

EARTHQUAKE

DEFINITIONS:

Earthquake – A sudden slip on a fault and the resulting ground shaking and radiated seismic energy caused by the slip; or by volcanic or magmatic activity; or other sudden stress changes in the earth.

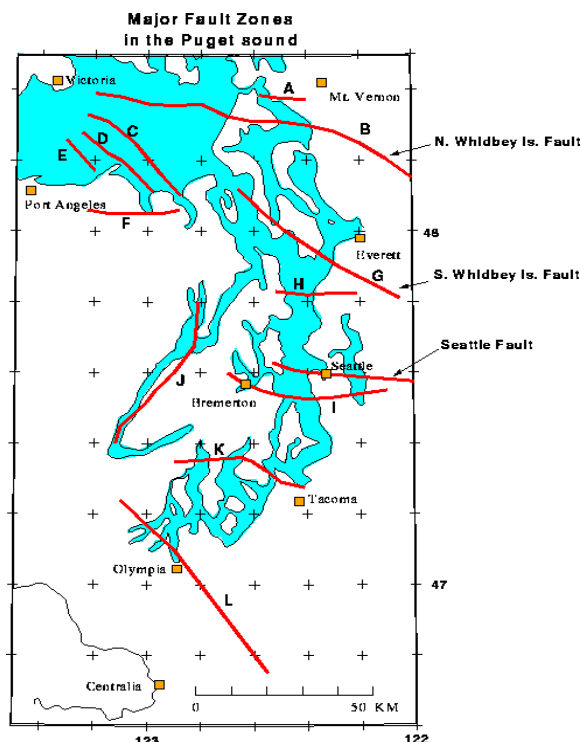
Epicenter – The point on the earth's surface vertically above the focus, the point in the crust where a seismic rupture begins.

Focus – The point within the earth where an earthquake rupture starts.

Liquefaction – A process by which water-saturated sediment temporarily loses strength and acts as a fluid similar to when a person wiggles their toes in the wet sand near the water at a beach.

Seiche – The sloshing action of an enclosed body or partially enclosed body of water from earthquake shaking.

Tsunami – A sea wave of local or distant origin that results from large-scale seafloor displacements associated with large earthquakes, major submarine slides, or exploding volcanic islands.



BACKGROUND INFORMATION:

Washington ranks second in the nation (after California) among states susceptible to earthquake loss according to a Federal Emergency Management Agency (FEMA) study. More than 1,000 earthquakes are recorded in the state annually, the majority of these occurring in the Puget Sound region. Most of these earthquakes are so small that only very sensitive instruments can detect them – a small number of these earthquakes cause shaking and occasional damage. Depending upon the magnitude and depth of an earthquake, the effects of an earthquake can be felt over large geographical areas.

Large oceanic and continental tectonic plates move over the surface of the earth at a rate of a few centimeters each year. Where these plates

collide stresses build up eventually releasing energy as earthquakes.

Washington State is located near the middle of an offshore tectonic plate convergent boundary called the Cascadia Subduction Zone that extends from southern British Columbia to northern California. The inland extent of related earthquake activity is the Cascade Mountain Range where the volcanoes mark the melting edge of the subducting (sinking) Juan de Fuca Plate.

HISTORY:

Of the many earthquakes that occur in our region on an annual basis, only a few are large enough to cause ground shaking and property damage. Washington State has experienced at least 20 damaging earthquakes during the past 125 years. Earthquakes in 1949 and 1965 (with magnitudes of 7.1 and 6.5 respectively) killed 15 people and caused more than \$200,000,000 (1984 dollars) in damage throughout several counties. The most recent damaging earthquake in Western Washington occurred on February 28, 2001. This earthquake, called the Nisqually Earthquake, was a deep, 6.8 magnitude earthquake located approximately 12 miles northeast of Olympia in the Puget Sound. One person died of a heart attack, 700 people were injured; damages were greater than \$1,000,000,000 as a result of the Nisqually Earthquake. **In Skagit County, public damage totaled almost \$175,000 and 402 private damage claims were submitted to FEMA totaling just over \$479,000.**

