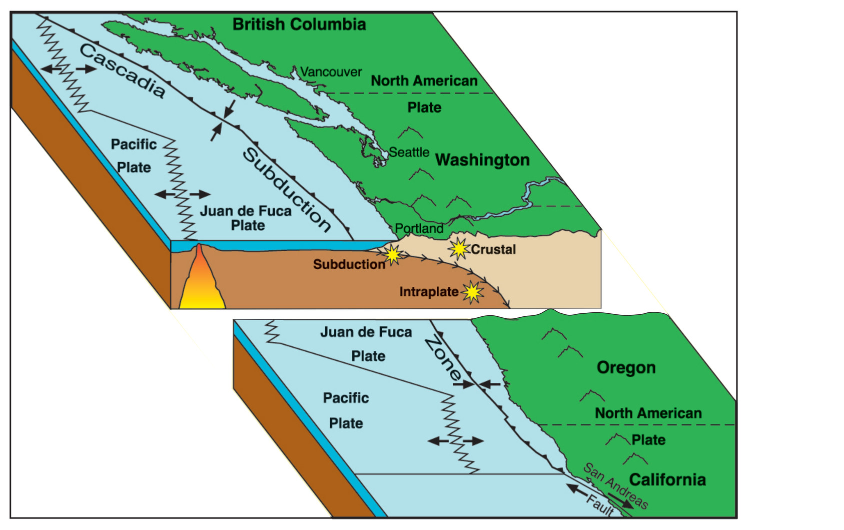

Figure 1. Schematic diagram showing the regional plate tectonic setting of the Pacific Northwest. Cross section shows the location of the three seismic source zones: subduction, intraplate, and crustal faults. (Modified from Black and others, 2000.)

INTRODUCTION

The Interstate 5 highway (I-5) corridor, which stretches from Mexico to Canada, is both the main economic artery of the Pacific Northwest and home to the majority of Oregonians and Washingtonians. Accordingly, most regional utility and transportation systems have major components located within the I-5 corridor. For the purposes of this map, we refer to these essential systems as lifeline systems. The Pacific Northwest section of I-5, the I-5 urban corridor, extends from Eugene, Oregon, to the border of Canada. The population of this region is rapidly increasing with the bulk of growth and economic development centered in the cities of Eugene, Salem, and Portland, Oregon, and Olympia, Tacoma, Seattle, Everett, and Bellingham, Washington.

Lifeline Systems in Earthquake Country

Economic success in the I-5 urban corridor heavily depends on critical lifeline systems, such as highways, railroads, pipelines, ports, airports, communications, and electrical power. Natural disasters that disrupt these lifeline systems can cause substantial economic losses. For example, if during a major winter windstorm, falling trees break power lines and disrupt electrical systems causing loss of power at smaller distribution substations. Subsequent widespread power outages will affect businesses and hundreds of thousands of residents. Larger scale natural disasters, such as earthquakes, present more complex challenges because they tend to affect and disable many lifeline systems at once. For example, failures in the highway system after an earthquake may make restoration of critical electrical power substations or sewer treatment plants more difficult. As a result, determining priorities and strategies for recovery becomes increasingly difficult due to the potential simultaneous failures of several systems.

As the 2001 Nisqually earthquake reminded us, Washington's Puget Sound region is earthquake country. Large-magnitude, damaging earthquakes struck Olympia in 1949 and Seattle in 1965, and the 2001 Nisqually earthquake occurred very near the epicenter of the 1949 event. In addition to these large events, smaller magnitude earthquakes are felt in the Puget Sound region about once a month. In contrast, the southern part of the I-5 urban corridor, between Eugene and Salem, Oregon, has experienced very few felt earthquakes this century. However, during the last decade earth scientists have uncovered evidence that suggests the entire I-5 urban corridor, from Eugene to Vancouver, B.C., is at risk from great off-shore subduction zone earthquakes, perhaps as great as magnitude 9.

Lifelines Systems and Earthquake Hazards

Understanding where major lifeline systems are located in relation to earthquake hazards and population centers is an important first step in developing mitigation strategies that can make the I-5 urban corridor lifeline systems more earthquake resistant and expedite economic recovery after an earthquake. Lifeline systems are complex multi-layered networks that cross through many communities and regions of varying levels of earthquake hazards.

To meet the need for an integrated graphical representation of lifeline systems, geology, and earthquake hazards, the U.S. Geological Survey (USGS), in cooperation with public agencies and private companies, developed a series of maps of the I-5 urban corridor for planners, emergency response providers, elected officials, and other people who live and work in this area. We divided the I-5 urban corridor from Cottage Grove, Oregon, to the U.S.- Canada border into four regions. This map covers the region between Cottage Grove at the southern end of the map to Woodburn, Oregon, to the north, and provides an overview of the lifeline systems and the corresponding earthquake hazards.

The lifeline systems and geology shown on the map are greatly simplified. Most systems are shown in a general way for graphical purposes and may not be accurate in detail. In several locations where one system overlies another, the map symbols have been adjusted so that the systems are more distinctly visible. The surface geology also has been simplified to show regionally consistent geological characteristics throughout the entire study area of other maps in this series (Cottage Grove, Oregon, to Vancouver, British Columbia). Therefore, this map should not be used for any site-specific purpose. Any site-specific consideration will require more detailed geotechnical and geological data than are presented in this map.

The shaded-relief base map depicts the topography over which regional geology is draped. Individual geologic studies (see Explanation, front of map) are compiled, generalized, and the data categorized as areas probably less hazardous (light green) or probably more hazardous (beige) in the event of an earthquake. Simplified lifeline systems that are superimposed on the geological base and featured include: major electric power transmission lines, water supply pipelines, major sewer pipelines and treatment plants, liquid fuel pipelines, natural gas pipelines, and major ports and airports. Also shown are recent earthquakes of magnitude 2.0 and larger and historically important earthquakes estimated to be larger than magnitude 5. In the map area, the only seismic event known to be greater than magnitude 5 is the magnitude 1993 5.7 Scotts Mills earthquake east of Salem.

GEOLOGY AND EARTHQUAKE HAZARDS

Despite the lack of recent, large, damaging earthquakes, earth scientists now understand that earthquake hazards in the Willamette Valley are greater than previously known. This may seem at odds with the experience of long-time residents who can recall only the large earthquakes farther north in Olympia in 1949 and Seattle, Washington, in 1965; in contrast, Oregon is relatively quiet. The Nisqually earthquake on February 28, 2001, only seemed to further highlight the Puget Sound area of Washington as the region more exposed to earthquake hazards. However, two earthquake source regions in Oregon have drawn the attention of earth scientists: the Cascadia subduction zone and shallow crustal faults. In the early 1990s, scientists reached a broad consensus that geologic evidence supports the history of great subduction zone earthquakes of magnitude 8 to 9 that on average strike the Oregon coast every 500 to 600 years and shake the western interior of the state. In addition, earth scientists are beginning to develop an understanding of shallow faults near the earth's surface that may further influence earthquake hazard assessments for this part of the I-5 urban corridor. The growing understanding of these two fault zones sharpens awareness of earthquake hazards in the Willamette Valley.

