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Open-File Report

OFR-03-10

Earthquake and Landslide Hazard Maps, and Future Earthquake Damage Estimates, for Clackamas County, Oregon

by
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NOTE

Maps in this publication depict relative earthquake and landslide hazard zones on the basis of limited data, as described in the text. **They cannot serve as a substitute for site-specific investigations by qualified practitioners.** At any point, site-specific data may give results that differ from those shown on the map.

The Oregon Department of Geology and Mineral Industries is publishing this study because the information furthers the mission of the Department. To facilitate timely distribution, OFR-03-10 has not been edited to our usual standards.

Other publications with information about Clackamas County earthquake hazards include:

B-99. Geology and geologic hazards of northwest Clackamas County

IMS-15. Earthquake scenario map for the Portland, Oregon, metro area

IMS-8. Relative earthquake hazard maps for Canby-Barlow-Aurora, Woodburn-Hubbard, Silverton-Mt.Angel, Stayton-Sublimity-Aumsville, Lebanon, Sweet Home

IMS-4. Map showing faults,bedrock geology, and sediment thickness of the west half of the Oregon City 1:100,000 quad

IMS-1. Relative EQ hazard map of Portland Metro region

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1.0 EXECUTIVE SUMMARY

Information about the earthquake and landslide hazards of Clackamas County was developed and used to improve the county's ability to estimate earthquake damage and losses. Several products have been generated as part of this project, including:

1. Digital GIS layers for the county, depicting:
   a. Relative ground shaking amplification hazards,
   b. Liquefaction hazard areas,
   c. Regional landslide hazards,
   d. Historic landslide areas,
   e. Individual landslide impact locations,
2. An updated building inventory for seismic damage and loss analyses (integrated into HAZUS),
3. An improved HAZUS study region (incorporating the new relative hazard layers, the updated building inventory, and an improved bridge layer), and
4. Damage and loss estimates for two earthquake scenarios:
   a. A magnitude 6.8 Portland Hills Fault earthquake, and
   b. A magnitude 9.0 Cascadia Subduction Zone earthquake.

The relative hazard maps in this report can serve as a starting point for identifying problem areas that should be further evaluated. In general, ground shaking amplification and liquefaction hazards are highest in the young, soft alluvial sediments of the Willamette Valley and along other major stream channels. Landslide hazards are highest in steep, mountainous terrain and at the base of steep canyons. Historic landslide sites and individual impact locations, identified in the accompanying GIS files, also pose significant hazards for development.

The regional hazard information developed in this study was combined with updated information on building and other infrastructure data in Clackamas County in order to assess potential damages and losses for various earthquake scenarios. The information was consolidated into a computer program called HAZUS (the updated HAZUS study region is included with this report), which is a federally developed program used to model various earthquake scenarios and estimate associated damages and losses. Two scenarios were modeled as part of this study: a magnitude 6.8 Portland Hills scenario expected to cause on the order of $3.7 billion in total building damage; and a magnitude 9.0 Cascadia Subduction Zone event, with total building damage estimated at $940 million.

The combined products from this study are a useful tool for regional planning for future natural disasters, and for post-disaster response and recovery. The relative hazard maps highlight areas of higher and lower concern for earthquake effects and landslides. The damage and loss estimates are a tool for projecting resource requirements for various earthquake scenarios. Together, these tools can be used to identify and evaluate areas where natural hazard information, dissemination, and mitigation activities can be targeted for most efficient use of resources.

2.0 INTRODUCTION

Earthquakes and landslides pose significant hazards in many parts of Oregon. Extremely significant coastal earthquakes along the Cascadia Subduction Zone (magnitudes ~9.0) have occurred many times in our geologic past (Atwater, 1987; Yamaguchi and others, 1997). Scientific consensus is that we can expect them to happen again (Clague and others, 2000). Smaller crustal earthquakes, which can be more damaging in local areas than subduction zone earthquakes, also pose significant risks because of the proximity of many faults to urban areas. Important reminders of the dangers and effects of local earthquakes include the magnitude 5.6 earthquake that occurred near Scotts Mills in 1993 and the Klamath Falls earthquakes (magnitudes 5.9 and 6.0) that occurred later that year. Combined, these earthquakes caused more than $40 million in direct damage, and there were two fatalities in the Klamath Falls earthquakes (Wiley and others, 1993).

Many parts of Oregon are also highly susceptible to landslides. Particularly in the mountainous portions of the state, landslides pose significant threats to people and infrastructure. As population growth continues to expand development into steeper terrain, greater losses are likely to occur. Most of our landslide damages have been associated with severe winter storms where landslide losses can exceed $100 million in direct damage (such as the February 1996 event—see FEMA, 1996). Annual average maintenance and repair costs for landslides are over $10 million (Wang and others, 2002). Landslides induced by earthquake shaking are likely in many parts of Oregon, and losses associated with sliding in moderate-to-large earthquakes are likely to be significant.

This study was initiated by Clackamas County as part of Project Impact[1] efforts to better address earthquake and landslide hazards. The two main objectives of this study were to develop a set of countywide maps to identify areas of relatively lower and higher earthquake and landslide hazards, and to improve the county's capability to estimate earthquake damage and losses. The body of this report describes the results for these two main components (the relative hazard maps, and the earthquake damage and loss modeling using HAZUS).

[1] For more on Clackamas County Project Impact, please see http://www.co.clackamas.or.us/emergency/projectimpact.htm.

3.0 PREVIOUS WORK

A number of previous studies have been conducted in Clackamas County to identify natural hazards, assess risks, and mitigate hazards. In our current efforts, we attempted to build on this large body of work and contribute to the growing understanding of the hazards affecting the county, as well as highlight some possible ways the county can address these hazards.

For the hazard mapping components of this study, we used a number of geologic maps and related data previously developed. Specific sources of geologic information referenced include: Burns and others (1997), Gannett and Caldwell (1998), Hampton (1972), Madin (1994), Miller and Orr (1984a and 1984b), O'Connor and others (2001), Orr and Miller (1986), Sherrod and Scott (1995), Tolan and Beeson (1999), Walker and McLeod (1991), and White (1980). In addition to traditional geologic mapping, natural hazard maps have previously been developed for portions of the county, including: Beaulieu (1974), Brunengo (1978), Mabey and others (1993), Mabey and others (1997), Wang and others (1998), Madin (1990), Madin and Wang (1999a, b), Schlicker and Finlayson (1979), and Schlicker and Deacon (1967).

For the earthquake damage and loss estimation portion of this study, we were also able to use information from several existing data sources and publications. A particularly valuable report specific to Clackamas County geohazards loss estimation was developed by G&E Engineering (1998). The G&E Engineering report includes county inventory information, background discussion of natural hazards in the county, as well as initial loss estimations for earthquakes, floods, winter storms (including landslides), and electrical power outages. The G&E Engineering report is a compilation of data that was used in the development of the Phase I All Hazard Mitigation Plan for Clackamas County. Other valuable earthquake damage and loss publications referred to in this study include statewide damage and loss studies conducted by Wang (1998) and later summarized in Wang and Clark (1999).

In terms of prioritizing mitigation efforts and preparing for natural hazards, Clackamas County is a national leader. With the county's recent adoption of the Clackamas County Natural Hazards Mitigation Plan, the county has demonstrated its commitment to addressing natural hazards. This hazard mitigation plan, available for viewing at http://www.co.clackamas.or.us/emergency/hmp.htm, was developed as a collaboration, with input from a Hazard Mitigation Advisory Committee that included stakeholders within the county, as well as state and federal partners. The plan is an excellent example of deciding on the priorities of community natural hazards and risks, and was recently recognized by the Federal Emergency Management Agency (FEMA) as the first "federally approved" mitigation plan qualified under FEMA Interim Final Rule (IFR), 44 CFR Part 201—a significant accomplishment.

The following sections provide rather general coverage of the broad topics of geologic hazard mapping and earthquake damage and loss estimation, and there is a wealth of complementary information that can be referenced for further detail. Some sources of additional information are cited in individual sections of the text, but for good overall reviews of earthquake hazards in the Pacific Northwest, Rogers and others (1998) is recommended; for a good summary of landslide types and characteristics, Turner and Schuster (1996) is an excellent resource; and for a summary of potential uses of natural hazard maps in Oregon, Spangle Associates (1998) is a valuable reference.

4.0 CLACKAMAS COUNTY SETTING

Clackamas County covers an area of 4,870 square kilometers (1,879 square miles) and is bounded by Multnomah County to the north, Washington and Yamhill Counties to the west, Marion County to the south, and Wasco and Hood River Counties to the east (Figure 1). Elevations range from approximately 15 meters (50 feet) at the banks of the Willamette River at the western edge of the county to 3,424 meters (11,235 feet) at the peak of Mt. Hood, the highest point in the Oregon Cascade Range Mountains. Two physiographic provinces in Clackamas County include the Willamette River Valley and the Cascade Range provinces. The Willamette River Valley to the west is characterized by predominately flat and gentle topography, while the Cascade Range province to the east is characterized by mountainous, densely forested topography.

The geology, topography, and climate of Clackamas County are all conducive to a number of natural hazard effects including floods, landslides, windstorms, volcanic eruptions, and earthquakes. The risks associated with earthquakes and landslides in particular are increasing as population continues to expand and push development into more marginal terrain. “The inevitability of natural hazards, and the growing population and activity within the county create an urgent need to develop strategies, coordinate resources, and increase public awareness to reduce risk and prevent loss from natural hazard events” (Clackamas County Hazard Mitigation Plan, 2002).[2]

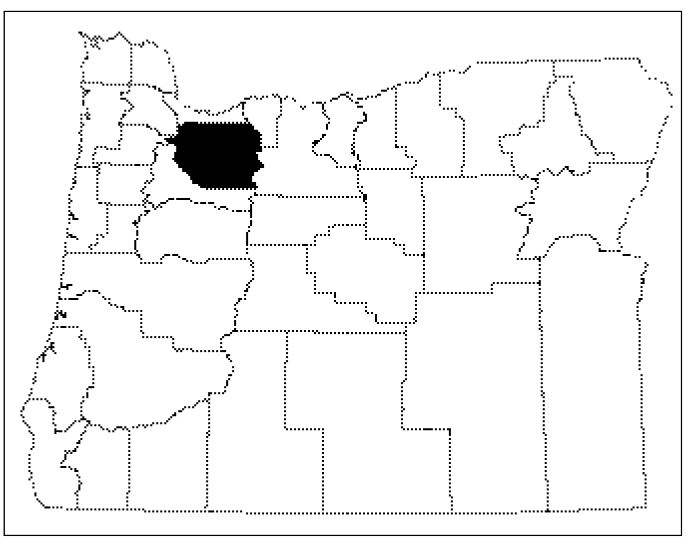

Figure 1. Map showing location of Clackamas County.

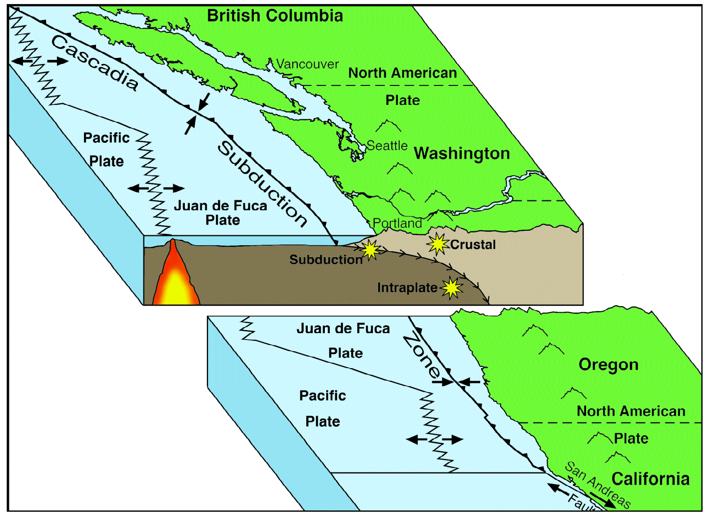

Figure 2. Three earthquake sources: subduction, intraplate, and crustal.

4.1 Overview of Potential Earthquake Sources

Earthquake effects are a very real threat in Clackamas County, and can come from any one of three types of sources: crustal, intraplate, and subduction zone events (Figure 2). The most common earthquakes in the Pacific Northwest are crustal earthquakes, which occur in the North American plate at relatively shallow depths of 10–20 kilometers (6–12 miles) below the surface. The 1993 magnitude 5.6 earthquake at Scotts Mills (Madin and others, 1993) and the 1993 magnitude 5.9 and 6.0 Klamath Falls main shocks (Wiley and others, 1993) are examples of crustal earthquakes.

Intraplate earthquakes occur within the remains of the Juan de Fuca plate subducting beneath North America. Intraplate earthquakes have caused damage in the Puget Sound region in 1949, 1965, and recently in the magnitude 6.8 Nisqually Earthquake in 2001. These types of earthquakes typically occur at depths of 40–60 kilometers (25–37 miles).

[2] Much more background information on the Clackamas County setting, geography, geology, economic base, and history is also included in the Clackamas County Hazard Mitigation Plan, which is available on the web at http://www.co.clackamas.or.us/emergency/hmp.html.

Great subduction zone earthquakes occur around the world where the plates that make up the surface of the Earth collide. When the plates collide, one plate is shoved ("subducts") beneath the other, where it is reabsorbed into the mantle. This dipping interface between the two plates is the site of some of the most powerful earthquakes ever recorded, often having magnitudes of 8.0 to 9.0+ on the moment magnitude scale. The 1960 Chilean (magnitude 9.5) and the 1964 Great Alaska (magnitude 9.2) earthquakes were subduction zone earthquakes (Kanamori, 1977). The Cascadia subduction zone, which lies off the Oregon and Washington coasts, has been recognized for many years. Though there have been no earthquakes on the Cascadia subduction zone during our short 200-year historical record, various studies have found widespread evidence that very large earthquakes have occurred repeatedly in the past, most recently about 300 years ago, in January, 1700 (e.g., Atwater, 1987; Yamaguchi and others, 1997). Best available evidence indicates that these earthquakes occur, on average, every 500–540 years; and observed intervals between individual events range from about 200 to about 1,000 years (Atwater and Hemphill-Haley, 1997).

All three types of earthquakes threaten Clackamas County. However, because the strength of shaking decreases with increasing distance from the earthquake source, the most severe shaking in the county will likely result from shallow local crustal earthquakes. The most severe damage inflicted by earthquakes is commonly associated with areas that experience one or more of the following phenomena:

1. Amplification of ground shaking by "soft" soil columns;
2. Liquefaction of water-saturated sand, silt, or gravel, creating areas of "quicksand;" and
3. Landslides.

Fortunately, each of these effects can be evaluated before an earthquake occurs if the nature and properties of the geologic materials and soils at sites are known (Bolt, 1993). This is a focus of this study, and we have developed map identification tools to evaluate each of these earthquake hazards.

4.2 Overview of Landslide Types and Characteristics

Landslides also pose significant hazard in Clackamas County, and can take many different shapes and forms. The general term "landslide" refers to the range of geologic failures including rock falls, debris flows, earth slides, and other mass movements (Figure 3). Most slope failures in Clackamas County are complex combinations of these distinct types, but the generalized groupings provide a useful means for framing discussion of slide characteristics, identification methods, and potential mitigation alternatives.

4.2.1 Technical Factors

Landslides can be initiated in marginally stable slopes by a number of natural and human disturbances. Processes and conditions that can trigger slope failure include such things as earthquake shaking (Figure 4), volcanic eruptions, deforestation, and rapid snow melt (Turner and Schuster, 1996). Two of the most common triggering events in the Pacific Northwest are intense rainfall and human alterations.

Intense rainfall and associated water infiltration into zones of weakness can trigger landslide failures by reducing the frictional resistance to sliding, increasing water pressures within slope masses, and adding weight. Typically, all three of these mechanisms combine during longer duration, heavy precipitation or rain-on-snow events to trigger landslides. Studies into the cause and effect of major rainfall storms and landslides indicate that there are general threshold rainfall values above which landslides (and particularly debris flows) become significantly more widespread and numerous (Keefer and others, 1987; Wilson, 1997; Wilson and Wieczorek, 1995). Based on data from the 1996 and 1997 storms in the Pacific Northwest, DOGAMI has developed benchmarks for rainfall threshold values that can be used in landslide warning systems. Evaluations of climatic data in comparison with landslide occurrences indicate that rainfall intensity/duration combinations of 40% of mean December rainfall in a 24-hour time period, 25% of mean December rainfall in a 12-hour period, or 15% of mean December rainfall in a 6-hour period are likely to trigger

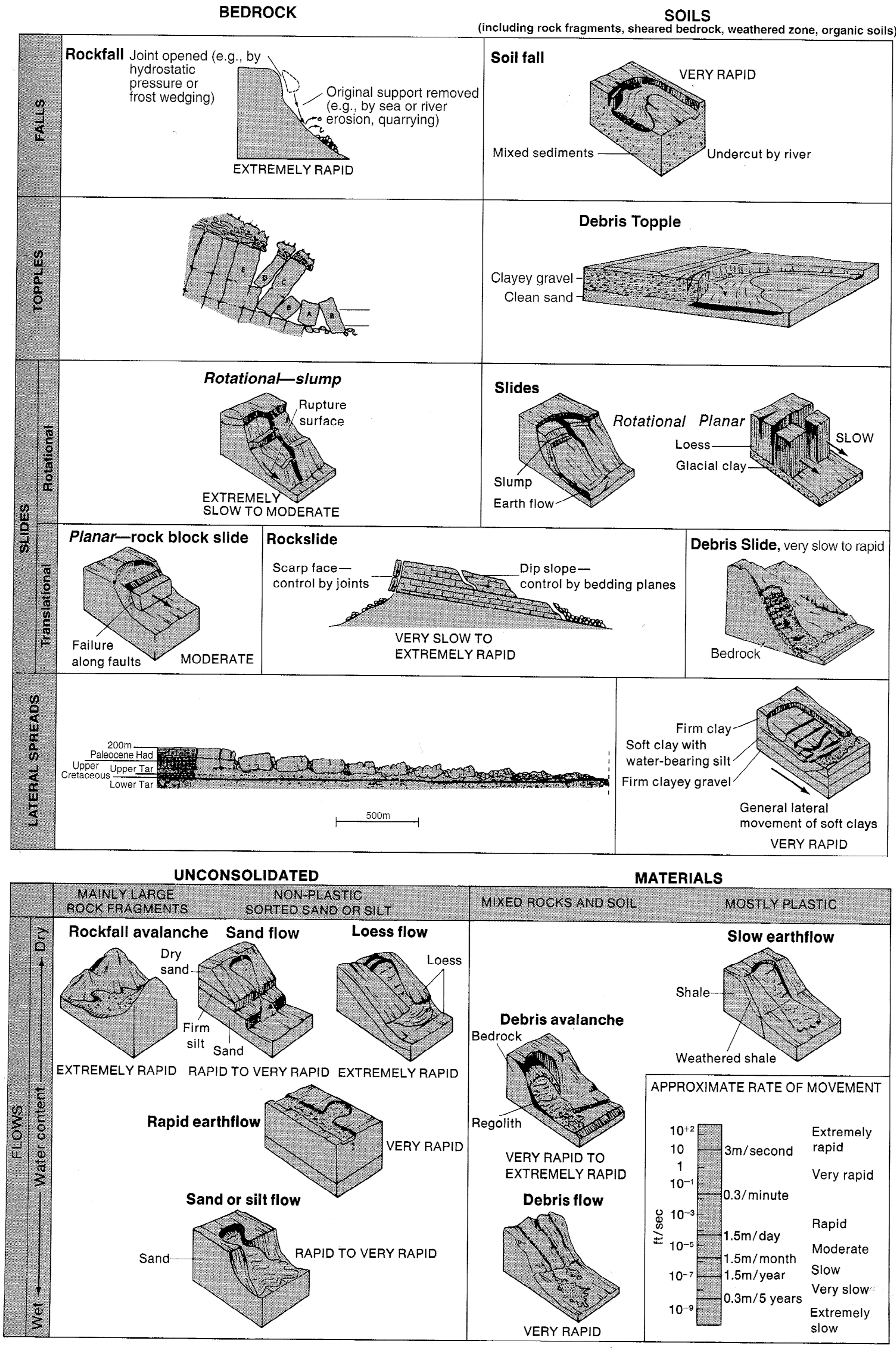

Figure 3 Landslide types (from Ritter and others, 1995).

Figure 4. Landslides following the 2001 magnitude 6.8 Nisqually earthquake.

widespread landslide activity in steep terrain areas of western Oregon and Washington (Wiley, 2000). While these thresholds are general and based on regional data, the results provide some valuable guidance for when to anticipate widespread landslide activity during the onset of heavy rainfall.

Human development and associated modifications to the natural environment can also cause or exacerbate slope instability. Construction of roads, buildings and other infrastructure typically involves earth movement and redirection of water. Excavations that remove materials from the base of marginally stable slopes, and infrastructure that redirects water to hazardous areas are two of the most common instigators of slope failures. It is critical that the geotechnical consequences of slope alterations are evaluated in the planning and subsequent developments on or near steep slopes and in historic landslide areas. Examples of the consequences for unwise siting of infrastructure are widespread. Within this region, large and devastating landslides in and around Kelso, Washington have captured national attention. Even closer to home, over 700 landslides were recorded in the Portland metropolitan region in 1996 alone (Burns, 1998). While these Portland metropolitan-area slides occurred in both natural and human-altered slopes, it was determined that 76% of the failures were either caused or exacerbated by human activity (Burns, 1998). In a similar study in and around Seattle, human alterations were associated with over 75% of the recorded landslides (Nashem and Laprade, 1999).

