GEOLOGIC HAZARDOUS AREAS IN WASHINGTON STATE

LANDSLIDES, EARTHQUAKES, VOLCANOES, TSUNAMIS - THEY ALL HAPPEN IN WASHINGTON

SW Washington Section American Planning Association - July 21, 2016

Stephen Slaughter, LEG
Landslide hazards program coordinator
Washington Geological Survey
Washington Department of Natural Resources
Geologists are never at a loss for paper weights.

-Bill Bryson, author
Geologic hazards

- **Earthquakes**
- **Tsunamis**
- **Landslides**

*We learn geology the morning after the earthquake.*

- Ralph Waldo Emerson
HAZARD AND RISK

• Many ways to define risk
• Risk composed of three components
  • Consequences (hazard or expected negative outcome)
  • Likelihood (probability)
  • Context of the situation under consideration (human health and safety, social, economic, environment, etc.)

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>VH</td>
<td>Very high</td>
<td>Risk is imminent; short-term reduction required; long-term reduction plan must be developed and implemented</td>
</tr>
<tr>
<td>H</td>
<td>High</td>
<td>Risk is unacceptable; long-term risk reduction plan must be developed and implemented in a reasonable time frame. Planning should begin immediately</td>
</tr>
<tr>
<td>M</td>
<td>Moderate</td>
<td>Risk may be tolerable; more detailed review required; reduce risk to as low as reasonably practicable (ALARP)</td>
</tr>
<tr>
<td>L</td>
<td>Low</td>
<td>Risk is tolerable; continue to monitor and reduce risk to as low as reasonably practicable (ALARP)</td>
</tr>
<tr>
<td>VL</td>
<td>Very low</td>
<td>Risk is broadly acceptable; no further review or risk reduction required</td>
</tr>
<tr>
<td>Likelihood Descriptions</td>
<td>Indices</td>
<td>Probability Range</td>
</tr>
<tr>
<td>----------------------------------------------------------------------------------------</td>
<td>--------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Event typically occurs at least once per year</td>
<td>Almost certain</td>
<td>&gt;0.9</td>
</tr>
<tr>
<td>Event typically occurs every few years</td>
<td>Very likely</td>
<td>0.1 to 0.9</td>
</tr>
<tr>
<td>Event is expected to occur every 10 to 100 years</td>
<td>Likely</td>
<td>0.01 to 0.1</td>
</tr>
<tr>
<td>Event is expected to occur every 100 to 1,000 years</td>
<td>Possible</td>
<td>0.001 to 0.01</td>
</tr>
<tr>
<td>Event is expected to occur every 1,000 to 10,000 years</td>
<td>Unlikely</td>
<td>0.0001 to 0.001</td>
</tr>
<tr>
<td>Event is expected to occur less than every 10,000 years</td>
<td>Very unlikely</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

**Multi-hazard Risk Evaluation Matrix**

<table>
<thead>
<tr>
<th>Indices</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incidental</td>
<td>Minor</td>
<td>Moderate</td>
<td>Major</td>
<td>Severe</td>
<td>Catastrophic</td>
<td></td>
</tr>
</tbody>
</table>

**Description of expected negative outcomes (Consequences)**
<table>
<thead>
<tr>
<th>Likelihood Descriptions</th>
<th>Indices</th>
<th>Probability Range</th>
<th>Multi-hazard Risk Evaluation Matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Event typically occurs at least once per year</td>
<td>Almost certain</td>
<td>&gt;0.9</td>
<td>M</td>
</tr>
<tr>
<td>Event typically occurs every few years</td>
<td>Very likely</td>
<td>0.1 to 0.9</td>
<td>L</td>
</tr>
<tr>
<td>Event is expected to occur every 10 to 100 years</td>
<td>Likely</td>
<td>0.01 to 0.1</td>
<td>L</td>
</tr>
<tr>
<td>Event is expected to occur every 100 to 1,000 years</td>
<td>Possible</td>
<td>0.001 to 0.01</td>
<td>VL</td>
</tr>
<tr>
<td>Event is expected to occur every 1,000 to 10,000 years</td>
<td>Unlikely</td>
<td>0.0001 to 0.001</td>
<td>VL</td>
</tr>
<tr>
<td>Event is expected to occur less than every 10,000 years</td>
<td>Very unlikely</td>
<td>&lt;0.0001</td>
<td>VL</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Indices</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incidental</td>
<td>Minor</td>
<td>Moderate</td>
<td>Severe</td>
<td>Catastrophic</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Heath and Safety</strong></td>
<td>No impact</td>
<td>Slight impact; recoverable within days</td>
<td>Minor injury</td>
<td>Serious injury or personal hardship; recoverable within weeks or months</td>
<td>Fatality or serious personal long-term hardship</td>
<td>Multiple fatalities</td>
</tr>
<tr>
<td><strong>Environment</strong></td>
<td>Insignificant</td>
<td>Localized short-term impact; recovery within days or weeks</td>
<td>Localized long-term impact; recovery within weeks or months</td>
<td>Widespread long-term impact; recoverable within weeks or months</td>
<td>Widespread impact; not recoverable within the lifetime of the project</td>
<td>Irreparable loss of a species</td>
</tr>
<tr>
<td><strong>Social and Cultural</strong></td>
<td>Negligible impact</td>
<td>Slight impact to social and cultural values; recoverable within days</td>
<td>Moderate impact to economic to social and cultural values; recovery within weeks or months</td>
<td>Significant impact to social and cultural values; recovery within months or years</td>
<td>Partial loss of social and cultural values; not recoverable within the lifetime of the project</td>
<td>Complete loss of social and cultural values</td>
</tr>
<tr>
<td><strong>Economic</strong></td>
<td>Negligible; no business interruption</td>
<td>&lt;$10,000 business interruption loss or damage to public or private property</td>
<td>&lt;$100,000 business interruption loss or damage to public or private property</td>
<td>&lt;$1M business interruption loss or damage to public or private property</td>
<td>&lt;$10M business interruption loss or damage to public or private property</td>
<td>&gt;$10M business interruption loss or damage to public or private property</td>
</tr>
</tbody>
</table>

