6.0 EARTHQUAKES

Historically, awareness of seismic risk in Oregon has generally been low, among both the public at large and public officials. This low level of awareness reflected the low level of seismic activity in Oregon, at least in recent historical time. However, beginning in the early 1990s, awareness of seismic risk in Oregon has increased significantly. Factors in this increased awareness include the 1993 Scotts Mills earthquake in Clackamas County, the 1990s changes in seismic zones in the Oregon Building Code which increased seismic design levels for new construction in western Oregon and widespread publicity about the occurrence of large magnitude earthquakes on the Cascadia Subduction Zone.

Awareness of seismic risk in Oregon has also increased because of the devastating earthquakes and tsunamis in Indonesia in 2004 and Japan in 2011. The geologic settings for the Indonesia and Japan earthquakes are virtually identical to the Cascadia Subduction Zone.

Before reviewing the levels of seismic hazards and risk in Multnomah County, we first present a brief earthquake “primer” to review earthquake concepts and terms.

6.1 Earthquake Primer

Earthquakes are most often described by their magnitude (M), which is a measure of the total energy released by an earthquake. The most common magnitude is the “moment magnitude” which is calculated by seismologists from the amount of slip (movement) on the fault causing the earthquake and the area of the fault surface which breaks during the earthquake. Moment magnitudes are similar to the Richter magnitude, which was used for many decades but has now been replaced by the moment magnitude.

Moment magnitudes use a numerical scale which ranges from 0 to 9+. The magnitudes for the four largest earthquakes recorded worldwide and selected Oregon earthquakes are shown below in Table 6.1.

Table 6.1
Earthquake Magnitudes: Examples

Earthquake	Magnitude
Largest Earthquakes Worldwide	
1960 Chile	9.5
1964 Prince William Sound, Alaska	9.2
2004 Sumatra, Indonesia	9.1
2011 Japan	9.0
Selected Oregon Earthquakes	
1700 Cascadia Subduction Zone	9.0
1993 Klamath Falls	6.0
1993 Scotts Mills	5.6
2001 Nisqually (Washington)	6.8

In evaluating earthquakes, it is important to recognize that the earthquake magnitude scale is not linear, but rather logarithmic. Each one step increase in magnitude, for example from M7 to M8, corresponds to an increase of about a factor of 30 in the amount of energy released by the earthquake, because of the mathematics of the magnitude scale.

Thus, a M7 earthquake releases about 30 times more energy than a M6, while a M8 releases about 30 times more energy than a M7 and so on. Thus, a great M9 earthquake releases nearly 1,000 times more energy than a large earthquake of M7 and nearly 30,000 times more energy than a M6 earthquake.

The public often assumes that the larger the magnitude of an earthquake, the "worse" the earthquake. Thus, the "big one" is the M9 earthquake and smaller earthquakes such as M6 or M7 are not the "big one". However, this is true only in very general terms. Larger magnitude earthquakes affect larger geographic areas, with much more widespread damage than smaller magnitude earthquakes. However, for a given site, the magnitude of an earthquake is <u>not</u> a good measure of the severity of the earthquake at that site.

Rather, for any earthquake, the intensity of ground shaking at a given site depends on four main factors:

- Earthquake magnitude,
- Earthquake epicenter, which is the location on the earth's surface directly above the point of origin of an earthquake,
- Earthquake depth, and
- Soil or rock conditions at the site, which may amplify or deamplify earthquake ground motions.

An earthquake will generally produce the strongest ground motions near the earthquake with the intensity of ground motions diminishing with increasing distance from the epicenter.

For Multnomah County, a great magnitude 9.0 earthquake on the Cascadia Subduction Zone would result in widespread damage. However, this earthquake is not the worst case scenario for Multnomah County. Rather, a smaller, nearby earthquake such as a M7.1 on the Portland Hills Fault would result in higher levels of ground shaking and damage than a M9.0 Cascadia Subduction Zone earthquake.

In general, earthquakes at or below M5 are not likely to cause significant damage, even locally very near the epicenter. Earthquakes between about M5 and M6 are likely to cause relatively minor to moderate damage near the epicenter. Earthquakes of about M6.5 or greater (e.g., the 2001 Nisqually earthquake in Washington) can cause major damage, with damage usually concentrated fairly near the epicenter. Larger earthquakes of M7+ cause damage over increasingly wider geographic areas with the potential for very high levels of damage near the epicenter. Great earthquakes with M8+ can cause major damage over wide geographic areas. A M9 earthquake on the Cascadia Subduction Zone could affect the entire Pacific Northwest from British Columbia, through Washington and Oregon, and as far south as Northern California.

The intensity of ground shaking varies not only as a function of M and distance but also depends on soil types. Soft soils may amplify ground motions and increase the level of damage. Thus, for any given earthquake there will be contours of varying intensity of ground shaking. The intensity will generally decrease with distance from the earthquake, but often in an irregular pattern, reflecting soil conditions (amplification) and possible directionality in the dispersion of earthquake energy.

There are many measures of the severity or intensity of earthquake ground motions. A very old, but commonly used, scale is the Modified Mercalli Intensity scale (MMI), which is a descriptive, qualitative scale that relates severity of ground motions to types of damage experienced. MMIs range from I to XII.

More useful, modern intensity scales use terms that can be physically measured with seismometers, such as the acceleration, velocity, or displacement (movement) of the ground. The most common physical measure, and the one used in this mitigation plan, is Peak Ground Acceleration or PGA. PGA is a measure of the intensity of shaking, relative to the acceleration of gravity (g). For example, 1.0 g PGA in an earthquake (an extremely strong ground motion) means that objects accelerate sideways at the same rate as if they had been dropped from the ceiling. 10% g PGA means that the ground acceleration is 10% that of gravity and so on.

Damage levels experienced in an earthquake vary with the intensity of ground shaking and with the seismic capacity of structures. Ground motions of only 1 or 2% g are widely felt by people; hanging plants and lamps swing strongly, but damage levels, if any, are usually very low. Ground motions below about 10% g usually cause only slight damage. Ground motions between about 10% g and 30% g may cause minor to moderate damage in well-designed buildings, with higher levels of damage in poorly designed buildings. At this level of ground shaking, only unusually poor buildings would be subject to potential collapse. Ground motions above about 30% g may cause significant damage in well-designed buildings and very high levels of damage (including collapse) in poorly designed buildings. Ground motions above about 50% g may cause significant damage in most buildings, even those designed to resist seismic forces.

6.2 Oregon Earthquakes

Earthquakes in Western Oregon, and throughout the world, occur predominantly because of plate tectonics - the relative movement of plates of oceanic and continental rocks that make up the rocky surface of the earth. Earthquakes can also occur because of volcanic activity and other geologic processes.

The Cascadia Subduction Zone is a geologically complex area off the Pacific Northwest coast from Northern California to British Columbia. In simple terms, several pieces of oceanic crust (the Juan de Fuca Plate, Gorda Plate and other smaller pieces) are being subducted (pushed under) the crust of North America. This subduction process is responsible for most of the earthquakes in the Pacific Northwest as well as for creating the volcanoes in the Cascades. Figure 6.1 shows the geologic (plate-tectonic) setting of the Cascadia Subduction Zone.

There are three source regions for earthquakes that can affect the Multnomah County area:

1) "interface" earthquakes on the boundary between the subducting oceanic plates and the North American plate,

2) "intraplate" earthquakes within the subducting oceanic plates, and

3) "crustal" earthquakes within the North American Plate.

The geographic and geometric relationships of these earthquake source zones are shown in Figures 6.2 and 6.3.

The "interface" earthquakes on the Cascadia Subduction Zone may have magnitudes of up to 9.0 or perhaps 9.2, with probable recurrence intervals of 500 to 800 years. The last major earthquake in this source region occurred in the year 1700, based on current interpretations of Japanese tsunami records. Such earthquakes are the great Cascadia Subduction Zone earthquake events that have received attention in the popular press. These earthquakes occur about 20 to 60 kilometers (12 to 40 miles) offshore from the Pacific Ocean coastline. Ground shaking from such earthquakes would be very strong near the coast and moderately strong ground shaking would be felt throughout Multnomah County, with the level of shaking decreasing towards eastern Multnomah County.

Figure 6.1
Cascadia Subduction Zone
(Cascadia Region Earthquake Working Group (2005): Cascadia Subduction Zone Earthquakes: A Magnitude 9.0 Earthquake Scenario)

