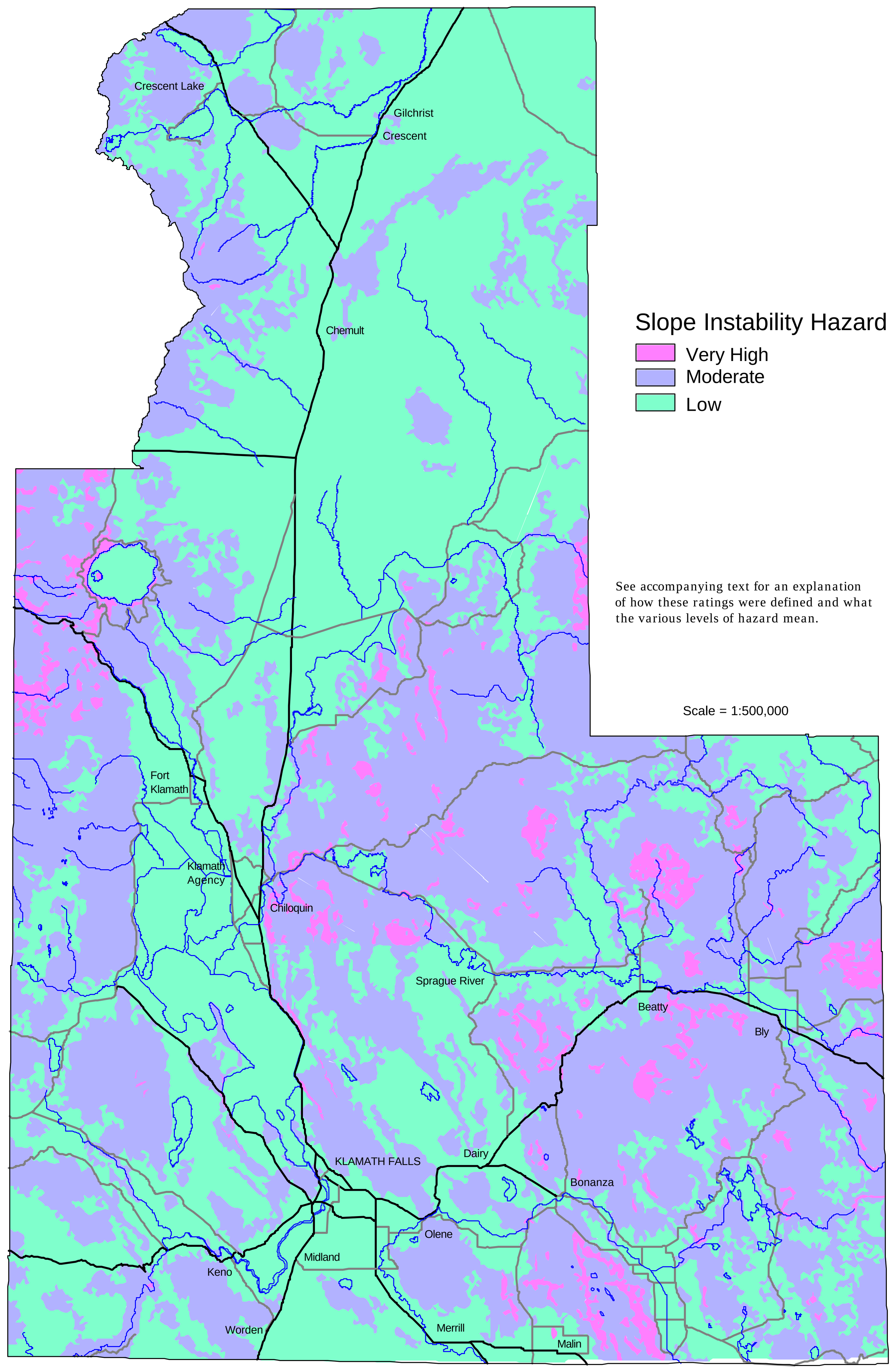
STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
JOHN D. BEAULIEU, STATE GEOLOGIST

# Relative Earthquake Hazard Maps of Ground Motion Amplification, Liquefaction, and Slope Instability in Klamath County, Oregon
2000