Significant Earthquakes in Washington State				
(Information obtained from Washington State Military Department, Emergency Management Division)				
Date	Time (PST)	Depth	Magnitude	Approximate Location
December 14, 1872	2140 Hours	shallow	7.4 Richter	North Cascades
December 12, 1880	2040 Hours		5.5 Richter	Puget Sound
April 30, 1882	2248 Hours	deep	6.0 Richter	Olympia Area
November 29, 1891	1521 Hours		5.0 Richter	Puget Sound
March 6, 1893	1703 Hours	shallow	4.9 Richter	Southeast Washington
January 3, 1896	2215 Hours		5.7 Richter	Puget Sound
March 16, 1904	2020 Hours		5.3 Richter	Olympic Mountains
January 11, 1909	1549 Hours	deep	6.0 Richter	Puget Sound
August 18, 1915	0605 Hours		5.6 Richter	North Cascades
January 23, 1920	2309 Hours		5.5 Richter	Puget Sound
July 17, 1932	2201 Hours	shallow	5.2 Richter	Central Cascades
July 15, 1936	2308 Hours	shallow	5.7 Richter	Southwest Washington
November 12, 1939	2346 Hours	deep	5.7 Richter	Puget Sound
April 29, 1945	1216 Hours		5.5 Richter	Central Cascades
February 14, 1946	1914 Hours	40 Km	6.3 Richter	Puget Sound
April 13, 1949	1155 Hours	54 Km	7.1 Richter	Puget Sound
August 5, 1959	1944 Hours	35 Km		Northwest Cascades
April 29, 1965	0728 Hours	63 Km	6.5 Richter	Puget Sound
February 13, 1981	2209 Hours	7 Km	5.5 Richter	South Cascades
April 13, 1990	2133 Hours	5 Km	5.0 Richter	Deming Area
January 28, 1995	1911 Hours	16 Km	5.0 Richter	17.6 Km NE of Tacoma
May 2, 1996	2104 Hours	7 Km	5.3 Richter	10.2 Km NE of Duvall
June 23, 1997	1113 Hours	7.4 Km	4.9 Richter	5.5 Km NE of Bremerton
July 2, 1999	1743 Hours	41 Km	5.1 Richter	8.2 Km N or Satsop
February 28, 2001	1054 Hours	52.4 Km	6.8 Richter	17.6 Km NE of Olympia

In recent years, geologists have discovered evidence that very large earthquakes have occurred repeatedly in the past. The interval between these very large earthquakes is estimated to range from 100 to 1,000 years. Some of this evidence includes:

- Massive block landslides within Lake Washington.
- Large rock avalanches on the Olympic Peninsula.
- Possible tsunami deposits at West Point in Seattle and at Cultus Bay on Whidbey Island.

The 1964 Alaska Earthquake measured 9.2 on the Richter Scale and caused widespread destruction in the City of Anchorage as well as other areas of Alaska and was noted on land and sea as far away as the Caribbean. This earthquake caused tsunamis along the West Coast of Canada, the United States, and in Hawaii. In addition, this earthquake caused seiche action in rivers, lakes and bayous as far away as the Gulf Coast of Louisiana and Texas resulting in minor damage.

