CHAPTER 12.
EARTHQUAKE

12.1 GENERAL BACKGROUND

12.1.1 How Earthquakes Happen

> **DEFINITIONS**
>
> **Earthquake**—The shaking of the ground caused by an abrupt shift of rock along a fracture in the earth or a contact zone between tectonic plates. Earthquakes are typically measured in both magnitude and intensity.

The Puget Sound region is seismically active, with hundreds of earthquakes occurring each year. Most are so small that only sensitive instruments can detect them. However, at least 20 damaging earthquakes have occurred in Western Washington during the past 125 years. Large quakes in 1946, 1949, 1965 and 2001 killed 16 people and caused more than $2 billion in damage. The Pacific Northwest has been studied extensively in recent years, yielding valuable new insights. It is now generally agreed that three source zones exist for Puget Sound quakes: a shallow (crustal) zone; the Cascadia Subduction Zone; and a deep, intra-plate "Benioff" zone. These are shown in Figure 12-1. More than 90 percent of Pacific Northwest earthquakes occur along the boundary between the Juan de Fuca plate and the North American plate.

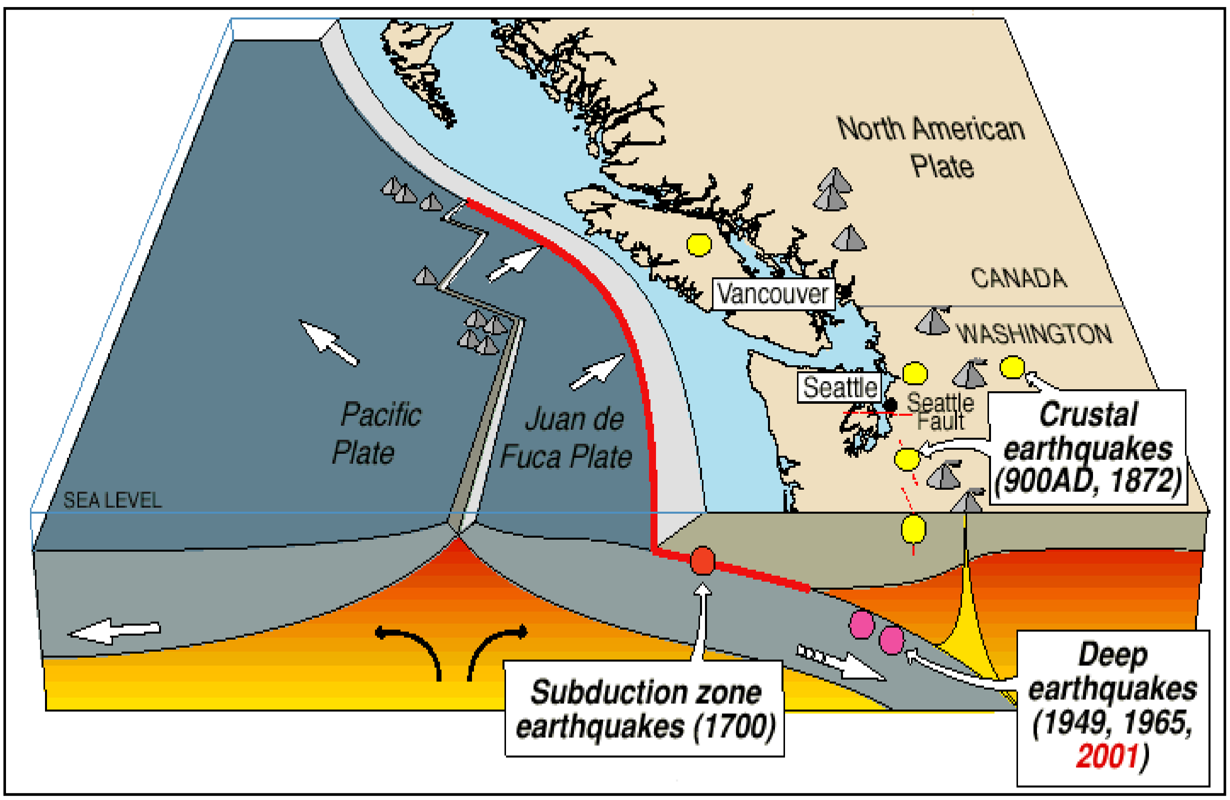

Figure 12-1. Earthquake Types in Western Washington

Geologists classify faults by their relative hazards. Active faults, which represent the highest hazard, are those that have ruptured to the ground surface during the Holocene period (about the last 12,000 years). Potentially active faults are those that displaced layers of rock from the Quaternary period (the last 1,800,000 years). Determining if a fault is "active" or "potentially active" depends on geologic evidence, which may not be available for every fault. Although there are probably still some unrecognized active faults, nearly all the movement between the two plates, and therefore the majority of the seismic hazards, are on the well-known active faults.

Faults are more likely to have earthquakes on them if they have more rapid rates of movement, have had recent earthquakes along them, experience greater total displacements, and are aligned so that movement can relieve accumulating tectonic stresses. A direct relationship exists between a fault's length and location and its ability to generate damaging ground motion at a given site. In some areas, smaller, local faults produce lower magnitude quakes, but ground shaking can be strong, and damage can be significant as a result of the fault's proximity to the area. In contrast, large regional faults can generate great magnitudes but, because of their distance and depth, may result in only moderate shaking in the area.

12.1.2 Classifying and Measuring Earthquakes

Earthquakes are classified according to the amount of energy released as measured by magnitude or intensity scales. While several scales have been defined, currently the most commonly used are the moment magnitude, or Mw, and the modified Mercalli intensity. Estimates of moment magnitude roughly agree with estimates using other scales, such as the local magnitude scale commonly called the Richter scale. One advantage of the moment magnitude scale is that, unlike other magnitude scales, it does not saturate at the upper end. That is, there is no value beyond which all large earthquakes have about the same magnitude. For this reason, moment magnitude is now the most often used estimate of large earthquake magnitudes. Table 12-1 presents a classification of earthquakes according to their magnitude. Table 12-2 compares the moment magnitude scale to the modified Mercalli intensity scale.

Another element of earthquake hazard assessment is the calculation of expected ground motion. This involves determining the annual probability that certain ground motion accelerations will be exceeded, then summing the annual probabilities over the time period of interest. The most commonly mapped ground motion parameters are the horizontal and vertical peak ground accelerations (PGA) for a given soil or rock type. Maps of PGA values form the basis of seismic zone maps that are included in building codes, including the International Building Code and its predecessor the Uniform Building Code.

