inspection. The statutes allow DOGAMI to make site-specific requests for additional data collection based on site characteristics. During both field and office reviews, DOGAMI receives assistance from specialists in other agencies.

In addition to reclamation plan forms, regulations, and statutes, guidelines were developed in 1995 to assist applicants and staff reclamationists. The guidelines list the types of additional baseline data that may be needed prior to permitting. They were written with the recognition that some sites inherently present a greater risk to natural resources than others and require more data collection and analysis prior to permit approval to provide sufficient certainty in natural resource protection. The guidelines were developed with review and input by state agencies, aggregrate operators, and consulting firms.

With respect to slope stability, these guidelines request a written plan to explain how the resource will be protected in situations where downslope risk to waters of the state is high or the probability of slope failure is high. The necessary information may range from a report describing preexisting conditions (springs, slumps, hummocky terrain, and ancient landslide features) to a geotechnical investigation and design.

The DOGAMI guidelines include parameters to evaluate the downslope risk to waters of the state. Table 2 shows the parameters determining high risk for slopes.

Complete information is often unavailable during the development stages of a quarry. As a site is mined, site conditions may change, or additional information may become available. The performance-based standards in the DOGAMI regulations allow a more flexible response to changing conditions than rigid construction-based standards for each activity or mine. This flexible regulatory approach relies on a field inspection program and operator cooperation to recognize and correct situations before they become problems.

III.

The following text discusses three case histories of aggregate mines that illustrate the application of Oregon's reclamation program.

Mosier Quarry

This is a basalt quarry site where mining began in the 1950s to help build the Columbia River Highway. It is located 75 mi east of Portland in Wasco County. Ownership at the site includes both public and private property. The quarry properties cover lands located in the City of Mosier urban growth boundary and within the Columbia River Gorge National Scenic Area and encompass several hundred acres (Figure 1).

The quarried areas are situated in the Pomona Member of the Columbia River Basalt Group and consist of talus deposits in ancient landslide terrain.

Intermittent mining by the Oregon Department of Transportation (ODOT) over the last several decades on the public property has caused slope movement. The effect of the slope movement is the formation of a head scarp in the talus and exposure of unweathered angular basalt blocks. This is considered a visual impact that should be avoided, because the scarp can be seen from key viewing areas within the boundaries of the National Scenic Area.

A large basalt block, 190 ft thick, has separated from the ground above. The block is sliding on a thin interbed of volcanic tuff. Mining occurs on the talus material below the block.

No potential impacts to other natural resources exist as a result of the current slope movement or the risk of continued slope movement. An intermittent stream is on ODOT property, and the Columbia River is nearby, but the amount of erodable fines present and the potential for erosion are both minimal.

In 1993, the owner of the private quarry section

Table 2. *Guideline parameters for high downslope risk to waters of the state*

Slopes	Fills of waste rock, overburden, or soils	Depth of cuts in rock steeper than 1½H:1V	Depth of cuts in soil
>60%	>2 ft	>20 ft	—
>30%	>25 ft	>100 ft	>20 ft
15%–30%	>25 ft or any storage within 300 ft of a stream	—	—

Figure 1. Mosier Quarry properties, aerial view to the east. Aggregate mining on ODOT property developed headscarp right of center. Photo courtesy of Landslide Technology, Division of Cornforth Consultants, Inc., Portland.

requested that Wasco County authorize land use approval to renew and expand the mining area on the talus slope below the basalt block. Because of the issues surrounding this site, Wasco County officials requested DOGAMI participation in the land use hearings. DOGAMI advised that the site could be safely mined if the mine plan was sequenced and designed to address geotechnical issues. Land use approval was conditioned on DOGAMI approval of a mine plan that was technically feasible and would protect visual resources.

The National Scenic Area boundary runs across the upper part of the talus slope and the block that has slid. Consequently, impacts of mineral extraction must be confined to the property below or outside the scenic boundary. The mine company hired an engineering firm. Borings recently completed on the ODOT property were studied. Additional borings were performed, and inclinometers were installed on the private parcel. A phased extraction and reclamation plan using calculations of slope stability was developed to minimize the risk of slope stability problems. The plan requires excavation of a key trench to penetrate through a clay interbed and replace it with higher strength rock. This allows removal of the talus below the key and protects the slope above.

