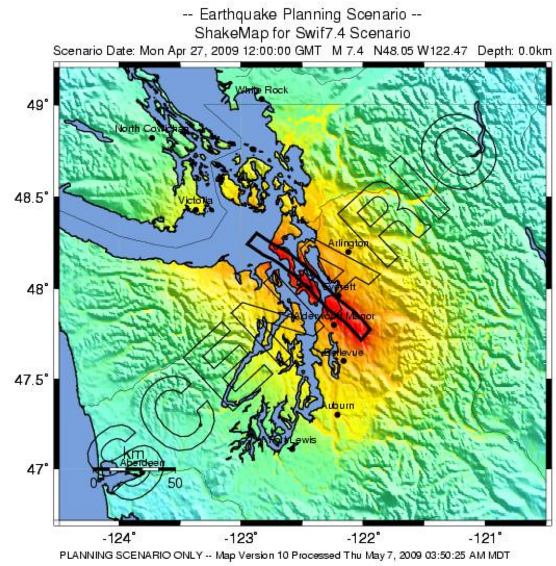
Understanding Earthquake Hazards in Washington State

Modeling a Magnitude 7.4 Earthquake on the Southern Whidbey Island Fault Zone

Geologic Description

The southern Whidbey Island fault (SWIF) stretches from the vicinity of Victoria, B.C., across Puget Sound as far as the Cascade Range. This scenario was modeled on the part of the SWIF from Woodinville to just west of Whidbey Island. The SWIF has been assessed by the USGS as capable of generating the largest crustal earthquake in Puget Sound.

The SWIF was originally envisioned as a single, steeply dipping, north-side-down fault reaching from Port Townsend to Woodinville. Over the past 15 years, geological and geophysical studies have extended the SWIF beyond this and reinterpreted the SWIF as a broad, north-side-up fault zone (6–11 kilometers; 4–7 miles wide) dipping steeply to the northeast. It has now been traced to the eastern Strait of Juan de Fuca. Seismic tomography has tracked the fault along the northwestern margin of the Port Townsend basin, where it is thought to merge with the Darrington–Devils Mountain fault zone near Victoria, B.C.



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Figure 1. ShakeMap for a M7.4 earthquake on the southern Whidbey Island fault. The black polygon is the modeled fault rupture for this scenario.

Geologic mapping has extended the SWIF from the eastern edge of Puget Sound southeastward to the vicinity of North Bend. Lidar and aeromagnetic data confirm that the SWIF projects onto the mainland near Everett and continues southeast towards Woodinville. A series of faults and folds in the Snoqualmie area have recently been mapped that likely correlate with the SWIF. These faults merge with mapped faults on Rattlesnake Mountain near North Bend and continue southeast into the Cascade Mountains.

Current researchers used aeromagnetic data to correlate faults in the Yakima fold and thrust belt with faults west of the Cascades. In their model, geophysical lineaments and mapped structures associated with Umtanum Ridge pass through the Cascades and merge with geophysical lineaments and mapped structures on and near Rattlesnake Mountain in western Washington. If this model is correct, the SWIF now extends about 385 kilometers (240 miles), from Victoria, B.C., to Hanford, Washington.

Paleoseismology: Radiocarbon and stratigraphic data collected from sites on either side of the SWIF on Whidbey Island showed that the sea-level histories of the two sites were not comparable. Instead, the relative sea-level curves diverged 3,200 to 2,800 years ago, suggesting 1 to 2 meters of uplift along the north side of the fault. This suggests the fault has been active in the past. Based on these calculations, researchers concluded that the SWIF is capable of producing a magnitude 6.5 to 7.0 earthquake.

Washington Military Department Emergency Management Division
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Excavations across several scarps near Woodinville revealed evidence of at least four earthquakes since deglaciation about 16,000 years ago, the most recent being less than 2,700 years ago. In light of this and other research, the potential size of an earthquake on the SWIF was revised to M7.5.

