STATE OF OREGON

DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

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Preliminary Seismic Hazard and Risk Assessments in Tillamook County, Oregon

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SUMMARY

Tillamook County is facing high seismic hazards and risk due to its proximity to the Cascadia subduction zone. Many great earthquakes have occurred along the Cascadia subduction zone in the past, with the most recent one of about M 9.0 in 1700 (Clague and others, 2000). Strong ground shaking from future subduction zone earthquakes can last three minutes or more and will be dominated by long-period ground motions (Clague and others, 2000). This long-period and long-duration ground shaking could cause widely spread ground deformations, such as liquefaction and slope failure, similar to those associated with the M 9.2 Alaska earthquake in 1964 (Graves, 1964). Although we do not know when the next Cascadia subduction earthquake will occur, we can assess the potential earthquake hazards, including general ground shaking hazard, ground shaking amplification, liquefaction, and earthquake-induced slope failure hazards, as well as the potential damages and losses. The subduction earthquakes can also generate tsunamis. Tsunami hazards and the potential damages and losses caused by tsunamis are not evaluated in this study.

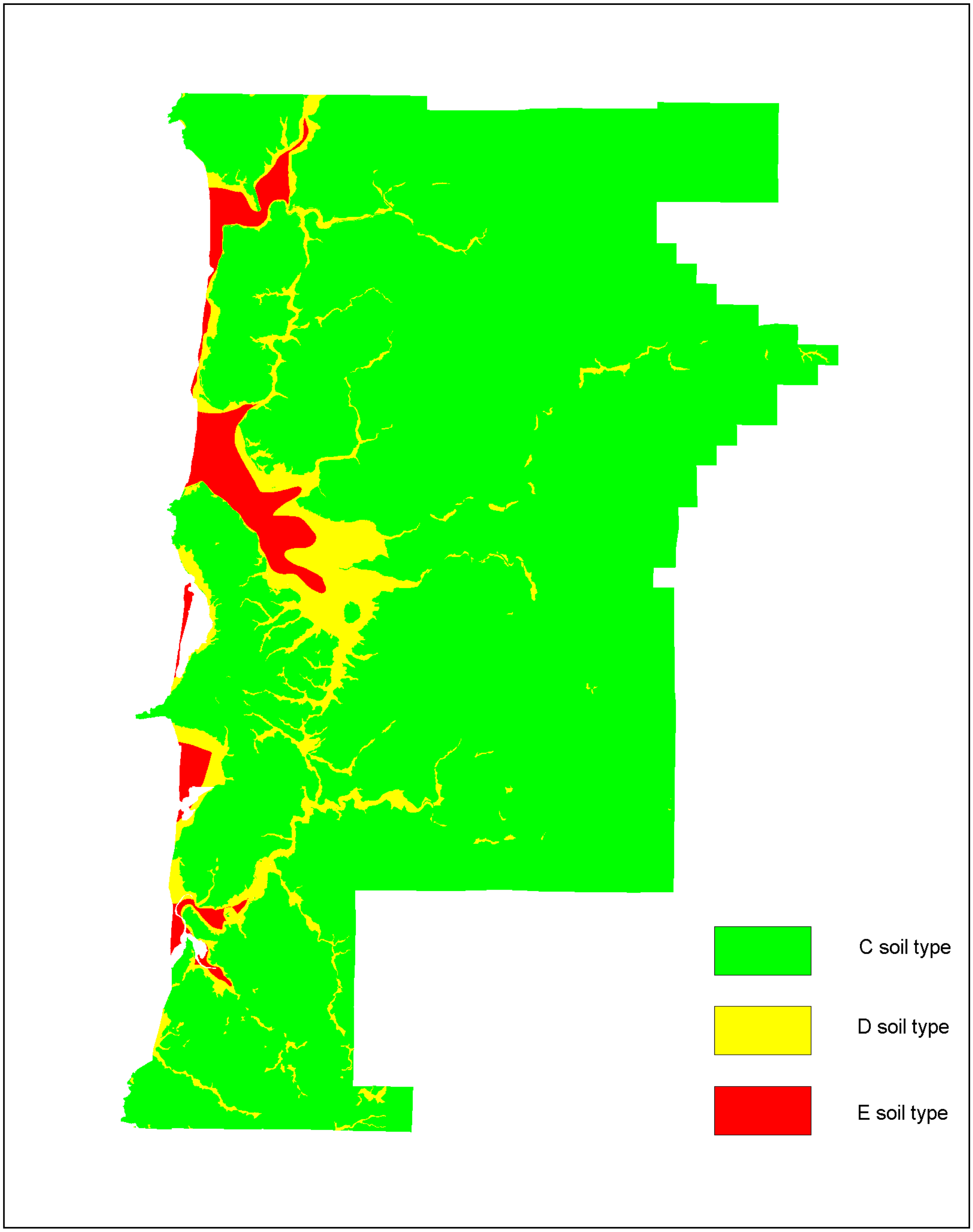
This project is an effort to assess the potential earthquake hazards and risk posed by the Cascadia subduction earthquakes to Tillamook County. The first step was to develop relative hazard maps. The relative seismic hazard maps depict the potential for ground motion amplification, liquefaction, and earthquake-induced landslides due to local geologic conditions. The relative seismic hazard maps for Tillamook County were developed from geological, geophysical, geotechnical, hydrological, and topographical data. These maps show that areas with the highest ground amplification and liquefaction hazard are concentrated in the bays and valleys and along the coast, while areas with high earthquake-induced landslide hazard are primarily in the steeper mountainous areas. Landslides are also expected along the coastal bluffs. Information on slope instability along coastal bluffs and existing coastal landslides can be found in report O-01-03 by DOGAMI (2001).

HAZUS99, a seismic-risk-assessment software developed by the Federal Emergency Management Agency (FEMA) (National Institute of Building Sciences [NIBS], 1999) was used to assess seismic risk in Tillamook County. The building inventory, augmented by sample building surveys (Rad and Hasenberg report, 2000) shows that there are over 8,827 households in Tillamook County with a total population of about 21,570 (1990 Census Bureau data), about 18,000 buildings with a total square footage of about 26 millions and replacement value of $1.66 billion (1994 dollars). The augmented building data, relative seismic hazard maps, and other inventories contained in HAZUS99 were used to estimate damages and losses for two scenarios: a M 8.5 Cascadia subduction earthquake 20 km offshore and the probabilistic ground shaking hazard with a 500-year recurrence interval (Frankel and others, 1996). These scenarios incorporated the county's population for winter residents and did not use the notably higher summer population values.

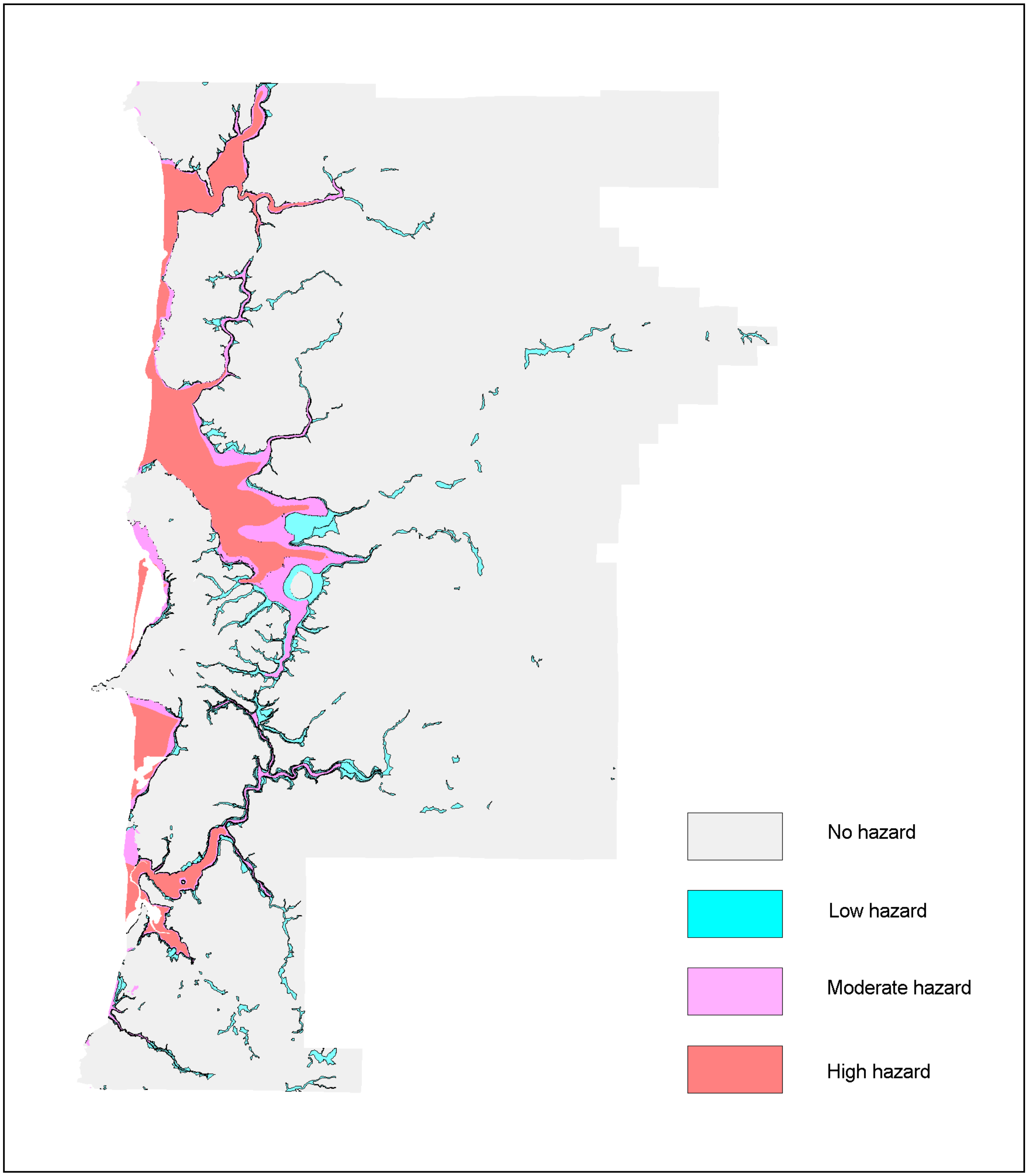
The two scenarios result in similar damages and losses to Tillamook County. Not including tsunami damage, the M8.5 Cascadia subduction scenario could cause:

1. Moderate or greater damage to 47% of all the buildings (~7,225) in the county, and extensive or greater damage to 21% of all the buildings (~2,488).