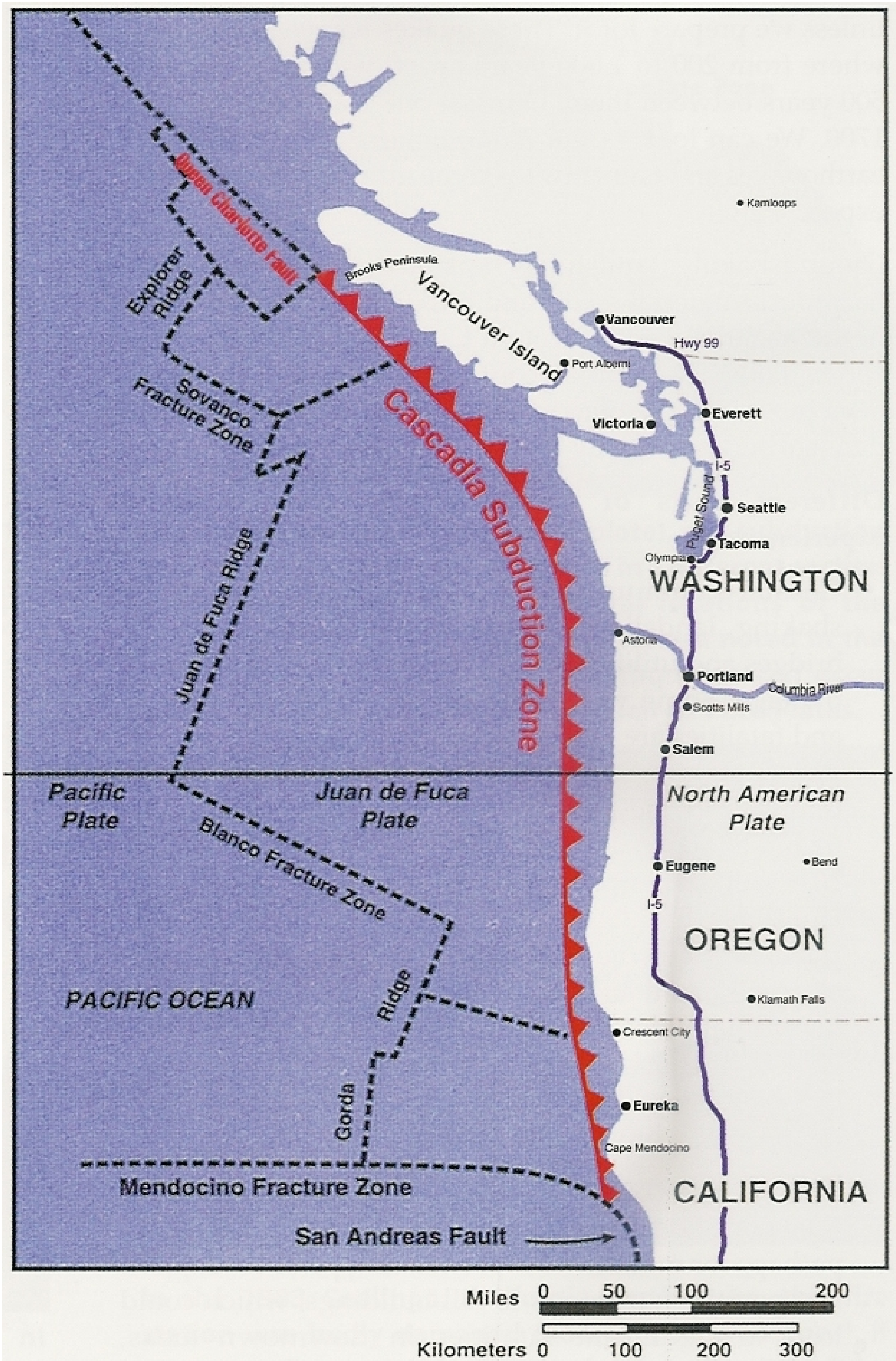
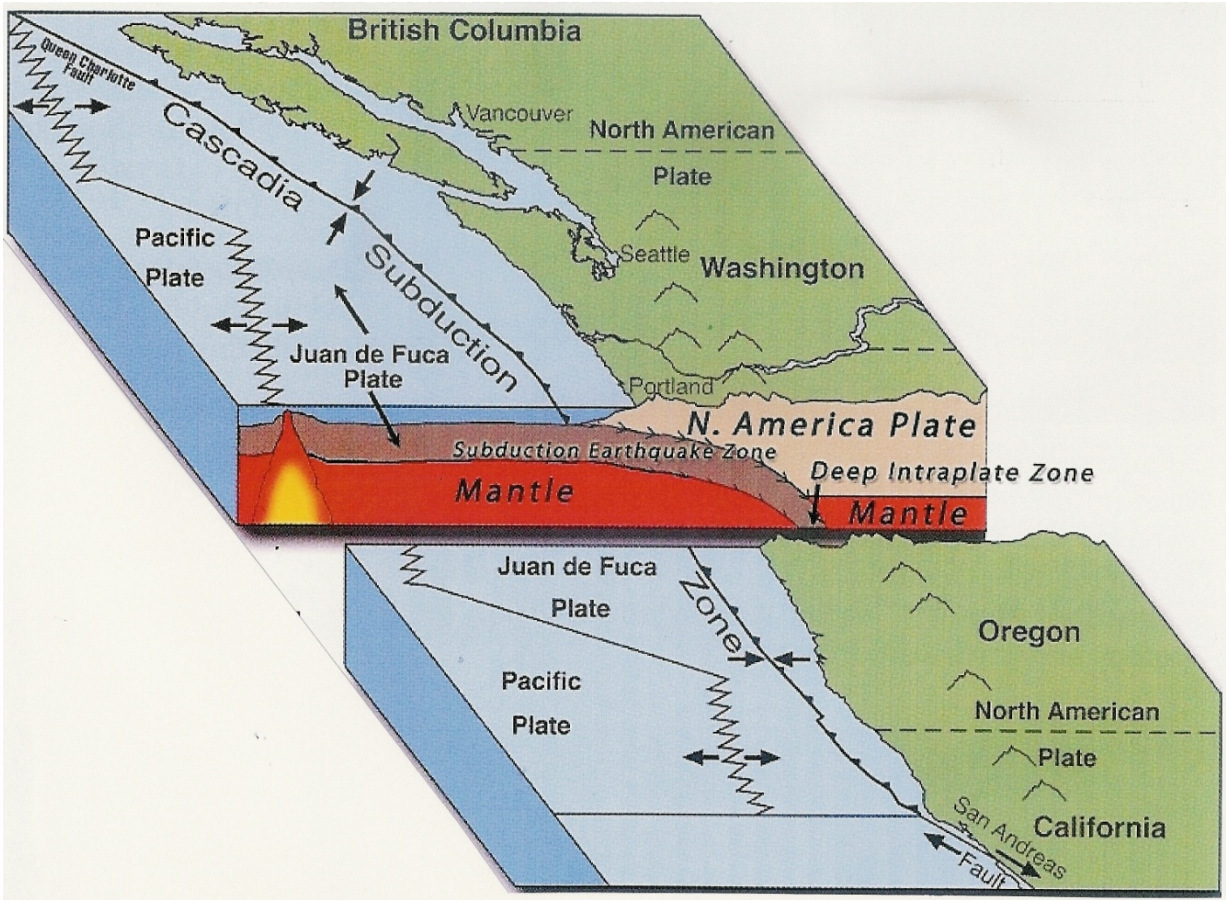


Figure 6.2
Cascadia Subduction Zone: Cross Section
(Cascadia Region Earthquake Working Group (2005): Cascadia Subduction Zone Earthquakes: A Magnitude 9.0 Earthquake Scenario)

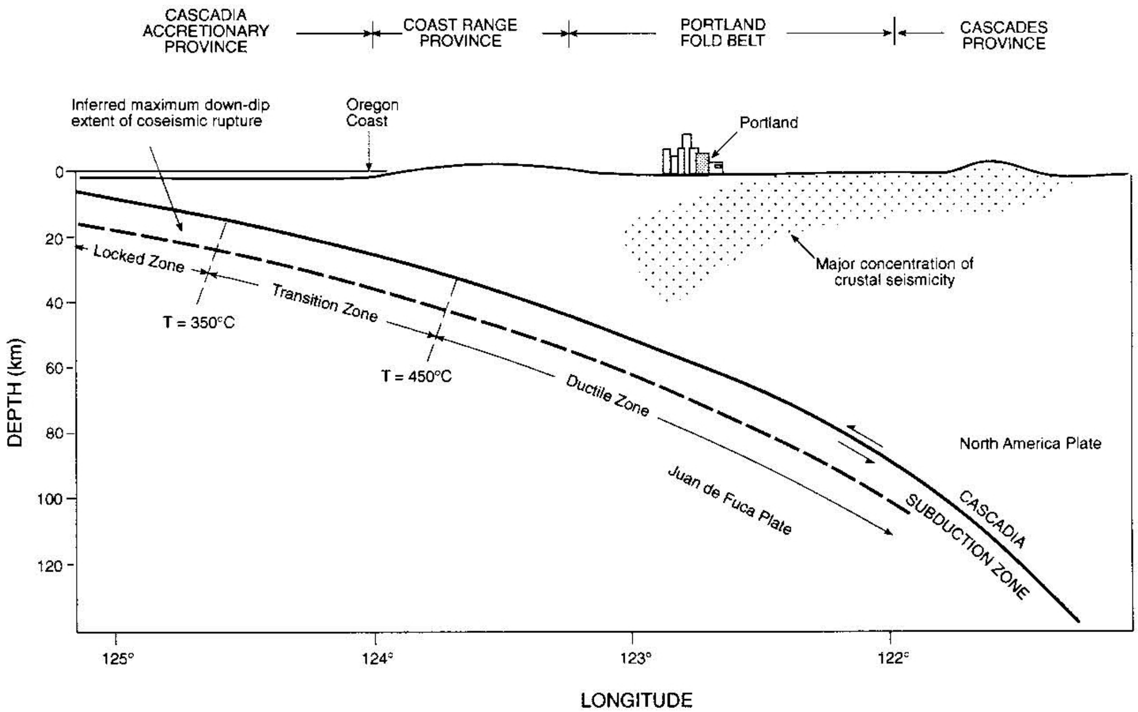


Interface earthquakes occur on the boundary between the subducting plate and the North American plate.

The "intraplate" earthquakes occur within the subducting oceanic plate. These earthquakes may have magnitudes up to about 7.5, with probable recurrence intervals of about 500 to 1000 years (recurrence intervals are poorly determined by current geologic data). These earthquakes occur quite deep in the earth, about 30 or 40 kilometers (18 to 25 miles) below the surface with epicenters that would likely range from near the Pacific Ocean coast to about 50 kilometers (30 miles) inland. Thus, epicenters from these types of earthquakes could be located west of Portland. Ground shaking from such earthquakes would be very strong near the epicenter and strong ground shaking would be felt throughout all of Multnomah County, with the level of shaking decreasing towards eastern Multnomah County.

Crustal earthquakes occur within the North American plate, above the subducting plate, as shown in Figure 6.3 on the following page.