Geologic Setting

Pacific Northwest earthquakes occur in three source zones: along the Cascadia subduction plate boundary, within the subducting plate (called the intraplate or Benioff zone), and within the crust of the overlying North American Plate (fig. 1). Earthquakes from all three zones threaten the Willamette Valley.

Cascadia Subduction Zone

The forces that produce earthquakes in western Oregon are generated as the Juan de Fuca oceanic plate moves northeastward with respect to the North American continent at an average rate of about 4 centimeters (1.5 inches) per year along the Pacific Northwest coast (figs. 1 and 3). At the zone of contact between the North America and Pacific Plates, the Juan de Fuca Plate slides (or subducts) beneath the North American continent and sinks slowly into the earth's mantle, producing the Cascade volcanoes and earthquakes. The zone of the shallow, east-dipping subducting plate is called the Cascadia Megathrust fault (fig. 3). During subduction, the eastward motion of the Juan de Fuca Plate is absorbed by compression of the overriding North American Plate, generally resulting in little slip on the Cascadia Fault. However, geological evidence provided by buried soil layers, dead trees (Atwater and Hemphill-Haley, 1997; Jacoby and others, 1997; Benson and others, 2001), and tsunami deposits (Nelson and others, 1995; Kelsey and others, 2002) indicate that about every 500 to 600 years, the upper portion of the shallowly dipping Cascadia Fault ruptures offshore and releases this compression and causes great earthquakes of magnitude 8 to 9. The last such earthquake occurred on January 26, 1700 (Atwater and others, 2005) (fig. 3).

When the Cascadia subduction zone ruptures, it will likely cause:

1) Severe ground motions along the coast, with shaking in excess of 0.8g peak horizontal acceleration in many locations, as shown in figure 4 (Frankel and others, 1996; 2002; Peterson and others, 2008). The unit 1g is the acceleration of gravity and is used as a measurement of the severity of earthquake ground motion). The central Willamette Valley can expect ground motions of about 0.2g in the areas of less hazardous geology (light green regions on map). Shaking levels will be greater westward toward the coast (fig. 4);

2) Strong shaking that can last for two to four minutes as the earthquake propagates along the fault and long-period seismic waves that can affect very tall structures and high bridges;

3) Shaking effects that can significantly damage the regional lifeline systems in all of Cascadia's major population centers, from Vancouver, B.C., to Eugene, Oregon;

4) Tsunamis that are generated by sudden uplift of the sea floor above the Cascadia Fault. Effects of past tsunamis have recently been mapped and include marine sediments deposited inland and ancient drowned forests.

Intraplate Zone

As the Juan de Fuca Plate subducts beneath North America, it becomes denser than the surrounding mantle rocks and breaks apart under its own weight creating earthquakes within the Juan de Fuca Plate. Beneath Puget Sound, the Juan de Fuca Plate reaches a depth of 40 to 60 km and begins to bend even more steeply downward, forming a "knee" (see cross section in fig. 1). The knee is the location where the largest intraplate zone earthquakes occur, such as the 1949 and 2001 events beneath Olympia, Washington, and the 1965 event beneath the Seattle-Tacoma International Airport in Seatac, Washington.

The same mechanisms that cause deep earthquakes beneath the Puget Sound in Washington may be active in Oregon. The lack of significant historic intraplate seismicity beneath western Oregon makes it difficult to assess the potential hazards. However, although there have been a few intraplate earthquakes beneath the Coast Range and Willamette Valley, there is one notable event. In 1963 a magnitude 4.6 intraplate earthquake occurred near Mary's Peak, northwest of Corvallis, Oregon. This is the most southerly known intraplate event of this size in Oregon.

We do know that intraplate earthquakes have several distinctive characteristics. Because intraplate earthquakes occur at depths of 35 kilometers or more, the high frequency ground-motion energy attenuates before it reaches the earth's surface. Therefore, on rock, peak ground accelerations are expected to be about 0.2g to 0.3g, for even the very largest earthquakes. However, we note that 0.2g shaking level can cause substantial damage to poorly built structures and the shaking can be amplified in shallow, soft soils. Also, intraplate earthquakes tend to be felt over much broader areas than crustal zone earthquakes of comparable magnitude. Finally, based on earthquake studies in the Puget Sound region, significant aftershocks are not expected for intraplate earthquakes beneath western Oregon.

Crustal Zone

The third earthquake source zone is the crust of the North American Plate. Crustal zone earthquakes are typically small magnitudes, relative to subduction zone earthquakes, and usually are not felt. These earthquakes are the most common in western Oregon. The magnitude 5.6, 1993 Scotts Mills earthquake (map and fig. 2) is the largest known crustal zone earthquake in western Oregon occurring since a crustal event estimated to be magnitude 6.8 occurred in 1873 near the coast at the California-Oregon border. Most of the larger events plotted in figure 2 are aftershocks of the Scotts Mills earthquake.

There are many mapped faults in the Willamette Valley thought to be active during the Quaternary, or last two million years (fig. 2; and see U.S. Geological Survey Quaternary Fault Database, http://earthquake.usgs.gov/regional/qfaults/). However, for most of these faults, not enough is known to estimate how often the faults have ruptured during the past 10,000 years and what magnitude earthquakes could occur. Consequently, the hazards from shallow crustal earthquakes are poorly understood. Yeats and others (1996) noted that most of the mapped faults typically consist of short segments that strike largely either northwest or northeast. It is not clear whether some of the faults we have highlighted in figure 2, such as the Corvallis and Waldo Hills Frontal Faults and the Mill Creek Fault, might be part of a larger fault system or behave individually. The proximity of the Scotts Mills earthquake to the Mt. Angel Fault (fig. 2) has led some earth scientists to suggest that the fault is active, although the rate of surface-faulting events or the maximum size earthquakes to be expected has not been determined (Blakely and others, 2000). There also are questions whether the Mt. Angel Fault might connect with the Gales Creek Fault to the northwest thus providing a longer earthquake source area of the combined faults (Blakely and others, 2000). Ground motions from crustal earthquakes of moderate size, magnitude 6 to 6.5, can produce strong shaking on rock exceeding 0.4g that can have major effects on buildings and lifelines. Therefore, better understanding of the mechanisms and possible activity of the crustal faults in western Oregon is important in lowering the uncertainty in earthquake hazard assessments.

LIFELINE VULNERABILITY TO EARTHQUAKES

The vulnerability of lifeline systems to earthquakes is related to the type and condition of structures and to the severity of the earthquake. Lifeline system building structures are vulnerable to earthquake shaking, just as are residential and commercial building structures. There are many types of critical structures and components that are found in lifeline systems, such as distribution equipment, transmission towers, or pipelines. Damage to one of these system components may disrupt the capacity of the entire system to function.

Pipelines: Water, Wastewater, Liquid Fuel, and Natural Gas

Buried pipelines that carry water, wastewater, natural gas, and liquid fuel can be vulnerable to damage due to surface faulting, liquefaction and lateral spreading, and landslides. Pipelines constructed of brittle materials are the most vulnerable because they are not able to bend and flex. Older, low-pressure distribution systems, such as water and natural gas, are often cast of brittle cast iron pipe. Brittle asbestos cement pipe is also used in many water systems. Pipelines constructed of relatively ductile materials such as steel and ductile iron are more resistant to earthquake-induced failure. Buried pipelines in liquefiable soils are susceptible to damage rates an order of magnitude larger than those in stable soils. If liquefaction occurs, joint restraint is also important to prevent ruptures. Modern welded joints used on gas and liquid fuel lines, and "restrained" joints used for some water pipelines are preferred in areas subject to liquefaction.