Building codes that include seismic provisions specify the horizontal force due to lateral acceleration that a building should be able to withstand during an earthquake. PGA values are directly related to these lateral forces that could damage short-period structures (single-family dwellings). Longer period response components determine the lateral forces that damage larger structures with longer natural periods (apartment buildings, factories, high-rises, bridges). Table 12-3 summarizes damage potential by PGA factors compared to the Mercalli scale.

The impact of an earthquake on structures and infrastructure is largely a function of ground shaking, liquefaction and distance from the source of the quake. Liquefaction generally occurs in soft, unconsolidated sedimentary soils. A program called the National Earthquake Hazard Reduction Program (NEHRP) creates maps based on soil characteristics so that locations potentially subject to liquefaction may be identified. Table 12-4 summarizes NEHRP soil classifications.

12.2 HAZARD PROFILE

Hundreds of earthquakes occur in the Puget Sound region each year. While the majority of these events register a magnitude of 3 or lower on the Richter scale, earthquakes measuring up to 7.1 have been recorded. Recent studies suggest that earthquakes of a Magnitude 8 or greater have occurred in the region and that similar seismic events are possible in the future. Several major faults are located in the vicinity. Small shallow earthquakes (up to Magnitude 4) associated with these faults are likely. Shallow earthquakes of greater magnitude are expected to occur infrequently in this area.

TABLE 12-1.
EARTHQUAKE MAGNITUDE CLASSES

Magnitude Class	Magnitude Range (M = magnitude)
Great	M > 8
Major	7 <= M < 7.9
Strong	6 <= M < 6.9
Moderate	5 <= M < 5.9
Light	4 <= M < 4.9
Minor	3 <= M < 3.9
Micro	M < 3

TABLE 12-2.
EARTHQUAKE MAGNITUDE AND INTENSITY

Magnitude (Mw)	Intensity (Modified Mercalli)	Description
1.0 – 3.0	I	I. Not felt except by a very few under especially favorable conditions
3.0 – 3.9	II – III	II. Felt only by a few persons at rest, especially on upper floors of buildings. III. Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it is an earthquake. Standing cars may rock slightly. Vibrations similar to the passing of a truck.
4.0 – 4.9	IV – V	IV. Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like a heavy truck striking building. Standing cars rocked noticeably.
5.0 – 5.9	VI – VII	VI. Felt by all; many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight. VII. Damage negligible in buildings of good design and construction; slight in well-built ordinary structures; considerable in poorly built or badly designed structures. Some chimneys broken.
6.0 – 6.9	VIII – IX	VIII. Damage slight in specially designed structures; considerable damage in ordinary buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. IX. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
7.0 and higher	X and higher	X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent. XI. Few, if any masonry structures remain standing. Bridges destroyed. Rails bent greatly. XII. Damage total. Lines of sight and level are distorted. Objects thrown into the air.

**TABLE 12-3.
MERCALLI SCALE AND PEAK GROUND ACCELERATION COMPARISON**

Mercalli Scale	Potential Damage	Estimated PGA
I	None	0.017
II-III	None	0.017
IV	None	0.014-0.039
V	Very Light	0.039-0.092
VI	None to Slight; USGS-Light	0.02-0.05
	Unreinforced Masonry-Stair Step Cracks; Damage to Chimneys; Threshold of Damage	0.04-0.08 0.06-0.07 0.06-0.13 0.092-0.18
VII	Slight-Moderate; USGS-Moderate	0.05-0.10
	Unreinforced Masonry-Significant; Cracking of parapets	0.08-0.16 0.10-0.15
	Masonry may fail; Threshold of Structural Damage	0.1 0.18-0.34
VIII	Moderate-Extensive; USGS: Moderate-Heavy	0.10-0.20
	Unreinforced Masonry-Extensive Cracking; fall of parapets and gable ends	0.16-0.32 0.25-0.30 0.13-0.25 0.2 0.35-0.65
IX	Extensive-Complete; USGS-Heavy	0.20-0.50
	Structural collapse of some un-reinforced masonry buildings; walls out of plane. Damage to seismically designed structures	0.32-0.55 0.50-0.55 0.26-0.44 0.3 0.65-1.24
X	Complete ground failures; USGS- Very Heavy (X+); Structural collapse of most un-reinforced masonry buildings; notable damage to seismically designed structures; ground failure	0.50-1.00

**TABLE 12-4.
NEHRP SOIL CLASSIFICATION SYSTEM**

NEHRP Soil Type	Description	Mean Shear Velocity to 30 m (m/s)
A	Hard Rock	1,500
B	Firm to Hard Rock	760-1,500
C	Dense Soil/Soft Rock	360-760
D	Stiff Soil	180-360
E	Soft Clays	< 180
F	Special Study Soils (liquefiable soils, sensitive clays, organic soils, soft clays >36 m thick)	

Earthquakes can last from a few seconds to over five minutes; they may also occur as a series of tremors over a period of several days. The actual movement of the ground in an earthquake is seldom the direct cause of injury or death. Casualties may result from falling objects and debris because earthquakes can shake, damage or demolish buildings and other structures. Disruption of communications, electrical power supplies and gas, and sewer and water lines should be expected. Earthquakes may trigger fires, dam failures, landslides or releases of hazardous material, compounding their disastrous effects.

12.2.1 Past Events

Historically, Snohomish County earthquake activity has been slightly above the Washington State average. It is 268 percent greater than the overall U.S. average. Table 12-5 lists past seismic events that have impacted the Puget Sound region.