Cochran Quarry

The Cochran Quarry is located near a former historic sawmill site with the same name west of Timber in the Coast Range in western Washington County. This 98-acre parcel is situated adjacent to the Port of Tillamook Bay railroad. The rail runs between Tillamook and Hillsboro. In 1991, Washington County determined the quarry parcel to be a significant mineral resource and zoned it for mining. The quarry is situated in the Tillamook Volcanics. Pennoyer Creek, a perennial tributary to the Salmonberry River, flows below the site and the rail line. The Salmonberry River is rated by some as having the largest remaining stocks of native sea-run cutthroat trout in the state.

Seeps occurring where the quarry's storm water retention ponds were to be constructed had been mapped as wetlands. Approval for wetland fill was obtained from the Division of State Lands. Approval for the pond design and construction was obtained from the State Department of Environmental Quality (DEQ). The Salmonberry River, located several miles downstream from the pond discharge point along Pennoyer Creek, needed protection as an important fish habitat. To provide such protection, DEQ required that the ponds be designed to accommodate heaviest storm runoff (a 100-year/24-hour event). However, in designing the appropriate ponds, the design engineers hired by the mine company may not have considered slope stability conditions.

State agency approvals were obtained to begin construction in the fall of 1992, and mining began in 1993. Crushed rock was railed into the Portland market during 1993 and 1994.

In November 1994, tension cracks appeared in the crusher site area. In the winter of 1995, the site showed slope movement that was interpreted by a DOGAMI geotechnical investigation to be the reactivation of an ancient "slump earth flow" landslide feature. The storm water retention ponds located at the debris runout portion of the ancient landslide appeared to increase the risk to slope stability. Quarry operation was halted, and the operator was required to provide geotechnical data, dewater the storm water retention ponds and redirect storm water flow.

In the resulting geotechnical investigation, several borings were drilled and inclinometers and piezometers installed that confirmed and defined the reactivated landslide. The storm water retention ponds were viewed by DOGAMI as the first order of concern for protecting Pennoyer Creek. Draining of the ponds seems to have improved slope stability at the site.

As landslide features developed at the site, the crushing plant was removed. The mine company monitored

