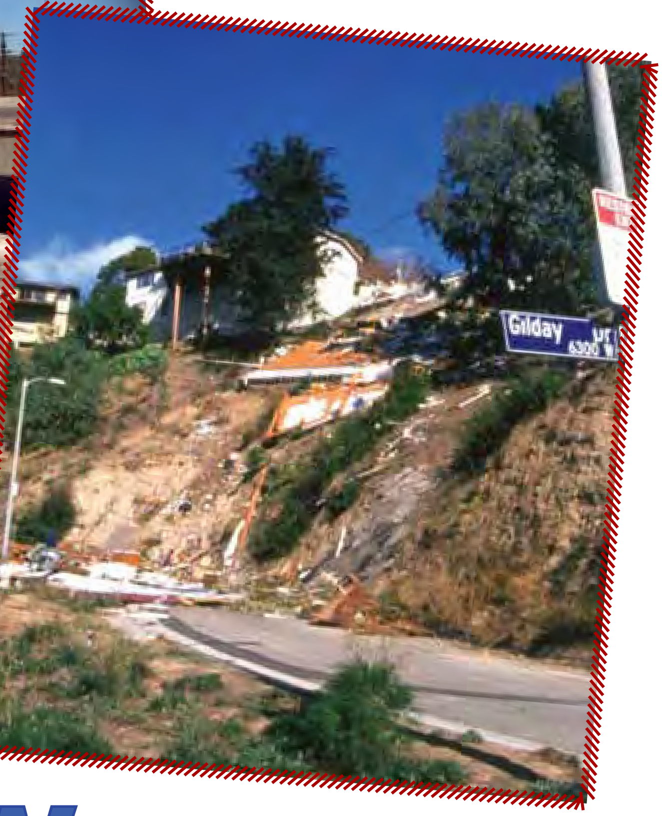

Cascadia Shallow Earthquakes

2009

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Cascadia Region Earthquake Workgroup
Sharing Information to Promote Mitigation

Shallow earthquakes

Shallow earthquakes pose a serious risk to Cascadia. Small shallow earthquakes shake the region every day. A few of the larger events in Cascadia history are listed starting on page 15.

A 1983 earthquake, magnitude (M) 6.4, in Coalinga, California shows how much damage a moderate-sized event can do to a small town. Nearly one hundred people suffered injuries, though fortunately no one died. Property damage included condemned houses and buildings (some from fire) and hundreds of homes with minor damage. In all, losses were an estimated $50 million (in 2000 US dollars)

At the same time, Coalinga showed how preparation can help a community recover. Building damage was much more serious in older structures that did not meet the building codes in force at the time of the earthquake. Most of the public buildings, including the fire and police stations, schools, and the city's hospital had been upgraded, reducing injuries and damage. And, because these buildings were operational directly after the earthquake, a faster response and recovery were possible.

Many cities in the Cascadia region have old, unreinforced masonry (URM) buildings not retrofitted to current safety standards. Because these buildings are among the most dangerous in an earthquake, a moderately sized earthquake here could create significantly greater casualties and damage than in Coalinga.

Shallow earthquakes generally include aftershocks. They may occur in swarms, which are small events that last for days to years. Other types of earthquakes that occur in the area are classified as subduction or deep. It is important to note that the Cascades have many small earthquakes, especially on Mt. St. Helens and Mt. Hood, which are not related to volcanic activity. More information about earthquakes and preparation can be found at www.crew.org.

Scientists have researched major faults and their potential for damage. Knowing where large future earthquakes may occur can help focus earthquake preparations most effectively and efficiently. This information can be consolidated on a hazard map.

The US Geological Survey (USGS) produced specific maps for the Seattle area. A group of government and private scientists, engineers, city officials, and others used these maps to create a scenario for a shallow earthquake in Seattle. It includes maps and text that describe potential damage in bridges, utility systems, hospitals, and more. This report can be used to tailor specific preparation measures, some of which can dramatically reduce damage.

There are hazard maps for many other cities, though the amount of detail varies; some include an analysis of their current level of risk. These can also be used to target earthquake preparations. Generalized scenario maps for possible earthquakes near Vancouver, BC, Spokane, WA, Portland, OR, and Klamath Falls, OR are included in this report starting on page 20.

Some maps delineate areas most at risk from primary earthquake hazards: ground shaking, ground failure (landslides and lateral spreading), and in a small number of specific places, a tsunami. Secondary hazards include building vulnerabilities, fire, and hazardous material spills. Areas at risk from these hazards may be compiled by local communities.

There are many ways to promote earthquake resiliency—reducing the original damage and allowing a faster recovery. A few of these are:

Building codes

- Stronger building standards for critical facilities like fire/police stations, schools, and hospitals.
- Securing chimneys and parapets from falling.
- Strengthening existing buildings.

Planning

- Identify places of greatest risk and consider land use controls to discourage or restrict the quantity and types of structures that can be built.
- Prepare a recovery plan *before* an earthquake.

Public Education

- Prepare and distribute publications or other media with earthquake information.
- Encourage all families, businesses, and government offices to have earthquake kits and plans.

Preparation is more cost-effective than cleaning up after an earthquake. Steps a community can take before an earthquake include:

- Identify and characterize potential earthquakes;
- Quantify the risk (what might be damaged from earthquakes);
- Build a team to develop strategies for making the most cost-effective, long-term decisions;
- Determine your resources;
- Consider a range of strategies to address the risk before making a decision;
- Integrate the chosen strategies into long-term plans for ongoing success.

Living with earthquakes

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Earthquakes and other natural processes like volcanoes, landslides, and floods all sculpt the scenery that makes the Cascadia region such a beautiful place in which to live. However, these processes also can be hazardous. Earthquakes cannot be avoided, but we can continue to prosper if we plan and prepare for them.

Most common earthquakes

Shallow, also called crustal, earthquakes shake the Cascadia region every day. These earthquakes generally occur at depths of less than 20 miles (35 kilometers) within the crust of the North America plate. Over the course of a year, thousands of such earthquakes occur in the area, though only a dozen or so may be felt and few have been large enough to cause damage since the development of large cities in Cascadia. These earthquakes can range from very small to magnitude (M) 7.5. The magnitude scale is logarithmic; each whole number increase represents an earthquake ten times greater in size. A M5 event will rattle people but probably create mostly minor damage. A M7, which would be 100 times greater than a M5 event, could devastate cities and cause fatalities.

Deep and subduction zone earthquakes also occur in Cascadia. More information about these three types of earthquakes can be found starting on page 3.

Even a moderate shallow earthquake can produce extensive damage. Generally, the area along the fault suffers the largest ground shaking. A shallow earthquake generally produces greater damage than a similar-sized deep earthquake.

Cascadia stretches 800 miles (1,300 km) long, from the Brooks Peninsula on Vancouver Island, BC to Cape Mendocino, California. Active geologic processes, including earthquakes and the development of the Cascade Range, affect the entire region. Map: Christopher Scott, University of Washington College of Built Environments

When brick, exterior walls fail, as in this store in Coalinga, they can injure people, block sidewalks and streets, or bring down utility lines. Photo: M. G. Hopper, United States Geological Survey (USGS)

Some structures in Coalinga totally failed, while nearby buildings had only limited damage. In the upper right corner is a building destroyed by fire. Open fronts at street level a few blocks away had only glass breakage. Photo credit: Earthquake Engineering Research Institute (EERI)

As our population grows and becomes more densely packed into cities, our risk increases. The infrequency of moderate to large shallow earthquakes causes an additional hazard: complacency and lack of preparation for the inevitable damage that will occur.

Recovering after an earthquake

Preparation can reduce casualties and property damage, and can help a community recover more quickly. Coalinga, California is an example of a small city that rebuilt after suffering major damage from a shallow earthquake. On May 2, 1983, a M6.4 earthquake shook the city. Thousands of aftershocks followed.

Coalinga's experience is especially relevant to the dozens of small to moderately sized cities in the Cascadia region, where similar-sized earthquakes are expected (though some areas will experience much higher magnitude events). Downtown areas with concentrations of unreinforced masonry (URM) buildings are at great risk for moderate to severe damage even in moderate earthquakes.

Nearly one hundred people in Coalinga were injured, but none died. Property damage was estimated at more than $50 million (in 2000 US dollars). About 60 percent of area residences were damaged. URMs were heavily damaged. Utilities were disrupted. The 8-block downtown commercial district in Coalinga was almost completely destroyed. Fire, often a secondary hazard after an earthquake, destroyed some buildings. However, buildings constructed within 20 years of the earthquake with earthquake-resistant features fared quite well, showing the importance of updating building codes.

Since the earthquake, the Coalinga area has regained its economic health. A new prison, industrial park, medical center, mental health hospital, and expanded parks and recreation facilities have been built. The population has increased from 8,000 in 1983 to over 18,000 today.

Coalinga was prepared in many ways thanks to state laws enacted decades prior to the event, and the general earthquake preparedness culture of California.

Unfortunately, most areas of Cascadia are not as prepared; many do not even understand the hazard an earthquake represents. A similar-sized earthquake in many populated areas of Cascadia would result in fatalities. Upgraded building codes, public education, and emergency management training were a few of the measures that helped Coalinga recover from the earthquake. These tools are available to all cities, counties, states, and provinces in Cascadia to help prepare before disasters strike.

Different types of earthquakes

Earthquakes in most of Cascadia result directly or indirectly from the convergence of the continental North America plate with two oceanic plates: the Juan de Fuca and Gorda plates. The oceanic crust is denser than the continental crust, so the Juan de Fuca and Gorda plates sink, or subduct, beneath the North America plate. Stress builds up on the interface between the plates, and on faults within the plates themselves. Faults are surfaces within the Earth that occasionally break, releasing stored up stresses as earthquakes.

Shallow earthquakes

The subduction of tectonic plates does not happen easily. The continental and seafloor plates get stuck along the interface between them. In addition, the collision causes the overlying plate to crumple, and stresses to build on faults within it. Shallow earthquakes occur when these faults break, relieving the stress.

Other processes cause stresses to build on crustal faults. For example, southeast Oregon is part of the Basin and Range province, where the stresses result from a pulling apart and thinning of the more interior reaches of the North America plate.

The 1946 Vancouver Island earthquake (M7.3) caused a chimney to fall through the roof at this school. New building codes In both Canada and the United States require much stronger structures, but thousands of schools and other buildings have not been updated to meet current codes. Photo: Natural Resources Canada (NRCan)

Just a few of the large, shallow earthquakes in the history of Cascadia include: two on Vancouver Island, BC (M7.3 in 1946 and M7.0 in 1918), the North Cascades earthquake in 1872 near Chelan, Washington with a magnitude now calculated at 6.8, and an approximately M7 earthquake on the Seattle fault about 1,100 years ago. Geologists have found evidence of many other magnitude 7 earthquakes, especially around the Puget Sound area. Throughout most of Cascadia, there is the possibility for potentially destructive events of M6 or greater. Aftershocks are common with shallow earthquakes. After a large event, more damage from aftershocks can be expected.