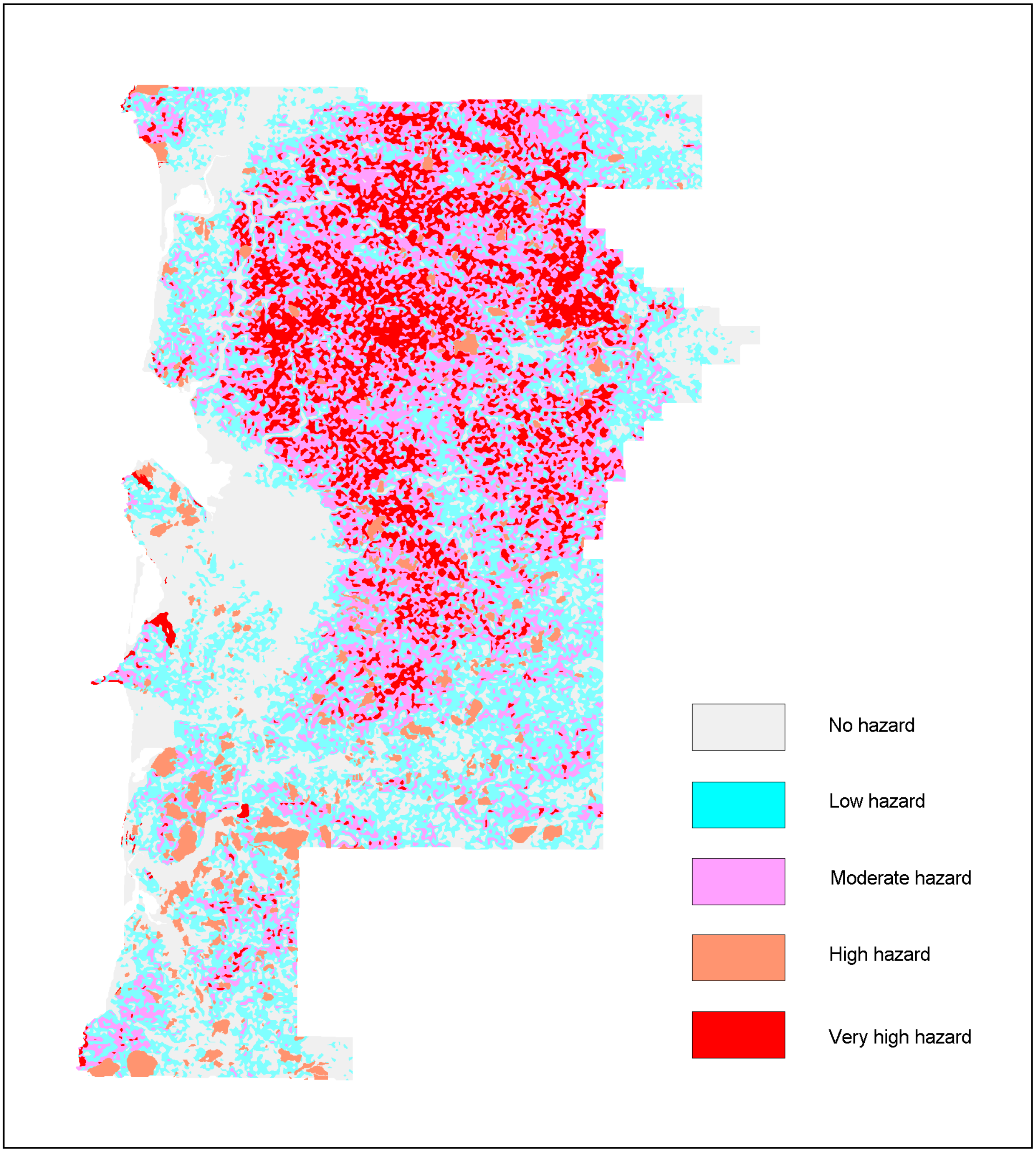
2. A total of $350 million in economic losses due to direct building damage and related effects such as content loss, relocation costs, proprietor's income loss and rental losses.
3. 123 first aid injuries, 24 injuries requiring non-critical hospitalization, 4 life-threatening injuries, and 3 immediate deaths.



Map 1: Ground motion amplification map hazard. Categories as follows: C soil type, low hazard; D soil type, moderate hazard. E soil type, high hazard



Map 2: Liquefaction potential hazard map.



Map 3: Earthquake-induced landslide hazard potential.

INTRODUCTION

Since the late 1980s, earthquake hazards have been recognized as one of the major natural hazards in Oregon. Scientists have revealed that Oregon has experienced many damaging earthquakes in the past (Atwater, 1987; Heaton and Hartzell, 1987; Weaver and Shedlock, 1989). The great Cascadia subduction earthquakes have occurred many times in the past along the northwest Pacific coast, most recently on January 26, 1700 (Clague and others, 2000). Future subduction earthquakes pose a great seismic threat to Tillamook County and other coastal communities.

Although earthquakes cannot be prevented or predicted, earthquake hazards can be assessed on the basis of geological, geophysical, geotechnical, hydrological, and topographical information. The probabilistic seismic hazard maps of Geomatrix Consultants, Inc (1995) and the U.S. Geological Survey (Frankel and others, 1996) provide assessments of the general ground shaking hazard on a bedrock site in Oregon. The Oregon Department of Geology and Mineral Industries (DOGAMI) publication GMS-100 depicts probabilistic ground shaking hazard in Oregon, including Tillamook County, at 500-, 1,000-, and 5,000-year return periods (Madin and Mabey, 1996). These maps provide a general seismic hazard level for the State of Oregon. The ground motion design level in the State of Oregon 1998 edition Structural Specialty Code (Oregon Building Codes Division, 1998) is based on these probabilistic seismic hazard assessments. Figure 1 shows the peak ground acceleration on a bedrock site at a 500-year return interval in Tillamook County (Frankel and others, 1996). We also know that ground shaking from the great Cascadia subduction earthquake will be long-period and long-duration (Clague and others, 2000).

It is well documented that the earthquake hazards are also affected by local surface and subsurface conditions. For example, during the 1985 Mexico earthquake, great damage resulted from ground motion amplified by near-surface soft soils in Mexico City (Seed and others, 1986). The 1989 Loma Prieta earthquake caused severe damage from amplified ground motion and liquefaction in the soft soils of the Marina district of San Francisco (Holzer, 1994). The September 1993 Klamath Falls earthquake induced a large rock slide on a susceptible slope on U.S. Highway 97 about 2.9 km south of Modoc Point, which hit a southbound vehicle and killed the driver (Keefer and Schuster, 1993).

Three phenomena generally will be induced by ground shaking during a strong earthquake: (1) amplification of ground shaking by a “soft” soil column; (2) liquefaction of water-saturated sand, silt, or gravel, creating areas of “quicksand;” and (3) landslides, including rock falls and rock slides, triggered by shaking, even on relatively gentle slopes. These effects can be evaluated through an examination of properties of the geologic materials and soils in an area. DOGAMI has performed evaluations of these three effects in many communities in Oregon (e.g., Mabey and others, 1995a,b,c,d; Wang and Leonard, 1996; Madin and Wang, 1999, 2000a,b,c; Black and others, 2000a,b; and Wang and Wang, 2000). These relative earthquake hazard maps depict the relative hazards of ground motion amplification, liquefaction, and earthquake-induced landslide/rockslide due to the local geologic, hydrologic, and topographic conditions.

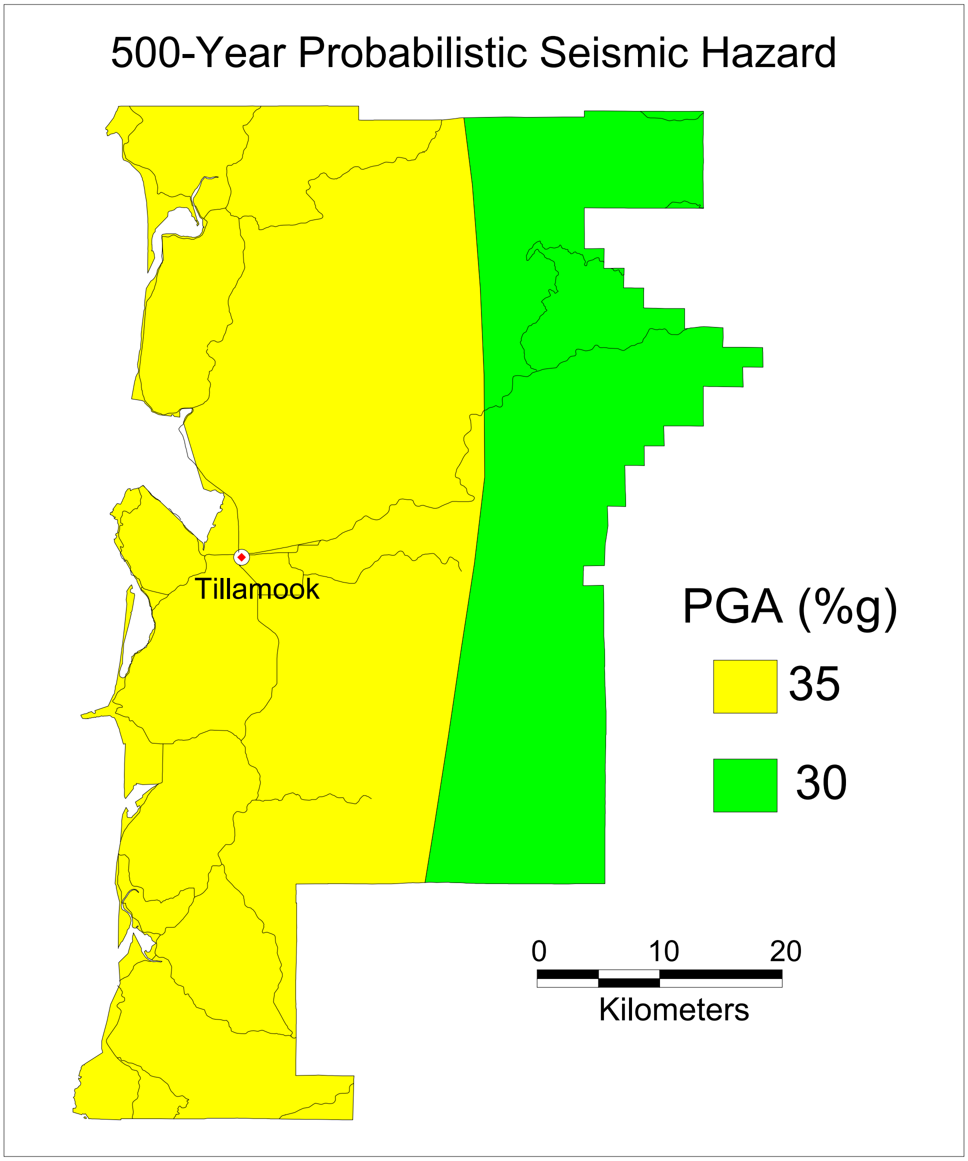


Figure 1. Peak ground acceleration (PGA) expected in Tillamook County, Oregon, with a frequency of occurrence of once in 500 years (Frankel and others, 1996).

The relative earthquake hazard maps and the general ground shaking hazard maps provide a comprehensive earthquake hazard assessment. These maps, combined with the economic exposure, such as building stocks and lifeline facilities, can be used to evaluate the earthquake risk with HAZUS99. The information from the seismic risk assessment will help local governments, land use planners, and emergency managers to prioritize areas for hazard mitigation and risk reduction.

RELATIVE SEISMIC HAZARD MAPPING

One of the most important elements of relative earthquake hazard evaluation is the development of a geologic model. Different types of relative hazards are related to different geologic conditions. For analysis of the amplification and liquefaction hazards, the distribution and thickness of unconsolidated sediments overlying bedrock is important. For analysis of the landslide hazard, bedrock geology of the steeper slopes (>25° or 47%) is important. For intermediate slopes (10° - 25° or 9% - 47%), the physical characteristics of the soil and colluvium covering the bedrock is of prime importance. The geologic model is generally developed from a combination of surface geologic mapping, surface shear wave refraction/reflection, geotechnical subsurface investigations, and water-well records.