**IMS-20**
Earthquake Hazard Maps and Seismic Risk Assessment for Klamath County, Oregon

By Zhenming Wang and Yumei Wang

## Relative Slope Hazard Map

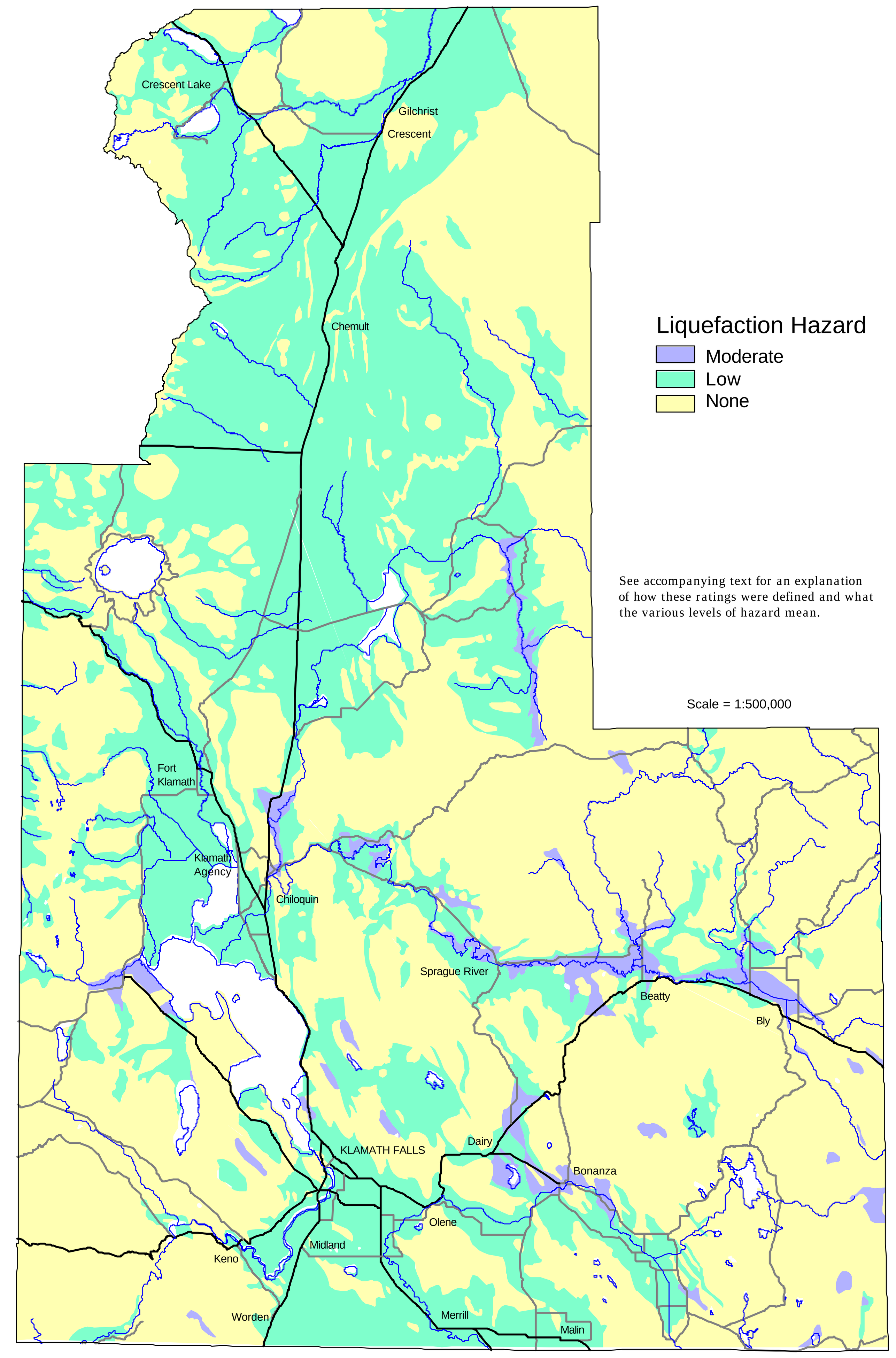



Slope Instability Hazard
- Very High
- Moderate
- Low

See accompanying text for an explanation of how these ratings were defined and what the various levels of hazard mean.