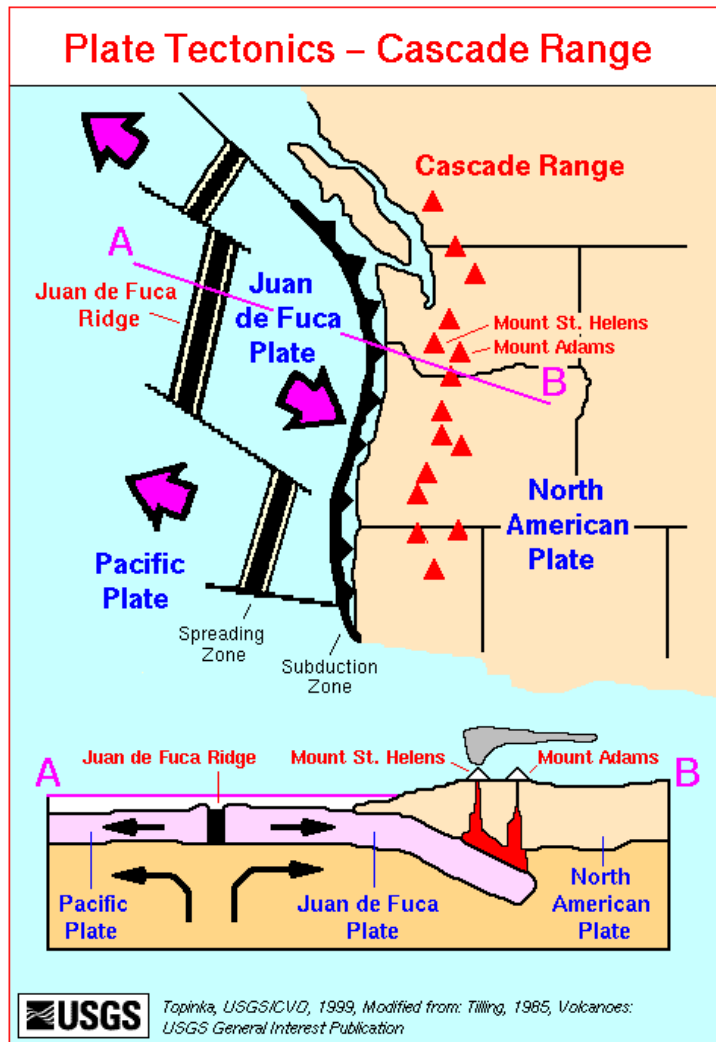
HAZARD IDENTIFICATION:

In recent years, scientists have greatly expanded their knowledge concerning the seismic vulnerability of the Puget Sound region. Seismologists have identified three distinct sources of earthquakes in the Pacific Northwest.

Shallow (crustal zone) earthquakes that occur along near-surface faults and fractures within the Earth’s crust at depths less than 30 Kilometers.

Shallow earthquakes with magnitudes of up to 7 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 damage in Skagit County than any other kind of disaster. Fortunately, great crustal earthquakes are quite rare and occur perhaps only once every 1,000 years.

Deep (intraplate) earthquakes that occur from faulting in the subducting (Juan de Fuca) plate, usually at depths between 50 and 70 Kilometers of the Earth’s surface.