Surface geologic information in Tillamook County from Schlicker and others (1972), Beaulieu (1973), Wells and others (1994) reveals that most of Tillamook County is underlain by consolidated or semiconsolidated Tertiary sedimentary/volcanic strata (bedrock), except in the bays and river valleys, which are underlain by unconsolidated Quaternary sediments. The Quaternary sediments are composed of beach and dune sand (Holocene), fluvial and estuarine mud, clay, silt, sand, and gravel (Holocene/Pleistocene), colluvial clay, silt, sand, and gravel (Holocene/Pleistocene), and landslide debris (Holocene/Pleistocene) (Schlicker and others, 1972; Beaulieu, 1973; Glenn, 1978; and Peterson and Darienzo, 1989; Wells and others, 1994). Figure 2 shows a simplified surface geologic map for Tillamook County.

The soil units and their distribution and thickness were determined for this study from SH-wave (a shear-wave with particle motion parallel to the ground surface) refraction/reflection data, surface geologic maps, water-well and coring data, as well as geotechnical subsurface investigations. The water-well data were obtained from the Oregon Department of Water Resources (ODWR). The locations of the water wells used in this project were not field checked. Further data sources were core data from Glenn (1978); results of preliminary analysis of seismic profiles from Tillamook Bay by Peterson and Darienzo (unpublished data, 1989); and unpublished geotechnical investigations for bridge foundations conducted by the Oregon Department of Transportation (ODOT) and Tillamook County. The scope of this project only allows limited field investigations, mostly in Tillamook Bay area (Tillamook-Garibaldi). The locations of geophysical investigations and other data used in this project are shown in Figure A-1 of **Appendix A**.

SH-wave refraction/reflection techniques (Wang and others, 1998; Wang, 1999) were used to measure shear wave velocity and determine subsurface geology. SH-wave data were collected at 37 sites in the county for this project (Fig. A-1). The SH-wave data were processed on a PC computer using the commercial software SIP by Rimrock Geophysics, Inc. (version 4.1, 1995), and WinSeis by the Kansas Geological Survey (version 1.0, 2000). The key step for data processing is to identify the refractions and reflections from different horizons. Arrival times of the refractions were picked and used to generate shear wave velocity models interactively on the PC. For reflections, shear wave velocity models were derived from velocity analysis with WinSeis. The shear wave velocity models derived from the refraction and reflection data are listed in Table A-1 of **Appendix A**.

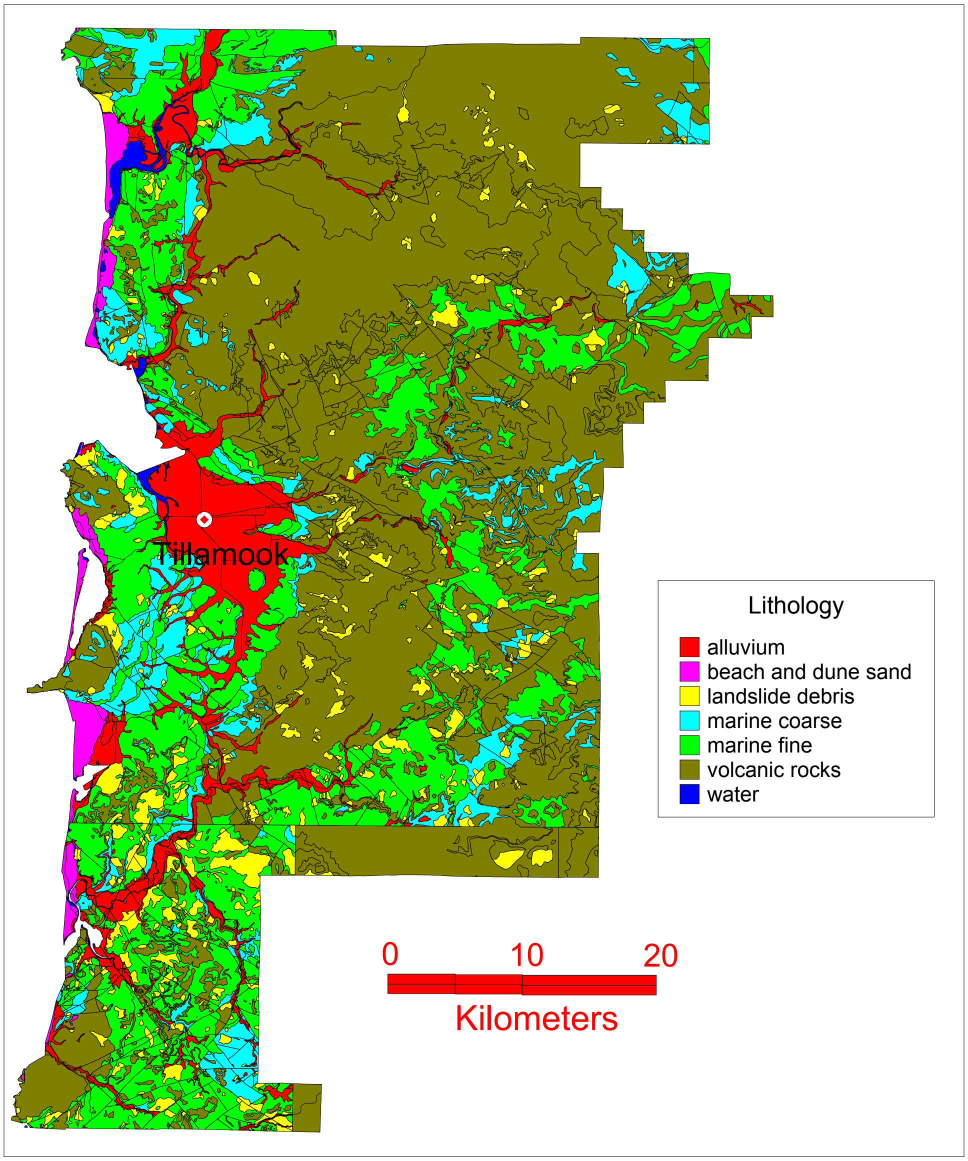


Figure 2. **Simplified geologic map of Tillamook County, Oregon.**

The surface and subsurface geologic, geophysical, geotechnical, and water-well data (Table A-1) were used to generate a three-dimensional geologic model using the GIS software MapInfo™ and Vertical Mapper™. Three soil units, Holocene fluvial and estuarine deposits, Holocene/Pleistocene fluvial/colluvial deposits, and Pleistocene gravel, were identified and mapped in the Tillamook Bay area. These geologic units and their engineering properties are listed in Table 1. In other areas of Tillamook County, all unconsolidated Quaternary deposits, including Holocene fluvial and estuarine deposits, Holocene/Pleistocene fluvial/colluvial deposits, and Pleistocene gravel, were mapped as one unit due to few field investigations and available data. Table 2 lists the geologic units and their generalized engineering properties in Nehalem Bay, Netarts Bay, and the Sandlake and Nestucca Bay areas.

Table 1. Geologic units and their engineering properties in Tillamook Bay area.

Geologic Unit	Average Shear wave velocity (m/s)	Average N-value (blows/ft)	Liquefaction Susceptibility
Holocene Fluvial and Estuarine deposits	86	6	Very high
Holocene/Pleistocene Fluvial/Colluvial deposits	198	19	Low to moderate
Pleistocene gravel	540	36	None
Bedrock	683	n.a.	None

Table 2. Geologic units and their engineering properties in Nehalem, Netarts, and Sandlake and Nestucca Bay areas.

Geologic Unit	Average Shear wave velocity (m/s)	Average N-value (blows/ft)	Liquefaction Susceptibility
Unconsolidated Quaternary deposits	203	8	Moderate to High
Bedrock	683	n.a	None

Ground shaking amplification

The soils and soft sedimentary rocks near the surface can modify bedrock ground shaking caused by an earthquake. The modification can increase (or decrease) the strength of shaking and change the frequency of the shaking. The nature of the modifications is determined by the thickness of the geologic materials and their physical properties, such as stiffness. The method used to evaluate these modifications was developed by FEMA (Building Seismic Safety Council, 1994). This method was adopted in the 1997 version of the Uniform Building Code (International Conference of Building Officials [ICBO], 1997) and will henceforth be referred to as the UBC-97 methodology. This 1997 version of the Uniform Building Code (UBC) was adopted by the State of Oregon in October 1998, with Oregon amendments, and in this form is the *State of Oregon 1998 Structural Specialty Code* (Oregon Building Codes Division, 1998).

The UBC-97 methodology defines six soil categories that are based on average shear wave velocity, the standard penetration test (SPT) value, or undrained shear strength in the upper 100 ft (30 m) of the soil column (Table 3). The six soil categories are hard rock (A), rock (B), very dense soil and soft rock (C), stiff soil (D), soft soil (E), and special soils (F). Category F soils are very soft soils that require site-specific evaluation. Correspondingly, the ground motion amplification hazard ranges from none (categories A,B) to low (category C) to moderate (category D) to high (categories E,F).

Table 3. UBC-97 Soil Profile Types **(ICBO, 1997).**

Soil Type	Soil Name	Average Soil Properties for Top 30 m (100 feet)		
		Shear wave Velocity, Vs (m/s)	Standard Penetration Test, N (blows/foot)	Undrained Shear Strength s_u (kPa)
S_A	Hard Rock	>1,500	-	-
S_B	Rock	760 to 1,500		
S_C	Very Dense Soil and Soft Rock	360 to 760	>50	>100
S_D	Stiff Soil	180 to 360	15 to 50	50 to 100
S_E	Soft Soil	<180	<15	<50
S_F	Soil Requiring Site-specific Evaluation			

The ground motion amplification map of Tillamook County, generated using the UBC-97 method, is included as Map 1 and shows that three ground amplification hazard zones are found in Tillamook County, ranging from low (C-type soil) to high (E-type soil). Most areas in Tillamook County have low to moderate ground motion amplification hazard (C and D type soils), except the bay areas which have high ground motion amplification hazard (E and F type soils).

Liquefaction

Liquefaction is a phenomenon in which shaking of a saturated soil causes its material properties to change so that it behaves as a liquid. In qualitative terms, the cause of liquefaction was described very 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). Unsaturated soils will not liquefy, but they may settle. If an earthquake induces liquefaction, several things can happen: The liquefied layer and everything lying on top of it may move downslope. Alternatively, it may oscillate with displacements large enough to rupture pipelines, move bridge abutments, or rupture building foundations. 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 damage resulting from an earthquake can be dramatically increased over what shaking alone might have caused.

The liquefaction hazard potential can be evaluated based on the age, depositional environment, engineering properties of the geologic unit, and hydrologic condition. Youd and Perkins (1978) found that the liquefaction potential for different sediments is related to the age and depositional environment of the deposit. Table 4 shows how the authors related liquefaction potential to age for several continental deposits. The Quaternary soils in Tillamook County are young (Holocene) and water saturated. These soils are the most susceptible to liquefaction (Tables 1 and 2). The liquefaction potential can be analyzed in detail in terms of ground shaking strength, SPT, and the depth to water table (Seed and Idriss, 1978) or shear-wave velocity of soils (Andrus and Stokoe, 1996). Seed and Idriss (1978) and Andrus and Stokoe (1996) methods were used to further analyze liquefaction potential for those soils with high susceptibility to liquefaction based on the age and depositional environments. The analyses were performed based on the assumption of high ground water level and ground motions from an M 8.5 Cascadia subduction earthquake 20 km offshore. The analyses indicate that the Holocene and Holocene/Pleistocene estuarine and fluvial soils in the Tillamook Bay area and Quaternary estuarine and fluvial soils in other areas of Tillamook County will liquefy during the long-duration shaking.