Figure 6.3
Cascadia Subduction Zone: Cross Section (Portland Area) – Showing Crustal Earthquake Locations
(Wong et al. (1993), Strong Ground Shaking in the Portland, Oregon, Metropolitan Area, Oregon Geology, Volume 55, Number 6)



"Crustal" earthquakes within the North American plate are possible on faults mapped as active or potentially active as well as on unmapped (unknown) faults. The relationship between the subducting plate and crustal earthquakes in the greater Portland area is shown above in Figure 6.3.

Historical earthquake epicenters in northwest Oregon and portions of Washington are shown below in Figure 6.4. There have been dozens of mostly small earthquakes recorded in or near Multnomah County. A summary of the more significant historical earthquakes in Oregon is provided in Table 6.2.

Figure 6.4
Earthquake Epicenters in Northwest Oregon from 1841 to 2002

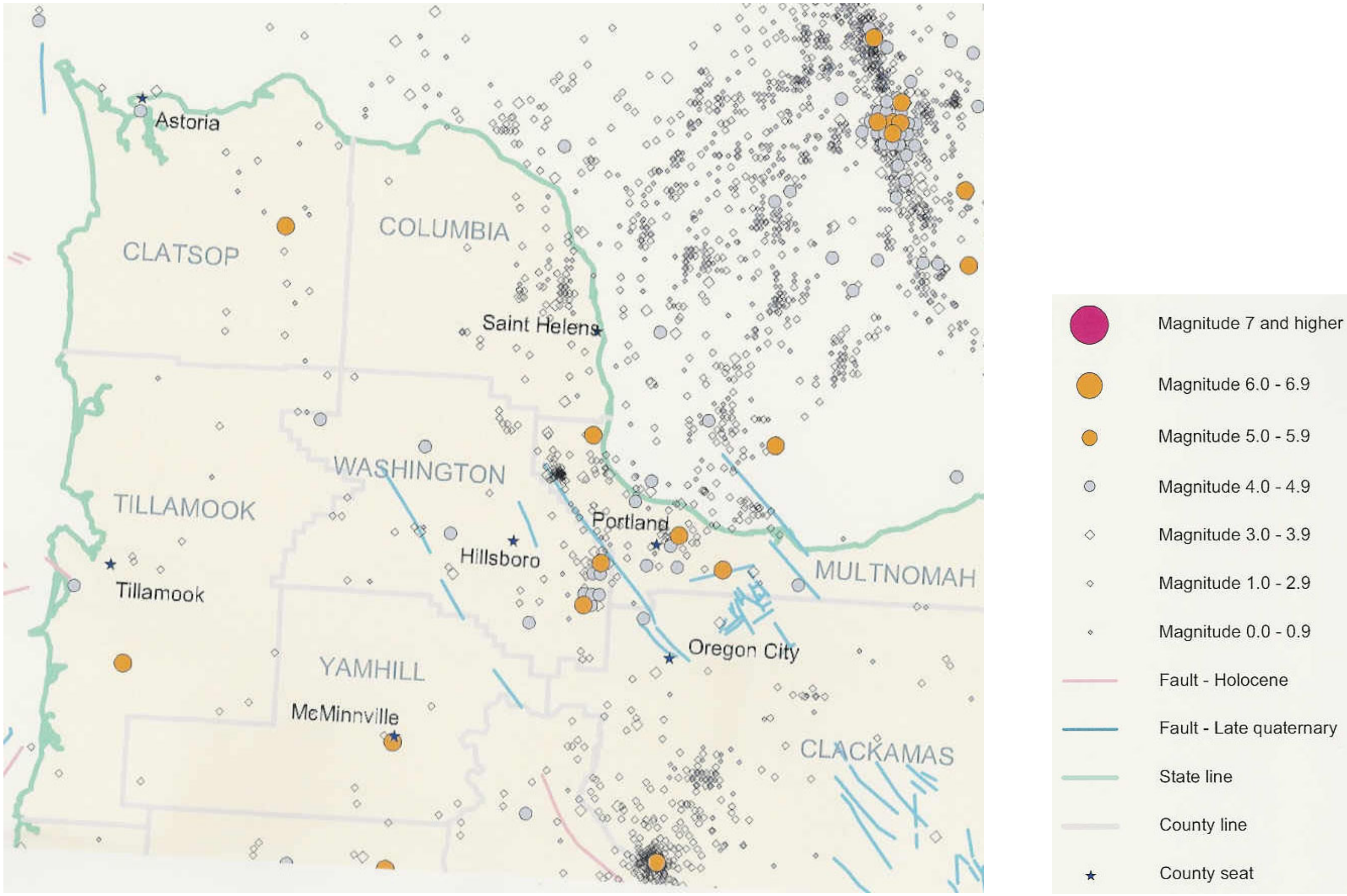


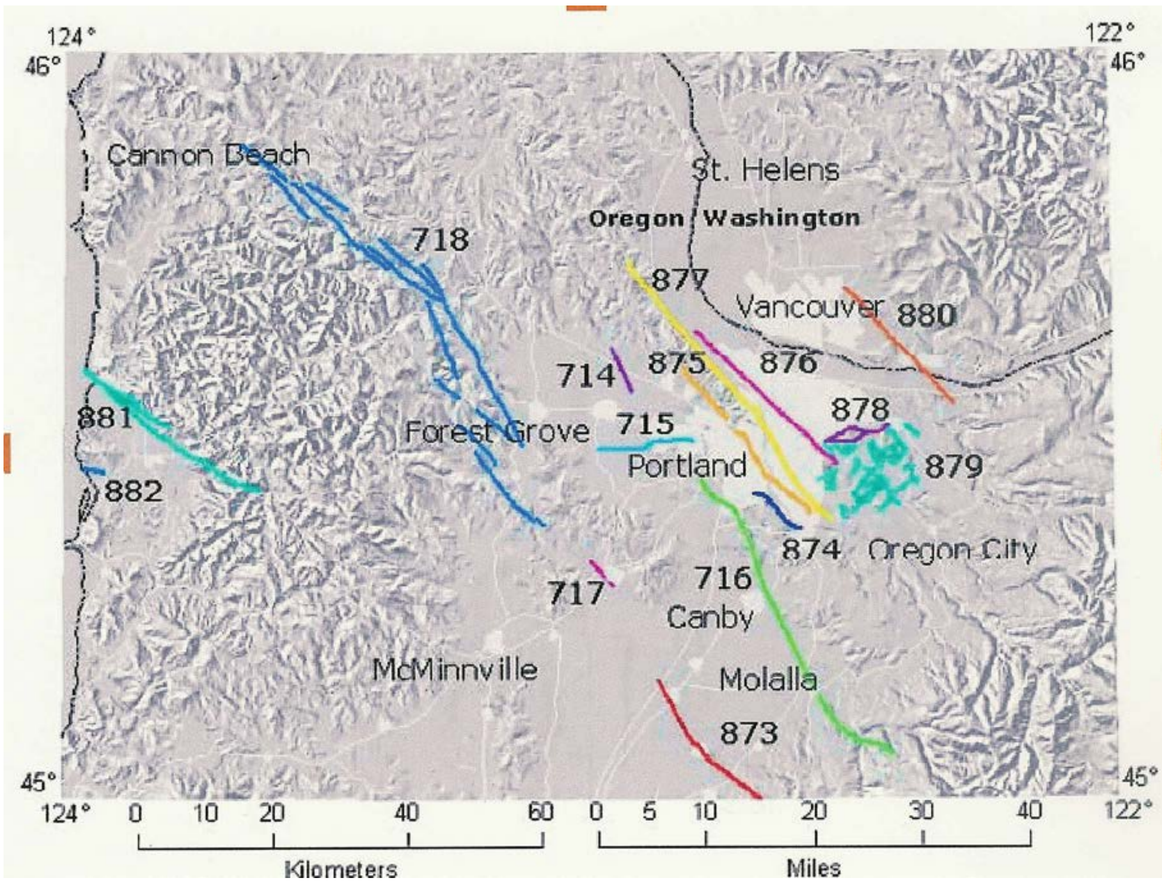
Table 6.2
Significant Historical Earthquakes Affecting Northwest Oregon

DATE	LOCATION	SIZE (M)	COMMENTS
Approximate Years 1400 BCE*, 1050 BCE, 600 BCE, 400, 750, 900	Offshore, Cascadia Subduction Zone (CSZ)	Probably 8.0 –9.0	Based on studies of earthquake and tsunami at Willapa Bay, Washington. These are the mid-points of the age ranges for these six events. * BCE: Before the Common Era
January, 1700	CSZ	Approx. 9.0	Generated a tsunami that struck Oregon, Washington, and Japan; destroyed Native American villages along the coast
October, 1877	Portland area	5.2	Two events were reported that day. The estimated felt area was approximately 41,000 square kilometers. Chimney damage reported
February, 1892	Portland area	5.0	No major damage occurred
December, 1941	Portland area	4.5	Felt by most Portland residents. Shattered windows and cracked plaster in Hillsboro and Sherwood.
April, 1949	Olympia, WA	7.1	Significant damage in Washington. Minor damage in NW Oregon
December, 1953	Portland area	4.5	Cracked plaster and caused objects to fall in Portland.
November, 1961	Portland area	5.0	Principal damage from cracked plaster
November, 1962	Portland area	5.5	Shaking lasted up to 30 seconds; chimneys cracked; windows broken; furniture moved
December, 1963	Portland area	4.5	Books and pictures fell in Plains
March 25, 1993	Scotts Mills	5.6	On Mt. Angel-Gales Creek fault. $30 million damage (including Oregon Capitol Building in Salem) (FEMA-985-DR-OR)
February, 2001	Nisqually, WA	6.8	Felt in the region, no damage reported

Source: Wong, Ivan and Jacqueline Bolt, November 1995, A Look Back at Oregon's Earthquake History, 1841-1994, *Oregon Geology* pp. 125-139.

