

Cascadia Subduction Zone Earthquakes:

A magnitude 9.0 earthquake scenario

**The Cascadia Region
Earthquake Workgroup
2005**



Cascadia Region Earthquake Workgroup
Sharing Information to Promote Mitigation

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CREW (Cascadia Region Earthquake Workgroup)

This Scenario was prepared by the Cascadia Region Earthquake Workgroup (CREW). We are a partnership of the private and public sectors, created to help our area prepare for earthquakes. We know that magnitude (M) 8 to 9 earthquakes have occurred in our region and will occur again, on average, every 500 years.

This report is the result of many years of research, discussion, and debate. It is based on computer modeling funded by CREW and on other research about earthquakes in the region. We are providing the information in this report to help government agencies, businesses, and families understand the potential effects of a subduction earthquake. It is only a general assessment of how we might fare in a M9.0 earthquake. Because there are so many variables in earthquakes, the actual event will undoubtedly be different than the damage illustrated in these pages. Statements made in the text are for general planning purposes only. But the information here can be used to help our region set priorities among the many steps we can take to make us safer.

Special thanks to the many people who worked on this document and those who offered invaluable insights and comments, especially Bob Freitag and the Board of Directors of CREW. Thanks to Linda Noson (Noson and Associates) and Ron Langhelm (FEMA Region X) for adapting HAZUS software to better represent a Cascadia subduction zone event, and to Art Frankel and Mark Petersen (both with the US Geologic Survey in Golden, Colorado) who did the ground motion calculations. Finally, thanks to James Roddey and Lou Clark (Oregon Department of Geology and Mineral Industries) for the graphic design and writing of the report.

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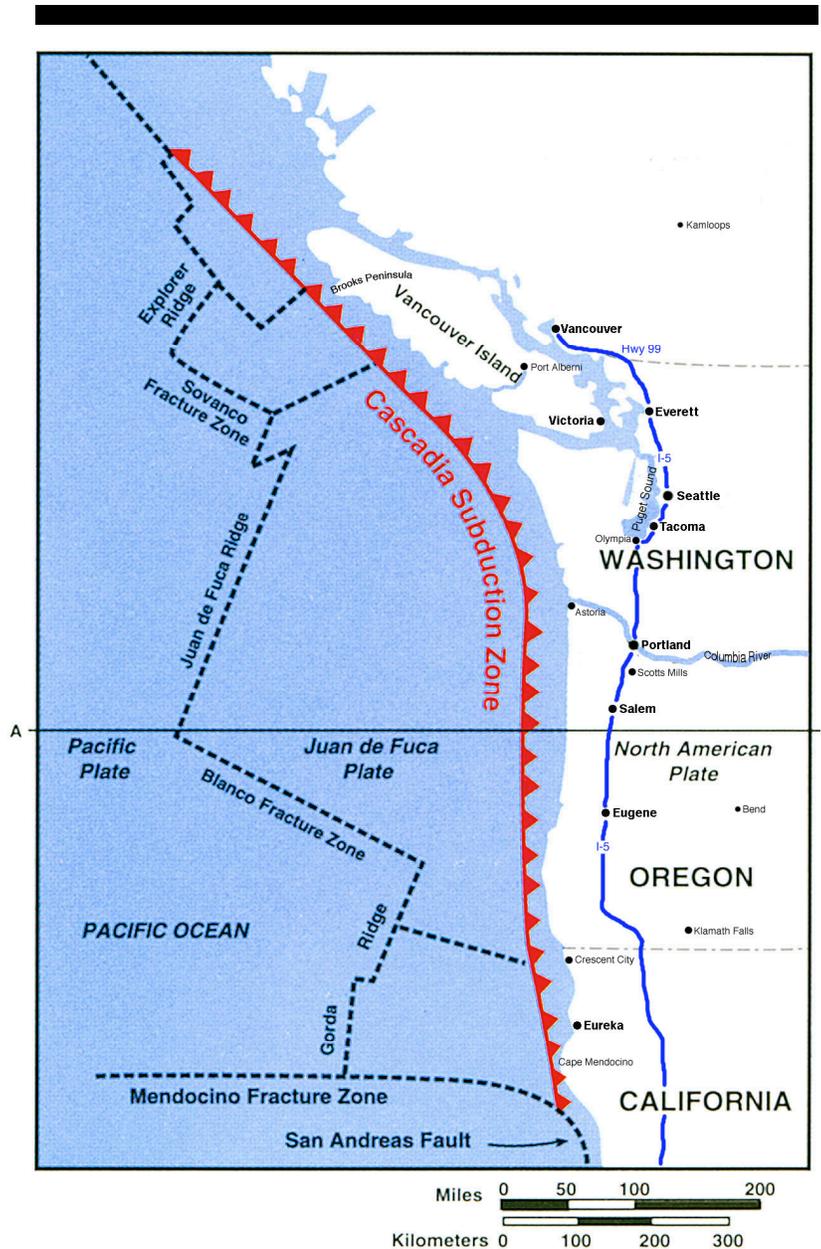
To find out about earthquake preparation or for additional information on earthquakes, go to
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Cascadia subduction zone earthquakes:

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M9.0 Earthquake Scenario

From the Brooks Peninsula on Vancouver Island to Cape Mendocino in northern California, the Cascadia subduction zone is where the Juan de Fuca plate meets the North American plate. This meeting has created an 800 mile (1,300 kilometers) long earthquake fault called the Cascadia subduction zone. Earthquakes generated here have far more widespread effects than other types of quakes in the region.

When a magnitude (M) 8 to 9 subduction earthquake occurs, it will cause many fatalities and much damage unless we prepare for it. These quakes have occurred anywhere from 200 to 1,000 years apart, with an average of 500 years between them. Our last one was on January 26, 1700. We can look to the 2004 Sumatra and 1964 Alaska earthquakes and tsunamis for some guidance as to what to expect.

Groundshaking, landslides, liquefaction, tsunamis, fires, hazardous material spills, and building damage are some of the hazards we face from a Cascadia subduction zone earthquake. The ground could shake for four minutes, even more in some places. This will create unprecedented damage and potentially thousands of casualties.

Different parts of Cascadia will have different experiences.

- **Coastal communities** will be subjected to strong shaking, landslides, and tsunamis. Buildings, roads, bridges and utility lines will suffer varying amounts of damage. Some will be destroyed. Extensive injuries and fatalities are likely. Within minutes, a tsunami will arrive, making it essential that residents and visitors understand the need to head for higher ground or inland as soon as the shaking stops. Coastal Highway 101 will be impassable over large stretches, and landslides through the Coast Range will sever highway travel between the coast and inland areas. Destruction of roads, runways, ports, and rail lines will leave individual cities isolated. Residents and visitors will have to do much of the work of rescuing those trapped in the rubble and will be responsible for the immediate clean-up and organization to distribute relief supplies.
- **Along the I-5/Hwy 99 corridor**, utilities and transportation lines in some areas could be disrupted, perhaps for months. This particular type of earthquake is especially hazardous to tall buildings, which could lead to significant fatalities in downtown areas. Buildings that would be unscathed in a more typical 30-second quake might be severely damaged after several minutes of shaking. Long bridges and utility

lines are also at risk, which could create serious long-term economic losses. Landslides could block east-west travel through the Cascades. As the center of our regional transportation network, closures at any point here could have far-reaching consequences.

- **East of the Cascades**, communities can expect a lower level of shaking. Even so, they will feel economic effects from the regional damage and will be important staging points for recovery efforts in Cascadia.

The more we plan now, the easier it will be to use this event as a way to transform our region and our economy, rather than simply become victims of a natural disaster. Important steps include:

- Educating residents and visitors about the dangers and encouraging individual preparedness;
- Reducing the risk for essential public facilities, such as hospitals, schools, and police, and fire stations;
- Retrofitting high risk buildings such as unreinforced masonry, tilt-up structures, and some tall buildings;
- Upgrading transportation infrastructure

A Cascadia earthquake will seriously affect our region, but it won't destroy us. We will rebuild our cities, our neighborhoods, and our businesses. The time it takes us to recover will depend largely on what preparations we make before the earthquake.

The most serious effect for the region could be the disruption of utilities and transportation systems.