The liquefaction potential hazard map in Tillamook County is shown as Map 2. The map shows that areas with moderate to high liquefaction potential are concentrated along rivers and in the bays.

Table 4. Estimated Susceptibility of Continental Deposits to Liquefaction (Youd and Perkins, 1978).

Type of deposit	**Likelihood that Cohesionless Sediments, When Saturated, Would Be Susceptible to Liquefaction (by Age of Deposit)**			
	<500 yr	Holocene	Pleistocene	Pre-Pleistocene
River channel	Very high	High	Low	Very low
Flood Plain	High	Moderate	Low	Very low
Alluvial fan and Plain	Moderate	Low	Low	Very low
Lacustrine and playa	High	Moderate	Low	Very low
Colluvium	High	Moderate	Low	Very low
Talus	Low	Low	Very low	Very low
Tuff	Low	Low	Very low	Very low
Residual soils	Low	Low	Very low	Very low

Earthquake-induced landslides

Slope instability resulting from strong shaking will be a significant threat in Tillamook County. The analysis of slope instability for this study is based on state-of-practice dynamic analysis for slope stability and empirical correlation of slope stability with engineering properties of materials, along with manipulation of data on local topography, engineering geology, and hydrology, using GIS tools (Wang and others, 1998).

Different analytical techniques are applied for different slope categories to account for varying observed failure mechanisms. Gentle slopes between 0º and 10º (0%-18%) were assigned low earthquake-induced slope hazard because it was found that the slopes in this range have very low susceptibility for earthquake-induced failure (Jibson and others, 1998; McCrink and Real, 1996). Moderate slopes (10º - 25º) produce larger numbers of rotational slumps and translational block slides in soil (Keefer, 1984). Moderate slopes were analyzed using a dynamic slope stability analysis that incorporates slope inclination, engineering geologic characteristics of geologic units, and shaking parameters from design earthquakes as inputs. Steep slopes (>25º or 47%), most commonly fail by rock falls, rock slides, and debris slides (Keefer, 1984), and were analyzed using the empirical relationships that relate slope stability to degree of weathering, strength of cementation, spacing and openness of rock fractures, and hydrologic conditions (Keefer, 1984, 1993).

These analyses were performed using the GIS programs MapInfo and Vertical Mapper. A digital elevation model (DEM) with a grid spacing of 30 m (98 ft) was used for topographic modeling. The GIS programs use the DEMs to calculate the slope angle at each point in the grid. This slope angle is one of the inputs into the stability analyses. The analyses for the different slope categories are described in detail below:

Existing Landslides

The movement characteristics of existing landslides are highly variable, ranging from active movement to stable. Although most earthquake-induced landslides occur in materials not previously involved in sliding (Keefer, 1984), it requires site-specific studies to understand the nature of any existing landslide. Therefore it was assumed that the slip planes of mapped landslides are at reduced shear strength of unknown value, and that the slide masses are inherently unstable under earthquake loading. Existing landslides are conservatively assigned to the high hazard category. No analytical techniques were applied.

Steep Slopes (>25º or 47%)

Slopes >25º (47%) are particularly vulnerable to bedrock failures. Keefer (1984, 1993) noted that more than 90% of earthquake-induced slope failures on rock slopes were rock falls and rock slides; typically thin, highly disrupted landslides that move at high velocities. The physical characteristics of rock masses underlying steep slopes are of fundamental importance in evaluating their susceptibility to earthquake-induced slope failure. The physical properties of rock include degree of weathering, degree of induration, nature and spacing of fractures, and hydrologic conditions. Keefer (1993) developed a decision tree (Fig. 3) to assess hazard potential for steep slopes (>25º or 47%). The decision tree (Fig. 3) was used in this project to analyze hazard potential of steep slopes (>25º or 47%). Previous investigations (Schlicker and others, 1972; Beaulieu, 1973) and limited outcrop investigations conducted by the authors indicate that most of the rocks exposed in Tillamook County are intensely weathered and poorly indurated. Considering the long-duration ground shaking from Cascadia subduction earthquakes (Clague and others, 2000), a very high hazard potential was assigned to all areas with steep slopes (>25º or 47%).

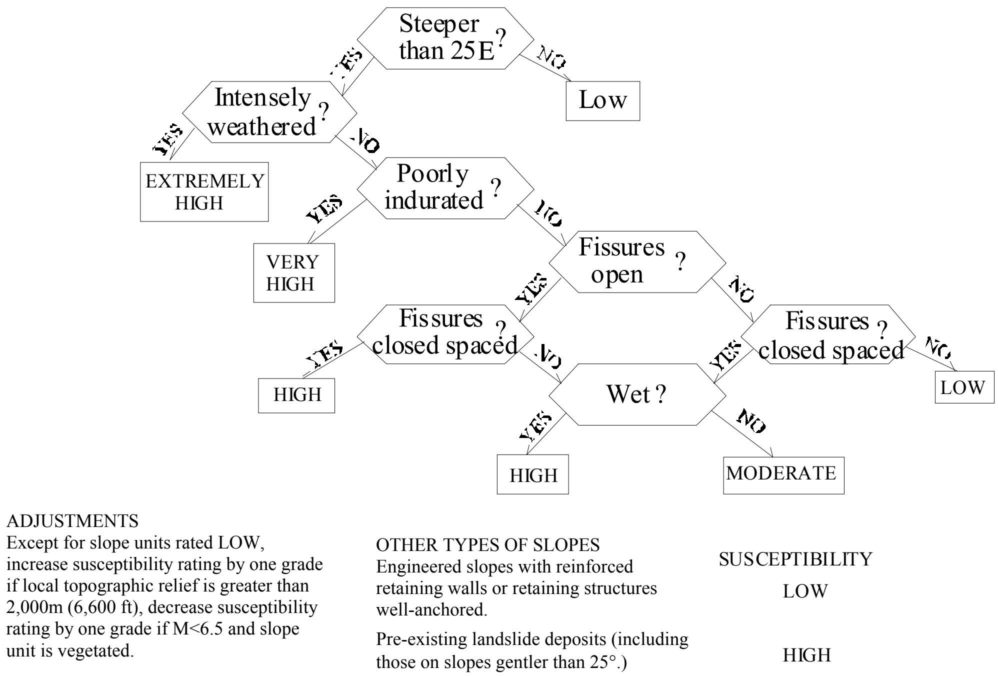


Figure 3. Decision tree for evaluation of earthquake-induced rock slope hazard (Keefer, 1993).

Moderate slopes (10º - 25º)

The stability analysis for moderate slopes is based on the dynamic slope stability analysis of Newmark (1965) as verified and extended to regional-scale work by Wilson and Keefer (1983, 1985), Wieczorek and others (1985), Jibson (1993, 1996), and Jibson and Keefer (1993). The procedure to assign hazard categories takes several steps. First, using infinite slope analysis, the static factor of safety is calculated for each grid element. This factor of safety is then used to calculate the *critical acceleration*, which is the acceleration required to overcome friction and initiate sliding in the soil mass. The critical acceleration is then used in conjunction with earthquake input parameters to calculate the total displacement that is expected to occur during the design earthquake.

The factor of safety (FS) for an infinite slope in material having both frictional and cohesive strength is given by:

$$FS = \left(\frac{c'}{\gamma H \sin\alpha}\right) + \frac{\tan\phi'}{\tan\alpha} - \frac{m\gamma_w \tan\phi'}{\gamma \tan\alpha}$$

where c' and φ' are the effective cohesion and friction angles, α is the slope angle, γ and γ_w are the material and water unit weights, H is the slope-normal thickness, and m is the proportion of the slab thickness that is saturated. In this study, it was assumed that the slope-normal thickness (H) and the material unit weight (γ) are constant and equal to 2.5 m and 1.76 g/cm^3 (110 lbs/ft^3), respectively. It is also assumed that the slope is fully saturated (m=1). Under these assumptions, equation (1) can be simplified as

$$FS = \frac{c'}{43.2\sin\alpha} + \frac{0.43\tan\phi'}{\tan\alpha}$$

The critical acceleration of a potential earthquake-induced landslide block is

$$a_c = (FS-1)\sin\alpha$$

The parameters used to calculate critical acceleration are listed in Table 5. Newmark displacement, in cm, is given by Jibson and others (1998) as

$$\log D_N = 1.521 \log I_a - 1.993\, a_c + 1.546$$

where I_a is Arias intensity in m/s and related to earthquake magnitude, M, and epicentral distance, R, (Wilson and Keefer, 1985) as

$$\log I_a = \mathbf{M} - 2\log R - 4.1$$

A M 8.5 subduction zone earthquake 20 km offshore was used for slope stability analysis in this project. This is approximately equivalent to an Arias Intensity (I_a) of 63 meters per second.

Finally, the total displacement was used to assign that element of slope to a hazard category. Hazard categories used for this project were:

1) Low – displacement <10 cm (0.4-3.9 in).
2) Moderate – displacement 10 -100 cm (3.9-39 in).
3) High – displacement > 100 cm (39 in).

Table 5. Geologic units and assigned engineering properties.

Geologic Unit	c' (kPa)	φ' (°)
Alluvium	20	25
Beach and dune sand	0	15
Landslide debris	n.a.	n.a.
Coarse marine sediments	40	30
Fine marine sediments	30	25
Volcanic rocks	50	35

The results from the analyses for four slope categories were combined to construct the earthquake-induced landslide hazard potential map in Tillamook County (Map 3). The map shows that earthquake-induced landslide hazards are of great concern in Tillamook County.

SEISMIC RISK ASSESSMENT

Sound earthquake risk reduction plans should use detailed risk assessment based on the best available data. DOGAMI completed a seismic risk assessment for the State of Oregon (Wang and Clark, 1999), utilizing the earthquake risk assessment software, HAZUS97, from the Federal Emergency Management Agency (NIBS, 1997), and statewide hazard information (Wang and Clark, 1999). A preliminary seismic risk information in Tillamook County was included in the statewide risk assessment (Wang and Clark, 1999). The information used in these coarse regional studies included a default building data in HAZUS97 and statewide seismic hazard data.

In this study, seismic risk assessment for Tillamook County was performed utilizing the seismic hazard maps developed in this project and the newly released HAZUS99 software by FEMA (NIBS, 1999). The building inventory provided in HAZUS99 for the county was augmented by extrapolating sample surveys from three census block groups (Rad and Hasenberg report, 2000).

Building Inventory

The default building inventory of HAZUS99 was derived from a nationwide database analysis (NIBS 1999). This default inventory might not reflect the characteristcs of building stocks in Tillamook County. With partial support from Oregon Emergency Management (OEM), a sample building survey was conducted by Portland State University (PSU) (Rad and Hasenberg report, 2000). The survey was conducted with the rapid visual screening method published in FEMA Publication 154 (Applied Technology Council, 1988) as a "sidewalk" survey in which the buildings are viewed by the surveyor from the exterior only. The surveyor records the building construction type, occupancy type, area, estimate of building age, story height, and some more detailed information about the building's construction. The survey was completed in three census block groups that include portions of the communities of Netarts, Tillamook, and Rockaway.

The sample surveys were extrapolated using 1990 US Census population figures to complete a building inventory for the entire county. This extrapolated building inventory was augmented with data from other sources, including the HAZUS99 default data for uncommon occupancy types, the Tillamook County telephone directory, and the USGS quadrangle maps for farm locations. The HAZUS99 analysis was run based on this extrapolated building inventory.

The survey data indicate that:

1. The building composition of the nonresidential buildings in Tillamook County was much more limited than the default building types. This will affect the damage calculations, since earthquake damage is computed from building construction type.