Identified crustal earthquake faults in the vicinity of Multnomah County are shown in Figure 6.5.

Figure 6.5
USGS Mapped Crustal Faults Near Multnomah County
(USGS Earthquake Hazards Program – Quaternary Fault and Fold Database)



The faults numbered in Figure 6.5 above, include the following faults relatively close to Multnomah County:

- Oatfield Fault (875)
- East Bank Fault (876)
- Portland Hills fault (877),
- Grant Butte Fault (878),
- Damascas – Tickle Creek Fault Zone (879), and
- Lacamas Lake Fault (880).

The above faults are all listed as “Class A” faults by the USGS, which means that there is solid geological evidence for fault movements during the Quaternary geologic period – that is, within the past 1.6 million years. The estimated slip rate on all of these faults is less than 0.2 mm per year. Return periods for earthquakes on these faults are not well known, but are probably at least several thousand years and perhaps 10,000 years or more.

Based on the historical seismicity in Western Oregon and on analogies to other geologically similar areas, small to moderate earthquakes up to M5 or M5.5 are possible almost anyplace in Multnomah County. Such earthquakes would be mostly smaller than the 1993 Scotts Mills earthquake (M5.6). There is also a possibility of larger crustal earthquakes in the M6+ range, albeit, in the absence of known, mapped faults, the probability of such events is likely to be low.

6.3 Seismic Hazards for Multnomah County

The current scientific understanding of earthquakes is incapable of predicting exactly where and when the next earthquake will occur. However, the long term probability of earthquakes is well enough understood to make useful estimates of the probability of various levels of earthquake ground motions at a given location.

The current consensus estimates for earthquake hazards in the United States are incorporated into the 2008 USGS National Seismic Hazard Maps. These maps are the basis of building code design requirements for new construction. For Multnomah County, the level of seismic hazards varies significantly with location within the county, generally decreasing towards the east. 2008 USGS seismic hazard data for three locations within the county are shown below in Table 6.3.

Table 6.3
2008 USGS Seismic Hazard Data for Multnomah County
(Approximate Values for Firm Soil Sites)

Probabilistic Ground Motion	PGA (% of g)		
Location	Portland[1]	Troutdale[2]	Bonneville[3]
Longitude	122.857	122.386	121.947
10% in 50 years	30.3%	28.0%	20.7%
2/3rds of 2% in 50 years	32.2%	34.8%	23.0%
2% in 50 years	48.3%	42.7%	34.5%

[1] Near Skyline Elementary School

[2] Near Troutdale Elementary School

[3] Near Bonneville Dam

The ground shaking values in Table 6.3 are expressed as a percentage of g, the acceleration of gravity. For example, the 10% in 50 year PGA value means that over the next 50 years there is a 10% probability of this level of ground shaking or higher. Any of these levels of ground shaking are high enough to cause significant to substantial damage in vulnerable buildings. The 2/3rds of the 2% in 50 year ground motion is the level of ground motion required for the design of new buildings in the International Building Code.

The 2008 USGS seismic hazard data for the area are also shown graphically in Figure 6.6, which shows the level of seismic hazard generally decreasing eastward. The values shown on these maps are lower than those shown above in Table 6.2 because the map contours are for rock sites. Ground motions on soil sites will generally be significantly higher than for rock sites.

Figure 6.6a
USGS Seismic Hazard Map
PGA value (%g) with a 10% Chance of Exceedance in 50 years

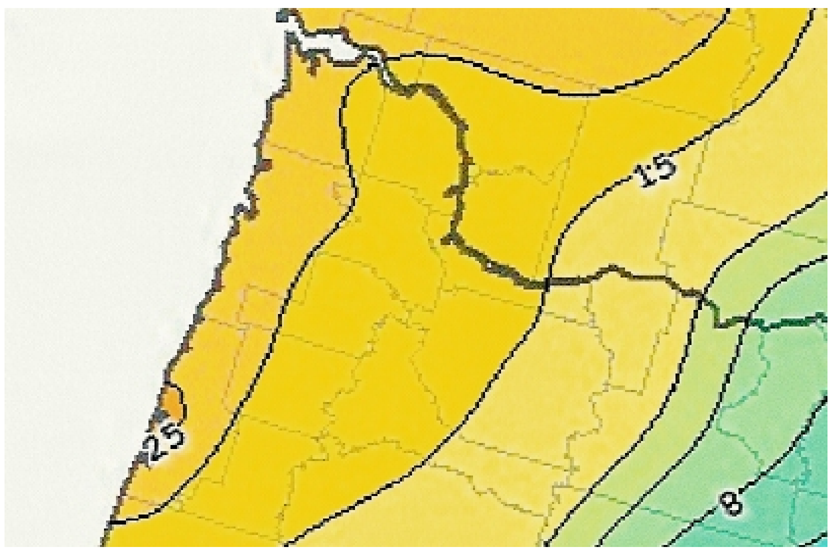
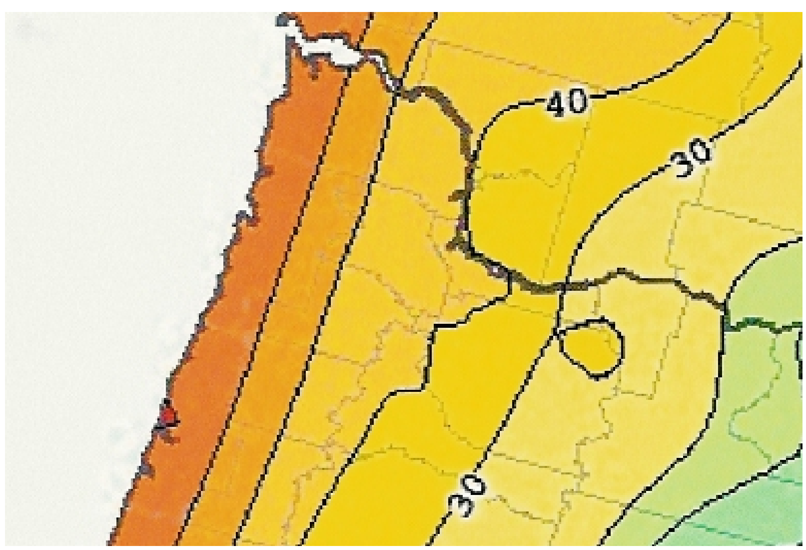


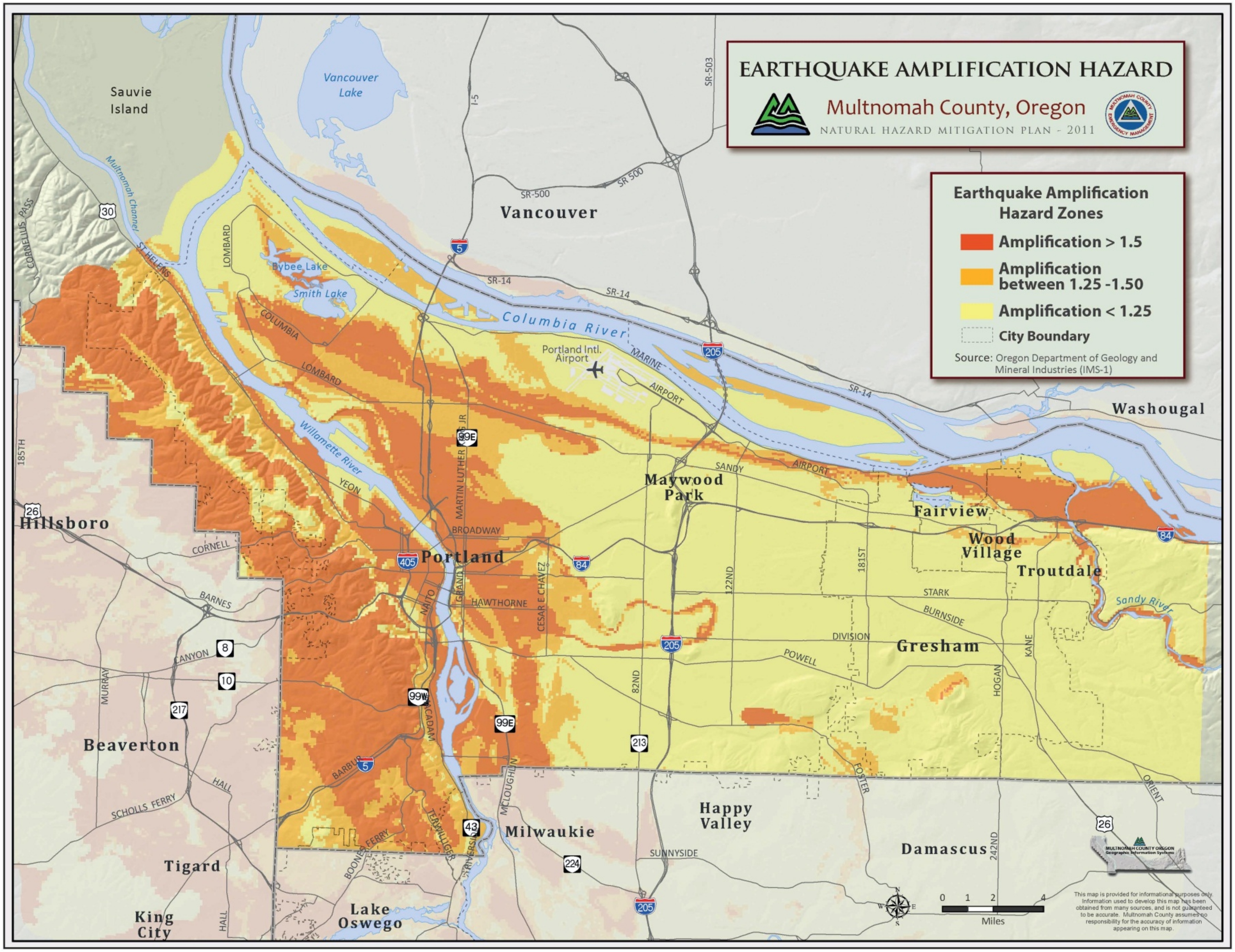
Figure 6.6b
USGS Seismic Hazard Map
PGA value (%g) with a 2% Chance of Exceedance in 50 years



The hazard maps shown above are probabilistic earthquake ground motions for rock sites. Earthquake ground motions may be significantly higher for soil sites, which may amplify ground motions. Figure 6.7 on the following page shows areas within Multnomah County subject to amplification of ground motions. Buildings and infrastructure in these areas will generally suffer more damage in any given earthquake than similar buildings and infrastructure located in areas not subject to amplification of earthquake ground motions.