Type of Earthquake

Most earthquake hazards result from ground shaking caused by seismic waves that radiate out from a fault as it ruptures. Seismic waves transmit the energy that is released: The bigger the quake, the larger the waves and the longer they last. Several factors affect the strength, duration, and pattern of shaking:

- The type of rock and sediment layers that the waves travel through.
- The dimensions and orientation of the fault and the characteristics of rapid slippage along it during an earthquake.
- How close the rupture is to the surface.

Deep vs. Shallow: The magnitude 7.4 earthquake modeled for the southern Whidbey Island fault zone is a shallow or crustal earthquake. Shallow quakes tend to be much more damaging than deep quakes of comparable magnitude (such as the M6.8 Nisqually earthquake in 2001). This is primarily because in deeper quakes, the seismic waves have lost more energy by the time they reach the surface.

Aftershocks: Unlike deep earthquakes, which usually produce few or no aftershocks strong enough to be felt, a M7.4 shallow earthquake would likely be followed by many aftershocks, a few of which could be large enough to cause additional damage.

Photo: FEMA/Kevin Galvin

Figure 2. Historic buildings in Seattle's Pioneer Square damaged during the M6.8 Nisqually earthquake in 2001.

Other Earthquake Effects

Tsunamis: Some earthquakes may rupture a fault at the surface of the ground. If this offsets the floor of Puget Sound, it could generate a local tsunami. Delta failures and landslides caused by the shaking may also create or amplify tsunamis. Geological and historical evidence shows that landslides and failures of the sediments in river deltas have generated tsunamis within Puget Sound in the past.

Liquefaction: If sediments (loose soils consisting of silt, sand, or gravel) are water-saturated, strong shaking can disrupt the grain-to-grain contacts, causing the sediment to lose its strength. Increased pressure on the water between the grains can produce small geyser-like eruptions of water and sediment called *sand blows*. Sediment in this condition is liquefied and behaves as a fluid. Buildings on such soils can sink and topple, and foundations can lose strength, resulting in severe damage or collapse. Pipes, tanks, and other structures that are buried in liquefied soils will float upwards to the surface.

Artificial fills, tidal flats, and stream sediments are often poorly consolidated and tend to have high liquefaction potential. For example, in the southern Whidbey Island scenario, the liquefaction susceptibility of many river valleys and deltas—such as the land on either side of the Stillaguamish and Snohomish rivers—is rated moderate to high.

Landslides: Earthquake shaking may cause landslides on slopes, particularly where the ground is water-saturated or has been modified (for example, by the removal of stabilizing vegetation). Steeper slopes are most susceptible, but old, deep-seated landslides may be reactivated, even where gradients are as low as 15%. Catastrophic debris flows can move water-saturated materials rapidly and for long distances, mostly in mountainous regions. Underwater slides are also possible, such as around river deltas.

BE PREPARED WHEREVER YOU ARE: **Develop a plan and a disaster supply kit. When you're prepared, you feel more in control and better able to keep yourself and your family safe.**

LEARN MORE ABOUT WHAT YOU CAN DO: **www.emd.wa.gov**

Hazus Results for the SWIF Scenario

Hazus is a nationally applicable standardized methodology developed by FEMA to help planners estimate potential losses from earthquakes. Local, state, and regional officials can use such estimates to plan risk-reduction efforts and prepare for emergency response and recovery.

Hazus was used to estimate the losses that could result from a M7.4 deep earthquake on the southern Whidbey Island fault zone (SWIF). Such an event is expected to impact eighteen counties in Washington.

Injuries: The number of people injured is likely to be high, particularly if the earthquake occurs during or at the end of the business day. Snohomish County is projected to have the highest number of injured (2,000–6,000), followed by King and Island. Many are likely to require hospitalization; hundreds of injuries may be life-threatening if not treated promptly. Hundreds of fatalities are also likely, the majority in Snohomish, King, and Island counties.

Damage: This earthquake is projected to damage buildings in all of the affected counties. Snohomish, King, and Island counties account for the greatest number (over 288,000) and may suffer damage to the highest percentages of their building stocks. In many cases, damage will be slight to moderate, but a large number of buildings are projected to suffer extensive damage (over 10,000 in Snohomish County alone). Thousands of buildings may collapse or be in imminent danger of collapse, especially in Island, Snohomish, and King counties. Many un-reinforced masonry and non-ductile concrete 'tilt up' buildings will experience partial to total collapse. Most damaged structures will be residential, commercial, and industrial, but the total includes buildings of all types and occupancy classes.