Subduction earthquakes

The interface between the downgoing and overlying plates in a subduction zone is a giant fault. If it breaks all at once, a massive earthquake results, like the 2004 event that occurred off the coast of Indonesia and generated a tsunami in the Indian Ocean. The Cascadia subduction zone is much the same as that earthquake setting. The initial earthquake could be as large as M9 and be felt throughout the Cascadia region. Aftershocks will be frequent and some are likely to be large enough to cause more damage. More complete information can

URMs pose many problems in earthquakes. These cars were damaged by the failure of an unreinforced brick wall. Here, only a parking lot is compromised, but if the bricks fall into the street, pedestrian and car traffic will be affected until the area has been cleaned up. If there is a great deal of damage, it can take days or weeks to clear all the streets of debris. Photo: M.G. Hopper, USGS

Earthquakes in Cascadia			
	Shallow	**Subduction**	**Deep**
Frequency	Small shallow earthquakes are recorded every day in Cascadia and damaging shallow earthquakes occur every few decades. Any single fault may produce an earthquake every few hundred to thousands of years, but there is an abundance of faults within the crust.	Geological evidence suggests an average of 500 years between major events.	Damaging deep earthquakes occur every 10-30 years in the Puget Sound area, and less frequently elsewhere.
Length of shaking	Few seconds to less than a minute	Strong shaking will likely be felt for several minutes, stressing buildings more than shorter events.	Few seconds to less than a minute
Highest expected M	In Cascadia the largest magnitude shallow earthquake expected is about M7.5.	As large as M9.	Usually less than M7.5.
Aftershocks	Numerous aftershocks are likely.	Many aftershocks will occur, creating the potential for additional damage.	Few aftershocks.
Tsunami	Tsunamis are unlikely, though there could be a local tsunami from shaking-induced landslides, or from shallow earthquakes occurring under Puget Sound, the Strait of Georgia, or large lakes and rivers.	A destructive tsunami will quickly hit the Cascadia coast, and travel across the Pacific Ocean toward Alaska, Hawaii, and Asia.	No tsunami is expected.
Expected damage	Can be substantial near epicenter and along fault, but damage is localized	Substantial damage throughout entire Cascadia region.	Less damage than in similar sized shallow earthquakes, but felt over a larger area
Past dates	1946 Vancouver Island (M7.3), 1993 Scotts Mills, Oregon (M5.6), two 1993 Klamath Falls, Oregon (M6.0 each), and 1954 Eureka, California (M6.5) events.	The last great Cascadia earthquake occurred on January 26, 1700. Previous great earthquakes occurred in the years (approximately) 900, 750, and 400.	2001 Nisqually (M 6.8), the 1965 Seattle (M6.5), and the 1949 Olympia (originally measured M 7.1, now revised to M6.8) earthquakes in Washington.

be found at www.crew.org in the publication *Cascadia Subduction Zone Earthquakes: A magnitude 9 earthquake scenario.*

Deep earthquakes

Deep earthquakes occur within the subducting Juan de Fuca and Gorda plates as they sink and deform beneath the North America plate. While descending, they are subjected to high temperatures and pressures that cause changes in the rock. These changes lead to earthquakes with unique characteristics. For example, deep earthquakes do not generally produce many—or any—aftershocks. Because the earthquake is deeper, the area directly above the fault experiences weaker shaking than in a similar-sized shallow earthquake, but shaking is felt over a wider area. More complete information can be found at www.crew.org in the publication *Cascadia Deep Earthquakes.*

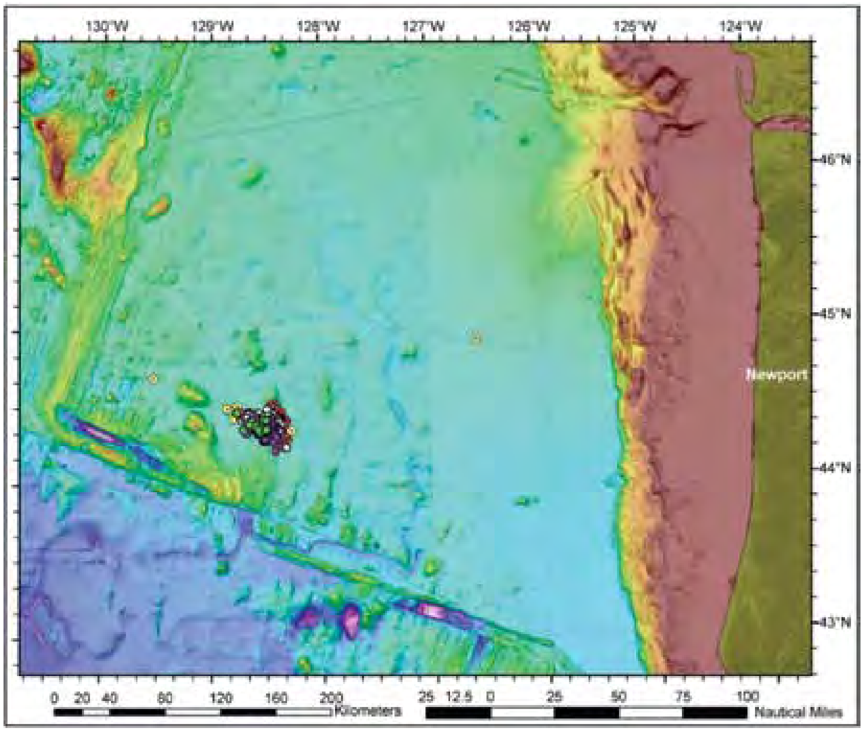
Earthquake swarms

Earthquake swarms are a series of small, shallow earthquakes that may last for days to years. A swarm is a localized cluster of earthquakes, with no one shock being conspicuously larger than the other shocks of the swarm. They occur in a variety of geologic environments and are not known to indicate any change in the long-term seismic risk of the region. Swarm characteristics are, in fact, a feature of much of the seismicity east of the Cascades in Oregon and Washington.

A sequence of small earthquakes shook Spokane, Washington from May through November 2001. Part of this sequence behaved like a typical swarm; part of it behaved like a mainshock–aftershock sequence. More than 75 earthquakes were recorded. The earthquakes were very shallow, some only a mile or two deep. The strongest shock in the Spokane sequence was on November 11, a M4.0, followed by M3.1 and M3.3 events over the next few hours. Many of the tiny earthquakes started with loud noises that sounded like explosions or the pounding of heavy equipment. A few bricks were shaken from chimneys and knickknacks rattled, but the greatest impact was to fray the nerves of Spokane's residents.

Nonetheless, the sequence reminded citizens about the need to prepare for natural hazards, and students participated in earthquake drills, reinforcing the advice to drop, cover, and hold when the ground shakes. Since the end of the

The last damaging earthquake in Cascadia was the M6.8 Nisqually event on February 28, 2001. This debris from a URM in Olympia fell in an alley and no one was hurt. Because it was a deep earthquake, the intensity of the shaking was less than it would have been in a similar-sized shallow earthquake. Photo: University of Washington Civil Engineering Department



Swarms also occur on the seafloor. Scientists recorded more than 600 earthquakes in the first 10 days of April, 2008, off the central Oregon coast. These small earthquakes do not cause tsunamis. The colored dots represent earthquakes on different days. Map: Hatfield Marine Science Center

earthquakes in 2001, there has been little activity. The cause of the swarm remains a mystery to seismologists.

Other locations with earthquake swarms or sequences in the past few decades include Seattle and in the Columbia Basin particularly near Richland, Washington; Jordan Valley, Lakeview, Adele, and Maupin in Oregon; and offshore from Vancouver Island in British Columbia.

Earthquakes do not mean eruptions

Most earthquakes in the immediate vicinity of volcanoes do not foreshadow impending eruptions. For example, Mt. Hood in northern Oregon, experiences earthquake swarms every few years without accompanying volcanic activity. One swarm began on January 11, 1999 and included several magnitude 3 earthquakes, with most of the activity about 4 miles (7 kilometers) south-southeast of Mt. Hood. In 2008, there were 14 small earthquakes of magnitudes less than 1.6 between April 28 and November 18.

However, the Cascades Volcano Observatory (CVO) continuously monitors earthquake activity in the Cascades. Seismometers track the numbers and sizes of tiny earthquakes that can indicate magma movement. If any of the Cascades have earthquakes that may be evidence of volcanic activity, the CVO will closely track the activity to give as much warning as possible before a potential eruption.

Reading seismograms

Seismograms record the P and S seismic waves that radiate from an earthquake.

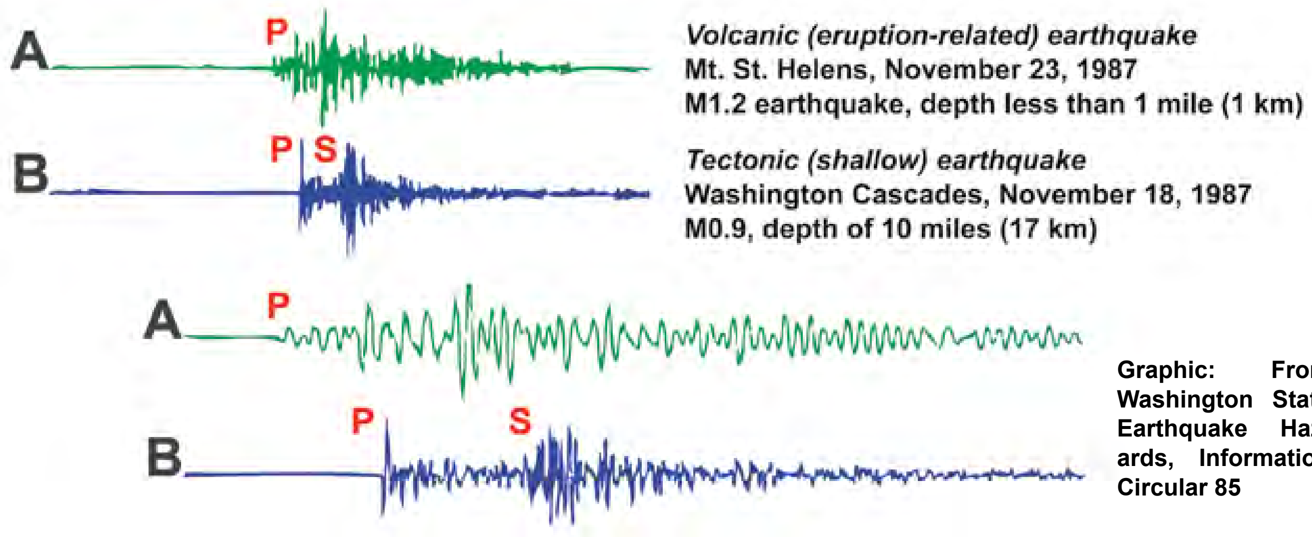
A P (primary) wave is compressional. It shakes the ground in the same, and the opposite, direction the wave is moving.

An S (shear) wave shakes the ground perpendicular to the direction the wave is moving. It travels more slowly than the P wave.

Volcanic (movement of magma) earthquakes and tectonic (shallow, not eruption-related) earthquakes can both occur around volcanoes like those of the Cascade Range. The seismograms below illustrate how the two types of earthquakes can produce different shaking patterns.

Earthquake A is from the volcanically active Mt. St. Helens. Earthquake B is an earthquake that is not connected to a volcanic process. (The second set is simply the first seismograms expanded in time to show more detail.)

The shape of the P wave is more abrupt in the shallow earthquake and diminishes regularly. The arrival of the S wave creates another spike.



Volcanic (eruption-related) earthquake
Mt. St. Helens, November 23, 1987
M1.2 earthquake, depth less than 1 mile (1 km)

Tectonic (shallow) earthquake
Washington Cascades, November 18, 1987
M0.9, depth of 10 miles (17 km)

Graphic: From Washington State Earthquake Hazards, Information Circular 85

Turning science into safety

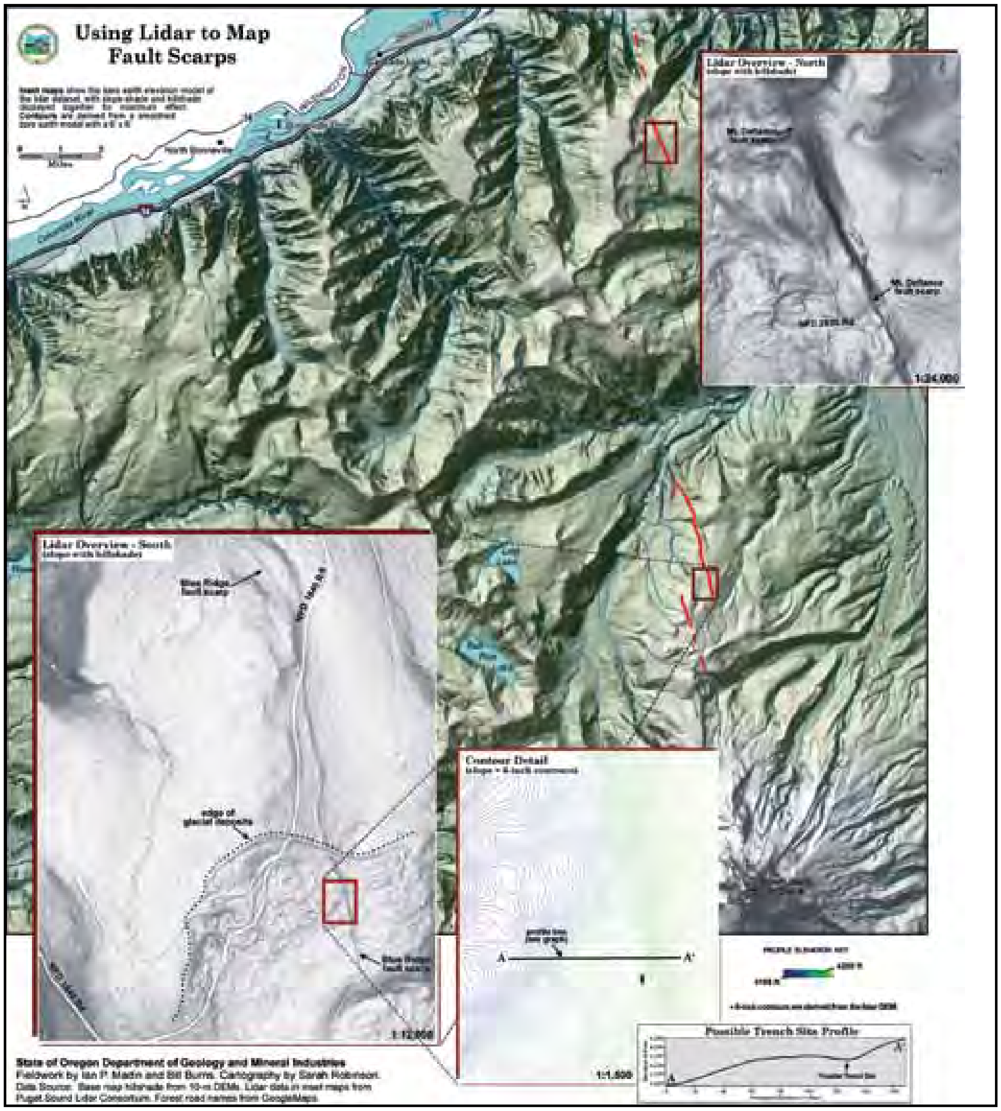
There are many challenges in understanding the earthquake history of Cascadia, as well as forecasting how, when, and where future earthquakes might occur. However, scientists have made great strides in the last decade.