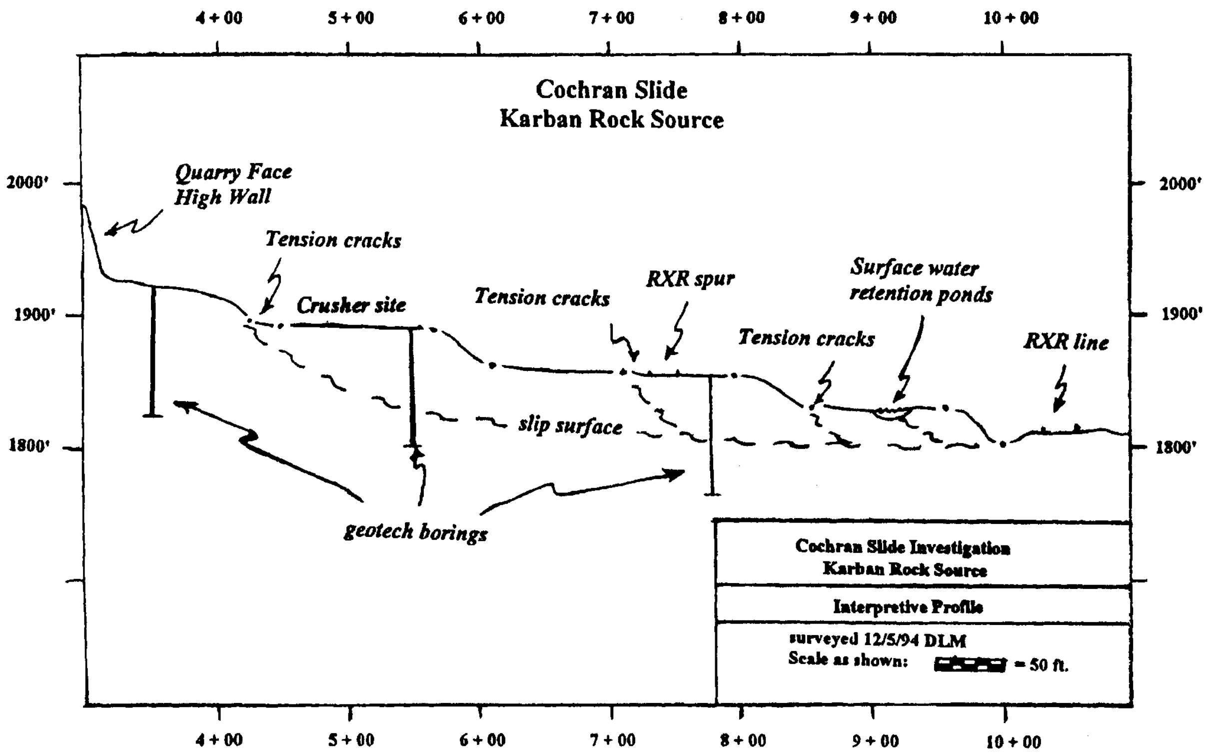

Figure 2. Section profile of slope movement at the Cochran Quarry. Figure drawn by Dave Michael, Oregon Department of Forestry.

the site and maintained equipment and materials for storm water and erosion control work. Slide movement affected the crusher pad, a reject storage area west of the crusher, the storm water retention ponds and ditches, the load-out facilities along the rail spur, and the main railroad line.

The slide halted year-round production at the site. Since 1994, this approximately 20-acre site is used only for short-term, small-scale crushing projects during the summer. During the summer of 1996, the original storm water retention ponds were removed, and the land was reclaimed. Year-round production is not possible until newly located storm water retention ponds are designed and built.

The storm water retention ponds had been located immediately upslope from the railroad main line. Cochran Pond and Pennoyer Creek are located on the opposite side of the railroad line. Periodic episodes of sedimentation have reached Pennoyer Creek. However, measurable amounts of sediment were not found in the creek channel downstream from the operation. Since fish cannot migrate up Pennoyer Creek because they are stopped by a waterfall, impacts to the sea-run cutthroat were likely minimal.

American Sand and Gravel

Sand and gravel extraction and processing began at this site in the early 1970s. The 92-acre property is located near Barton in Clackamas County. The gravel source is an elevated terrace above the Clackamas River valley. Water draining from the site enters an unnamed tributary to Deep Creek, which then enters the Clackamas River 3–4 mi below the site. The Clackamas River is a protected scenic waterway at this location.

The mine is situated in the Troutdale Formation, a series of interbedded layers of gravel, sand, and silt. At this location, it has a gravelly seam about 100 ft thick. The gravels have an overburden layer of silts and clays that ranges up to 40 ft in thickness. Below the Troutdale Formation lies the Sandy River Mudstone. This lower formation is a fine-grained rock that tends to be an impermeable barrier to groundwater. At the contact between the two formations along the Clackamas River valley wall, seeps and springs are found.

These seeps and springs are located on the terrace escarpments, and wetlands occur on the flatter slopes below. The steep terrace escarpments are characterized by debris-flow and debris-avalanche landslide areas and talus slopes. Because of these features, the 1979

Figure 3. Slope failure at American Sand and Gravel site below processing area. Impacted wetlands located in background. Photo taken in 1993 by E. Frank Schnitzer.

DOGAMI Bulletin 99, *Geology and Geologic Hazards of Northwestern Clackamas County*, mapped the escarpments as landslide hazards.

This site has had a history of slope stability problems. The unstable slope conditions that had existed before any mining activity were exacerbated by such past mining practices as sidecasting overburden over the outslopes, creating fills, building ponds, or otherwise ponding water on fill slopes.

In the late 1970s, DOGAMI inspected the site, noted unstable slope conditions, and ordered ponds removed from fills on the outslopes. Through most of the 1980s, Clackamas County regulated the site under delegated authority from the DOGAMI Mined Land Reclamation Program. DOGAMI reassumed regulation of the site from Clackamas County in 1991. At that time, several slides were present on the slope below the operation, and sediment was polluting the unnamed tributary to Deep Creek.