2. Building size in Tillamook County is much smaller than that of the default data. This will affect the damaged building counts from HAZUS.
3. Certain groups of occupancy types were underrepresented in the default data, such as hotels, restaurants, and agricultural buildings, due to the character of the county economy. Other occupancy types were overrepresented for the same reason, such as warehouses and heavy industry.

For analysis purposes, the buildings in the Tillamook County inventory were classified in two groups, depending on the age of the building. Buildings built prior to the 1970's were give a Low Code-inferior construction designation (also referred to as Pre-Code in the HAZUS literature) to account for their age and the resistance level to which they were built. Buildings built in the 1970's or after were designated as Moderate Code-code level of construction that is appropriate for buildings built in UBC seismic zones 2B and 3.

The augmented building inventory contains 8 census tracts (42 census block groups), over 8,827 households with a total population of about 21,570 (1990 Census Bureau data), about 18,000 buildings with a total square footage of about 26 million, and a building replacement value of $1.66 billion (1994 dollars). Table 6 lists the building counts in different occupancy classes and building types. A detailed building inventory is presented in Appendix B.

Table 6. Building counts in different occupancy classes and building type in Tillamook County.

Occupancy		**Building**	
Class	Count	Type	Count
Residential	16,218	Wood	16,860
Commercial	882	Steel	7
Industrial	95	Concrete	179
Agriculture	905	Precast Concrete	1
Religion	39	Reinforced Masonry	337
Government	145	Unreinforced Masonry	72
Education	17	Mobile Homes	848
Total	**18,303**	**Total**	**18,303**

Essential and Lifeline Inventories

HAZUS99 also contains essential and lifeline inventories (Tables 7 and 8). These inventories were used in seismic risk assessment.

Table 7. Essential Facility Inventory

Hospital	2 (112 beds)
School	31
Fire Station	10
Police Station	11
Emergency Operation	1

Table 8. Transportation System Lifeline Inventory

System	Component	#locations/ segments	Replacement Value (millions of dollars)
Highway	Major Roads	19	2,075
	Bridges	65	129
	Tunnels	0	
		Subtotal	2,204
Railways	Rail Tracks	1	53
	Bridges	0	0
	Tunnels	0	0
	Facilities	0	0
		Subtotal	53
Port	Facilities	1	2
Airport	Facilities	4	26
	Runways	4	112
		Subtotal	138
TOTAL			2,397

Input Seismic Hazards

To determine the hazard parameters in a particular tract, HAZUS overlays the hazard maps and the tract and takes hazard parameters at the centroid of the tract. This simply overlay might not reflect the reality of census tract. Figure 4 shows UBC soil type overlay over developed land in the city of Tillamook and surrounding. In census tract -500, much of the buildings are in the western section of the city of Tillamook and in the commercial strip development along highway 101 north of the town where have high amplification and liquefaction hazards. The centroid of tract –500 has low amplification (C type soil) and none liquefaction hazards. For this reason, the input seismic hazard parameters (ground motion amplification, liquefaction, and induced slope failure) in each census tract (Table 9) were determined by visually comparing overlays of the hazard maps, USGS quadrangle maps, zoning maps, and census tracts.

Table 9. Hazard parameters in each census tract used in the HAZUS analysis.

Census Tract	Soil Type	Landslide Hazard	Liquefaction Hazard	Water Table Depth
41057960100	D	Moderate (V)	Low	0 feet
41057960200	E	Low (I)	High	0 feet
41057960300	D	Low	Low	0 feet
41057960400	D	Low	Low	0 feet
41057960500	E	Moderate	Low	0 feet
41057960600	D	Moderate	Low	0 feet
41057960700	D	Low	Low	0 feet
41057960800	D	Moderate	Low	0 feet

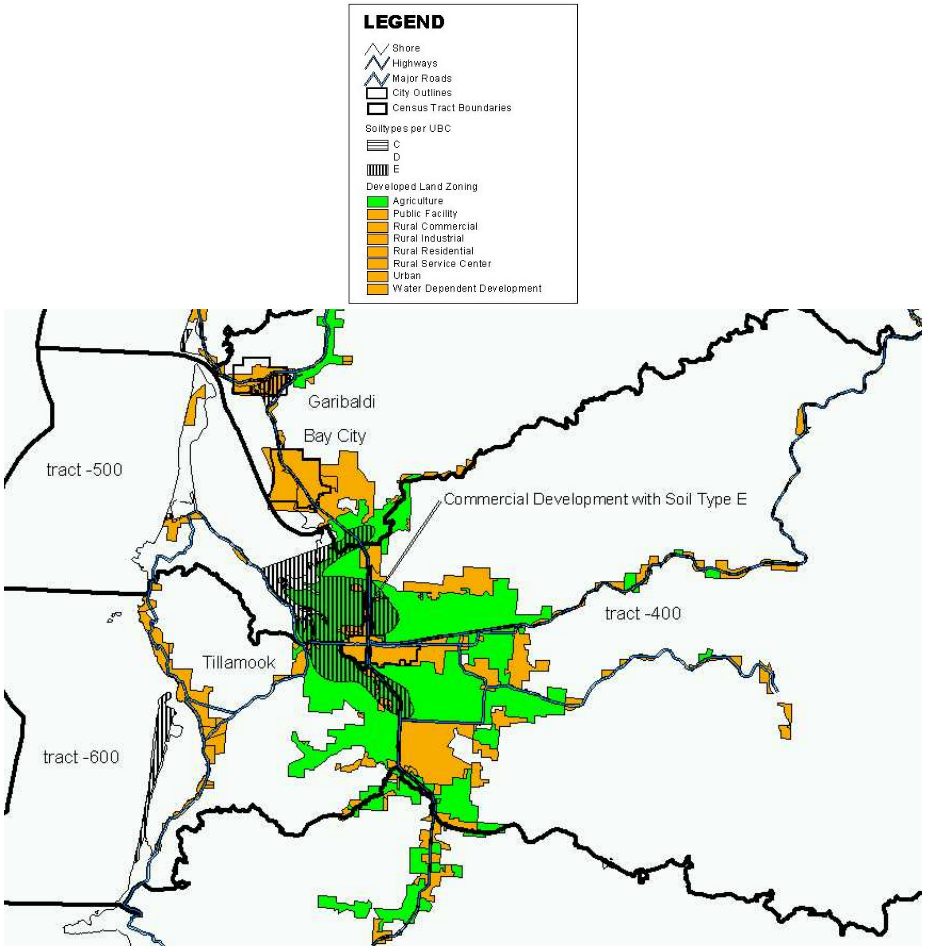


Figure 4. Soil Type overlay over developed land in the city of Tillamook and surrounding area.

Building damage due to liquefactions and earthquake-induced landslides is modeled in HAZUS as a permanent ground displacement. Census tracts with a liquefaction potential range from 2% of the developed land in a low potential area to 25% in a very high potential area that will be subject to liquefaction. The program checks to see if the threshold magnitude for the potential has been reached. The threshold magnitude depends on the potential category and the water table depth. If the threshold magnitude has been reached for the tract, then HAZUS adds buildings to the extensive and complete damage categories. The program treats earthquake-induced landslide in the same way as liquefaction. Unfortunately, it is not possible to model in HAZUS the loss of life that may occur if a catastrophic landslide or liquefaction occurs. This is certainly a possibility in a great earthquake of long duration, given the topographic and geological characteristics of Tillamook County.

Earthquake Scenarios

Due to its proximity to the Cascadia Subduction Zone, the subduction zone earthquakes will pose predominant risk in Tillamook County. Two scenarios were chosen in this study for HAZUS analyses:

- An 8.5 magnitude event on the Cascadia Subduction Zone – The "M8.5 CSZ Model" - The M8.5 Cascadia Subduction Zone Model describes a typical earthquake on the Cascadia Subduction Zone Fault. The magnitude of 8.5 (moment magnitude) is an event in which about half of the length of the fault would rupture. This was modeled as having the rupture zone parallel to the coast of Oregon at a distance of 20 km.
- Probabilistic ground shaking hazard with 500-year return period – The "500 Year Model" - The ground motion for this scenario is based on the hazard maps created by the U. S. Geological Survey for the National Seismic Hazard Mapping Project (Frankel and others, 1996). This earthquake scenario was modeled as a long duration event for the purpose of computing seismic demand.

Ground motions from the two scenarios are comparable. Figure 5 shows that the peak ground acceleration (PGA) values are nearly the same for small coastal tracts, but for the M8.5 CSZ Model the shaking drops off more noticeably in the eastern portions of the county. The 500 Year Model shows fairly uniform shaking.

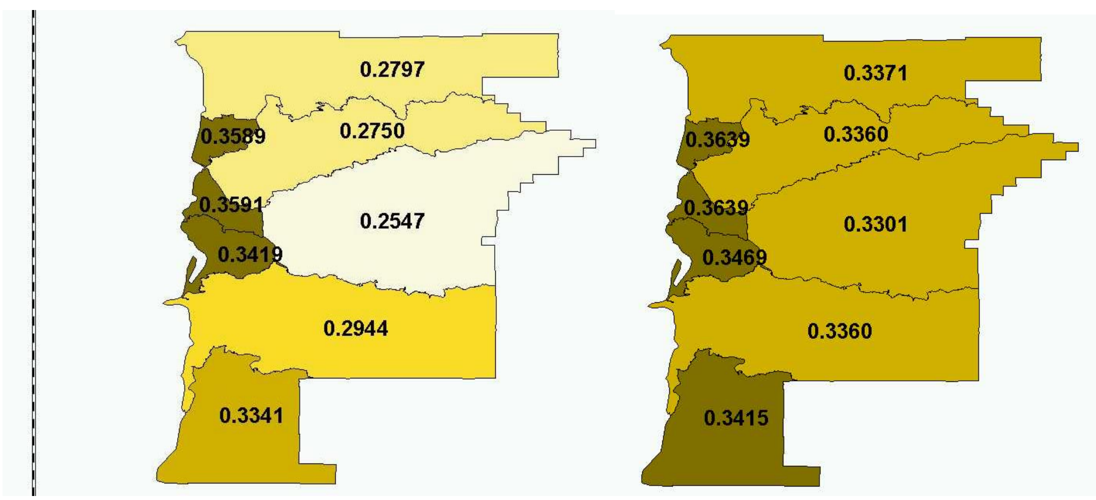


Figure 5. Comparison of ground shaking at centroid of census tracts for the two HAZUS earthquake scenarios. The scenario on the left is the peak ground acceleration (PGA) for the M8.5 CSZ Model, with the earthquake source shown by the dashed line to the west (left) off the coast at about 20 km. On the right the 500 Year Model PGA values are shown.

Damage and Loss Estimates

The damage and loss estimates from the two scenarios are summarized in Table 10. The M8.5 CSZ Model predicts at least slight damage to about 13,115 buildings, with losses on the order of $350 million. All hospitals, schools, and police and fire stations would be expected to have at least moderate damage. 31 bridges would also be expected to be damaged, with 14 completely damaged. The 500 Year Model predicts at least slight damage to all the buildings, with loss on the order of $440. All hospitals, schools, and police and fire stations would be expected to have at least moderate damage. 40 bridges would also be expected to be damaged, with 18 completely damaged. Damages and losses are detailed in Appendix C.

Table 10. Summary of damage and loss estimates from the two scenarios.