Scale = 1:500,000

## Relative Liquefaction Susceptibility Map

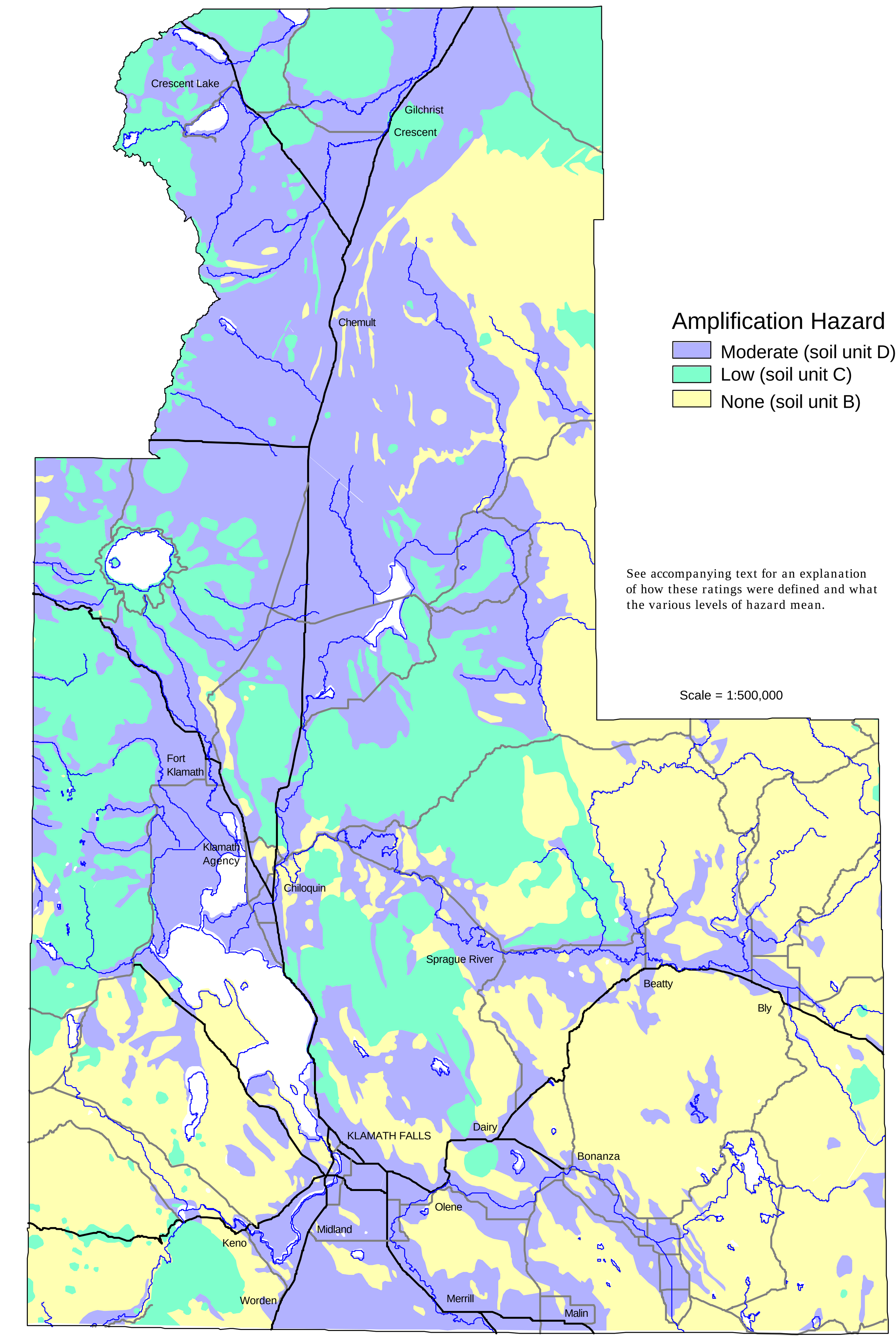



Liquefaction Hazard
- Moderate
- Low
- None

See accompanying text for an explanation of how these ratings were defined and what the various levels of hazard mean.

Scale = 1:500,000

## Relative Ground Motion Amplification Hazard Map

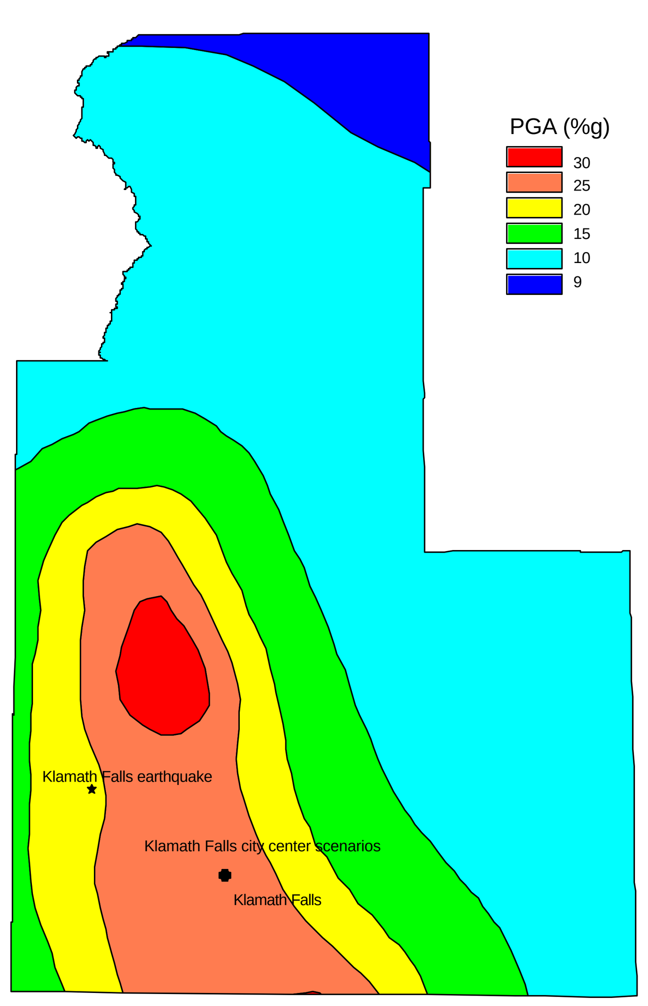



Amplification Hazard
- Moderate (soil unit D)
- Low (soil unit C)
- None (soil unit B)

See accompanying text for an explanation of how these ratings were defined and what the various levels of hazard mean.

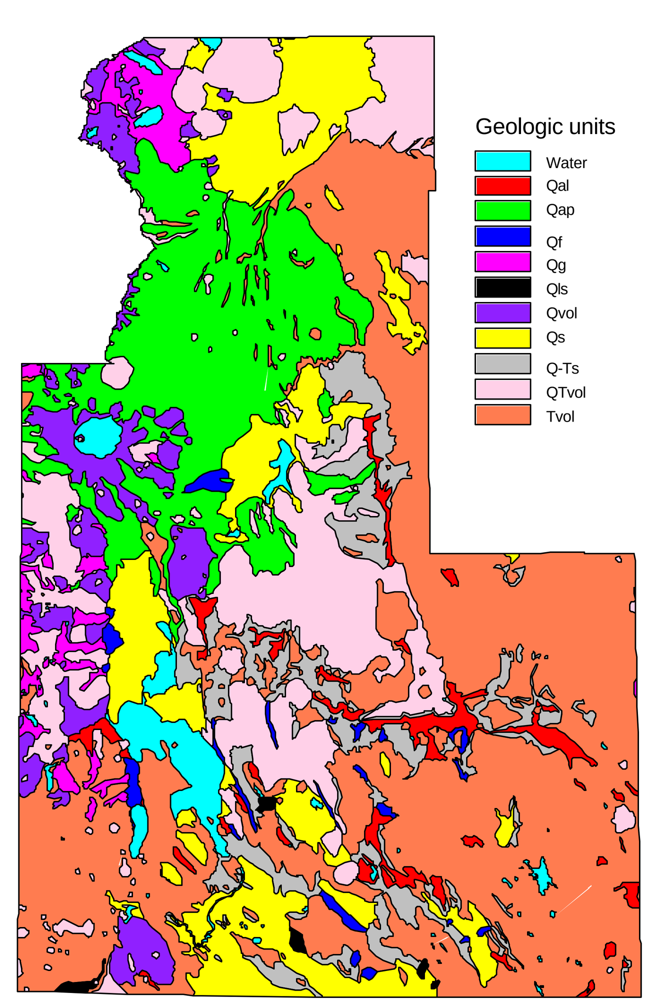
Scale = 1:500,000

Figure 1. Maximum peak ground acceleration (PGA, in percent g) expected in Klamath County from earthquakes with a frequency of occurrence of once in 500 years, after Frankel and others (1996).