Earthquakes occur on faults; bigger earthquakes occur on bigger faults. A first step in assessing earthquake hazards is locating and characterizing the region's major faults. Many faults, particularly smaller ones, are entirely buried beneath the surface so indirect methods must be used to find them. In some places small earthquakes help delineate large faults, but many small Cascadia earthquakes do not correspond to known faults.

To find and define buried faults, geologists and geophysicists interpret images of the subsurface geologic structure. Like the sound waves that produce ultrasound images or electromagnetic waves that construct X-rays, scientists use seismic and other types of signals to construct images of what lies below ground.

Faults are often hidden by the dense plant coverage that blankets most of Cascadia. Or they may be eroded by the region's abundant water. A tremendous new tool in the search for faults is Lidar (Light Detection and Ranging). This remote sensing imagery produces very high-resolution topographic maps covering broad areas. Lidar images have revealed the existence and extent of many previously unknown major faults.

Knowing the location of a fault is important, but so is knowing how often it causes an earthquake. A recurrence interval is the average time period between earthquakes of roughly the same size—



Lidar can be used to find fault traces and landslides that are difficult to see on the surface because of land cover. This map shows a portion of Mt. Hood with steep slopes and dense forests. The insets show The Mt. Defiance and Blue Ridge fault scarps, and the edge of glacial deposits, that can be difficult to find by traditional geologic mapping techniques. Map: Oregon Department of Geology and Mineral Industries (DOGAMI)

Landslides can be triggered by earthquakes that shake areas with water-saturated soils, a common occurrence in the rainy parts of Cascadia. They can block roads, but they can also disrupt utility lines, which may be more detrimental to the recovery of an area. The street light and utility pole in the picture above have both obviously been affected by this earthquake. Underground pipelines are not as easily seen but can also be affected. A buried water main and buried fiber optic main were both ruptured. Co-located lifelines can be interdependent and affect each other. Photo: Yumei Wang, DOGAMI

usually hundreds or thousands of years. To forecast an earthquake on a specific fault is difficult. The range of uncertainty may be hundreds of years.

Although all these factors mean that the probability of an earthquake on any single fault may be low, the likelihood becomes significant when considering an area with numerous faults, which is the case for much of Cascadia. For example, in the Puget Sound region there is a 15% chance of a M6.5 or greater shallow earthquake of within a 50-year span. The specific time, fault, and damage cannot be forecasted, but we know that there will be destructive earthquakes in the future.

No one wants to experience a damaging earthquake, but we actually benefit from small events in several ways. Scientifically, earthquakes provide opportunities to learn about their causes, how they grow and move along faults, and their effects. The occurrence of earthquakes often provides motivation for enhanced study and mitigation.

For example, in 1949 a deep earthquake between Olympia and Tacoma caused substantial damage in Seattle, especially to waterfront structures built on pilings and to buildings on filled ground in the Duwamish River valley and on the former tide-flat area at the south end of Elliott Bay. This led Seattle to become the first place in the Pacific Northwest to adopt codes containing earthquake design considerations.

A deep earthquake in 1965 with approximately the same magnitude and location as 1949 shook Seattle again. These damaging events motivated scientists to investigate the earthquake potential in the region. A variety of imagery and geophysical data helped to define the scale and dimensions of area faults and regional tectonics. These included Lidar, aeromagnetic, gravity, and seismic maps and images that allow scientists to map the subsurface. Scientists also noted clues that many of the faults were active. A series of studies revealed drowned forests in Lake Washington, tree ring anomalies, prehistoric landslides and rockfalls, tsunami sands, and disturbed lake sediments—all with occurrence dates of about 1,100 years ago.

Putting all these pieces together confirmed that Seattle is crossed by a fault zone—a complex web of east-west trending faults—that caused an earthquake about that time. At some points, the Seattle fault zone lies nearly under Interstate 90 and Lake Sammamish. The maximum magnitude of an earthquake on the fault zone is about M7.3. Likely consequences of a Seattle fault earthquake are discussed on page 10.

Earthquake hazards

Ground shaking: Most earthquake damage results from the shaking caused by seismic waves passing beneath buildings, roads, and other structures. Some soil types amplify earthquake shaking, particularly deep, soft soils, especially on valley bottoms and areas of artificial fill. Most areas at risk can be identified from soil studies done for land use planning and development, or on geologic maps.

Ground failure: Loose sandy soils saturated with water can liquefy—lose the cohesion between grains that gives them the ability to support any weight—during earthquake shaking. These soils are prevalent along rivers, streams, and lakes. Liquefaction can undermine the foundations and supports of buildings, bridges, pipelines, and roads and cause the ground to slide toward lakes or rivers. Earthquakes can also trigger landslides, either immediately or days or weeks later.

Tsunami: Tsunamis result from a rapid vertical displacement of the bottom surface of a water body. Most faults in Cascadia won't directly generate tsunamis because they do not uplift the seafloor. However, earthquakes in the Puget Sound, Strait of Georgia, or Strait of Juan de Fuca areas could cause a tsunami. In addition, landslides generated by intense shaking can produce localized tsunamis.

Hazard maps

Earthquake hazard maps of various sorts turn scientific information into tools for improvement in: design and construction in areas of urban development; siting of infrastructure; emergency planning and response; and rating of insurance policies. Knowing where damage is most likely to occur allows safety programs to be focused where they will be most effective. It is important to know the location of the most vulnerable buildings, utilities, and neighborhoods. Typically, hazard maps display the ground shaking levels expected. These can be based on all earthquakes likely to affect the mapped area within a certain time window (probabilistic maps), or a single anticipated earthquake regardless of when it is likely to occur (deterministic maps). The latter are often used in scenarios, in which the consequences of the shaking to our built environment, economy, and other societal impacts are estimated.

For long-term planning and building codes, probabilistic maps are most often used. The USGS has produced a new series of such hazard maps specifically for the City of Seattle. These maps provide a much higher-resolution view of the potential for strong earthquake shaking than previously available versions. Contact your local geologic agency or emergency manager to see what maps are available for other cities in Cascadia.

Liquefaction and ports

The M6.9 Kobe earthquake in 1995 showed what a shallow earthquake can do to a major port.

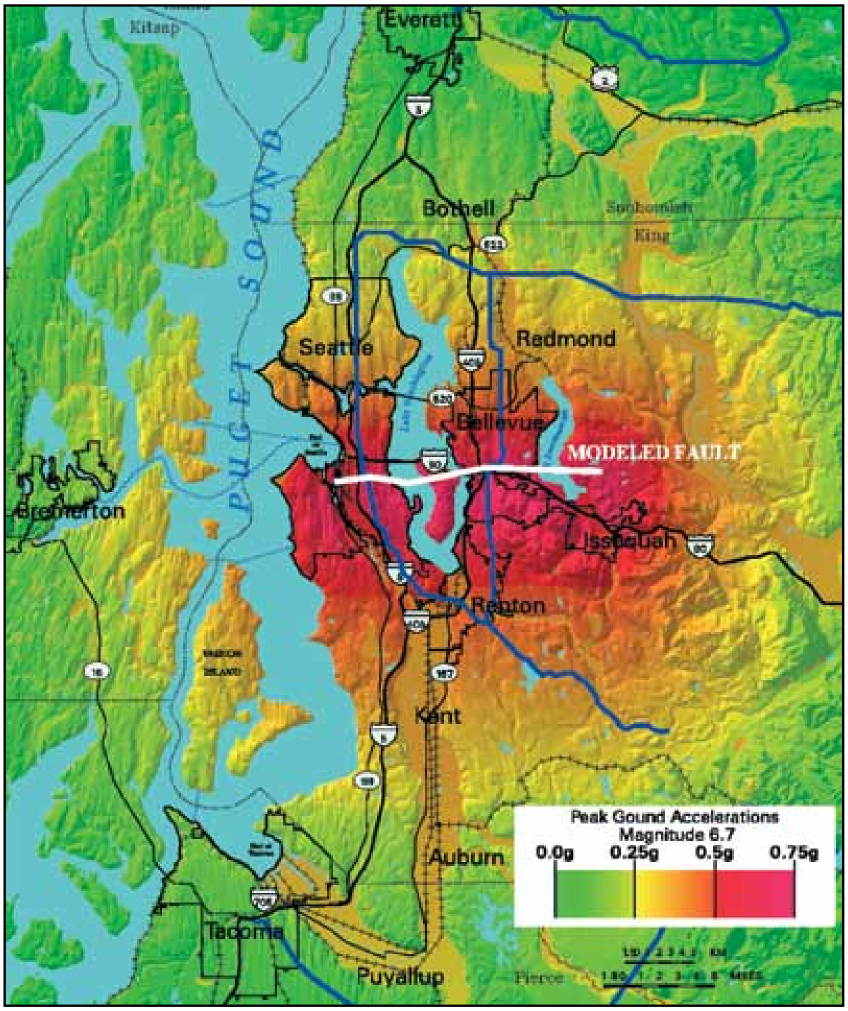
Port facilities tend to be at special risk from earthquakes because of the soils on which they are constructed. Soft soils, typical of coastal sands and silts or river alluvium, often liquefy, causing structures to collapse. Kobe's port is among the last of its economic sectors to recover.

After only four years, Kobe's economy had recovered 75% to 90% of its pre-earthquake capacity. One notable exception is the Port of Kobe, which permanently lost container shipping business to other Asian ports. Before the earthquake it was the largest port in Japan; it is now only fourth. The port still handles only 85% of the container cargo volume it did in 1995.

This crane, road to the port facilities, and numerous trucks were damaged by the M6.9 Kobe earthquake. Similar types of damage might be seen in Cascadia ports. Photo: EERI

Seattle earthquake scenario

Effective mitigation and response planning requires accurate forecasts of potential damage. One way to develop a forecast is to run a scenario earthquake. A multi-disciplinary team of engineers, planners, geologists, seismologists, economists, and emergency managers spent thousands of hours examining the implications of a M6.7 earthquake on the Seattle fault. One of the tools used to predict losses was HAZUS, short for Hazards US, developed by the Federal Emergency Management Agency and the National Institute of Building Sciences. This loss-estimation tool can help communities describe the effects of a scenario earthquake. The following information is taken from Seattle Scenario report, available at www.crew.org.



This map of Seattle shows what areas are most likely to be hazardous in an earthquake. The colors refer to hazardous areas, with red as the highest hazard. The white line is the Seattle fault. Black lines are highways. Blue lines are main lines for the area's water system. Many of the utility main lines are at danger of breaking from ground shaking or liquefaction in an earthquake with an epicenter in the region. Map: Seattle Fault Scenario Report

The Seattle fault earthquake scenario describes the potential for badly damaged homes, office buildings, manufacturing plants, schools, port facilities, utilities, and transportation routes. Areas closest to the fault rupture could be most severely affected. Collapsed structures and highway bridges might kill or injure thousands. Communication links could be swamped or broken, making communications difficult if not impossible throughout the region.

Police, fire, and medical aid units could receive hundreds of calls for help, but clogged and damaged roadways might severely limit their ability to respond.

In summary: "During the past 25 years, significant advancements have improved the awareness and understanding of the region's earthquake vulnerability. Seismic mitigation programs in our state have improved the earthquake performance of certain infrastructure and reduced risks to the public. However, regional and state leaders must use this opportunity to not only continue existing efforts but also to reinvigorate past efforts that have stalled. New seismic risk reduction programs and directives—derived from the hard lessons learned from the significant earthquake losses experienced by neighboring states and Seattle's sister city Kobe, Japan—are needed. There is much to accomplish. The time to act is now."