Natural gas and liquid fuel pipeline systems constructed of steel and modern welded joints have performed well except in the most extreme conditions of large permanent ground displacements. Pipeline joints welded using older techniques are in some cases more brittle, and have failed.

During an earthquake, it is common for many water pipelines on soft soils to fail and to quickly drain the water system. Furthermore, after a failure, water is not available for fire suppression that would result from an earthquake. This scenario occurred following the 1995 Kobe, Japan, 1994 Northridge, California, 1989 Loma Prieta, California, 1923 Tokyo, Japan, and 1906 San Francisco, California, earthquakes. After the most damaging earthquakes, such as Kobe, the water service was not fully restored for more than two months.

Sewer pipelines, often gravity-operated systems, are vulnerable to flotation if the ground around them liquefies. A change in grade can impair system operation. In the 1965 Seattle earthquake, a 108-inch diameter sewer was damaged when it floated upwards approximately two feet. The 1989 Loma Prieta, particularly in Santa Cruz, and the 1995 Kobe earthquakes caused similar damage.

The 2001 Nisqually earthquake caused approximately 25 water pipeline failures, fewer than 10 natural gas distribution line failures, one sewer system failure, and no natural gas transmission or liquid fuel line failures.

Tanks and Reservoirs

Earthquakes cause liquids, such as water and liquid fuels, to slosh in tanks and reservoirs. Sudden ground motion and subsequent movement of the base of a tank can load a tank wall beyond capacity. As sloshing continues, an unanchored tank can rock and break connecting piping. Furthermore, rocking can cause the tank to buckle or burst. Sloshing can also damage tank roofs and immersed components such as baffles and sludge rakes. During the Nisqually earthquake approximately 15 water tanks were damaged, none catastrophically (fig. 5). Liquid fuel tanks have been damaged and their contents caught on fire. Earthen reservoirs and dams can also be vulnerable to liquefaction and embankment failure. In Southern California, liquefaction damaged the Lower Van Norman Dam during the 1971 San Fernando earthquake, although no catastrophic water release occurred.

Electrical Power Facilities

Regional electrical power systems were out of service following the 1995 Kobe, 1994 Northridge, and 1989 Loma Prieta earthquakes. Such failures are often due to self-protecting features that are engineered into the system and can often be restored within 24 to 72 hours. Many of the power failures in the Seattle area during the 2001 Nisqually earthquake were of this type.

The most vulnerable components of electrical power systems typically are high voltage porcelain insulators. The higher the voltage, the larger and more vulnerable the insulator is to strong shaking. As a result, high-voltage substations, particularly 230 kV and higher, can be vulnerable to earthquake ground motion. Live tank circuit breakers, commonly used in Oregon, have not performed well in earthquakes. Rigid busses that connect substation equipment can transfer dynamic loads from other equipment and exacerbate insulator failures. If well anchored, lower voltage equipment functions well. Ground motions from the Nisqually earthquake were not strong enough to produce significant damage at most substations.

Power poles and towers have performed well, except when they are rooted in unstable soils where landslides or liquefaction can occur. In the 1993 Landers, California, earthquake, a fault ruptured through the base of a four-legged transmission tower. The tower was distorted but it did not collapse. Ground shaking can cause low-voltage power lines to slap together causing short circuits. Higher voltage power lines have greater separation, and thus are less prone to short circuits.

Highways

Bridges are usually the most vulnerable components of highway systems. More robust bridge design standards were developed in the 1970s and 1980s. Consequently, bridges predating the newer standards may be more prone to failure. Bridge decks can slide off their seats if the seats are too narrow or the seats are not adequately restrained. Supporting columns can buckle if they are overloaded and not designed to be adequately ductile. Single-span bridges supported on abutments perform better. Liquefaction can cause bridge foundations to move and spans they support to slide off their foundations.

The Nisqually earthquake caused significant damage to about a dozen bridges and highway structures (fig. 6), but none collapsed. In downtown Seattle, a major highway intersection at the junction of Interstate 5 and Interstate 90 was closed for several weeks for inspections and repairs. Bridge damage caused closure of northbound lanes of Interstate 5 for 12 hours in Chehalis, Washington (northern edge of map area), and the Alaska Way viaduct in Seattle was closed intermittently for weeks to assess and repair earthquake damage. In Olympia, the Deschutes Parkway was closed for weeks due to lateral spreading (fig. 7). Landslides caused closure of Washington highways 101, 202 and 302 (fig. 8).

Railways

In general, railway bridges perform well because they are designed to carry very large loads. Earthquakes in the U.S. and Japan have not tested the resistance of railroad bridges to liquefaction or lateral spreading, however, but either mode of ground failure could cause loss of bridge approaches. In addition, hazards such as failed overpasses, building debris, and ground failures could affect railroad right of ways.

Airports

Airport runways may be vulnerable to liquefaction. In the 1989 Loma Prieta earthquake, 3,000 feet at the end of the main runway of the Oakland Airport were taken out of service when liquefied sand erupted through runway joints. The 2001 Nisqually earthquake caused a similar runway failure at Boeing Field where most of the largest liquefaction zones correlated with old river channels. Airport control tower glass is vulnerable, as many tower structures were not adequately designed to transfer the roof load to the structure. Control towers at both the Seattle-Tacoma International (fig. 9) and Boeing Field airports were damaged during the Nisqually earthquake.

Figure 5. Water tank anchor damage caused by the Nisqually earthquake. The anchor is about 6" in length. (Photograph by Don Ballantyne).

Figure 6. Short-column damage at Holgate overcrossing of Interstate 5 in Seattle caused by Nisqually earthquake. (Photograph by Mark Eberhard, University of Washington).

Figure 7. Road failure at Capital Lake in Olympia caused by liquefaction and lateral spreading. This roadway also failed in the 1949 and 1965 earthquakes. (Photograph by Steve Kramer, University of Washington).

Figure 8. Road failure on Washington highway 302 caused by landslides during the Nisqually earthquake. (Photograph by Don Ballantyne.)

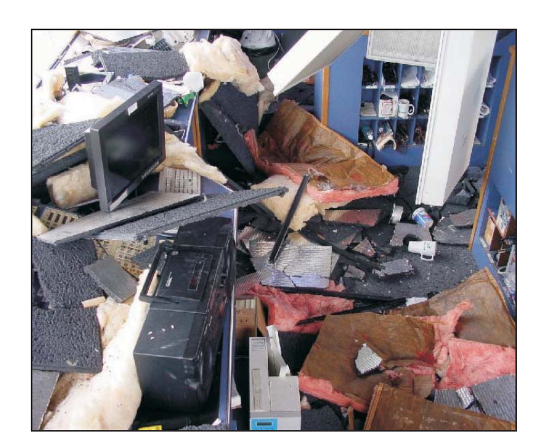

Figure 9. Control tower damage at Seattle-Tacoma International Airport caused by the Nisqually earthquake. No one was seriously injured by the debris. (Photograph by Carl Nelman, Boeing Company).