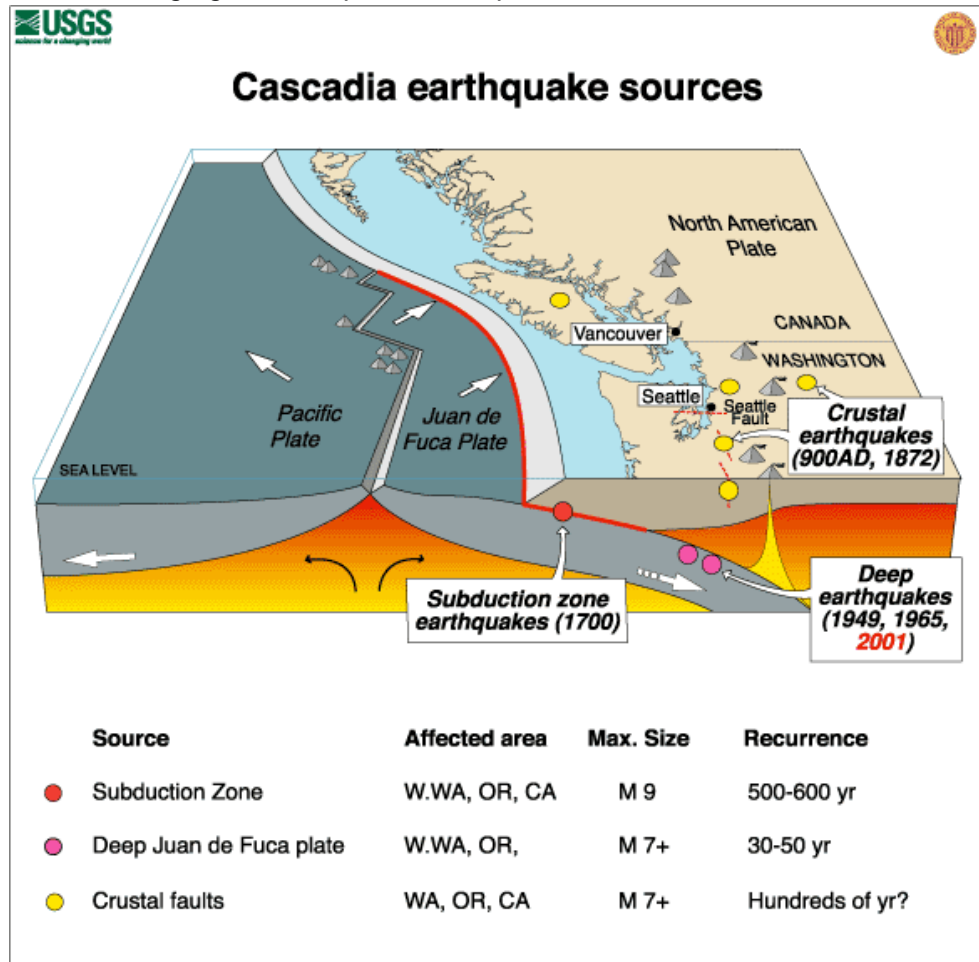


Deep or intraplate earthquakes with magnitudes ranging from 6 to 7 (or greater) on the Richter Scale are very likely to occur in Western Washington. The largest of these events recorded in recent years were the 1949 Olympia Earthquake with a magnitude 7.1 on the Richter Scale and the 2001 Nisqually Earthquake with a magnitude 6.8 on the Richter Scale. Scientists estimate the recurrence interval for this type of earthquake to be 30 to 40 years for a magnitude 6.5 (Richter) event and 50 to 70 years for a magnitude 7.0 (Richter) event. Because of their depth, intraplate earthquakes are least likely to produce significant aftershocks.

Subduction (Subduction Zone) earthquakes are caused by the release of the friction and stresses generated as two converging tectonic plates slide past one another. The world's greatest earthquakes are observed at subduction zone boundaries.

Subduction earthquakes have the potential of being large quakes (with magnitudes exceeding 8 on the Richter Scale) that may affect a large geographical area and may be accompanied by tsunamis and large aftershocks.

The figure to the right shows the relationship of the subducting Juan de Fuca Plate and the overriding North American Plate as they contact each other and attempt to move in opposite directions from each other.



Earthquakes cause damage primarily by strong ground shaking and secondarily from the effects of ground failures as well as tsunamis and seiches. Ground failures caused by earthquakes include fault rupture, ground cracking, slumps, landslides, rock falls, liquefaction, uplift and subsidence.

As a rule, the severity of ground shaking generally decreases with distance from the earthquake source. Given an earthquake of a certain magnitude, the severity of ground shaking will

generally lessen the farther you are located from the epicenter of the earthquake or the deeper the earthquake occurs.

There are several faults and fault zones that have been identified in the Puget Sound area; the Seattle Fault, South Whidbey Island Fault, and the North Whidbey Island Fault to name a few.

Skagit County is home to many faults, most of which are inactive. However, according to the Washington State Department of Natural Resources Geology Division, the Devils Mountain Fault that runs generally east to west through the central part of the county has recently been determined to be active. There are many other fault lines that have been identified in Skagit County including The Bellingham Bay—Lake Chaplain Fault, the Ross Lake Fault and the Hamilton Fault, which may or may not be active. (Source: Alternative Interpretations of the Seismic and Geologic Hazards to the Skagit Nuclear Power Site, Eric Cheeney, 1977)

The following list is a compilation of comments and suggestions made by various stakeholders and the public regarding possible problems that could result from an earthquake.