**TABLE 12-5.
HISTORICAL EARTHQUAKES IMPACTING THE PUGET SOUND REGION**

Date	Magnitude	Epicenter Location
1872	7.2	North Cascades
1882	6.0	Olympic area
1909	6.0	Puget Sound
1915	5.6	North Cascades
1918	7.0	Vancouver Island
1920	5.5	Puget Sound
1932	5.3	Central Cascades
1939	5.8	Puget Sound
April 1945	5.7	8 miles south-southeast of North Bend
January 13, 1949	7.0	8 miles east-northeast of Olympia
April 29, 1965	6.6	11 miles north of Tacoma
February 14, 1981	5.5	Mt. St. Helens
May 3, 1996	5.3	Duvall
July 1996	5.4	5 miles east-northeast of Duvall
November 1996	2.9	Puget Sound
February 1997	3.0	Southeast of Seattle
April 1997	4.9	Puget Sound off Vashon Island
June 1997	2.7	Puget Sound
July 1997	3.1	Duvall
February 1998	2.8	Northeast of Seattle
March 1998	3.1	Pierce County
July 3, 1999	5.8	5 miles north of Satsop
February 28, 2001	6.8	Olympia (Nisqually)
March 2001	3.4	Tacoma
May 2002	4.2	Friday Harbor, San Juan Islands
July 2002	3.1	North Bend
January 2009	4.5	Near Kingston

The following are the four most significant earthquakes on record for Snohomish County:

- **1872, 75 Miles Northeast of Everett—**This shallow earthquake had a magnitude of 7.4 on the Richter scale. It occurred approximately 75 miles northeast of Everett near Mount Baker and just east of the Cascade crest (largest recorded earthquake in Washington). No record of any fatalities in Snohomish County.
- **1949, Nisqually Delta Area North of Olympia**—This earthquake had a magnitude of 7.1 on the Richter scale. The Snohomish County zone that experienced most intense effects is along the South Stillaguamish River valley from Granite Falls to Arlington, and along the Snohomish and Skykomish River valleys from Everett to Snohomish and Monroe. Within this area, the effects included fallen chimneys and building cornices; cracked plaster; broken water and gas mains; damaged docks, bridges, and water storage tanks; cracked ground and pavement; and landslides, mudflows and debris slides.
- **1996, Duvall**—This earthquake had a magnitude of 5.6 on the Richter scale. Near the epicenter, merchandise fell off shelves and at least one resident reported a cracked chimney. In Snohomish County, 16,000 residents were reportedly without power for several hours as a result of breakers tripping in four substations. There was, however, no report of physical damage to electrical power facilities.
- **2001, Nisqually Delta Area North of Olympia**—This earthquake had a magnitude 6.8 on the Richter scale. Snohomish County had combined public and private sector damage between $2 million and $3 million. There were 13 minor injuries. A few older unreinforced masonry structures suffered significant damage, but there were no building collapses in the County. The greatest shaking and highest percentage of damaged structures were in the main river valleys and communities along the rivers: Darrington, Sultan, Monroe and Snohomish.

12.2.2 Location

Where Earthquakes Occur

Cascadia Subduction Zone

In Western Washington, the primary plates of interest are the Juan De Fuca and North American plates. The Juan De Fuca plate moves northeast with respect to the North American plate at a rate of about an inch and a half per year. The boundary where these plates converge, the Cascadia Subduction Zone, lies approximately 50 miles offshore of the west coastline and extends from the middle of Vancouver Island in British Columbia to northern California. As it collides with the North American plate, the Juan De Fuca plate slides beneath the continent and sinks into the earth’s mantle. The sliding of one plate below another is called “subduction.” Subduction zone earthquakes occur as a direct result of the convergence of these two plates. Earthquakes at subduction zone boundaries produce the world’s greatest earthquakes. A subduction earthquake off the coast of Washington or Oregon where the plates converge would typically have a minute or more of strong ground shaking at Magnitude 8 to 9.5 on the Richter scale. Usually, damaging tsunamis and numerous large aftershocks immediately follow these types of earthquakes.

There are no reports of such earthquakes in the Cascadia Subduction Zone off the Oregon or Washington coast since the first written records of permanent occupation by Europeans in 1833. However, scientific evidence suggests that there may have been as many as five of these energy releases in the past 2,000 years, with an irregular recurrence interval of 150 to 1,100 years. Written tsunami records from Japan, correlated with studies of partially submerged forests in coastal Washington and Oregon, give a probable date for the most recent of these huge quakes as January 26, 1700.

Since the installation in 1969 of a multi-station seismograph network in Washington, there has been no evidence of even small subduction-type earthquakes in the Cascadia region, indicating that the plates are locked. However, parts of subduction zones in Japan and Chile also appear to have had very low levels of seismicity prior to experiencing great earthquakes. Therefore, the historical seismic inactivity observed along the coastal region of Washington and Oregon does not negate the possibility of an earthquake there with a magnitude greater than 8. Recent measurements near Seattle indicate that significant strain is accumulating parallel to the direction of convergence between the Juan de Fuca and North America plates, as would be expected prior to a great thrust earthquake off the coast of Oregon, Washington and British Columbia.

Benioff Deep Zone

Western Washington can experience deep earthquakes of Magnitude 6 to 7.4 on the Richter scale. This occurs within the Juan de Fuca plate at depths of about 30 to 40 miles. As the Juan de Fuca plate moves beneath North America, it becomes denser than the surrounding mantle rocks and breaks apart, causing Benioff zone earthquakes. The largest Benioff zone earthquakes occur where the Juan de Fuca plate begins to bend even more steeply downward, forming a knee.

The largest of these events recorded in modern times were the 7.1-magnitude Olympia earthquake in 1949 and the 6.8 magnitude Nisqually earthquake in 2001. Strong shaking during the Olympia earthquake lasted about 20 seconds. During the Nisqually quake, shaking lasted from about 30 seconds to more than 2 minutes. Since 1870, there have been seven deep earthquakes in the Puget Sound basin with measured or estimated magnitudes of 6.0 or larger. The epicenters of all of these events have been within about 50 miles of each other between Olympia and just north of Tacoma. Scientists estimate the recurrence interval for this type of quake to be 30 to 40 years for magnitude 6.5, and 50 to 70 years for magnitude 7.0. Because of their depth, intra-plate earthquakes are least likely to produce significant aftershocks.

Crustal Zone

The third source zone is the crust of the North American plate. These are known as shallow earthquakes. Shallow earthquakes with a magnitude of 7 or more on the Richter scale can happen anywhere in the Puget Sound region. Such earthquakes have the potential to cause greater loss of life and property than any other kind of disaster. Fortunately, great crustal quakes do not seem to happen very often—perhaps no more than once every 1,000 years.

The structure of the crust in the Puget Sound area is complex, with large sedimentary rock-filled basins beneath Tacoma, Seattle and Everett. The Seattle basin is the deepest, at about 5 to 6 miles. In addition to the 1872 Mount Baker earthquake, seismologists have found evidence that a devastating crustal quake occurred on a fault near Seattle approximately 1,100 years ago. The Duvall Fault near Lake Margaret on the King-Snohomish County border has produced two Magnitude 5.3 earthquakes in the past 70 years (1932 and 1996). How many other crustal faults pose significant earthquake hazards to the Puget Sound region is not yet known, but geologists and geophysicists are studying the South Whidbey Island Fault and the Olympia Fault for evidence of young earthquakes. In addition, a potential Everett fault has been identified and is currently being researched.