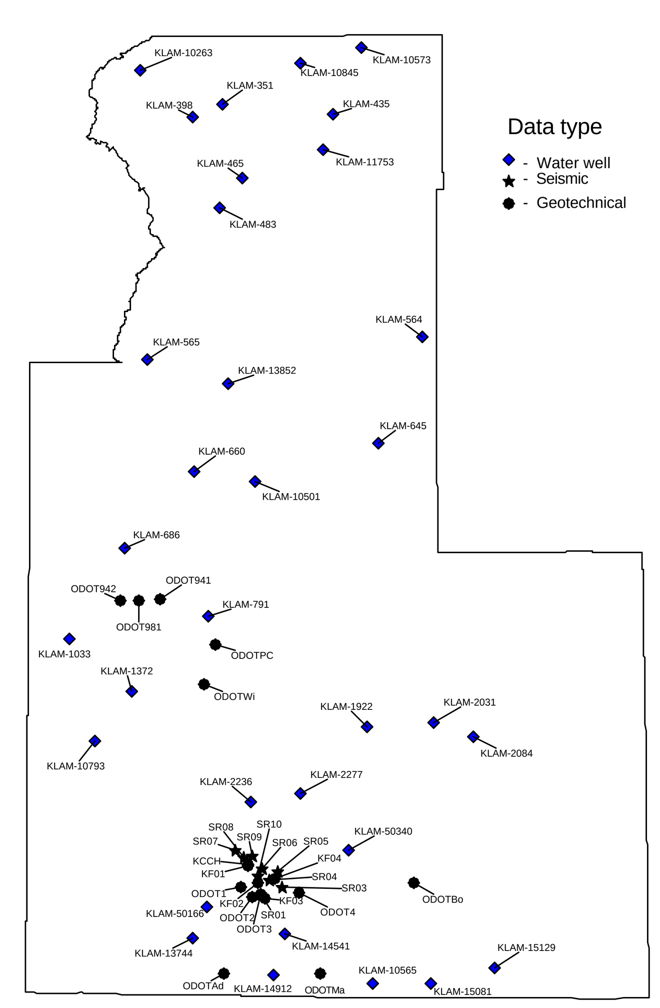

Scale = 1:1,000,000

Figure 2. Simplified geologic map of Klamath County after Walker and MacLeod (1991). See unit descriptions in Table 2 of the accompanying text.



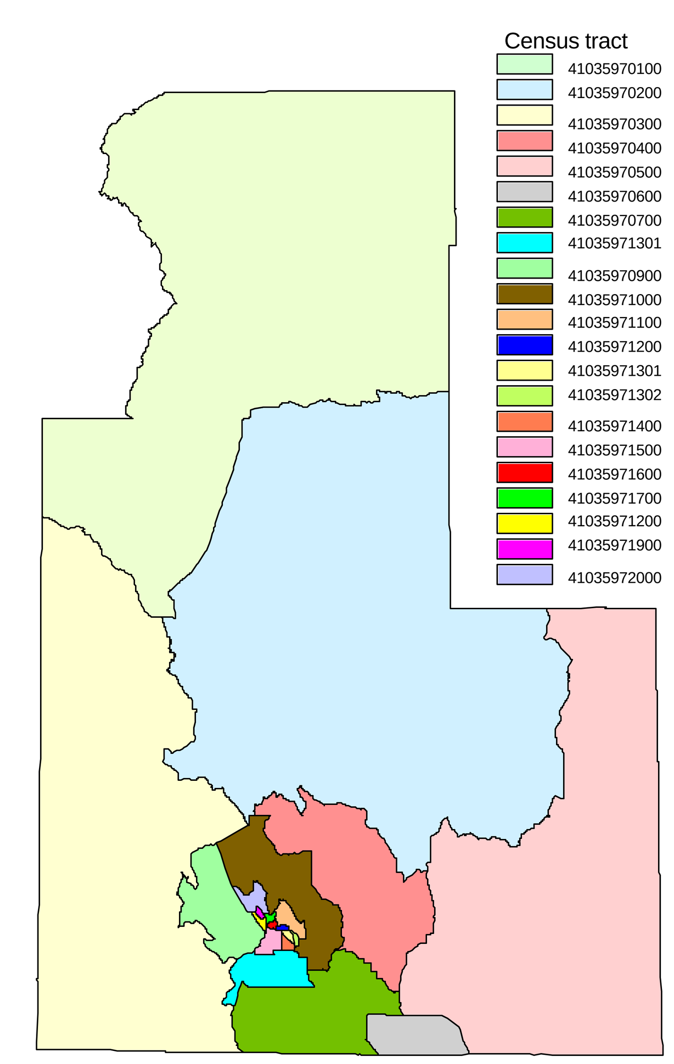

Scale = 1:1,000,000

Figure A-1. Location map of data point sites in Klamath County as listed in Table A-1 of the accompanying text.

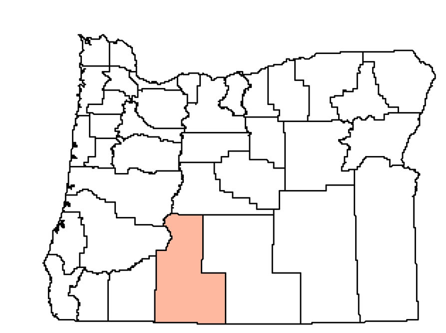



Scale = 1:1,000,000

Figure B-1. Map of census tracts in Klamath County as used in Appendix B of the accompanying text.