While landslides can take many different shapes and forms, fundamentally, all failures occur at the point when the strength of the slope-forming materials is exceeded by the stresses acting upon them. Some significant variables in the evaluation of the susceptibility of an area to landslides include the following:

1. Slope geometry—steep slopes tend to be more susceptible to mass wasting;
2. Geologic material properties—strengths vary considerably from hard, intact rock to weak, unconsolidated soils;
3. Precipitation—rainfall can cause erosion from impact on bare soil and trigger the mobilization of landslides, particularly debris flows;
4. Moisture content and water flow (which are associated with precipitation)—infiltration can greatly reduce shear strength along slide planes and increase driving forces;
5. Geologic discontinuities (such as faults, bedding planes, foliation, and joints)—zones of separation and/or contacts in geologic materials can act as conduits for infiltration and planes of weakness along which a slope may fail;
6. Seismic activity—shaking can increase driving forces, raise the pore pressure, and induce new landslides or trigger slope movement within dormant slides;
7. Human activity—poor drainage design, over cutting of steep slopes, and addition of weight to a slope can all lead to slope instabilities;
8. Land cover—the type and density of vegetation have an impact on slope stability. Soil reinforcement increases with root strength, density and length. Heavy storms can trigger very destructive debris flows on slopes that have been denuded by logging or wildfires.

The evaluation of slope stability requires the measurement or estimation of modeling inputs, including: the surface geometry of the slope, types and thicknesses of geologic materials, geotechnical properties (strengths, unit weights, grain size characteristics, etc.), depth to failure surface(s) and hydrologic conditions (water elevation and flow characteristics) (see Turner and Schuster, 1996 for more info). The determination of these parameters usually involves a combination of geologic mapping, borehole sampling, laboratory testing, and installation of monitoring equipment to determine hydrologic characteristics and/or zones of shear.

Prior to developing remedial measures for slope instability on a site-specific basis, however, it is helpful to have a solid grasp of the regional tendency for landslide activity based on a synthesis of geologic, topographic, climatologic, and historical data. The maps developed as part of this study allow for systematic, objective evaluations of slope hazards at a regional scale. This can naturally lead to identification of specific sites that warrant attention, which is a fundamental goal of this project.

5.0 CLACKAMAS COUNTY HAZARD MAPPING

Although the specific location and the exact timing of natural hazards are quite difficult to forecast with accuracy, we do have tools for planning and forecasting. From historical observations of natural hazards, as well as scientific modeling of phenomena such as landslides and liquefaction, several key hazard characteristics can be identified. In addition, significant advances in computer modeling and GIS capabilities have improved our ability to develop regional hazard identification tools that produce models with more detail and maps that are more useful.

The following sections briefly describe the development of GIS map layers that the county can use to consistently identify regional earthquake and landslide hazard areas. The earthquake hazard layers are ground shaking, amplification, and liquefaction. For landslides, the mapping includes a countywide relative hazard map, a regional map of historic landslide areas, and an inventory of specific landslide locations consolidated from the 1996-97 storm events.

Table 1. Ground shaking amplification site classes (from the 1997 NEHRP Provisions).

Site Class	Site Class Description	Shear Wave Velocity (m/sec)	
		Minimum	Maximum
A	**HARD ROCK** Eastern United States sites only	1500	
B	**ROCK**	760	1500
C	**VERY DENSE SOIL AND SOFT ROCK** Untrained shear strength $u_s \geq 2000$ psf ($u_s \geq 100$ kPa) or $N \geq 50$ blows/ft	360	760
D	**STIFF SOILS** Stiff soil with undrained shear strength 1000 psf $\leq u_s \leq$ 2000 psf (50 kPa $\leq u_s \leq$ 100 kPa) or $15 \leq N \leq 50$ blows/ft	180	360
E	**SOFT SOILS** Profile with more than 10 ft (3 m) of soft clay defined as soil with plasticity index PI > 20, moisture content w > 40% and undrained shear strength u_s < 1000 psf (50 kPa) (N < 15 blows/ft)		180
F	**SOILS REQUIRING SITE SPECIFIC EVALUATIONS** **1. Soils vulnerable to potential failure or collapse under seismic loading:** e.g. liquefiable soils, quick and highly sensitive clays, collapsible weakly cemented soils. **2. Peats and/or highly organic clays** (10 ft (3 m) or thicker layer) **3. Very high plasticity clays:** (25 ft (8 m) or thicker layer with plasticity index >75) **4. Very thick soft/medium stiff clays:** (120 ft (36 m) or thicker layer)		

5.1 Ground Shaking Amplification Map

It is well known that local soil conditions can significantly affect the response of individual sites during an earthquake (Kramer, 1996). Although earthquake site response is complicated (and depends on such things as the frequency and duration of the shaking, subsurface stratigraphy and material properties, and surface topography), useful generalizations can be made about the performance of various areas. For example, thick deposits of soft soil tend to amplify the shaking of long-period ground motions, such as those associated with subduction zone earthquakes. Sites with shallow soil profiles are not likely to amplify ground motions. The degree of amplification greatly affects the performance of infrastructure in earthquake events—with substantially higher concentrations of damage in areas with high amplification factors (Holzer, 1994; Seed and others, 1988).

A common means of categorizing regional ground shaking amplification hazards was developed by the National Earthquake Hazard Reduction Program (NEHRP) (FEMA, 1997). The NEHRP 1997 method classifies geologic locations into one of six geology/soil categories generally labeled Hard Rock (Type A), Rock (Type B), Very Dense Soil and Soft Rock (Type C), Stiff Soils (Type D), Soft Soils (Type E), and Soils Requiring Site Specific Evaluations (Type F). Table 1 summarizes some of the defining characteristics of these categories.

We developed the ground shaking amplification map based generally on the NEHRP 1997 method of categorizing relative hazards. As explained in more detail in Appendix A, we started by geographically combining available GIS data from previous hazard studies with surface geology layers. With the available information compiled, we assigned NEHRP 1997 susceptibility classes

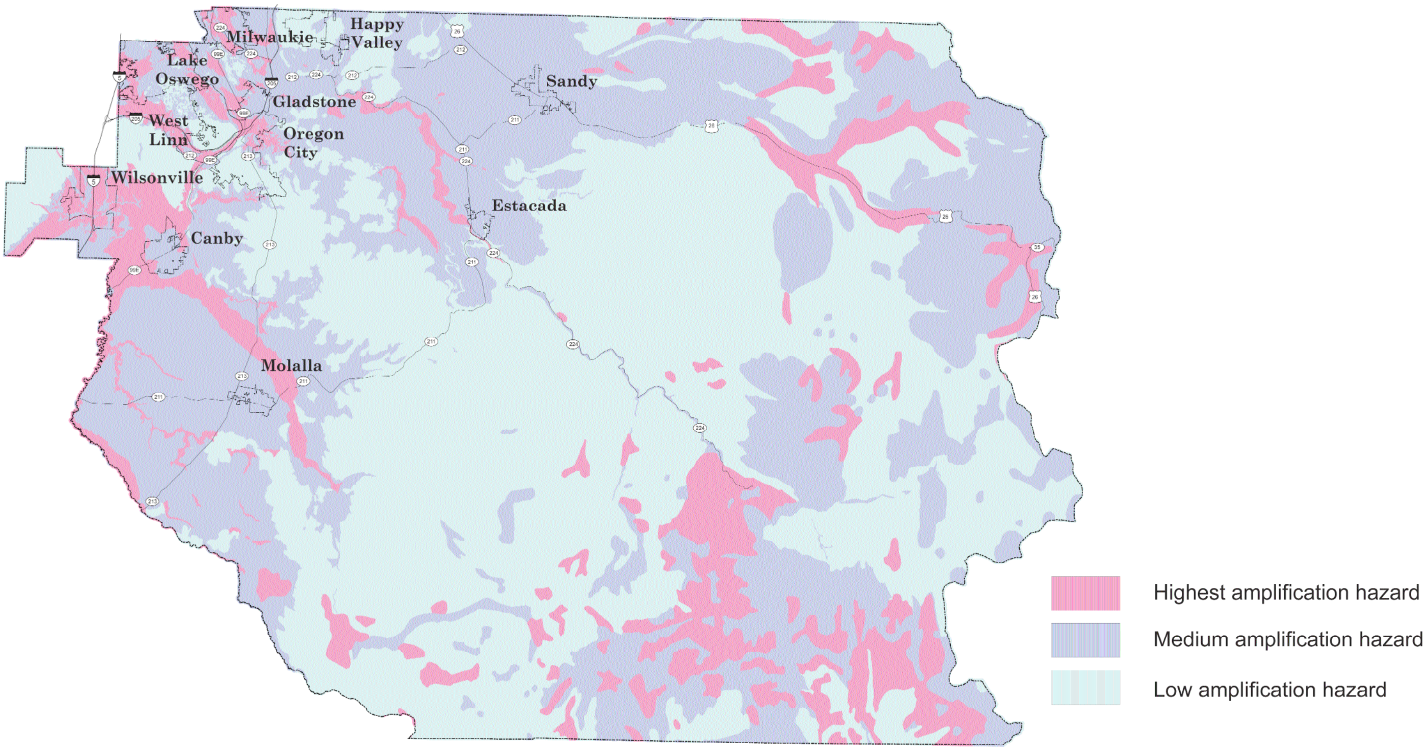

Figure 5. Ground shaking amplification hazard map for Clackamas County.

based on the dominant lithologies for each geologic unit in the study area, checked source data boundaries, and simplified the GIS outputs into relative hazard classes—Low, Moderate, and High.

The resulting map is not intended to be used in place of site-specific studies. The simple 3-class scale of Low, Moderate, and High reflects limitations in the scale and quality of the base data on which the maps are based, particularly in the eastern portions of the county. These relative hazard classes generally correspond to the NEHRP classes as follows: Low corresponds generally to NEHRP Type B, Moderate is predominately Type C with some Type D, and High is predominately Type D with some Type E and F. There were no Type A areas mapped within the county (Type A profiles are not common on the west coast of the United States). Type E and Type F soils were combined with Type D soils in the High category primarily because the scale of the available geologic mapping precluded accurate delineation of small pockets of these soil types. It is, however, most likely that Type E and Type F soils are located along and adjacent to streams and rivers in Clackamas County.

A small-scale version of the resulting GIS map layer is shown as Figure 5. In general, areas characterized by loose, Quaternary sedimentary deposits are mapped as Moderate and High hazard for ground shaking amplification (mostly D/E/F type soil profiles). Most of the areas adjacent to the major rivers in the more populated western portion of the county are mapped as Moderate and High hazard. Upland areas in the western part of the county, and almost all of the middle portions of the county are mapped as Low ground motion amplification hazard, reflecting bedrock exposures and thin mantles of soil overlying rock. The eastern portion of the county is varied, with competent bedrock areas mapped as Low hazard, dense soil areas mapped as Moderate hazard, and younger landslide and alluvial deposit areas mapped as High hazard for ground shaking amplification.

5.2 Liquefaction Hazard Map

Liquefaction is a phenomenon in which the violent shaking of a saturated soil (e.g., by an earthquake) can cause a temporary loss of strength, and in some cases actually cause the affected materials to flow similar to a fluid (Figure 6). In qualitative terms, the cause of liquefaction is described well by Seed and Idriss (1982): "If a saturated sand is subjected to ground vibrations, it tends to compact and decrease in volume; if drainage is unable to occur, the tendency to decrease in volume results in an increase in pore water pressure, and if the pore water pressure builds up to the point at which it is equal to the overburden pressure, the effective stress becomes zero, the sand loses its strength completely, and it develops a liquefied state." Soils that liquefy tend to be young, loose, granular soils that are saturated with water (National Research Council, 1985).

Figure 6. Liquefaction example from the 2001 magnitude 6.8 Nisqually earthquake.

If an earthquake induces liquefaction, several things can happen:

1. The liquefied layer and everything lying on top of it may move down slope;
2. The liquefied layer may oscillate with displacements large enough to rupture pipelines, move bridge abutments, or rupture building foundations; and
3. Light objects, such as underground storage tanks, can float toward the surface, and heavy objects, such as buildings, can sink.

Typical displacements can range from centimeters to meters. Thus, if the soil at a site liquefies, the total damage resulting from an earthquake can be dramatically increased from that caused by shaking alone.

Liquefaction hazards can be evaluated a number of ways, but for regional mapping, it is common to assess the hazards using a classification system developed by Youd and Perkins (1978). Table 2 summarizes the liquefaction susceptibility rating system developed by Youd and Perkins (1978). The method simply takes into account the geologic environment of the soil deposition and the general age of deposits. These general criteria can and should be supplemented with local information on the material properties for different units and more detailed analyses such as those outlined in Kramer (1996).

To develop a regional liquefaction hazard map for Clackamas County, we started by collecting the best available geologic information, like we did in the assessment of ground shaking amplification hazards. Hazard groupings were primarily based on lithologies and checked with individual data points. The steps used to develop the liquefaction hazard map and original data sources are listed in full in Appendix A. With the available information compiled, we assigned liquefaction susceptibility classes based on the dominant lithologies for each geologic unit in the study area, checked source data boundaries, and simplified the GIS outputs into four relative hazard classes: None/Very Low, Low, Moderate, and High.

A small-scale version of the GIS map layer for liquefaction hazards is included as Figure 7. Areas with Moderate to High liquefaction susceptibilities are concentrated along the rivers and flood plains in the Willamette Valley, Cascade Range tributaries, and major stream valleys within the Cascade Range. Older river terrace and Missoula Flood deposits in the Willamette Valley were assigned a lower liquefaction hazard, yet are still considered susceptible to liquefaction in larger earthquakes. It is important to note that the quality and scale of the available base maps precluded identification of all liquefaction hazard areas, particularly in the eastern portion of the county.

Table 2. Liquefaction susceptibility rating system (from Youd and Perkins, 1978).

Type of Deposit	General Distribution of Cohesionless Sediments in Deposits	Likelihood that Cohesionless Sediments when Saturated would be Susceptible to Liquefaction (by Age of Deposit)			
		<500 yr Modern	Holocene <11 ka	Pleistocene 11 ka - 2 Ma	Pre-Pleistocene >2 Ma
(a) Continental Deposits					
River channel	Locally variable	Very High	High	Low	Very Low
Flood plain	Locally variable	High	Moderate	Low	Very Low
Alluvial fan and plain	Widespread	Moderate	Low	Low	Very Low
Marine terraces and plains	Widespread	—	Low	Very Low	Very Low
Delta and fan-delta	Widespread	High	Moderate	Low	Very Low
Lacustrine and playa	Variable	High	Moderate	Low	Very Low
Colluvium	Variable	High	Moderate	Low	Very Low
Talus	Widespread	Low	Low	Very Low	Very Low
Dunes	Widespread	High	Moderate	Low	Very Low
Loess	Variable	High	High	High	Unknown
Glacial till	Variable	Low	Low	Very Low	Very Low
Tuff	Rare	Low	Low	Very Low	Very Low
Tephra	Widespread	High	High	?	?
Residual soils	Rare	Low	Low	Very Low	Very Low
Sebka	Locally variable	High	Moderate	Low	Very Low
(b) Coastal Zone					
Delta	Widespread	Very High	High	Low	Very Low
Esturine	Locally variable	High	Moderate	Low	Very Low
Beach					
High Wave Energy	Widespread	Moderate	Low	Very Low	Very Low
Low Wave Energy	Widespread	High	Moderate	Low	Very Low
Lagoonal	Locally variable	High	Moderate	Low	Very Low
Fore shore	Locally variable	High	Moderate	Low	Very Low
(c) Artificial					
Uncompacted Fill	Variable	Very High	---	---	---
Compacted Fill	Variable	Low	---	---	---

5.3 Landslide Hazard Maps

Consistent with the high variability of landslide types and triggering mechanisms, there are a number of methods we could have employed to model landslide hazards. In this study, we used a combination of approaches to develop three primary landslide hazard identification products described in the next three subsections. The first is a regional landslide hazard map that distinguishes different areas based on the simple combination of slope gradient derived from a 10-meter Digital Elevation Model (DEM)[3] and generalized material type. The second product is a GIS compilation of historic landslide areas derived from published geologic reports and geohazards studies. The third landslide hazard identification product is a GIS database of known landslide locations (point and polyline features) derived from previous DOGAMI compilation efforts following the major 1996 and 1997 Oregon storm events (Hofmeister, 2000). Two companion products to this report that may be used with these GIS layers (but are not included) are:

1. DOGAMI IMS-22 maps that specifically addresses "rapidly moving landslide" hazards (Hofmeister and others, 2002)
2. Maps developed by the U.S. Geological Survey, Cascades Volcano Observatory (CVO) to identify

[3]A DEM is a digital representation of topography, usually consisting of a regularly spaced series of points (a grid) with elevation values assigned to geographic coordinates (such as latitude, longitude). The grid spacing (10-meters in this case) refers to the map view distance between the grid points.

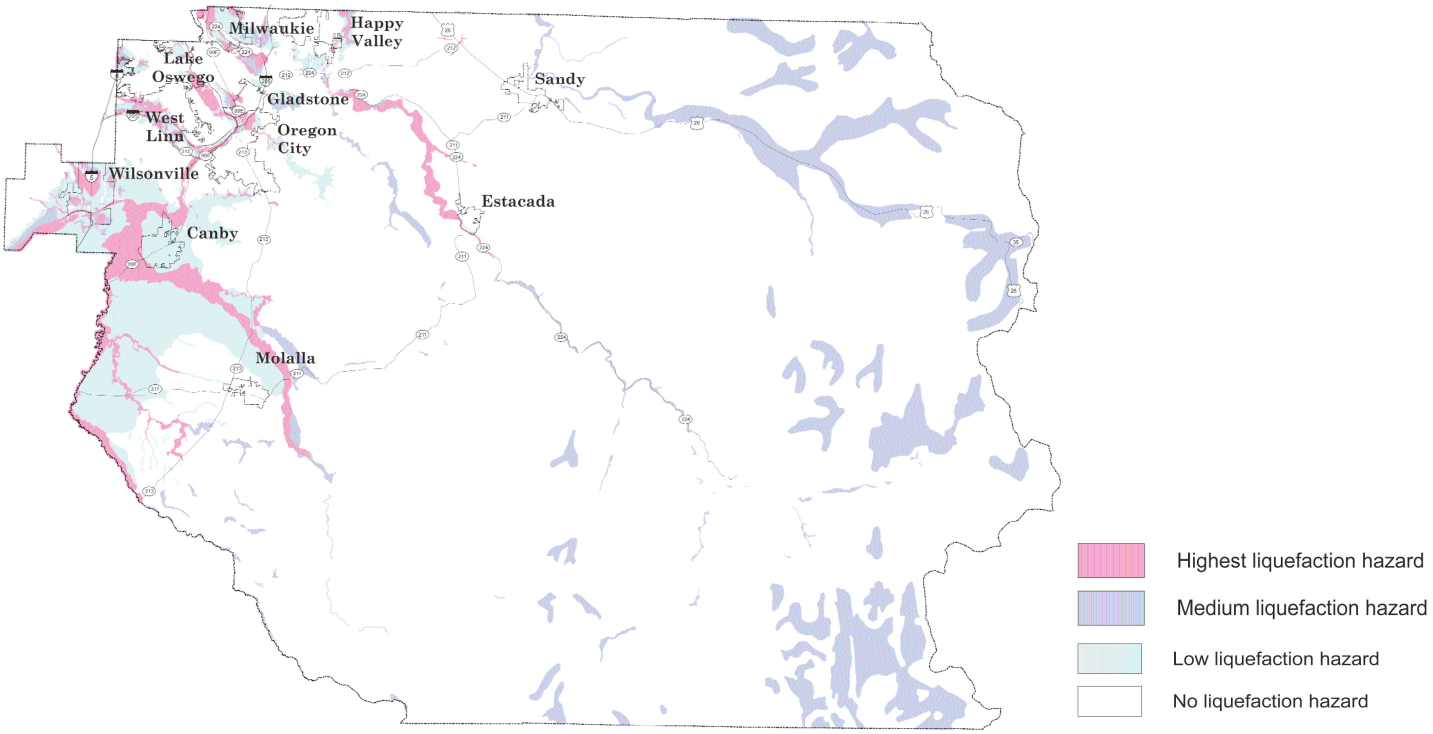

Figure 7. Liquefaction hazard map for Clackamas County.

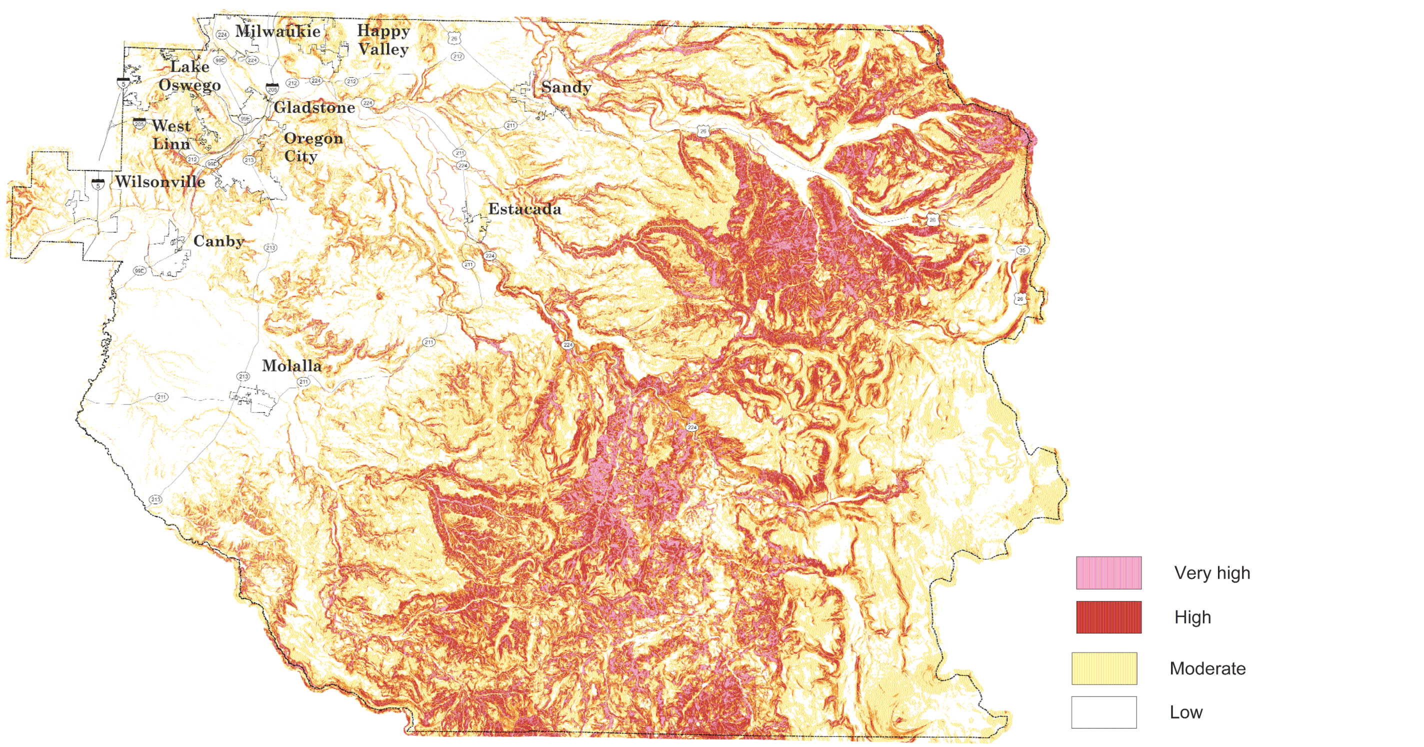

Figure 8. Landslide hazard map for Clackamas County.

potential volcanic debris flow paths ("lahars") and other volcanic hazards for Mt. Hood (Scott and others, 1997).

