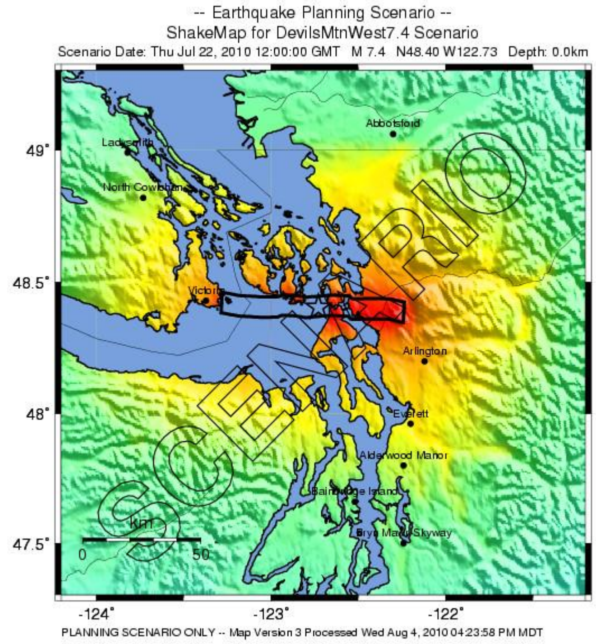
Modeling a Magnitude 7.4 Earthquake on the Western Section of the Darrington–Devils Mountain Fault Zone

Geologic Description

The Darrington–Devils Mountain fault zone is located in southern Skagit County and northern Snohomish County. It forms the northern boundary of the Everett basin and lies along a series of high-amplitude aeromagnetic anomalies that extend from the Cascade Mountains to Vancouver Island, B.C.

This fault zone was originally named the Devils Mountain fault for exposures on Devils Mountain near Mount Vernon, Washington, where it separates Mesozoic rocks from Tertiary deposits. Later, another segment, called the Darrington fault zone, was identified where northeast-trending faults juxtapose Mesozoic mélange against Eocene rocks near the town of Darrington. In 1994, the two zones were combined into the Darrington–Devils Mountain fault zone (DDMFZ).

Lidar (light detection and ranging) mapping along this fault zone revealed several potential fault scarps. Trenches across scarps on Whidbey Island exposed faulted and folded glaciomarine drift. Mostly high-angle reverse faults (with a few normal faults and low-angle reverse faults), these display approximately 1 to 4.5 meters (3–15 feet) of vertical separation and about 2 meters (6.5 feet) of left-lateral displacement. Radiocarbon ages from these trenches show that the deformation likely occurred during two earthquakes: the first 1,100 to 2,200 years ago; the second 100 to 500 years ago. Three trenches excavated across a low scarp (less than 1 meter high) east of Mount Vernon exposed faulted glacial deposits and sheared bedrock, with vertical separation of approximately 0.5 meter (1.6 feet). Flower structures and abrupt facies changes across faults suggest a component of lateral slip: trenches excavated parallel to faults exposed



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 western section of the Darrington–Devil's Mountain fault zone. The black polygon is the modeled fault rupture surface.

offset glacial channels and bedrock shears indicating right-lateral displacement of 1 to 3.5 meters (3–11.5 feet).

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 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.

Deep vs. Shallow: The M7.4 scenario earthquake modeled for the western section of the Darrington–Devils Mountain fault zone is a shallow or crustal earthquake. Shallow quakes tend to be more damaging than deep quakes of comparable magnitude (such as the deep 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 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 Puget Sound, it could generate a local tsunami. Delta failures and landslides caused by the shaking will also likely 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 this DDMFZ scenario, the liquefaction susceptibility of the land on either side of the Skagit River 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.

Photo: J.K. Nakata, U.S. Geological Survey

Figure 2. Liquefaction causes a building to sink and collapse during the 1989 Loma Prieta earthquake in San Francisco, California.

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Hazus Results for the Darrington–Devils Mountain (West) 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 scenario earthquake on the western section of the Darrington–Devils Mountain fault zone in southern Skagit County. Such an event is expected to impact twelve counties in Washington, with the most significant effects apparent in Skagit, Snohomish, and Island counties.

Injuries: The number of people injured in this scenario is likely to be high, particularly if the earthquake occurs during the business day. Skagit County is expected to suffer the highest number of casualties. Although the majority of the injured will not require hospitalization, numerous serious and potentially life-threatening injuries are anticipated. Many fatalities are also likely if the event occurs during the afternoon or early evening; more than 50 fatalities are estimated for Skagit County.

Damage: The earthquake will damage thousands of buildings in all of the affected counties, but the numbers are highest in Skagit (29,448), Snohomish (16,471), and Island (12,477) counties. In Skagit County, 3,300 buildings will be extensively damaged and more than 1,100 will collapse or be in danger of collapse (complete damage). Most of the damaged buildings will be residential, but commercial and industrial structures also account for a large part of the total. Many unreinforced masonry structures will experience partial to full 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. Skagit County accounts for over $998 million of the total loss estimate, followed by Island (almost $277 million), Snohomish ($262.5 million), and King (over $135 million).