Economic Losses Due to Damage: Capital stock losses are the direct economic losses associated with damage to buildings, including the cost of structural and non-structural damage, damage to contents, and loss of inventory. Snohomish and King counties account for the largest portion of the capital stock loss estimate (over $9 billion).

SOUTHERN WHIDBEY ISLAND SCENARIO EARTHQUAKE	
End-to-end length of fault (kilometers)	92
Magnitude (M) of scenario earthquake	7.4
Number of counties impacted	18
Total injuries (*severity 1, 2, 3, 4) at 2:00 PM	7,793
Total number of buildings extensively damaged	17,502
Total number of buildings completely damaged	6,258
Income losses in millions	$2,224
Displaced households	13,948
People requiring shelter (individuals)	8,106
Capital stock losses in millions	$10,315
Debris total in millions of tons	3.57
Truckloads of debris (25 tons per truckload)	142,960
People without power (Day 1)	115,230
People without potable water (Day 1)	188,457

Table 1. Summary of significant losses in the magnitude 7.4 southern Whidbey Island earthquake scenario. Among the counties most likely to be affected are Island, King, Pierce, San Juan, Skagit, Snohomish, and Whatcom.

***Injury severity levels: 1—requires medical attention, but not hospitalization; 2—not life-threatening, but does require hospitalization; 3—hospitalization required; may be life-threatening if not treated promptly; 4—victims are killed by the earthquake**

Income losses, including wage losses and loss of rental income due to damaged buildings, are also highest in Snohomish County (over $1 billion) and King County (more than $763 million).

Impact on Households and Schools: The number of people without power or water is projected to be highest in King, Snohomish, and Island counties, and these counties account for most of the displaced households and individuals in need of shelter. The earthquake is most likely to affect the functionality of schools in Snohomish and Island counties.

Debris Removal: Following an earthquake, debris (brick, wood, concrete, and steel) must be removed and disposed of. Much of this will come from King and Pierce counties (over 3 million tons).

Estimates vs. Actual Damage: Although the M7.4 earthquake scenario for the southern Whidbey Island fault zone was modeled using the best scientific information available, it represents a simplified version of expected ground motions. The damage resulting from an actual earthquake of similar magnitude is likely to be even more variable and will depend on the specific characteristics and environment of each affected structure.

Other Tools: Community planners can also look at how a large earthquake may impact local resources and people's lives and livelihoods. The following graphs illustrate variations in such impacts: The first shows the levels of shaking that residents are likely to experience; the second shows possible impacts on services and business sectors. Even where structural damage to buildings is slight, the shaking may be strong enough to damage furnishings and inventories.