Table 3. Landslide hazard class assignments based on the combination of material type categories (Low, Moderate, or High) and slope gradient values in degrees.

	0-5	5-10	10-15	15-20	20-30	30-40	>40
Low	None	None	Low	Low	Moderate	High	Very High
Moderate	None	None	Low	Moderate	High	Very High	Very High
High	None	Low	Moderate	High	Very High	Very High	Very High

5.3.1 Regional Landslide Hazards

The first major landslide hazard identification product developed in this study, the regional landslide hazard map, was derived using an approach similar to the Wilson and Keefer (1985) methodology employed within HAZUS. The method essentially combines two important factors relating to landslide susceptibility: slope gradient and geologic material strength. In regional applications such as this study, slope gradient is derived from digital elevation models (in this case, a 10-meter DEM). Geologic material strength was inferred from soil unit mapping by the USDA Natural Resource Conservation Service (USDA, 1981) and the USDA Forest Service (USDA, 1979). The units from these two sources were grouped into three simple classes—Low, Medium, and High—based on the unit characteristics identified in the soils reports and our comparisons with other landslide hazard information available for portions of the county (Mabey and others, 1997; Brunengo, 1978; Schlicker and Finlayson, 1979; Beaulieu, 1974; Madin and Wang, 1999a, b; Burns and others, 1998; Hofmeister, 2000; Walker and Duncan, 1989; Mt. Hood GIS data available at http://www.reo.gov/mth/mth_data_www.htm). In these material type assignments, the vast majority of the units were assigned to the Medium class and only units with substantially divergent characteristics were assigned to the Low and High categories. The units falling into these Low and High classes are summarized in Appendix B.

Hazard classes of None, Low, Moderate, High, and Very High were derived from the combination of the slope map and the material type categories according to Table 3. This table was developed specifically for this project, and reflects the structure of the Wilson and Keefer (1985) method employed within HAZUS.

The resulting landslide hazard map with relative designations Low, Mod, High, and Very High is shown as Figure 8. The relative hazard map depicts locations of higher and lower relative hazard at 10-meter grid spacing based on general material type and slope. Steep slopes tend to dominate the higher hazard zones throughout the county. Much of the mountainous Mt. Hood National Forest is identified as having an elevated landslide hazard, but steeper portions of the lowland Willamette Valley also have elevated landslide hazards. For example, areas of notable historic activity such as along the banks of the Willamette River north of Canby and the canyons east of Oregon City are highlighted as higher susceptibility areas on the landslide hazard map.

5.3.2 Historic Landslide Areas

Slopes that have failed in the past often remain in a weakened state, and many landslide areas tend to fail repeatedly over time. In some cases, areas that have previously failed have assumed rather subtle geometries and these areas may or may not be highlighted on relative hazard maps that emphasize slope (such as the one described in the previous subsection). Though the slopes can be more subtle, previously failed areas are still particularly important to identify, as they may still pose a substantial hazard for future instability.

In this study, we built a preliminary GIS database compilation of historic landslide areas by collecting data from Schlicker and Finlayson (1979), Hampton (1972), Orr and Miller (1986), Madin (1994), Sherrod and Scott (1995), Tolan and Beeson (1999), Miller and Orr (1984a, b), unpublished data from Leonard Orzol at the U.S. Geological Survey, and the Mt. Hood National Forest "Landslide" "Earthflow" and "Landform" layers available at http://www.reo.gov/mth/mth_data_www.htm. The methods employed to identify historic slide areas in these studies included such things as aerial photograph assessments, topographic map interpretations, and limited field reconnaissance. Using these sources, we simply used GIS operations to select areas mapped as landslide deposits and/or digitized the original maps to develop the database of known landslide areas.

The current GIS layer includes 1,527 historic landslide areas. Some of these landslide areas, however, overlap each other because of variations in interpretation by the individual mappers. For sources in the Willamette Valley, we performed some manual editing to minimize duplication of landslide entries by selecting the most topographically accurate source. For the sources in the Mt. Hood National Forest, however, there were major differences in the level of detail of the mapping between three valuable landslide map sources: the "Landslides" layer, and the landslide portions of the "Landform" and "Earthflow" layers. Rather than pick and choose polygons between these layers, we included all of them in this study for completeness.

While the existing information is not comprehensive, future efforts can build on and refine the data. An example of an add-on project is currently underway in the Mt. Hood National Forest (Tom Deroo, personal conversation). Mt. Hood Forest personnel are using the previously compiled GIS landslide data to focus more detailed studies in parts of the forest. Using the original mapping to prioritize areas, they are able to target specific watersheds for localized landslide topography mapping and fill in data gaps.

5.3.3 Landslide Impact Inventory

The third Clackamas County landslide map product is an inventory that was derived from a larger regional study previously conducted by DOGAMI (Hofmeister, 2000). This previous study incorporated information compiled by a number of federal, state, and local data sources following the 1996-97 storms in Oregon (Hofmeister, 2000). The Clackamas County subset of the statewide database consists of 882 impact locations. While the amount and quality of the associated data varies considerably, as discussed more fully in Hofmeister (2000), the format is easily expandable to include additional events as they are recorded. For example, the simple data form in Appendix C can be used in conjunction with the initial GIS database to efficiently gather new data on smaller numbers of landslide events. For more widespread events with larger numbers of landslide effects, GIS and/or spreadsheet applications can be used to efficiently incorporate new information and expand on this initial GIS file.

Landslide impact inventories are very valuable for tracking and monitoring historic effects, as well as planning for and mitigating future effects. Such inventories are also helpful for evaluating regional trends, calibrating existing hazards, and for developing new hazard identification and mitigation tools (see, for examples, Turner and Schuster, 1996). In general, the more extensive and complete the available base information, the more accurate follow-on studies can be.

5.4 Clackamas County Hazard Map Limitations

The Clackamas County hazard maps were developed with the best data available and with what were considered to be the most appropriate models. Yet, several limitations are worth noting. These limitations underscore that any relative hazard map is generally useful for regional applications, but should not be used as an alternative to site-specific studies in critical areas.

1. While it is possible to check for errors in the GIS and database operations, it is unfortunately not feasible to fully verify the original data on which the analyses are based. The geologic data in the less populated eastern portions of the county was particularly limited in terms of scale, and the available GIS layers were poorly georeferenced. Manual edits were made to try and improve some areas, but time constraints prohibited extensive modifications.
2. Within the Portland Metro region, the hazard zones identified in IMS-1 (Mabey and others, 1997) were predominately preserved. This mapping used

numerical estimations that resulted in some small pockets of hazard that may or may not reflect actual variations. We tested options for "cleaning" this file, but decided in the end to preserve most of the IMS-1 zones. Caution should be exercised when interpreting very small areas of elevated or reduced hazard within larger zones of constant hazard.

3. The hazard layers were developed from original sources that vary in scale, methods of development, and quality. Changes subsequent to the period of the original mapping—such as advancement of rock quarry boundaries, construction of large structures, and other land modifications—could affect the hazard ratings in some areas. Land modification is not expected to be a significant source of error, but it can be important in some areas.
4. Hazard classes were assigned based on regional data with substantial scatter. The most representative values were selected, but geologic materials do vary regionally and locally. Site-specific geologic features, such as the presence of daylighting discontinuities, unfavorably dipping bedding planes, seams of local weakness, and other causes of localized instability cannot realistically be determined on a regional basis for each cell. Yet these can be critical factors for particular areas.

Because of these limitations, the maps should not replace site-specific studies. However, the relative hazard maps can serve as useful tools for estimating the regional effects of future earthquake and landslide events.

6.0 EARTHQUAKE DAMAGE AND LOSS MODELING

The second major component of this study was to develop improved data and capabilities for the county to assess earthquake damages and losses. The purpose of damage and loss estimation is generally to evaluate resource requirements for earthquake effects and identify areas where pre-planning and mitigation can be implemented most effectively.

The state of the science in earthquake damage and loss estimation has improved dramatically over the last several years and new tools allow for relatively quick and reasonably accurate regional loss estimation. One such tool is the HAZUS[4] computer program developed by the Federal Emergency Management Agency (FEMA), the National Institute of Building Sciences (NIBS), and a host of other public and private partners (FEMA, 1999). The HAZUS software can be used to model a variety of earthquake scenarios and estimate regional damages, including building damage, lifeline damage (roads, utilities), injuries, and others.

A number of default databases are included within the HAZUS program. The majority of this data is based on national-scale information that often does not accurately reflect local conditions. To better account for local variability, the default databases in HAZUS can be updated with local information; and the software is designed specifically to incorporate user-specific updates to the data inputs (FEMA, 1999). In this study, we incorporated updates to the built environment data and the regional hazard maps presented in the preceding sections. With the HAZUS study region data updated, we ran several test scenarios and the results from two of them are summarized in the latter parts of this section.

6.1 Improvements to the HAZUS Built Environment Data

The collection of additional information and refinement of existing data on the built environment in Clackamas County was an important step to develop more refined data for the earthquake damage and loss estimation used in HAZUS. The key components of the built environment that were addressed in this study included updating information about the general building stock (e.g., characteristics of residential dwellings, business offices, warehouses), the essential facilities (e.g., hospitals, fire stations, emergency service centers), and the bridge inventories for the county.

Primary sources of information used to develop this updated information included:

1. A database of 9,519 commercial, industrial, and multi-family buildings within the Portland Metropolitan area boundary that was created from building surveys conducted between 1993 and 1997 by the Portland State University Department of Civil Engineering as a part of a regional earthquake assessment for Metro. The surveys were completed with the original FEMA-154 survey forms, and the results of the surveys were collected into a database (Metro, 1998).
2. Individual FEMA-154/HAZUS surveys of the essential facilities buildings. The survey forms were originally developed for screening the Oregon Department of Administrative Service inventory of state-owned structures. The surveys contain information from the FEMA-154 moderate-code form (FEMA, 1988) as well as occupancy types required for the HAZUS program. The buildings surveyed for Clackamas County include the major hospitals, fire stations, and police stations, public, and some private, schools not already included in the Metro database. In addition to visiting the sites, some of the data in the survey forms were obtained

[4] FEMA has developed a web site specifically for the HAZUS program that includes directions for obtaining the free software, user's manuals, technical manuals, and a host of related information: http://www.fema.gov/hazus/.

from facility managers for the buildings.

3. Geographic data files available from Clackamas County. This information included county tax lots (a subset of the complete tax assessor database dated Spring, 2002), a county K-12 school GIS file, and a police station GIS file, plus some other GIS information such as a file for Clackamas County streets. The tax lot file included tax lot numbers, addresses, building value, limited amounts of building area and use classifications, and general land use classifications.
4. U.S. Census 2000 data. Data includes numbers of housing units broken down by building, year built categories, population, etc. Data was developed from a sample taken from detailed census forms distributed to about 1/6 of the county residents. More information can be obtained from the U.S. Census Bureau American Fact Finder website: http://factfinder.census.gov.
5. Metro RLIS tax lot GIS shape file for Clackamas County. This file was derived from the Clackamas County tax assessor information, and dated the year 2000 (Eric Bohard, personal communication). It is, therefore, contemporaneous with the U.S. Census information.
6. GIS information available from the City of Wilsonville. This data included buildings within the city limits, building areas, number of units, and permit dates.
7. The Database Initiative Project available online from the Oregon Department of Education (http://dbi.ode.state.or.us/reportinfstructure.htm). This database was helpful in providing building areas and year built.

The following sections briefly describe the results of the updates to the default HAZUS components that were modified in this study. Appendix D provides additional detail and lists of values assigned to the current HAZUS study regions.

6.1.1 Building Inventories

The improved building inventory for Clackamas County (see Appendix D) consists of two main parts:

1. The general building stock, which is used to characterize the overall inventory of buildings in the county.
2. Essential facilities, which includes inventories of schools, hospitals, fire stations, police stations, and emergency operations centers.

6.1.1.1 The General Building Stock

The information that was used to generate the general building stock inventory was obtained from county tax assessor and GIS records, rapid surveys conducted by METRO for commercial buildings within the metropolitan boundary, and U.S. Census data. The general building stock inventory is aggregated by census tracts, and contains a total of 327 million square feet[5] of building area, 206 million of which is single-family residences. The buildings are categorized into classes of seismic vulnerability by their age and their construction type. The most common building construction types in Clackamas County are wood framed (more of these than all the other classes combined), followed by lesser amounts of reinforced concrete block, steel light framed, pre-cast concrete "tilt-up", and concrete shear wall buildings.

6.1.1.2 Essential Facilities

The essential facilities information was collected from the METRO surveys and additional surveys done specifically for this project. The inventory consists of 266 public K-12 school buildings, 46 private K-12 school buildings, 22 college or university buildings, four hospitals, four emergency operations centers, 47 fire stations, and 10 police stations. Buildings are individually categorized into classes of seismic vulnerability based on age and

[5]Units in this section and Appendix D are provided in the English system (as opposed to metric) to match the input units for the HAZUS program.

construction type. These buildings exhibit a wide range of ages, construction types, and seismic vulnerability. Several seismic rehabilitation projects are ongoing in these buildings in some areas of the county.

6.1.1.3 Summary of the Updated Building Inventory Compared to the HAZUS Default Data

One can fairly easily compare the updated study data to the HAZUS 99 default data (FEMA, 1999). Some summary numbers of how the magnitude of the improved building inventory data compares to the original HAZUS default data include:

- Total building area increased by 59% over the HAZUS default data.
- Single family residences increased by 75%.
- Commercial building area increased by 60%.
- Industrial building area increased by 24%.
- Government and school building area increased by 451%.

6.1.2 The Bridge Inventory

The Clackamas County bridge inventory was also enhanced in the HAZUS study region. The HAZUS default database contained 178 bridges for Clackamas County. However, 23 of these bridges were outside the county boundary and were deleted. After modifying the HAZUS default file, additional bridges from Clackamas County GIS files were added in two groups. The first add-on group consisted of 88 bridges located on major highways in Clackamas County. ODOT descriptions were not available for this first group so they were given a "general" classification (see FEMA, 1999). The second group consisted of 179 add-on bridges located on secondary highways. About 75% of the bridges in this second group had available ODOT descriptions. Merging the three groups of bridges, a total of 422 bridges are now included in the enhanced and more accurate bridge inventory file.

6.2 Inputting the Relative Hazard Maps

In addition to the built environment data updates, the relative hazard maps described in the previous section were used to update the HAZUS study region. To input the maps into HAZUS, specific formats and classifications are required. For ground shaking amplification hazard, the GIS polygons were incorporated into HAZUS by assigning the hazard polygons as follows: Low = Type 2, Moderate = Type 3, High = Type 4. For liquefaction, the layer hazard classes were assigned None/Very Low = Type 0, Low = Type 2, Moderate = Type 3, and High = Type 4. For landslides, we tested a number of options for incorporating the detailed hazard map information into the HAZUS program. Due to significant limitations in the number of polygons possible for input to HAZUS and diminishing returns in terms of improvements to the overall damage and loss estimation, however, we ended up going with the standard approach of assigning average values to each census tract within the county.

In addition to the GIS polygon inputs for the hazard mapping in HAZUS, assignment of representative census tract defaults had to be updated within the study region for ground shaking amplification and liquefaction hazards. The selections of representative census-tract values were made by comparing overlays of the detailed hazard maps, U.S. Geological Survey topographic quadrangle maps, and zoning maps to the census tract boundaries. The updated map layers and census tract selections are included in the HAZUS study region included with this report.

6.3 Sample Scenarios and Results

There are a number of active faults that may cause damage in Clackamas County (Frankel and others, 2002) and the updated HAZUS regions included with this report allow one to run any number of earthquake scenarios. To test the model and provide some examples, however, we have included results from two sample scenarios:

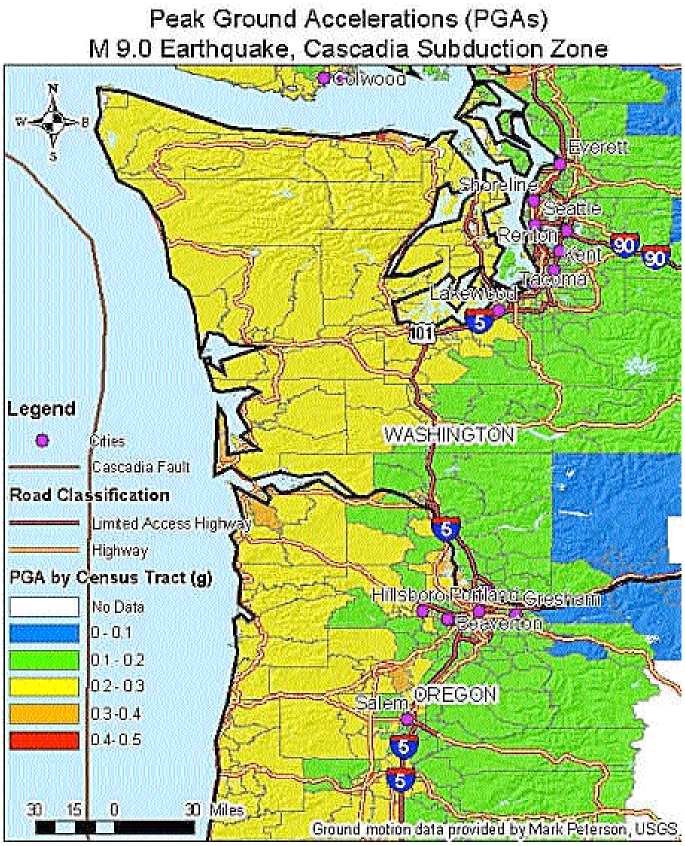

Figure 9. Peak ground accelerations (pga) for the CREW magnitude 9.0 Cascadia Subduction Zone scenario.

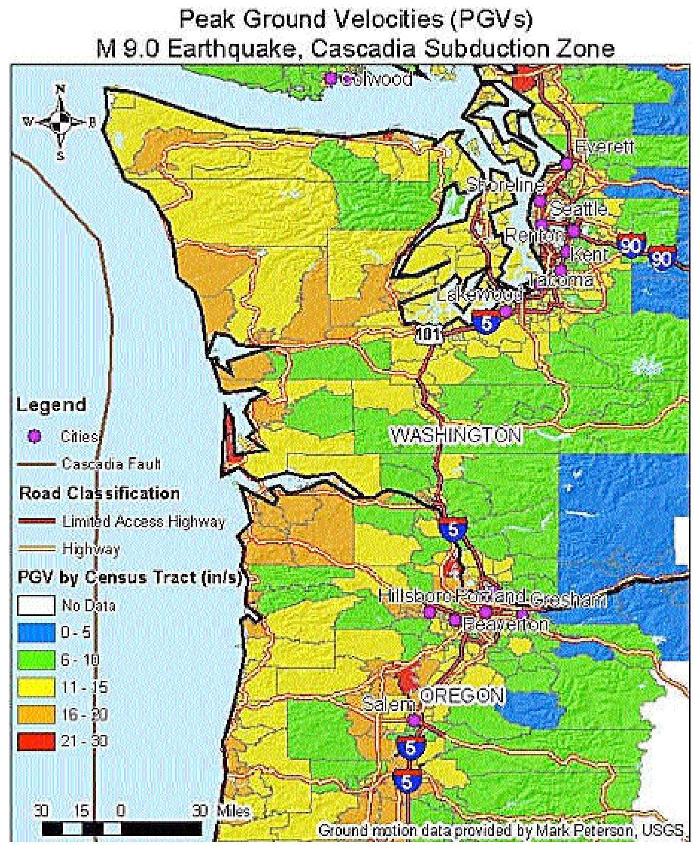

Figure 10. Peak ground velocities (pgv) for the CREW magnitude 9.0 Cascadia Subduction Zone scenario.

1. A magnitude 6.8 Portland Hills Fault earthquake
2. A magnitude 9.0 Cascadia Subduction Zone earthquake scenario developed by the Cascadia Region Earthquake Workgroup (CREW, 2003)

For the magnitude 6.8 Portland Hills Fault earthquake scenario, we defined the fault source using the "Arbitrary event" option within HAZUS, and the fault parameters are summarized on Page 6 of Appendix E. For the Cascadia Subduction Zone earthquake scenario, we used the "User-defined event" option within HAZUS to incorporate ground motion maps developed by CREW to model a magnitude 9.0 earthquake. The CREW maps were developed based on ground motion data provided by Mark Peterson at the U.S. Geological Survey, and Figures 9 and 10 show CREW regional peak ground acceleration (pga) and peak ground velocity (pgv) maps, respectively (CREW, 2003). The CREW earthquake scenario required the input of four sets of GIS files that are included within the HAZUS study region.

Global summary results from running the model for these two scenario earthquake scenarios are provided in Appendices E and F. The results from both models show that either earthquake would result in significant losses in Clackamas County. Of the two scenarios, the Portland Hills Fault earthquake is the most damaging. Results of the two scenarios are compared in Table 4.

The comparison table shows the expected damage from the Portland Hills Fault earthquake to be about four times more than the damage from the Cascadia Subduction Zone earthquake. Two factors should be used to assess the risk posed by the scenarios: the amount of expected damage, and the relative likelihood of an earthquake on these two faults. In the last two decades, the Cascadia Subduction Zone has been extensively studied and the average recurrence interval for this event is expected to be about 500 years. The recurrence interval of the Portland Hills Fault is less constrained, but recent studies have found evidence that suggests it has been active since the last Ice Age, about 12,000 years ago (Madin and Hemphill-Haley, 2001; Wong and others, 2001).