In addition to damaging homes, businesses, property, and the environment, an earthquake in Skagit County could potentially result in the following:

- Utilities (above and below ground) including telephone, electricity, natural gas, water, and sewer as well as private wells and water systems could be damaged or destroyed.
- Transportation routes and/or systems including roads, bridges, railroad, and ferry transport may be damaged or destroyed.
- Emergency services could be totally overwhelmed and not able to respond to emergency situations due to damaged facilities and/or equipment, a lack of personnel, or damaged transportation routes.
- Critical facilities such as 9-1-1 centers, hospitals, emergency operations centers, fire stations, water treatment plants, and wastewater treatment facilities may be damaged or destroyed.
- Large areas of the county may be subject to liquefaction and/or land movement causing even greater damage in certain areas.
- Large hazardous materials incidents may occur as the result of damage to local oil refineries and chemical plants.
- Levees and salt-water dikes may be damaged.
- Large hydroelectric dams located in eastern Skagit County and Whatcom County may be damaged or possibly fail causing possible flooding of those areas located within the 100-year and possibly the 500-year floodplain.

- Localized seiche action in local waters may result in increased levels of damage along shoreline areas within the county.
- The arrival of outside resources to assist with debris removal, repair of critical facilities, and sheltering of victims may be delayed due to severe damage in adjacent counties with larger populations and needs.
- The overall economy of the county and possibly the region could be affected.

VULNERABILITY ASSESSMENT:

In the simplest of terms ... the entire population is vulnerable to the effects and impacts of a large (magnitude greater than 7 Richter) earthquake. The floodplains of the Skagit River and Samish River are particularly vulnerable due to large areas of lahar deposits that underlay the alluvial soils of the area. Liquefaction of these soils as the result of a large earthquake is a serious concern. In addition, all commercial and residential buildings, government infrastructure, transportation systems, communication systems, utilities, and ultimately, the overall economy of Skagit County are vulnerable to the effects and impacts of a large earthquake.

The time of day at which an earthquake occurs is critical. Greater numbers of people are away from their homes and separated from other family members during high commute times or during the regular business day thereby increasing the level of chaos in the event of a major earthquake.

Possible types of damage from an earthquake may include but will probably not be limited to:

- Cracking and/or structural failure of foundations, chimneys, decorative cornices, parapet walls, and cantilevered porches or roofs.
- Wall failure in older buildings of non-reinforced masonry construction.
- Damage to waterfront buildings and piers built on pilings and artificial fill.
- Structural damage or failure of bridges.
- Damage to streets and roads.
- Damage to railways and airport facilities.
- Broken water lines and natural gas lines.
- Power and communication failures due to damage of electrical and telephone distribution systems.

In the event that an earthquake causes considerable damage, grocery stores, banks, gasoline stations, and similar services may be closed. In addition, citizens should expect and prepare in advance for a significant delay in fire, emergency medical, law enforcement, and other day-to-day government services. As a general rule, citizens should be prepared to survive on their own for a minimum of 72 hours following a large magnitude earthquake that causes major damage to transportation and communication systems as well as roads and bridges.

In the event of a major earthquake, large areas of western Skagit County lying within the floodplains of the Samish River and the Skagit River are susceptible to liquefaction. In addition, steep and/or unstable slopes in various locations throughout the county are susceptible to

landslides. Large earthquake events may cause large-scale landslides or avalanches on steep mountains slopes as well as possible structural failure of hydroelectric dams located on the Baker River and Skagit River in Eastern Skagit County.

Bridges are the most vulnerable component of highway transportation systems and the loss of bridges will have a direct effect the delivery of emergency services to a large number of Skagit County citizens. Very few bridges in Skagit County have been retrofitted to withstand the effects of a major earthquake. In addition, bridge foundations are typically located in soils susceptible to liquefaction thereby allowing bridge piers to move and bridge girders to collapse.

