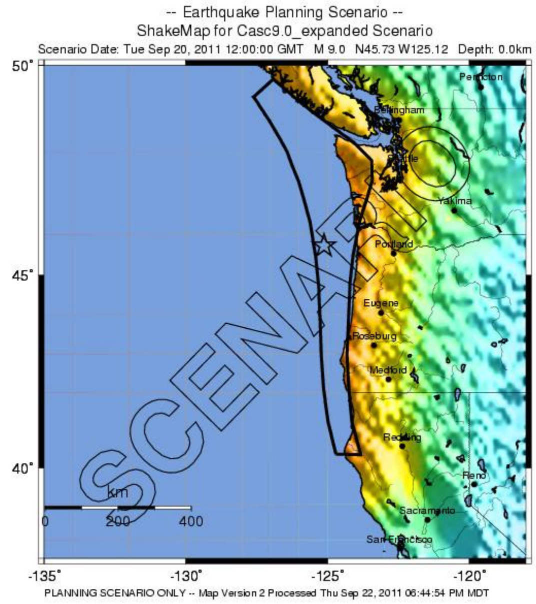
Modeling a Magnitude 9.0 Earthquake on the Cascadia Subduction Zone off the Pacific Coast

Geologic Description

The coastline of the northwestern U.S. and Canada is bordered by an active subduction zone where the Juan de Fuca plate is subducting, or being pushed, beneath the North American plate. Currently, the subduction zone is considered locked (that is, it is not slipping). Strain is therefore accumulating on the locked interface between the plates. Plate convergence is estimated to be between 3 and 4 centimeters per year and possibly as high as 5.8 centimeters per year (the long-term geologically estimated rate).

The M9.0 Cascadia scenario is based on an approximately 1,000 kilometer (620 mile)-long rupture of the Cascadia subduction zone megathrust fault. The rupture extends from Cape Mendocino, California, to central Vancouver Island, Canada. This scenario is based on geologic evidence that indicates such ruptures occurred on the megathrust in the past: The last rupture was on January 26, 1700. Geologic evidence suggests that the average recurrence of ~M9.0 earthquakes along the Cascadia megathrust is about 500 years, but recurrence intervals vary, ranging from about 250 years to over 1,000 years. The effects of these earthquakes include strong ground shaking that goes on for several minutes, subsidence and/or uplift of coastal areas, liquefaction, and tsunami. Aftershocks will be both strong and numerous (possibly M7 or higher).



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 M9.0 earthquake on the Cascadia megathrust. The black polygon offshore is the modeled fault rupture for this scenario.

Type of Earthquake

Most earthquake hazards result from ground shaking caused by seismic waves that radiate out from a fault when it ruptures. Seismic waves transmit the energy released by the earthquake: 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 of the ground.

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Subduction Zone Earthquakes: Subduction zone earthquakes occur where the Juan de Fuca oceanic plate is being forced under the North American plate. An earthquake is produced when pressure that has built up along this zone causes the plates to slip suddenly and rapidly past each other. Shaking from the M9.0 earthquake modeled in this scenario will be felt over the entire region and may last for several minutes. This event is similar to the 2011 Tohoku earthquake and tsunami in Japan.

Aftershocks: Unlike deep earthquakes, such as the M6.8 Nisqually earthquake in 2001, which usually produce few or no aftershocks strong enough to be felt, a M9.0 subduction zone earthquake will be followed by thousands of aftershocks, a few of which could be large enough to cause additional damage and produce tsunamis.

Other Earthquake Effects

Tsunamis: A M9.0 Cascadia subduction zone earthquake is expected to generate a massive tsunami that will reach the coast of Washington about 20 to 30 minutes after the earthquake; waves may continue to strike the coastline for the next 12 to 24 hours. (Tsunami waves will also travel across the Pacific Ocean.) Delta failures and landslides caused by the shaking may also create or amplify tsunami waves.

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 upward to the surface.

Artificial fills, tidal flats, and stream sediments are often poorly consolidated and tend to have high liquefaction potential.