Another contrast between the two earthquake scenarios is the duration of shaking. Although the Cascadia Subduction Zone earthquake will not produce as violent a shaking episode as the Portland Hills Fault earthquake, the duration of strong shaking will be much longer. The Cascadia Subduction Zone earthquake may have a two-to-three minute duration of shaking as opposed to 20-30 seconds of strong shaking for the Portland Hills Fault earthquake. Due to some poor scientific and engineering constraints on the effect of the longer duration Cascadia Subduction Zone shaking, damages may be more severe than indicated by the current damage and loss estimation.

It is worth comparing the results of the current study with previous estimates of earthquake losses in Clackamas County, including Wang (1998) and G&E Engineering (1998). The statewide seismic risk assessment conducted by Wang (1998) indicated that a magnitude 8.5 Cascadia subduction zone earthquake could cause on the order of 130 injuries and fatalities and $320 million in building losses in Clackamas County. The Wang (1998) statewide study used HAZUS97 (FEMA, 1997—a predecessor to the HAZUS 99 SR2 software used in this study). The study was also based on default inventory data that underestimates the existing infrastructure and population base in Clackamas County.

The G&E Engineering (1998) report modeled a Portland Hills Magnitude 6.9 event, with a maximum ground acceleration of 0.48g. The estimated direct building damage for this scenario was $3.98 billion with 210 predicted fatalities and a like number of major injuries—the most damaging earthquake modeled in the study. The inventory data that G&E Engineering (1998) used was from 1990. Also, the predicted losses were based on the fact that all the buildings were assumed to be built to a low seismic standard.

The building inventory updates in this study account for changes in sectors of the building stock built since 1990 and buildings that have been built to a higher seismic standard. Given the improvements to the Clackamas County building inventory since both the Wang (1998) and G&E Engineering (1998) studies, plus shifts in building construction quality, and the slightly different scenario magnitudes used in this study, our results appear to be consistent.

6.4 HAZUS Modeling Limitations

The HAZUS study regions included with the data CD allow a user to run a variety of default and custom scenarios, as well as to evaluate probabilistic losses. This allows users a maximum amount of flexibility. It is important to note, however, that while HAZUS produces

Table 4. Comparison of the HAZUS results for the two sample scenarios in Clackamas County: a magnitude 6.8 Portland Hills Fault earthquake and a magnitude 9.0 Cascadia Subduction Zone earthquake.

Impact(s) estimated by HAZUS for Clackamas County	M 6.8 Portland Hills Fault	M 9.0 Cascadia Subduction Zone
Maximum ground acceleration (fraction of g)	0.47 g	0.18 g
Direct losses from building damage	$3.65 billion	$940 million
Moderate or greater damage to total building stock	40% of total building stock	12% of total building stock
Transportation system losses	$132 million	$43 million
Deaths (during afternoon business hours; losses much less if earthquake occurs at night)	190	39
Total injuries and casualties	3200	900
Displaced households	5400	700
Fully functional fire/police stations day after the earthquake	10 out of 47	44 out of 47
Functional bridges the day after the earthquake	310 out of 422	401 out of 422

statistically reasonable results, rather large uncertainties are associated with this type of modeling. These uncertainties arise from such things as the spatial variability of ground motions, aggregation of built environment data (primarily averaged by census tracts), and variations or errors in empirically derived algorithms implemented within the program (FEMA, 1999). These factors all limit the ability to precisely calculate regional damages and losses. HAZUS results should, therefore, only be used as order-of-magnitude estimates and any decision-making based on the results should consider the large uncertainties in the analyses.

7.0 POTENTIAL USES OF THE STUDY DATA

The primary purpose of the Clackamas County map and loss estimation tools provided with this study is to enable follow-on risk assessments and to focus resource allocation towards vulnerable areas. In general, the relative hazard maps should serve as useful tools for differentiating areas of higher and lower hazards. This spatial information is basic to emergency and land use applications, and the following short sections provide an overview of some common uses of the relative hazard maps and the earthquake damage and loss data.

The items discussed below are just a few potential applications. It is likely that the county will find unique and new applications to suit particular needs, above and beyond the discussion included here.

7.1 Emergency management applications

A particularly valuable use of the maps and loss estimation products is to aid in emergency management activities such as the development and refinement of emergency response plans, public outreach activities, selection of appropriate safe-haven sites, hazard response drills, and estimation of resource impacts for various earthquake hazard scenarios (Spangle Associates, 1998). A recent example of the latter two was the Oregon QuakeX ’03 earthquake exercise that Clackamas County participated in. Preliminary HAZUS results from this study were used by the county to tailor and refine emergency response activities during the mock earthquake drill.

In related applications, the county and others can now use the available landslide and liquefaction hazard maps to better identify infrastructure that is more or less likely to be damaged by major earthquakes and/or landslide-producing storm events. For example, by combining the hazard maps with transportation layers, potential road-blockages can be identified and alternative corridors identified. Similarly, the hazard maps can be combined with other information (such as the locations of hazardous waste facilities) to evaluate potential effects and to plan for emergency response.

HAZUS inputs and outputs are also tailored to address specific emergency management and emergency planning needs. HAZUS results provide estimates during various earthquake scenarios of such things as the number of displaced individuals needing shelter, medical facility needs (for minor and major injuries), and locations to concentrate rescue and recovery vehicles to limit damages. These estimates can be compared and contrasted with information on currently available facilities and resources within the county.

7.2 Land use planning, zoning, and regulations

Common applications of the study outputs in the realm of land use planning, zoning, and regulations include input to comprehensive planning and the development of hazard ordinances. While we reiterate the relative hazard maps are not appropriate for site-specific evaluations, they are valuable for regional screening for hazards and the selection of appropriate areas to focus further site-specific studies.

The landslide layers are particularly suitable for incorporation into county and city hillside development ordinances (along with the IMS-22 hazard zones in Hofmeister and others, 2002).[6] The liquefaction hazard map can also be used for regional screening of locations where further review may be warranted, and could be integrated into relevant local ordinances. The amplification hazard map is not as well suited for ordinance implementations because site amplification can generally be accounted for in standard infrastructure design phases. Therefore, amplification hazards are typically addressed by the adoption and enforcement of building code standards (Spangle Associates, 1998).

[6]Numerous examples exist of effective hillside ordinances in Oregon. One model that DOGAMI recently reviewed is the City of Salem implementation of the IMS-22 data using a risk matrix approach (City of Salem, 2003).

7.3 Evaluations of lifelines and other regionally distributed infrastructure

"Lifelines" is a general term used to refer to critical transportation and utility infrastructure, including roads and highways, railroads, airports, bridges, over-passes and under-passes, natural gas pipelines, electric lines, and water distribution systems. Many lifelines are characterized by components that are dispersed over broad geographic areas that often require regional (as opposed to site-specific) risk assessments. The hazard maps presented in this report can be particularly useful for estimating and mitigating damage to lifelines.

HAZUS includes regional risk assessment algorithms for lifelines, but assessments can also be made outside the HAZUS program and are not limited specifically to lifeline components. Any number of geographically dispersed infrastructure components can be evaluated by identifying the intersections of hazard zones with infrastructure inventories. It is relatively common in Oregon to incorporate regional hazard maps into the planning stages for lifelines such as natural gas pipelines and water distribution systems, and it is also appropriate in some cases to use the relative hazard maps to screen the planning process of larger developments. Comparing the maps to various development plans can provide valuable feedback on locations that may be worth avoiding (higher hazard areas) and locations where a denser concentration of structures may be preferable (in lower hazard areas).

7.4 Earthquake retrofit programs

While it is usually more cost-effective to take steps toward mitigation before development occurs, the reality is that we have a lot of existing buildings and other infrastructure components—and most were built prior to the incorporation of earthquake considerations into design codes. With some existing infrastructure, it makes sense to upgrade (or "retrofit") to higher earthquake design standards.

Critical and essential facilities, including fire, hospital, police stations, emergency centers and school buildings, are particularly important to the community and should ideally be designed to withstand earthquake shaking. These buildings have now been catalogued in this study and incorporated into the updated HAZUS building database and study region. Using this compiled information, essential facilities can now be more efficiently evaluated and prioritized for earthquake retrofits (by such methods as benefit-cost analyses).

7.5 Ongoing data consolidation efforts

The information included with this study is a substantial improvement upon previously available earthquake and landslide hazard information for the county. It is, however, based on data sources and evaluation techniques that will improve with time and attention. As reliable new information becomes available, we encourage the county to update these products.

With the landslide hazard data, in particular, the GIS layers for historic landslide areas and the landslide impact inventory can serve as an excellent starting point, but we encourage the county to build on the data by incorporating any additional information that becomes available. We also hope that, in the future, specific inventory efforts will be conducted to add to the available information base.

Similarly, the HAZUS study regions should be updated with additional local information. We focused specifically on the building inventory and hazard map parts of HAZUS in this study, but multiple other default files in HAZUS can be updated to take advantage of the many additional modeling capabilities within the program. For example, dam-break flood hazards can be evaluated using HAZUS if a properly formatted dam inventory is developed. Similarly, other inventory files and/or other parameters (e.g., local economic variables) used by HAZUS can be updated wherever and whenever more accurate local information is available for input.

These aforementioned examples are just a few of many potential applications that can build on the results from this study. Much more information on these and other applications can be found in related references such as Spangle Associates (1998), FEMA (2002), and Turner and Schuster (1996).

8.0 ACKNOWLEDGEMENTS

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10.0 APPENDIX A:

Steps and Sources Used to Develop the Clackamas County Ground Shaking Amplification and Liquefaction/Lateral Spread Hazard Layers

The following steps were used to develop the ground shaking amplification and liquefaction/lateral spread layers for Clackamas County:

1. Started by combining available digital GIS data from previous hazard studies and surface geology layers. The layers used include (full references listed at the end):
   - IMS-1 amplification and liquefaction layers (Mabey et al., 1997)
   - IMS-7 amplification and liquefaction layers (Madin and Wang, 1999)
   - IMS-8 amplification and liquefaction layers (Madin and Wang, 1999)
   - GMS-60 Damascas quad (Madin, 1994)
   - O'Connor's Willamette Valley Compilation (O'Connor et al., 2001)
   - Gannet and Caldwell (1998)
   - Leonard Orzol's combination of Gannett and Caldwell (1998) w/ the 500k state geo map (unpublished)
   - Ian Madin's modified version of the 500k state map (unpublished—derived from Walker and McLeod, 1991)
2. Compared and contrasted these layers with other available reports (listed in the references section at the end of this appendix) and data points (well logs and shear wave velocity profiles) to determine which polygons should serve as the primary basis for the susceptibility classifications.
3. Assigned susceptibility classes based on dominant lithologies for each unit in the study area.
4. Visually checked edges for inconsistencies and manually overrode inconsistent units.
5. Cleaned files by converting the UBC and liquefaction class assignments to a uniform GIS grid file and re-converted the grid files to clean polygon regions.
6. Manually shifted poorly characterized polygons in the Mt. Hood National Forest, clipped the original polygon file, and redid step 5 to develop the final output.

10.1 Additional notes (from local to regional):

1. DOGAMI IMS-1 (Mabey et al. 1997) zones are predominately preserved, with some UBC and liquefaction designations overwritten for better edge-matching. For liquefaction, quaternary sediments (except "gravel") with no liquefaction hazard in IMS-1 were globally overwritten to a liquefaction class of 1 (very low).
2. O'Connor formed the primary basis for the rest of the valley portions (outside of IMS-1).
3. GMS 60 (Damascus quad) and Gannet and Caldwell (1998) polygons were used outside the IMS-1 and O'Connor boundaries.
4. Madin's polygons from Walker and McLeod (1991) were used where no other data was available, and the areas were manually modified to better match the 7.5-minute USGS topographic base maps and available raster geologic data.

10.2 Appendix A Map References

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11.0 APPENDIX B:

Soil Map Designations for the Regional Landslide Hazard Mapping

11.1 Hazard Assignments for the SSURGO Units (NRCS, 1981):

HIGH

Coburg silty clay loam

Conser silty clay loam

Cove silty clay loam

Dayton silt loam

Cascade silt loam, stony substratum

Cazadero silty clay loam

Cottrell silty clay loam

Delena silt loam

Dystrochrepts

Hardscrabble silt loam

Helvetia silt loam

Jory silty clay loam

Jory stony silt loam

Kinney cobbly loam

Laurelwood silt loam

Mccully gravelly loam

Memaloose loam

Nekia silty clay loam

Saum silt loam

Borges silty clay loam

Springwater loam

Woodburn silt loam

LOW

Rock outcrop-cryochrepts complex

Witzel-rock outcrop complex

Newanna-rock outcrop complex

Multnomah silt loam

Newberg fine sandy loam

Newberg loam

11.2 Hazard Assignments for the Mt Hood SRI Units (USDA, 1979):

HIGH

2—Unstable sideslopes adjacent to major drainageways

15/15a/15w—Steep to very steep, unstable drainageways

103—Pyroclastic rock formation

LOW

7—Igneous rock outcrop

200/200s/200-7/201/201h/202/202a/204—Igneous rock formations

12.0 APPENDIX C:

Sample Landslide Inventory Data Sheet

(modified from Hofmeister, R.J., 2000, Slope failures in Oregon: GIS inventory for three 1996/97 storm events: *Oregon Department of Geology and Mineral Industries Special Paper 34*)

Recorder Information

Name: ____________________________ Phone Number: ________________________

Title: ____________________________ e-mail: ____________________________

Company/Department: ____

Landslide Characteristics

1) **Landslide ID:** ______________

2) **Landslide Name (if any):** ________________________________

3) **Location of Slide:**

Coordinates (e.g. Longitude/Latitude): ____________________________

Source of Location (e.g. field mapping on 1:24K Quads) or other (e.g. map attached, address, description): ____________________________

____

4) **Date(s) of Slide Activity:** _______________

5) **Estimated Dimensions:**

Length ________ feet (Conversions: 1 meter = 3.28 ft; 1 yard = 3 ft)

Width _________ feet

Depth _________ feet

Volume ________ $feet^3$ (Conversions: 1 $meter^3$ = 35.3 ft^3; 1 $yard^3$ = 27 ft^3)

Estimations from (e.g. field evaluation, aerial photos): ________________

____

6) **Predominate Type of Material:**

a) Rock __

b) Debris (coarse soils) __

c) Earth (fine soils) __

d) Fill __

7) **Predominate Type of Movement:**

a) Fall/Topple __

b) Flow __

c) Slide: Translational __

Rotational __

d) Spread __

8) **Other Slide Characteristics:**

a) Approximate original slope (e.g. 30 +/- 5 degrees): ____________________

Estimated from (e.g. inclinometer, 1:24K USGS topo map): ________________

b) Slide occurred in (please check all that apply):

__ Forested area __ Rural area

__ Harvested area __ Urban area

c) Contributing Factors (please check all that apply):

__ Road construction

__ Other construction:

__ Pre-existing slide

d) Damage caused by slide: ________________________________

9) **Additional Comments (please continue on back):**

Appendix D: Building Inventory Analyses for Clackamas County, Oregon

This appendix describes the development of an improved building inventory for Clackamas County, Oregon, used in the FEMA hazard analysis program HAZUS (FEMA, 1999). The HAZUS building inventory consists of two main parts:

1) **General building stock**, which is used to characterize the overall inventory of buildings in the county, and
2) **Essential facilities**, which includes databases of information on individual buildings for the various classes of essential facilities, including schools, hospitals, and emergency services.

As mentioned in the main text, the primary sources of information used to construct the inventory were the following:

- A database of 9,519 commercial, industrial, and multi-family buildings within the Portland Metropolitan area boundary that was created from building surveys conducted between 1993 and 1997 by the Portland State University Department of Civil Engineering as a part of a regional earthquake assessment for Metro. The surveys were completed with the original FEMA-154 survey forms, and the results of the surveys were collected into a database (Metro, 1998).
- Individual FEMA-154/HAZUS surveys of the essential facilities buildings. The survey forms were originally developed for screening the Oregon Department of Administrative Service inventory of state-owned structures. The surveys contain information from the FEMA-154 moderate-code form (FEMA, 1988) as well as occupancy types required for the HAZUS program. The buildings surveyed for Clackamas County include the major hospitals, fire stations, and police stations, public (and some private) schools not already included in the Metro database. In addition to visiting the sites, some of the data in the survey forms were obtained from facility managers for the buildings.
- Geographic data files available from Clackamas County. This information included county tax lots (a subset of the complete tax assessor database dated Spring, 2002), a county K-12 school GIS file, and a police station GIS file, plus some other GIS information such as a file for Clackamas County streets. The tax lot file included tax lot numbers, addresses, building value, limited amounts of building area and use classifications, and general land use classifications.
- U.S. Census 2000 data. Data includes numbers of housing units broken down by building, year built categories, population, etc. Data was developed from a sample taken from detailed census forms distributed to about 1/6 of the county residents. More information can be obtained from the U.S. Census Bureau American Fact Finder website: http://factfinder.census.gov.
- Metro RLIS tax lot GIS shape file for Clackamas County. This file was derived from the Clackamas County tax assessor information, and dated the year 2000 (Eric Bohard, personal communication). It is, therefore, contemporaneous with the U.S. Census information.
- GIS information available from the City of Wilsonville. This data included buildings within the city limits, building areas, number of units, and permit dates.

- The Database Initiative Project available online from the Oregon Department of Education (http://dbi.ode.state.or.us/reportinfstructure.htm). This database was helpful in providing building areas and year built.

General Building Stock

The data input to the HAZUS program for the general building stock consists of the following information:

- Square foot area of buildings by specific occupancy types, for each census tract in the county. There are a total of 52 census tracts in the county.
- Occupancy to model building type mapping. This data is crucial to determining the quantities of each structural building type in each tract, since square foot area is only input per occupancy type.
- Average building size in each occupancy category. This data is needed to generate building counts in the program.

The commercial and industrial building areas were determined primarily from the METRO/PSU database and the Clackamas County tax lots. Residential building areas were determined from the RLIS tax lots, Clackamas County tax lots and the US Census data. Mapping between the occupancy and structural building types was determined from the METRO/PSU database, with the exception of single family residences, which are all categorized as light wood framing.

The essential facilities databases and map files were assembled from the METRO/PSU database, which contained surveys of most of the schools, hospitals, police and fire stations within the METRO boundary; additional surveys conducted for this projects to complete the dataset for the county; and county tax lot, school, and emergency services data.

The input data determined from the inventory project compares to the HAZUS default data in these key aspects:

- Total building area increased by 59% over the HAZUS default data.
- Single family residences increased by 75%.
- Commercial building area increased by 60%.
- Industrial building area increased by 24%.
- Government and school building area increased by 451%.

METRO/PSU SURVEY DATABASE

Since much of the Clackamas County building inventory is developed from the METRO/PSU building database, it is important to describe the characteristics of this database. The database consists of 9519 building records and includes the name of the building, address, area in square feet, year built, HAZUS specific occupancy category and HAZUS building type category, and many more fields. The building distribution by structure type is shown in Figure 1. The buildings are distributed by occupancy (use of the building) as shown in Table 1.

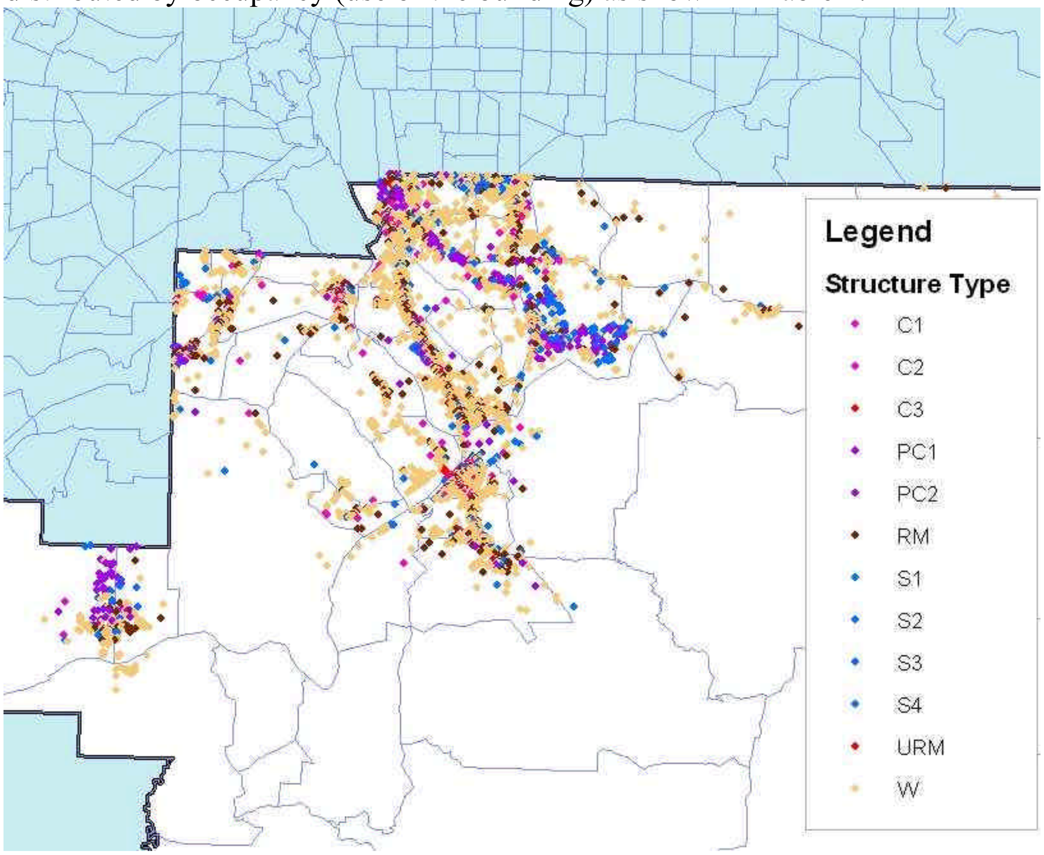

Figure 1. Buildings in the METRO/PSU database, categorized by structure type.

Table 1. METRO/PSU building distribution by HAZUS occupancy types.