Crustal earthquakes are the least predictable of Puget Sound’s seismic threats and are the most likely to be followed by significant aftershocks. Following a great crustal earthquake of Magnitude 7.0 or more, one of the greatest dangers to human life is that buildings or other structures damaged in the initial shock but still in use and believed safe could collapse in a strong aftershock.

Maps of Earthquake Impact in Snohomish County

The impact of an earthquake is largely a function of the following components:

- Ground shaking (ground motion accelerations)
- Liquefaction (soil instability)
- Distance from the source (both horizontally and vertically).

Mapping that shows the impacts of these components was used to assess the risk to earthquakes within the planning area. While the impacts from each of these components can build upon each other during an earthquake event, the mapping looks at each component individually, so each map is mutually exclusive of the other. For example, liquefaction classifications have no direct correlation to soil classifications. The mapping used in this assessment is described below.

Shake Maps

A shake map is a representation of ground shaking produced by an earthquake. The information it presents is different from the earthquake magnitude and epicenter that are released after an earthquake because shake maps focus on the ground shaking produced by the earthquake, rather than the parameters describing the earthquake source. An earthquake has only one magnitude and one epicenter, but it produces a range of ground shaking at sites throughout the region depending on the distance from the earthquake, the rock and soil conditions at sites, and variations in the propagation of seismic waves from the earthquake due to complexities in the structure of the earth’s crust. A shake map is designed as a rapid response tool to portray the extent and variation of ground shaking throughout an affected region immediately following significant earthquakes.

Ground motion and intensity maps are derived from peak ground motion amplitudes recorded on seismic sensors (accelerometers), with interpolation based on estimated amplitudes where data are lacking, and site amplification corrections. These readings are recorded by state and federal agencies. Color-coded instrumental intensity maps are derived from empirical relations between peak ground motions and Modified Mercalli intensity.

A probabilistic seismic hazard map shows the hazard from earthquakes that geologists and seismologists agree could occur. The maps are expressed in terms of probability of exceeding a certain ground motion, such as the 10-percent probability of exceedance in 50 years. This level of ground shaking has been used for designing buildings in high seismic areas. Maps 12-1 and 12-2 illustrate the estimated ground motion for the 100-year and 500-year probabilistic earthquakes in Snohomish County.

Earthquake scenarios describe the expected ground motions and effects of specific hypothetical large earthquakes for a region. Maps of these scenarios can be used to support all phases of emergency management. For the Snohomish County planning area, shake maps are available for two scenarios:

- Devil’s Mountain Fault Scenario—This scenario is for a Magnitude 7.1 event with a shallow depth and epicenter 14 miles northeast of Arlington. This scenario is illustrated in Map 12-3.
- South Whidbey Island Fault Scenario—The South Whidbey Island Fault scenario is for a Magnitude 7.4 event with a depth of 0 miles and an epicenter 2 miles northeast of Langley. This scenario is illustrated in Map 12-4.

NEHRP Soil Maps

NEHRP soil types define the locations that will be significantly impacted by an earthquake. NEHRP Soils B and C typically can sustain low-magnitude ground shaking without much effect. The areas that are most commonly affected by ground shaking have NEHRP Soils D, E and F. Map 12-5 shows NEHRP soil classifications in the county.

Liquefaction Maps

In general areas with NEHRP Soils D, E and F are also susceptible to liquefaction, a secondary effect of an earthquake in which soils lose their shear strength and flow or behave as liquid, thereby damaging structures that derive their support from the soil. If there is a dry soil crust, excess water will sometimes come to the surface through cracks in the confining layer, bringing liquefied sand with it, creating sand boils, colloquially called "sand volcanoes." Soil liquefaction maps are useful tools to assess potential damage from earthquakes. Map 12-6 shows the liquefaction susceptibility in Snohomish County.

12.2.3 Frequency

The USGS has created a map of peak ground acceleration that takes into account current information on several fault zones. The Puget Sound area is in a higher-risk area, with a 2 percent probability in a 50-year period of ground shaking from a subduction zone event exceeding 70 percent of gravity. Figure 12-2 shows the expected peak horizontal ground motions for this probability (USGS Web Site, 2007).

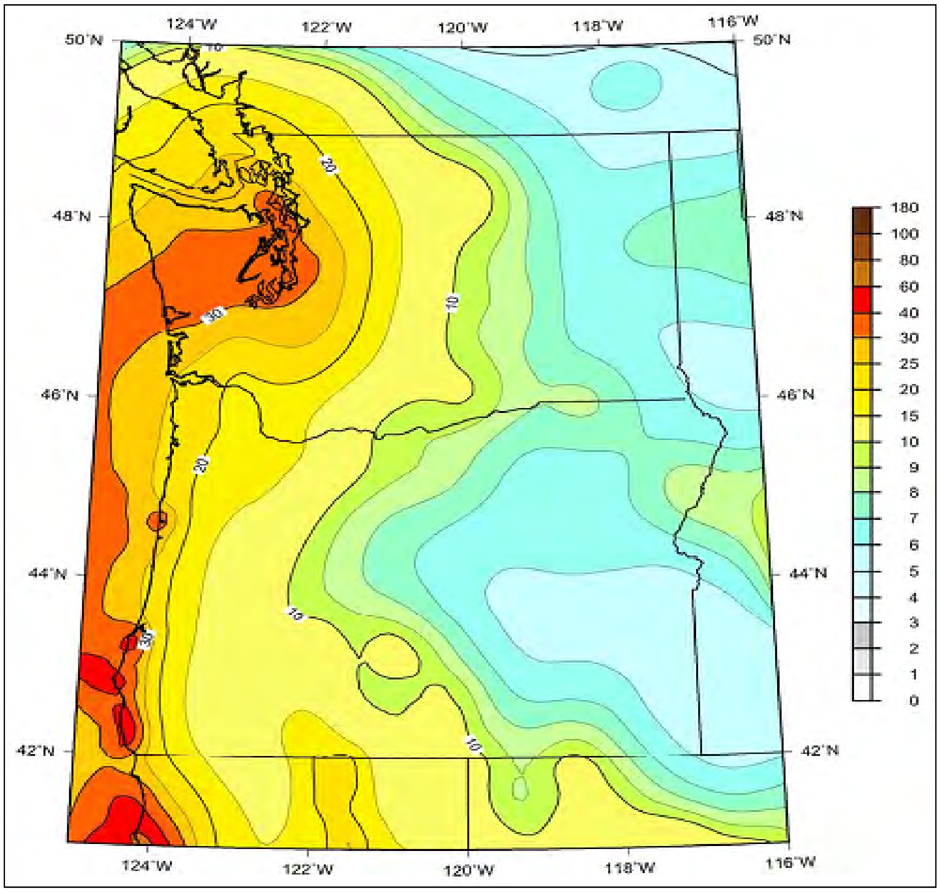

Figure 12-2. Peak Acceleration (%g) with 10-Percent Probability of Exceedance in 50 Years