In 1964, the control tower at Anchorage, Alaska International Airport fell during the M9.2 earthquake. It was a split-level structure that was seven stories high on one side and built of reinforced concrete. Photo: USGS

Cascadia and Earthquakes

Stretching from Brooks Peninsula on Vancouver Island to Cape Mendocino, the Cascadia subduction zone is where the Juan de Fuca Plate meets the North American Plate along an 800 mile (1,300 kilometers) long line off the Pacific coast. The Juan de Fuca Plate is the seafloor and is made up of heavier rocks than the continental mass of the North American Plate. These two pieces of the Earth's crust constantly push against each other, and the seafloor subducts, or sinks, below North America. This process is responsible for much of the scenery of Cascadia, including the development of the Cascade Range.

As we've seen in south Asia, a subduction zone earthquake will affect an entire region. Because of the widespread area that will feel the shaking, even areas without great building damage will be affected by outages in utilities, transportation, and other systems.

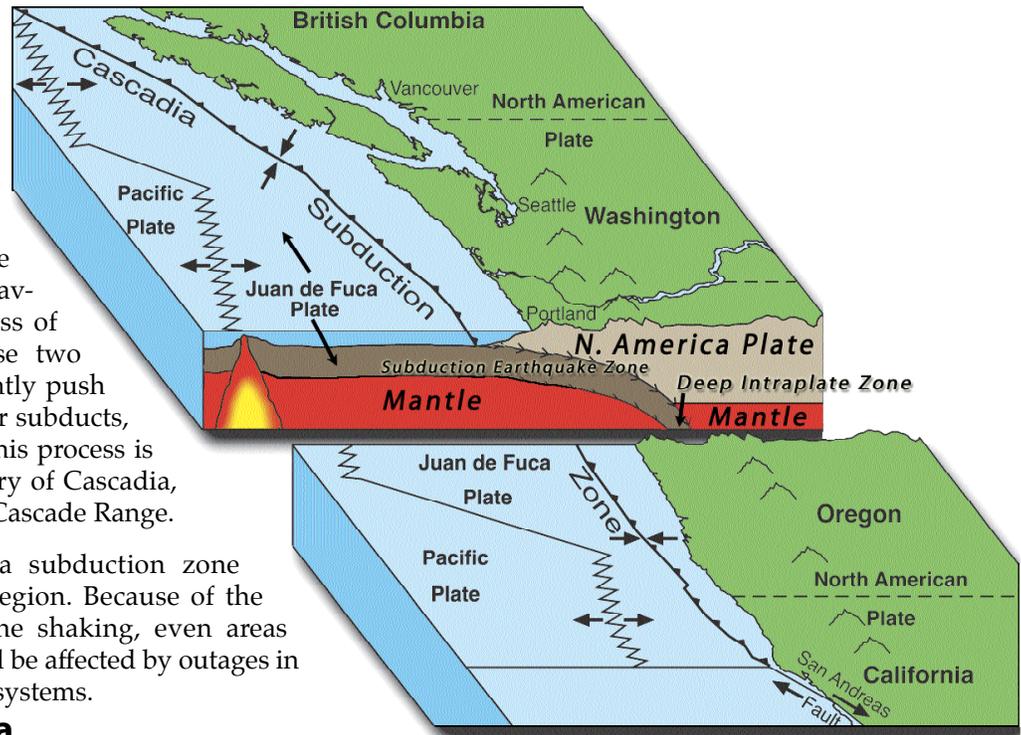
Earthquakes in Cascadia

Southwestern British Columbia, western Washington and Oregon, and northwestern California make up Cascadia — an area that is periodically shaken by three different types of earthquakes.

All types of earthquakes can trigger landslides and liquefaction (when soil liquifies during shaking). Each type, however, starts at a different depth underground and has different characteristics.

Shallow/Crustal — Most earthquakes are a result of fault movement in the crust, a relatively thin layer on the Earth's surface.

- Shallow quakes are usually less than magnitude (M) 7.5.
- The strongest shaking in crustal earthquakes typically occurs near the rupture plane of the fault on which the earthquake occurs.
- Most Cascadia quakes are shallow, such as the quakes centered at Vancouver Island, British Columbia in 1946 (M7.3) and Scotts Mills, Oregon in 1993 (M5.6).
- Small, shallow earthquakes are recorded every day in Cascadia; damaging quakes occur every few decades.
- Strong shaking generally lasts 20-60 seconds, although it could be longer in localized areas.



Shallow (or crustal), deep (or intraplate), and subduction zone earthquakes are each initiated in a different section of the Earth's interior. The general locations of the subduction and deep intraplate zones are noted in the above graphic. Shallow crustal earthquakes can occur widely in the North American and Juan de Fuca Plates.



In the 1983 Coalinga, California earthquake, this fire station was badly damaged (note the skewed door). If rescue equipment can't get out of the station, it can't be used when needed after an earthquake. Photo: M.G. Hopper, USGS



Liquefaction can destroy roads, as the 2001 Nisqually, Washington earthquake did to this street outside Olympia. Many stretches of Highway 101 and other coastal roads in Cascadia are vulnerable to this type of destruction. Photo: T. Walsh, Washington Division of Geology and Earth Resources



This area on the Kenai Peninsula permanently dropped, or subsided, 3 feet during the 1964 Alaska earthquake. The shallow roots of these spruce trees were then below high tide and they were killed by repeated inundation in salt water. Photo: USGS

- Damage is most likely to occur in vulnerable structures located relatively close to the fault on which the earthquake occurs, where the shaking is strongest.
- Aftershocks are common and may cause further disruption.
- There could be a local tsunamis from landslides, or from shallow earthquakes occurring under Puget Sound, the Strait of Georgia, or other bodies of water including lakes and rivers.

Deep/Intraplate — There is a zone of earthquakes occurring below 18 miles (30 kilometers) in depth on fractures in the subducting Juan de Fuca plate.

- Deep quakes are usually less than M7.5.
- The 2001 Nisqually, Washington quake (M6.8) and 1949 Olympia quake (originally measured M7.1, now revised to M6.8) were deep earthquakes.
- Damaging deep earthquakes occur every 10-30 years.
- Because the original earth movement is so deep, the seismic energy disperses over a much larger area than in a shallow quake. The shaking is felt over a large area and is less intense near the epicenter. Damage is less than in a similar-sized shallow quake.
- Few, if any, aftershocks occur.
- No tsunami is expected, although landslides could trigger local tsunamis.

Subduction zone — The subducting seafloor of the Juan de Fuca plate is being pushed beneath the continental North American plate. The contact between these two plates periodically ruptures in large, subduction zone earthquakes.

- Earthquakes centered along the Cascadia subduction zone can be M9.
- The last Cascadia earthquake was January 26, 1700. Previous quakes were in the years (approximately) 900, 750, and 400 AD.
- Geological evidence suggests an average of 500 years between events.
- Depending on location, strong shaking might be felt for several minutes.
- Injuries and fatalities could number in the thousands, and hundreds of buildings could be destroyed.
- A destructive tsunami will quickly hit the Cascadia coast and travel across the Pacific Ocean.
- Aftershocks up to M7 are common, creating the potential for additional damage.

Hazards in a subduction zone earthquake

Ground response — Earthquakes release energy that travels through the earth in waves. Subduction quakes are richer in long-period waves, which are most dangerous for tall buildings, long bridges or long, above-ground pipelines. This is a different pattern than in a typical shallow quake, where the greatest effect is on short buildings.

Some soil types cause earthquake waves to amplify, causing increased shaking and damage. The risk of amplification increases when you are on deep, soft soils, especially on valley bottoms and areas of artificial fill.

These soils can be identified before an earthquake, as one measure of the risk a community might face. Most areas at risk are already identified with soil studies in land use planning and development.

Following a large subduction quake, there will be months of aftershocks, some perhaps as large as M7. Some of these aftershocks could cause significant new damage.

Ground failure — Sandy soils saturated with water can liquefy, or behave like a liquid, during an earthquake. Major earthquake destruction is often found on these soils that are prevalent along rivers, streams, and lakes. Liquefaction can seriously damage buildings, bridges, pipelines, and roads by undermining their foundations and supports.

Earthquakes can also trigger landslides. The last earthquake-related death in Oregon was in 1993, when falling rock smashed a truck in Klamath Falls. A subduction zone earthquake will probably trigger landslides and rockfalls on the steep slopes of the Coast and Cascade Ranges. Other areas might also be at risk.

Tsunami — A subduction zone earthquake would generate a tsunami, which is actually a series of waves. The number of large waves and their height will depend on local conditions. In some cases, waves may be up to 30 feet (10 meters) high, flooding everything in their path. The sequence of the waves sweeping inland, then out again, could last 10 to 12 hours. The first wave could arrive a few minutes after the earthquake, again depending on local conditions.