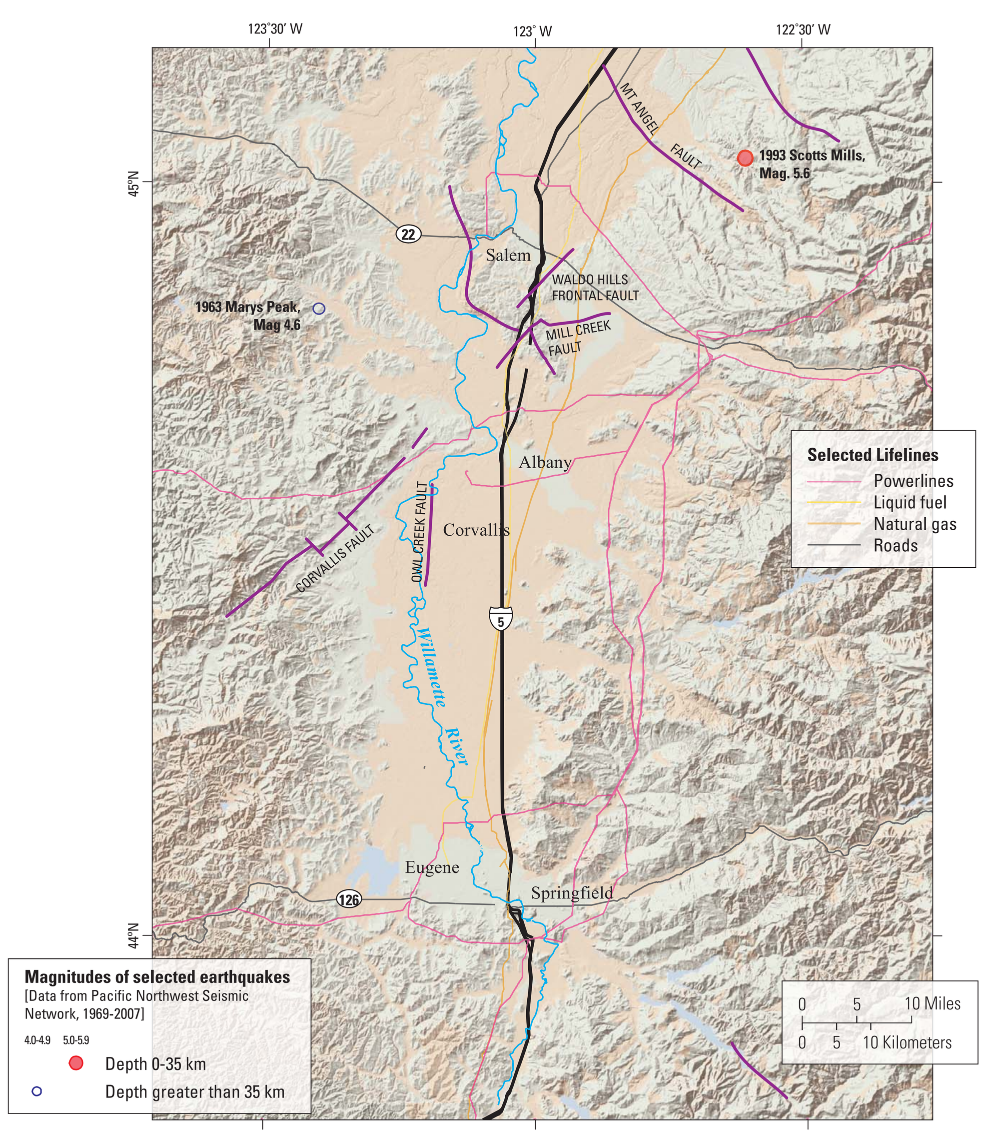

Figure 2. Faults and selected lifelines in the Willamette Valley and vicinity. Purple lines indicate faults, some discussed in text (Yeats and others, 1996; Blakely and others, 2000; U.S. Geological Survey, 2006). Power lines are shown in magenta, liquid fuel in yellow, natural gas in orange, and major roads in black (see front of lifelines). Red circles indicate selected crustal earthquakes; purple circles indicate earthquakes deeper than 35 km. Only the 1993 Scotts Mills earthquake (magnitude 5.6) is greater than magnitude 5 in the map area. Earthquakes from PNSN catalog (www.pnsn.org). Areas of higher relative earthquake hazard in beige and lower hazard in light green.

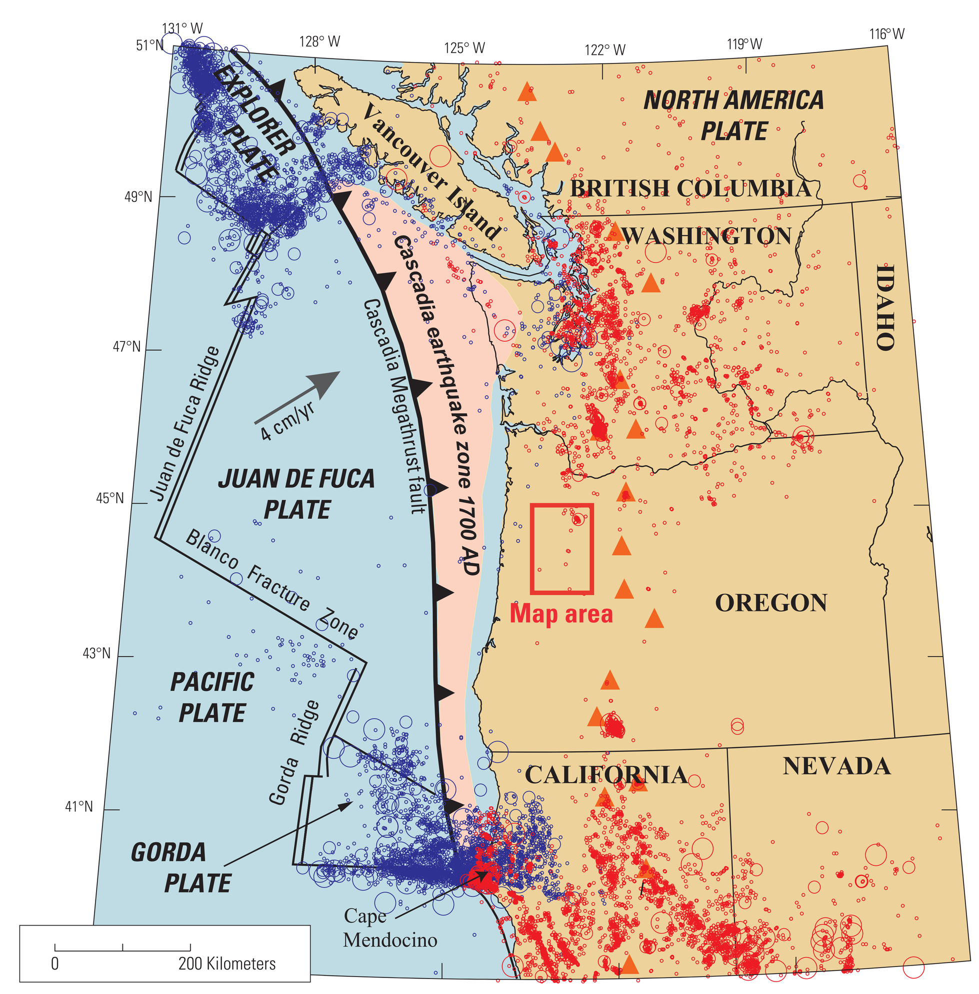

Figure 3. Known earthquakes in Cascadia greater than magnitude 6 since about 1870, magnitude 5 since 1950, and earthquakes of magnitude 2 and greater located by the modern seismograph networks and catalogued by the University of Washington (www.ess.washington.edu). Earthquakes are grouped into two broad zones: shallow crustal earthquakes, red; earthquakes in the intraplate zone and the shallow portion of the Juan de Fuca Plate, purple.