Earthquake resiliency

There are many ways to increase a community's resiliency—its ability to withstand and recover from an earthquake.

Below are some potential earthquake hazards, and approaches to reducing them. Two specific ways communities can effectively mitigate are the application of building codes and planning.

Buildings: The buildings most at risk in an earthquake include URMs and non-ductile concrete-frame buildings. URMs are generally built with brick walls and wood or concrete floors that are poorly connected to the walls. Non-ductile concrete frames have very little steel reinforcement and are very brittle when subjected to earthquake shaking.

Wood-frame homes generally fare well in earthquakes, but chimneys and brick facings can collapse and windows can break. Buildings need to be securely fastened so they do not separate from their foundations or utility lines.

Building design also affects its resiliency when shaken. Those with simple shapes tend to respond better. Parts of individual structures or closely spaced, adjacent buildings may pound against each other. Soft stories, such as parking levels, open retail space, and other floors with insufficient strength are more susceptible to collapse in earthquakes.

This building was of older, non-ductile, reinforced concrete-frame construction. End walls collapsed and separated from the main unit over the full height of the building. Photo: M. Celebi, USGS

After shaking and liquefaction, the ground must resettle. Differential settlement can cause structures to tilt.

The most common type of damage, but easiest to prevent, is nonstructural. Relatively inexpensive strengthening can ensure that when shaken, furniture doesn't tip over, objects don't fall off shelves or walls, pipes don't break, and parapets don't fall.

Utility systems: Our world depends on having electricity, telephones, running water, and other utilities. Shaking and liquefaction can cause significant breaks in these systems.

Fire: Broken electrical services and gas lines may ignite and provide fuel for fires, and broken water lines hinder firefighters' efforts.

Hazardous materials: Hazardous materials from commercial, industrial, and household sources (for example, ammonia and bleach) can be stored so they aren't likely to spill or mix when their containers are broken.

Building codes

Building codes reduce building failures, which in turn reduce earthquake-related injuries and fatalities, and the time and effort needed for a community to recover. However, it is important to note that current building codes in most of Cascadia

Lateral spreading and differential settling broke up this road and brick walkway. The same processes can severely damage buildings. Photo: Yumei Wang, DOGAMI

Failure of pendant light fixtures in this elementary school library could have caused injuries if the room had been occupied. Strengthening nonstructural elements in homes, schools, and offices can often be done easily and relatively inexpensively. Photo: EERI

are life-safety standards—only meant to ensure that a building does not collapse during an earthquake and that people will be able to exit after the shaking. Additional design measures are required for a building to be usable immediately after an earthquake. Critical facilities like hospitals, emergency centers, and long-span bridges have higher standards. A brief review of how and why codes have developed demonstrates their effectiveness.

The Field Act, passed on April 10, 1933, required stringent standards for school construction in California. This Act was a response to a M6.2 earthquake near Long Beach, California that occurred in the early morning hours of March 10, 1933. URMs, including many school buildings, failed catastrophically. People realized that if the earthquake had struck when school was in session the loss of life would have been appalling. No Field Act school has ever failed in an earthquake, showing the importance of building codes.

In 1955, the state of Washington adopted a comprehensive law that required hospitals, schools, and public buildings to resist probable earthquake intensities. Of course, at that time, the extent of the earthquake hazard to Washington and the rest of Cascadia was not well understood, so those standards have been upgraded several times.

Critical facilities such as hospitals and fire stations may need to be operational after an earthquake. In some places, critical facilities are built to a higher standard so they can continue to function after a major earthquake. The 1994 Hospital Facilities Seismic Safety Act requires all California hospitals meet immediate occupancy standards for a 500-year earthquake by 2030.

In 2001, Oregon passed legislation that required emergency facilities (hospitals, fire, emergency operation centers, and police stations) meet life safety standards by 2022 and public schools (K-12, community colleges and university buildings with more than 250 occupants) by 2032. Voters passed ballot measures allowing state general obligation bonds to pay for this earthquake mitigation. In 2009, Oregon launched the first state-funded seismic rehabilitation grant program, which provides up to $1.5 million to high risk schools and emergency facilities.

A 2004 initiative by the British Columbia provincial government earmarked $1.5 billion over a

Built in 1952, Fire Station #1, is the largest in Portland. Its original concrete frame made it susceptible to serious damage in an earthquake. Strengthening work on the station, completed in 2009, included injecting cement into the soil beneath the building to prevent liquefaction and building settlement. It should now be in working order after an earthquake, serving downtown Portland. Photo Credit: Peck Smiley Ettlin Architects

15-year period to upgrade 700 schools to new earthquake standards.

Homeowners can also reduce their chances of earthquake damage. One of the first actions a homeowner can take to protect a house against earthquake damage is to make sure it is bolted to its foundation and the chimney is reinforced. If a house shifts off its foundation, the walls and roof may still be intact, but utility lines will be severed and chimneys may fall. In Washington and Oregon, homes built after 1975 must be bolted to their foundations.

The International Building Code (IBC) has been adopted in Oregon, Washington, and California. The IBC brings the most current understanding of the earthquake hazard together with the best engineering practices to withstand it. Exact details will vary from place to place because of local conditions, but structures built from now into the future will be better equipped to handle earthquake stresses. Newer building codes address not just the expected average ground shaking, but also take into account local variations in soil types and their responses to shaking (like potential liquefaction).

On January 17, 1995 a M6.9 earthquake occurred near Kobe, Japan. Cars, bikes, and buildings fell into the bay. Liquefaction and flooding were common near the waterfront. Areas like this can be designated parks, open spaces, or require special design and engineering. Photo credit: Dr. Roger Hutchison. Image provided by the National Geophysical Data Center

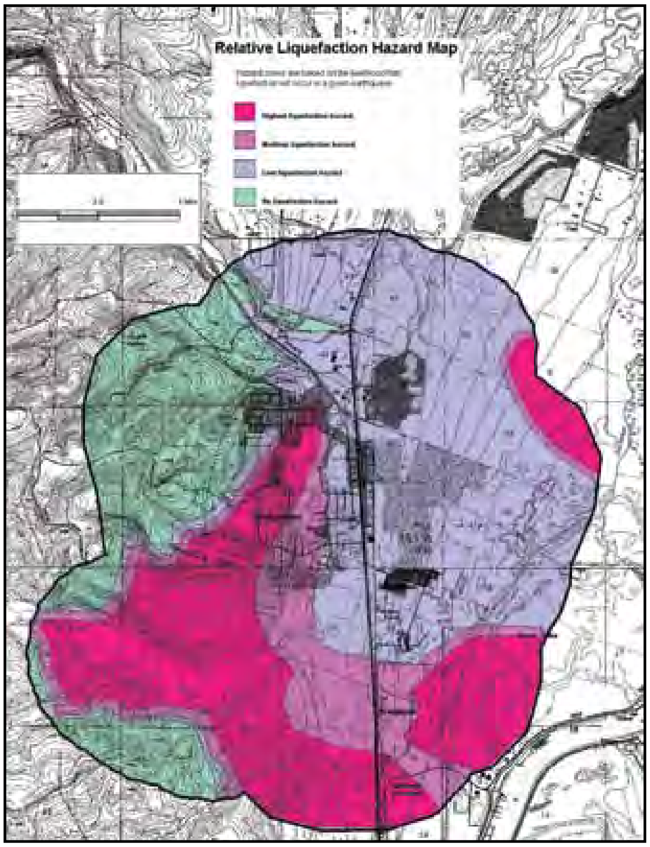
The 1995 National Building Code (NBC) required buildings in British Columbia to withstand an earthquake with a 10% chance of occurring in 50 years (the average life-expectance of a building). The 2005 NBC outlined much stricter criteria, requiring buildings to withstand greater earthquake forces.

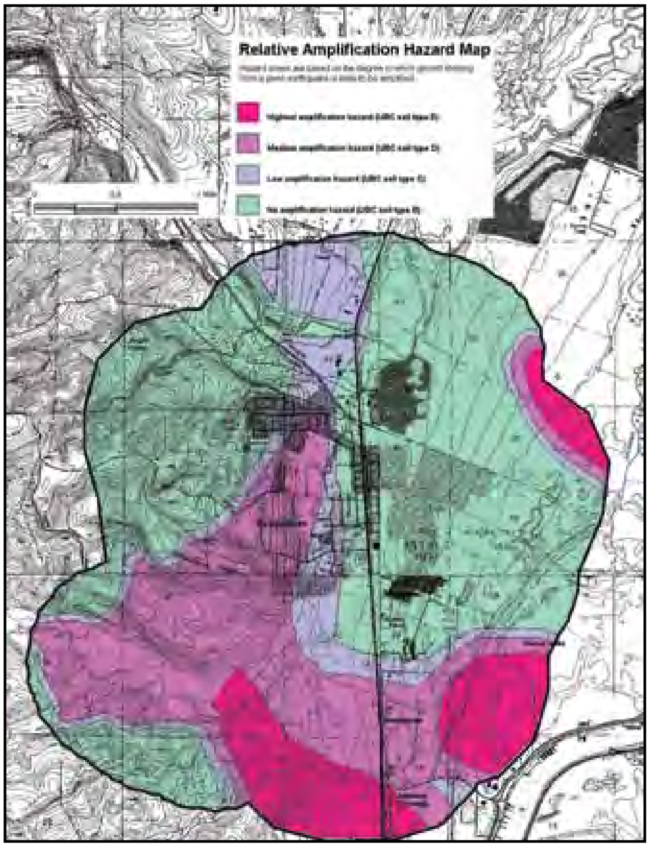
Though codes, design, and construction have improved immensely, the process continues. Updated information about earthquakes and construction techniques will be integrated into future building codes.

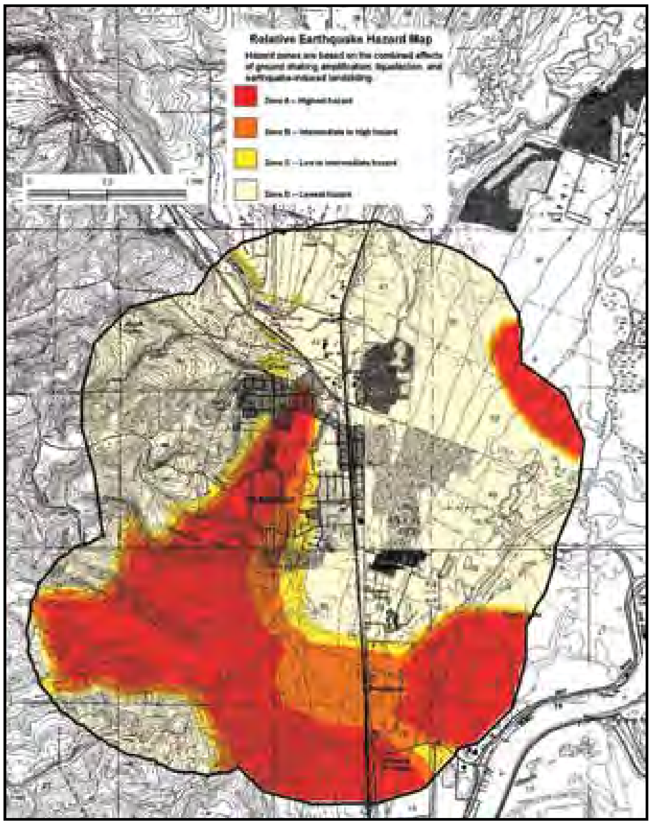
Planning

Building codes improve the safety of future buildings, but they do not affect structures already in place. An important step in preventing fatalities and damage is to identify the most vulnerable buildings, like URMs, and find ways to upgrade or replace them. In some cases, a community will decide to relocate a public building to a safer site. This can be done in stages, as resources permit, using special programs like tax incentives, low interest loans, and perhaps federal, state, or provincial funds. The best time to address structural and nonstructural deficiencies is in conjunction with other planned major renovations.

Land use planning can help communities identify the best places to build, as well as areas that might be better preserved as open space or parks. Steep slopes and areas with soils that hold water present special dangers in earthquakes. It may be prudent to restrict building in those areas, or require special reinforcement for critical facilities.







These three maps show relative earthquake hazards in Scappoose, Oregon, a small town close to the Columbia River. The bottom left map shows the relative amount of amplification expected in different areas. The top left map shows liquefaction, an expected hazard so close to a major river. These two hazards, along with a similar landslide map, have been combined into a single map, above. The accompanying text in the complete report explains in detail what each level on the maps represent. These maps can be used for planning land use or emergency response by showing the most hazardous areas of town. Maps: DOGAMI

Previous shallow earthquakes

Many shallow earthquakes have been felt throughout the Cascadia region. Some have caused damage, even in sparsely populated areas, but most importantly, previous events provide useful lessons for assessing likely consequences of future earthquakes. (Note: All dollar figures in the following summaries have been adjusted to 2000 US values.)