<table>
<tr><th></th><th></th><th colspan="3">M8.5 CSZ Model</th><th colspan="3">500 Year Model</th></tr>
<tr><td rowspan="6">Building Damaged</td><td>Damage Level</td><td colspan="2">Residential</td><td>Total</td><td colspan="2">Residential</td><td>Total</td></tr>
<tr><td>Slight</td><td colspan="2">5,604</td><td>5,930</td><td colspan="2">5,739</td><td>6,069</td></tr>
<tr><td>Moderate</td><td colspan="2">4,142</td><td>4,737</td><td colspan="2">5,138</td><td>5,746</td></tr>
<tr><td>Extensive</td><td colspan="2">1,119</td><td>1,584</td><td colspan="2">1,259</td><td>1,687</td></tr>
<tr><td>Complete</td><td colspan="2">431</td><td>904</td><td colspan="2">716</td><td>1306</td></tr>
<tr><td>Total</td><td colspan="2">11,296</td><td>13,155</td><td colspan="2">12,852</td><td>14,808</td></tr>
<tr><td rowspan="5">Casualties</td><td rowspan="2">Severity 1
(Medical treatment without hospitalization)</td><td>2 a.m.</td><td>2 p.m.</td><td>5 p.m.</td><td>2 a.m.</td><td>2 p.m.</td><td>5 p.m.</td></tr>
<tr><td>47</td><td>123</td><td>57</td><td>67</td><td>144</td><td>68</td></tr>
<tr><td>Severity 2
(Hospitalization but not life threatening)</td><td>8</td><td>24</td><td>13</td><td>11</td><td>27</td><td>12</td></tr>
<tr><td>Severity 3
(Hospitalization and life threatening)</td><td>1</td><td>4</td><td>6</td><td>0</td><td>3</td><td>1</td></tr>
<tr><td>Severity 4
(Fatalities)</td><td>0</td><td>3</td><td>2</td><td>0</td><td>3</td><td>1</td></tr>
<tr><td rowspan="2">Shelter</td><td>Displaced Households
(# households)</td><td colspan="3">227</td><td colspan="3">354</td></tr>
<tr><td>Short Term Shelter
(# people)</td><td colspan="3">160</td><td colspan="3">255</td></tr>
<tr><td rowspan="3">Economic Loss</td><td>Property Damage losses ($millions)</td><td colspan="3">236</td><td colspan="3">306</td></tr>
<tr><td>Business Interruption losses ($millions)</td><td colspan="3">114</td><td colspan="3">134</td></tr>
<tr><td>Total ($ millions)</td><td colspan="3">350</td><td colspan="3">440</td></tr>
</table>

Table 10 shows that the estimates for the M8.5 CSZ Model are somewhat lower than the estimates for the 500 Year Model. This is due to the ground shaking hazards at the centroid of the census tracts from the M8.5 CSZ scenario are somewhat lower than those from the 500 Year scenario (Figure 5).

The shelter summary reports from HAZUS show results that are computed from the number of households listed in the 1990 US Census data (8,827 households). The calculation methodology used by HAZUS is that 100% of single family dwellings in the complete damage state will have their households displaced. For the M8.5 CSZ Model, number of displace households is listed as 227, and short-term shelter needs list an additional 160 persons. Although this number seems low compared with the number of residential buildings in the complete damage state, a fair number of the single family dwellings in Tillamook County are vacation homes and many of the multifamily units are hotels and motels. Also, the sample surveys were conducted in 1999 whereas the census data is from 1990. The year 2000 Census results may shed some light on this figure. For the 500-Year Model, the shelter needs are 354 displaced households and 255 persons needing short-term shelter. These requirements may also be larger depending on power outages and potable water needs, which were not included in the model.

Casualty results in HAZUS are based on injuries and deaths from building damage and bridge damage only. Not included in the estimate are injuries and deaths resulting from fires following the earthquake, tsunamis, landslides, dam failures, or a release of toxic substances. As these can be major contributors to casualties, caution must be used in interpreting the HAZUS results. The functions used to compute the building and bridge casualties are also based on available historical data, which according to the HAZUS User's Manual is "not of the best quality". Data for developing such functions is usually gathered long after the earthquake occurs and the level of detail is low. Casualty figures computed in HAZUS are given for 2 p.m., 2 a.m., and 5 p.m., as the distribution of population in various building occupancy categories and on the highways depends on the time of day. Population exposure is computed and then the casualty functions are engaged based on percentage of buildings in each of the damage states. One anomalous result is that the 500-Year Model predicts fewer severe casualties (life-threatening injuries and immediate deaths) than the M8.5 CSZ Model. This may be due somewhat to rounding errors since the actual numbers are very low.

HAZAUS analyses predicts there would be only 12% of emergency facilities, 10% of schools, and 64% of communication facilities functional at the day following the earthquake for the M8.5 CSZ scenario. For the 500-Year scenario, model predicts that only 10% of emergency facilities, 9% of schools, and 64% of communication facilities will be functional.

The default data listed 19 road segments, 65 highway bridges, and 4 runways. The M8.5 CSZ model predicts that 31 highway bridges would suffer at least moderate damage, of which 14 would be complete damage. The 500 Year model also predicts that 31 highway bridges would suffer at least moderate damage, of which 14 would be complete damage. The roads and airport facilities are expected to remain fully functional according to either model; however permanent ground displacements in areas of liquefaction hazards (such as bays) and landslides blocking highways are likely to occur.

CONCLUSIONS

Great Cascadia subduction zone earthquakes have occurred many times in the past along the Pacific Northwest coast, the most recent one on January 26, 1700 (Clague and others, 2000). Future subduction zone earthquakes pose great seismic hazards and risk to Tillamook County. Strong ground shaking from the subduction zone earthquakes will likely last three minutes or more and be dominated by long-period ground motions (Clague and others, 2000). This long-period and long-duration ground shaking will cause wide spread ground failures. The ground shaking hazard from the Cascadia subduction earthquakes has been assessed and is available in such publications as DOGAMI's map GMS-100 (Madin and Mabey, 1996) and the probabilistic hazard maps of the United States Geological Survey (USGS) (Frankel and others, 1996). These maps provide a general seismic hazard level from all seismic sources. The ground motion design level in the *State of Oregon 1998 Structural Specialty Code* (Oregon Building Codes Division, 1998) is based on these probabilistic seismic hazard assessments.

However, the earthquake hazards are also affected by local surface and subsurface conditions. Three phenomena generally will be induced by ground shaking during a strong earthquake: (1) amplification of ground shaking by a "soft" soil column; (2) liquefaction of water-saturated sand, silt, or gravel, creating areas of "quicksand;" and (3) landslides, including rock falls and rock slides, triggered by shaking, even on relatively gentle slopes. These effects depend on the local geologic, hydrologic, and topographic conditions. Therefore, they are called *relative earthquake hazards*. These relative hazards in Tillamook County were assessed utilizing the best available geological, geotechnical, and water-well data and limited field investigations. The maps show that the areas with high ground amplification and liquefaction hazards are concentrated in the bays and valleys and along the coast, while the areas with high earthquake-induced landslide hazard are spread out over mountainous areas. Hazards from coastal landslides, including along the steep bluffs, can be found in O-01-03 (Allan and Priest, 2001).

Sample building surveys were conducted in the Netarts, Tillamook, and Rockaway census block groups. The survey data were analyzed and used to augment the building inventory provided by HAZUS99. The augmented building inventory and other inventories provided by HAZUS99 were used to assess seismic risks in the county for two scenarios: a M 8.5 Cascadia subduction zone earthquake 20 km offshore and the probabilistic ground shaking hazard with a 500-year recurrence interval (Frankel and others, 1996).

The results indicate that the damage and losses from the two scenarios are devastating. Not including tsunami damage, which would be concentrated in low-lying coastal areas, the M8.5 Cascadia subduction scenario could cause at least slight damage to 13,115 buildings, more than hundred injuries and deaths, and $350 million in losses. The 500-year probabilistic ground shaking hazard scenario could cause at least slight damage to 12,852 buildings, more than hundred injuries and deaths, and $440 million in losses. These models include population statistics for winter residents. In the summer, the resident population can be three times larger. Consequently, the casualties from an earthquake occurring in the summer are expected to be higher.

Models also predict severe impact on the lifeline and essential facilities. For the M8.5 scenario, only 12% of emergency facilities, 10% of schools, and 64% of communication facilities would be functional at the day following the earthquake. 31 highway bridges would suffer at least moderate damage, of which 14 would be complete damage. For the 500-Year scenario, only 10% of emergency facilities, 9% of schools, and 64% of communication facilities would be functional. 31 highway bridges would suffer at least moderate damage, of which 14 would be complete damage.

DISCUSSION

Hazard Maps

The *Relative Earthquake Hazard Maps,* including ground amplification, liquefaction, and earthquake-induced landslide hazards in Tillamook County were evaluated based on local geologic, topographic, and hydrologic conditions. The local geologic conditions including thickness and engineering properties of geologic materials were derived from the available existing geological, geotechnical, coring, and water-well data and limited field investigations (geophysics) and used to construct three dimensional geologic models using the GIS software, MapInfo™ and Vertical Mapper™. According to the scope of this project, limited field investigations were conducted, most of which were concentrated in Tillamook Bay area (Tillamook-Garibaldi) with few in other areas in Tillamook County. Consequently, a better geologic model with four geologic units in Tillamook Bay area was constructed, while the geologic models in other areas in the county have only two geologic units.

Ground motion amplification hazard was derived from the three dimensional geologic models with 30m by 30m grid space using the GIS software and assigned hazard value using the UBC-97 methodology. Liquefaction hazard was derived in the similar way as ground amplification hazard and assigned hazard value based the age and depositional environment of the geologic units and simplified the-state-of-practice engineering analysis. Earthquake-induced landslide hazard was derived from surface geology, slope distribution (30m DEM), existing landslides, and infinite slope model analysis. Limited field investigations were conducted to check and map landslides along the coastal zone, but not effort was made to check and map landslides in other areas. In this study, we used 30m DEM to derive slope distribution which could not pick up some small scale steep slopes such as bluff along the coast. All the hazards were evaluated under the worst hydrologic condition: 100% saturation or 0 m groundwater table.

The *Relative Earthquake Hazard Maps* delineate those areas most likely to experience damage in a given earthquake. This information can be used to develop a variety of hazard mitigation strategies such as:

Emergency response and hazard mitigation

One of the key uses of these maps is to develop emergency response plans. The areas indicated as having a higher hazard would be the areas where the greatest and most abundant damage will tend to occur. Planning for disaster response will be enhanced by the use of these maps to identify which resources and transportation routes are likely to be damaged.

Land use planning

The location of future urban expansion or intensified development should also consider earthquake hazards. Requirements placed on development could be based on the hazard zone in which the development is located. For example, the type of site-specific earthquake hazard investigation that is required could be based on the hazard.

Lifelines

Lifelines include road and access systems including railroads, airports, and runways, bridges, and over- and underpasses, as well as utilities and distribution systems. The *Relative Earthquake Hazard Map* and its component single-hazard maps are especially useful for expected-damage estimation and mitigation for lifelines. Lifelines are usually distributed widely and often require regional as opposed to site-specific hazard assessments. The hazard maps presented here allow quantitative estimates of the hazard throughout a lifeline system. This information can be used for assessing vulnerability as well as deciding on priorities and approaches for mitigation.