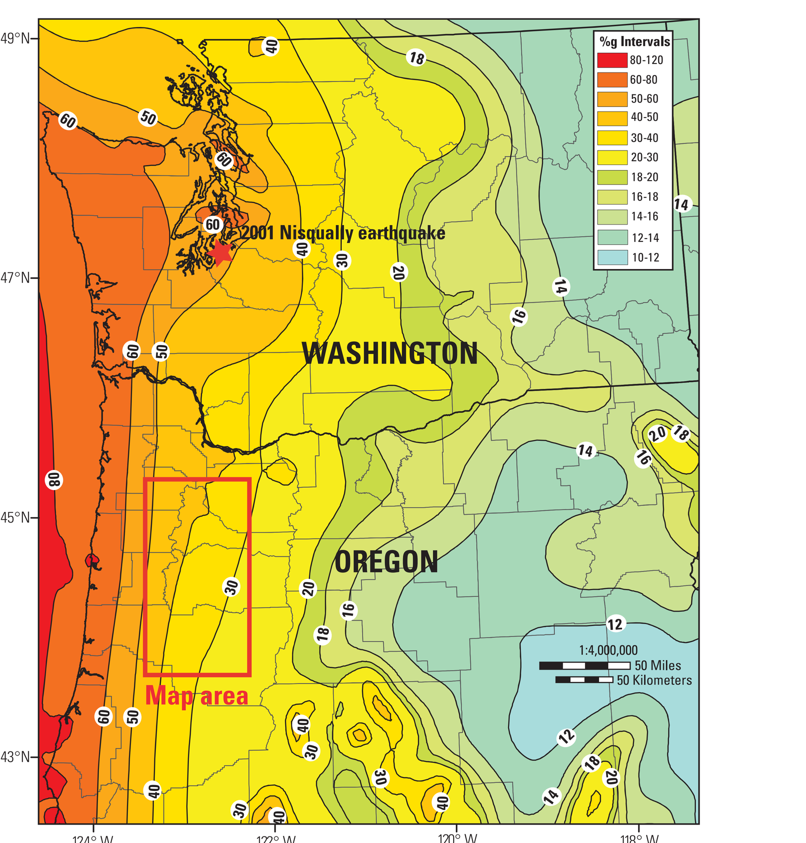

Figure 4. 2008 probabilistic seismic hazard map for portions of Oregon and Washington. The map shows the ground motions (%g) with a 2% probability of being exceeded in 50 years. Details are given in Frankel and others (1996; 2002), Peterson and others (2008), and at http://earthquake.usgs.gov/research/hazmaps/.

LIFELINE SYSTEMS ON THE MAP

The map shows how the major regional lifeline systems connect with population centers. Representing highways, railroads, electrical transmission lines, and petroleum and natural gas pipelines is relatively straightforward since these systems are regional. However, representing local water and wastewater systems is more difficult because there are many local systems in the Willamette Valley. With the assistance of local agencies, we have selected and schematically shown only major water and wastewater systems for the five cities that have populations greater than 40,000 (table 1). These cities represent about 50 percent of the population in 2000 in the five central and southern Willamette Valley counties (table 2). In addition, the service area for water and wastewater utilities extends outside the city boundaries so that these five systems shown on the map serve an estimated 65 percent of the population in the Willamette Valley.

Central/Southern Willamette Valley Cities	Population(2000)
Eugene	138,615
Salem	137,785
Springfield	52,864
Corvallis	49,400
Albany	41,145
Population Total	419,809

Table 1. Population of major cities in central and southern Willamette Valley

Central/Southern Willamette Valley Counties	Population(2000)
Lane	322,959
Marion	284,834
Linn	103,069
Benton	78,153
Polk	62,380
Population Total	851,395

Table 2. Population of major counties in central and southern Willamette Valley

Water

There are five large water suppliers in the Willamette Valley region: Salem, Albany, Corvallis, Eugene, and Springfield. Watersheds in the Cascade Range supply Eugene, Albany, and Salem. The McKenzie River feeds the Eugene system, while Albany's system relies on the South Santiam River, and the Salem system relies on the North Santiam River. Springfield is supplied by groundwater from a local aquifer, and the system has emergency connections with Eugene's system. Corvallis relies on water from both the Willamette River and Rock Creek, located in the Coast Range.

The map shows where surface water of rivers and reservoirs enters the water pipeline transmission systems and shows the transmission systems connections to their terminal reservoirs or major distribution branches.

Wastewater

Four wastewater systems in the map area serve the five largest cities. One system serves the Eugene-Springfield area. Each system has a wastewater plant that discharges into the Willamette River. Selected treatment plants and major sewer lines, generally selected by pipe diameter, are shown on the map.

Electrical Power

The major electric power provider in the Pacific Northwest is the Bonneville Power Administration (BPA), which transmits the region's electricity from hydroelectric plants along the Columbia and Snake Rivers to the I-5 urban corridor. BPA sells power to the major distributors in the region: Portland General Electric, Pacific Power, and Eugene Water and Electric Board. Each of these distributors also has capacity to generate power. Much of the power transmitted by BPA moves through 500 kV, 230 kV, and 115 kV transmission lines shown on the map.

Natural Gas

Williams Natural Gas Pipeline Company supplies natural gas to the Willamette Valley. Pipelines generally run parallel to I-5 and continue south of the map area to Grants Pass, Oregon. Unlike the Portland or Seattle areas, where gas can be supplied either from a north-south or east-west pipeline, there is no alternate route to the gas supply line from the north available for the southern Willamette Valley.

Liquid Fuel

The Willamette Valley is served by a steel, 8-inch diameter liquid fuel line, operated by Kinder Morgan Energy Partners, which connects to a pipeline owned by BP-Amoco Pipeline Company in Portland. The BP-Amoco pipeline transports liquid fuel in a pair of pipelines (16-inch and 20-inch) from refineries in northwestern Washington south to Renton near Seattle. One pipeline continues from Renton to Portland and then south into the Willamette Valley, which receives much of its gasoline through this pipeline. The pipeline terminates in the Eugene area.