British Columbia

1946 Vancouver Island

Canada's largest historic onshore earthquake was a M7.3 event that occurred at 10:15 a.m. on Sunday, June 23, 1946. The epicenter was in the Forbidden Plateau area of central Vancouver Island, and was felt as far away as Prince Rupert, British Columbia and Portland, Oregon. Two deaths resulted; one person drowned when a small boat capsized in an earthquake-generated wave, and another died from a heart attack in Seattle. The earthquake knocked down 75% of the chimneys in the closest communities of Cumberland, Union Bay, and Courtenay and did considerable damage in Comox, Port Alberni, and Powell River. A number of chimneys were shaken down in Victoria. Many unreinforced masonry buildings (URMs) were damaged. Landslides and liquefaction caused damage to transportation infrastructure.

1918 Vancouver Island

This large earthquake, about M7, occurred just after midnight on December 6. Its epicenter was near the west coast of Vancouver Island. The Estevan Point lighthouse suffered some damage, as did the Nootka lighthouse. It was felt south to Washington and east to Kelowna.

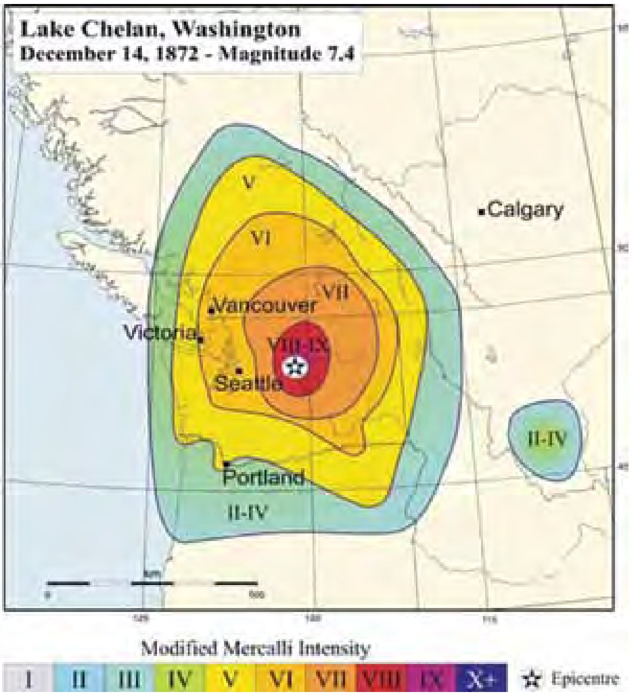
Washington

1995 Robinson Point

At 11:23 PM on January 28, a M5.0 earthquake occurred near Robinson Point (on Vashon Island, midway between Seattle and Tacoma). The event included one foreshock of M1.8 earlier in the day and relatively few aftershocks for a shallow earthquake of its size (only 28 aftershocks recorded through June 1995). This event highlights an enigma of shallow earthquakes in Cascadia: the faulting at depth cannot easily be correlated with geologic evidence of faulting near the surface. Minor damage was reported in Auburn, Tacoma, and Puyallup; liquefaction occurred as far away as Snoqualmie; shaking was felt as far away as Salem, Oregon and Vancouver, British Columbia.

When strong shaking occurs, serious damage can result if a building is not attached to its foundation, like this house during 1946 earthquake on Vancouver Island.

It is important that older houses be retrofitted to be attached to their foundations. Building codes require this for new construction. Photo: Geological Survey of Canada



The Lake Chelan earthquake caused considerable damage, even considering the small amount of development in 1872. (This earthquake, originally estimated at M7.4, has been recalculated at M6.8.) A similar event today could be very expensive in terms of injuries and recovery. The Modified Mercalli Intensity scale (see sidebar on page 20 for an explanation of levels), used on the map above, is based on how strongly people feel an earthquake, as well as specific levels of damage. In general, people can feel an earthquake as low as level II, minor damage starts at level V, and substantial damage is expected at level VIII. Map: NRCan

1996 Duvall

On May 2, a M5.3 earthquake was centered near Duvall, northeast of Seattle, in nearly the same location as a magnitude 5.2 earthquake on July 17, 1932. Aftershocks continued for months. Instrumental recordings of the earthquake shaking were particularly useful in revealing the potential for ground shaking levels to be amplified by the sediments of the Fraser River Delta in British Columbia, possibly by as much as six times relative to motions where sediments were thin or absent. The mainshock was felt from southern British Columbia to northern Oregon and east to Wenatchee. Residents of the Duvall-Monroe area reported items knocked from shelves and broken china and glassware. Seattle's Kingdome was evacuated during a Mariners' game.

1990 Deming

In April, a swarm of earthquakes shook the area of Deming, northeast of Bellingham and southeast of Vancouver, BC. The largest were M4.3, M4.0, M5.0, and M4.0 between April 2 and 14. In all, the swarm, which lasted through most of the rest of the year, included nearly 100 small and moderate earthquakes. The activity wasn't unusual for the area. A M5.2 event was recorded in 1931, and a M4.0 event occurred as recently as 2005. Even the M5.0 event caused little more damage than knocking pictures off walls, bottles off store shelves and cracking mirrors, although it temporarily closed the US-Canada border crossing at Blaine.

1981 Elk Lake

The M5.5 Elk Lake (near Mt. St. Helens) earthquake occurred on February 13. The earthquake had an exceptionally vigorous aftershock sequence, with more than 1,000 aftershocks recorded. Though it was felt over a wide area, little damage was reported in the rural land it shook. As is often the case, the locations of the abundant aftershocks were helpful in delineating the buried fault that caused the earthquake. Curiously, few earthquakes occurred in the epicentral region during the seven years of monitoring prior to 1981, but nine months before the Elk Lake mainshock nearly the same spot experienced a swarm of small earthquakes lasting about two months. The epicenter was in the center of the St. Helens Seismic Zone, a 56-mile (90-km) long zone that trends north-northwest through Mt. St. Helens.

1872 Lake Chelan

Washington's largest historic shallow earthquake was on December 14, with an epicenter near Lake Chelan. Its assigned magnitude of M6.8 is based on historic records of damage and other earthquake affects at Victoria and Seattle. It was felt south to Eugene, Oregon, north into British Columbia (probably even into

Alaska), and east to Montana and Alberta. Aftershocks were felt for two years.

The earthquake caused huge landslides throughout the Cascades. It reportedly triggered a massive slide at Ribbon Cliff (between Entiat and Winesap) that blocked the Columbia River for several hours. Ground fissures opened around Chelan and at spots on the east side of the Columbia River. At Chelan Falls, a geyser appeared and spouted water as much as 30 feet (9 meters) into the air for several days.

Oregon

1993 Klamath Falls

M6.0 earthquakes struck Klamath Falls on September 20 at 8:28 PM and 10:45 PM. These were felt as far north as Eugene and as far south as Redding, California. Two people died: one man was crushed in his truck by a rockslide and one woman had a heart attack. In all, more than 1,000 buildings were damaged, including some houses that shifted off their foundations. Damage totaled $12 million. Three highways leading to Klamath Falls were temporarily closed because of rockslides or concern about possible damage to bridges. An aftershock of M5.4 occurred on December 4, causing additional damage at Klamath Falls and slight damage at Tulelake, California. The number of casualties might have been higher if the events had not happened at night when most people were in their homes, not in dangerous buildings or walking on downtown streets.

1993 Scotts Mills

A M5.6 earthquake centered under Scotts Mills at 5:34 AM on March 25 was felt from Seattle in the north to Roseburg, Oregon in the south. The earthquake may have occurred on a buried segment of the Mount Angel Fault, but a 6-mile (10-km) separation between the epicenter and evidence of this fault exposed at the surface makes this association speculative. About 200 aftershocks were recorded and 11 were large enough to be felt. The largest aftershock, a M3.9, occurred three months after the mainshock.

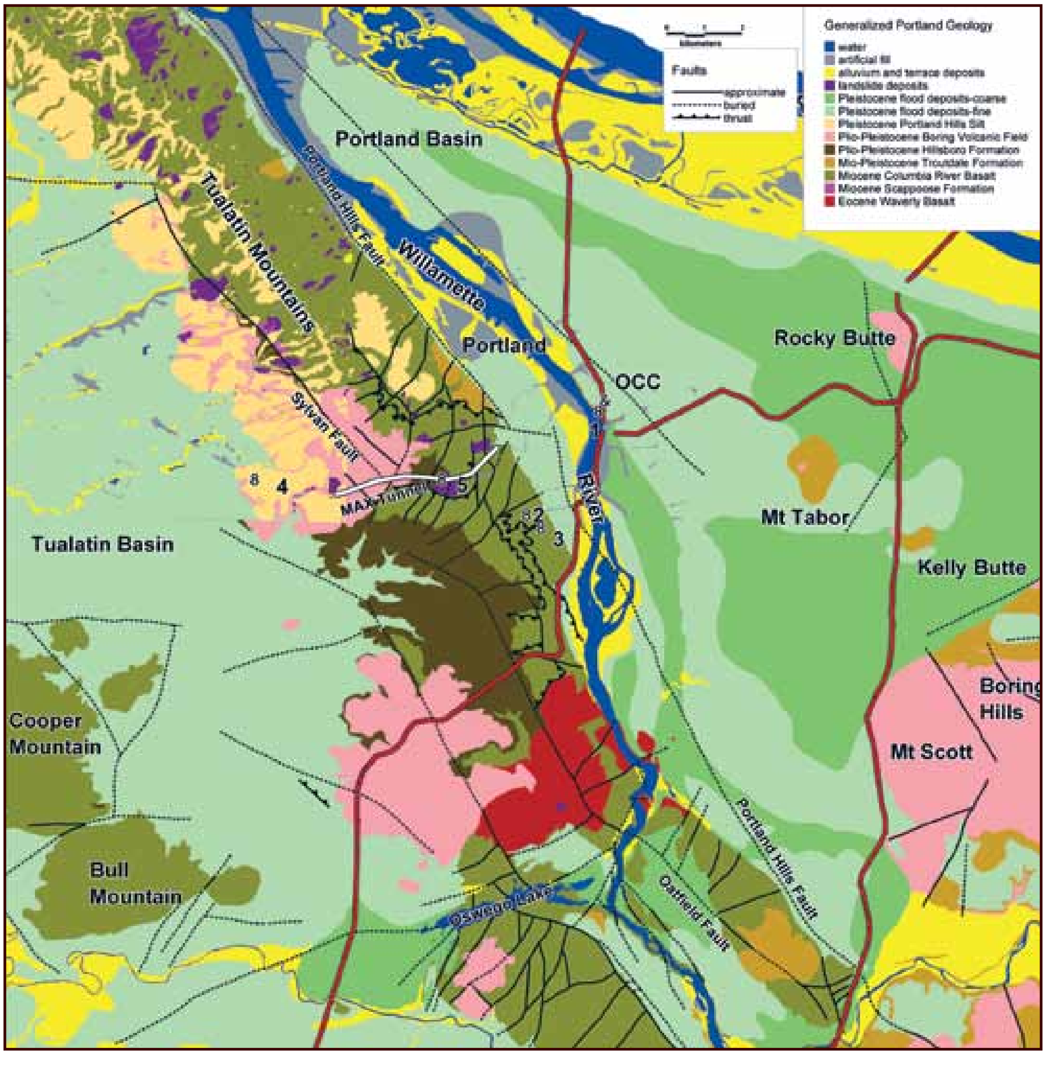
The two most noted buildings damaged were Molalla High School, which was destroyed, and the State Capitol in Salem, which had major structural damage. Many older brick churches, schools, and commercial buildings were damaged, especially in Mt. Angel, Woodburn, and Newberg. The State Highway 18 bridge near Dayton was closed for four days. Nearly $40 million in damage occurred. Few injuries were reported, probably because most people were still at home in bed.

1962 Portland

A M5.2 earthquake occurred about 10 miles (15 km) northeast of Portland at 8:36 PM on November 5. The

Landslides and rockfalls are common after earthquakes in Cascadia. The rockfall here on Hwy 97 north of Klamath Falls spilled onto the road and killed a man driving by. Photo: DOGAMI

cities of Portland and Vancouver, Washington sit atop a sedimentary basin bounded by faults. However, this earthquake appears to have occurred on a previously unrecognized fault buried beneath the basin fill. Portable seismic stations were installed after the earthquake and 50 aftershocks were recorded in 18 days. The mainshock was felt north to Seattle, west to the ocean, south through the Willamette Valley, and east through the Cascades. Typical damage included fallen chimneys, cracked plaster and cement, broken windows, and fractured large tank structures and wells. A survey of local newspapers shows little attention paid to the earthquake, probably because the area was still recovering from an extratropical cyclone (known locally as the Columbus Day storm) that hit three weeks earlier and caused 46 deaths.