Engineering

The hazard zones shown on the *Relative Earthquake Hazard Maps* **should not** serve as a substitute for site-specific evaluations based on subsurface information gathered at a site. The calculated values of the individual component maps used to make the *Relative Hazard Maps* may, however, be used to good purpose in the absence of such site-specific information, for instance, at the feasibility-study or preliminary-design stage. In most cases, the quantitative values calculated for these maps would be superior to a qualitative estimate based solely on lithology or non-site-specific information. Any significant deviation of observed site geology from the geologic model used in the analyses indicates the need for additional analyses at the site.

It is very important to recognize the limitations of these *Relative Earthquake Hazard Maps*, which in no way include information with regard to the probability of damage to occur. Rather, they shows that when shaking occurs, the damage is more likely to occur, or be more severe, in the higher hazard areas. Neither should the higher hazard areas be viewed as unsafe. These limitations are originated from the nature of regional mapping, scarcity of data, and computer modeling.

Risk Assessment

HAZUS99 was developed by FEMA and the National Institute of Building Sciences (NIBS) as a tool for developing reliable earthquake damage and loss estimates that are essential to decision-making at the local, region, state, and national levels of government. HAZUS99 contains huge default database ranging from building stock, lifeline facilities, to fragility functions, developed from nationwide available data. Some default data may not reflect the reality in Tillamook County. In this study, only effort being made was to improve building data in the county by extrapolating the sample building surveys. The survey data shows 1) The building composition of the nonresidential buildings in Tillamook County was much more limited than the default building types, 2) Building size in Tillamook County is much smaller than that of the default data, and 3) Certain groups of occupancy types were underrepresented in the default data, such as hotels, restaurants, and agricultural buildings, due to the character of the county economy. Other occupancy types were overrepresented for the same reason, such as warehouses and heavy industry. This suggests that data improvement is needed for better risk assessment in Tillamook County.

The results from both models show that residential and governmental structures are expected to fare the best in an earthquake. Commercial buildings are expected to be hardest hit from the analyses, although in reality agricultural buildings will probably fare worse, due to the fact that they are the most likely to be built on “bottomland”, or loose soil that is also susceptible to liquefaction, and according to the building department in Tillamook County, usually are pole barns with no foundations. Notwithstanding, commercial structures are more likely to contain people who may be harmed in an earthquake. The results also show that wood structures are predicted to fare the best and concrete and unreinforced masonry structures are expected to fare the worst. The concrete structures in Tillamook County are usually older buildings and are often clad with brick veneer. These types of buildings are generally poor performers. Unreinforced masonry buildings are the poorest performers.

The risk assessment using HAZUS can provide the basis for developing mitigation policy, for developing and testing emergency preparedness and response plans, and for planning for post disaster relief and recovery. However, cautions must be exercised in using the risk information due to the uncertainty and data quality inherited from the program – HAZUS99 and input data.

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Appendix A. SH-wave, Geotechnical, Coring, and Water Well Data

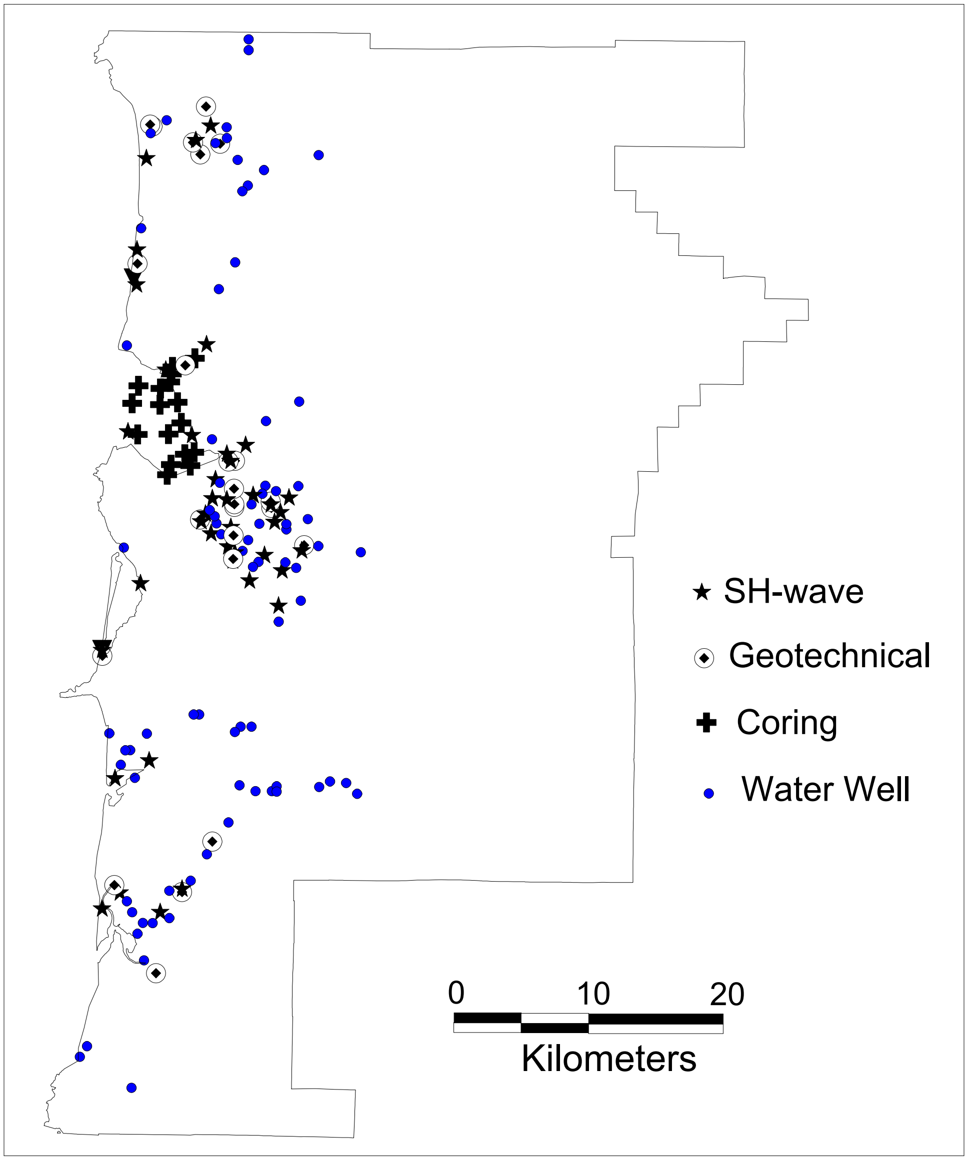

Figure A-1. Locations of geophysical, geotechnical, coring, and water well data.

Table A-1. Shear-wave velocities.

SITE	LAYER_1	L1_THICK	L1_VSORN	LAYER_2	L2_THICK	L2_VSORN	LAYER_3	L3_THICK	L3_VSORN	LAYER_4	L4_THICK	L4_VSORN
TC01		0.0	0.0	Top soil	2.5	168.0		0.0	0.0	Bedrock	0.0	
TC02	Silt/clay with o	8.0	75.0	sand/silt with gra	8.5	129.0	Gravel and sa	32.5		Bedrock	0.0	0.0
TC03	Silt or clay	4.0	90.0	sand/silt with gra	11.0	180.0	Gravel and sa	0.0			0.0	0.0
TC04	Mud/clay or silt	6.0	77.0	sand/silt with gra	38.7	224.0	Gravel and sa	0.0	0.0		0.0	0.0
TC05	Mud/clay or silt	12.0	97.0	sand/silt with gra	16.5	171.0		0.0	0.0		0.0	0.0
TC06		0.0	0.0	top soil	3.0	88.0	Gravel	0.0			0.0	0.0
TC07		0.0	0.0	sand/silt with gra	14.8	147.0		0.0	0.0	Bedrock	0.0	579.0
TC08		0.0	0.0	residual soil	2.0	120.0	Gravel and sa	0.0			0.0	0.0
TC09	Silt/clay with o	5.0	85.0	sand/silt with gra	8.0	112.0	Gravel	0.0			0.0	0.0
TC10		0.0	0.0	sand/silt with gra	3.0	177.0	Gravel	0.0			0.0	0.0
TC11		0.0	0.0	residual soil	8.0	329.0		0.0	0.0	Bedrock	0.0	788.0
TC12	Mud/clay or silt	3.0	53.0	sand/silt with gra	7.0	151.0	sandy Gravel	0.0			0.0	0.0
TC13	Mud/clay or silt	3.0	78.0	sand/silt with gra	16.0	208.0	sandy Gravel	0.0			0.0	0.0
TC14		0.0	0.0	sand/gravel	4.0	315.0	Gravel	0.0			0.0	0.0
TC15	Silt/clay with o	12.5	100.0		0.0	0.0		0.0	0.0		0.0	0.0
TC16		0.0	0.0	Sand/silt with gra	7.0	207.0	Gravel/bedroc	0.0			0.0	0.0
TC17		0.0	0.0	Sand/gravel with s	10.0	122.0		0.0	0.0	bedrock	0.0	0.0
TC18	Clay/silt with o	11.0	0.0	Sand/silt with gra	15.8	238.0	Gravel	21.7	0.0	Bedrock	0.0	0.0
TC24	Mud/clay with sa	31.6	0.0	Sand/silt with gra	39.0	0.0	Gravel	0.0	0.0		0.0	0.0
TC33	Silt/clay with o	11.0	94.0	Sand/silt with gra	0.0	0.0		0.0	0.0		0.0	0.0
TC34	Silt/clay with o	20.0	120.0	sand/silt with gra	0.0	376.0		0.0	0.0		0.0	0.0
TC35	Blue/black sandy	13.3	133.0	Sand with silt/gra	19.2	210.0	Gravel	0.0			0.0	0.0
TC36	Fill and Clay/sa	13.6	111.0		0.0	0.0	Gravel	4.7	0.0	Bedrock	0.0	0.0
TC37	Top Soil	1.0	118.0	sand with silt/gra	4.5	178.0	Gravel	0.0			0.0	0.0
Tillam1		0.0	0.0	top soil	2.5	330.0	Gravel	0.0			0.0	0.0
Tillam2	Mud/clay or silt	2.0	112.0	sand/silt with gra	9.0	230.0	Gravel and sa	0.0			0.0	0.0
Tillam3	Mud/clay or silt	4.0	35.0	sand/silt with gra	26.0	184.0	Gravel and sa	0.0	0.0		0.0	0.0
TC19	Top soil	3.0	145.0	Dune sand	17.0	278.0	Bedrock	0.0			0.0	0.0
TC20	Fill (sand)	10.0	167.0	Dune sand	0.0	276.0		0.0	0.0		0.0	0.0
TC21		5.0	0.0		25.0	195.0	(bedrock)	0.0			0.0	0.0
TC22	Dun sand	58.7	244.0	Bedrock	0.0	0.0		0.0	0.0		0.0	0.0
TC23	Top soil	5.0	79.0	Fluvial	57.0	289.0	Bedrock	0.0			0.0	0.0
TC25	Estuarine sedime	12.4	92.2	Bedrock	0.0	683.0		0.0	0.0		0.0	0.0
TC26	Dune sand	31.5	219.0	Bedrock	0.0	0.0		0.0	0.0		0.0	0.0
TC27	Dune sand	9.0	153.0	Dune sand (old)	36.7	336.0	bedrock	0.0	0.0		0.0	0.0
TC28	Top soil	4.5	149.0	Bedrock	0.0	556.0		0.0	0.0		0.0	0.0
TC29	Dune sand	0.0	198.0		0.0	0.0		0.0	0.0		0.0	0.0
TC30	Top soil	6.0	122.0		20.0	237.0	Bedrock	0.0	0.0		0.0	0.0
TC31	Fluvial clay & g	14.0	0.0	Gravel & clay	10.5	0.0	Bedrock	0.0	0.0		0.0	0.0
TC32	Fluvial	15.1	131.0	Gravel(bedrock)	18.6	625.0	Bedrock	0.0	0.0		0.0	0.0