The bridges listed below are necessary to maintain emergency evacuation routes and deliver emergency services within Skagit County:

- Deception Pass State Route 20 Bridge (state)
- Skagit River Interstate 5 Bridge (state)
- Skagit River State Route 9 Bridge (state)
- Skagit River State Route 536 Bridge (state)
- Skagit River South Fork Bridge (county)
- Skagit River North Fork Bridge (county)
- Skagit River Dalles Bridge (county)
- Skagit River Rockport Bridge (county)
- Skagit River Riverside Bridge (municipal)
- Swinomish Channel State Route 20 Bridge (state)
- Swinomish Channel Rainbow Bridge (county)
- Baker River State Route 20 Bridge (state)
- Sauk River Government Bridge (county)

In addition to the potential loss of bridges, numerous roads may be damaged or otherwise unusable due to soil liquefaction, landslides, severe ground cracking, uplifting, or subsidence.



Photo courtesy of Washington State Military Department, Emergency Management Division

Railways are also highly vulnerable to soil liquefaction, landslides, severe ground cracking, uplifting, and subsidence. Railway routes in Skagit County are owned and operated by the Burlington Northern-Sante Fe Railroad. In Skagit County, these routes are located along shorelines and traverse the floodplains of the Skagit River and the Samish River thereby making them especially vulnerable to liquefaction, landslides, severe ground cracking, uplifting, and subsidence.

Airport facilities are also highly vulnerable to soil liquefaction, landslides, severe ground cracking, uplifting, and subsidence. The 2001 Nisqually Earthquake caused severe damage to the control tower at Seattle-Tacoma International Airport and ground cracking damaged the runway at

Boeing Field. In addition, airports are highly dependent upon electrical power to maintain radar and communication systems.

The City of Anacortes, Port of Anacortes, as well as the Shell and Tesoro oil refineries located on Marches Point in western Skagit County are dependent upon substantial marine facilities such as piers, wharfs, and docks to conduct and support business trade and economic development. Construction of these facilities typically involves shoreline landfill and pilings that are vulnerable to liquefaction resulting in pile failure, loss of load carrying capacity, and possible failure of supported structures.

We are all dependent upon pipelines for the delivery and distribution of natural gas and potable water and the disposal of wastewater. Due to large amount of commercial and residential development within the floodplain of the Skagit River, the majority of underground pipelines in Skagit County are located in soils that are vulnerable to liquefaction. The City of Anacortes water system could be especially vulnerable to the effects of a major earthquake. Two water transmission lines run side-by-side for a distance of 17 miles connecting the City of Anacortes Water Treatment Plant located on the Skagit River near Mount Vernon with their distribution system within the City of Anacortes. One of these lines is 36" in diameter; the second line is comprised of a 24" diameter portion and a 36" diameter portion. Plans are currently being considered that will increase the size of the 24" diameter portion of this second line to 36" diameter. This same system also supplies water to various areas of unincorporated Skagit County, the Town of La Conner, the oil refineries on Marches Point, as well as the City of Oak Harbor and Naval Air Station Whidbey Island located in Island County.

In addition to water, wastewater, and natural gas distribution pipelines, several major transmission pipelines carrying oil, gasoline, and natural gas are located within Skagit County. Some of these lines (in addition to one large water transmission pipeline) cross the Samish River and Skagit River – some of these pipeline crossings are located underground and some are located aboveground supported by cable suspension structures.

Two large oil refineries (Shell and Tesoro) and a chemical plant are located in the Western portion of the county on Marches Point near the City of Anacortes. In addition, Olympic Pipe Line Company owns and operates a 20 million gallon fuel storage tank facility and pump station within Skagit County. Each of these facilities have numerous storage tanks containing liquid hydrocarbons – some of these tanks have capacities that exceed 12.8 million gallons. During earthquake events ground movement may cause connecting piping to break and the liquids contained in these tanks may slosh resulting in partial or complete failure of the tanks. Upon tank failure, these liquid fuels may explode and burn.

There are several earth-fill dams located in Skagit County. The majority of these dams are small, are located in sparsely populated or remote areas, and would have a minor impact on nearby areas should a failure occur.

Skagit County Public Utility District # 1 owns and maintains two earth-fill dams located East of Mount Vernon near Gilligan Creek. These earth-fill dams contain Judy Reservoir with a total water storage capacity of 4,630 acre-feet or 1.5 billion gallons. The reservoir is located in a sparsely populated area but due to the storage capacity of the reservoir and the topography of

the area, a sudden failure of either of these earth-fill dams could severely impact areas located downstream of the reservoir causing damage to homes and loss of life.