The USGS estimated that a Cascadia Subduction Zone earthquake has a 10 to 15 percent probability of occurrence in 50 years, and a crustal zone earthquake has a recurrence interval of about 500 to 600 years. In general, it is difficult to estimate the probability of occurrence of crustal earthquake events. Earthquakes on the South Whidbey Island and Seattle Faults have a 2 percent probability of occurrence in

50 years. A Benioff zone earthquake has an 85 percent probability of occurrence in 50 years, making it the most likely of the three types. There is not yet enough information on the Devil's Mountain Fault—North Whidbey Fault complex to determine the probability of occurrence of an event on this complex.

12.2.4 Severity

The severity of an earthquake can be expressed in terms of intensity or magnitude. Intensity represents the observed effects of ground shaking on people, buildings, and natural features. Magnitude is related to the amount of seismic energy released at the hypocenter of the earthquake. It is based on the amplitude of the earthquake waves recorded on instruments. Magnitude is thus represented by a single, instrumentally determined value. Intensity varies depending on the location with respect to the earthquake epicenter. The expected magnitude of earthquakes in Snohomish County by type is as follows:

- Cascadia Subduction Zone—9.0 for approximately 4 minutes with aftershocks
- Benioff—7.1 with no aftershocks
- Crustal (North Whidbey-Devil's Peak Complex, South Whidbey Island, Possible Everett Fault)—7.1 with some aftershocks

12.2.5 Warning Time

There is currently no reliable way to predict the day or month that an earthquake will occur at any given location. Research is being done with warning systems that use the low energy waves that precede major earthquakes. These potential warning systems give approximately 40 seconds notice that a major earthquake is about to occur. The warning time is very short but it could allow for someone to get under a desk, step away from a hazardous material they are working with, or shut down a computer system.

12.3 SECONDARY HAZARDS

Earthquakes can cause large and sometimes disastrous landslides and mudslides. River valleys are vulnerable to slope failure, often as a result of loss of cohesion in clay-rich soils. Soil liquefaction occurs when water-saturated sands, silts or gravelly soils are shaken so violently that the individual grains lose contact with one another and float freely in the water, turning the ground into a pudding-like liquid. Building and road foundations lose load-bearing strength and may sink into what was previously solid ground. Unless properly secured, hazardous materials can be released, causing significant damage to the environment and people. Earthen dams and levees are highly susceptible to seismic events and the impacts of their eventual failures can be considered secondary risk exposure to earthquakes.

12.4 CLIMATE CHANGE IMPACTS

The impacts of global climate change on earthquake probability are unknown. Some scientists say melting glaciers could induce tectonic activity. As ice melts and water runs off, tremendous amounts of weight are shifted on the Earth's crust. As newly freed crust settles back to its original, pre-glacier shape, it could cause seismic plates to slip and stimulate volcanic activity according to research into prehistoric earthquakes and volcanic activity. NASA and USGS scientists found that retreating glaciers in southern Alaska may be opening the way for future earthquakes (NASA, 2004).

The secondary impacts of earthquakes could be magnified by climate change. Soils saturated by repetitive storms could fail during seismic activity due to the increased saturation. Dams storing increased volumes of water due to changes in the hydrograph could fail during seismic events. Fire risks associated with earthquakes could be significantly enhanced by drought conditions triggered by climate change. There are currently no models available to estimate these impacts.

12.5 EXPOSURE

12.5.1 Population

The entire population of Snohomish County is potentially exposed to earthquakes. Although the vulnerability is low, cities are more at risk than rural areas due to higher density. Towns are also more vulnerable because they are typically located in small valleys alongside streams, which typically have softer soils. Many communities in Snohomish County have buildings that were built during the beginning of the 20th century and were not subject to the building codes implemented over the last 30 years, which require that structures be able to better withstand earthquakes. Ornamentation (such as parapets) and chimneys may be shaken loose during an earthquake and fall on people walking below.

12.5.2 Property

According to the Snohomish County Assessor, there are 235,928 buildings in Snohomish County, with a total assessed value of $93.5 billion. The majority of these buildings (94.3 percent) are residential. Since all structures in the planning area are susceptible to earthquake impacts to varying degrees, this represents the exposure to seismic events within the County. All are considered to be exposed to the earthquake hazard. The Washington State Building Code Council identifies significant milestones in building and seismic code requirements that directly affect the structural integrity of development in Washington. Using these time periods, the planning team used HAZUS to identify the number of structures within the County by date of construction. Table 12-6 shows the results of this analysis.

TABLE 12-6.
AGE OF STRUCTURES IN SNOHOMISH COUNTY

Time Period	Number of Structures Built in Snohomish County	Significance of Time Frame
Pre-1933	14,269	Before 1933, there were no explicit earthquake requirements in building codes. State law did not require local governments to have building officials or issue building permits.
1933-1940	3,112	In 1940, the first strong motion recording was made.
1941-1960	24,501	In 1960, the Structural Engineers Association of California published guidelines on recommended earthquake provisions.
1961-1975	38,311	In 1975, significant improvements were made to lateral force requirements.
1976-1994	85,036	In 1994, the Uniform Building Code was amended to include provisions for seismic safety.
1994 - present	70,699	Seismic code is currently enforced.
Total	**235,928**	

The number of structures does not reflect the number of total housing units, as many multi-family units and attached housing units are reported as one structure. Approximately 30 percent of the planning area's structures were constructed after the Uniform Building Code was amended in 1994 to include seismic safety provisions. Approximately 6 percent of the structures were built before 1933 when there were no building permits, inspections, or seismic standards.