Appendix B. Building Inventory in Tillamook County

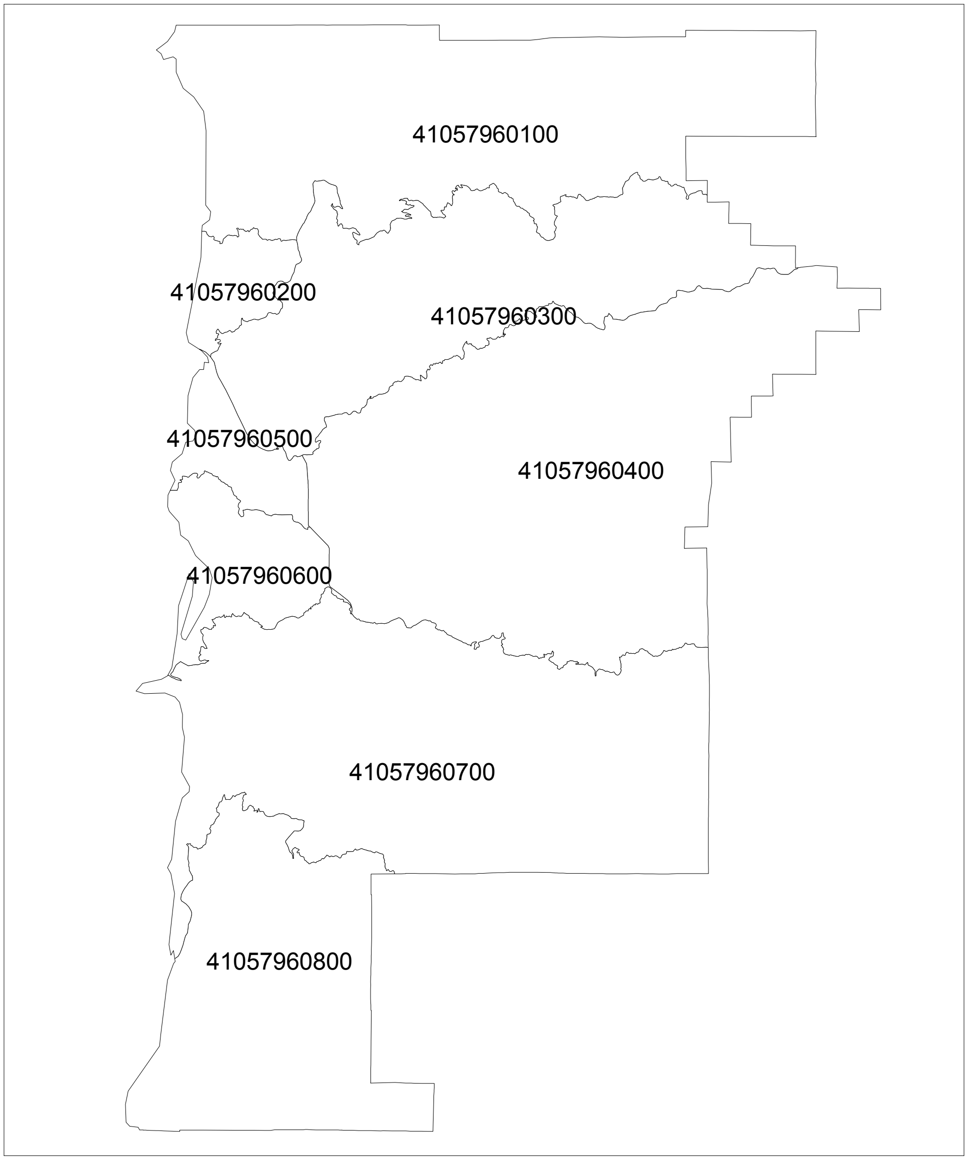

Figure B-1. Census tracts in Tillamook County.

Table B-1. Building inventory (general occupancy) in Tillamook County.

TRACT	RES	COM	IND	AGR	REL	GOV	EDU	TOTAL
41057960700	1819	41	4	72	8	17	0	1961
41057960100	2579	159	28	84	3	24	4	2881
41057960200	1536	67	4	0	2	17	1	1627
41057960300	1929	78	7	66	3	18	2	2103
41057960400	4226	242	29	317	13	37	4	4868
41057960800	1764	40	10	120	1	17	0	1952
41057960500	891	229	12	90	7	1	7	1237
41057960600	1474	26	1	156	2	14	0	1673
Total	16218	882	95	905	39	145	18	18302

Table B-2. Building inventory (general building type) in Tillamook County.

TRACT	WOOD	STEEL	CON-CRETE	PRE-CAST	RMASONRY	URM-MASONRY	MOBILE	TOTAL
41057960700	1820	0	6	0	17	4	114	1961
41057960100	2733	1	26	0	45	13	64	2882
41057960200	1566	0	9	0	18	5	29	1627
41057960300	1933	1	11	0	23	6	129	2103
41057960400	4384	2	62	0	119	21	279	4867
41057960800	1812	0	6	0	19	4	111	1952
41057960500	1069	3	56	1	80	16	13	1238
41057960600	1543	0	3	0	16	3	109	1674
Total	16860	7	179	1	337	72	848	18304

Table B-3. Building value (thousand dollars) per general occupancy in Tillamook County.

TRACT	RES	COM	IND	AGR	REL	GOV	EDU	TOTAL
41057960700	146926	8547	742	4595	5645	799	251	167505
41057960100	226564	34323	5133	5360	2117	1833	3165	278495
41057960200	137992	14004	1233	0	1411	1488	1720	157849
41057960300	152497	16952	2115	4211	2117	1525	1328	180745
41057960400	334042	47402	7945	20293	9173	2793	4307	425956
41057960800	142330	8241	2120	7657	706	1158	235	162447
41057960500	74480	58578	4229	5743	4939	66	5068	153103
41057960600	116289	5205	379	9955	1411	1026	0	134266
Total	1331120	193252	23896	57814	27519	10688	16074	1660366

Table B-4. Building value (thousand dollars) per building type in Tillamook County.

TRACT	WOOD	STEEL	CON-CRETE	PRE-CAST	RMASONRY	URM-MASONRY	MOBILE	TOTAL
41057960700	158864	69	2193	6	2767	968	2636	167505
41057960100	260191	313	5982	76	7813	2621	1499	278495
41057960200	150000	64	2578	26	3389	1118	673	157849
41057960300	169486	172	2922	22	3719	1425	2998	180745
41057960400	382601	546	14305	103	18134	3808	6459	425956
41057960800	155324	38	1436	6	2290	788	2566	162447
41057960500	111525	674	23119	171	14308	2996	310	153103
41057960600	128450	57	873	14	1777	564	2531	134266
Total	**1516441**	**1933**	**53408**	**424**	**54197**	**14288**	**19672**	**1660366**

Table B-5. Average square footage (thousand square feet) for specific occupancy types.

SPECIFIC OCCUPANCY	SPECIFIC OCCUPANCY DESCRIPTION	AVERAGE SQUARE FEET PER BUILDING
RES1	single family	1.10
RES2	mobile home	0.47
RES3	multi-family	5.19
RES4	hotel/motel	1.73
RES5	dormitory	30.00
RES6	nursing home	45.00
COM1	retail store	2.48
COM2	wholesale sales	1.67
COM3	service station	2.88
COM4	office	3.52
COM5	bank	2.59
COM6	hospital	95.00
COM7	medical office	4.60
COM8	restaurant/bar	2.34
COM9	theater	4.80
COM10	parking garage	9.00
IND1	heavy industry	50.00
IND2	light industry	20.00
IND3	food/drug manufacturing	21.00
IND4	metals processing	16.00
IND5	high technology	17.00
IND6	construction	3.00
AGR1	farming	4.50
REL1	church	7.50
GOV1	general government	0.65
GOV2	police/fire stations	3.20
EDU1	k-12 schools	9.19
EDU2	colleges and universities	25.00

Appendix C. Damages and Losses

C-1. Damages and losses from an M8.5 Cascadia subduction earthquake scenario

Table C-1-1. Expected building damage by general occupancy.

SUMMARY DATA	Exposure	Damage Counts				
General Occupancy Category	Building Count	None	Slight	Moderate	Extensive	Complete
Agriculture	905	39	96	292	264	212
Commercial	882	127	166	225	152	209
Education	18	2	3	5	4	4
Government	145	30	36	40	21	18
Industrial	95	15	18	23	17	21
Religious	39	6	7	10	7	9
Residential	16,218	4,884	5,604	4,142	1,119	431

Table C-1-2. Expected building damage by structure type.

SUMMARY DATA	Exposure	Damage Counts				
Building Type	Building Count	None	Slight	Moderate	Extensive	Complete
Wood	16,860	4,351	5,214	4,566	1,817	911
Steel	7	0	1	2	3	2
Concrete	179	4	10	33	43	89
Precast Concrete	1	0	0	0	0	0
Reinforced Masonry	337	39	30	69	82	117
Unreinforced Masonry	72	1	3	10	16	41
Mobile Home	848	10	50	185	309	294

Table C-1-3: Functionality of Essential Facilities.

Type of Facility	Functionality the day following the earthquake
Emergency Response (Police, Fire, Emergency Response Centers)	12%
Schools	10%
Communications	64%

Table C-1-4: Expected Damage to the Transportation System

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	19			19	19
	Bridges	65	31	14	31	38
	Tunnels	0	0	0	0	0
Port	Facilities	1	0	0	1	1
Airport	Facilities	4	2	0	4	4
	Runways	4	0	0	4	4

C-2. Damages and losses from the 500-year probabilistic hazard scenario

Table C-2-1. Expected building damage by general occupancy.

SUMMARY DATA	Exposure	Damage Counts				
General Occupancy Category	Building Count	None	Slight	Moderate	Extensive	Complete
Agriculture	905	24	110	264	221	286
Commercial	882	74	157	252	157	241
Education	18	1	3	6	4	4
Government	145	15	36	48	22	22
Industrial	95	8	17	27	17	26
Religious	39	3	7	11	7	11
Residential	16,218	3,408	5,739	5,138	1,259	716

Table C-2-2. Expected building damage by structure type.

SUMMARY DATA	Exposure	Damage Counts				
Building Type	Building Count	None	Slight	Moderate	Extensive	Complete
Wood	16,860	2,983	5,361	5,371	1,753	1,391
Steel	7	0	0	2	3	2
Concrete	179	2	12	31	40	94
Precast Concrete	1	0	0	1	0	0
Reinforced Masonry	337	14	27	79	85	132
Unreinforced Masonry	72	1	1	8	17	45
Mobile Home	848	3	29	188	278	350

Table C-2-3: Functionality of Essential Facilities

Type of Facility	Functionality the day following the earthquake
Emergency Response (Police, Fire, Emergency Response Centers)	10%
Schools	9%
Communications	64%

Table C-2-4: Expected Damage to the Transportation System

System	Component	Number of Locations				
		Locations/ Segments	At Least Mod. Damage	Complete Damage	With Functionality > 50 %	
					After Day 1	After Day 7
Highway	Roads	19			19	19
	Bridges	65	40	18	31	31
	Tunnels	0	0	0	0	0
Port	Facilities	1	0	0	1	1
Airport	Facilities	4	3	1	1	4
	Runways	4	0	0	4	4