Highways

Traffic volume along the I-5 urban corridor ranges from 25,000 vehicles per day near Cottage Grove to over 80,000 per day near Woodburn. In the Eugene urban area, both I-5 and I-105 handle about 60,000 vehicles per day. In a post-earthquake emergency, the routes parallel to I-5, such as Oregon 99W, may be important as initial corridors for relief efforts. Traffic counts on Oregon 99W generally are less than 15,000 vehicles per day between major population centers. Most of the I-5 bridges were constructed between the late 1950s and the mid-1970s.

Truck traffic on I-5 is vital to the regional economy. In a study of 17 western states, including heavily populated Texas and California, the Eugene-to-Portland section of I-5 ranks second in truck tonnage and Portland-to-Eugene ranks fourth (Oregon Department of Transportation, 2000). Furthermore, the Seattle-to-Portland section of I-5 ranks first in truck tonnage.

There are three primary east-west highway routes and none have daily traffic counts exceeding 5,000 vehicles per day into the area at the edges of the map. The Salem area is served by Oregon 22, which connects westward to the Oregon coast and eastward to US 20 and Bend by way of Santiam Pass. The Albany-Corvallis area is on US 20 and is connected with Newport on the coast and Bend to the east. Oregon 34 provides an alternate west-to-east link between Corvallis and the eastern Willamette valley, by-passing Albany. Oregon 126 connects the Eugene area to US 20 west of Santiam Pass. Route 126 also provides a link between Eugene and the Oregon coast. To the south, Oregon 58 links Eugene to the Crater Lake National Park area, Klamath Falls, and southeastern Oregon, crossing the Cascades at Willamette Pass. Again, traffic volumes flowing into the map area are small, below 5,000 vehicles per day at Willamette Pass. However, about 1,500 trucks use the pass daily, so Oregon 58 is economically very important to the southern Willamette Valley.

Railroads

The Union Pacific Railroad dominates freight traffic movement in the Willamette Valley. About half of Oregon's 63 million tons of rail freight moves through the Willamette Valley. The Eugene area is second to Portland in generating railroad shipping tonnage in Oregon. The Central Oregon and Pacific (CORP) and the Pacific and Western (P & W) are the two main short line railroads that service the map area. The CORP lines run west and south from Eugene, whereas the P & W lines run in a wider corridor approximately parallel to I-5. Six daily passenger trains, 3 northbound and 3 southbound, run from Eugene to Portland and on to Seattle.

Airports

The Eugene Airport, Mahlon Sweet Field, is the fifth largest commercial airport in the Oregon and Washington region. The airport serves approximately 750,000 passengers and 55,000 landings annually and is the primary air cargo point for the southern Willamette Valley.

Earthquake Distribution

The Cascadia subduction region stretches the length of the Pacific Northwest coastline, so it is useful to consider the distribution of earthquakes across the entire plate boundary system and examine the regional picture formed by integrating all these earthquake source zones. Compared with earthquakes in the intraplate zone, crustal events are much more widespread, occurring over much of northwestern California and most of Washington. However, figure 3 shows that there are relatively few earthquakes in Oregon and that the Willamette Valley is particularly quiet. In spite of the fact that scientists know from field studies that subduction events are possible, there are no recent Cascadia zone earthquakes that have been located in Oregon. Thus, in the absence of recent significant seismic data, figure 3 illustrates the importance of conducting more detailed geological field studies and examining evidence of historical earthquakes in order to reduce the uncertainty in earthquake hazard assessment.

Probabilistic Ground Motion Map

A useful representation of earthquake shaking hazards is a probabilistic seismic hazard map. Based on local geologic and seismic data, the USGS has developed probabilistic seismic hazard maps for the entire country (Frankel and others, 1996; 2002; Petersen and others, 2008). These seismic hazard maps underpin seismic building codes and many highway construction standards. The probabilistic hazard map (fig. 4) shows the expected peak horizontal ground motions on a rock site with a 2 percent probability of being exceeded within a time frame of 50 years. Figure 4 includes all three potential earthquake sources for the Northwest: subduction zone, intraplate zone, and crustal faults. Along the Oregon Coast, the seismic hazard is dominated by the north-south Cascadia subduction zone. Moving eastward into the Willamette Valley, the map contours are oriented north-south to the south, but from Linn County northward the contours curve northeastward. This change reflects increased rates of seismicity that originate in the northern Oregon Cascade Range (fig. 3) and increased rates at Scotts Mills (figs. 2 and 3). The eastward bulge of the contours indicates higher expected ground motions in the Seattle area and reflects the high rate of large-magnitude intraplate earthquakes that have occurred and can be expected in this region.

The east-west oval contour indicates the relatively higher hazard potential in central Puget Sound region and also reflects current scientific understanding of the Seattle fault zone. This illustrates how increasing the detailed geologic knowledge of an individual fault may change hazard assessment. For example, an area of higher hazard potential around the Seattle fault was indicated in recently updated seismic hazard maps because field and seismic studies demonstrated that large (M 7.0) earthquakes occurred on the Seattle fault in the past. Geologic studies in western Oregon are in progress to examine faults and update the regional seismic hazard assessments.

Earthquake Hazards

Even though there is considerable uncertainty as to how often earthquakes may hit the Willamette Valley region, it is possible to evaluate and improve estimates of potential earthquake damage. Ground shaking occurs in a wide area following an earthquake. Because of the complexity of the three source zones, it is useful to implement the probabilistic hazard map (fig. 4) as an initial guide to determine areas of strong shaking. However, unconsolidated young deposits often amplify low to moderate ground motions, sometimes by a factor of two or more. Poorly consolidated soils are typically found in river and stream valleys and areas of artificial fill. The relative hazard maps prepared by DOGAMI discuss key factors affecting amplification (see for instance Madin and Wang, 2000). Therefore, areas of young, unconsolidated deposits (beige on map) are considered more susceptible to intense ground motions than areas of rock or well-consolidated sediments (light green on map). Significant sections of the lifeline systems in the Willamette Valley traverse areas of unconsolidated materials that may amplify ground motions.

Generally, many of the same areas subject to amplified ground shaking are also susceptible to liquefaction. In areas of unconsolidated, young deposits (beige on map), strong shaking can increase pore pressure within water-saturated soil causing the soil to lose shear strength, or liquefy, and to lose the ability to support large loads, such as buildings and roads. In areas adjacent to a riverbank, or on a slope, lateral ground motion can move and disrupt buried pipelines and foundations. Thus, the beige-shaded areas that are susceptible to liquefaction carry additional hazard significance.

Steep slopes can produce landslides during earthquakes. An important lesson for the Willamette Valley from the large earthquakes in Puget Sound area is that not all landslides occur in the first few minutes following an earthquake but can occur days later. In 1949, a large landslide near Tacoma, Washington, slipped three days after the earthquake. The steep slopes along the edges of the Willamette Valley, often near regional lifeline corridors, are candidates for earthquake-induced failure, though we have not delineated these areas on this map.

As earth scientists improve their understanding of crustal fault behavior in the Willamette Valley, it is possible that fault surface rupture may become a concern. In the Seattle, Washington, area, recent discovery of young faults breaking at the surface has identified a fault zone in central Puget Sound where surface rupture could occur. Although for any given earthquake the chances of surface rupture may be small, it may be appropriate to consider such a possibility.