Occupancy	**Description**	**Number of Buildings**
RES1	Single Family Dwelling	49
RES2	Mobile Home	0
RES3	Apartment/Condo	4161
RES4	Temporary Lodging	57
RES5	Institutional Dormitory	35
RES6	Nursing Home	85
COM1	Retail Store	604
COM2	Warehouse	414
COM3	Personal/Repair	368
COM4	Office	466
COM5	Bank	58
COM6	Hospital	5
COM7	Medical Office	147

COM8	Entertainment	277
COM9	Theater	2
COM10	Parking	544
IND1	Heavy Industry	0
IND2	Light Industry	481
IND3	Food/Drug	12
IND4	Metals/Minerals	0
IND5	High Technology	0
IND6	Construction	12
AGR1	Agriculture	0
REL1	Religion/Church	170
GOV1	General Government	293
GOV2	Emergency Response	76
EDU1	K-12 Schools	245
EDU2	Colleges/Universities	20
None		938

The buildings in the METRO/PSU database were also classified according to the specific building type categories required by HAZUS. The building type categories, which are specific construction styles describing the construction material, seismic bracing system, and building height are the classifications needed to determine damage predictions.

Table 2. METRO/PSU building distribution by HAZUS building types.

Model Building Type	**Description**	**Count**
W1	Wood, Light Framed	4711
W2	Wood, Heavy Framed or Large	2438
S1L	Steel Moment Resisting Frame	345
S1M	Steel Moment Resisting Frame	9
S2L	Steel Braced Frame	3
S3	Steel Light Frame	450
S4L	Steel Frame with Concrete Shear Walls	26
S4M	Steel Frame with Concrete Shear Walls	4
C1L	Concrete Moment Resisting Frame	31
C1M	Concrete Moment Resisting Frame	14
C1H	Concrete Moment Resisting Frame	1
C2L	Concrete Shear Wall	245
C2M	Concrete Shear Wall	13
C2H	Concrete Shear Wall	1
C3L	Concrete with Masonry Infill	3
PC1	Precast Tilt-up	357

PC2L	Precast Concrete Frame	5
URML	Unreinforced Masonry	42
URMM	Unreinforced Masonry	2
RM1L*	Reinforced Masonry	817
RM1M*	Reinforced Masonry	2

*All reinforced masonry buildings are classified as RM1, as this is the more common type. Floor and roof framing were not noted in the surveys.

CLACKAMAS COUNTY AND RLIS TAX LOT FILES

There are approximately 135,000 tax lots in Clackamas County with buildings. The breakdown of land uses in the tax lots from the year 2000 information in the RLIS tax lot file is shown in Table 3. The more recent database from Clackamas County reveals a similar breakdown, although not quite as specific (the building use field was largely unpopulated). The more recent data does show an increase in residential tax lots.

These databases contain two fields which were used to determine the aggregated building areas: building area and building value. The building area fields are populated mainly by residential properties, the extent of which can be seen in Figures 2 and 3. Also, not all residences have an associated building area, even though they are listed as having a building value. Therefore, the area fields were used to gauge the average building area, and value per square feet, but the total quantities were derived from the building value. For non-residential properties, building areas and value per square feet were determined from surveys, the ODE Database Initiative and the METRO/PSU database.

Table 3. Land use of tax lots in Clackamas County from the RLIS data.

LAND USE	Description	Count
AGR	agriculture	8,389
COM	commercial	3,559
FOR	forestry	8,946
IND	industrial	1,399
MFR	multi-family housing	3,312
RUR	rural	9,921
SFR	single family residential	84,269
VAC	vacant	15,537
TOTAL		**135,332**

Table 4. Land use of tax lots in Clackamas County from the Clackamas County data.

LAND USE	Description	Count
COM	commercial	4,414
EDU1	education	225

GOV1	government	1,785
IND	industrial	1,744
REL1	religious	502
RES	residential, general	84,448
RES1	single family residential	18,786
RES2	mobile homes	219
RES3	multi-family housing	3,598
RES4	hotel, motel	141
VACANT	vacant	19,604
TOTAL		**135,466**

METHODS FOR DETERMINING THE COMPOSITION OF THE COUNTY GENERAL BUILDING STOCK

Three methods were used to determine areas of the general building stock for Clackamas County:

- For single family and multi family residences, the building square foot areas were obtained from the tax lot files (RLIS and Clackamas County) and the US Census data.
- For schools (EDU1 and EDU2), hospitals (COM6), and emergency services buildings (GOV2), building square foot areas were summed directly from the building surveys.
- For other building occupancy types, building square foot areas were obtained from analyzing the METRO/PSU building database plus the Clackamas County tax lot file.

Single Family Residences

Single family residences for Clackamas County were taken from the RLIS tax lot file. The reason for using the RLIS building areas rather than the more recent Clackamas County building areas is the fact that the RLIS tax lot file differentiated between single and multi family residences. The method used was to determine the sum of the reported building areas for single family residences for each tract, then perform this calculation for each tract:

$A_{total} = A_{area} \times V_{value} \div V_{area}$

A_{total} = total <CATEGORY> bldg area for the tract
A_{area} = bldg area of nonzero area <CATEGORY> buildings for the tract
V_{value} = value of all <CATEGORY> buildings in the tract
V_{area} = value of nonzero area <CATEGORY> buildings in the tract

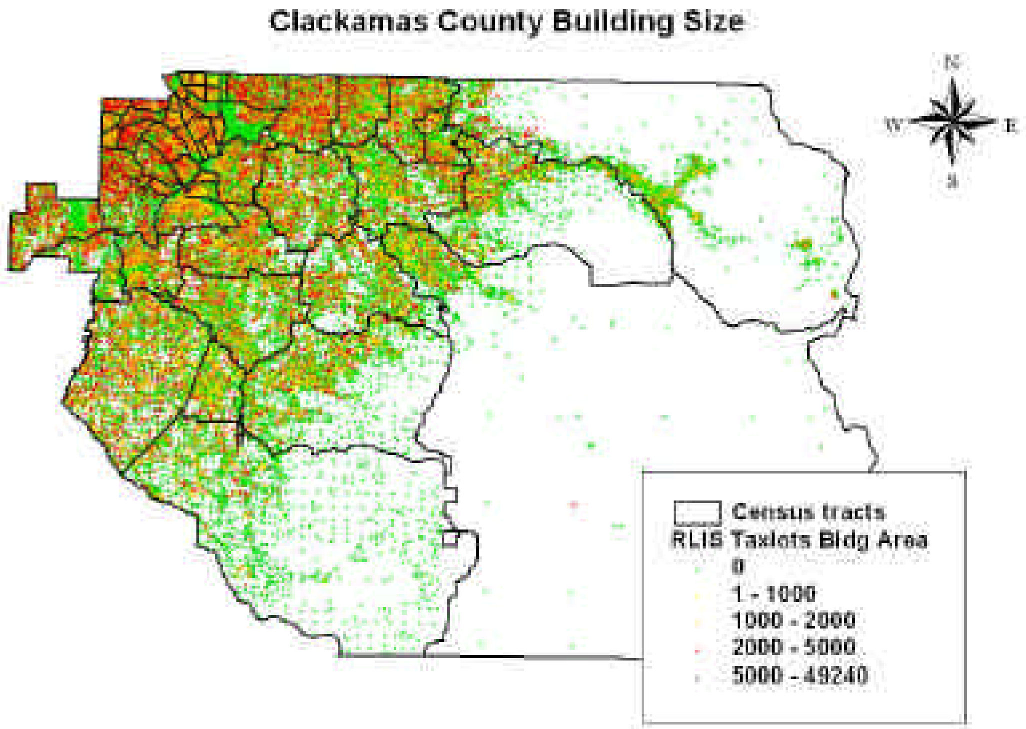

Figure 2. Building areas in the RLIS tax lot file. Building areas listed are residential. Some of the residential buildings are listed with no area but a nonzero building value. Large commercial zones are pure green (no listed areas).

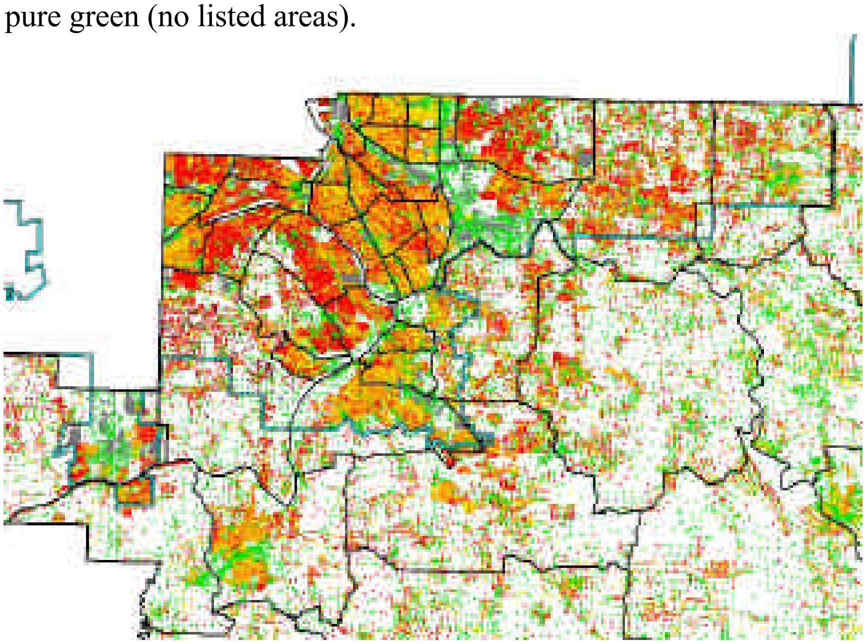

Figure 3. Building areas in the Clackamas County tax lot file (northwest corner of the county), using the same key as the RLIS tax lot file in Figure 2. Building areas listed are residential. The blue boundary line is the METRO boundary.

Nonzero value building counts of single family residences in the RLIS data were compared to the US Census detached housing units for each tract in the county. The results are shown in Table 5, which shows close agreement between the two for tracts within the METRO boundary, and fair agreement outside the boundary.

Table 5. METRO/PSU building distribution by HAZUS occupancy types.

Last 5 Digits of Census Tract Number	**Counts of RLIS Single Family tax lots SFR + RUR**	**Counts of US Census Single Family Units**	**Ratio of RLIS/Census**	**Relationship of Census Tract to METRO boundary**
20100	1456	1266	1.150	IN
20200	1890	1743	1.084	IN
20301	2523	2387	1.057	IN
20302	1180	1151	1.025	IN
20401	1883	1819	1.035	IN
20402	2712	2656	1.021	IN
20501	1217	1203	1.012	IN
20502	3761	3641	1.033	IN
20600	2401	2282	1.052	IN
20700	1174	1111	1.057	IN
20800	809	804	1.006	IN
20900	1172	1244	0.942	IN
21000	1543	1535	1.005	IN
21100	1797	1643	1.094	IN
21200	664	678	0.979	IN
21300	1807	1737	1.040	IN
21400	1424	1437	0.991	IN
21500	1441	1366	1.055	IN
21601	1093	1121	0.975	IN
21602	1162	1120	1.038	IN
21700	1388	1427	0.973	IN
21800	2728	2643	1.032	IN
21900	895	825	1.085	IN
22000	2101	1997	1.052	IN
22101	1786	1749	1.021	IN
22102	3079	3030	1.016	IN
22201	355	381	0.932	IN
22202	3909	3904	1.001	IN
22300	1844	1973	0.935	**PART**
22400	1244	1107	1.124	IN

22500	2068	2002	1.033	IN
22600	3826	3569	1.072	**PART**
22701	2336	2492	0.937	**PART**
22702	1671	1888	0.885	**PART**
22800	1418	1053	1.347	**PART**
22900	3649	3713	0.983	**OUT**
23000	1849	2174	0.851	**PART**
23100	1567	1862	0.842	**OUT**
23200	2847	2842	1.002	**PART**
23300	1523	1492	1.021	**PART**
23401	1115	1214	0.918	**OUT**
23402	1851	1720	1.076	**OUT**
23500	1229	1305	0.942	**OUT**
23600	826	1097	0.753	**OUT**
23700	1010	1304	0.775	**OUT**
23800	956	1868	0.512	**OUT**
23900	1896	1681	1.128	**OUT**
24000	417	664	0.628	**OUT**
24100	1011	1301	0.777	**OUT**
24200	1266	1331	0.951	**OUT**
24301	2788	3191	0.874	**OUT**
24302	1320	1467	0.900	**OUT**

Multi-family Housing

Multi-family housing building areas were more difficult to correlate between the data sources, due to the fact that tax lots contain multiple units, and the definition of what constitutes multi-family housing can vary between the datasets. The City of Wilsonville data were analyzed to determine an average unit size of about 1,000 sq. ft., much larger than that estimated between the RLIS data and the US Census data in Table 6. The RLIS values were used, and were computed similarly to the single family values. In addition, a value computed from the US Census counts was used in the tracts with zero areas computed from RLIS. The formula used was the average area (398 sq. ft.) multiplied by the US Census count for these tracts.

Table 6. Estimated multi-family housing areas per census tract. Areas listed are in square feet. The last column contains the values used in the HAZUS region.

Last 5 Digits of Census Tract Number	**MFR AREA from RLIS**	**US CENSUS MFR COUNTS**	**AVG AREA, S.F.**	**MFR ESTIMATE**
20100	108,797	449	242	108,797

20200	566,696	1198	473	566,696
20301	1,213,599	2574	471	1,213,599
20302	191,435	445	430	191,435
20401	157,540	244	646	157,540
20402	8,305	28	297	8,305
20501	748,753	670	1,118	748,753
20502	340,002	680	500	340,002
20600	166,225	425	391	166,225
20700	45,987	252	182	45,987
20800	577,440	1275	453	577,440
20900	60,282	406	148	60,282
21000	75,847	342	222	75,847
21100	69,335	517	134	69,335
21200	347,465	1201	289	347,465
21300	112,274	421	267	112,274
21400	272,233	588	463	272,233
21500	188,745	326	579	188,745
21601	258,593	917	282	258,593
21602	207,920	738	282	207,920
21700	589,225	899	655	589,225
21800	249,116	907	275	249,116
21900	104,649	511	205	104,649
22000	52,440	330	159	52,440
22101	199,693	447	447	199,693
22102	1,382,845	2535	546	1,382,845
22201	762,533	1799	424	762,533
22202	202,744	380	534	202,744
22300	90,623	374	242	90,623
22400	179,958	693	260	179,958
22500	17,532	1090	16	17,532
22600	384,161	1355	284	384,161
22701	1,284,516	2614	491	1,284,516
22702	68,179	408	167	68,179
22800	402,391	1077	374	402,391
22900	457,439	1378	332	457,439
23000	-	30	-	11,939
23100	-	14	-	5,571
23200	-	45	-	17,908
23300	-	50	-	19,898
23401	-	12	-	4,775
23402	126,313	548	230	126,313

23500	1,401	28	50	1,401
23600	-	6	-	2,388
23700	-	24	-	9,551
23800	-	59	-	23,479
23900	135,332	569	238	135,332
24000	-	327	-	130,132
24100	-	45	-	17,908
24200	31,883	297	107	31,883
24301	366,967	248	1,480	366,967
24302	-	62	-	24,673
	12,807,411		**398**	**13,075,634**

Finally, a comparison is made between the quantities computed as described from the RLIS data and the Clackamas County data. These are given in Table 7, and show that the total RLIS values add up to 94.6% of the Clackamas County data. The totals can also be compared to the HAZUS default value of 137,000,000 sq. ft. for combined residential areas RES1 and RES3. The estimate from RLIS is 60% greater than the default HAZUS value.

Mobile Homes/Manufactured Homes

Mobile home and manufactured home areas were not given in any of the tax lot files or the METRO/PSU data. The City of Wilsonville data did contain mobile homes, and an average size in Wilsonville is about 1400 sq. ft. This figure may be high – all the Wilsonville average values for residences exceeded the county average, due to the fact that newer dwellings are on average larger than older dwellings. However, without any other data to contradict it, this is the average size used. Unit numbers are from the US Census estimate.

Table 7. Comparison between computed RLIS building areas and total residential building areas for the Clackamas County data. Quantities listed are square foot area.

Last 5 Digits of Census Tract Number	**RLIS MFR AREA ESTIMATE**	**RLIS SFR AREA ESTIMATE**	**RLIS AREA TOTAL**	**CLACKAMAS COUNTY RES* AREA**
20100	108,797	3,754,609	3,863,406	3,793,400
20200	566,696	5,208,907	5,775,603	5,736,539
20301	1,213,599	6,732,701	7,946,301	8,179,900
20302	191,435	2,165,927	2,357,362	2,316,548
20401	157,540	3,630,085	3,787,625	3,585,015
20402	8,305	8,111,039	8,119,343	7,730,408
20501	748,753	3,663,231	4,411,984	5,143,748
20502	340,002	10,179,483	10,519,485	12,142,241

20600	166,225	6,254,682	6,420,907	6,016,544
20700	45,987	2,519,096	2,565,084	2,498,345
20800	577,440	1,953,403	2,530,843	2,714,208
20900	60,282	2,148,097	2,208,379	2,250,038
21000	75,847	2,638,690	2,714,537	2,616,471
21100	69,335	3,227,589	3,296,924	3,110,612
21200	347,465	1,371,671	1,719,136	2,258,665
21300	112,274	3,490,815	3,603,089	3,609,240
21400	272,233	2,980,128	3,252,361	3,232,763
21500	188,745	4,644,688	4,833,433	3,290,923
21601	258,593	1,553,012	1,811,604	2,071,899
21602	207,920	3,188,284	3,396,204	2,357,674
21700	589,225	3,065,464	3,654,689	3,690,823
21800	249,116	5,869,621	6,118,737	6,183,152
21900	104,649	1,528,859	1,633,508	1,712,763
22000	52,440	5,014,090	5,066,530	4,107,258
22101	199,693	3,849,574	4,049,268	3,738,448
22102	1,382,845	6,812,002	8,194,847	8,962,315
22201	762,533	601,899	1,364,432	1,837,703
22202	202,744	10,809,582	11,012,326	11,309,676
22300	90,623	4,886,924	4,977,547	5,275,980
22400	179,958	3,144,723	3,324,681	2,784,744
22500	17,532	3,834,899	3,852,431	4,001,822
22600	384,161	9,059,403	9,443,564	8,334,196
22701	1,284,516	6,556,985	7,841,500	8,082,757
22702	68,179	5,081,891	5,150,070	6,489,612
22800	402,391	3,143,760	3,546,151	4,002,129
22900	457,439	8,061,917	8,519,356	8,148,977
23000	11,939	3,566,031	3,577,970	4,803,101
23100	5,571	2,979,214	2,984,786	4,351,240
23200	17,908	6,646,580	6,664,488	7,450,392
23300	19,898	3,404,492	3,424,390	3,628,166
23401	4,775	2,282,630	2,287,406	2,716,945
23402	126,313	3,940,910	4,067,223	3,999,248
23500	1,401	2,065,522	2,066,922	2,940,640
23600	2,388	1,413,752	1,416,140	2,412,389
23700	9,551	1,724,515	1,734,065	3,054,664
23800	23,479	1,725,683	1,749,162	4,335,027
23900	135,332	3,868,335	4,003,667	3,491,226
24000	130,132	605,186	735,317	1,419,025
24100	17,908	1,811,118	1,829,026	2,676,130

24200	31,883	2,280,325	2,312,208	2,701,146
24301	366,967	4,779,622	5,146,589	5,112,620
24302	24,673	2,055,277	2,079,950	3,024,120
	13,075,634	**205,886,923**	**218,962,557**	**231,433,615**

Schools, Hospitals and Emergency Services.

These building areas were computed directly from building areas listed in the METRO/PSU database or buildings surveyed for this inventory. The building areas were obtained either from estimates made in the field, the ODE Database Initiative for schools, or by METRO during the assembly of the METRO/PSU database. The buildings surveyed for this inventory included 59 emergency services buildings, 4 hospitals and 56 schools, most of which were in Clackamas County outside of the Metro boundary.

Commercial, Industrial, and Religious Properties

This group of calculations includes all building occupancies not calculated previously. These types of buildings are well represented in the METRO/PSU database, and include a substantial portion of the building areas for each category. For the census tracts represented by the METRO/PSU database, building values other than residential total 3.9 billion dollars in the database as opposed to 1.4 billion dollars not included (from tax lots not represented by the database).

For non-residential buildings, the building square foot area field is not populated in the tax lot databases. The building value field is populated. Also, both building values and areas are given for buildings in the METRO/PSU database, so a procedure was developed from the METRO/PSU data to estimate the building areas based on building values listed in the tax lot databases for the remainder of the buildings in the county. An outline of the procedure is as follows:

1. Determine correlation between general occupancy categories derived from Clackamas County land use field and HAZUS specific occupancy categories for the buildings in the METRO/PSU database. These relationships are to be used to convert from the general occupancies to specific occupancies in other tax lots of the county. Correlation is based upon building value, not building areas, since the conversion will be made with building values. Table 8 shows the correlation table.
2. Aggregate building values for tax lots without METRO/PSU buildings by census tract and general occupancy categories derived from Clackamas County land use field.
3. Use the correlation relationships described in step 1 to convert building values into the HAZUS specific occupancy categories for each tract.
4. Convert from building value to building area using the average value/area ratio computed per tract from the buildings in the METRO/PSU database. If a per tract ratio is not available, then average value/area ratio for the entire database is used.

This procedure was tested on the METRO/PSU buildings, to see if building areas could be estimated by using the building values and general occupancy categories for their tax lots. Results are shown in Table 9. The results show that about 85% of the building areas in the database were recovered. About 7-1/2%, or half of the 15% discrepancy, is due to buildings which had listed area in the METRO/PSU database but no building value listed in the tax lot file. The no building value listing was not due to tax exemption status; tax exempt buildings have listed values, and the no value buildings were diversely distributed between the building occupancy categories. The explanation for the rest of the discrepancy is undetermined.

The building areas for the actual METRO/PSU database were then computed, and the building areas for non-METRO/PSU tax lots were estimated by the method described above, and added to the areas for the METRO/PSU buildings. Refer to Table 20 for the completed building areas.