Portland, like many other cities in Cascadia, is a place of hills and valleys. Earthquakes can contribute to the development of each. This map of the Portland area shows a number of faults. The Portland Hills, Oatfield, and Sylvan faults, for example, are all associated with uplifted areas. (There are also hills created from extinct volcanic vents.) Most of the known faults are buried; there may be more to be discovered. Which faults are active and how often each causes a major earthquake are topics still being researched. Map: Ian Madin, DOGAMI

1936 Milton-Freewater

On July 15, a M5.7 earthquake occurred at 11:08 PM, centered near Milton-Freewater. Two foreshocks preceded it. More than 20 moderate aftershocks occurred during the night, and stronger ones were felt on July 18 and August 4 and 27. The mainshock was felt throughout most of Washington, Oregon, and northern Idaho. Total damage amounted to about $1 million. Walla Walla suffered the most damage, including a brief closure of the train station. One concrete residence collapsed at Umapine. Cracked plaster and fallen chimneys were reported throughout the area. The ground was badly cracked, including some pavement, and there were marked changes in the flow of well water.

1877 Portland

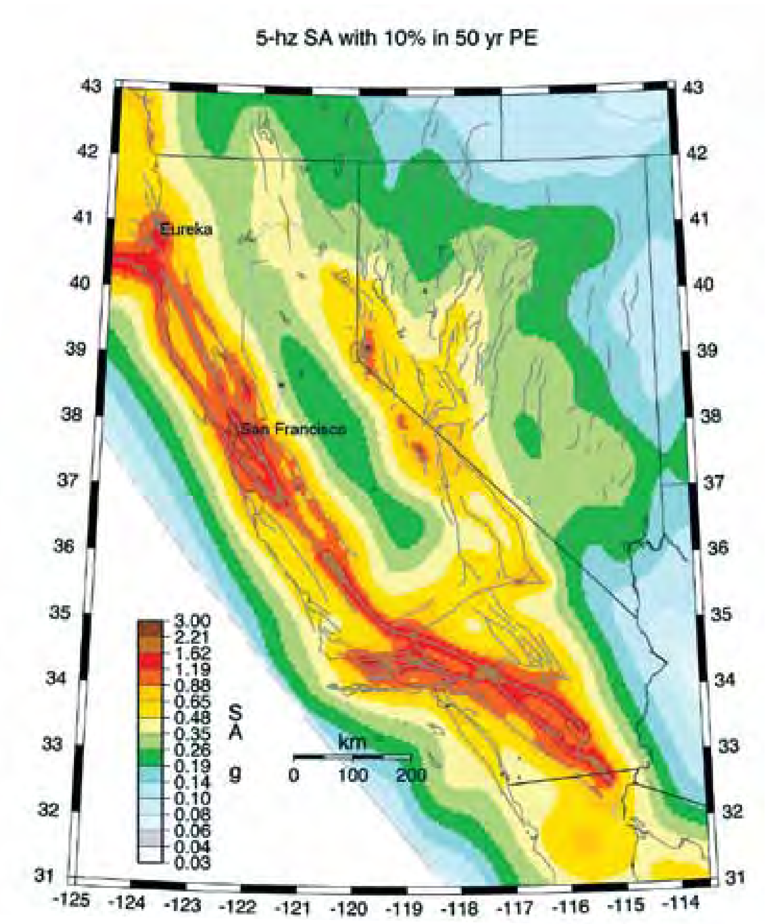
At 1:53 PM on October 12 an earthquake probably centered east of Portland shook the city (assigned M5.3). People throughout Multnomah and Clackamas Counties ran into the street when the shaking started. The major structural damage was fallen chimneys, cracked plaster walls, and broken windows. Nonstructural damage included glasses, bottles, and plates rattling off shelves. Similar types of damage were recorded south to Clackamas County and east to Cascade Locks, Oregon. People as far west as Astoria, Oregon felt it, but suffered no damage.

California

1980 Humboldt County

A M7.2 earthquake in Humboldt County on November 8, the largest of the area in decades, injured six people and caused estimated damage of $4 million. Most of the damage occurred southeast of Eureka where utility pipes broke, minor structural damage occurred, and two sections of an overpass on U.S. Highway 101 collapsed onto the railroad tracks below. It was felt over a large area—north to Eugene, south to the San Francisco bay area, and east to Fallon, Nevada. The mainshock and most of its numerous aftershocks occurred on a large, left-lateral, strike-slip offshore fault. This area, one of the most seismically active parts of California, is near the Mendocino Triple Junction where the Gorda, Juan de Fuca, and North America plates collide.

Ground failures were common especially near the epicenter. These included numerous small landslides; liquefaction that caused slumping along the Eel River and along the sand spit at Big Lagoon; and cracks in roads and parking lots, especially in water saturated alluvial materials.



Northwest California—part of Cascadia—is the most seismically active area of the state, accounting for up to 25 percent of earthquake events. The 1980 Humboldt earthquake was not unusual for this region. This map shows spectral accelerations (a measure of ground movement) expected within a 500-year period. This is important for planning and building codes. Gray lines are known faults; many more may exist. Map: USGS

1954 Eureka, California

A M6.5 earthquake on December 21 ruined the holidays for many people in Eureka. One person died when he fell into Humboldt Bay, and several people were injured by falling objects. The earthquake and a strong aftershock on December 30 caused property damage estimated at $13 million.

In Eureka, the City Hall and the Humboldt County Courthouse were severely damaged. The main damage in both Arcata and Eureka was to chimneys, plaster, plate-glass windows, and merchandise in stores, but several old and poorly constructed brick walls bulged, and some parapets fell. Damage to structures and underground pipelines occurred in areas of unstable ground. The shock caused only slight structural damage to reinforced concrete and concrete block and wood-frame buildings in the Eureka-Arcata areas. Between Eureka and Arcata, U.S. Highway 101 was cracked and bulged in places.

Earthquake scenarios

Scenario maps can help communities, states, and provinces prepare for earthquakes. They give an indication of the kinds of earthquakes that may effect Cascadia in the future.

Scenario map uses

The general information on a scenario map can help residents, businesses, first responders, and recovery planners, as well as many other groups. It can be incorporated into many kinds of plans. A few examples include:

- Family emergency kits
- Emergency response plans
- Business continuity plans
- Community recovery projects
- Long-term mitigation and preparation.

On pages 22-23 are scenario maps that show how shallow earthquakes could affect some communities in Cascadia.

Four epicenters are shown: the Strait of Georgia, British Columbia; Spokane, Washington; Portland, Oregon; and Klamath Falls, Oregon.

Each epicenter is marked by a star and surrounded by a rectangle that represents the rupture zone around each epicenter. (Rupture refers to movement along the fault, not to a break in the ground surface.) Potential earthquake effects are shown in intensities, not magnitudes.

These maps can be used as inputs in HAZUS, a model developed by the Department of Homeland Security Federal Emergency Management Agency (FEMA) to forecast earthquake damage and losses. Information on expected ground motions can be loaded into HAZUS. The program then produces estimates of potential damage to buildings, utilities and roadways, and more, as well as forecasts for injuries at various times of day. HAZUS can be used as a starting point for earthquake preparation and response planning.

Intensity

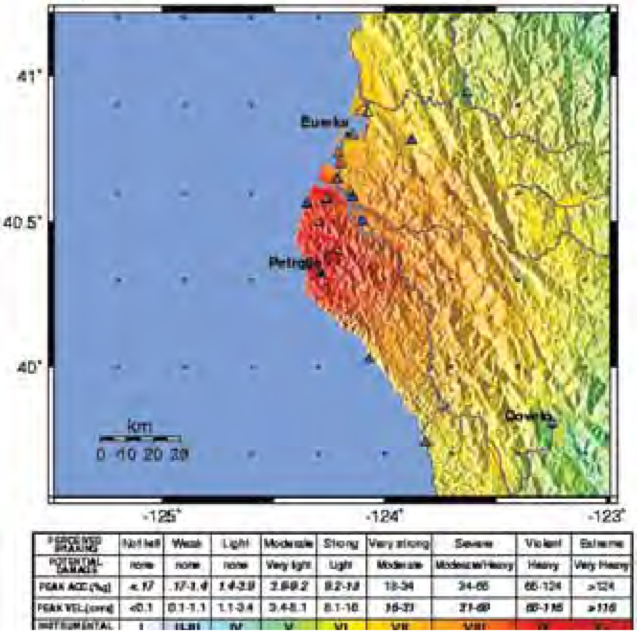
Intensity is related to, but not the same, as magnitude. It is a qualitative measure determined from observations and effects on people, buildings and other structures, and the natural environment. It is not mathematical and so is measured on a different scale than magnitude. Commonly, the Modified Mercalli Intensity scale (see sidebar) is used in North America.

Intensity

The map below illustrates intensities from a 1992 earthquake in northern California. It translates the Modified Mercalli Scale into colors. Areas with few or no effects are shaded in blues and greens, with yellows and red showing more severe ground shaking and damage.

As expected, the highest intensities on this map are nearest the epicenter (the star). In this earthquake, 95 people were injured and damage (in 2000 US dollars) was estimated at nearly $100 million.

1992 Cape Medocino M7.1



Each earthquake is assigned a single magnitude, reflecting ground shaking at the epicenter. However, intensities for the same earthquake can vary, depending on factors like ground conditions and distance from the fault. Map: USGS

Higher intensities generally result in more damage. The intensity near the epicenter and along the rupture zone will generally be the highest. This effect can be seen on each of the maps, with small, red areas generally closest to the rupture zone, with the extensive amount of blue--where some may feel the earthquake motions, though not necessarily all.

Potential damage

Some previous earthquakes are recapped earlier, starting on page 15. These give you an idea of the kind of damage and losses that can be expected in future shallow earthquakes.

The scenario reports in this paper use a simplified intensity scale. In general, no damage is expected for areas in the blue zone. Light damage might occur in the green to yellow zone. Substantial damage to URMs may occur in the middle of the yellow zone. The upper end of the orange zone through the red zone indicates increasing injuries and structural damage. Intensities in this zone can cause serious damage, and also trigger landslides on steep slopes with saturated soils. Buildings could be severely damaged, even collapse, and the possibilities of fatalities increase.

Limitations

The scenario maps in this paper are not predictions or forecasts of future earthquakes. They simply provide an indication of the damage shallow earthquakes might cause.

The sites included are general markers for where an earthquake might be centered. Earthquakes in other locations will occur.

It is important to remember that these maps are broad generalizations of expected shaking patterns, and do not include the effects of variations in local soil types.

The effect of any earthquake will depend on the distance to the epicenter, how deep it is, soil types, and building types.

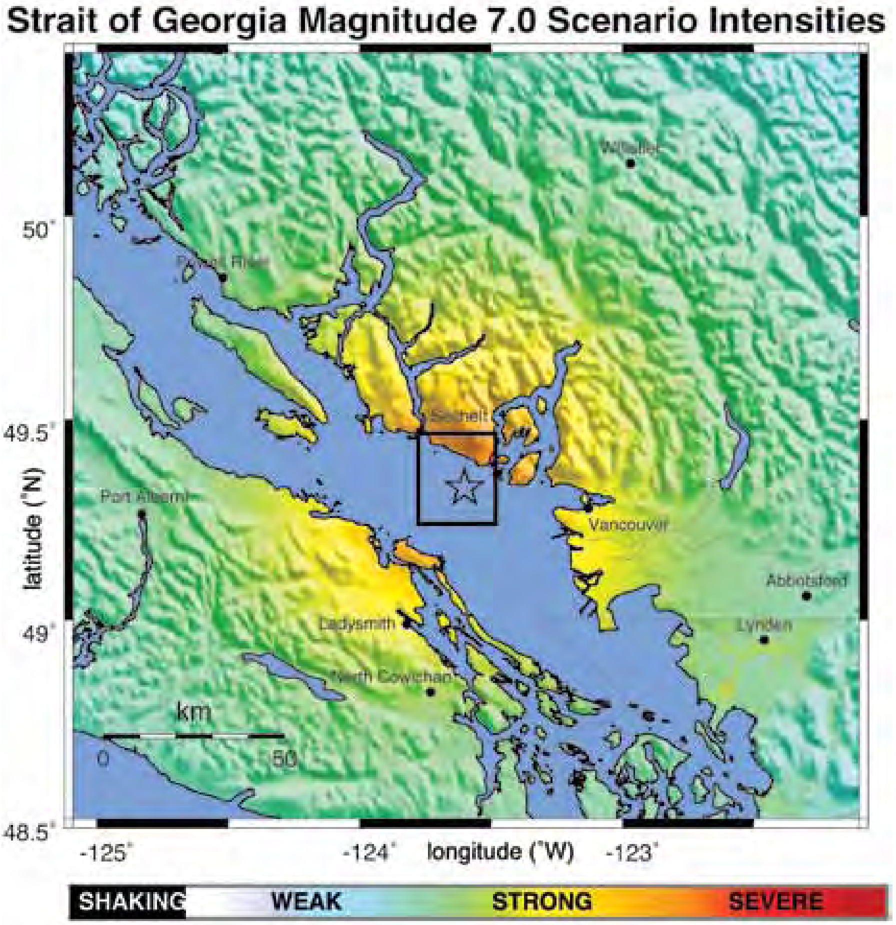
In many areas, the intensity will be higher than indicated.