12.5.3 Critical Facilities and Infrastructure

All critical facilities in Snohomish County are exposed to the earthquake hazard. Table 12-7 lists the number of each type of facility exposed.

TABLE 12-7.
SNOHOMISH COUNTY CRITICAL FACILITIES EXPOSED TO THE EARTHQUAKE HAZARD

Medical and Health	39	Bridges	466
Government Functions	74	Water supply	36
Protective Functions	107	Waste water	46
Schools	243	Power	5
Hazmat	67	Communications	5
Other Critical Functions	31	**Total**	**1,119**

The critical facilities identified for this plan are classified in the HAZUS-MH program as facilities (buildings), hazardous material sites, or infrastructure. Hazardous materials releases from fixed facilities and transportation-related releases can occur during an earthquake event. Transportation corridors such as I-5, SR-2, SR-9 and the BNSF railroad can be disrupted during an earthquake and release materials into the surrounding environment. Facilities holding hazardous materials are of particular concern because of possible isolation of neighborhoods surrounding them. There are 42 businesses that have Tier II hazardous materials on NEHRP D soils and 20 on NEHRP E and F soils. During an earthquake, structures storing these materials could rupture and leak into the surrounding area, a river or Puget Sound, having a disastrous effect on the environment.

12.5.4 Environment

Environmental problems as a result of an earthquake can be numerous. Secondary hazards will likely have some of the most damaging effects on the environment. Earthquake-induced landslides in landslide-prone areas can significantly impact surrounding habitat. It is also possible for streams to be rerouted after an earthquake. This can change the water quality, possibly damaging habitat and feeding areas. There is a possibility of streams fed by groundwater drying up because of changes in underlying geology.

12.6 VULNERABILITY

The data in this section was generated using the HAZUS-MH program for earthquakes. Once the location and size of a hypothetical earthquake are identified, HAZUS-MH estimates the intensity of the ground shaking, the number of buildings damaged, the number of casualties, the amount of damage to transportation systems and utilities, the number of people displaced from their homes, and the estimated cost of repair and clean up.

12.6.1 Population

Three population groups were identified as particularly vulnerable to earthquake hazards:

- **Linguistically Isolated Populations**——1,222 persons are listed as being linguistically isolated (they do not speak English as their native language) in the census blocks on NEHRP D, E and F soils. This is about 6 percent of the people in these census blocks. They are particularly vulnerable during earthquake events because of communication issues with the predominantly English-speaking media and government. A difficulty arises when there is an urgent need to inform non-English speaking residents of an earthquake event or response.

- **Population below Poverty Level**—8,149 people are listed as being below the poverty level within the census blocks on NEHRP D, E and F soils. They make up about 9 percent of the population. These people are vulnerable because they may not have the financial ability to secure or improve their homes to prevent or mitigate earthquake damage. Poorer residents are also less likely to have insurance to compensate for losses in earthquakes. This means that poorer residents have the most to lose during an event, and at the same time are the least prepared to deal with losses.
- **Population over 65 Years Old**—17,184 people are over 65 years old in the census blocks on NEHRP D, E and F soils. This makes up about 19 percent of the total population. This population group is vulnerable because they are more likely to need special medical attention, which may not be available due to isolation caused by earthquakes. Elderly residents also have more difficulty leaving their homes during earthquake events and could be stranded in dangerous situations. About 6 percent of the over-65 population has income below the poverty line and is extremely vulnerable.

12.6.2 Property

Loss estimates for the planning area were generated for the 100-year and 500-year earthquake events as well as the two scenario events through a Level 2 analysis using HAZUS-MH. The results of these analyses are summarized in Tables 12-8 and 12-9. The data are segregated into structural and non-structural categories. Structural losses represent damage to individual structures. Non-structural losses represent the cost of contents, inventory, relocation, income loss, rental loss, and wage loss. A summary of results is as follows:

- For a 100-year earthquake, the estimated damage potential is $616 million, or 0.51 percent of the total assessed value for the planning area.
- For a 500-year earthquake, the estimated damage potential is $4.4 billion, or 4.73 percent of the total assessed value for the planning area.
- For a 7.1-magnitude event on the Devils Mountain Fault, the estimated damage potential is $274 million, or 0.10 percent of the total assessed value for the planning area.
- For a 7.4-magnitude event on the South Whidbey Island Fault, the estimated damage potential is $6.7 billion, or 7.21 percent of the total assessed value for the planning area.

Other potential losses estimated by HAZUS-MH include the following:

- A 100-year event within the planning area could displace up to 2,022 households, with over 1,200 persons needing short-term shelter. A 500-year event could displace up to 7,848 households with over 4,500 persons requiring short-term shelter.
- A Devil’s Mountain event could displace up to 40 households, with over 25 persons needing short-term shelter. A South Whidbey Island Fault event could displace up to 11,083 households with over 6500 persons requiring short-term shelter.
- A 100-year event could create as much as 370,000 tons of debris to be removed, and a 500-year event could create as much as 1,641,288 tons of debris within the planning area.
- A Devil’s Mountain fault event could generate as much as 79,000 tons of debris, and a South Whidbey Island Fault event could generate over 2.3 million tons of debris.

