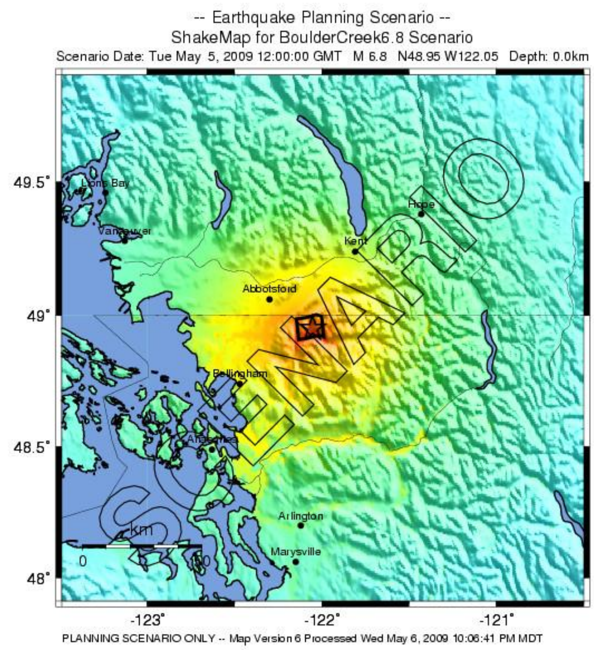
Modeling a Magnitude 6.8 Earthquake on the Boulder Creek Fault Zone in Whatcom County

Geologic Description

The Boulder Creek fault zone in northern Whatcom County consists of at least two fault strands. The M6.8 earthquake scenario for the zone is based on a 10.8 (6.7 mile)-kilometer-long rupture of one of these fault strands near the town of Kendall. Known as the Boulder Creek fault, this strand appears on early geologic maps of the area as a normal fault separating Eocene sedimentary rocks from Mesozoic metamorphic and igneous rocks. A second strand of the fault zone (unnamed) is located along the north side of the Nooksack River near Glacier, Washington. Both faults show geological evidence of earthquakes in the recent past.

Lidar (light detection and ranging) images of Whatcom County revealed two fault scarps along the North Fork Nooksack River. One scarp lies on the mapped trace of the Boulder Creek fault between Kendall and Maple Falls (Kendall scarp). The other (Canyon Creek) lies near an inferred fault. The Kendall scarp is about 4.3 kilometers (2.7 miles) long, south-side-up, and has a maximum preserved height of about 3 meters (9.8 feet). The Canyon Creek scarp is about 2 kilometers (1.2 miles) long, south-side-up, and has a maximum height of about 4 meters (13 feet).

Four trenches dug across the Kendall scarp and one dug across the Canyon Creek scarp exposed faulted and folded glacial outwash deposits and Holocene soils. The trenches reveal a history of large earthquakes on the fault through the Holocene. The youngest earthquake occurred about 1,000 years ago and had 40 to 70 centimeters (15.8–28 inches) of reverse vertical separation. The next oldest occurred about 2,800 to 3,200 years ago. It had between ~25 centimeters (9.8 inches) and 1.7 meters (5.6 feet) of reverse vertical separation. These two earthquakes account for between ~80 and 95% of the total scarp height, suggesting that the earlier folding event created only a small scarp or that little of the original scarp was preserved on the landscape prior to the earthquake about 3,000 years ago.



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 M6.8 earthquake on the Boulder Creek fault.

Type of Earthquake

Most earthquake hazards result from ground shaking caused by seismic waves that radiate out from a fault

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when it ruptures. Seismic waves transmit the energy released by the earthquake: The bigger the earthquake, 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 of the ground.

Deep vs. Shallow: The M6.8 scenario earthquake modeled for the Boulder Creek fault is a shallow or crustal earthquake. Shallow quakes tend to be much more damaging than deep earthquakes of comparable magnitude (such as the deep M6.8 Nisqually earthquake in 2001). This is primarily because in deeper earthquakes, 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 M6.8 shallow earthquake like the one in this scenario would likely be followed by many aftershocks, a few of which could be large enough to cause additional damage.