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. Tsunami damage at Onagawa, Ishinomaki, after the M9.0 Tohoku earthquake near Japan's east coast on March 11, 2011.

(Photo: NOAA/NGDC: Shunichi Koshimura)

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Hazus Results for the Cascadia Subduction Zone 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 M9.0 earthquake on the Cascadia subduction zone. Such an event is expected to impact 23 counties in Washington. Among the most affected by the earthquake are Clallam, Grays Harbor, Jefferson, King, Mason, Pacific, and Pierce. *(These estimates do not include losses due to tsunami impacts.)*

Injuries: The number of people injured in this scenario will be high. Estimates vary by location, ranging from several dozen (as in Jefferson County) to nearly 2,000 (in King County). Although many of the injuries will not be life-threatening, people in every county will require medical attention and, in many cases, hospitalization. Potentially life-threatening injuries and fatalities are expected; these are likely to be more numerous if the earthquake happens during the afternoon or early evening.

Damage: King County will have the greatest number of damaged buildings (more than 130,000). For other counties, the number is lower, but it often represents a much greater proportion of the county's building stock (as in Clallam, Grays Harbor, Pacific, and Mason counties). Most of the damaged buildings will be residential, but the number of commercial and industrial structures is also extremely high. The degree of damage will vary, but extensive damage to thousands of buildings is expected in Clallam, Grays Harbor, King, Mason, Pacific, and Pierce counties. Structural collapse (complete damage) of thousands of buildings is also expected (more than 3,000 in Clallam County).

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. For this scenario, the estimates are substantial, ranging from more than $78 million in Jefferson County to over $3 billion in King County.

Cascadia Subduction Zone Scenario Earthquake	
End-to-end length of fault (kilometers)	1,100
Magnitude (M) of scenario earthquake	9.0
Number of counties impacted	23
Total injuries (*severity 1, 2, 3, 4) at 2:00 PM	7,534
Total number of buildings extensively damaged	43,681
Total number of buildings completely damaged	8,768
Income losses in millions	$3,811
Displaced households	18,385
People requiring shelter (individuals)	11,630
Capital stock losses in millions	$11,994
Debris total in millions of tons	5.68
Truckloads of debris (25 tons per truckload)	227,240

Table 1. Summary of significant losses in the M9.0 Cascadia subduction zone earthquake scenario. Among the most affected counties are Clallam, Grays Harbor, Jefferson, King, Mason, Pacific, and Pierce.

***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**

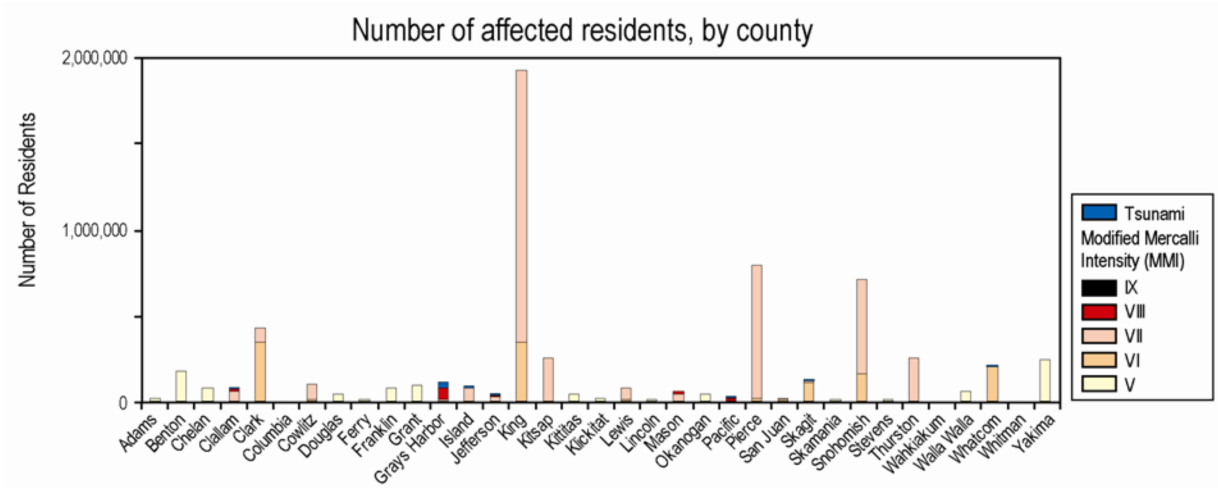
Income losses, including wage losses and loss of rental income due to damaged buildings, are high: King County alone accounts for over $1 billion.