Description of expected negative outcomes (Consequences)
RISK MANAGEMENT

• Mitigate the hazard
  • Retaining walls, seismic retrofit...

• Avoid the hazard
  • Build elsewhere, change zoning...

<table>
<thead>
<tr>
<th>Level</th>
<th>Risk Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>VH</td>
<td>Very high</td>
<td>Risk is imminent; short-term reduction required; long-term reduction plan must be developed and implemented</td>
</tr>
<tr>
<td>H</td>
<td>High</td>
<td>Risk is unacceptable; long-term risk reduction plan must be developed and implemented in a reasonable time frame. Planning should begin immediately</td>
</tr>
<tr>
<td>M</td>
<td>Moderate</td>
<td>Risk may be tolerable; more detailed review required; reduce risk to as low as reasonably practicable (ALARP)</td>
</tr>
<tr>
<td>L</td>
<td>Low</td>
<td>Risk is tolerable; continue to monitor and reduce risk to as low as reasonably practicable (ALARP)</td>
</tr>
<tr>
<td>VL</td>
<td>Very low</td>
<td>Risk is broadly acceptable; no further review or risk reduction required</td>
</tr>
</tbody>
</table>
Plate motions give rise to earthquake hazards from three different source zones, each with different recurrence intervals and potential consequences.
Deep earthquakes

Cascadia earthquake sources

<table>
<thead>
<tr>
<th>Source</th>
<th>Affected area</th>
<th>Max. Size</th>
<th>Recurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subduction Zone</td>
<td>W.WA, OR, CA</td>
<td>M 9</td>
<td>500-600 yr</td>
</tr>
<tr>
<td>Deep Juan de Fuca plate</td>
<td>W.WA, OR,</td>
<td>M 7+</td>
<td>30-50 yr</td>
</tr>
<tr>
<td>Crustal faults</td>
<td>WA, OR, CA</td>
<td>M 7+</td>
<td>Hundreds of yr?</td>
</tr>
</tbody>
</table>
SEVEN DEAD, 59 INJURED: EARTHQUAKE LOSS HEAVY

Temblor Lasts Two Minutes; Olympia Area Is Evacuated

Military Police Patrol Downtown Seattle

Epicenter 11 miles northeast of Olympia
More than two dozen buildings damaged
Dozens of injuries; no South Sound deaths

6.8 QUAKE

State buildings shut till Monday

Residents: ‘Our building was dancing’
The Bayview market in Olympia lost stock from unsecured merchandise toppling off the shelves.

Nonstructural hazards can be mitigated easily and cost-effectively.
These examples of nonstructural damage are from the Natural Resources Building in Olympia from the Nisqually earthquake.
Simple restrainers are an effective mitigation
Because these earthquakes are deep, they are less damaging than shallow events like the Northridge in California.
Crustal earthquake sources

<table>
<thead>
<tr>
<th>Source</th>
<th>Affected area</th>
<th>Max. Size</th>
<th>Recurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subduction Zone</td>
<td>W.WA, OR, CA</td>
<td>M 9</td>
<td>500-600 yr</td>
</tr>
<tr>
<td>Deep Juan de Fuca plate</td>
<td>W.WA, OR,</td>
<td>M 7+</td>
<td>30-50 yr</td>
</tr>
<tr>
<td>Crustal faults</td>
<td>WA, OR, CA</td>
<td>M 7+</td>
<td>Hundreds of yr?</td>
</tr>
</tbody>
</table>