Casualties and damage from tsunamis may be high. Deaths can be minimized if people evacuate to higher ground or sufficiently far inland immediately after the ground stops shaking.



Ground response at different locations means there can be dramatically different levels of damage in the same quake. This car, crushed in the 1989 Loma Prieta, California earthquake, was in an area where there was a great deal of building failure. Falling bricks or parapets can cause injuries and damage on the streets and sidewalks below. Photo: C. E. Meyer, USGS



The 1964 Alaskan subduction zone earthquake weakened many buildings in Seward, then a tsunami swept much of the debris away. Thirteen people died here. Photo: USGS



The ground response to earthquake waves can result in ruptured gas mains, which can start fires, and broken water mains, which makes it hard to fight fires. These smoldering remains are from the 1989 Loma Prieta, California earthquake. Photo: J. K. Nakata, USGS



The interaction of building type and ground response can be seen in how these two buildings were affected by the 1964 Alaska quake. The Hillside Apartment Building had extensive damage, while the adjacent three-story wood-frame dwelling with the tall chimney had almost none. In general, when wood frame buildings in Anchorage were damaged, it was from some type of ground failure. Photo: USGS

Secondary hazards

Fire — Fire often destroys property after an earthquake. Ruptured gas lines may provide fuel, and broken water lines hinder firefighters' efforts. Gas lines turned off to prevent fire may not be restored for days, causing other hardships.

Hazardous materials — Hazardous materials may be spilled from commercial or industrial sources, but they can also be released in households. Serious problems can happen if the contents of several containers mix—such as ammonia and chlorine bleach.

Building vulnerabilities — Building vulnerability is one factor we can control. As we've learned more about the earthquake danger in Cascadia, building codes have been upgraded. We also can now analyze which buildings will be most vulnerable in an earthquake. The American Society of Civil Engineers has published ASCE 31-02, *Seismic Evaluation of Existing Buildings*, to help assess building risk. The National Research Council of Canada has published NRCC-36941, *Guidelines for the Seismic Evaluation of Existing Buildings*.

In a subduction zone quake, many buildings are at some risk. In particular, unreinforced masonry buildings (URMs), generally with brick walls and wood or concrete floors, may be dangerous. There are thousands of these buildings throughout Cascadia. Even though most URMs are one to five stories, they may not be able to withstand the duration of shaking. However, even these buildings can be retrofitted to better withstand strong ground shaking.

The amount of damage to a building in any type of earthquake will depend on:

- Intensity and duration of shaking
- Distance from the fault
- Local soil conditions
- Amount of water in the soil
- Slope of hillsides
- Building construction

In general, the soil types most affected in an earthquake are:

- Loose, sandy, saturated soils that may liquefy
- Artificial fill (not engineered to withstand shaking)
- Soft soils that can amplify earthquake shaking



There is no structural damage in this bedroom after being shaken by the 1989 Loma Prieta, California earthquake, but several of the items that fell could have caused injuries. Photo: C. E. Meyer, USGS

Single-family wood-frame homes rarely collapse and generally fare well in earthquakes, although prolonged shaking may increase their level of damage. Chimneys and brick facings can collapse and windows can break. If not securely fastened together, a house may separate from its foundation, disconnecting utility lines and making the house unlivable.

The design of buildings, as well as construction material, is important. The more square or rectangular a building shape, the more likely it can withstand shaking. Structures that have had several additions often have irregular shapes, and the various parts of the building may pound against each other. Pounding can also occur when buildings that are built close together knock against each other. Another common cause of damage is a soft story — a floor with insufficient strength relative to the floors above. Often the problem is a garage or open retail space located at ground (or street) level that makes up the bottom story of a building.

All buildings can suffer nonstructural damage, resulting in injuries and economic losses. Falling debris like bookshelves, light fixtures, and computers can be dangerous, even at home. Furniture moving across a floor, pipes breaking and spilling contents, and parapets falling from buildings are just a few things that have caused injuries in previous earthquakes.

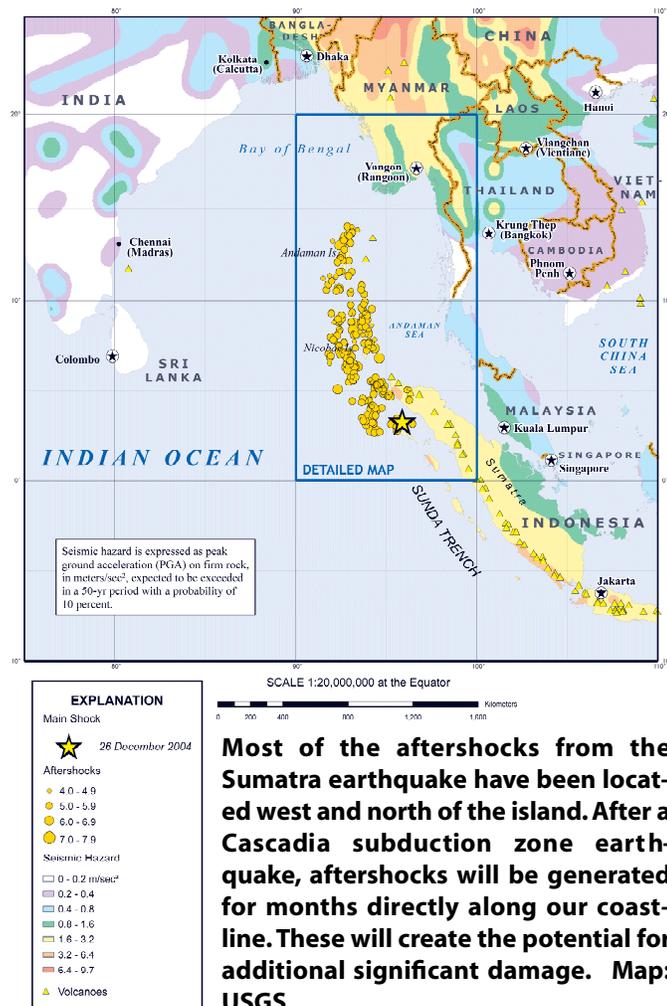


Building damage is not always readily apparent. These residents camped in their own front yard for temporary housing. The house was in the restricted area of heavily damaged downtown Coalinga in 1983. Photo: H. G. Wilshire, USGS



In the 1964 Alaska earthquake, this fourteen-story reinforced concrete apartment building in Anchorage was severely damaged by the ground shaking it endured. Photo: USGS

Sumatra Earthquake, 2004



Most of the aftershocks from the Sumatra earthquake have been located west and north of the island. After a Cascadia subduction zone earthquake, aftershocks will be generated for months directly along our coastline. These will create the potential for additional significant damage. Map: USGS

Cascadia is served by the West Coast/Alaska Tsunami Warning Center. It monitors potential tsunami activity in the Pacific Ocean so we will not be surprised by damaging tsunamis from distant earthquakes.

The tsunami that devastated the Indian Ocean basin in December 2004 was triggered by a magnitude 9.0 earthquake about 60 miles (100 kilometers) off the coast — a quake similar in some respects to what we expect along the Cascadia subduction zone. More than a million people lost their homes, and more than 300,000 died or remain missing. Although there are major differences between the geology, buildings, and city sizes of Sumatra and Cascadia, there are some important lessons we can take from this tragedy.

Victims of a distant tsunami

India, Sri Lanka, Thailand, and other countries suffered what scientists call a distant tsunami. People in these countries didn't feel the earthquake: the shaking was either minimal or nonexistent. The effects of the tsunami waves were still devastating. In Sri Lanka, it is estimated that 66% of the fishing fleet was destroyed.

Cascadia coasts can also experience distant tsunamis. The 1964 Alaska earthquake produced the most recent distant tsunami that damaged ports and towns along our coastline. Even without a warning system, it caused fewer than 20 deaths in Cascadia.

An important new tool for protection from future distant tsunamis is the West Coast/Alaska Tsunami Warning Center. Its mission is to rapidly locate and size major earthquakes in the Pacific basin, determine their tsunami potential, predict tsunami arrival times and, when possible, runup on the coast, and provide timely and effective tsunami information and warning bulletins for the Pacific coastal populations of California, Oregon, Washington, British Columbia, and Alaska.

Since 1980, the Warning Center has issued 11 tsunami warnings. The time to issue these warning has ranged from 8 to 14 minutes. With a distant tsunami, this gives governments, businesses, and people time to prepare for the expected waves.