Areas shown in dark red-orange have the highest levels of amplification, with the light orange areas having less amplification and the yellow areas having minor or no amplification of earthquake ground motions.

Figure 6.7
Areas Subject to Amplification of Earthquake Ground Motions



The level of seismic hazard for locations within Multnomah County can also be expressed as a "seismic hazard curve." A seismic hazard curve shows the annual probability of exceeding the full range of possible earthquake ground motions.

For Multnomah County, the example seismic hazard curve in Figure 6.8 below shows that there is about a 1% (0.01) annual chance of ground motions of 10% g or higher, and about a 0.2% (0.002) annual chance of ground motions of about 30% g or higher. This example is for Troutdale: as discussed previously, earthquake ground motions within Multnomah County will generally be higher to the west and lower to the east.

Figure 6.8
Multnomah County: Example Seismic Hazard Curve

Seismic Hazard Data by Latitude - Longitude

OREGON

Version 2.0 July 02, 2009

Project Name:	Troutdale Elementary School
Address:	648 SE Harlow
City, State, Zip:	Troutdale, OR
Date:	April 1, 2011
User Name:	KA. Goettel

Enter Site Latitude-Longitude in degrees-minutes-seconds OR in decimal degrees

	Degrees	Minutes	Seconds	Decimal
Latitude:	45.53632			45.536320
Longitude:	122.38599			122.385990

Enter Project Site Soil/Rock Type: D **Soil/Rock entries must match letter codes exactly.**

Soil Rock Choices:

Rock	AB
Very Dense Soil	C
Firm Soil	D
Soft Soil	E
Very Soft Soil	F

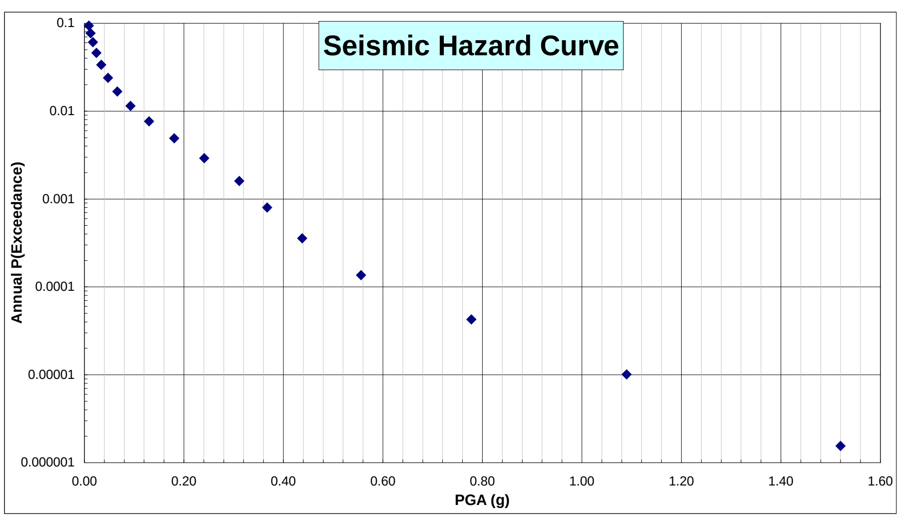
Soil/Rock types and definitions as per IBC 2003 (2006).

If soil/rock unknown, use Firm Soil D as default.

Site specific geotechnical analysis encouraged for Soil F

Site Hazard Data

PGA	Annual P
0.008800	9.404E-02
0.012320	7.725E-02
0.017248	6.080E-02
0.024112	4.605E-02
0.033792	3.364E-02
0.047344	2.395E-02
0.066176	1.676E-02
0.092752	1.148E-02
0.129888	7.659E-03
0.180600	4.918E-03
0.240845	2.922E-03
0.311280	1.609E-03
0.367382	8.031E-04
0.437891	3.571E-04
0.556000	1.359E-04
0.778000	4.266E-05
1.090000	1.012E-05
1.520000	1.549E-06
2.130000	1.551E-07



2/3rds of 2% in 50 year PGA value: 0.285

Reference PGA values:	g	% g
10% in 50 years:	0.280	28.0%
5% in 50 years:	0.348	34.8%
2% in 50 years:	0.427	42.7%

PGA values are shown as fractions of g, the acceleration of gravity. Thus, for example, 0.500 means 0.5 g or 50% of g.

6.4 Other Aspects of Seismic Hazards in Multnomah County

Much of the damage in earthquakes occurs from ground shaking which affects buildings and infrastructure. However, there are several other consequences of earthquakes that can result in very high levels of damage in some locations, including: liquefaction, settlement, lateral spreading, landslides, dam failures and tsunamis.

6.4.1 Liquefaction, Settlement and Lateral Spreading

Liquefaction is a process where loose, wet sediments lose strength during an earthquake and behave similarly to a liquid. Once a soil liquefies, it will tend to settle vertically and/or spread laterally. With even very slight slopes, liquefied soils tend to move sideways downhill (lateral spreading). Settling or lateral spreading can cause major damage to buildings and to buried infrastructure such as pipes and cables.

Figure 6.9 shows areas with Multnomah County with high liquefaction potential. Even in areas mapped as high liquefaction potential, liquefaction does not occur in all such areas or in all earthquakes. However, in larger earthquakes with strong ground shaking and long duration shaking, liquefaction is likely in many of the high liquefaction potential areas. Settlements of a few inches or more and lateral spreads of a few inches to several feet are possible. Even a few inches of settlement or lateral spreading may cause significant damage to affected buildings or infrastructure.

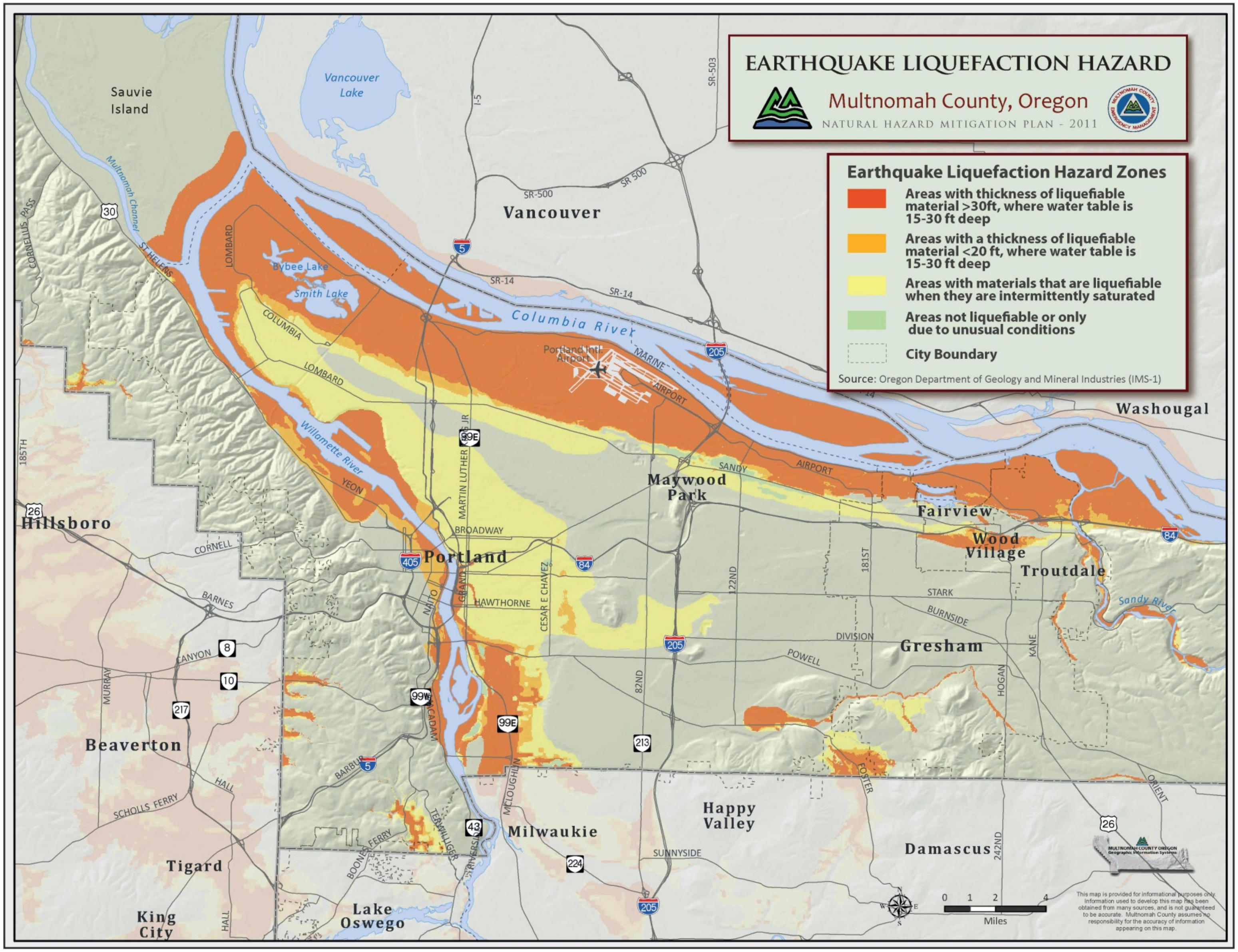
In Figure 6.9, the darkest red-orange areas have very high liquefaction potential, while the light orange and yellow areas have high and moderate liquefaction potential, respectively. The green areas have low or nil liquefaction potential.