ABOUT THE MAP

The base map was derived from a U.S. Geological Survey 30-meter digital elevation model (DEM). Shorelines and streams originate from USGS digital line graphs (DLG) derived from 1:100,000-scale maps (see http://edc.usgs.gov/geodata). This map is based on material originally published in U.S. Geological Survey Open-File Report 99-387 (Haugerud, and others, 1999).

Earthquakes and Geologic Units on the Map

There have been very few earthquakes located or detected in the Willamette Valley since a modern seismograph was installed in Corvallis in 1962. Earthquakes recorded and located since 1969 by the Pacific Northwest Seismic Network (http://www.pnsn.org) are shown on the map and range in magnitude between 2.0 to 5.7. The earthquakes are divided into shallow, crustal earthquakes (< 35km) shown in red and earthquakes with epicenters deeper than 35km shown in purple. Nearly all located earthquakes occurred in the crust of the North American Plate and most are located in the northeastern portion of the map area and are aftershocks of the 1993 Scotts Mills event. All aftershocks for this event were less than magnitude 3.5 (Madin and others, 1993).

The only other notable earthquake in the map area is a deep earthquake that occurred in 1963 northwest of Corvallis. This magnitude 4.6 earthquake was intraplate type similar to the 2001 Nisqually earthquake and is the largest known intraplate earthquake in Oregon from the California border north to the Columbia River.

The geologic units in the map area have been simplified into two basic units reflecting relative seismic hazard: 1) young, unconsolidated deposits and 2) consolidated deposits. Beige colors represent predominantly young, unconsolidated fluvial and alluvial deposits, which are susceptible to liquefaction, ground amplification, and/or landslides triggered by a seismic event. Light green represents bedrock and older, well-consolidated surface rocks and deposits considered to be less subject to earthquake-related liquefaction, amplification, or landslides. Generally, hilly areas adjacent to the valley floor are considered less prone to earthquake hazards and are categorized as seismically less hazardous (light green on map) areas. The exception is hilly areas prone to landsliding (beige on map). The valley floors are typically covered by younger and less-consolidated surface deposits and are therefore categorized as more susceptible to earthquake hazards (beige). The beige and light green categories are determined solely on the basis of geologic information and did not incorporate engineering analyses. Geologists working on this project reached a consensus on which mapped geologic units should be placed into each category of relative earthquake hazard, and this map follows previous study guidelines (Wang and Leonard, 1996; Mabey and others, 1997; Madin and Wang, 2000a-c; Palmer and others, 2004; Burns and others, 2008). We compiled geological information from several data sources (Walker and McLeod, 1991; Wang and others, 1996; Black and others, 2000; Madin and others, 2000a-c; Hofmeister and others, 2003; Burns and others, 2008), and the geologic background reflects prioritizing the most recent studies and highest resolution data based on mapping scale. Compiling and layering of different geologic sources into the map geologic background occasionally result in abrupt artificial boundaries due to data source boundaries. Please refer to references and the legend inset map for more details.

The lowest resolution data compose the background geology of the map and are based on the 1:500,000 scale Oregon geology map developed by Walker and McLeod (1991) and the 1:100,000 scale Washington National Earthquake Hazards Reduction Program (NEHRP) maps (Palmer and others, 2003; Palmer and others, 2004). Young, unconsolidated sediments of the Walker and McLeod (1991) map, such as alluvial and fluvial sands and gravels and some older marine sedimentary rocks, are considered to be more susceptible to ground motions during an earthquake (beige on map). Based on response to ground shaking during an earthquake, the very near surface units of the Washington NEHRP map (Palmer and others, 2004) data are divided into units ranging from hard rock to soft soils. The boundary between stiff soils and very dense soil/soft rock (NEHRP values D/C) is categorized in this map as the distinction between higher (beige on map) or lower (light green on map) soil susceptibility, respectively, to amplification during an earthquake (Palmer and others, 2004).

The highest resolution data (1:62,500 to 1:24,000 scale) are simplified from recent Oregon Department of Geology and Mineral Industries (DOGAMI) and Washington State Department of Natural Resources reports, referred to as Interpretive Map Series (IMS) and Geologic Map Series (GMS) (Wang and others, 1996; Black and others, 2000; Madin and others, 2000a-c; Hofmeister and others, 2003; Burns and others, 2008). Data from the IMS and GMS studies constitute the top layer of geologic data on this map. These studies characterize sites based on soil and rock susceptibility to amplification, liquefaction and landsliding during an earthquake. Wang and others (1998) and Wang and Madin (2001) describe the integration of the three site response components into six relative earthquake hazard zones, A through F. Types A-C are lower relative earthquake hazard (light green on this map) categories, and D-F are surface deposits that are considered higher relative earthquake hazard category (beige on this map). Units characterized as 'high' or 'very high' hazard susceptibility to amplification, liquefaction and landsliding during and earthquake in reports by Burns and others (2008) and Hofmeister and others (2003) are designated higher earthquake hazard (beige) on this map. Communities included in the map area that have completed relative earthquake hazard maps are shown in the inset map of the Explanation.

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MORE INFORMATION

There are many good sources for more information concerning earthquakes and the effects of earthquakes in the Willamette Valley. The Oregon Department of Geology and Mineral Industries has considerable expertise in evaluating and explaining earthquake issues (http://www.oregongeology.com) and Oregon Emergency Management has information available regarding earthquake response and mitigation (http://www.oregon.gov/OMD/OEM/index.shtml). Both of these sites have many links to other resources. Current earthquake activity is available at www.pnsn.org. Complete details for national hazard maps can be found at the following USGS site: http://earthquake.usgs.gov/research/hazmaps/. The Federal Emergency Management Agency maintains a long list of materials related to earthquake preparedness, mitigation, and response planning (www.fema.gov). The American Red Cross has details on personal preparedness (www.redcross.org). The Cascadia Regional Earthquake Workgroup (www.crew.org) is regional private-public partnership dedicated to increasing earthquake mitigation efforts in the Pacific Northwest.