Earthquake and near-tsunami victims

The island of Sumatra, Indonesia bore the brunt of the initial earthquake and local tsunami in December. The actual rupture that caused the initial earthquake lasted 3 to 4 minutes, although the shaking was felt longer in areas with soft soils. But the truly terrifying event was the tsunami that hit Indonesia minutes after the earthquake. Along the coastline closest to the epicenter of the quake, the tsunami waves were devastating. Both structures and vegetation were swept away.

As expected in an event of this size, there was a great deal of damage to infrastructure and many buildings were destroyed, leading to a large number of casualties and long delays in getting emergency supplies to the hardest-hit areas. Runways at airports were damaged and roads were disrupted, which continues to make the relief effort difficult and frustrating. Hundreds of thousands of people will need food, water, and shelter to be supplied for the foreseeable future.

Three hours after the quake, there was an aftershock measuring M7.1. There have been at least 13 aftershocks of M6.0 or larger. Each aftershock carries some risk of causing more damage, and each one further disturbs whatever peace of mind Sumatrans have been able to regain.

On a positive note, children were able to go back to school in Banda Aceh a month after the earthquake, even as water and food were still being flown in. Even though school buildings and supplies had been destroyed, the symbolism of the act was crucial; the community proved that it will have a future.

We are better prepared

Our building codes require buildings to be much more resilient to earthquakes than those in Indonesia. Our schoolchildren are taught how to protect themselves in earthquakes. Many communities have earthquake maps that delineate potential hazard areas. With this information, communities, individuals, and businesses can take steps to prepare for major quakes.

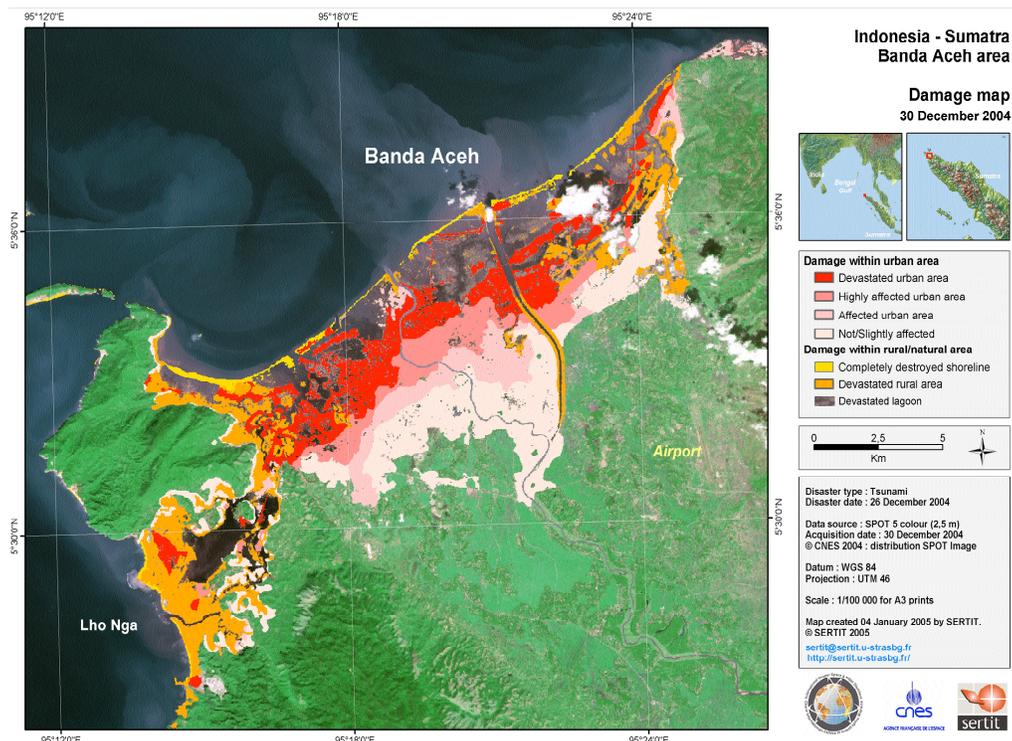
We are also much more able to deal with what scientists call a local tsunami — one that reaches the coastline within minutes of a subduction earthquake.

Federal, state, provincial, and local governments work together to map tsunami evacuation routes, prepare educational materials for schools, and coordinate information that goes to the public. We can minimize loss of life by being aware of the danger and knowing what to do.

Our challenge now is to build on the groundwork we've already laid, to continue to reduce the danger from earthquakes and tsunamis along Cascadia.

In Cascadia, we have spent more than a decade preparing for a subduction earthquake and tsunami.

We are more prepared inland, but the most exposed and vulnerable areas of our coast will still be devastated.



This map of damage in Banda Aceh, the city most affected by the earthquake and tsunami, shows that even in areas of major destruction, tsunamis can be avoided by going uphill or sufficiently far inland. Educating people to start moving as soon as the shaking stops can save lives. In Cascadia, many communities have evacuation routes, complete with published maps and road signs to guide residents and visitors to safety.

Alaska Earthquake, 1964



Before the earthquake, the sidewalk in front of these Anchorage stores on the right was at the level of the street on the left. Note that buildings and pavement not involved in the 11 foot (3 meter) landslide show little damage. Photo: USGS

To estimate what damage a Cascadia subduction quake might wreak, we can review the 1964 Good Friday earthquake in Alaska. This quake measured M9.2 and the strong shaking lasted 4 to 6 minutes, depending on local conditions. Most damage on land came from ground failure. A devastating tsunami followed the earthquake, causing far more loss of life than the earthquake itself. Twelve people died from the quake; 119 people died from the tsunami.

Wood-frame houses and other short buildings — Most homes were not damaged and in many areas, books didn't even fall off shelves. However, the Turnagain neighborhood in Anchorage lost many homes because of a landslide that stretched along the coast for more than a mile (almost two kilometers).

Most short buildings had little damage, unless they were in an area of landslides, liquefaction, or other ground failure. Fourth Street in downtown Anchorage dropped 20 feet (6 meters), destroying a number of buildings.

Tall structures — Most multi-story buildings suffered some structural damage. The control tower at Anchorage airport collapsed, but the one-story terminal building was undamaged.

Transportation — Most highways, rail lines, and airport runways could be used after the quake, except in areas where soils liquefied. In some of these cases, damage was extreme.

Bridges — More than 250 bridges in Alaska were damaged; 50 partly or completely collapsed. In areas where the bridge footings were in gravels rather than sand or silt, there was little damage.

Ports — Anchorage, Kodiak, Valdez, and Seward suffered major deformation of docks and pipe supports, largely from landslides or land subsidence.

Utilities — Electric transmission lines and pipelines in areas with liquefaction or ground failure were seriously damaged.

Tsunami — Alberni and Port Alberni on Vancouver Island suffered over \$10 million US in damage.

The 30 foot (10 meter) high tsunami dealt the death blow to the city and harbor of Valdez. The destruction caused by liquefaction and the tsunami led residents to rebuild their community four miles (six kilometers) away.

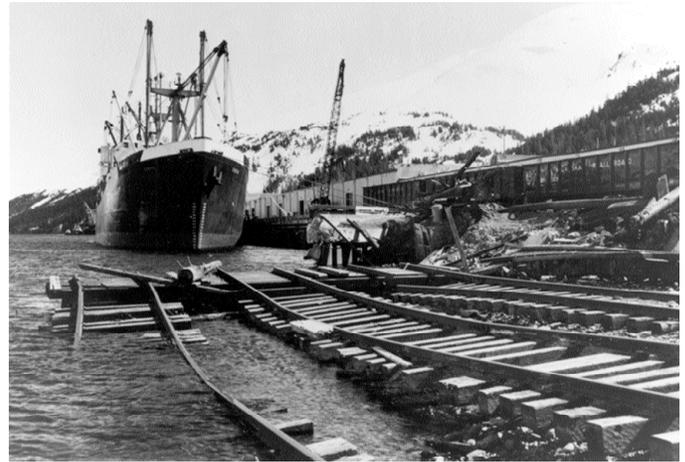


The first wave in a tsunami is not always the most destructive. In Crescent City, California, it was the fourth wave that resulted in 10 deaths. Another four people died on an Oregon beach. The coasts of British Columbia, Washington, and Hawaii suffered damage, but had no fatalities.

Millions of dollars of property damage were caused by the waves. Port facilities were particularly hard hit. Docks that were detached and twisted by the earthquake were then battered by the debris that was flung on land by the waves.