Results for commercial and industrial buildings, without any corrections for no value tax lots, total 71.3 million sq. ft. for the method described above. This can be compared to 42.6 million sq. ft. for the HAZUS default data, based on the 1990 US Census figures and national averages. The estimated areas are 67% greater than the HAZUS default values. This is a large increase, but it is only 7% more than the increase for residential areas. One characteristic that may inflate the calculated areas is the fact that new construction calculated from building values will generally be higher in average value per area than older construction.

In another comparison, the total building area computed from building values listed in the RLIS tax lot database is 35.6 million sq. ft. for the commercial and industrial categories, and 56.5 million sq. ft., including commercial, industrial, agricultural, and forestry categories. A comparison was run for tract values for both the calculated commercial areas and the RLIS areas. The results are shown in Table 10. The RLIS areas did not correlate well with the tract characters and the areas were far below the known areas from the METRO/PSU database. Also, the RLIS agriculture and forestry areas did not improve the correlation. Therefore, the commercial building area estimate was not adjusted due to its difference with the RLIS data.

The completed building areas in thousand square feet are listed for all occupancy types and census tracts in Table 20.

Table 8. Correlation table between general occupancy categories derived from Clackamas County land use field and HAZUS specific occupancy categories. This was computed on the tax lots populated by the buildings in the METRO/PSU database. Refer to Table 1 for descriptions of HAZUS specific occupancy types.

HAZUS occupancy	**no category**	**COM**	**EDU1**	**GOV1**	**IND**	**REL1**	**RES**	**RES1**	**RES2**	**RES3**
COM1	**2.8%**	**30.6%**	0.0%	0.4%	**2.0%**	**1.2%**	0.1%	0.0%	0.0%	0.1%
COM10	**5.1%**	0.2%	0.0%	0.0%	0.0%	0.1%	**2.3%**	0.3%	**0.5%**	**1.9%**
COM2	**18.9%**	**7.9%**	0.3%	0.0%	**45.9%**	0.3%	0.4%	**7.6%**	**12.3%**	0.0%

COM3	**0.5%**	**4.5%**	0.0%	0.3%	**1.6%**	0.2%	**0.8%**	0.0%	**3.5%**	0.2%
COM4	**11.9%**	**20.2%**	0.2%	**2.2%**	**6.9%**	0.2%	0.2%	0.1%	**26.9%**	**3.3%**
COM5	0.0%	**2.4%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
COM6	0.0%	0.5%	0.0%	0.0%	0.0%	**9.5%**	0.0%	0.0%	0.0%	0.0%
COM7	0.0%	**5.2%**	0.2%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
COM8	0.0%	**10.2%**	0.0%	0.3%	0.1%	0.0%	**3.6%**	**8.0%**	**3.0%**	0.1%
COM9	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
EDU1	**11.1%**	**0.9%**	**96.1%**	0.2%	0.0%	**6.8%**	**0.9%**	**6.2%**	0.0%	0.0%
EDU2	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
GOV1	0.0%	**0.9%**	**0.5%**	**90.6%**	**0.9%**	0.0%	**7.9%**	**1.7%**	0.0%	0.0%
GOV2	0.0%	**8.0%**	0.0%	**3.8%**	0.4%	0.0%	**0.7%**	0.0%	0.0%	0.0%
IND2	**15.9%**	**1.2%**	0.1%	0.2%	**39.2%**	**1.1%**	**0.6%**	**1.3%**	0.0%	0.1%
IND3	0.0%	0.0%	0.0%	0.0%	**2.8%**	0.0%	0.0%	0.0%	0.0%	0.0%
IND6	0.0%	0.5%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
REL1	0.0%	0.2%	0.4%	0.0%	0.0%	**77.3%**	**2.6%**	**6.5%**	0.0%	0.0%
RES1	**33.6%**	0.1%	**1.7%**	0.0%	0.0%	0.1%	**2.0%**	**2.8%**	**1.8%**	0.1%
RES3	0.0%	**0.9%**	0.1%	**0.9%**	0.0%	**2.9%**	**77.1%**	**61.6%**	**52.1%**	**83.2%**
RES4	0.0%	**4.6%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RES5	0.0%	0.0%	0.3%	0.0%	0.0%	0.3%	**0.8%**	0.0%	0.0%	0.0%
RES6	0.0%	**1.0%**	0.0%	**1.2%**	0.0%	0.0%	0.0%	**3.9%**	0.0%	**10.9%**

Table 9. Check of method for estimating building areas for commercial and industrial properties. Check compares known buildings in the METRO/PSU database with a reconstruction of this data from the tax lot data. Tracts outside the 80%-125% range are shown in bold.

Last 5 Digits of Census Tract Number	**Building areas computed from tax lot info for METRO/PSU buildings**	**Actual building areas for METRO/PSU buildings**	**Comparison between actual and estimated building areas**
20100	683,840	807,285	84.7%
20200	2,255,643	3,441,926	**65.5%**
20301	3,052,225	3,045,598	100.2%
20302	2,314,351	2,576,755	89.8%
20401	1,277,587	1,510,837	84.6%
20402	330,011	347,989	94.8%
20501	114,675	113,198	101.3%
20502	1,576,311	1,620,592	97.3%
20600	958,366	1,199,781	**79.9%**

20700	400,796	413,340	97.0%
20800	4,156,619	6,640,593	**62.6%**
20900	850,606	848,069	100.3%
21000	1,438,829	1,308,832	109.9%
21100	765,746	762,653	100.4%
21200	1,696,480	2,280,094	**74.4%**
21300	958,495	1,069,971	89.6%
21400	1,102,678	1,496,368	**73.7%**
21500	4,098,269	6,295,264	**65.1%**
21601	1,435,755	1,624,111	88.4%
21602	1,704,687	1,268,642	**134.4%**
21700	1,856,346	2,624,591	**70.7%**
21800	1,787,727	2,016,421	88.7%
21900	671,610	848,949	**79.1%**
22000	1,042,311	1,202,664	86.7%
22101	577,960	849,783	**68.0%**
22102	13,168,967	13,243,049	99.4%
22201	2,418,224	4,761,252	**50.8%**
22202	1,480,400	1,344,774	110.1%
22300	2,074,900	1,701,077	122.0%
22400	2,228,415	2,388,678	93.3%
22500	1,500,161	1,672,807	89.7%
22600	2,972,734	4,353,087	**68.3%**
22701	7,272,010	9,228,893	**78.8%**
22702	3,128,250	1,436,414	**217.8%**
22800	375,930	670,932	**56.0%**
23000	12,252	30,525	**40.1%**
23200	489,879	457,255	107.1%
23300	580,466	814,637	**71.3%**
TOTAL	**74,810,510**	**88,317,686**	**84.7%**

Table 10. Comparison between RLIS commercial building areas and building areas estimated from the METRO/PSU database and the Clackamas County tax lot building values.

Last 5 Digits of Census Tract Number	Commercial Building Area Estimate from METRO/PSU and Clackamas County Taxlot Data	METRO/PSU Commercial Areas Alone	RLIS Commercial Areas
20100	530,083	496,483	415,149
20200	1,519,005	1,338,213	347,365
20301	1,411,334	594,385	926,051
20302	2,699,049	1,638,115	1,321,448
20401	493,257	367,978	109,960
20402	32,179	25,865	8,085
20501	426,830	-	69,501
20502	339,992	249,593	131,089
20600	178,247	159,232	120,152
20700	308,085	124,143	106,109
20800	3,357,952	3,086,852	299,765
20900	217,620	195,505	148,883
21000	266,615	254,816	6,478
21100	171,817	165,253	76,139
21200	206,343	195,353	59,150
21300	308,781	299,235	117,419
21400	774,911	756,514	160,961
21500	2,770,912	2,297,658	148,888
21601	920,521	857,572	133,549
21602	438,200	424,281	169,064
21700	904,511	861,143	633,005
21800	784,706	749,001	119,512
21900	328,079	304,440	542,123
22000	299,819	201,985	87,736
22101	171,280	86,885	51,513
22102	12,288,015	7,609,869	996,726
22201	2,882,240	1,950,779	623,517
22202	857,424	561,704	14,380
22300	519,388	423,802	327,351
22400	972,870	932,386	2,050,209
22500	555,315	478,041	521,383

22600	2,808,937	2,074,424	294,767
22701	6,415,367	4,048,426	509,354
22702	648,373	324,964	582,202
22800	237,483	68,950	47,306
23000	59,234	8,400	312,284
23200	385,537	272,647	6,782
23300	396,761	328,335	12,050
22900	1,660,111		68,781
23100	209,786		39,300
23401	363,553		115,409
23402	717,233		312,295
23500	136,528		13,578
23600	12,463		845
23700	232,066		71,731
23800	278,413		39,623
23900	977,222		488,183
24000	16,666		470
24100	80,065		16,185
24200	437,907		698,026
24301	1,273,306		4,240,124
24302	70,901		15,832
TOTAL	**55,353,292**	**34,813,227**	**18,727,786**

OCCUPANCY TO MODEL BUILDING TYPE MAPPING SCHEMES

A mapping scheme gives a breakdown of the square foot area for each occupancy category into the building construction types. These building construction types are categorized in the HAZUS User's Manual and are referred to as Model Building Types. See Table 2 for descriptions. The mapping scheme also categorizes buildings into the following groups:

- Seismic code which was enforced when the buildings were built. The levels correspond roughly to the following Uniform Building Code (UBC) seismic zones:
  - i. high code – UBC seismic zone 4
  - ii. moderate code – UBC seismic zone 2B
  - iii. low code – UBC seismic zone 1

  See Figure 4 for a more complete description.
- Building construction compared to the governing code – built to code, inferior to code, or superior to code.

HAZUS uses occupancy categories as the determining factor in building size. The square foot inventories are input by occupancy category and then mapped by the program into building construction types. Building construction types are the broad categories used for determining the damage to buildings in an earthquake. Building damage curves are also sub-categorized by the code standard to which the building was designed. Refer to Figure 4 for the code classifications for the general building stock.

Table 5.20 Guidelines for Selection of Damage Functions for Typical Buildings Based on *UBC* Seismic Zone and Building Age

UBC Seismic Zone (NEHRP Map Area)	Post-1975	1941 - 1975	Pre-1941
Zone 4 (Map Area 7)	High-Code	Moderate-Code	Pre-Code (W1 = Moderate-Code)
Zone 3 (Map Area 6)	Moderate-Code	Moderate-Code	Pre-Code (W1 = Moderate-Code)
Zone 2B (Map Area 5)	Moderate-Code	Low-Code	Pre-Code (W1 = Low-Code)
Zone 2A (Map Area 4)	Low-Code	Low-Code	Pre-Code (W1 = Low-Code)
Zone 1 (Map Area 2/3)	Low-Code	Pre-Code (W1 = Low-Code)	Pre-Code (W1 = Low-Code)
Zone 0 (Map Area 1)	Pre-Code (W1 = Low-Code)	Pre-Code (W1 = Low-Code)	Pre-Code (W1 = Low-Code)

Figure 4. HAZUS Code classifications for buildings of various ages and Uniform Building Code seismic zones for the general building stock. Classifications which apply to Oregon are highlighted.

In order to create a mapping scheme, a sample of buildings must be taken in which one has both occupancy and building type information. This information is not available for all of the buildings in the county, but it is available for buildings in the METRO/PSU database and also the essential facilities surveys. For the occupancy types represented by these data, mapping schemes can be developed. A notable exception is single family residences, which are not represented in the datasets for building construction type. However, since most single family construction in Oregon is light wood framing, this is the assumed type for this major section of the building inventory.

The strategy for occupancy types other than single family residences was to generate the mapping schemes from the METRO/PSU data, based on the mean age of buildings in the tract. Three sets of mapping schemes were developed – one for tracts with a composite mean age of 1960, another for tracts with a composite mean of 1970, and a third with a mean composite age of 1982. Building ages were determined from the buildings listed in the METRO/PSU database plus the tax lots in the Clackamas County tax lot file which do not contain METRO/PSU buildings. Building ages are averaged by count of buildings (or tax lots).

Predominant building construction types are very dependent upon the age of the building. Figure 5 illustrates the building construction types for the METRO/PSU database which contains mainly commercial, industrial, government, and multi-family housing occupancy types. Wood framed commercial buildings were not common for the first half of the twentieth century, since many large American cities were burned in the late 1800's or early 1900's. Unreinforced masonry and lightly reinforced concrete were the predominant commercial building types in this period. There has been a steady shift of construction types since World War II, as skilled labor prices have increased, building codes for earthquakes have evolved, and markets have globalized. Wood framed, steel framed, precast concrete tilt-up and reinforced masonry building types dominated the commercial building stock in Oregon in the late 1900's.

Another important characteristic about age groupings for buildings is that seismic performance is dependent upon age – for any given building type, the older buildings were built to a less stringent building code, plus older buildings may be in poor condition from factors related to age (i.e., corrosion, dry rot, mortar deterioration, exposure, fatigue). Therefore, age is the single most important characteristic of a group of buildings which will influence seismic performance.

In creating the age-based building mapping schemes, all the Clackamas County tracts were classified by their mean building ages into Old, Mid-range, or New categories. The composite mean ages for the Old, Mid-range, and New categories were also determined from all the buildings included in the tracts so classified. A statistical t-test was used to determine that the tract fit best in its assigned category. Figure 6 illustrates the distribution of building age in all the tracts of the county.

In addition to the tract-age separations, the buildings in the general stock were further classified into the following sub-categories based on Figure 4 from the HAZUS technical manual and the Oregon state building codes:

Table 11. Building classifications within mapping schemes are also based upon the age of the building according to this scheme.

Year Built	**Code**	**Condition (Bias)**
to 1940	Low	Inferior (Poor)
1941 to 1977	Low	To Code
1978 to present	Moderate	To Code

The building occupancy types classified as described above were the commercial, industrial, religious, and all residential building types except for single family and mobile homes. Mapping scheme data for essential facilities such as emergency services, schools and hospitals were developed directly from the survey data for the tract groups. Single family residences were classified as W1, light wood framing, and mobile homes classified as MH, mobile homes. Age categories of single family and multifamily residential were determined from the RLIS tax lot database.

The completed mapping schemes are shown in Tables 14 to 19. Numbers in the mapping schemes represent the percentage of the total square foot areas that will be in a construction type category, for any particular occupancy category. Combined with the square foot areas in Table 20, one can figure out the square foot area totals for the building type categories. Building counts are then calculated in HAZUS using the average square foot building areas in Table 21.

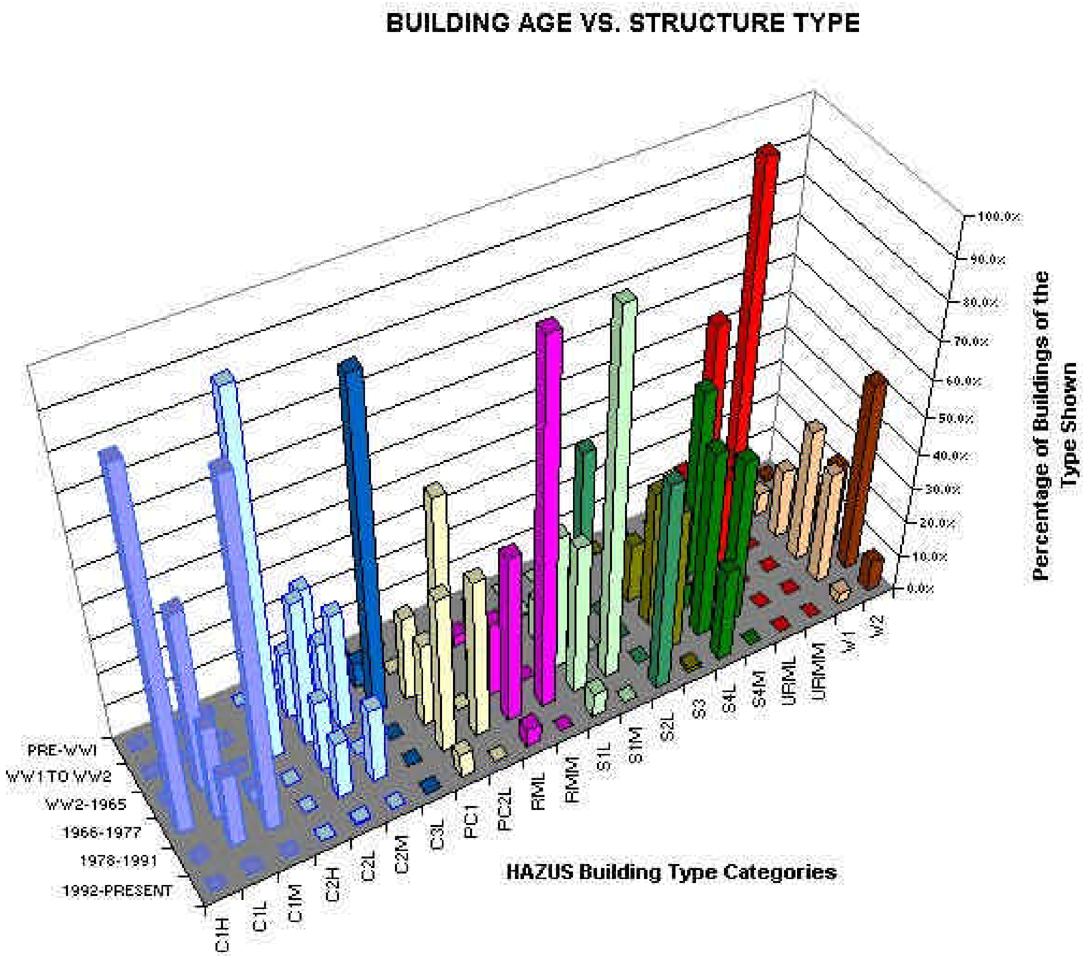

Figure 5. Building construction types vs. age for the buildings in the METRO/PSU database.

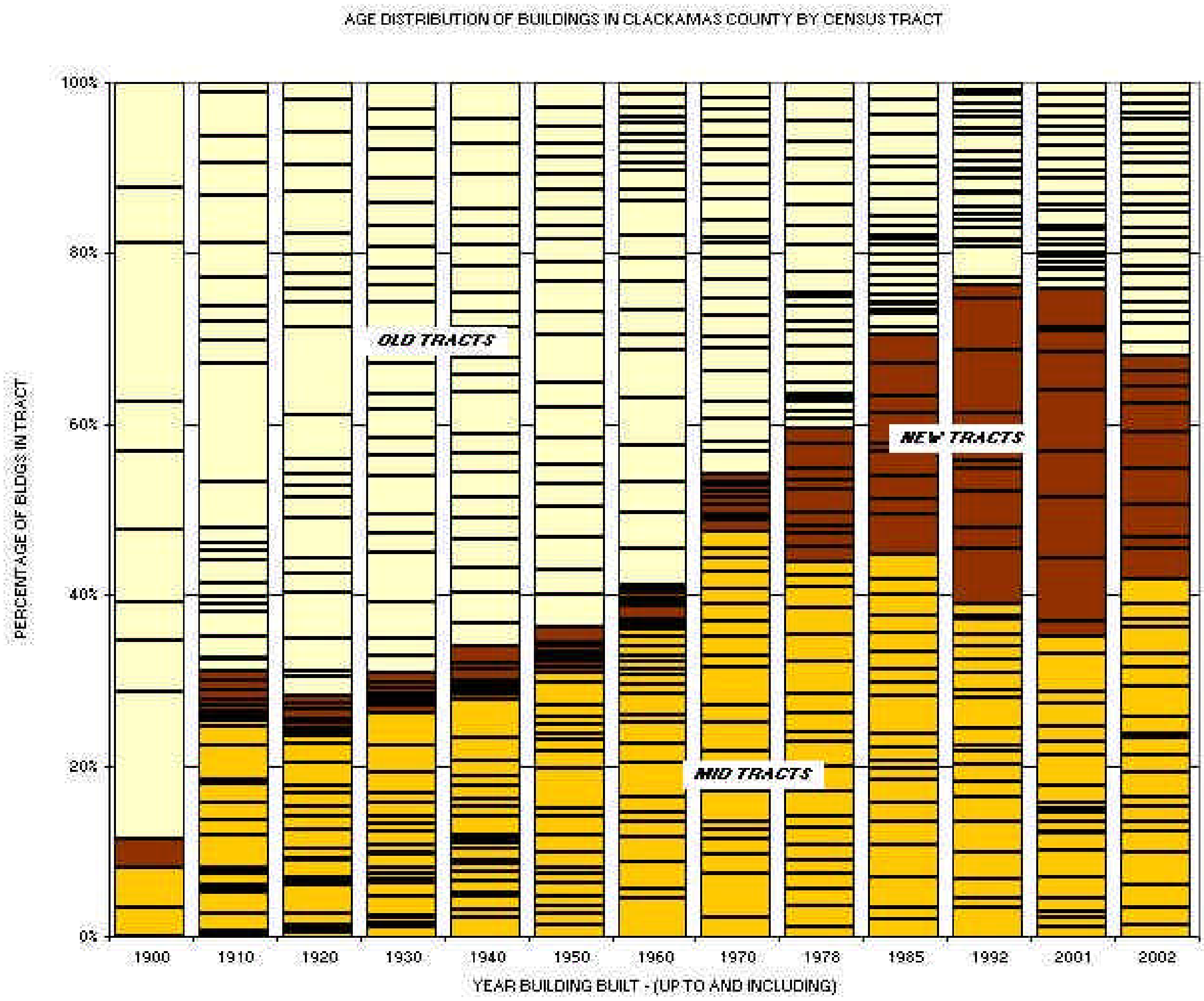

Figure 6. Graph of building age distributions for the 3 mapping schemes.

ESSENTIAL FACILITIES DATA FOR CLACKAMAS COUNTY

As mentioned previously, particular data was collected from surveys for the essential facilities of Clackamas County. Information for the compilation came primarily from sidewalk surveys conducted by Portland State University during the METRO/PSU survey, additional survey work conducted by Portland State University for this study, and information obtained from the facilities managers of the buildings surveyed. Additional information for schools was available from the Database Initiative which is available from the ODE web site, other school websites, and GIS files from Clackamas County.

Fire station construction types, year built, and year seismically upgraded were all verified for the county. Most police stations were also verified for these items. Fire stations and smaller police stations are amongst the most simple essential facilities structures to classify and verify construction. The HAZUS analysis of these should provide a reasonably good picture of the vulnerability of these systems.