Impact on Households and Schools: The number of people without power or water will be highest in King County (followed by Pierce, Grays Harbor, Pacific, and Clallam). King, Grays Harbor, and Pierce counties will have the highest number of displaced households and individuals in need of shelter. The functionality of many schools will be seriously affected by the earthquake. In Pacific County, functionality will initially be as low as 12%.

Debris Removal: Following this earthquake, debris (brick, wood, concrete, and steel) will have to be removed and disposed of. King County alone accounts for more than 1 million tons, Grays Harbor for 740,000 tons, and Pierce for 583,000 tons.

Estimates vs. Actual Damage: Although this M9.0 earthquake 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 King County, a greater number of residents will be exposed to very strong shaking, whereas Grays Harbor, Pacific, Mason, and Clallam counties, although less populated, will experience even more intense ground motions.



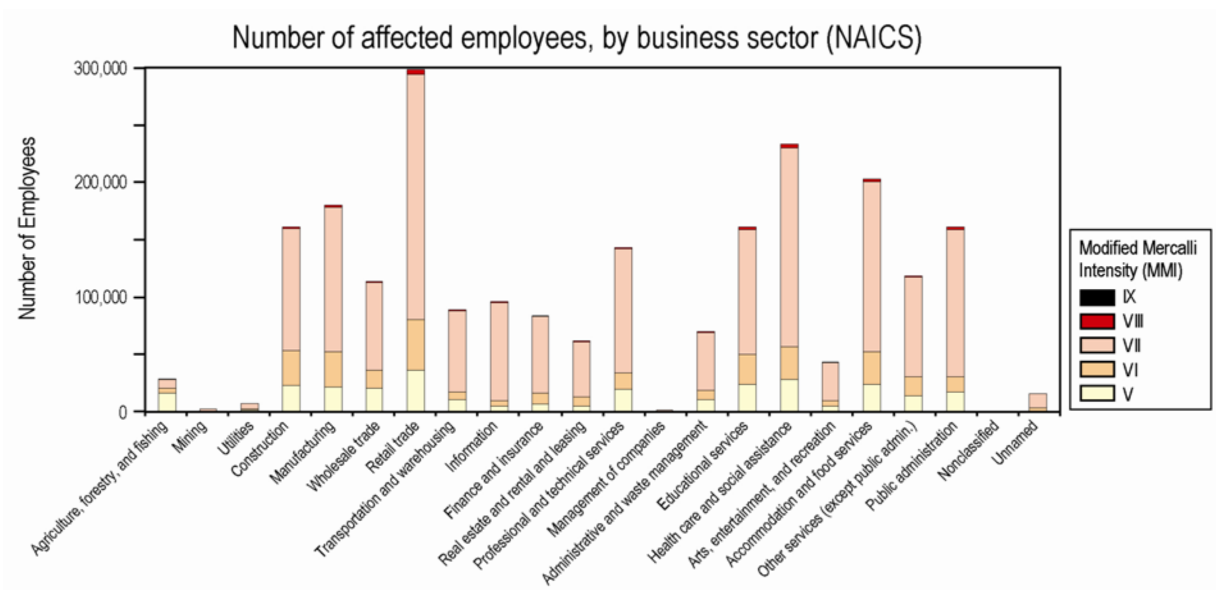


Figure 3. Number of residents and employees affected by the M9.0 earthquake projected for the Cascadia subduction zone. Modified Mercalli Intensity (MMI) classes indicate peak ground acceleration (PGA) values and the impact of the shaking.

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.