The very high and high liquefaction areas include broad areas along the Columbia River, significant areas along both the Willamette and Sandy Rivers and smaller areas along several streams. These areas include Portland International Airport, significant portions of the cities of Portland, Troutdale and Wood Village. Within unincorporated Multnomah County, areas at risk of liquefaction include parts of Sauvie Island, areas along the Columbia River east of Troutdale and areas along the Sandy River and several streams.

6.4.2 Landslides

Earthquakes can also induce landslides, especially if an earthquake occurs during the rainy season and soils are saturated with water. The areas prone to earthquake-induced landslides are largely the same as those areas prone to landslides in general. As with all landslides, areas of steep slopes with loose rock or soils are most prone to earthquake-induced landslides**.** See Chapter 8 Landslides for a more detailed discussion of landslides.

Figure 6.9
Areas with High Liquefaction Potential



6.4.3 Dam Failures

Earthquakes can also cause dam failures in several ways. The most common mode of earthquake-induced dam failure is slumping or settlement of earthfill dams where the fill has not been properly compacted. If the slumping occurs when the dam is full, then overtopping of the dam, with rapid erosion leading to dam failure is possible. Dam failure is also possible if strong ground motions heavily damage concrete dams. Earthquake induced landslides into reservoirs have also caused dam failures.

Earthquake-induced dam failures are addressed in more detail in Chapter 6 Floods, which includes a section on dam failures that could affect Multnomah County.

6.4.4 Tsunamis and Seiches

Tsunamis, which are sometimes incorrectly referred to as "tidal waves," result from earthquakes which cause a sudden rise or fall of part of the ocean floor. Such movements may produce tsunami waves, which have nothing to do with the ordinary ocean tides.

In the open ocean, far from land, in deep water, tsunami waves may be only a few inches high and thus be virtually undetectable, except by special monitoring instruments. These waves travel across the ocean at speeds of several hundred miles per hour. When such waves reach shallow water near the coastline, they slow down and can gain great heights.

Tsunamis affecting the Oregon coast can be produced from very distant earthquakes off the coast of Alaska or elsewhere in the Pacific Ocean. For such tsunamis, the warning time for the Oregon coast would be at least several hours. However, interface earthquakes on the Cascadia Subduction Zone can also produce tsunamis. For such earthquakes the warning times would be very short, only a few minutes. Because of this extremely short warning time, emergency planning and public education are essential before such an event occurs.

Multnomah County, while not located on the coast, would not be directly affected by tsunamis on the Oregon Coast. A tsunami surge could extend up the Columbia River, perhaps as far inland as Multnomah County. However, because of the considerable distance from the coast, the effects would be very minimal or nil. That is, the increase in water level would be immeasurable or perhaps just a few inches, with no damage.

A similar earthquake phenomenon is "seiches" which are waves from sloshing of inland bodies of waters such as lakes, reservoirs, or rivers. Seiches may result in damages to docks and other shorefront structures and to dams. For Multnomah County, seiches could also cause localized damages to reservoirs or tanks.

6.5 Scenario Earthquake Loss Estimates for Multnomah County

6.5.1 Summary Results

There are a wide range of possible earthquakes that may affect Multnomah County, including not only Cascadia Subduction Zone earthquakes and crustal earthquakes on known faults but also crustal earthquakes on as yet unknown faults. The USGS national seismic hazard maps (cf. Figure 6.6) include contributions from unknown faults, which are statistically possible anywhere in Multnomah County and vicinity. Most likely earthquakes on as yet unknown faults would be relative small, most likely with magnitudes less than M6. However, earthquakes as large as M6 or M6.5 on unknown faults are also possible.

The range of possible earthquakes affecting Multnomah County was explored using FEMA's HAZUS loss estimation software: HAZUS-MH-MR5, Version 10.0.0. HAZUS loss estimates for specified scenario earthquakes are intended for regional planning purposes and provide general indications of the extent of damages, economic losses and casualties.

For Multnomah County, we evaluate four scenario earthquakes:

- M9.0 earthquake on the Cascadia Subduction Zone,
- M7.05 earthquake on the Portland Hills Fault,
- M6.0 earthquake on the Portland Hills Fault, and
- M6.8 earthquake on the Mount Angel Fault.

The HAZUS results presented below are based on the "level one" data built into the HAZUS software. The national inventory data used by HAZUS are estimates for each census tract. In some cases, these data may be incomplete or inaccurate. The results should not be interpreted as indicating the exact damages, losses or casualties for each scenario earthquake – the exact levels of damages, losses and casualties cannot be predicted before an earthquake occurs. Rather, the results illustrate the relative severity of consequences for Multnomah County for each of the four earthquake scenarios and the approximate levels of damages and casualties expected.

Summary HAZUS loss estimates for the four scenario earthquakes listed above are given in Table 6.4. The Cascadia M9.0 HAZUS run was made using the USGS shakemap ground motions for Cascadia M9.0 earthquake. The other scenarios were run using the UGSS-based earthquake hazard data and ground motion attenuation relationships in HAZUS.

Table 6.4
Summary Impacts for Multnomah County
Four Scenario Earthquakes

Category	Cascadia M9.0	Portland Hills M7.05	Portland Hills M6.0	Mount Angel M6.8
Damages and Losses				
Number of Damaged Buildings - Total	203,516	456,165	180,035	65,711
Number of Damaged Buildings - Slight Damage	126,601	198,628	139,249	57,867
Number of Damaged Buildings - Moderate Damage	54,450	149,973	33,640	7,140
Number of Damaged Buildings - Extensive Damage	20,714	62,256	6,338	660
Number of Damaged Buildings - Complete Damage	1,751	45,308	808	44
Building-Related Damages and Economic Losses	$7,979,000,000	$47,345,000,000	$6,667,000,000	$2,274,000,000
Transportation Systems Damages	$597,000,000	$4,064,000,000	$816,000,000	$180,600,000
Utility Systems Damages[1]	$23,000,000	$84,000,000	$18,290,000	$9,680,000
Total Damages and Losses	$8,599,000,000	$51,493,000,000	$7,501,290,000	$2,464,280,000
Casualties				
Injuries (2 pm)	3,448	45,414	2,612	881
Injuries (2 am)	1,104	12,074	691	418
Deaths (2 pm)	91	3,417	100	24
Deaths (2 am)	15	626	12	7

[1] Utility systems damages are for potable water only.

The estimated deaths and injuries are significantly lower during nighttime hours than during daytime hours, because more people are in wood frame residential buildings, which generally perform reasonably well in earthquakes.

The damage, loss and casualties estimates differ substantially for the four scenario earthquakes because of the combination of two factors:

- Magnitude of the earthquake, and
- Location of the earthquake vis-à-vis Multnomah County.

The M9.0 earthquake on the Cascadia Subduction Zone is the most likely great earthquake to affect Multnomah County, with an estimated return period of about 300 to 500 years. However, the worst case scenario earthquake is not the M9.0 on the Cascadia Subduction Zone but rather the M7.05 on the Portland Hills Fault. Because the Portland Hills Fault is located within Multnomah County the levels of ground shaking and thus, damages, losses and casualties are much higher than for the larger, but further away M9.0 on the Cascadia Subduction Zone.

The damage, loss and casualty estimates shown above in Table 6.4 are for all of Multnomah County. The vast majority of these losses are expected within the incorporated cities, with only a very small fraction expected for the unincorporated areas. Per the 2010 Census data shown in Chapter 2, the population of the unincorporated areas is only about 2% of the County's population. However, the fraction of the County's building stock and infrastructure within the unincorporated areas is less than 2% because the rural areas are predominantly residential.

Furthermore, the majority of the building stock in the unincorporated areas consists of small wood-frame homes, which have less earthquake vulnerability than unreinforced masonry and several other building types which are concentrated in the older sections of the incorporated cities. Given these considerations, the fraction of total earthquake damages and losses expected in the unincorporated areas from any of the scenario earthquakes is likely to be significantly less than 2%, with the fraction of deaths and injuries likely to be much less than 2%.

Current estimates for the return periods of these four scenario earthquakes are summarized in Table 6.5.

Table 6.5
Estimated Return Periods for Scenario Earthquakes

Scenario Earthquake	Return Period (Years)	Probability in 50 Years	Last Event
M9.0 Cascadia	300 to 500	10% to 15%[1]	January 1700
M7.05 Portland Hills	14,000	0.35%	Unknown
M6.0 Portland Hills	1,500	3.50%	Unknown
M6.8 Mount Angel	14,500	0.34%	Unknown

[1] Long-term average. Probability over the next 50 years may be substantially higher.

For the Cascadia M9.0 earthquake, 10% to 15% probability over the next 50 years represents the long-term average. However, because the last such earthquake occurred in 1700, the probability over the next 50 years may be substantially higher. Earthquake faults have "memory." That is, immediately after the M9.0 earthquake in 1700, the probability of another M9.0 earthquake was very low, almost nil. With increasing time, the stress gradually builds up on the fault and the probability gradually increases over time. The longer the time period since the last great earthquake, the higher the probability that the next great earthquake will occur.

Furthermore, the M9.0 earthquake corresponds to fault rupture over the entire fault zone. There is also paleoseismic evidence for partial ruptures of the northern and southern segments of the Cascadia Fault Zone with earthquake magnitudes greater than 8.0.

Recent research by Professor Goldfinger at Oregon State University has identified 41 very large earthquakes, M8.2 or higher, on the Cascadia Subduction Zone over the past 10,000 years. Many of these earthquakes occurred on the southern segment of the fault, from Newport south to Northern California. Considering the time interval since the last M9.0 earthquake and the likelihood of M8+ earthquakes, the total probability of large Cascadia earthquakes over the next 50 years may be substantially higher than 10% to 15%.

