UNDERSTANDING EARTHQUAKE HAZARDS IN WASHINGTON STATE

Modeling a Magnitude 6.8 Earthquake on the Lake Creek–Boundary Creek Fault Zone in Clallam County

Geologic Description

The M6.8 earthquake scenario for the Lake Creek–Boundary Creek fault zone is based on a 30 kilometer (19 mile)-long rupture of the fault between Lake Crescent and east Port Angeles, Washington. The Lake Creek–Boundary Creek fault zone is one of three east-west-trending, north-dipping fault zones along the north flank of the Olympic Mountains. The fault cuts Eocene and older rocks; where visible at the surface, the Paleocene Crescent Formation along the north side of the fault is faulted against younger Eocene sedimentary rocks (Hoko River Formation) south of the fault, suggesting reverse motion on the fault.

Lidar (light detection and ranging) images reveal a 30 kilometer (19 mile)-long topographic lineament following the trace of the Lake Creek–Boundary Creek fault. Along parts of the lineament, scarps about 2 meters (7 feet) high face opposite directions, suggesting a lateral component of movement along the fault. Five trenches excavated across the scarp exposed faulted and folded glacial deposits: one trench contains basalt bedrock thrust over Quaternary glacial deposits; however, most of the faults have normal displacement. Flower structures suggest a significant but unknown amount of lateral displacement. Radiocarbon ages from faulted soils and scarp-derived colluvium suggest two earthquakes between 2,000 and 600 years ago. Stratigraphic relations and radiocarbon ages in one trench suggest an earlier earthquake that was less than 5,000 years ago.

Type of Earthquake

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

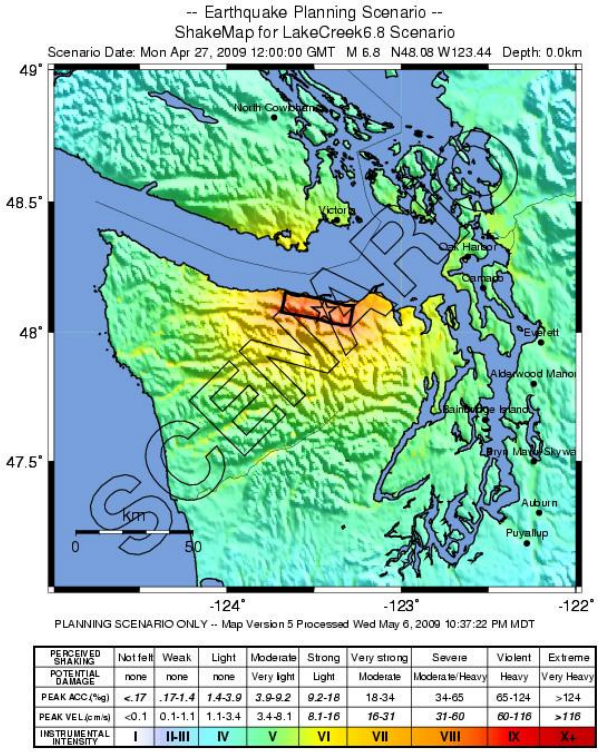

Figure 1. ShakeMap for a M6.8 earthquake on the Lake Creek–Boundary Creek fault. The black polygon is the modeled fault rupture for this scenario.

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.

Washington Military Department
Emergency Management Division
WASHINGTON STATE DEPARTMENT OF Natural Resources
USGS science for a changing world
FEMA

Deep vs. Shallow: The M6.8 scenario earthquake modeled for the Lake Creek–Boundary Creek 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 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 after-shocks, a few of which could be large enough to cause additional damage.

Other Earthquake Effects

Tsunamis: Some earthquakes may rupture a fault at the surface of the ground. If this offsets the floor of a body of water, 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 sometimes 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 structural 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 Lake Creek–Boundary Creek scenario, the liquefaction susceptibility of the Dungeness River delta 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.

Figure 2. The M6.8 Nisqually earthquake in 2001 caused this landslide at U.S. Highway 101, northwest of Olympia. (Photo: Karl Wegmann/ WADNR)

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 Lake Creek–Boundary 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 losses that could result from a M6.8 earthquake on the Lake Creek–Boundary Creek fault zone in Clallam County. Such an event is expected to impact 14 counties in Washington, with the most significant effects apparent in Clallam County.

Injuries: Several hundred people are expected to be injured in this earthquake, most in Clallam County. Fewer injuries are anticipated in other counties, and most of these are not expected to require immediate medical attention. In Clallam County, many of the injured will require hospitalization, and some injuries will be life-threatening. Some fatalities are also likely, particularly if the event occurs in the afternoon or during the evening commute.

Damage: The earthquake will damage some buildings in all of the affected counties, but the greatest number will be in Clallam County. More than half of this county's building stock may suffer some damage; of these buildings, more than 1,600 could be extensively damaged and over 400 might collapse or be in danger of collapse. The damage to buildings in other counties will range from slight to moderate. In all counties, the majority of damaged buildings will be residential, but commercial and industrial structures will also make up a sizable part of the total. Many unreinforced masonry structures will most likely collapse.

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. Clallam County accounts for the largest portion of the capital stock loss estimate (over $445 million), followed by King (about $31 million), Snohomish (over $9 million), Kitsap ($7.5 million), and Whatcom ($5.6 million).