Seward, Kodiak, and Whittier lost structures that withstood the earthquake, but could not stand up to the force of the tsunami waves.

Ground deformation — In many places, the shoreline was permanently changed. Kodiak Naval Station sank almost 6 feet (2 meters), while much of the Prince William Sound uplifted an average of 6 feet (2 meters).



Shaking, tsunami, fire, and a submarine landslide all contributed to the damage of railroad and port facilities at Whittier, Alaska. Photo: US Army.

1964 Alaska Good Friday quake damage and possible Cascadia parallels

Valdez

Similar effects expected along Cascadia coast/Hwy 101 corridor

Damage primarily from tsunami

80% of the homes destroyed

Hospital and school leveled

Water and sewer lines damaged

Tsunami waves brought debris into the city

Harbor destroyed

City evacuated

Anchorage

Similar effects expected along I-5/Hwy 99 corridor

Damage from ground shaking and ground failure

30 block area in downtown destroyed by landsliding

2 schools destroyed

Airport control tower collapsed

City sewer system destroyed

2,000 people left homeless (from a population of 55,000)

9 people killed

Most wood frame homes undamaged

Fairbanks

Similar effects expected east of the Cascades

Damage from ground shaking

Windows broken and chimneys fell

Crescent City, California

Similar effects possible in US and Canada outside of Cascadia

Damage from tsunami

300 buildings destroyed and 10 people died

Japan

Similar effects across the Pacific expected after a Cascadia quake

Damage from tsunami

Oyster and pearl harvest disrupted



The Alberni Valley on Vancouver Island in British Columbia had 350 homes and buildings damaged from the tsunami generated by the Alaska earthquake 1,100 miles (1,800 kilometers) away. Photo: Port Alberni Online.

Scenario M9.0 Earthquake

A regional disaster

What follows is a scenario of how a great subduction zone earthquake could affect Cascadia. It is important to pick a specific date, because the effects of an earthquake in cold, rainy December will be different than in dry, summer months. The time is important because the highest number of casualties would probably happen in the afternoon when people are at work, and when there are more people on the beach.

For this scenario, assume there has been:

- A M9.0 earthquake
- On the second Tuesday in July
- At 4 PM.

This earthquake could be catastrophic. It will certainly be larger than local or regional resources can respond to. Help from the national level, in both the US and Canada, will be needed. Other Pacific Rim countries may be affected by tsunami damage or trade disruptions. It will be a long-term event, affecting the economies of the US, Canada, other Pacific countries, and their trading partners for years to come.

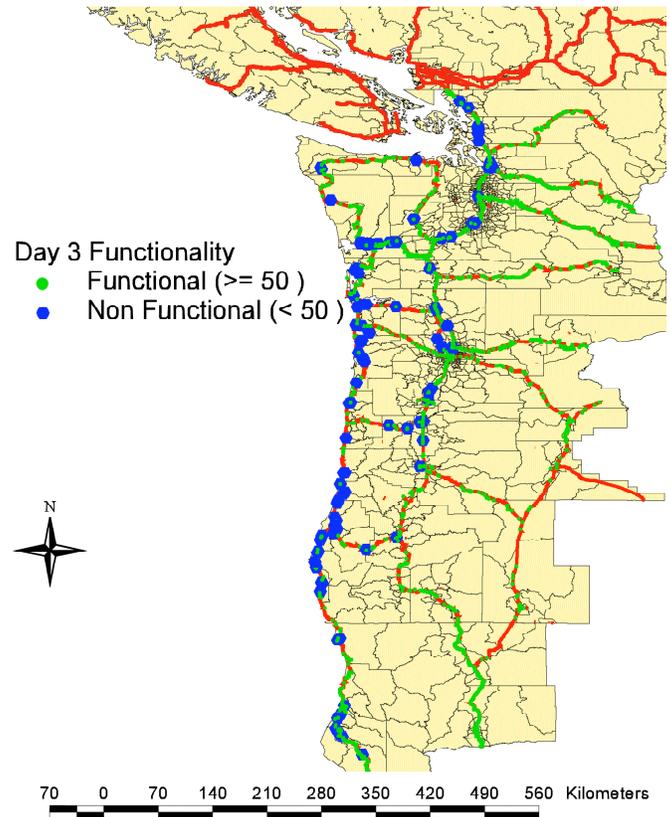
Different locations, different experiences

In the following pages are descriptions of one possible aftermath of a subduction earthquake. The damage will be dramatically different going from west to east. There are so many variables that firm predictions cannot be made, but we can estimate likely effects. Nothing in this section should be taken as a specific forecast for any particular area.

This earthquake will affect every business, government agency, nonprofit organization, and individual in the region.

Cascadia includes the land from the ocean shore to the eastern foothills of the Cascades, from Brooks Peninsula in the north to Cape Mendocino in the south. This earthquake will affect far more area than that. In this report we are including only Cascadia and the land directly east of us, but there will be widespread effects across the US and around the Pacific Rim.

The widespread physical damage from a great subduction earthquake will result in unprecedented economic losses. It will be critical to get businesses running as soon as possible to provide materials needed for recovery, and to provide the jobs necessary for the long-term economic health of Cascadia.



Cascadia Scenario Bridge Functionality

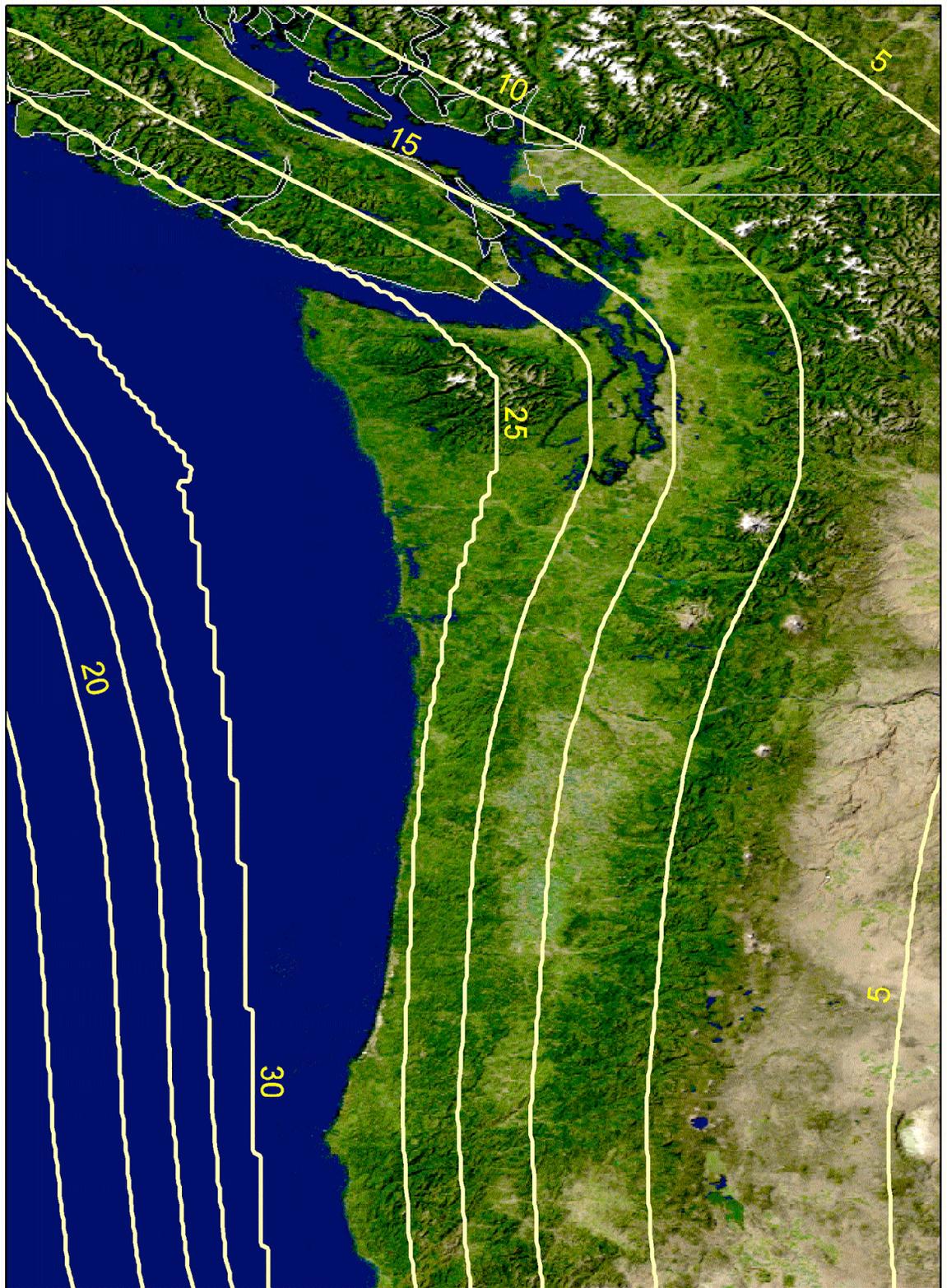
Each blue dot represents a bridge that is out of service three days after the earthquake. This is only one possible outcome, not a listing of all bridges that will be damaged. The effects of liquefaction or tsunamis, either of which could create more damage at a specific site, were not included. Segments shown in green would likely be functional.