DARRINGTON–DEVILS MOUNTAIN (WEST) SCENARIO	
End-to-end length of fault (kilometers)	80
Magnitude (M) of scenario earthquake	7.4
Number of counties impacted	12
Total injuries (*severity 1, 2, 3, 4) at 2:00 PM	1,119
Total number of buildings extensively damaged	4,864
Total number of buildings completely damaged	1,439
Income losses in millions	$391
Displaced households	1,971
People requiring shelter (individuals)	1,448
Capital stock losses in millions	$1,866
Debris total in millions of tons	0.65
Truckloads of debris (25 tons per truckload)	25,920
People without power (Day 1)	10,176
People without potable water (Day 1)	29,697

Table 1. Summary of significant losses in the M7.4 Darrington–Devils Mountain (West) earthquake scenario. The counties most likely to be significantly affected are Island, King, 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**

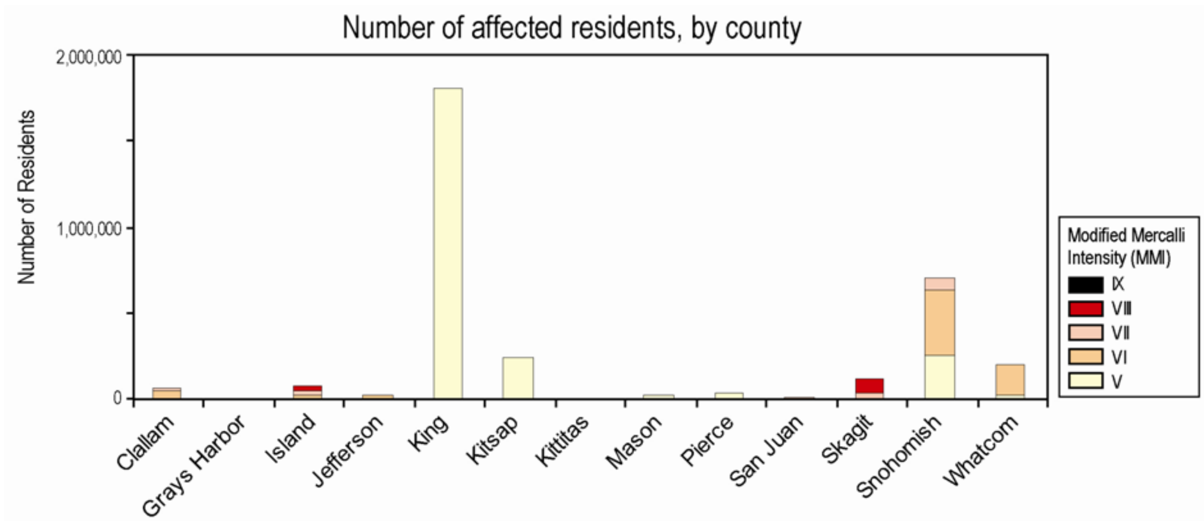
Income losses, including wage losses and loss of rental income due to damaged buildings, are highest in Skagit (nearly $259 million), Island ($55 million), and Snohomish (more than $39 million) counties.

Impact on Households and Schools: The number of people without power or water may be highest in Skagit County. This county also accounts for most of the displaced households and individuals in need of shelter. Schools in Skagit County will be only 40% functional on Day 1 following the earthquake.

Debris Removal: After an earthquake, debris (brick, wood, concrete, and steel) must be removed and disposed of. Much of this will come from Skagit County (about 429,000 tons), along with Island and Snohomish counties (168,000 tons combined).

Estimates vs. Actual Damage: Although this M7.4 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 the possible impact on different services and business sectors. Note that in King County, a greater number of residents will be exposed to less severe shaking, whereas Skagit, Island, and Snohomish counties, although less populated, will experience more intense ground motions.



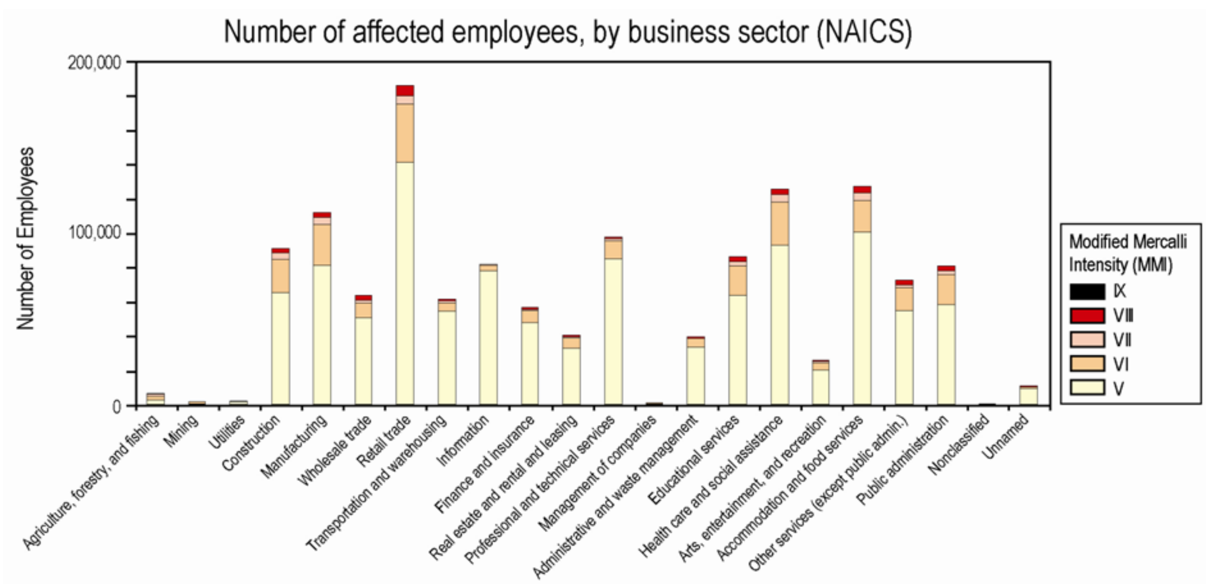


Figure 3. Number of residents and employees affected by the M7.4 earthquake projected for Darrington–Devils Mountain (West). Modified Mercalli Intensity (MMI) classes indicate peak ground acceleration (PGA) values and the impact of shaking.

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.