After the reclamation bond was increased from $10,000 to $140,000, the operating permit was issued by DOGAMI in 1992. Within a short time, the permittee violated the permit by sidecasting overburden in a landslide hazard area. In January 1993, DOGAMI issued a "Closure Order," which resulted in the shutdown of the operation plus reclamation and interim stabilization of approximately 10 acres.

The area where overburden was illegally sidecast had experienced slope stability problems and remained unstable. Lack of access and the potential for destabilizing unaffected areas on steep slopes led to the decision not to unload the slope with earth moving equipment. Most of the sediments eroding from this area were trapped in a bermed wetland adjacent to the unnamed drainage. The wetland was covered by a reclamation plan and bond.

In 1995, a new operator leased the processing site and proposed to mine the nearly level ridge top (0- to 10-percent slopes) above the terrace escarpments. For this proposal, baseline data requirements included three borings in the expansion area, so that information on the angle of the contact between the Troutdale Formation and the Sandy River Mudstone could be obtained. During the summer of 1996, three borings were completed with conventional water-well drilling equipment. The drilling data suggest that the contact in the expansion area slopes toward the west and the existing processing site and away from the terrace escarpments.

In 1997, wild fish tagged by the Oregon Department of Fish and Wildlife (ODFW) were observed passing by this site as they went up the Deep Creek channel to seek out another tributary for spawning. In the interest of habitat protection, DOGAMI expressed concerns about resumption of mining at this site. DOGAMI permit conditions were written with certain restrictions to mining and processing activities: They had to provide the assurance that downstream water quality would be protected during mining and reclamation and that the existing unstable slope conditions would not be aggravated by additional mining or storage of overburden or water. The applicant was required to obtain a geotechnical evaluation of the slope above the processing site and its potential to affect Judd Road that runs along the north boundary of (and below) the site.

Prior to approval of the current plan, negotiated agreements between DOGAMI and the mine company specified restrictions to protect slope stability. Future mining will occur on a cutslope ranging from 2H:1V to 3H:1V. All overburden stripped in the expansion area will be hauled away from the site. With no loading in the expansion area, the probability of failure is now low. However, even though the risks are low, visual monitoring of the area will continue during future inspections of the site. Due to the slope stability concerns, the operator is prohibited from using recognized unstable areas for storage of rejects or aggregrate. The operation is also required to shut down if turbidity levels in the creek violate DEQ standards. □

DOGAMI PUBLICATIONS

Released May 1, 1998

Geologic map of the Tucker Flat quadrangle, Union and Baker Counties, Oregon, by Ian P. Madin. Geological Map Series GMS–110, scale 1:24,000, $6.

Index to geologic maps of Oregon by U.S. Geological Survey topographic quadrangle name, 1883–1997, by Peter L. Stark, rev. by Ronald P. Geitgey and Klaus K.E. Neuendorf. Open-File Report O–97–33, 65 pages, $6.

Mined Land Reclamation Program status map, Douglas County, Oregon. Oregon Department of Geology and Mineral Industries MLR Status Map 10, scale 1:250,000, $10.

Mined Land Reclamation Program status map, Marion County, Oregon. Oregon Department of Geology and Mineral Industries MLR Status Map 24, scale 1:250,000, $10.

The two MLR status maps are the first of a set planned for all counties of the state, with annual updates. They show all mining sites contained in the database record of the Mined Land Reclamation Program, differentiating between open and closed sites, various types of reclamation requirements, and nonmetal and metal mining sites. The overall status of the program is indicated by acres of land reclaimed and acres subject to reclamation. Completion of the map set is planned in increments of two maps per month. □

(Continued from page 64)

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Editor's note

The author, Paul D. Komar, has just published a new book in which he describes and discusses comprehensively the processes and forces that shape and change the coastline of the Pacific Northwest.

This book, ***The Pacific Northwest coast: Living with the shores of Oregon and Washington***, is now available from the Nature of the Northwest Information Center for $18.50 (plus $3 for shipping).

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