Figure 2. This road failure at Sunset Lake in Tumwater, Washington was caused by the M6.8 Nisqually earthquake in 2001. (Photo: Steve Palmer/Washington State Department of Natural Resources)

Other Damaging Effects

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 ground to lose its strength. Increased pressure on the water between the grains sometimes produces 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 structural collapse. Pipes, tanks, and other structures that are buried in liquefied soils will float upward 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 Boulder Creek scenario, the liquefaction susceptibility of the land on either side of the Skagit and Nooksack 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.

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Hazus Results for the Boulder Creek 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 earthquake-induced losses that could result from a M6.8 scenario earthquake on the Boulder Creek fault in Whatcom County. Such an event is expected to impact eight counties in Washington, with the most significant effects apparent in Whatcom and Skagit counties.

Injuries: The estimated number of people injured in this scenario is relatively low. The majority of injuries requiring medical attention or hospitalization occur in Skagit and Whatcom counties.

Damage: Buildings in most counties are likely to incur only slight damage, with moderate damage in a few cases. Skagit, Whatcom, and Snohomish counties may have the greatest number of buildings affected by this earthquake. Of these, most will be residential. Although damage will be slight to moderate for the majority of structures, 77 buildings will be extensively damaged. All of these structures are in Skagit and Whatcom counties and include residential, agricultural, commercial, and industrial buildings.

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. Whatcom County accounts for the largest portion of the capital stock loss estimate (about $85 million), followed by Skagit (just under $16 million) and Snohomish (about $3 million).

Income losses, including wage losses and loss of rental income due to damaged buildings, are also highest in Whatcom County (approximately $10.5 million) and Skagit County (nearly $2 million).

BOULDER CREEK FAULT SCENARIO EARTHQUAKE	
End-to-end length of fault (kilometers)	11
Magnitude (M) of scenario earthquake	6.8
Number of counties impacted	8
Total injuries (*severity 1, 2, 3, 4) at 2:00 PM	15
Total number of buildings extensively damaged	77
Income losses in millions	$13
Capital stock losses in millions	$106
Debris total in millions of tons	0.02
Truckloads of debris (25 tons per truckload)	760

Table 1. Summary of significant losses in the M6.8 Boulder Creek earthquake scenario. The eight counties likely to be affected are Whatcom, Skagit, Snohomish, Clallam, Island, San Juan, King, and Jefferson.

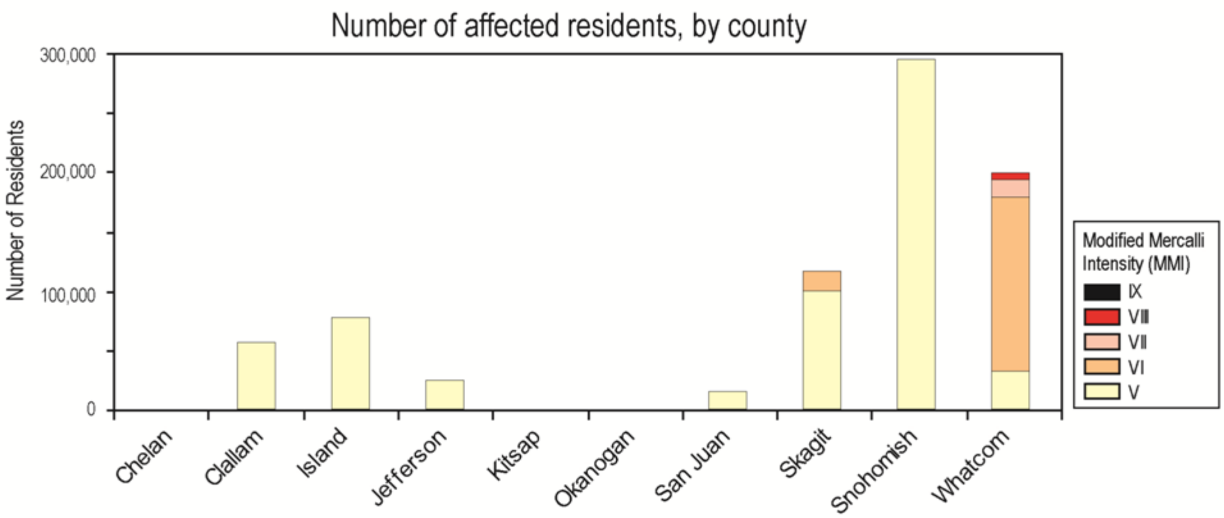
***Injury severity levels: 1—requires medical attention, but not hospitalization; 2—not life-threatening, but does require hospitalization; 3—hospitalization required; may be life-threatening if not treated promptly; 4—victims are killed by the earthquake**