Scale = 1:1,000,000



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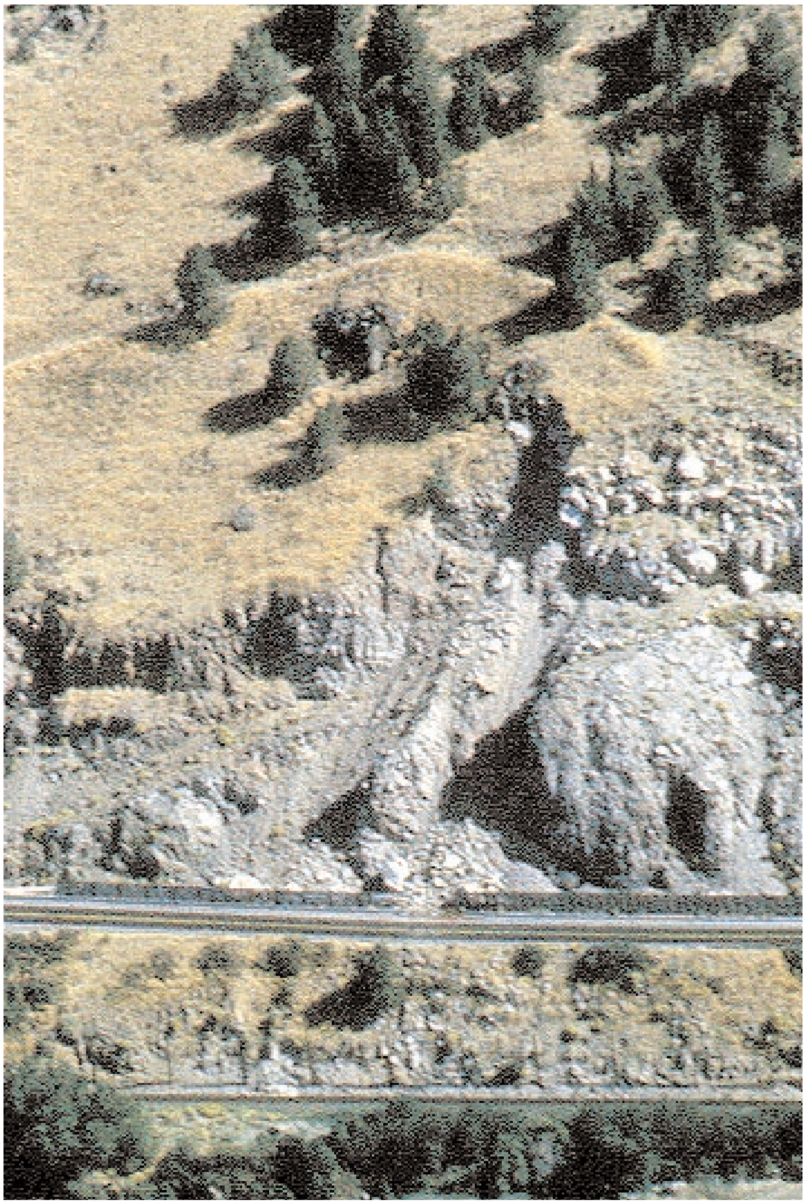
# Earthquake Hazard Maps and Seismic Risk Assessment for Klamath County, Oregon



STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

2002

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**Interpretive Map Series**

**IMS-20**

# Earthquake Hazard Maps and Seismic Risk Assessment for Klamath County, Oregon

By
Zhenming Wang and Yumei Wang,
Oregon Department of Geology and Mineral Industries

2002

**Oregon Department of Geology and Mineral Industries Interpretive Map Series**

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## IMPORTANT NOTICE FOR THE INCLUDED RELATIVE EARTHQUAKE HAZARD MAPS

These maps depict earthquake hazard zones that are based on limited geologic and geophysical data, as described in the text. **The maps are not a substitute for site-specific investigations by qualified practitioners.** At any point in the map areas, site-specific data may give results that differ from those shown on the maps. Some appropriate uses for the maps are discussed in the text. For a complete understanding of the earthquake hazard, consultation of the following Department publication is also recommended: Madin, I.P., and Mabey, M.A., 1996, *Earthquake hazard maps for Oregon*: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-100. For the Klamath Falls metropolitan area, similar maps have been published as DOGAMI Interpretive Series map IMS-19.

**Cover Photo**

Rock slide on U.S. Highway 97 between Modoc Point and Klamath Falls. The slide, caused by the Klamath Falls earthquakes of 1993, breached the roadside barrier, and a large boulder hit a southbound vehicle, killing the driver. Photo by David K. Keefer, U.S. Geological Survey.

## CONTENTS

**Interpretive Map Series**

## IMS–20

# Earthquake Hazard Maps and Seismic Risk Assessment for Klamath County, Oregon

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**ABSTRACT**

The 1993 Klamath Falls earthquakes (magnitude [M] 5.9 and 6.0) caused damage to more than 1,000 buildings and $10 million in losses. Although we do not know when the next damaging earthquake will occur, we can assess the potential earthquake hazards, including general ground shaking hazard and the relative seismic hazards, as well as the potential damages and losses. With support from the Federal Emergency Management Agency (FEMA), we developed the earthquake hazard maps and estimated the potential damage and losses for Klamath County.

The first step was to develop general ground shaking (probabilistic) hazard maps and relative hazard maps (for ground motion amplification, liquefaction, and landslide/rockslide potential). The general ground shaking hazard maps depict either probabilistic ground shaking hazard at different return periods or ground shaking hazard from a scenario earthquake at a given site on bedrock. The relative seismic hazard maps depict the relative potential for ground motion amplification, liquefaction, and landslides or rockslides due to the local geologic conditions. These maps provide a comprehensive earthquake hazard assessment for Klamath County. In the second step, these maps were used in the seismic risk evaluation program HAZUS99.