REFERENCES

Atwater, B.F., Hemphill-Haley, E., 1997, Recurrence intervals for great earthquakes of the past 3500 years at northeasternWillapa Bay,Washington: U.S. Geological Survey Professional Paper 1576, 108 p.
Atwater, B.F., Musumi-Rokkaku, S., Satake, K. Tsuji, Y., Ueda, K., and Yamaguchi, D.K., 2005, The orphan tsunami of 1700—Japanese clues to a parent earthquake in North America: U.S. Geological Survey Professional Paper 1707, 133 p. (published jointly by University of Washington Press, Seattle).
Benson, B.E., Atwater, B.F., Yamaguchi, D.K., Amidon, L.J., Brown, S.L., and Lewis, R.C., 2001, Renewal of tidal forests in Washington State after a subduction earthquake in A.D. 1700: Quaternary Research, 56, p. 139–147.
Black, G.L., Wang, Z., Wiley, T.J., Wang, Y, and Keefer, D.K., 2000, Relative earthquake hazard map of the Eugene-Springfield metropolitan area, Lane County, Oregon: Oregon Department of Geology and Mineral Industries Interpretive Map Series IMS-14, 16 p., 1 map sheet, scale 1:48,000.
Blakely, R.J., Wells, R.E., Tolan, T.L., Beeson, M.H., Trehu, A.M., and Liberty, L.M., 2000, New aeromagnetic data reveal large strike-slip faults in the northern Willamette Valley, Oregon: Geological Society of America Bulletin, v. 112, p. 1,225-1,233.
Burns, W.J., Hofmeister, R.J., and Wang, Y., 2008, Geologic hazards, earthquake and landslide hazard maps, and future earthquake damage estimates for six counties in the mid/southern Willamette Valley including Yamhill, Marion, Polk, Benton, Linn, and Lane Counties, and the City of Albany, Oregon: Oregon Department of Geology and Mineral Industries Interpretive Map Series IMS-24, 3 cds.
Clague, J.J., Bobrowsky, T., Hutchinson, I., 2000, A review of geological records of large tsunamis at Vancouver Island, British Columbia, and implications for hazard: Quaternary Science Reviews 19, p. 849–863.
Frankel, A., Mueller, C., Barnhard, T., Perkins, D., Leyendecker, E.V., Dickman, N., Hanson, S., and Hopper, M., 1996, National Seismic Hazard Maps, June 1995 documentation: U.S. Geological Survey Open-File Report 96-532, 110 p.
Frankel, A.D., Peterson, M.D., Mueller, C.S., Haller, K.M., Wheeler, R.I., Leyendecker, E.V., Wesson, R.L., Harmsen, S.C., Cramer, C.H., Perkins, D.M., and Rukstales, K.S., 2002, Documentation for the 2002 update of the National Seismic Hazard Maps: U.S. Geological Survey Open-File Report 02-420, 33 p., 6 pls.
Haugerud, R.A., Ballantyne, D.B., Weaver, C.S., Meagher, K.L., and Barnett, E.A., 1999, Lifelines and earthquake hazards in the greater Seattle area: U.S. Geological Survey Open-File Report 99-387, 1 sheet, scale 1:31,000.
Hofmeister, R.J., Hasenberg, C.S., Madin, I.P., and Wang, Y., 2003, Earthquake and landslide hazard maps in Clackamas County, OR: Oregon Department of Geology and Mineral Industries Open File Report O-03-09/O-03-10, 1 cd.
Jacoby, G.C., Bunker, D.E., and Benson, B.E., 1997, Tree-ring evidence for an A.D.1700 Cascadia earthquake in Washington and northern Oregon: Geology, v. 29, p. 999–1002.
Kelsey, H.M., Witter, R.C., and Hemphill-Haley, E., 2002, Plate-boundary earthquakes and tsunamis of the past 5500 years, Sixes River estuary, southern Oregon: Geological Society of America Bulletin 114, p. 298–314.
Mabey, M.A., Black, G.L., Madin, I.P., Meier, D.B., Youd, T.L., Jones, C.F., and Rice, J.B., 1997, Relative earthquake hazard map of the Portland metro region, Clackamas, Multnomah, and Washington Counties, Oregon: Oregon Department of Geology and Mineral Industries Interpretive Map Series IMS-1, scale 1:62,500.
Madin, I.P., Priest, G.R., Mabey, M.A., Malone, S., Yelin, T.S., and Meier, D., 1993, March 25, 1993, Scotts Mills earthquake Oregon's wakeup call: Oregon Geology, v. 55, no. 3, p. 51-57.
Madin, I.P., and Mabey, M.A., 1996, Earthquake hazard maps for Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-100, 1 plate, 4 maps.
Madin, I.P., and Wang, Z., 2000a, Relative earthquake hazard maps for St. Helens-Columbia City-Scappoose, Sandy, Hood River, McMinnville-Dayton-Lafayette, Newberg-Dundee, Sheridan-Willamina, Dallas, Monmouth-Independence: Oregon Department of Geology and Mineral Industries Interpretive Map Series IMS-7, 1 CD, scale 1:24,000.
Madin, I.P., and Wang, Z., 2000b, Relative earthquake hazard maps for Canby-Barlow-Aurora, Woodburn-Hubbard, Silverton-Mt. Angel, Stayton-Sublimity-Aumsville, Lebanon, Sweet Home: Oregon Department of Geology and Mineral Industries Interpretive Map Series IMS-8, 1 CD, scale 1:24,000.
Madin, I.P., and Wang, Z., 2000c, Relative earthquake hazard maps for selected urban areas in western Oregon: Ashland, Cottage Grove, Grants Pass, Roseburg, Sutherlin-Oakland: Oregon Department of Geology and Mineral Industries Interpretive Map Series IMS-9, 21 p., 1 map sheet, scale 1:24,000.
Nelson, A.R., Atwater, B.F., Bobrowsky, T., Bradley, L.-A., Clague, J.J., Carver, G.A., Darienzo, M.E., Grant, W.C., Krueger, H.W., Sparks, R., Stafford Jr., T.W., and Stuiver, M., 1995, Radiocarbon evidence for extensive plate-boundary rupture about 300 years ago at the Cascadia subduction zone: Nature, 378, p. 371–374.
O'Connor, J.E., Sarna-Wojcicki, A., Wozniak, K.C., Polette, D.J., and Fleck, R.J., 2001, Origin, extent, and thickness of Quaternary geologic units in the Willamette Valley, Oregon: U.S. Geological Survey Professional Paper 1620, 52 p., 1 plate.
Oregon Department of Transportation, 2000, Transportation key facts 2000: Oregon State Transportation Commission, 40 p.
Petersen, Mark D., Frankel, Arthur D., Harmsen, Stephen C., Mueller, Charles S., Haller, Kathleen M., Wheeler, Russell L., Wesson, Robert L., Zeng, Yuehua, Boyd, Oliver S., Perkins, David M., Luco, Nicolas, Field, Edward H., Wills, Chris J., and Rukstales, Kenneth S., 2008, Documentation for the 2008 update of the United States National Seismic Hazard Maps: U.S. Geological Survey Open-File Report 2008–1128, 61 p. http://earthquake.usgs.gov/research/hazmaps/
U.S. Geological Survey, 2006, Quaternary fault and fold database of the United States: http://earthquake.usgs.gov/regional/qfaults/.
Wang, Y., and Leonard, W.J., 1996, Relative earthquake hazard maps of the Salem East and Salem West quadrangles, Marion and Polk Counties, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-105, 10 p., 4 plates, scale 1:24,000.
Wang, Y., Weldon, R., and Fletcher, D., 1998, Creating a UBC soil map for Oregon: Oregon Geology, v. 60, no. 4, p. 74-78.
Wang, Z., and Madin, I.P., 2001, Preliminary earthquake hazard and risk assessment and water-induced landslide hazard in Benton County, Oregon: Oregon Department of Geology and Mineral Industries Open File Report 0-01-05, 10 p.
Yeats, R.S., Graven, E.P., Werner, K.S., Goldfinger, C., and Popowski, T., 1996, Tectonics of the Willamette Valley, Oregon: U.S. Geological Survey Professional Paper 1560, v. 1, p. 183-222, 4 plates.

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Earthquake Hazards and Lifelines in the Interstate 5 Urban Corridor: Cottage Grove to Woodburn, Oregon

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See regional geology and lifeline systems on shaded-relief map on reverse side.