TABLE 12-8.
EARTHQUAKE BUILDING LOSS POTENTIAL—PROBABILISTIC

	Estimated Earthquake Losses by Occupancy Class					
	100- Year Probabilistic Earthquake			500- Year Probabilistic Earthquake		
Jurisdiction	Structural	Contents	**Total**	Structural	Contents	**Total**
Arlington	$14,205,640	$4,876,980	**$19,082,620**	$67,196,423	$22,600,529	**$89,796,951**
Bothell	$22,321,500	$6,351,130	**$28,672,630**	$105,205,693	$27,455,735	**$132,661,428**
Brier	$8,923,020	$2,491,460	**$11,414,480**	$40,082,224	$10,143,671	**$50,225,896**
Darrington	$993,582	$276,983	**$1,270,565**	$4,318,043	$1,454,742	**$5,772,784**
Edmonds	$57,131,800	$17,171,360	**$74,303,160**	$257,911,067	$68,850,828	**$326,761,895**
Everett	$134,586,730	$40,967,883	**$175,554,613**	$713,355,851	$198,024,244	**$911,380,096**
Gold Bar	$3,398,380	$884,904	**$4,283,284**	$15,092,036	$4,142,900	**$19,234,936**
Granite Falls	$4,820,100	$1,307,360	**$6,127,460**	$21,070,582	$6,035,830	**$27,106,413**
Index	$462,607	$120,756	**$583,363**	$2,037,105	$557,933	**$2,595,038**
Lake Stevens	$13,713,530	$3,957,719	**$17,671,249**	$64,841,303	$19,066,733	**$83,908,036**
Lynwood	$54,494,241	$16,314,050	**$70,808,291**	$251,344,713	$67,403,814	**$318,748,527**
Marysville	$39,144,580	$11,406,785	**$50,551,365**	$185,242,714	$54,475,203	**$239,717,917**
Mill Creek	$15,862,950	$4,357,370	**$20,220,320**	$81,826,411	$20,556,537	**$102,382,948**
Monroe	$18,146,470	$5,843,350	**$23,989,820**	$89,272,396	$27,771,397	**$117,043,793**
Mountlake Terrace	$26,933,670	$8,099,540	**$35,033,210**	$123,871,473	$33,280,522	**$157,151,995**
Mukilteo	$29,046,340	$9,434,670	**$38,481,010**	$145,109,777	$42,066,047	**$187,175,824**
Snohomish	$15,240,830	$4,508,810	**$19,749,640**	$76,552,624	$21,724,180	**$98,276,804**
Stanwood	$6,028,510	$1,866,740	**$7,895,250**	$31,985,016	$9,264,762	**$41,249,778**
Sultan	$3,165,950	$920,523	**$4,086,473**	$14,045,271	$4,241,924	**$18,287,195**
Woodway	$3,169,012	$951,940	**$4,120,951**	$7,130,099	$1,850,373	**$8,980,472**
Unincorporated County	$1,612,460	$474,927	**$2,087,387**	$1,166,869,412	$321,081,182	**$1,487,950,594**
Total	**$473,401,902**	**$142,585,240**	**$615,987,141**	**$3,464,360,233**	**$962,049,086**	**$4,426,409,320**

TABLE 12-9.
EARTHQUAKE BUILDING LOSS POTENTIAL—SCENARIO EVENTS

	Estimated Earthquake Losses by Occupancy Class					
	7.1 M Devil's Mountain Fault			7.4 M S. Whidbey Fault		
Jurisdiction	Structural	Contents	**Total**	Structural	Contents	**Total**
Arlington	$19,462,483	$10,891,264	**$30,353,747**	$37,657,801	$12,582,124	**$50,239,925**
Bothell	$1,364,603	$526,804	**$1,891,407**	$164,903,807	$43,851,305	**$208,755,112**
Brier	$346,066	$201,025	**$547,091**	$45,966,792	$12,538,838	**$58,505,630**
Darrington	$1,257,451	$703,639	**$1,961,089**	$2,360,334	$788,457	**$3,148,791**
Edmonds	$2,891,170	$2,662,992	**$5,554,162**	$163,568,446	$51,427,146	**$214,995,593**
Everett	$25,583,690	$11,144,793	**$36,728,483**	$1,335,291,869	$378,798,466	**$1,714,090,335**
Gold Bar	$434,700	$254,528	**$689,228**	$1,957,479	$787,073	**$2,744,552**
Granite Falls	$3,784,534	$351,080	**$4,135,614**	$10,711,645	$3,425,112	**$14,136,757**
Index	$61,321	$35,906	**$97,227**	$267,463	$107,555	**$375,019**
Lake Stevens	$4,154,543	$1,155,412	**$5,309,955**	$29,475,576	$10,796,511	**$40,272,087**
Lynwood	$2,596,698	$1,216,427	**$3,813,125**	$211,014,025	$62,125,503	**$273,139,529**
Marysville	$24,431,008	$11,449,077	**$35,880,085**	$256,685,532	$68,645,033	**$325,330,565**
Mill Creek	$978,633	$788,324	**$1,766,957**	$228,230,008	$54,374,975	**$282,604,982**
Monroe	$5,304,172	$522,829	**$5,827,000**	$201,270,084	$57,607,818	**$258,877,902**
Mountlake Terrace	$1,233,615	$923,497	**$2,157,112**	$66,009,900	$22,478,599	**$88,488,499**
Mukilteo	$3,210,776	$1,153,549	**$4,364,325**	$331,391,977	$96,465,900	**$427,857,877**
Snohomish	$3,465,274	$817,978	**$4,283,252**	$150,997,863	$41,710,555	**$192,708,418**
Stanwood	$13,103,206	$4,419,507	**$17,522,713**	$74,814,203	$19,548,658	**$94,362,861**
Sultan	$1,228,802	$254,528	**$1,483,330**	$6,526,895	$2,141,546	**$8,668,440**
Woodway	$60,676	$455,533	**$516,209**	$2,381,977	$941,582	**$3,323,559**
Unincorporated County	$67,858,307	$40,761,096	**$108,619,403**	$1,943,861,917	$532,480,558	**$2,476,342,475**
Total	**$182,811,728**	**$90,689,788**	**$273,501,514**	**$5,265,345,593**	**$1,473,623,314**	**$6,738,968,908**

12.6.3 Critical Facilities and Infrastructure

Level of Damage

The inventory of critical facilities as defined by the Steering Committee was entered into HAZUS-MH to determine the vulnerability of these facilities to earthquake damage. Critical facilities were categorized into the following levels of vulnerability: no damage, slight damage, moderate damage, extensive damage, or complete damage. HAZUS-MH calculated the probability of damage under each of these categories for the 100-year probabilistic event and the South Whidbey Island Fault event. These events were selected because they have the highest probability of occurrence (100-year event) and the largest potential impact on the planning area (South Whidbey Island Fault event). Tables 12-10 and 12-11 summarize the results.