Particular attention was paid to clarifying the lists of currently used public school buildings. It was not always possible to verify construction types and year built/seismically upgraded with building facility managers for all the school districts; however, this information is recorded when available. Some private schools were surveyed but these received minimal attention in the survey. School buildings can often be a conglomerate of construction types, ages, and inter-connections. The HAZUS damage predictions for these buildings will therefore be less accurate than that for the fire and police stations.

Hospital information was obtained from facility managers for all 4 major hospitals in Clackamas County – however these structures are amongst the most complex buildings in the county, with numerous construction types and seismic bracing systems connected together into highly complex forms. A simplistic individual building analysis of the type which HAZUS employs really cannot predict very well the response of such structures. Also, since these buildings are places where injured persons will be treated in an emergency such as an earthquake, a more in depth analysis of their preparedness is highly recommended.

Essential facilities are classified in a manner similar to that of the general building stock. Building damage curves are categorized by the code standard to which the building was designed. They are sub-categorized into condition (bias) categories of inferior (poor) condition, built to code (standard condition), and superior condition which is used for specially designed structures. Refer to Figure 7 for the code classifications for essential facilities in the HAZUS technical manual. Note that essential facilities built under modern codes in regions of high seismicity are specially designed to withstand higher forces than ordinary buildings. Accordingly, the essential facilities in Clackamas County were categorized according to Table 12.

Table 6.10 Guidelines for Selection of Damage Functions for Essential Facilities Based on *UBC* Seismic Zone and Building Age

UBC Seismic Zone (NEHRP Map Area)	Post-1973	1941 - 1973	Pre-1941
Zone 4 (Map Area 7)	Special High-Code	Moderate-Code	Pre-Code (W1 = Moderate-Code)
Zone 3 (Map Area 6)	Special Moderate-Code	Moderate-Code	Pre-Code (W1 = Moderate-Code)
Zone 2B (Map Area 5)	Moderate-Code	Low-Code	Pre-Code (W1 = Low-Code)
Zone 2A (Map Area 4)	Low-Code	Low-Code	Pre-Code (W1 = Low-Code)
Zone 1 Map Area 2/3)	Low-Code	Pre-Code (W1 = Low-Code)	Pre-Code (W1 = Low-Code)
Zone 0 (Map Area 1)	Pre-Code (W1 = Low-Code)	Pre-Code (W1 = Low-Code)	Pre-Code (W1 = Low-Code)

Figure 7. HAZUS Code classifications for buildings of various ages and Uniform Building Code seismic zones for essential facilities. Classifications which apply to Oregon are highlighted.

Table 12. Building classifications within mapping schemes are also based upon the age of the building according to this scheme.

Year Built or Seismic Upgrade	Code	Condition (Bias)
to 1940	Low	Inferior (Poor)
1941 to 1977	Low	To Code
1978 to 1992 or upgraded after 1992	Moderate	To Code
Built after 1992	Moderate	Superior

HAZUS DEFAULT DATA VS. THE RESULTS OF THIS STUDY

One can run comparisons of the study data to the HAZUS 99 default data (FEMA, 1999). HAZUS default data is compiled from national data which includes US Census data (1990 census for HAZUS 99). Referring to Table 13, the single family residence total shows an increase of nearly 75%, which could largely be attributed to population growth from 1990. Most residential categories show an increase in area from the default values, with exceptions being multifamily housing and institutional dormitories.

Commercial building area increased by 60%, same as the overall increase in building area. Industrial building area increased by 24%. Religious buildings stayed close to the same amount of building area as the HAZUS default data. Government and school buildings are 451% greater in the study data set.

Looking at the totals, the study data set contains 59% more building area than the HAZUS default data.

APPENDIX D: REFERENCES

Federal Emergency Management Agency (FEMA), 1999, HAZUS, FEMA's tool for estimating potential losses from natural disasters: Available on CD-ROM disks from the Federal Emergency Management Agency (FEMA) or the National Institute of Building Sciences 1090 Vermont Avenue, NW, Suite 700 Washington, DC, 20005-4905, phone (202) 289-7800, fax (202) 289-1092, e-mail hazus@nibs.org. Internet http://www.fema.gov/HAZUS/

Metro, 1998, Evaluation of non-residential and multi-family residential buildings for seismic risk: Report prepared by Metro with the assistance from Portland State University, Civil Engineering Department, Funded by the Federal Emergency Management Agency, FEMA Contract No. EMS-96-CA-0055.

Table 13. A comparison of data from this study and HAZUS default data. Quantities are thousand square feet of building area for the entire county.

Occupancy Category	Description	Study Building Quantities	Default HAZUS Totals
RES1	Single Family Dwelling	205,887	117,956
RES2	Mobile Home	16,160	10,359
RES3	Apartment/Condo	13,075	19,060
RES4	Temporary Lodging	1,799	573
RES5	Institutional Dormitory	130	1,799
RES6	Nursing Home	416	243
COM1	Retail Store	17,162	7,789
COM2	Warehouse	19,716	9,722
COM3	Personal/Repair	3,237	3,327
COM4	Office	8,900	9,199
COM5	Bank	648	442
COM6	Hospital	859	797
COM7	Medical Office	1,907	1,488
COM8	Entertainment	3,101	2,152
COM9	Theater	131	40
COM10	Parking	100	-
IND1	Heavy Industry	-	4,864
IND2	Light Industry	15,076	3,210
IND3	Food/Drug	682	822
IND4	Metals/Minerals	-	381
IND5	High Technology	-	53
IND6	Construction	196	3,563
AGR1	Agriculture	-	1,818
REL1	Religion/Church	3,018	2,961
GOV1	General Government	5,477	558
GOV2	Emergency Response	519	30
EDU1	K-12 Schools	8,447	2,496
EDU2	College/University	645	258
TOTAL		**327,288**	**205,958**

APPENDIX E:
HAZUS 99-SR2: Earthquake Event Report

Region Name: Clackamas County with PDX Hills M6.8

Earthquake Scenario: PDX Hills M6.8 Arbitrary

Print Date: Sunday, June 15, 2003

Disclaimer:
The estimates of social and economic impacts contained in this report were produced using HAZUS loss estimation methodology software which is based on current scientific and engineering knowledge. There are uncertainties inherent in any loss estimation technique. Therefore, there may be significant differences between the modeled results contained in this report and the actual social and economic losses following a specific earthquake. These results can be improved by using enhanced inventory, geotechnical, and observed ground motion data.

Table of Contents

General Description of the Region

HAZUS is a regional earthquake loss estimation model that was developed by the Federal Emergency Management Agency and the National Institute of Building Sciences. The primary purpose of HAZUS is to provide a methodology and software application to develop earthquake losses at a regional scale. These loss estimates would be used primarily by local, state and regional officials to plan and stimulate efforts to reduce risks from earthquakes and to prepare for emergency response and recovery.

The earthquake loss estimates provided in this report was based on a region that includes 1 county(ies) from the following state(s):

- Oregon

Note:
Appendix A contains a complete listing of the counties contained in the region.

The geographical size of the region is 1,879 square miles and contains 52 census tracts. There are over 104 thousand households in the region and has a total population of 278,900 people (1990 Census Bureau data). The distribution of population by State and County is provided in Appendix B.

There are an estimated 129 thousand buildings in the region with a total building replacement value (excluding contents) of 22,329 million dollars (1994 dollars). Approximately 96% of the buildings (and 74% of the building value) are associated with residential housing.

The replacement value of the transportation and utility lifeline systems is estimated to be 5,345 and 3,395 million dollars (1994 dollars), respectively.

Building and Lifeline Inventory

Building Inventory

HAZUS estimates that there are 129,000 buildings in the region which have an aggregate total replacement value of 22,329 million dollars (1994 dollars). Figure 1 presents the relative distribution of the value with respect to the general occupancies. Appendix B provides a general distribution of the building value by State and County.

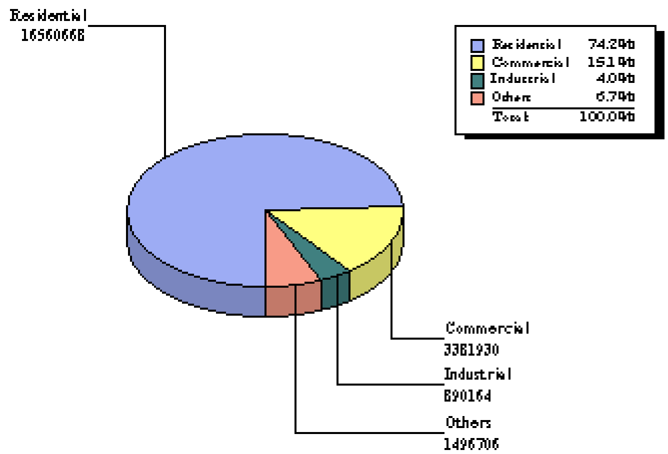

Figure 1: Building Exposure by Occupancy Type
(Thousands of dollars)

In terms of building construction types found in the region, wood frame construction makes up 88% of the building inventory. The remaining percentage is distributed between the other general building types.

Critical Facility Inventory

HAZUS breaks critical facilites into two (2) groups: essential facilities and high potential loss (HPL) facilities. Essential facilities include hospitals, medical clinics, schools, fire stations, police stations and emergency operations facilities. High potential loss facilities include dams, levees, military installations, nuclear power plants and hazardous material sites.

For essential facilities, there are 4 hospitals in the region with a total bed capacity of 566 beds. There are 334 schools, 47 fire stations, 10 police stations and 4 emergency operation facilities. With respect to HPL facilities, there are 39 dams identified within the region. Of these, 6 of the dams are classified as 'high hazard'. The inventory also includes 556 hazardous material sites, 0 military installations and 0 nuclear power plants.

Transportation and Utility Lifeline Inventory

Within HAZUS, the lifeline inventory is divided between transportation and utility lifeline systems. There are seven (7) transportation systems that include highways, railways, light rail, bus, ports, ferry and airports. There are six (6) utility systems that include potable water, wastewater, natural gas, crude & refined oil, electric power and communications. The lifeline inventory data is provided in Tables 2 and 3.

The total value of the lifeline inventory is over 5,597 million dollars. This inventory includes over 365 kilometers of highways, 426 bridges, 0 kilometers of pipes.

Table 2: Transportation System Lifeline Inventory

System	Component	# locations/ # Segments	Replacement value (millions of dollars)
Highway	Major Roads	49	3,653
	Bridges	422	532
	Tunnels	0	0
		Subtotal	4,185
Railways	Rail Tracks	53	141
	Bridges	4	20
	Tunnels	0	0
	Facilities	0	0
		Subtotal	161
Light Rail	Rail Tracks	0	0
	Bridges	0	0
	Tunnels	0	0
	Facilities	0	0
		Subtotal	0
Bus	Facilities	1	1
Ferry	Facilities	0	0
Port	Facilities	3	5
Airport	Facilities	31	211
	Runways	28	784
		Subtotal	995
		Total	**5,345**

Table 3: Utility System Lifeline inventory

System	Component	# Locations / Segments	Replacement value (millions of dollars)
Potable Water	Pipelines	0	0.0
	Facilities	0	0.0
	Distribution Lines	NA	1,292.0
		Subtotal	1,292.0
Waste Water	Pipelines	0	0.0
	Facilities	2	120.0
	Distribution Lines	NA	775.2
		Subtotal	895.2
Natural Gas	Pipelines	0	0.0
	Facilities	0	0.0
	Distribution Lines	NA	516.8
		Subtotal	516.8
Oil Systems	Pipelines	1	1.6
	Facilities	0	0.0
		Subtotal	1.6
Electrical Power	Facilities	1	100.0
	Distribution Lines	NA	387.6
		Subtotal	487.6
Communication	Facilities	15	30.0
	Distribution Lines	NA	172.3
		Subtotal	202.3
		Total	3,395.5

Earthquake Scenario

HAZUS uses the following set of information to define the earthquake parameters used for the earthquake loss estimate provided in this report.

Scenario Name	PDX Hills M6.8 Arbitrary
Type of Earthquake	Arbitrary event
Fault Name	NA
Historical Epicenter ID #	NA
Probabilistic Return Period	NA
Longitude of Epicenter	-122.642
Latitude of Epicenter	45.4678
Earthquake Magnitude	6.8
Depth (Km)	10
Rupture Length (Km)	33.4195
Rupture Orientation (degrees)	142.932
Attenuation Function	Project 97 West Coast

Building Damage

Building Damage

HAZUS estimates that about 51,288 thousand buildings will be at least moderately damaged. This is over 39,750% of the total number of buildings in the region. There are an estimated 4,371 buildings that will be completely destroyed. The definition of the 'damage states' is provided in Volume 1: Chapter 5 of the HAZUS technical manual. Table 4 below summaries the expected damage by general occupancy for the buildings in the region. Table 5 summaries the expected damage by general building type.

Table 4: Expected Building Damage by Occupancy

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Residential	34,493	96.36	36,581	97.35	35,406	95.61	13,154	92.28	3,853	88.15
Commercial	822	2.30	666	1.77	1,065	2.88	702	4.92	306	7.00
Industrial	137	0.38	87	0.23	186	0.50	179	1.26	130	2.97
Agriculture	0	0.38	0	0.00	0	0.00	0	0.00	0	0.00
Religion	68	0.19	66	0.00	87	0.23	39	0.27	13	0.30
Government	192	0.54	116	0.00	195	0.53	121	0.85	50	1.14
Education	84	0.23	61	0.16	91	0.25	59	0.41	19	0.43
Total	**35,796**		**37,577**		**37,030**		**14,254**		**4,371**	

Table 5: Expected Building Damage by Building Type (All Design Levels)

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Concrete	253	0.7	143	0.4	278	0.8	176	1.2	91	2.1
Mobile Homes	2,428	6.8	1,991	5.3	3,426	9.3	2,500	17.5	1,201	27.5
Precast Concrete	311	0.9	203	0.5	444	1.2	375	2.6	203	4.6
RM*	335	0.9	160	0.4	314	0.8	263	1.8	91	2.1
Steel	226	0.6	90	0.2	214	0.6	173	1.2	98	2.2
URM*	14	0.0	0	0.0	1	0.0	4	0.0	8	0.2
Wood	32,229	90.0	34,990	93.1	32,353	87.4	10,763	75.5	2,679	61.3

*Note:

RM Reinforced Masonry

URM Unreinforced Masonry

Essential Facility Damage

Before the earthquake, the region had 566 hospital beds available for use. On the day of the earthquake, the model estimates that only 103 hospital beds (18%) are available for use by patients already in the hospital and those injured by the earthquake. After one week, 35% of the beds will be back in service. By 30 days, 67% will be operational.

Table 6: Expected Damage to Essential Facilities

Classification	Total	# Facilities		
		Least Moderate Damage > 50%	Complete Damage > 50%	Functionality > 50% at day 1
Hospitals	4	3	0	0
Schools	334	129	2	55
EOCs	4	0	0	1
Police Stations	10	5	0	1
Fire Stations	47	9	0	10

Transportation and Utility Lifeline Damage

Table 7 provides damage estimates for the transportation system.

Table 7: Expected Damage to the Transportation Systems

System	Component	Number of Locations				
		Locations/ Segments	With at Least Mod. Damage	With Complete Damage	With Functionality > 50 %	
					After Day 1	After Day 7
Highway	Roads	49			49	49
	Bridges	422	123	46	310	343
	Tunnels	0	0	0	0	0
Railways	Tracks	0			53	53
	Bridges	4	1	0	4	4
	Tunnels	0	0	0	0	0
	Facilities	0	0	0	0	0
Light Rail	Tracks	0			0	0
	Bridges	0	0	0	0	0
	Tunnels	0	0	0	0	0
	Facilities	0	0	0	0	0
Bus	Facilities	1	1	0	1	1
Ferry	Facilities	0	0	0	0	0
Port	Facilities	3	0	0	3	3
Airport	Facilities	31	12	1	31	31
	Runways	28	0	0	28	28

Note: Roadway segments, railroad tracks and light rail tracks are assumed to be damaged by ground failure only. If ground failure maps are not provided, damage estimates to these components will not be computed.

Tables 8-10 provide information on the damage to the utility lifeline systems. Table 8 provides damage to the utility system facilities. Table 9 provides estimates on the number of leaks and breaks by the pipelines of the utility systems. For electric power and potable water, HAZUS performs a simplified system performance analysis. Table 10 provides a summary of the system performance information.

Table 8 : Expected Utility System Facility Damage

System	# of Locations				
	Total #	With at Least Moderate Damage	With Complete Damage	with Functionality > 50 %	
				After Day 1	After Day 7
Potable Water	0	0	0	0	0
Waste Water	2	1	0	0	2
Natural Gas	0	1	0	0	0
Oil Systems	0	0	0	0	0
Electrical Power	1	0	0	1	1
Communication	15	9	0	15	15
Total	**18**	**11**	**1**	**16**	**18**

Table 9 : Expected Utility System Pipeline Damage

System	Total Pipelines Length (kms)	Number of Leaks	Number of Breaks
Potable Water	0	0	0
Waste Water	0	0	0
Natural Gas	0	0	0
Oil	10	0	0
Total	10	0	0

Table 10: Expected Potable Water and Electric Power System Performance (Level 1)

	Total # of Households	Number of Households without Service				
		At Day 1	At Day 3	At Day 7	At Day 30	At Day 90
Potable Water	103,635	64,531	63,006	59,746	34,646	0
Electric Power	103,635	74,406	53,103	26,873	3,173	110

Induced Earthquake Damage

Fire Following Earthquake

Fires often occur after an earthquake. Because of the number of fires and the lack of water to fight the fires, they can often burn out of control. HAZUS uses a Monte Carlo simulation model to estimate the number of ignitions and the amount of burnt area. For this scenario, the model estimates that there will be 31 ignitions that will burn about 50 sq. mi (1.6% of the region's total area.) The model also estimates that the fires will displace about 500 people and burn about 40 million dollars of building value.

Debris Generation

HAZUS estimates the amount of debris that will be generated by the earthquake. The model breaks the debris into two general categories: a) Brick/Wood and b) Reinforced Concrete/Steel. This distinction is made because of the different types of material handling equipment required to handle the debris.

The model estimates that a total of 3.03 million tons of debris will be generated. Of the total amount, Brick/Wood comprises 35% of the total, with the remainder being Reinforced Concrete/Steel. If the debris tonnage is converted to an estimated number of truckloads, it will require 121,000 truckloads (@25 tons/truck) to remove the debris generated by the earthquake.

Social Impact

Shelter Requirement

HAZUS estimates the number of households that are expected to be displaced from their homes due to the earthquake and the number of displaced people that will require accommodations in temporary public shelters. The model estimates 5,444 households to be displaced due to the earthquake. Of these, 3,317 people (out of a total population of 278,900) will seek temporary shelter in public shelters.

Casualties

HAZUS estimates the number of people that will be injured and killed by the earthquake. The casualties are broken down into four (4) severity levels that describe the extent of the injuries. The levels are described as follows;

· Severity Level 1: Injuries will require medical attention but hospitalization is not needed.
· Severity Level 2: Injuries will require hospitalization but are not considered life-threatening
· Severity Level 3: Injuries will require hospitalization and can become life threatening if not promptly treated.
· Severity Level 4: Victims are killed by the earthquake.

The casualty estimates are provided for three (3) times of day: 2:00 AM, 2:00 PM and 5:00 PM. These times represent the periods of the day that different sectors of the community are at their peak occupancy loads. The 2:00 AM estimate considers that the residential occupancy load is maximum, the 2:00 PM estimate considers that the educational, commercial and industrial sector loads are maximum and 5:00 PM represents peak commute time.

Table 11 provides a summary of the casualties estimated for this earthquake

Table 11: Casualty Estimates

		Level 1	Level 2	Level 3	Level 4
2 AM	Residential	1,020	185	10	16
	Non-Residential	62	19	3	6
	Commute	1	1	1	0
	Total	1,083	204	14	23
2 PM	Residential	293	54	3	5
	Non-Residential	1,946	566	93	184
	Commute	3	4	6	1
	Total	2,242	623	102	190
5 PM	Residential	348	64	3	6
	Non-Residential	722	214	36	70
	Commute	7	10	16	3
	Total	1,077	288	55	79

Economic Loss

The total economic loss estimated for the earthquake is 4,881 million dollars, which represents 17 % of the total replacement value of the region's buildings. The following three sections provide more detailed information about these losses.

Building-Related Losses

The building losses are broken into two categories: direct building losses and business interruption losses. The direct building losses are the estimated costs to repair or replace the damage caused to the building and its contents. The business interruption losses are the losses associated with inability to operate a business because of the damage sustained during the earthquake. Business interruption losses also include the temporary living expenses for those people displaced from their homes because of the earthquake.

The total building-related losses were 4,685 million dollars. 22% of the estimated losses were related to the business interruption of the region. By far, the largest loss was sustained by the residential occupancies which made up over 64% of the total loss. Table 12 below provides a summary of the losses associated with the building damage.

Table 12: Building-Related Economic Loss Estimates

(Millions of dollars)

Category	Area	Residential	Commercial	Industrial	Others	Total
Building Loss	Structural	422.1	189.6	48.0	52.4	**712.0**
	Non-Structural	1,640.2	340.7	86.7	157.0	**2,224.6**
	Content	436.5	146.8	57.2	57.5	**698.0**
	Inventory	N/A	6.7	4.0	0.0	**10.7**
	Subtotal	2,498.8	683.7	195.8	266.9	**3,645.2**
Business Interruption Loss	Wage	16.7	130.3	5.0	21.5	**173.4**
	Income	7.4	96.8	3.0	3.8	**111.0**
	Rental	122.7	67.8	6.0	10.0	**206.4**
	Relocation	343.6	108.1	25.7	71.1	**548.6**
	Subtotal	490.3	403.0	39.7	106.4	**1,039.4**
	Total	2,989.1	1,086.7	235.5	373.4	**4,684.6**

Transportation and Utility Lifeline Losses

For the transportation and utility lifeline systems, HAZUS computes the direct repair cost for each component only. There are no losses computed by HAZUS for business interruption due to lifeline outages. Tables 13 & 14 provide a detailed breakdown in the expected lifeline losses.

HAZUS estimates the long-term economic impacts to the region for 15 years after the earthquake. The model quantifies this information in terms of income and employment changes within the region. Table 15 presents the results of the region for the given earthquake.