Klamath County has over 22,000 households with a total population of about 57,700 people (1990 Census Bureau data) and an estimated 23,000 buildings with a total square footage of 45,527,000 ft$^2$ and a building-replacement value of $3,134 million (1994 dollars). In addition to collecting these census data, a survey of 955 buildings was carried out by a team from the Oregon Institute of Technology (OIT) with a rapid visual screening (RVS) methodology modified from FEMA Publication 154. This survey showed that the building inventory provided in the HAZUS99 database did not accurately reflect the actual building stock in Klamath County.

The database in HAZUS99 and the data on 955 surveyed buildings, combined with the seismic hazard maps, were used to estimate damages and losses. The damage and loss estimates were modeled for four earthquake scenarios and produced the following results:

(1) The 1993 Klamath Falls earthquake scenario would cause damage to about 3,500 buildings, with losses of about $36 million, and several injuries—which is in the same magnitude as the reported damage and loss during the actual earthquake.

(2) A scenario earthquake of M 6.0, located at the Klamath Falls city center, would cause damage to about 10,000 buildings, with losses of about $246 million, and about 50 injuries and deaths.

(3) A scenario earthquake of M 6.5, also located at the Klamath Falls city center, would cause damage to about 13,000 buildings, with losses of about $387 million, and more than 100 injuries and deaths.

(4) The 500-year probabilistic earthquake hazard scenario would cause damage to about 16,800 buildings, with losses of about $522 million, and more than 200 injuries and deaths.

Among the 955 surveyed buildings, the four earthquake scenarios (1993 Klamath Falls, M 6.0, and M 6.5 at the city center; and the 500-year probabilistic hazard) would cause damage to about 104, 393, 567, and 474 buildings, respectively.

## INTRODUCTION

Since the late 1980s, earthquake hazards have been recognized as one of the major natural hazards in Oregon. Scientists revealed that Oregon has experienced many damaging earthquakes in the past (Atwater, 1987; Heaton and Hartzell, 1987; Weaver and Shedlock, 1989). The March 1993 Scotts Mills earthquake of magnitude (M) 5.6 and the September 1993 Klamath Falls earthquakes (M 5.9 and M 6.0) further demonstrated such potential hazard in Oregon, even though these earthquakes were moderate. The Scotts Mills earthquake resulted in significant damage (about $28.4 million) (Madin and others, 1993), while the Klamath Falls earthquakes caused two deaths and damaged more than 1,000 buildings (Wiley and others, 1993). The Klamath County Courthouse and Courthouse Addition suffered the greatest damage. The total damage caused by the Klamath Falls earthquakes was estimated at more than $7.5 million (Wiley and others, 1993).

Although earthquakes from a variety of sources, such as the Cascadia subduction zone and volcanic eruptions in the Cascade Range, might affect Klamath County, the earthquakes from crustal faults in Klamath County will dominate the hazard due to their proximity. Recent studies revealed that there are many active faults in Klamath County, some of them seismogenic (Hawkins and others, 1989; Sherrod and Smith, 1989; Pezzopane, 1993; Geomatrix Consultants, Inc., 1995; Bacon and others, 1999). The 1993 Klamath Falls earthquakes (M 5.9 and 6.0) occurred on one such fault zone, the western Upper Klamath Lake fault zone (Wiley and others, 1993).

Although earthquakes can not be prevented or predicted, the earthquake hazards can be assessed on the basis of geological, geophysical, and geotechnical information. The probabilistic seismic hazard maps of Geomatrix Consultants, Inc. (1995) and the U.S. Geological Survey (Frankel and others, 1996) provide the assessment 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 Klamath 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 (.pdf file on CD) shows the ground shaking hazard at a 500-year return interval in Klamath County (Frankel and others, 1996). The deterministic method, which is generally used for site-specific seismic hazard evaluation, can also be used both to evaluate the general ground shaking hazard and to generate ground shaking hazards from a scenario earthquake.

However, the earthquake hazard is also affected by local geologic conditions. For example, ground motion amplified by the near-surface soft soils resulted in great damage in Mexico City during the 1985 Mexico earthquake (Seed and others, 1986). The severe damage in the Marina district of San Francisco was caused by amplified ground motion and liquefaction during the 1989 Loma Prieta earthquake (Holzer, 1994). A large rock slide on the east side of U.S. Highway 97 about 2.9 km south of Modoc Point, which hit a southbound vehicle and killed the driver, was induced by the September 1993 Klamath Falls earthquake (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, if the nature and properties of the geologic materials and soils at the site are known (Bolt, 1993). DOGAMI has made great efforts to evaluate these three effects and has published many such maps of hazard due to local geologic conditions 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). These relative earthquake hazard maps depict the relative hazards of ground motion amplification, liquefaction, and earthquake-induced landslide/rockslide as they are due to the local geologic conditions.

The relative earthquake hazard maps and the general ground shaking hazard maps provide a comprehensive earthquake hazard assessment in Klamath County. These maps, combined with the economic exposure, such as building stocks and lifeline facilities, were used to evaluate the earthquake risk for Klamath County with HAZUS99, a seismic-risk-assessment software developed by the Federal Emergency Management Agency (FEMA) (National Institute of Building Sciences [NIBS], 1999). The information from the seismic risk assessment will help local governments, land use planners, and emergency managers to prioritize the areas for risk mitigation in Klamath County.