TABLE 12-10.
VULNERABILITY OF CRITICAL FACILITIES FROM A 100-YEAR EARTHQUAKE EVENT

Category	No Damage	Slight Damage	Moderate Damage	Extensive Damage	Complete Damage
Medical and Health	20	12	7	0	0
Government Functions	30	27	17	0	0
Protective Functions	45	33	25	4	0
Schools	127	107	6	3	0
Hazmat	—	—	—	—	—
Other Critical Functions	5	15	9	2	0
Bridges	400	28	20	18	0
Water supply	0	29	6	1	0
Waste water	0	15	31	0	0
Power	4	1	0	0	0
Communications	—	—	—	—	—
Total	**594**	**237**	**145**	**21**	**0**

TABLE 12-11.
VULNERABILITY OF CRITICAL FACILITIES FROM A SOUTH WHIDBEY ISLAND FAULT EVENT

Category	No Damage	Slight Damage	Moderate Damage	Extensive Damage	Complete Damage
Medical and Health	0	15	19	2	0
Government Functions	3	35	24	7	5
Protective Functions	5	51	35	10	6
Schools	74	107	56	5	1
Hazmat	—	—	—	—	—
Other Critical Functions	0	12	16	3	0
Bridges	149	70	46	103	98
Water supply	0	15	15	6	0
Waste water	0	10	21	14	1
Power	1	2	2	0	0
Communications	—	—	—	—	—
Total	**232**	**317**	**234**	**150**	**111**

Time to Return to Functionality

HAZUS-MH estimates the expected time required to restore critical facilities to fully functional use. HAZUS-MH presents this data in the form of percent probability of being functional at specified time increments post-event: 1, 3, 7, 14, 30 and 90 days after the event occurs. For example, HAZUS-MH may estimate that a facility has 5 percent chance of being fully functional at Day 3, and a 95-percent chance of being fully functional at Day 90. The functionality analysis was performed for all critical facilities and infrastructure components in the planning area for both the 100-year and South Whidbey Island Fault earthquake events. Results are summarized in Tables 12-12 and 12-13.

TABLE 12-12.
FUNCTIONALITY OF CRITICAL FACILITIES, 100-YEAR EARTHQUAKE

	# of Critical	Probability of Being Fully Functional (%)					
Planning Unit	Facilities	at Day 1	at Day 3	at Day 7	at Day 14	at Day 30	at Day 90
Medical and Health	39	71	72	92	92	99	100
Government Functions	74	73	73	88	89	98	99
Protective Functions	107	73	73	88	89	98	99
Schools	243	81	82	96	96	100	100
Other Critical functions	31	84	91	94	95	95	98
Bridges	466	**95**	**97**	**97**	**98**	**98**	**99**
Water supply	36	76	96	98	99	99	100
Waste water	46	49	82	95	96	97	99
Power	5	60	87	98	100	100	100
Communications	5	61	88	92	100	100	100
Total/Average	**1,052**	**72**	**85**	**94**	**96**	**98**	**99**

TABLE 12-13.
FUNCTIONALITY OF CRITICAL FACILITIES, SOUTH WHIDBEY ISLAND FAULT EARTHQUAKE

	# of Critical	Probability of Being Fully Functional (%)					
Planning Unit	Facilities	at Day 1	at Day 3	at Day 7	at Day 14	at Day 30	at Day 90
Medical and Health	39	22	23	53	53	88	93
Government Functions	74	35	35	65	65	86	91
Protective Functions	107	35	35	65	65	86	91
Schools	243	36	36	74	75	96	97
Other Critical functions	31	64	75	79	79	81	88
Bridges	466	77	80	82	83	84	89
Water supply	36	36	65	73	75	81	95
Waste water	46	21	49	68	72	82	96
Power	5	28	56	81	93	96	100
Communications	5	54	73	80	89	94	99
Total/Average	**1,052**	**41**	**55**	**73**	**76**	**88**	**94**

12.6.4 Environment

The environment vulnerable to earthquake hazard is the same as the environment exposed to the hazard.

12.7 FUTURE TRENDS IN DEVELOPMENT

The Washington Growth Management Act (36.70A RCW) established review and evaluation programs to monitor development and the densities at which it has occurred under each jurisdiction's comprehensive plan and development regulations. Using this information, an evaluation of the sufficiency of the remaining suitable residential, commercial and industrial land supply within urban growth areas (UGAs) to accommodate projected growth at development densities observed since the adoption of GMA plans is required at least every 5 years. This buildable lands report compares planned versus actual urban densities in order to determine whether the original plan assumptions regarding land use and supply were accurate.

Snohomish County's most recent buildable lands report was completed in October 2007. The methodology applied to this report excludes areas designated as "critical areas" from consideration as buildable lands due to the scope of regulations affecting such areas. The analysis assumes that these regulations will discourage development from these areas. The key findings of the buildable lands report are as follows:

- At the Countywide UGA level:
  - Urban densities are being achieved that are consistent with GMA comprehensive plans.
  - There is adequate land capacity outside of recognized critical areas to accommodate the adopted 2025 UGA population and growth targets.
- There appears to be a population growth target/capacity inconsistency within the Monroe UGA and an employment growth target/capacity inconsistency in the Lake Stevens UGA.
- The following areas appear to have very minor deficits in capacity relative to the 2025 population and employment targets:
  - The Gold Bar UGA and the City of Mill creek for population
  - The City of Brier, Town of Index, City of Marysville and Town of Woodway for employment.

  Given the uncertainties and limitation of the available data and methods, these minor differences do not indicate inconsistencies. But it is reasonable to review the initial results and monitor them over the next 5-year period.

Based on these findings, Snohomish County and its planning partners appear to be well equipped to deal with future growth and development. The geologic hazard portions of the planning area are heavily regulated pursuant to GMA mandates as well as provisions stipulated for seismic risk under the International Building Code. Development will occur in the planning area, but it will be regulated such that the degree of risk will be reduced through building standards and performance measures.

12.8 SCENARIO

A crustal zone earthquake affecting Snohomish County could have a magnitude of 8.0 or higher. Potential warning systems could give approximately 40 seconds notice that a major earthquake is about to occur. This would not provide adequate time for preparation. An earthquake of this magnitude would lead to massive structural failure of property on NEHRP C, D, E, and F soils. Levees and revetments built on these poor soils would likely fail, representing a loss of critical infrastructure. This event would cause secondary hazards including landslides and mudslides that would further damage structures. River valley hydraulic-fill sediment areas are also vulnerable to slope failure, often as a result of loss of cohesion in clay-rich soils. Soil liquefaction would occur in water-saturated sands, silts or gravelly soils.

12.9 ISSUES

Important issues associated with an earthquake include but are not limited to the following:

- Appropriate geotechnical standards should be established that take into account the probable impacts from earthquakes in the design and construction of new or enhanced facilities.
- The County has over 114 miles of earthen levees and revetments on soft, unstable soil. These soils are prone to liquefaction, which would severely undermine the integrity of these facilities.
- Earthquakes could trigger other natural hazard events such as dam failures, landslides or volcanic activity, which could severely impact County facilities.
- A worst-case scenario would be the occurrence of a large seismic event during a flood or high-water event. Levee failures would happen at multiple locations, increasing the impacts of the individual events.