Table 13: Transportation System Economic Losses

(Millions of dollars)

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Highway	Roads	3,652.8	5.9	0.2
	Bridges	532.0	77.6	14.6
	Tunnels	0.0	0.0	0.0
	Subtotal	4,184.8	83.5	2.0
Railways	Tracks	140.5	0.5	0.0
	Bridges	20.0	2.2	10.9
	Tunnels	0.0	0.0	0.0
	Facilities	0.0	0.0	0.0
	Subtotal	160.5	2.7	1.7
Light Rail	Tracks	0.0	0.0	0.0
	Bridges	0.0	0.0	0.0
	Tunnels	0.0	0.0	0.0
	Facilities	0.0	0.0	0.0
	Subtotal	0.0	0.0	0.0
Bus	Facilities	1.0	0.3	31.2
Ferry	Facilities	0.0	0.0	0.0
Port	Facilities	4.5	0.0	1.0
Airport	Facilities	210.5	45.5	21.6
	Runways	784.0	0.0	0.0
	Subtotal	994.5	45.5	4.6
		5,345.3	**132.1**	**2.5**

Table 14: Utility System Economic Losses

(Millions of dollars)

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Potable Water	Pipelines	0.0	0.0	0.0
	Facilities	0.0	0.0	0.0
	Distribution Lines	1,292.0	*NA*	*NA*
	Subtotal	1,292.0	0.0	0.0
Waste Water	Pipelines	0.0	0.0	0.0
	Facilities	120.0	54.7	45.6
	Distribution Lines	775.2	*NA*	*NA*
	Subtotal	895.2	54.7	6.1
Natural Gas	Pipelines	0.0	0.0	0.0
	Facilities	0.0	0.0	0.0
	Distribution Lines	516.8	*NA*	*NA*
	Subtotal	516.8	0.0	0.0
Oil Systems	Pipelines	1.6	0.0	0.0
	Facilities	0.0	0.0	0.0
	Subtotal	1.6	0.0	0.00
Electrical Power	Facilities	100.0	0.5	0.5
	Distribution Lines	387.6	*NA*	*NA*
	Subtotal	487.6	0.5	0.5
Communication	Facilities	30.0	9.3	30.9
	Distribution Lines	172.3	*NA*	*NA*
	Subtotal	202.3	9.3	30.9
	Total	**3,395.5**	**64.5**	**8.4**

Table 15. Indirect Economic Impact
(with outside aid)

Year(s)	1	2	3	4	5	6-15
Income Impact (millions $)	-31	-104	-138	-138	-138	-138
% Income Impact	-0.68	-2.27	-3.00	-3.00	-3.00	-3.00
Employment Impact (#)	53	44	0	0	0	0
% Employment Impact	0.05	0.04	0.00	0.00	0.00	0.00

Appendix A: County Listing for the Region

Oregon

- Clackamas

Appendix B: Regional Population and Building Value Data

State	County Name	Population	Building Value (millions of dollars)		
			Residential	Non-Residential	Total
Oregon					
	Clackamas	278,900	16,560	5,770	22,330
State Total		*278,900*	*16,560*	*5,770*	*22,330*
Region Total		**278,900**	**16,560**	**5,770**	**22,330**

Appendix F:
HAZUS 99-SR2: Earthquake Event Report

Region Name: Clackamas Co with CSZ Crew Scenario

Earthquake Scenario: CREW Scenario M9.0

Print Date: Sunday, June 15, 2003

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General Description of the Region

HAZUS is a regional earthquake loss estimation model that was developed by the Federal Emergency Management Agency and the National Institute of Building Sciences. The primary purpose of HAZUS is to provide a methodology and software application to develop earthquake losses at a regional scale. These loss estimates would be used primarily by local, state and regional officials to plan and stimulate efforts to reduce risks from earthquakes and to prepare for emergency response and recovery.

The earthquake loss estimates provided in this report was based on a region that includes 1 county(ies) from the following state(s):

- Oregon

Note:
Appendix A contains a complete listing of the counties contained in the region.

The geographical size of the region is 1,879 square miles and contains 52 census tracts. There are over 104 thousand households in the region and has a total population of 278,900 people (1990 Census Bureau data). The distribution of population by State and County is provided in Appendix B.

There are an estimated 129 thousand buildings in the region with a total building replacement value (excluding contents) of 22,329 million dollars (1994 dollars). Approximately 96% of the buildings (and 74% of the building value) are associated with residential housing.

The replacement value of the transportation and utility lifeline systems is estimated to be 5,345 and 3,395 million dollars (1994 dollars), respectively.

Building and Lifeline Inventory

Building Inventory

HAZUS estimates that there are 129,000 buildings in the region which have an aggregate total replacement value of 22,329 million dollars (1994 dollars). Figure 1 presents the relative distribution of the value with respect to the general occupancies. Appendix B provides a general distribution of the building value by State and County.

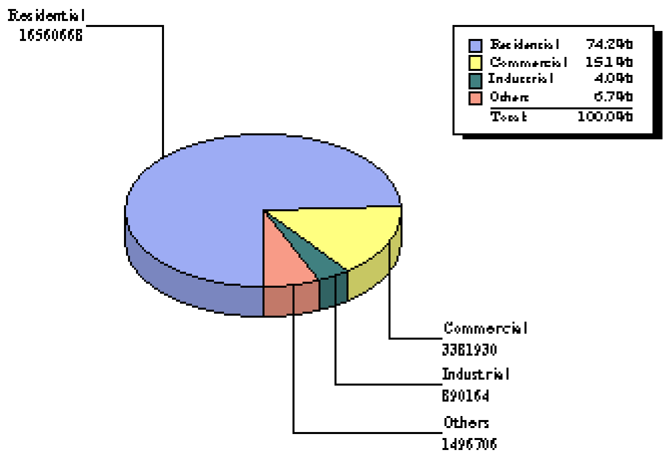

Figure 1: Building Exposure by Occupancy Type
(Thousands of dollars)

In terms of building construction types found in the region, wood frame construction makes up 88% of the building inventory. The remaining percentage is distributed between the other general building types.

Critical Facility Inventory

HAZUS breaks critical facilites into two (2) groups: essential facilities and high potential loss (HPL) facilities. Essential facilities include hospitals, medical clinics, schools, fire stations, police stations and emergency operations facilities. High potential loss facilities include dams, levees, military installations, nuclear power plants and hazardous material sites.

For essential facilities, there are 4 hospitals in the region with a total bed capacity of 566 beds. There are 334 schools, 47 fire stations, 10 police stations and 4 emergency operation facilities. With respect to HPL facilities, there are 39 dams identified within the region. Of these, 6 of the dams are classified as ‘high hazard’. The inventory also includes 556 hazardous material sites, 0 military installations and 0 nuclear power plants.

Transportation and Utility Lifeline Inventory

Within HAZUS, the lifeline inventory is divided between transportation and utility lifeline systems. There are seven (7) transportation systems that include highways, railways, light rail, bus, ports, ferry and airports. There are six (6) utility systems that include potable water, wastewater, natural gas, crude & refined oil, electric power and communications. The lifeline inventory data is provided in Tables 2 and 3.

The total value of the lifeline inventory is over 5,597 million dollars. This inventory includes over 365 kilometers of highways, 426 bridges, 0 kilometers of pipes.

Table 2: Transportation System Lifeline Inventory

System	Component	# locations/ # Segments	Replacement value (millions of dollars)
Highway	Major Roads	49	3,653
	Bridges	422	532
	Tunnels	0	0
		Subtotal	4,185
Railways	Rail Tracks	53	141
	Bridges	4	20
	Tunnels	0	0
	Facilities	0	0
		Subtotal	161
Light Rail	Rail Tracks	0	0
	Bridges	0	0
	Tunnels	0	0
	Facilities	0	0
		Subtotal	0
Bus	Facilities	1	1
Ferry	Facilities	0	0
Port	Facilities	3	5
Airport	Facilities	31	211
	Runways	28	784
		Subtotal	995
		Total	**5,345**

Table 3: Utility System Lifeline inventory

System	Component	# Locations / Segments	Replacement value (millions of dollars)
Potable Water	Pipelines	0	0.0
	Facilities	0	0.0
	Distribution Lines	NA	1,292.0
		Subtotal	1,292.0
Waste Water	Pipelines	0	0.0
	Facilities	2	120.0
	Distribution Lines	NA	775.2
		Subtotal	895.2
Natural Gas	Pipelines	0	0.0
	Facilities	0	0.0
	Distribution Lines	NA	516.8
		Subtotal	516.8
Oil Systems	Pipelines	1	1.6
	Facilities	0	0.0
		Subtotal	1.6
Electrical Power	Facilities	1	100.0
	Distribution Lines	NA	387.6
		Subtotal	487.6
Communication	Facilities	15	30.0
	Distribution Lines	NA	172.3
		Subtotal	202.3
		Total	3,395.5

Earthquake Scenario

HAZUS uses the following set of information to define the earthquake parameters used for the earthquake loss estimate provided in this report.

Scenario Name	CREW Scenario M9.0
Type of Earthquake	Use-defined event
Fault Name	NA
Historical Epicenter ID #	NA
Probabilistic Return Period	NA
Longitude of Epicenter	NA
Latitude of Epicenter	NA
Earthquake Magnitude	NA
Depth (Km)	NA
Rupture Length (Km)	NA
Rupture Orientation (degrees)	NA
Attenuation Function	NA

Building Damage

Building Damage

HAZUS estimates that about 15,473 thousand buildings will be at least moderately damaged. This is over 11,975% of the total number of buildings in the region. There are an estimated 941 buildings that will be completely destroyed. The definition of the 'damage states' is provided in Volume 1: Chapter 5 of the HAZUS technical manual. Table 4 below summaries the expected damage by general occupancy for the buildings in the region. Table 5 summaries the expected damage by general building type.

Table 4: Expected Building Damage by Occupancy

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Residential	83,078	96.88	25,952	95.96	10,714	90.00	3,057	85.70	838	89.05
Commercial	1,851	2.16	703	2.60	700	5.88	275	7.71	46	4.89
Industrial	276	0.32	129	0.48	185	1.55	109	3.06	29	3.08
Agriculture	0	0.32	0	0.00	0	0.00	0	0.00	0	0.00
Religion	122	0.14	72	0.00	62	0.52	10	0.28	1	0.11
Government	295	0.34	121	0.00	158	1.33	82	2.30	24	2.55
Education	135	0.16	68	0.25	86	0.72	34	0.95	3	0.32
Total	**85,757**		**27,045**		**11,905**		**3,567**		**941**	

Table 5: Expected Building Damage by Building Type (All Design Levels)

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Concrete	352	0.4	181	0.7	272	2.3	112	3.1	25	2.7
Mobile Homes	2,369	2.8	2,315	8.6	3,650	30.7	2,374	66.6	805	85.5
Precast Concrete	700	0.8	269	1.0	340	2.9	194	5.4	33	3.5
RM*	719	0.8	160	0.6	188	1.6	85	2.4	7	0.7
Steel	302	0.4	126	0.5	217	1.8	118	3.3	36	3.8
URM*	20	0.0	4	0.0	3	0.0	0	0.0	0	0.0
Wood	81,295	94.8	23,990	88.7	7,235	60.8	679	19.1	35	3.7

*Note:
RM Reinforced Masonry
URM Unreinforced Masonry

Essential Facility Damage

Before the earthquake, the region had 566 hospital beds available for use. On the day of the earthquake, the model estimates that only 283 hospital beds (50%) are available for use by patients already in the hospital and those injured by the earthquake. After one week, 67% of the beds will be back in service. By 30 days, 88% will be operational.

Table 6: Expected Damage to Essential Facilities

		# Facilities		
Classification	Total	Least Moderate Damage > 50%	Complete Damage > 50%	Functionality > 50% at day 1
Hospitals	4	0	0	2
Schools	334	90	0	248
EOCs	4	0	0	4
Police Stations	10	3	0	8
Fire Stations	47	1	0	44

Transportation and Utility Lifeline Damage

Table 7 provides damage estimates for the transportation system.

Table 7: Expected Damage to the Transportation Systems

System	Component	Number of Locations				
		Locations/ Segments	With at Least Mod. Damage	With Complete Damage	With Functionality > 50 %	
					After Day 1	After Day 7
Highway	**Roads**	49			49	49
	Bridges	422	72	13	401	420
	Tunnels	0	0	0	0	0
Railways	**Tracks**	0			53	53
	Bridges	4	0	0	4	4
	Tunnels	0	0	0	0	0
	Facilities	0	0	0	0	0
Light Rail	**Tracks**	0			0	0
	Bridges	0	0	0	0	0
	Tunnels	0	0	0	0	0
	Facilities	0	0	0	0	0
Bus	**Facilities**	1	0	0	1	1
Ferry	**Facilities**	0	0	0	0	0
Port	**Facilities**	3	0	0	3	3
Airport	**Facilities**	31	3	0	31	31
	Runways	28	0	0	28	28

Note: Roadway segments, railroad tracks and light rail tracks are assumed to be damaged by ground failure only. If ground failure maps are not provided, damage estimates to these components will not be computed.

Tables 8-10 provide information on the damage to the utility lifeline systems. Table 8 provides damage to the utility system facilities. Table 9 provides estimates on the number of leaks and breaks by the pipelines of the utility systems. For electric power and potable water, HAZUS performs a simplified system performance analysis. Table 10 provides a summary of the system performance information.

Table 8 : Expected Utility System Facility Damage

System	# of Locations				
	Total #	With at Least Moderate Damage	With Complete Damage	with Functionality > 50 %	
				After Day 1	After Day 7
Potable Water	0	0	0	0	0
Waste Water	2	0	0	2	2
Natural Gas	0	0	0	0	0
Oil Systems	0	0	0	0	0
Electrical Power	1	0	0	1	1
Communication	15	2	0	15	15
Total	**18**	**2**	**0**	**18**	**18**

Table 9 : Expected Utility System Pipeline Damage

System	Total Pipelines Length (kms)	Number of Leaks	Number of Breaks
Potable Water	0	0	0
Waste Water	0	0	0
Natural Gas	0	0	0
Oil	10	1	0
Total	10	1	0

Table 10: Expected Potable Water and Electric Power System Performance (Level 1)

	Total # of Households	Number of Households without Service				
		At Day 1	At Day 3	At Day 7	At Day 30	At Day 90
Potable Water	103,635	10,271	8,351	4,917	0	0
Electric Power	103,635	32,889	9,253	1,258	116	109

Induced Earthquake Damage

Fire Following Earthquake

Fires often occur after an earthquake. Because of the number of fires and the lack of water to fight the fires, they can often burn out of control. HAZUS uses a Monte Carlo simulation model to estimate the number of ignitions and the amount of burnt area. For this scenario, the model estimates that there will be 7 ignitions that will burn about 10 sq. mi (0.4% of the region's total area.) The model also estimates that the fires will displace about 100 people and burn about 10 million dollars of building value.

Debris Generation

HAZUS estimates the amount of debris that will be generated by the earthquake. The model breaks the debris into two general categories: a) Brick/Wood and b) Reinforced Concrete/Steel. This distinction is made because of the different types of material handling equipment required to handle the debris.

The model estimates that a total of 0.93 million tons of debris will be generated. Of the total amount, Brick/Wood comprises 28% of the total, with the remainder being Reinforced Concrete/Steel. If the debris tonnage is converted to an estimated number of truckloads, it will require 37,000 truckloads (@25 tons/truck) to remove the debris generated by the earthquake.

Social Impact

Shelter Requirement

HAZUS estimates the number of households that are expected to be displaced from their homes due to the earthquake and the number of displaced people that will require accommodations in temporary public shelters. The model estimates 699 households to be displaced due to the earthquake. Of these, 418 people (out of a total population of 278,900) will seek temporary shelter in public shelters.

Casualties

HAZUS estimates the number of people that will be injured and killed by the earthquake. The casualties are broken down into four (4) severity levels that describe the extent of the injuries. The levels are described as follows;

- Severity Level 1: Injuries will require medical attention but hospitalization is not needed.
- Severity Level 2: Injuries will require hospitalization but are not considered life-threatening
- Severity Level 3: Injuries will require hospitalization and can become life threatening if not promptly treated.
- Severity Level 4: Victims are killed by the earthquake.

The casualty estimates are provided for three (3) times of day: 2:00 AM, 2:00 PM and 5:00 PM. These times represent the periods of the day that different sectors of the community are at their peak occupancy loads. The 2:00 AM estimate considers that the residential occupancy load is maximum, the 2:00 PM estimate considers that the educational, commercial and industrial sector loads are maximum and 5:00 PM represents peak commute time.

Table 11 provides a summary of the casualties estimated for this earthquake

Table 11: Casualty Estimates

		Level 1	Level 2	Level 3	Level 4
2 AM	Residential	265	44	2	4
	Non-Residential	19	4	1	1
	Commute	0	0	0	0
	Total	284	48	3	5
2 PM	Residential	80	13	1	1
	Non-Residential	610	141	19	38
	Commute	1	1	1	0
	Total	690	155	21	39
5 PM	Residential	95	16	1	1
	Non-Residential	214	50	7	13
	Commute	2	2	3	1
	Total	311	68	11	15

Economic Loss

The total economic loss estimated for the earthquake is 1,331 million dollars, which represents 5 % of the total replacement value of the region's buildings. The following three sections provide more detailed information about these losses.

Building-Related Losses

The building losses are broken into two categories: direct building losses and business interruption losses. The direct building losses are the estimated costs to repair or replace the damage caused to the building and its contents. The business interruption losses are the losses associated with inability to operate a business because of the damage sustained during the earthquake. Business interruption losses also include the temporary living expenses for those people displaced from their homes because of the earthquake.

The total building-related losses were 1,282 million dollars. 27% of the estimated losses were related to the business interruption of the region. By far, the largest loss was sustained by the residential occupancies which made up over 46% of the total loss. Table 12 below provides a summary of the losses associated with the building damage.

Table 12: Building-Related Economic Loss Estimates

(Millions of dollars)

Category	Area	Residential	Commercial	Industrial	Others	Total
Building Loss	Structural	86.8	73.3	22.0	28.7	210.7
	Non-Structural	316.6	116.1	33.1	72.8	538.5
	Content	98.4	47.0	21.3	20.5	187.2
	Inventory	N/A	2.3	1.5	0.0	3.7
	Subtotal	501.8	238.6	77.8	121.9	940.1
Business Interruption Loss	Wage	6.9	55.4	2.3	12.4	77.1
	Income	3.1	39.7	1.4	2.1	46.3
	Rental	23.6	26.8	3.1	6.1	59.7
	Relocation	55.9	47.7	14.6	40.7	159.0
	Subtotal	89.5	169.6	21.5	61.4	342.0
	Total	591.3	408.2	99.3	183.3	1,282.1

Transportation and Utility Lifeline Losses

For the transportation and utility lifeline systems, HAZUS computes the direct repair cost for each component only. There are no losses computed by HAZUS for business interruption due to lifeline outages. Tables 13 & 14 provide a detailed breakdown in the expected lifeline losses.

HAZUS estimates the long-term economic impacts to the region for 15 years after the earthquake. The model quantifies this information in terms of income and employment changes within the region. Table 15 presents the results of the region for the given earthquake.

Table 13: Transportation System Economic Losses
(Millions of dollars)

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Highway	Roads	3,652.8	0.0	0.0
	Bridges	532.0	28.3	5.3
	Tunnels	0.0	0.0	0.0
	Subtotal	4,184.8	28.3	0.7
Railways	Tracks	140.5	0.0	0.0
	Bridges	20.0	0.1	0.5
	Tunnels	0.0	0.0	0.0
	Facilities	0.0	0.0	0.0
	Subtotal	160.5	0.1	0.1
Light Rail	Tracks	0.0	0.0	0.0
	Bridges	0.0	0.0	0.0
	Tunnels	0.0	0.0	0.0
	Facilities	0.0	0.0	0.0
	Subtotal	0.0	0.0	0.0
Bus	Facilities	1.0	0.1	6.6
Ferry	Facilities	0.0	0.0	0.0
Port	Facilities	4.5	0.0	0.0
Airport	Facilities	210.5	14.9	7.1
	Runways	784.0	0.0	0.0
	Subtotal	994.5	14.9	1.5
		5,345.3	**43.4**	**0.8**

Table 14: Utility System Economic Losses

(Millions of dollars)

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Potable Water	Pipelines	0.0	0.0	0.0
	Facilities	0.0	0.0	0.0
	Distribution Lines	1,292.0	*NA*	*NA*
	Subtotal	1,292.0	0.0	0.0
Waste Water	Pipelines	0.0	0.0	0.0
	Facilities	120.0	2.7	2.2
	Distribution Lines	775.2	*NA*	*NA*
	Subtotal	895.2	2.7	0.3
Natural Gas	Pipelines	0.0	0.0	0.0
	Facilities	0.0	0.0	0.0
	Distribution Lines	516.8	*NA*	*NA*
	Subtotal	516.8	0.0	0.0
Oil Systems	Pipelines	1.6	0.0	0.0
	Facilities	0.0	0.0	0.0
	Subtotal	1.6	0.0	0.00
Electrical Power	Facilities	100.0	1.4	1.4
	Distribution Lines	387.6	*NA*	*NA*
	Subtotal	487.6	1.4	1.4
Communication	Facilities	30.0	2.3	7.7
	Distribution Lines	172.3	*NA*	*NA*
	Subtotal	202.3	2.3	7.7
	Total	**3,395.5**	**6.4**	**0.8**

Table 15. Indirect Economic Impact
(with outside aid)

Year(s)	1	2	3	4	5	6-15
Income Impact (millions $)	-8	-27	-35	-35	-35	-35
% Income Impact	-0.18	-0.58	-0.77	-0.77	-0.77	-0.77
Employment Impact (#)	0	9	0	0	0	0
% Employment Impact	0.00	0.01	0.00	0.00	0.00	0.00

Appendix A: County Listing for the Region

Oregon

- Clackamas

Appendix B: Regional Population and Building Value Data

State	County Name	Population	Building Value (millions of dollars)		
			Residential	Non-Residential	Total
Oregon					
	Clackamas	278,900	16,560	5,770	22,330
State Total		*278,900*	*16,560*	*5,770*	*22,330*
Region Total		**278,900**	**16,560**	**5,770**	**22,330**