Crustal earthquakes
Washington’s earthquake history is spotty before ~1850s

- Very large earthquakes have long recurrence intervals, on the order of hundreds to thousands of years
- Evidence demonstrates substantial hazard from faults that have not ruptured since European settlement in the PNW
- Fault include the Seattle, Tacoma, southern Whidbey Island, Devil’s Mountain, Canyon River, Boulder Creek, Toppenish Ridge, Saddle Mountain, etc.
- All are capable of $>\text{M6.5}$ at shallow depths and therefore highly damaging
## Subduction zone earthquakes

The Cascadia subduction zone is a major geological feature along the Pacific Northwest coast of the United States and Canada. It is known for the potential for large earthquakes that can cause catastrophic damage. The subduction zone is where the Pacific Plate is being subducted under the North American Plate. The diagram illustrates the different earthquake sources and their associated characteristics:

<table>
<thead>
<tr>
<th>Source</th>
<th>Affected area</th>
<th>Max. Size</th>
<th>Recurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subduction Zone</td>
<td>W.WA, OR, CA</td>
<td>M 9</td>
<td>500-600 yr</td>
</tr>
<tr>
<td>Deep Juan de Fuca plate</td>
<td>W.WA, OR,</td>
<td>M 7+</td>
<td>30-50 yr</td>
</tr>
<tr>
<td>Crustal faults</td>
<td>WA, OR, CA</td>
<td>M 7+</td>
<td>Hundreds of yr?</td>
</tr>
</tbody>
</table>

The subduction zone earthquakes are significant due to the potential for extremely large magnitudes, with the most recent major event occurring in 1700. The deep earthquakes, which occur at greater depths, are less frequent but also pose a significant risk.
How do we know that Cascadia makes earthquakes? Some background. Washington is located in the northeast corner of the Ring of Fire.
Distribution of some of the world’s major volcanoes

Distribution of magnitude 5 or greater earthquakes 1980-1990
Geologic hazards

- Earthquake
- **Tsunami**
- Landslide

*If you can see or hear water, you’re probably living too close.*

-Stephen Slaughter
Note also that the coast of Washington has very few earthquakes, and none on the subduction zone. It was long thought that Cascadia was not active.
1960 M9.5 Chile earthquake

- Land level dropped up to 6 ft.
- Other places uplift was as much as 18 ft.
Queule Chile - Before
Queule Chile - After
1964 M9.2 Alaska
- Subsidence up to 6 feet
- Uplift as much as 30 ft.
This area in Prince William Sound was uplifted 33 feet, stranding seaweed high above the beach.
Drowned forest in Girdwood, AK - killed 1964

Drowned forest along the Copalis River, WA - killed 1700
Subsided marsh along the Niawiakum River, with tsunami-deposited sand.
What’s going on? Between earthquakes, shortening due to convergence causes uplift along the coast. The earthquake causes the abrupt subsidence of that uplift and stretching causes uplift closer to the fault.
We know a “big” earthquake occurred in the past, but how big an earthquake was this? The history of the PNW is short...
FOREIGN WAVES

...but the history of Japan is long.

Actual translation: Better fortune

1960 Chile
1837 Chile
1751 Chile
1730 Chile
1700?
1687 Peru
1586 Peru
1 hour after earthquake
14 hours

This demonstrated that the earthquake that generated the tsunami ruptured the entire subduction zone, requiring a magnitude of about 9
The USGS takes all of these potential sources and combines them into a probabilistic map of the expected level of ground shaking that is expected during the life of a building.
Simplified 2014 Hazard Map
2% probability of exceedance in 50 years of peak ground acceleration
GROUND RESPONSE: LIQUEFACTION
GROUND RESPONSE: SEISMIC SITE CLASS
Regardless of the type of earthquake, liquefaction susceptibility and ground shaking amplification maps can help assess local hazard and vulnerability. These need to be used in conjunction with the National Seismic Hazard map.
The Washington State Geologic Information Portal

The Portal's interactive map themes can be laid over a geographic base map with roads, towns, etc. Access the Geologic Information Portal at http://www.dnr.wa.gov/geologyportal.

www.dnr.wa.gov/geologyportal
• The interactive map application allows you to choose which layers to overlay.
• The application currently has different map themes, each of which can be accessed through the mapping application itself.
We have developed a seismic scenario catalog that allows every part of the state to investigate the scenario that is likely to be its most damaging.
For your area, this is most likely to be a magnitude 9 earthquake on the Cascadia subduction zone.
You can look at the Hazus estimates for likely damage to any other infrastructure element in the Hazus inventory.
Recently, the Washington Seismic Safety Committee completed a long-range plan to improve our ability to recover from and thrive after an earthquake of statewide significance.
And we assess geologic hazards and assist communities with hazard mitigation

- Earthquakes
- Tsunamis
- Landslides

And I saw my reflection in the snow covered hills
Till the landslide brought me down
-Fleetwood Mac
The landslides responsible for most significant damage in Washington are generally either:

- Slow moving, deep-seated (bedrock) landslides
- Rapid and shallow (soil/colluvium) landslides
WHAT’S SO IMPORTANT ABOUT LANDSLIDES?