Scenario maps are not specific

The maps on pages 22-23 are broad generalizations of expected shaking patterns. They do not include the effects of variations in local soil types.

In many areas, the intensity will be higher than indicated.

They are not predictions of specific events to come.

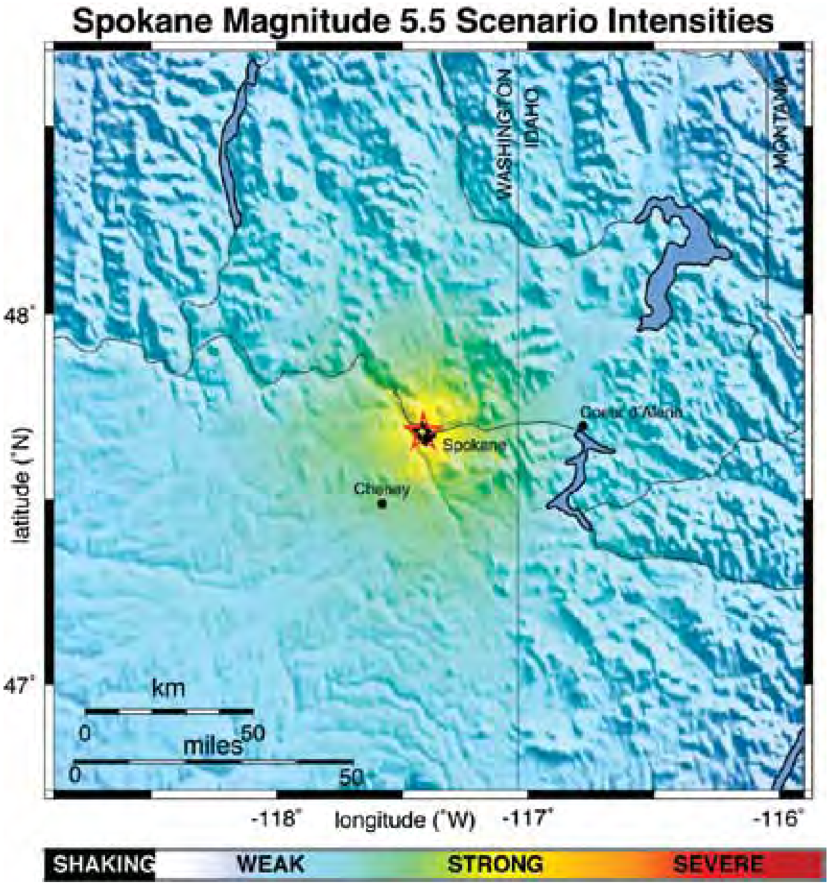


Strait of Georgia, British Columbia

The scenario of a magnitude 7.0 earthquake located in the Strait of Georgia at the site of frequent small earthquake activity would cause strong shaking in both Vancouver and Nanaimo. A larger scenario earthquake at this location, like the 1946 M7.3 Vancouver Island earthquake, would cause even stronger shaking in these cities. This map is calculated for shaking levels on firm soil. Increased shaking could be caused by soft soils and topography. Map: Art Frankel, USGS

Spokane, Washington

One of the features of recent Spokane earthquakes is that they were very shallow. Because of their closer proximity to the built environment, shallower earthquakes may be more damaging. Spokane still has a number of URMs, which are particularly vulnerable to earthquake damage. In addition, alluvium, such as that in the Spokane River valley, can amplify the effects of seismic waves. Map: Art Frankel, USGS

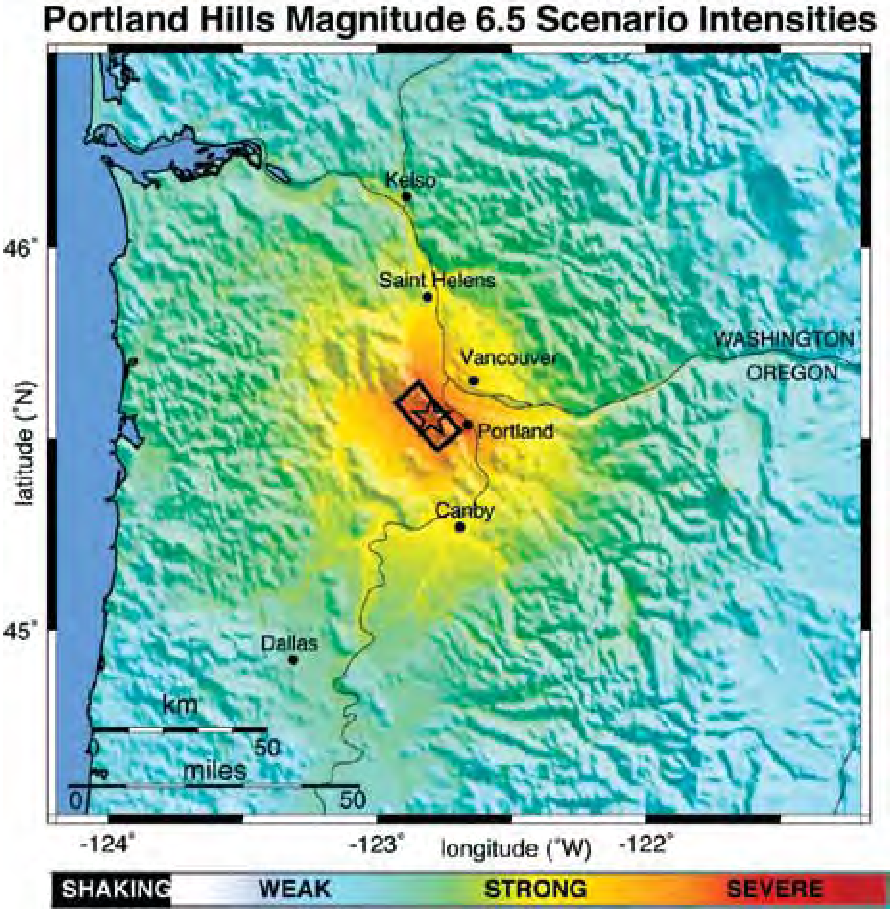


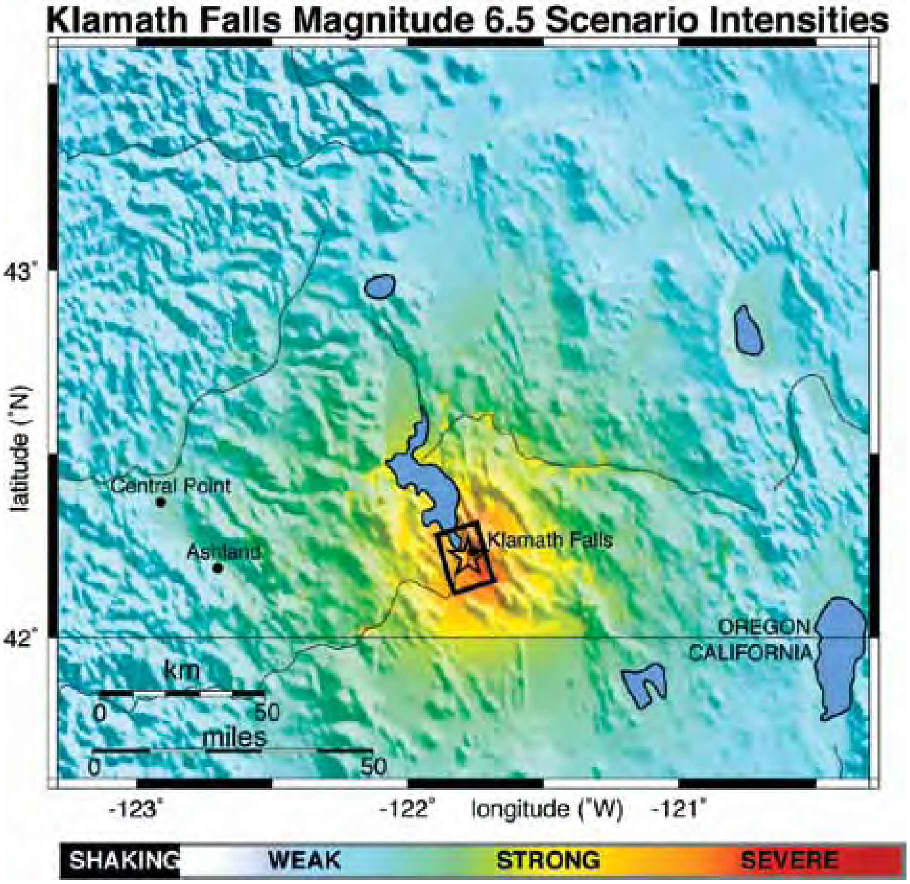
Portland Hills, Oregon

Critical energy infrastructure, including high voltage electricity transmission, fuel pipelines, tank farms, ports and facilities, is concentrated along the Willamette River in northwest Portland.

Development along the river bank overlies the Portland Hills fault system. In addition, five miles of this riverfront area near the St. Johns bridge include soft soils. This combination may produce catastrophic damage associated with liquefaction, lateral spreading, and release of hazardous materials.

To minimize extensive earthquake damage and untold ripple effects through energy and other systems, substantial improvements to infrastructure are needed. Map: Art Frankel, USGS


Portland Hills Magnitude 6.5 Scenario Intensities


Klamath Falls Magnitude 6.5 Scenario Intensities

Klamath Falls, Oregon

Strong to severe shaking can be expected in and around Klamath Falls with this M6.5 scenario earthquake.

Two smaller earthquakes (both M6.0) in 1993 caused substantial damage in the area, including two deaths and the destruction or demolition of several downtown buildings.

Because the magnitude scale is logarithmic, a M6.5 earthquake is roughly three times as large as M6.0 event. Buildings and bridges that weren't damaged in 1993 might be at risk in a larger earthquake if they have not been reinforced. Map: Art Frankel, USGS

Preparation protects

Engineering, building, and public education projects in many places show the importance of earthquake preparation. There are many actions individuals and families can take—for example, producing and practicing a family plan, storing water and food, securing items from falling, and bolting the foundation to its house. But many tasks to protect neighborhoods, cities, and businesses need to be coordinated with others, or rely on the public powers of government. This section focuses on preparation and mitigation at a community scale.

Reducing risks

Reducing risks from earthquakes involve several steps. These include:

1. Identify and characterize potential earthquake locations and magnitudes.
2. Quantify the risk (what might be damaged from earthquakes).
3. Build a team to develop strategies for making the most cost-effective, long-term decisions.
4. Determine your resources.
5. Consider a range of strategies to address the risk before making a decision.
6. Integrate the chosen strategies into long-term plans for ongoing success.

Projects to reduce future earthquake damage can be undertaken in steps, as resources are available and as understanding of earthquakes increases. For example, following the steps above, a city might:

1. Compile geologic and earthquake hazard maps,
2. Inventory buildings, and assess financial and social risks.
3. Select a team with representatives of appropriate businesses, government agencies, and not-for-profit organizations.
4. Inventory the number of geologists, building inspectors, engineers, emergency planners and responders, business leaders and others who can prepare a community for an earthquake, respond when one happens, and help rebuild after it is over.
5. Research what has worked elsewhere, or potentially new actions, then formulate strategies based on local hazards and resources.
6. Institutionalize your choices using planning, building codes, or other devices. A periodic review process is necessary to stay current with new information, increasing population, or changing resources.

Preparation saves lives and money

Earthquake preparation actions in a region as seismically active as Cascadia eventually pay for themselves. A study by economists Andrew Healy and Neil Malhotra shows that a dollar spent on prevention is more than ten times more valuable than a dollar spent on relief.