The importance of the map is in recognizing the pattern of widespread damage along the major transportation corridors of Hwy 101, I-5/Hwy 99, and across the Coast Range. This pattern can be applied to other types of structures in those areas, including tall buildings and long power lines and pipelines.

Information from the shaking map on page 13 has been incorporated into this map.

The HAZUS model used to produce this information was developed by the Department of Homeland Security Federal Emergency Management Agency (FEMA) to forecast earthquake damage.

Bridge information was not available for Canada.



This map shows Peak Ground Accelerations (PGAs). PGA is one measure of the strength of shaking. Higher PGAs generally result in more damage. Because this map shows average expected PGAs in an area, specific locations may have higher or lower PGAs, and significantly more or less damage. Site conditions such as soil and building type will affect the type and amount of damage at any given place.



In the 1992 Petrolia, California earthquake at the southern tip of the Cascadia subduction zone, landslides were widespread. They blocked or impeded traffic and hampered rescue and relief efforts on the few roads in the area. Photo: NOAA.

To a large extent, each coastal community is isolated for weeks, as landslides disrupt many sections of Highway 101.



Tsunami evacuation route signs like this one will be one of the most important tools for saving lives at the coast after a Cascadia earthquake. Photo: DOGAMI

Hwy 101 corridor/coast

Widespread damage and isolation

To a large extent, each coastal community is isolated for weeks, as landslides disrupt many sections of coastal Highway 101. Many communities on the coast are devastated by the combination of strong shaking, landslides, tsunami waves, and fire. Buildings, roads, bridges, and utility lines suffer varying amounts of damage. Some are destroyed.

Airports, sea ports, roads, and railroads close at least until they can be inspected; any of these facilities on land that liquefied will be closed for some time, making it difficult to bring in emergency supplies.

Public health issues become important, because of the number of casualties and the limited medical help available.

Here are two examples of what might happen in coastal towns, one with only marginal damage from a tsunami, one being swept through by the waves.

City on a bay

A young mother at home with two small children is knocked off her feet by the sudden, hard shaking of the ground. The children start crying and she crawls to them, grabs one in each hand and tries to shield them with her body. The activity table only a few feet away would provide protection, but it is too difficult to move against the shaking ground and squirming kids. She won't realize until tomorrow that her back and left arm were heavily bruised.

When the shaking stops, she tries to comfort the kids while getting them out of the house. She opens the front door and realizes that the steps are now almost a foot (one-third meter) away. The house, built in the 1920s, has shifted by that much. Even though she didn't see much damage inside the house, all utility lines have now been broken and the house has no water, sewer, gas, or electricity. A building inspector will post the home unsafe, and the family will have to rely on emergency resources for shelter, water and food.

The family starts walking to Dad's office to see if he's injured. He's fine. She is also eager for news, not having a battery-powered radio in the house. They find out that Highway 101 will be impassable for days. Several old, brick buildings in Old Town have partially collapsed. A tsunami has washed through the bay, which is now filled with debris.

The young woman is afraid the restaurant where she works no longer exists. Actually, it will only be closed for a week and will reopen to serve food to residents and the numerous relief workers who come to help with recovery.

Roads and railroads out of the area are not passable, but emergency supplies are being delivered by C-130 aircraft, which can land at the airport.

City on the seashore

The owner of a motel realizes at once what the shaking means and remembers to drop, cover, and hold under the front desk. After the shaking stops, staff and guests stream into the office. The NOAA weather radio broadcasts a tsunami warning. The motel staff have walkie-talkies to communicate, and the owner now uses that system to get damage reports from staff. Part of a second story wall collapsed, but everyone is able to get down the stairs and outside.

Many people have cuts, bruises, sprains, possibly broken bones, but there is time only for emergency first aid before taking the tsunami evacuation route. The owner knows they are in the inundation zone and it is critical to quickly get uphill to safety. He tells staff and guests to start moving, making sure that everyone hears his warning. There isn't enough time to convince those who argue with him, and with a mixture of determination to save lives, and guilt for the people staying behind, he picks up the registration list before leaving.

The crowd stays calm as they walk the evacuation route, a quarter-mile (half kilometer) uphill to the school that has been designated an emergency assembly area. Along the way, the group passes downed power lines, collapsed walls, and streets with deep cracks. Shortly after getting to the school yard, they watch water flood the town, tearing houses off their foundation and easily moving parked cars. After nearly an hour the water recedes, taking with it the wood, plaster, and metal it claimed. The outgoing water brings down a few buildings that withstood the incoming wave. Some people try to leave, thinking the danger is over, but they are convinced to wait until danger from all the tsunami waves has passed.

Residents in nearby houses take in elderly guests and families with children, making sure they are kept warm through the night. They also share food and water. Everyone eats and drinks sparingly, concerned about when new supplies will be available, since Hwy 101 is obviously unusable. Aftershocks disturb them through the night.

Of the original 100 registered guests, 45 make it to the assembly area. Later, 30 others who were in other places come back to the motel, leaving 25 dead or unaccounted for.

Until highways and the local airfield re-open a few weeks later, temporary shelter for residents and tourists and most rescue and recovery work must be provided for by people in the area, supplemented by military helicopter drops and boat landings.

As a permanent reminder of the power of the earthquake, the beach has permanently dropped three feet (one meter), leaving part of the original town under water.



In the 1971 San Fernando earthquake, the south stair tower (above) fell, and there was other structural damage at Olive View Hospital. Three people died and the building was evacuated. It is imperative to have hospitals and other essential facilities available during the crisis of a subduction zone earthquake. Photo: R. Kachadoorian, USGS

Escaping a tsunami

When you're at the coast, take just a moment to locate high ground you could get to after a big earthquake

Many cities have evacuation route signs posted and brochures printed. Some have designated assembly areas at the end of evacuation routes.

You can be in danger near the mouth of a coastal river, even if you can't see the ocean

Try to move to high ground and inland

Go on foot, don't drive

Stay at high ground until you get an official all-clear. A tsunami, which is actually a series of waves, can last many hours.



Transportation systems like railroads are fragile because a break in any spot can affect all traffic on the line. Ground response of loose, water-filled soils buckled this railroad bridge in the 1964 Alaska earthquake. Photo: USGS

Much of the response and rescue after a large earthquake is done by untrained neighbors and volunteers.



Debris from fallen buildings will trap people and make streets impassable. After the 1989 Loma Prieta, California earthquake, this group in Santa Cruz worked to rescue people. Photo: C. E. Meyer, USGS

I-5/Hwy 99 Corridor

Utilities, transportation, other systems disrupted

Throughout most of the area, electricity and telephone service — both traditional and cellular — are inoperable for at least a day. Some water, sewer, and natural gas services are interrupted because of broken pipelines. Even buildings with no structural damage have to close because they do not have adequate utilities. This results in lost wages and lost profits.

The resident of a wood-frame home is amazed that he can find no damage after such a long earthquake. His house was anchored to its foundation, the chimney had been reinforced, and internal shelves were anchored.

His children were playing at a neighbor's house and he runs to get them. The family spends an anxious night worried about Mom, who works across the river. She arrives home the next morning.

Neighbors meet together and plan to systematically check each house to see if anyone is trapped or injured. They also agree to pool their food and bottled water supplies. Several people volunteer to heat food on their barbecues. Other people with battery-operated radios offer to open their houses at specific times so everyone can hear the latest news. Where they exist, trained neighborhood emergency teams are activated to help their communities and coordinate with fire and police rescue activities.

In commercial areas, damage ranges from slight to substantial. In downtown areas of large cities, some old brick buildings and tall buildings suffer extensive damage.