## RELATIVE SEISMIC HAZARD ANALYSIS

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 (5°–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. A geologic model for the area inside the Klamath Falls urban growth boundary (UGB), derived from surface geologic mapping and geophysical and geotechnical investigations, as well as relative seismic hazard maps, has been generated by Black and others (2000a). The geologic model for Klamath County was derived from existing geologic maps, limited geotechnical and geophysical data, and water-well logs. The soils and rocks exposed in Klamath County are Quaternary and Tertiary continental sedimentary, volcanic, and volcaniclastic deposits (Sherrod and Pickthorn, 1992, Walker and MacLeod, 1991). The rock-engineering properties, such as degree of weathering and fracture, were evaluated by limited field investigations (Wang and others, 1999). The thickness and engineering properties of soils were obtained from the existing water-well logs and limited geotechnical and geophysical data. Water-well data were obtained from the Oregon Water Resources Department (OWRD). The locations of these water wells were not field checked. Figure 2 (.pdf file on CD) shows the simplified surface geologic map for Klamath County. The locations and detail information of water wells, and geotechnical and geophysical investigation sites are shown in Appendix A and Figure A–1 (.pdf file on CD). These data were used to generate the relative hazard maps.

### 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 or 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 was adopted by the State of Oregon in October 1998, with Oregon amendmends, 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 1). 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. The *Relative Ground Motion Amplification Hazard Map* for Klamath County (.pdf file on CD) identifies three prevalent soil units, B, C, and D, and assigns to them the amplification hazard ratings None (B), Low (C), and Moderate (D).

Because of data limitations, it is assumed that thickness and engineering properties for each soil or rock unit are uniform. The shear wave velocities or SPT values for the soil and rock units are listed in Table 2. The UBC–97 soil categories in Klamath County were generated with the average shear wave velocity of the top 30 m (100 ft). No A-type, E-type, or F-type soils are shown on the map due to limited data and mapping scale. However, A-type, E-type, and F-type soils might exist in some areas in Klamath County, especially E- and F-type soils along the rivers and lakes.

## 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

Table 1. *UBC–97 soil profile types (ICBO, 1997); n.d. = no data; n.a. = not applicable*

| **Soil type** | **Soil name** | **Average soil properties for top 30 m (100 ft)** | | |
|---|---|---|---|---|
| | | **Shear wave velocity** $V_s$ (m/s) | **Standard penetration test** N (blows/ft) | **Undrained shear strength** $s_u$ (kPa) |
| $S_A$ | Hard rock | >1,500 | n.d. | n.d. |
| $S_B$ | Rock | 760 to 1,500 | n.d. | n.d. |
| $S_C$ | 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 | n.a. | n.a. | n.a. |

Table 2. *Geologic units shown in Figure 2 and their thickness, average shear wave velocity ($V_s$), average standard penetration test value (N-value), and liquefaction potential; n.d. = no data*

| **Geologic unit** | **Average thickness (m)** | **Average shear wave velocity ($V_s$, in m/s)** | **Average standard penetration test value (N, in blows/ft)** | **Liquefaction potential** |
|---|---|---|---|---|
| Holocene alluvium (Qal) | 5 | 158 | 10 | Moderate |
| Mazama ash and pumice (Qap) | 6 | 158* | n.d. | Very low |
| Quaternary fanglomerate (Qf) | n.d. | 295* | n.d. | Very low |
| Pleistocene glacial deposits (Qg) | n.d. | 295* | n.d. | Very low |
| Quaternary landslide debris (Qls) | n.d. | 295* | n.d. | Very low |
| Quaternary volcanic rocks (Qv) | n.d. | 577 | n.d. | n.d. |
| Pleistocene lacustrine & fluvial deposits (Qs) | >30 | 332 | 25 | Low |
| Pleistocene-Pliocene sedimentary rocks (QTac) | 8 | 295 | 28 | n.d. |
| Quaternary-Tertiary volcanic rocks (QTv) | n.d. | 577 | n.d. | n.d. |
| Tertiary volcanic rocks (Tv) | n.d. | >760 | n.d. | n.d. |

* inferred

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.

In view of the limitations of available data, the *Relative Liquefaction Susceptibility Map* for Klamath County (.pdf file on CD) is based mainly on the age of the geologic units and their shear wave velocity (Table 2). Youd and Perkins (1978) found that the liquefaction potential for different sediments is related to the age of the deposit. Table 3 shows how the authors related liquefaction potential to age for several continental deposits. Accordingly, the liquefaction potential of the soil units in Klamath County is very low to low, except for Holocene alluvium (geologic unit Qal), which has moderate to high potential. Andrus and Stokoe (1996) found that the soils with a shear wave velocity of less than 200 m/s have liquefaction potential. Due to its distribution and thickness, as well as engineering properties, a moderate liquefaction potential was assigned to Holocene alluvium.

**Earthquake-induced landslides**

The hazard due to earthquake-induced landsliding, including rockslide and rockfall, was assessed with slope data and rock and soil engineering properties. The slope data were derived from U.S. Geological Survey digital elevation models (DEMs) with 100-ft (30-m) data spacing. The rock properties, such as degree of weathering and fracture, were evaluated by limited outcrop assessments. The rockslide and rockfall hazard was assessed with the method developed by Keefer (1984) and described by Wang and others (1999). The instability of soil slopes was assessed with a method developed by Keefer and Wang (1997), but this method was greatly simplified for the *Relative Slope Hazard Ma*p for Klamath County (.pdf file on CD) because of limited field data. Lateral spreading is a gentle slope failure due to liquefaction (Barlett and Youd, 1992). The liquefaction analysis indicates that the areas with moderate liquefaction hazard are small and concentrated along the river valleys and lakes in Klamath County. Therefore, no lateral-spreading analysis was performed in the county.

Table 3. *Estimated susceptibility of continental deposits to liquefaction (from Youd and Perkins, 1978)*

| | **Likelihood that cohesionless sediments, when saturated, are susceptible to liquefaction, by age of deposit** | | | |
|---|---|---|---|---|
| **Type 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 RISK ASSESSMENT

A sound earthquake risk mitigation plan must be based on a good risk assessment. DOGAMI completed a seismic risk assessment for the State of Oregon (Wang and Clark, 1999), utilizing a newly available earthquake risk assessment software, HAZUS97, from the Federal Emergency Management Agency (NIBS, 1997). Preliminary seismic risk information for Klamath County has been provided in Wang and Clark (1999). However, the information was derived from a federal default building database and limited seismic hazard data. In particular, the number of unreinforced masonry (URM) buildings was underestimated in the default database.