The return periods shown in Table 6.5 for the M7.05 Portland Hills and M6.8 Mount Angel scenarios are the 2008 USGS estimates. The return period for the smaller M6.0 Portland Hills scenario is estimated roughly as being about ten times less than that for the M7.05 scenario.

6.5.2 Earthquake Ground Motions for Scenario Earthquakes

The following maps show the variation in estimated earthquake ground motions for the four scenario earthquakes. The ground shaking maps for the Cascadia M9.0 and Portland Hills M6.0 scenarios are USGS shake maps which include the best available soil/rock data for the affected areas. The ground shaking maps for the Portland Hills M7.05 and Mount Angel M6.8 scenarios are based on HAZUS data, which is likely of lower spatial resolution than the USGS shakemaps.

Figure 6.10
Cascadia M9.0 Earthquake: Ground Motion

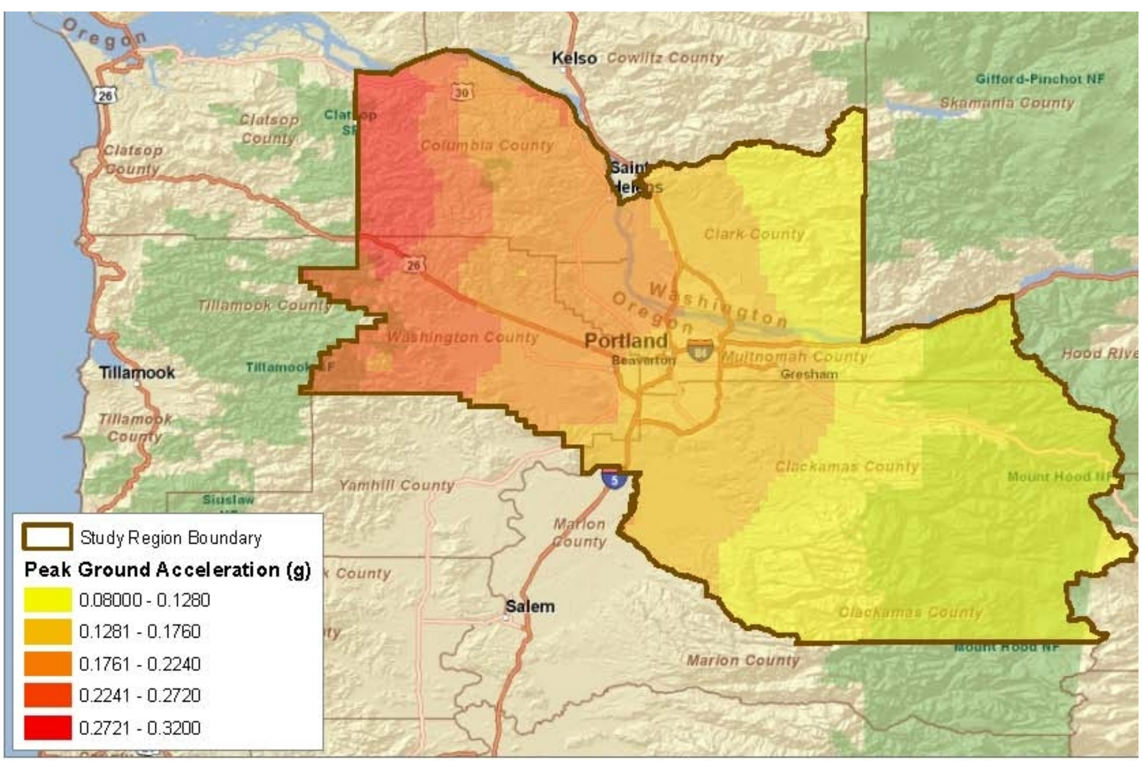


Figure 6.11
Portland Hills M7.05: Ground Motion

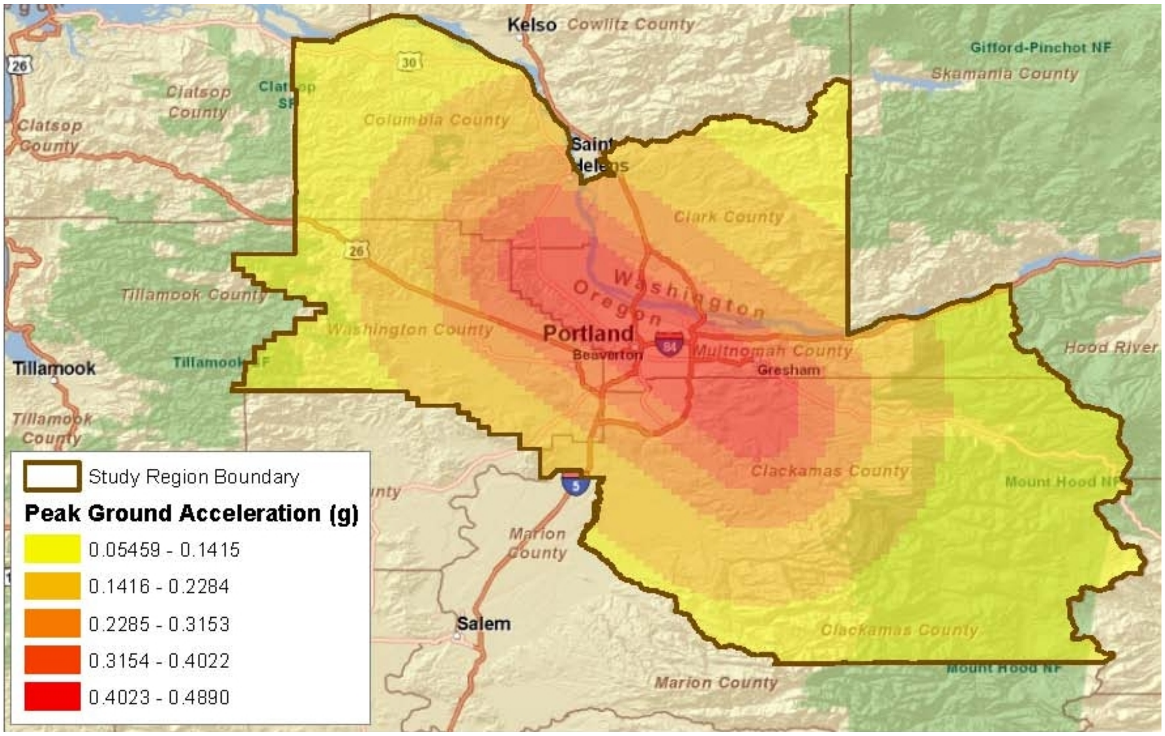


Figure 6.12
Portland Hills M6.0: Ground Motion

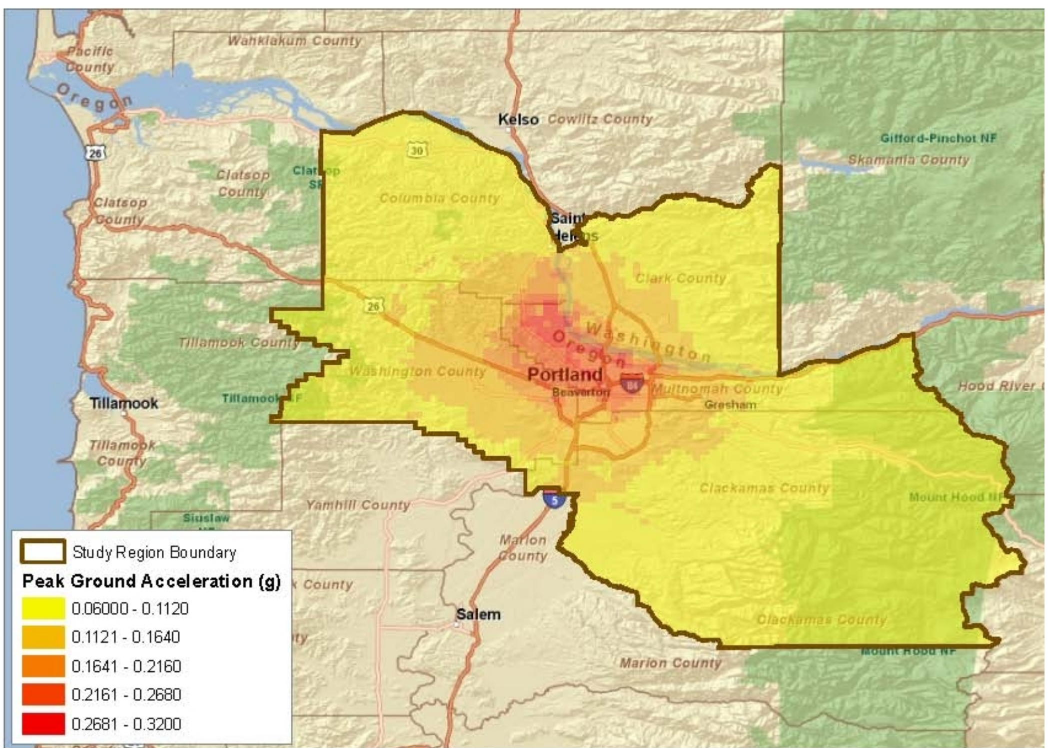
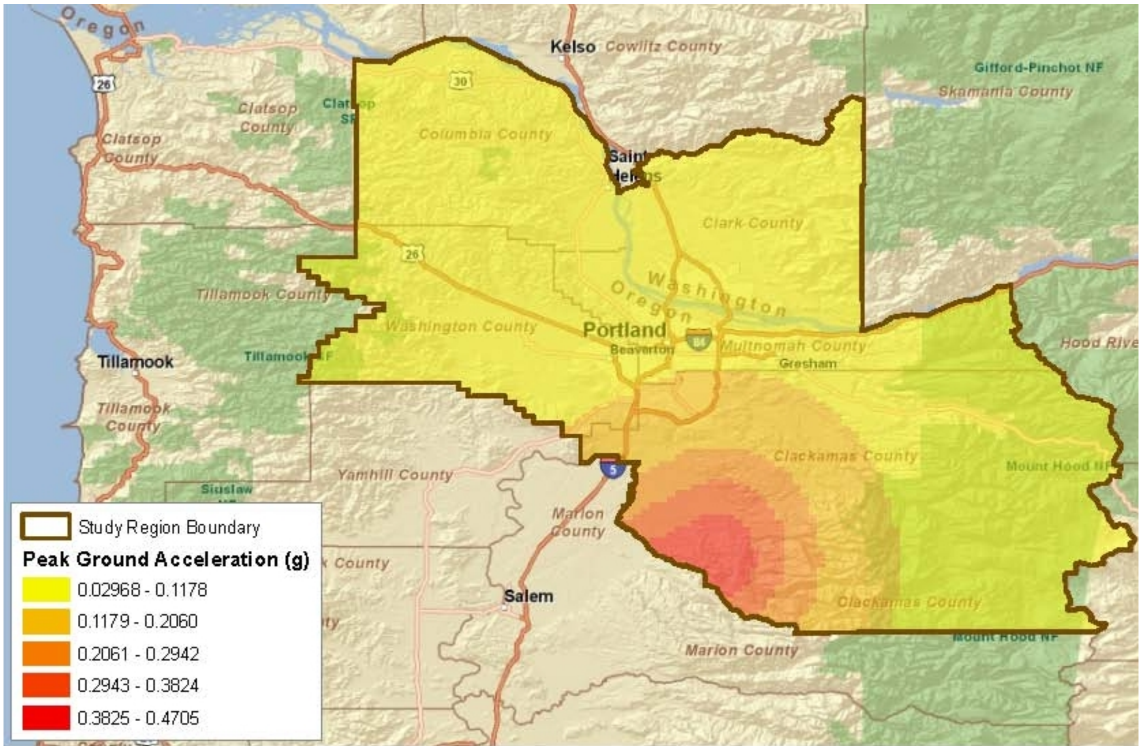