The West Pass Dike is an earth and rock-filled dam that is owned and maintained by Puget Sound Energy as part of the Baker River Project. The West Pass Dike is located in Eastern Whatcom County on the Baker River and has a water storage capacity of approximately 177,000 acre-feet. The West Pass Dike runs across a low area located to the West of the Upper Baker Dam for the purpose of impounding the waters of Baker Lake between the elevations of 680 feet and 724 feet. The West Pass Dike is located in a very remote area but a partial or total failure of this dam would most definitely have an impact on downstream areas as a result of large amounts of water entering Lake Shannon thereby leading to a possible overtopping the Lower Baker Dam near the Town of Concrete.

Puget Sound Energy and Seattle City Light own and operate large hydroelectric projects on the Baker River and Skagit River respectively. Only one of these dams, the Lower Baker Dam is located in Skagit County, the remaining dams are located in Whatcom County. All of these dams are of Portland Cement Concrete construction and are built and anchored to bedrock; the table below provides additional information regarding these dams.

Major Hydro-electric Dams Located in Eastern Skagit and Whatcom Counties (Information obtained from the United States Army Corps of Engineers)			
Name of Dam	Owner/Operator	River System	Storage Capacity
Lower Baker Dam	Puget Sound Energy	Baker River	160,000 Acre Feet
Upper Baker Dam	Puget Sound Energy	Baker River	285,000 Acre Feet
Gorge Dam	Seattle City Light	Skagit River	8,500 Acre Feet
Diablo Dam	Seattle City Light	Skagit River	90,000 Acre Feet
Ross Dam	Seattle City Light	Skagit River	1,435,000 Acre Feet

Due to their close proximity to Mount Baker, the Upper Baker Dam and the Lower Baker Dam are vulnerable to the effects of large-scale landslides, mudflows, lahars, and avalanches originating from the upper slopes of Mount Baker. Gorge Dam, Diablo Dam, and Ross Dam are not vulnerable to the hazards that could be caused by Mount Baker nor are any of the dams on the Baker River or the Skagit River vulnerable to similar hazards originating from Glacier Peak. Because of their location and the storage capacity of their reservoirs, the failure of any one of these dams will have a severe impact on the Eastern portion of Skagit County, the Town of Concrete, and those persons living within the floodway and floodplain of the Skagit River.

While large portions of Skagit County are vulnerable to ground failures caused by earthquakes, some areas in Western Skagit County may also be vulnerable to tsunamis and seiches.

Most Skagit County marine and shoreline areas are protected from the direct effects of tsunamis caused by distant earthquakes. However, the shoreline areas of Fidalgo Island, Guemes Island, Sinclair Island, Cypress Island, Samish Island, March's Point, the communities of La Conner and Bayview, as well as lakeshore areas may be vulnerable to seiche.

PROBABILITY and RISK:

Because of the infrequency of such devastating events, there is a **low probability** for a potentially damaging earthquake to occur that could result in many people being injured or killed and damaging private property, government infrastructure and the local economy. However, there is a **moderate to high risk** to the citizens, infrastructure, and economy of Skagit County should such an earthquake occur.

CONCLUSION:

It is difficult to identify any part of Skagit County that would not be vulnerable to a large earthquake.

The citizens of Skagit County need to be knowledgeable and understand the earthquake risk we all live with on a daily basis. People need to recognize that government is not able to totally protect them from the impacts of an earthquake. They need to take the necessary actions to prepare themselves, their families, and their businesses before an earthquake – not after.

The adoption and enforcement of building codes, land use planning, public awareness programs, school “Drop, Cover and Hold” training, and “Community Emergency Response Team” education and training are just part of the answer.

Future population increases and urban development will require that Skagit County continually re-assess the earthquake hazard. In addition, each business and citizen must accept the responsibility to take the necessary actions and prepare for the day a major earthquake occurs.