Parapets fall from several buildings, causing injury and clogging streets with debris. One tall, older, concrete-frame building collapses, causing many fatalities. Most buildings, however, do not have substantial structural damage.

Injuries are also concentrated in this area, but are found throughout the community. Many of them are people who work in buildings that have little structural damage, but who were hit by items falling off shelves in their offices.

Even in smaller cities, response to some areas is difficult because fallen bricks and other building debris has blocked roads. Some older fire stations, police stations, and hospitals are inoperable.

Several tilt-up warehouses have walls that partially collapse. Firefighters and police officers are overwhelmed and cannot respond, so people spend hours rescuing and giving first aid to their co-workers.

Because of the extent of damage across the region, many utility repairs that would normally take only a few hours now take days. The highest priorities for power restoration are utility stations, emergency resources (hospitals, fire stations), and high-density population areas (whether residential, commercial, or industrial). Until electricity is restored to water treatment facilities, there is no water.

For a few days, some cities, communities, or neighborhoods are isolated for a variety of reasons. Many cities in this area are accessed by roads that span one or more bridges. In some places, bridge damage closes roads, making it difficult or impossible to drive in or out of the city. In other areas, isolated landslides block roads.

On a larger scale, it is difficult to immediately bring in rescue workers and emergency supplies because of problems in the regional transportation corridors.

The I-5/Hwy 99 passage is the backbone of the area's transit. Even though there is debris and damage only in localized stretches, those few spots effectively shut down the ability to travel long distances on the north-south route. Bridges must be inspected, debris removed, and damage repaired or detours set up, before the corridor is open again.

Most of the ports in this region suffer some damage and are of limited use anyway, because shipping lanes need to be resurveyed before rivers are again navigable.

Cracked runways at airports built on areas of artificial fill or on liquefying soils are inoperable until inspection and repair work is completed. This could take hours, days, or weeks, depending on the amount of damage. Small airports may not be high on a priority list for repair.

Docks are damaged from liquefaction, and ferry service is disrupted throughout Puget Sound and British Columbia. Many islands are isolated, and communities on each side of the Sound are effectively separated.

Individuals, businesses, and governments across the world offer money, supplies, and personnel to help. In some areas, food, water, and temporary shelter are needed at first, but within a few days most people are back in their own homes.

In this zone, the economic centers of Portland, Seattle, and Vancouver are the highest priorities for outside rescue and recovery activities. Given the breaks in transportation and utility services, even some high priority areas don't get the resources they need until days after the quake. Communities in lower priority areas will need to be self-sustaining until emergency resources can be delivered, possibly for weeks.

Communities that fare the best are those who know what resources are available and have response plans that assume they will be isolated for a while.



Houses don't need to collapse to be evacuated. This house shifted off its foundation in the 1989 Loma Prieta, California quake and now all the utilities are disconnected. Photo: H. G. Wilshire, USGS

Communities that fare the best are those who know what resources are available and have response plans that assume they will be isolated for a while.



Even without structural damage, offices like this one after the 1989 Loma Prieta, California earthquake may be a mess with overturned bookcases, filing cabinets and desks. The safest way to protect yourself is get under a desk or table. DO NOT stand in a doorway. Photo: J. K. Nakata, USGS

In a city like Spokane, 300 miles (500 kilometers) east of the subduction zone, the community is affected even for those who don't feel the ground shake.



Businesses throughout Cascadia will be severely affected if they depend on coastal ports or river ports that are damaged (like those on the lower Columbia River). Photo courtesy CRIS, Inc.

To some extent, cities east of the Cascades benefit from becoming a hub for transportation, commercial, and government operations supporting the recovery of Cascadia.

East of the Cascades

Indirect economic effects

Some residents in the area feel the ground shake, but it is only a very weak version of the earthquake felt at the coast. In a city like Spokane, 300 miles (500 kilometers) east of the subduction zone, the community is affected, even for those who don't feel the ground shake.

Much of the area has little or no damage. Any serious damage is limited to relatively small pockets, generally those with soft, deep soils. Some tall buildings may have nonstructural damage, which could result in injuries.

Utilities and transportation systems are disrupted in some places, where supplies first come through pipelines west of the Cascades. East-west corridors through the mountains experience several rockfalls, which close highways and railroad lines. Connections to cities in the I-5/Hwy 99 corridor are lost for some period of time, depending on local conditions.

Emergency responders are overloaded from a combination of appropriate calls and others who are asking what happened.

Cities in this area are needed as coordination centers for the rescue, response, and recovery needed to the west. Especially in the first weeks after the quake, cities like Kamloops, Spokane, Bend, and Sacramento are important staging points. Businesses and government agencies that cannot operate their Cascadia offices set up temporary offices here to take advantage of the transportation corridors through these eastern cities.

Economic losses to both profits and wages may occur. Business effects include difficulty shipping grain and other products to markets. Sea ports and some river ports close to the Pacific Ocean are damaged, some severely. Shipping lanes in the lower Columbia and in other affected rivers must be resurveyed before ship traffic can resume. In addition, rail lines, trucking, and air traffic are overburdened by extra demands for products needed to rebuild western British Columbia, Oregon and Washington, and northern California.

To balance those challenges, these economies benefit to some extent from becoming hubs for transportation, commercial, and government operations supporting the recovery of Cascadia.

However, tourism to the region dramatically declines in the years following the earthquake, as news outlets focus on negative information about Cascadia.

Long-term recovery

Transformation after destruction

We cannot ignore or negate the power of a subduction zone earthquake. However, with planning, we can use the event to transform our region. For example, Hwy 101 can be rebuilt to current engineering standards, rather than continuing to be pieced together every winter after damage from rainstorms and landslides. This will give the coast a dependable transportation backbone on which to rebuild the future.

For a few months

Isolated coastal communities will have to deal with the destruction of much of their building stock, roads and utilities. Thousands of families may need temporary shelter for months, even years. Ports will be destroyed. Tourism, timber, and fishing industries will all be severely reduced after this quake.

Along the I-5/Hwy 99 corridor, many of the old, unsafe brick structures will be shaken down. Although this gives us an opportunity to build safer, energy-efficient, modern buildings, it also creates a problem. Older buildings are often used for low- or moderate-income housing, cheap office rentals, and warehouse space. Those needs will still exist, and it will take coordination to replace structures that serve the needs of working families and small businesses.



Using helicopters, the US Navy brought relief supplies to areas on Sumatra that could not be reached by road or airplane. Similar efforts will be necessary along the Cascadia coast. Photo: J. J. Kirk, US Navy

Stages of response and recovery

In July 2002, the US Army Corps of Engineers (USACE) invited nearly 200 people from federal, state, provincial, and local governments to a Cascadia subduction zone earthquake tabletop exercise. Their forecast of long-term needs included:

Priorities for the first 72 hours:

Save lives, by emergency personnel and neighborhood residents. Establish communications when telephone and electrical systems are seriously damaged. Assess bridges, roads, buildings and assess and repair infrastructure (power, water, sewer, gas, transportation). Remove debris to improve access for responders.

Priorities for the first 30 days:

Provide temporary shelter, food, water, and medical care. Restore electrical power, particularly to water treatment facilities, hospitals, emergency facilities. Remove debris, find appropriate locations for dumping material. Inspect buildings, including shoring unsafe buildings, and reevaluations after aftershocks. Repair transportation routes. Begin managing inventory control and distribution.

Priorities for 30 days to 6 months:

Continue damage inspection, aftershock reevaluation, and inspect new construction. Continue rebuilding infrastructure. Continue temporary shelter, food, water, and medical care. Move those in temporary shelters to more permanent housing, streamline resulting permit and land use planning processes. Manage debris, including sorting and recycling, prevent/treat health and environmental problems.

Modern, efficient transportation and utility lines can be built, making the area more attractive for business investment, tourists, and residents.



Debris management and removal will be an enormous job. For example, debris from the collapse of the World Trade towers amounted to 1.8 million tons. Photo: US Environmental Protection Agency

Businesses and local governments need to have employees make family emergency plans. That way, people can check on their families, then return to work for emergency or recovery activities.

East of the Cascades, small cities may become overwhelmed by becoming hubs for increased air, rail, and truck traffic. Shipping down the Columbia will be disrupted until the channel can be resurveyed and port facilities rebuilt.

Restoration of infrastructure critical to modern life (communications, potable water, fuel, sewage treatment) will take days, weeks, or months, depending on the amount of damage and access to the damaged area. For example, it might take weeks to reopen a damaged water treatment facility in a coastal town, because electricity and roads need to function before repairs can take place. In the Puget Sound area, a similar problem might be fixed in a few days because roads and utilities suffered less damage and there are more people and resources available for repairs.