Another study, done by the National Institute of Building Sciences, looked at a sample of hazard mitigation grants awarded by FEMA (the Federal Emergency Management Agency). Their cost-benefit analysis found that every $1 spent on mitigation saved society an average of $4. All of us, including government and business leaders, families and individuals, can work to make sure we are more prepared for the next earthquake — no matter when it happens.

It can be difficult to know where to start or what range of strategies is available. Listed below are a number of steps that can be taken to reduce future injuries and damage from earthquakes.

Identify and characterize potential earthquakes

Scientists and engineers can provide *expertise* with which to prepare realistic strategies. However, policy *choices* are the responsibility of business and community leaders, individuals, and governments.

Useful tools to understand the possible earthquakes at your location include:

- A national seismic hazard map to understand the general threat.
- More specific state, provincial, or regional seismic hazard and fault maps to help prioritize what areas may be more at risk. Remember that there are three kinds of earthquakes to prepare for, and both subduction and deep earthquakes may be felt over a wide area.
- Relative hazard and fault maps for your city or community. These maps are best used in conjunction with a geologic analysis explaining which faults are potentially active, as well as how often and how large earthquakes might be.
- Ground response, liquefaction, and landslide maps to estimate how local soil conditions and slopes might affect your area. A site-specific study may be required before allowing some types of structures to be built or to require special reinforcement of structures.

Quantify the risk

- FEMA 154, *Rapid Visual Screening of Buildings for Potential Seismic Hazards,* provides a system for sidewalk review of buildings to suggest which ones might be most vulnerable in an earthquake. Non-engineers can be trained to perform the survey.
- American Society of Civil Engineers (ASCE) 31, *Seismic Evaluation of Existing Buildings,* or other tools to inventory buildings. A companion paper, ASCE 41, *Seismic Rehabilitation of Existing Buildings,* can provide guidelines for future projects or regulations.

CREW

The Cascadia Region Earthquake Workgroup (CREW) is a coalition of private and public representatives working together to improve the ability of Cascadia communities to reduce the effects of earthquakes. This paper is one of a series to provide education and guidance to these communities and businesses.

Our goals:

- **Promote efforts to reduce the loss of life and property.**
- **Educate decision-makers to reduce risks associated with earthquakes.**
- **Foster productive links between scientists, critical infrastructure providers, businesses, and governmental agencies to improve the viability of communities after an earthquake.**

The University of Washington's Architecture Hall is one of the few remaining buildings from the Alaska-Yukon Pacific Exposition of 1908. As part of their Restore the Core program, UW is improving the seismic safety of their Seattle campus through systematic rehabilitation of older buildings. Strengthening work was performed from within the building to preserve its historic appearance. Photo: THA Architecture

The Department of Veterans Affairs Hospital in Seattle provides both in- and out-patient care for thousands of veterans around the Northwest. A seismic evaluation of the hospital identified weak connections in the seismic bracing. An earthquake could have fractured the connections and endangered patients and staff. Seismic strengthening work was completed while the hospital was occupied and will allow the building to remain operational after an earthquake on the Seattle fault. Photo: Degenkolb Engineers

- Inventory potential earthquake damage, including at-risk populations; vulnerable public facilities like roads, bridges, and buildings; and possible economic damage from businesses that will have to close, either temporarily or permanently.
- Remember that secondary hazards like fires, hazardous material spills, and tsunamis can also create damage.

Build a team

The whole community has a stake in preventing earthquake losses. The general economic health of an area can suffer after a damaging earthquake. Businesses and schools may have to close temporarily or permanently. Road and bridge damage may limit access to some parts of the area. Taxes or utility rates may need to be raised, or other services eliminated, to cover the additional emergency services provided or repair damage suffered.

The more people who are invested in a community plan, the more likely it is that the plan will be funded and implemented. In addition, bringing together a wide cross-section of people is likely to encourage debate and creative solutions that are constructive and cost-effective.

Actions taken by each can help to manage the risk, though no one party by itself can alleviate all possible risks. Creating partnerships can be a successful means of risk reduction.

Each community must balance its risk, the benefits and the liabilities of each possible strategy, and the resources and values of the community. A community may decide that earthquake risk-reduction programs are a low priority, based on a review of its total needs. However, this assignment should be based on objective analysis, not simply as a denial of the risk.

Though each place needs its own specific plan of action, reviewing a well-developed city or county ordinance from an analogous area can provide a good starting point in the development of a community-specific regulation.

Determine your resources

Resources include money, political power, diversification, and timing. A family, business, or community is less vulnerable if they have adequate money and/

or political power to prepare for an expected earthquake. That might mean local mapping, buying insurance, upgrading dangerous buildings, making use of earthquake and tsunami educational materials, or many other activities. Building partnerships with other people and groups may increase your resources. Where your capabilities are insufficient, there may be others at risk who will participate if asked.

Diversification is important, especially after a major earthquake. You are less vulnerable if your assets are not all damaged or lost in the same event. This will also protect you from other natural hazards like floods and wildfires.

Taking advantage of timing can increase your resources. Typically, more funding and projects are available just after a disaster. Even if you do not have resources for a specific project, it is still worthwhile to develop it on paper so you can be first in line when money becomes available.

Develop a range of strategies

Here is a range of strategies to consider. Not all these activities will be appropriate for all places. This list is not comprehensive, but can give you a starting place for your community's discussions.

Develop general maps that mention the risk of geologic hazards.

- Adopt small-scale maps with general information that will highlight areas needing further attention.
- Planning documents often contain a general description of hazards, without specific steps for mitigation. This can serve to keep the issue alive in times when resources are scarce. This may be an appropriate step to increase public awareness or provide a marker to remind the organization of the need for action at a later time.

Develop good geologic hazard maps that focus on the specific hazard for the specific area.

- Develop large-scale maps of areas with potential risks from earthquakes and adopt specific

The Interstate 5 (I-5) corridor, which stretches from Mexico to Canada (then continues as Hwy 99 in Canada), is both the main economic artery and the population center of the Pacific Northwest. Accordingly, most regional utility and transportation systems have major components located within the I-5 corridor. Breaks in these systems on the area of the map (Cottage Grove to Woodburn, Oregon) can affect many other cities in Cascadia. Map: E. A. Barnett and others, USGS

Map Your Neighborhood (MYN)

This award winning program in the state of Washington is designed to help neighborhoods prepare for disasters and is offered through many local emergency management offices.

MYN will help you:

- **Learn the *9 Steps to Take Immediately Following a Disaster* to secure your home and to protect your neighborhood. It's hard to think clearly following a disaster and these steps will help you to quickly and safely take actions that can minimize damage and protect lives.**
- **Identify the Skills and Equipment each neighbor has that would be useful in an effective disaster response. Knowing which neighbors have supplies and skills helps your disaster response be timely, and allows everyone to contribute to the response in a meaningful way.**
- **Create a Neighborhood Map identifying the locations of natural gas and propane tanks for quick response if needed.**
- **Create a Contact List that helps identify those with specific needs such as elderly, disabled, or children who may be home alone during certain hours of the day.**
- **Work together as a team to evaluate your neighborhood during the first hour following a disaster and take the necessary actions.**
- **Contact your local, state, or provincial emergency management office to implement an MYN program in your community.**

requirements aimed at tying information to property documents. This could include recording hazard information on deeds and waiver requirements.

- Develop or require characterization and remediation for specific sites at risk.

Provide public education to those making decisions in the hazard area.

- Implement a Map Your Neighborhood program (see sidebar) in your community.
- Require disclosure statements in real estate transactions.
- Require recording of hazard areas for discovery in title search activities.
- Prepare and distribute publications or other media with earthquake information. Use the backs of utility bills or inserts in credit card statements to relay short messages.
- All families, businesses, and government offices should have plans for reacting in an earthquake. Reinforcing the drop, cover, and hold message, and having evacuation plans and plans to communicate with others are key points. Regular drills help ensure employees and family members know what to do in case of an earthquake.

Facilitate voluntary preparedness and prevention.

- Provide for insurance, through the government and/or the private sector.
- Develop incentives for preparation programs.
- Remove incentives to develop at-risk areas.
- Provide for engineered solutions through disaster-based reconstruction.
- Develop partnerships, including self-funded improvement districts, to provide creative mitigation, such as a local improvement district to fund bracing of parapets.

Require mandatory mitigation of earthquake hazards.

- Develop long-range seismic risk reduction goals and objectives through the land use planning process.
- Implement restrictions through zoning administration and other land use controls.
- Develop building code controls that specifically address earthquake and associated landslide hazards.
- Require engineered solutions in building construction.
- Adopt grading ordinances, hillside development regulations, and subdivision ordinances, which are keyed to the severity of the earthquake hazard.
- Small-scale pilot projects are often times easier to implement rather than wholesale change. Focusing

on a small area at a time may make a new approach more acceptable to community stakeholders and decision-makers.

Implement prohibitions against construction in areas of extreme geologic hazard.

- Prohibit new construction except for facilities that can demonstrate lower-than-anticipated risk.
- Provide for rehabilitating selected structures or classes of structures using passive thresholds. Or mandate active thresholds for rehabilitation.
- Require highly dangerous structures to be removed from high-risk areas.

Make the strategy permanent

The selected strategy must be put into place permanently, so efforts will continue after the initial activities.

This may be done in many ways, including:

- Local ordinances (zoning, subdivision, development codes; parapet restrictions);
- Building code revisions;
- Continuing public education efforts;
- Periodic training through drills and other mechanisms;
- Emphasizing the importance of nonstructural measures;
- Chapters in emergency plans;
- Revising construction and design manuals;
- Internal business continuity plans;
- Incentives or disincentives, such as tax credits;
- Revised construction and design manuals for lifelines; and
- Coordinating efforts between potentially affected jurisdictions or businesses.

Tacoma Narrows Bridge

Knowing earthquake risks can help policy-makers decide which mitigation projects are the highest priority. Seismic upgrades for the new Tacoma Narrows Bridge was one decision that may save lives and money.

The original bridge was known as Galloping Gertie because wind through the Narrows would twist the roadway. Four months after it opened in 1940, the bridge collapsed. In 1949, construction crews were building the current Narrows bridge. They had just finished the towers when a M7.1 earthquake hit. The 21-ton steel cradle that held the main suspension cable fell 500 feet and sank to the bottom of the Narrows. It opened in 1950.

A second Tacoma Narrows bridge parallels the 1950 span and is now outfitted with state of the art engineering solutions. It is designed to make the bridge much more resistant to high wind gusts and expected ground shaking from earthquakes.

This will allow transportation corridors to reopen more quickly, bringing needed supplies for earthquake response and recovery.

The previous Molalla High School building, a three-story URM, opened in 1926. Damage from the M5.6 Scotts Mills earthquake in 1993 forced its closure. It happened during spring break, when the school was empty, which may have prevented serious injuries.

The district took the opportunity to forecast future needs and decided not to rebuild at the same location. Molalla High School is now housed on a larger campus with a stronger, more spacious building.

Many URM schools and other buildings in Cascadia could suffer a similar fate in future earthquakes. Communities can act now to plan how and when to replace these aging, potentially dangerous facilities. Photo: CREW

CREW

CREW (the Cascadia Region Earthquake Workgroup) is a partnership of the private and public sectors, created to help our area prepare for earthquakes. A variety of products about the region's earthquake threat and how to prepare for it are available as .pdf files on our website (www.crew.org). CREW wishes to thank Art Frankel for preparing the scenario maps for this publication, the Board members who spent hours providing and reviewing information, and JL Clark for its editing and design.

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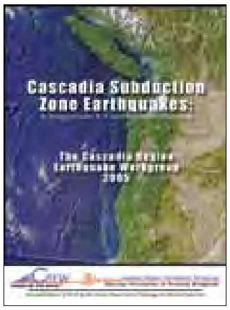
This 28-page report summarizes the threat from deep earthquakes, including measures taken that reduced damage in the 2001 Nisqually event.

Cascadia Deep Earthquakes

Photos on front cover: Damaged roads and bridges, landslides destroying houses, buildings with serious damage, and shelter for those left homeless can all be part of post-earthquake response and recovery needs. All photos: FEMA

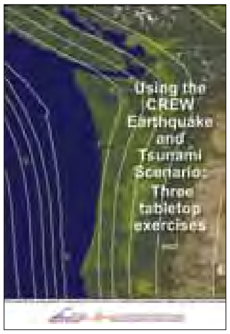


Cascadia Subduction Zone Earthquakes:

The Cascadia Region Earthquake Workgroup 2005

This 24-page report gives background information on earthquakes in Cascadia and presents a scenario of what a magnitude 9 earthquake might do to the region.

This 16-page report explains how other groups have used CREW scenarios and how you can use the lessons they learned to help your earthquake preparations.



Using the CREW Earthquake and Tsunami Scenario: Three tabletop exercises