Figure 6.13
Mount Angel M6.8: Ground Motion



6.5.3 HAZUS Results: Commentary and Caveats

Summary HAZUS loss estimates for the four scenario earthquakes listed were shown previously Table 6.3.

HAZUS results illustrate the relative severity of consequences for Multnomah County for each of the four earthquake scenarios and the approximate levels of damages and casualties expected. The numerical results should not be over-interpreted.

In addition to the results shown in Table 6.3 and the tables in the appendix, HAZUS generates many more detailed output reports. However, the detailed information in these output reports should be interpreted very cautiously because the results are based on limited data, which may be incomplete and/or inaccurate.

For reference, some of the detailed HAZUS results (which are not included in the summary information in this chapter) appear significantly inaccurate, including the following information which is included in the HAZUS output reports:

- The expected damage and functionality estimates for essential facilities (hospitals, schools, EOCs, police stations and fire stations) appear incomplete and possibly inaccurate.

- The expected damage and functionality estimates for transportation systems appear incomplete and possibly inaccurate.
- The expected damage and functionality estimates for utility systems are incomplete and possibly inaccurate. Damage estimates are provided for potable water only. The reported zero leaks/breaks for the potable water system, even for the M7.05 Portland Hills scenario and the estimated zero households without water or electric service appear completely unrealistic. Especially for this scenario, but also for the other scenarios, damage and outages are likely for all of the utility systems.

6.5.4 Qualitative Loss Estimates for Other Earthquakes

In addition to the four scenario earthquakes summarized above, there are numerous other earthquakes which could result in significant damage in Multnomah County. Qualitative loss estimates for several of these earthquakes are provided below.

As discussed in Section 6.2, earthquakes on the Cascadia Subduction Zone include deep intraplate earthquakes as well as the interface earthquake presented above. Deep intraplate earthquakes might have magnitudes ranging from the high M6 range to as much as M7.5. An example of such an earthquake is the Nisqually earthquake in Washington State.

Levels of ground shaking and damages, economic losses and casualties in Multnomah County from deep intraplate earthquakes would vary significantly depending on the location and depth of the epicenter and the magnitude of the earthquake. However, damage levels could be roughly comparable to those for the further-away M9.0 interplate Cascadia Subduction Zone earthquake discussed above.

There are also numerous mapped crustal faults near Multnomah County (cf. Figure 6.5) as well as a likelihood of other not yet known faults. A large earthquake M6+ could result in significant damages. The severity of damages, losses and casualties would vary markedly depending on the magnitude and location of such earthquakes. The damages, losses and casualties for such earthquakes would be significantly lower than those for the M6.0 Portland Hills scenario, for earthquakes that occurred in less heavily developed portions of Multnomah County.

6.6 Earthquake Hazard Mitigation Projects

6.6.1 Overview

There are a wide variety of possible hazard mitigation projects for earthquakes. The most common projects include: structural retrofit of buildings, non-structural bracing and anchoring of equipment and contents, and strengthening of bridges, utility systems and other infrastructure components.

Structural retrofit of buildings should not focus on typical buildings, but rather on buildings that are most vulnerable to seismic damage. For example, let's assume that there are 100 reinforced masonry buildings built well before current seismic requirements. A logical retrofit prioritization may consider several factors, including:

- Which of these 100 buildings have the most severe seismic deficiencies?
- Among the buildings with most severe seismic deficiencies, which ones have the highest occupancy and/or are critical service facilities such as hospitals, fire and police stations, and emergency shelter? Many jurisdictions also consider school buildings as high priorities for retrofits.
- Which buildings are located in higher seismic hazard areas, including areas subject to soil amplification, liquefaction or lateral spreading?
- Which of these buildings pose the greatest risk (which may be evaluated quantitatively as part of a benefit-cost analysis) considering the vulnerability, occupancy and importance of each building?
- Which possible seismic retrofits have the highest benefit-cost ratio?

Considerations such as those outlined above help jurisdictions determine their own priorities for seismic retrofits.

Non-structural bracing of equipment and contents is often the most cost-effective type of seismic mitigation project. Inexpensive bracing and anchoring may protect very expensive equipment and/or equipment whose function is critical such as medical diagnostic equipment in hospitals, computers, communication equipment for police and fire services and so on.

For utilities, bracing of control equipment, pumps, generators, battery racks and other critical components can be powerfully effective in reducing the impact of earthquakes on system performance. Such measures should almost always be undertaken before considering large-scale structural mitigation projects.

The strategy for strengthening bridges and other infrastructure follows the same principles as discussed above for buildings. The targets for mitigation should not be typical infrastructure but rather specific infrastructure elements that have been identified as being unusually vulnerable and/or are critical links in the lifeline system. For example, vulnerable overpasses on major highways would have a higher priority than overpasses on lightly traveled rural routes.

6.6.2 Mitigation Action Items for Earthquakes

Multnomah County's mitigation priorities for earthquake focus primarily on the unincorporated areas of the County and on County-owned buildings and infrastructure. The incorporated cities within the County have the primary responsibilities for buildings and infrastructure within their jurisdictions.

The action items in Table 6.6 on the following page, reflects these priorities. The action items include seismic evaluations and structural and nonstructural retrofits for County-owned buildings, with priorities generally similar to the post-disaster restoration priorities for County buildings shown in Appendix 4.

Similarly, for bridges with substantial seismic vulnerabilities, the County's priority is for County-owned bridges, especially those bridges essential for emergency access and egress.

Earthquake mitigation priorities also include the critical and essential buildings and infrastructure discussed in Chapter 4 and the other mitigation action items in Table 6.6.

The following table contains earthquake mitigation action items from the master Action Items table in Chapter 4.

Table 6.6
Earthquake Mitigation Action Items

Hazard	Action Item	Coordinating Organizations	Timeline	Plan Goals Addressed				
				Life Safety	Protect Property and Infrastructure	Emergency Management Capabilities	Public Awareness and Education	Environmental Stewardship
Earthquake Mitigation Action Items								
Short-Term #1	Evaluate the structural vulnerability of critical county buildings and retrofit or replace when necessary.	Facilities	Ongoing	X	X	X		X
Short-Term #2	Encourage school districts, fire agencies and private building owners to evaluate the structural vulnerability of buildings and retrofit or replace when necessary. Example: grant workshops.	Multnomah County Emergency Management	Annually	X	X	X	X	
Short-Term #3	Evaluate the nonstructural vulnerabilities in county buildings and implement mitigation measures where necessary, including: automatic seismic shut off values on gas lines, flexible connections to gas-fueled equipment, bracing of fire sprinklers, bracing of contents and others.	Facilities	1-2 Years	X	X	X		X
Short-Term #4	Obtain and update earthquake map data as it becomes available through DOGAMI and other partners.	GIS	Ongoing			X	X	
Short-Term #5	Complete and maintain an inventory of critical facilities and lifelines that are susceptible to severe disruption due to earthquake hazards.	Multnomah County Emergency Management	Ongoing		X	X	X	
Short-Term #6	Enhance Multnomah County's staff earthquake expertise by attending training classes on nonstructural mitigation, post-earthquake seismic evaluations of buildings, and FEMA mitigation grants.	Multnomah County Emergency Management	Ongoing	X	X	X	X	
Long-Term #1	Retrofit suspended ceilings including light fixtures as replacement becomes necessary.	Facilities	Ongoing	X	X			
Long-Term #2	Retrofit or replace key bridges with substantial seismic vulnerabilities.	Transportation	Ongoing	X	X	X	X	X
Long-Term #3	Seismic upgrades Multnomah County Courthouse	Facilities	5 Years	X	X			