LAKE CREEK–BOUNDARY CREEK SCENARIO EARTHQUAKE	
End-to-end length of fault (kilometers)	30
Magnitude (M) of scenario earthquake	6.8
Number of counties impacted	14
Total injuries (*severity 1, 2, 3, 4) at 2:00 PM	253
Total number of buildings extensively damaged	1,612
Total number of buildings completely damaged	407
Income losses in millions	$128
Displaced households	460
People requiring shelter (individuals)	283
Capital stock losses in millions	$518
Debris total in millions of tons	0.19
Truckloads of debris (25 tons per truckload)	7,680
People without power (Day 1)	9,095
People without potable water (Day 1)	544

Table 1. Summary of significant losses in the M6.8 Lake Creek–Boundary Creek earthquake scenario. The counties most likely to be affected are Clallam, Jefferson, King, Kitsap, Mason, Skagit, and Snohomish.

***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 Clallam County (over $122 million) and King County (about $2.5 million).

Impact on Households and Schools: The number of people without power or water will be highest in Clallam County. This county also accounts for most of the displaced households and individuals in need of shelter. In Clallam County, schools will be only 49% functional on Day 1 following the earthquake.

Debris Removal: Following an earthquake, debris consisting of brick, wood, concrete, and steel will have to be removed and disposed of. Much of this will come from Clallam County (182,000 tons). Together, King, Kitsap, Skagit, Snohomish, and Jefferson counties account for about 9,000 tons.

Estimates vs. Actual Damage: Although this M6.8 earthquake scenario 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 different services and business sectors. Note that in King County, a greater number of residents will be exposed to less severe shaking, whereas Clallam County, although less populated, will experience more intense ground motions.

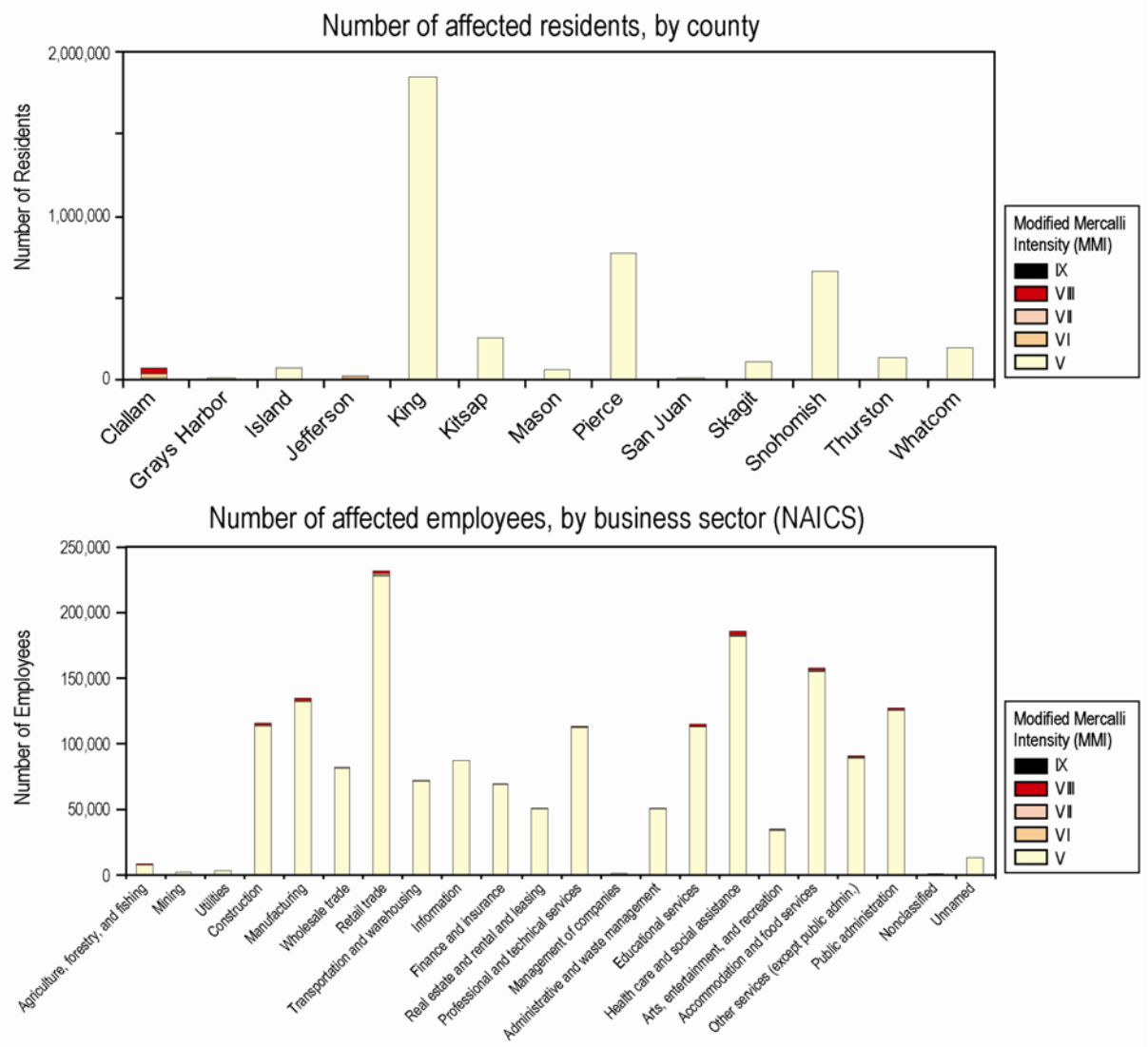

Figure 3. Number of residents and employees affected by the M6.8 earthquake in the Lake Creek–Boundary Creek scenario. Modified Mercalli Intensity (MMI) classes indicate peak ground acceleration (PGA) values and the impact of the shaking.

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.