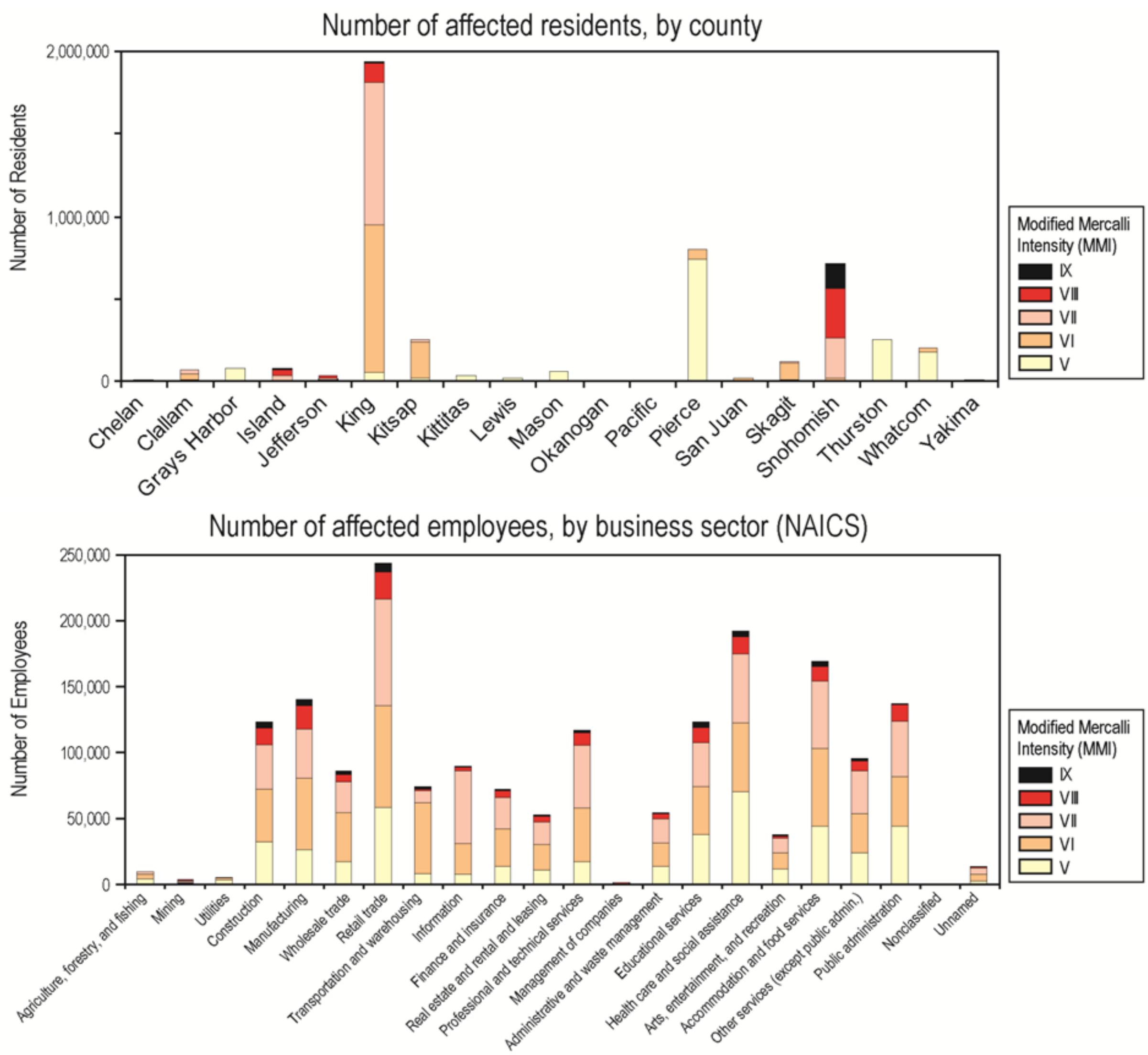

Figure 3. Number of residents and employees affected by the M7.4 earthquake projected for the SWIF scenario. The Modified Mercalli Intensity (MMI) classes indicate peak ground acceleration (PGA) values and the impact of the shaking.

V. Rather Strong (PGA 3.9–9.2 *g*)	Felt outside by most. Dishes and windows may break. Large bells ring. Vibrations like large train passing close to house.
VI. Strong (PGA 9.2–18 *g*)	Felt by all; people walk unsteadily. Many frightened and run outdoors. Windows, dishes, glassware broken. Books fall off shelves. Some heavy furniture moved or overturned. Cases of fallen plaster. Damage slight.
VII. Very Strong (PGA 18–34 *g*)	Difficult to stand. Furniture broken. Damage negligible in buildings of good design & construction; slight-moderate in other well-built structures; considerable in poorly built/badly designed structures. Some chimneys broken.
VIII. Destructive (PGA 34–65 *g*)	Damage slight in specially designed structures; considerable in ordinary substantial buildings (partial collapse); great in poorly built structures. Fall of chimneys, factory stacks, columns, walls. Heavy furniture moved.
IX. Violent (PGA 65–124 *g*)	General panic; damage considerable in specially designed structures; well designed frame structures thrown out of plumb. Damage great in substantial buildings: partial collapse. Buildings shifted off foundations.