• Landslides are the most poorly understood geologic hazard
  • People are surprised by landslides
• Internationally, between 2004-2010, 2620 fatal landslides killed a total of 32,322 people (Petley, 2012)
  • Excludes seismically-induced landslides
• US doesn’t keep statistics on landslides
  • In Washington, the average annual loss from landslides is >>$20 million
• Landslide damage is particularly costly to local government

• All geologic hazards can be insured...
  • Except landslides/earth movement
  • Litigation is often the only recourse left to those with landslide-damaged property
LANDSLIDE TRIGGERS

- Deep-seated
  - Tend to have a delayed response to climatic events
  - Generally triggered by the accumulation of rainfall over weeks or years
- Shallow landslides
  - Tend to respond quickly to climactic events
  - Occur during large storms and may accompany major floods
- Either can be triggered by earthquakes
• Kumamoto earthquake, Japan
• April 16, 2016
• M7.0, 6 mile depth
• >400 aftershocks
• “numerous” landslides
SIGNIFICANT LANDSLIDE EVENTS

- Storm-related, shallow-landslide events
- Named deep-seated landslides
  - Aldercrest-Banyan, Carlyon Beach, Rock Creek, Ledgewood, Hazel, SR530 “Oso”, Nile, Sunset Falls, etc.
PERKINS LANE LANDSLIDE, 1997

Reactivated deep-seated landslide in the Magnolia District of Seattle claimed five houses.
Tragedy struck on January 19, 1997 when a shallow landslide crushed the Herren home, killing all four family members.
Aldercrest-Banyan landslide, 1998

Two years of above-average rainfall reactivated a deep-seated landslide and destroyed 135 homes. FEMA buyouts at $0.30 to the dollar
Carlyon Beach Landslide

February 1999, after 3 years of above-average rainfall, movement began on a dormant landslide, forcing 36 families from their homes. No buyouts.
Coastal Zone Atlas, Carlyon Beach

Slope stability map of the Carlyon Beach area, Thurston County (near Olympia), 1980

Carlyon development
Mapped as intermediate to unstable terrain
December 2007, following an intense rain-on-snow event several thousand landslides occurred throughout SW Washington
October 11, 2009 a portion of the Stanford Pasture Landslide reactivated, destroying ¼ mile of SR410, rerouting the Naches River, and forever changing the Nile Valley community.
These houses in Whatcom Co. were damaged by debris flows.

Over 1000 landslides were triggered in January 2009 due to a Pineapple Express.
March 2013 landslide destroyed one home, two others red-tagged, and cut off access to 13 more homes.
Minor movement continues today, rendering it unsafe to stabilize the temporary road providing limited access to the affected homeowners.
And SR530 “Oso” landslide on March 22, 2014
What tools are available for planners to mitigate landslide hazards? Unfortunately, the availability and quality are uneven.
Puget Sound coastal bluff landslide hazard maps for Thurston Co.
The Washington State Geologic Information Portal

The Portal's interactive map themes can be laid over a geographic base map with roads, towns, etc. Access the Geologic Information Portal at http://www.dnr.wa.gov/geologyportal.

www.dnr.wa.gov/geologyportal
• Landslide hazard mitigation begins with hazard identification
You can, for instance, look at a map of landslides in the state (though it is a work in progress and definitely incomplete)
DNR LANDSLIDE HAZARDS PROGRAM

• Five landslide hazards geologists
• Emphasis is landslide mapping around population, infrastructure, highways
• Inventory, susceptibility, hazard, and vulnerability mapping
AFTERTHOUGHTS...

• Washington is susceptible to every major geologic hazard
• Mitigation of the hazard is one method to reduce your risk
• Avoidance of the hazard is the usually the simplest method to eliminate the risk
• DNR offers a suite of tools that identify geologic hazards and is continually developing new tools and products!
• DNR Division of Geology and Earth Resources (aka: Washington Geological Survey)
  www.dnr.wa.gov/geology

• DNR Washington State Geologic Information Portal
  www.dnr.wa.gov/geologyportal

• Washington Emergency Management Division
  www.emd.wa.gov/index.shtml

• Cascadia Region Earthquake Workgroup
  www.crew.org/

• USGS Landslide Hazards Program
  www.landslides.usgs.gov/