With many deaths expected from this event, there are political and public health issues that will need to be addressed. And, debris management will be a central activity. Massive amounts of material from damaged buildings will need to be disposed of to allow reconstruction. To adequately address recycling and environmental concerns, sites for debris collection need to be identified before the quake.

This event will overwhelm the ability of state, provincial, and local governments to provide traditional services, from fighting fires to issuing building permits. Many city halls, fire or police stations, jails, and schools will need significant repair or rebuilding. Emergency funding, supplies, and personnel will be needed for months or years.

Rebuilding for the future

With massive amounts of damage to our infrastructure, many businesses will have to close, denying their services to the community and leaving people without incomes. After other natural disasters, most businesses that closed haven't reopened.

We will have unexpected economic ripples. It's easy to predict that some businesses will move out of the area. It's more difficult to foresee the new opportunities that will only exist after the earthquake, in our rebuilt communities. But they will exist, and entirely new industries could spring from this massive shift in our landscape.

It will take years to recover from a Cascadia subduction zone earthquake. The tsunami that follows may damage not just us, but Alaska, Hawaii, Japan, and other Pacific Rim economic powers. The resources of the US, Canada, Japan, and other nations will be used to rebuild damaged areas, affecting the world economy.

After other disasters like hurricanes, communities have used the event to embark on a new plan for the future. We can prepare for this earthquake, recover from it, and build a future Cascadia that is still the place in which we want to live, work, and play.

What next?

The 3 Ds of disaster — deaths, dollars, and downtime — for a subduction zone earthquake could overwhelm Cascadia. Earthquake and tsunami hazard maps, drills for schools and businesses, and a tsunami warning system are just a few of the ways we've begun to prepare. But what should we do next?

Important considerations include:

- **Reducing the risk for critical public facilities, such as hospitals, schools, police, and fire** — If our essential facilities are not usable after an earthquake, there will be more deaths, less capacity to handle casualties and people made homeless, and an increase in response and recovery times. Funding, and possibly legislation, will be required to upgrade these essential services.
- **Retrofitting high risk buildings, such as unreinforced masonry (URM), tilt-up structures, and tall buildings not built to modern codes** — In most earthquakes, URMs and tilt-up structures are the leading cause of casualties. In Cascadia, they are often built on poor soils, increasing their risk, and a disproportionate number of schools and some other essential facilities are URMs. In a subduction zone earthquake, we must also consider the risk to tall buildings that are not engineered to resist long duration shaking damage.
- **Protecting transportation infrastructure** — Roads and bridges badly damaged by an earthquake will delay emergency response in the hours after the event, and restrict the movement of people and goods for months. Unusable airports, water ports, and railroads could slow down response and recovery efforts for months or years. If our ports closed for an extended time, shippers could permanently move to other ports, reducing our economic opportunities.
- **Continue public education efforts** — Most people who live in Cascadia know something about the earthquake risk, but they may not know how to prepare. Or they may not know what to do to protect themselves from a tsunami. Educating both residents and visitors will help prevent loss of life when the quake strikes.

A Cascadia earthquake will seriously affect our region, but it won't destroy us. We will rebuild our cities, our neighborhoods, and our businesses. The time it takes us to recover will depend largely on what precautions we take before the earthquake.



Warehouses at the toe of the Fourth Avenue landslide in Anchorage in 1964 were destroyed by compressional buckling and foreshortening. Much of the supply of food and drink for the city was stored in these buildings. Photo: USGS

California has led the way

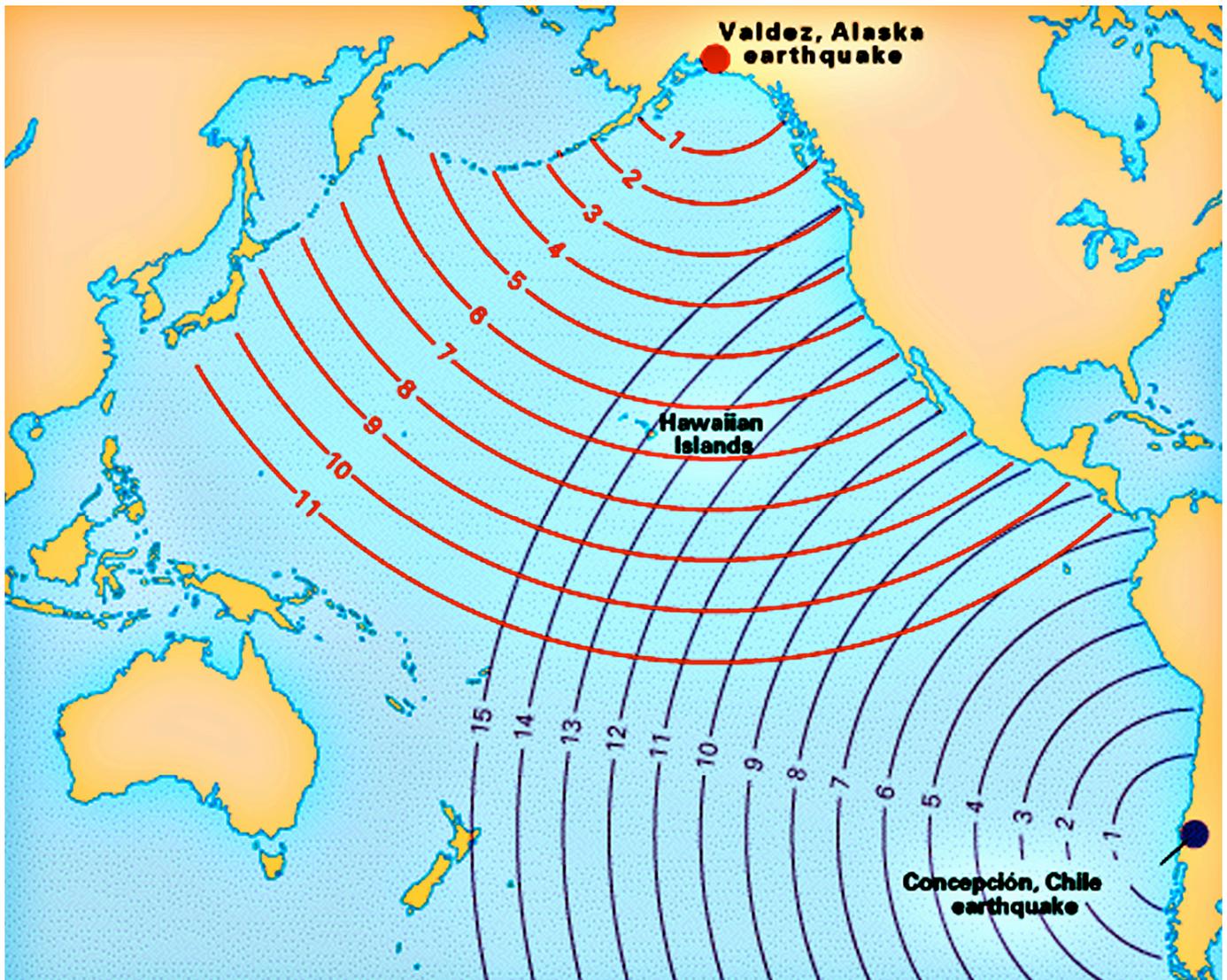
Critical facilities:

The Alquist-Priolo Act was enacted following the 1971 Sylmar earthquake, which resulted in the destruction of two major hospitals and the loss of 65 lives. It established a statewide seismic safety building standards program. Amendments to the Alquist Act made after the 1994 Northridge earthquake require all acute-care hospitals to remain operational after an earthquake. This program resulted in acute-care hospitals in California being operational immediately after recent earthquakes.

URM inventory and upgrade:

In 1986, California enacted a law requiring local governments in high seismic zones to inventory unreinforced masonry (URM) buildings, establish a loss reduction program, and report progress to the state by 1990. The level of compliance with this law is quite high, with about 98 percent of the 25,500 URM buildings in California now in some sort of loss-reduction program.

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This map shows the travel time (in hours) of the tsunami generated by the 1964 Alaska and the 1960 Chile earthquakes. A tsunami generated from a Cascadia subduction earthquake will have similar travel times across the Pacific. Trade across the Pacific basin could be disrupted if ports or manufacturing plants are damaged in Japan, China and other countries. Map: USGS.