Impact on Households and Schools: The majority of displaced households will occur in Whatcom and Skagit counties, with the largest number in Whatcom. The estimated number of individuals who will require shelter after the earthquake is moderately low. In this case, Whatcom County alone accounts for the total. The earthquake may impact the functionality of some schools on Day 1, particularly in Whatcom County; but for most counties, this impact is not expected to be significant.

Debris Removal: Following an earthquake, debris consisting of brick, wood, concrete, and steel will have to be removed and disposed of. The estimated total for this scenario is 19,000 tons (or 760 truck loads) of debris. All of this comes from Whatcom (16,000 tons) and Skagit (3,000 tons) counties.

Estimates vs. Actual Damage: Although the M6.8 earthquake scenario for the Boulder Creek 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 the possible impact on different services and business sectors. Note that in Snohomish County, a greater number of residents will be exposed to less severe shaking, whereas Whatcom and Skagit counties, although less populated, will experience more intense ground motions.



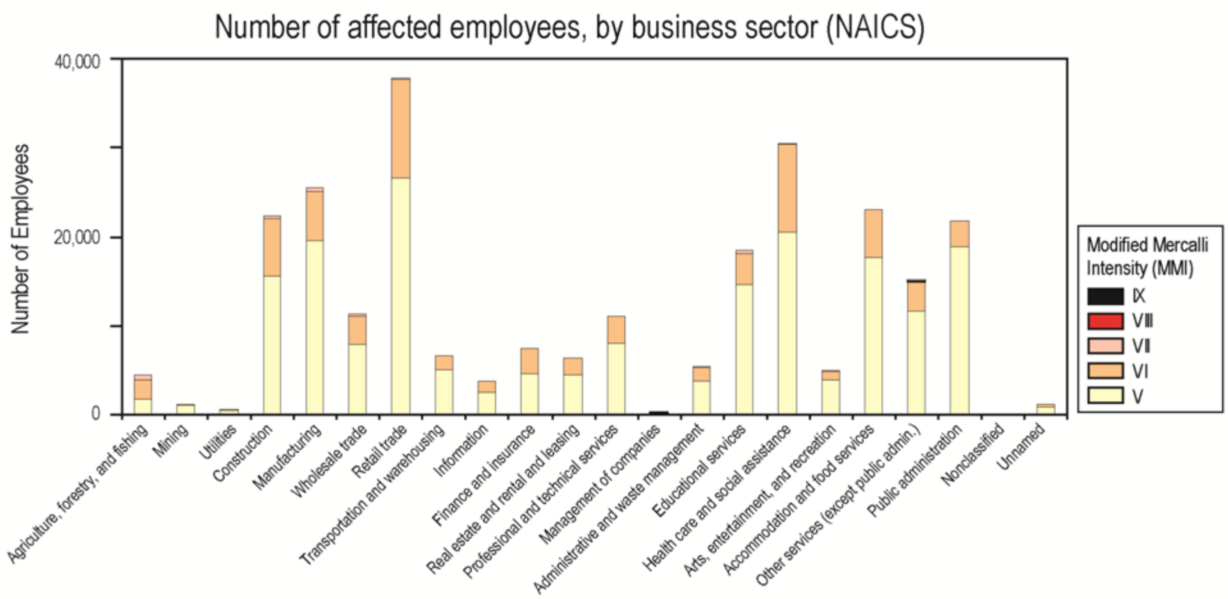


Figure 3. Number of residents and employees affected by the M6.8 earthquake projected for the Boulder Creek fault. The Modified Mercalli Intensity (MMI) classes indicate peak ground acceleration (PGA) values and the impact of the shaking.

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.