Consequently, in this study, we developed a better risk assessment for Klamath County, using the seismic hazard maps developed in this project and the newly released HAZUS99 software by FEMA (NIBS, 1999). A better building inventory was developed and included in the HAZUS99 database. Also, a seismic risk assessment was performed for the 955 Klamath County buildings that had been surveyed in a special project conducted by faculty and students of the Oregon Institute of Technology (Leever and Taha, 1999).

### Building and lifeline data

Klamath County has 20 census tracts (.pdf file on CD, Figure B–1) and over 22,000 households with a total population of about 57,700 (1990 Census Bureau data). The HAZUS99 default building database contains about 23,000 buildings with a total square footage of 45,527,000 ft$^2$ and a building replacement value of $3,134 million (1994 dollars). Table 4 lists the building counts in different occupancy classes and building types. Other inventories, such as essential facilities and lifelines, are also included in the database. Detailed building and lifeline inventories are listed in Appendix B.

Table 4. *Building counts in different occupancy classes and building types in the HAZUS99 database*

| Occupancy Class | | Building Type | |
|---|---|---|---|
| Residential | 22,629 | Wood | 17,599 |
| Commercial | 382 | Steel | 113 |
| Industrial | 57 | Concrete | 107 |
| Agriculture | 37 | Precast concrete | 101 |
| Religion | 42 | Reinforced masonry | 113 |
| Government | 3 | Unreinforced masonry | 220 |
| Education | 17 | Mobile homes | 4,914 |
| Total | 23,167 | Total | 23,167 |

The HAZUS99 building inventory was developed from census tract records and statewide statistical data. Because this inventory may not capture the building characteristics in Klamath County, a survey of 955 buildings was conducted by a team from the Oregon Institute of Technology (OIT) with the rapid visual screening method published in FEMA Publication 154 (Applied Technology Council, 1988). Table 5 lists the building counts in different occupancy classes and building types for the 955 surveyed buildings, which are unevenly distributed in 18 of 20 census tracts in Klamath County. A summary of this building survey is included in Appendix C. This survey shows that the building inventory in HAZUS99 does not reliably reflect the actual building stock in Klamath County. The HAZUS99 database lists only 220 URM buildings. However, 370 URM buildings were identified in the OIT building survey, although this survey was limited to only some areas in the county.

### Damage and loss estimates

The seismic damages and losses were modeled for several different earthquake scenarios (Table 6). The first earthquake scenario was a M 6.0 earthquake with

Table 5. *Building counts in different occupancy classes and building type from survey of 955 buildings*

| Occupancy Class | | Building Type | |
|---|---|---|---|
| Residential | 273 | Wood | 238 |
| Commercial | 435 | Steel | 96 |
| Industrial | 41 | Concrete | 42 |
| Agriculture | 4 | Precast concrete | 14 |
| Religion | 65 | Reinforced masonry | 195 |
| Government | 64 | Unreinforced masonry | 370 |
| Education | 61 | Mobile homes | 0 |
| Others | 12 | Others | 0 |
| Total | 955 | Total | 955 |

the source parameters similar to the 1993 Klamath Falls earthquake (M 6.0). Tables 7 and 8 show the estimated casualties at different times of the day and building-related economic losses from this scenario. The resulting estimates were several light and not life-threatening injuries and $36 million in building damage. During the actual 1993 Klamath Falls earthquake, there were two fatalities—a motorist killed by a rockfall on U.S. Highway 97 near Modoc Point and an elderly lady who died of a heart attack—and the building-related damages were estimated at about $10 million. The estimate of building-related damages from the 1993 Klamath Falls scenario earthquake is in the same magnitude as the reported damages during the 1993 Klamath Falls earthquake, but about three to four times higher. The uncertainty of the earthquake loss estimates in California was about a factor of 4 (Reichle and others, 2000). The possible explanations for the differences between HAZUS99 modeling and the estimates from the 1993 Klamath Falls earthquake could be (1) accuracy of the HAZUS99 building database, (2) many unreported losses due to small damages, and (3) the numerical errors and uncertainty.

The damage and loss estimates modeled for the other earthquake scenarios are summarized in Table 9. Detailed modeling results for these scenarios are included in Appendix D. The damages of 955 surveyed buildings were also modeled for all of the earthquake scenarios. Detailed damages of these 955 buildings from the four earthquake scenarios are listed in Appendix C.

Table 6. *Earthquake scenarios for damage and loss analysis in Klamath County; n.a. = not applicable*

| **Scenario name** | **Type of earthquake** | **Epicenter** | | **Magnitude** | **Depth (km)** | **Rupture length (km)** | **Rupture orientation (degrees)** |
|---|---|---|---|---|---|---|---|
| | | **Longitude** | **Latitude** | | | | |
| Klamath Falls (1993) | Scenario | -122.11 | 42.355 | 6.0 | 10 | 14.1 | 142 |
| 500-year hazard | Probabilistic | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. |
| Klamath Falls city center I | Scenario | -121.781 | 42.225 | 6.0 | 10 | 14.1 | 140 |
| Klamath Falls city center II | Scenario | -121.781 | 42.225 | 6.5 | 10 | 28.8 | 140 |

Table 7. *Casualty estimates from the 1993 Klamath Falls earthquake model. Severity levels as follows: Level 1 = Injuries will require medical attention but not hospitalization. Level 2 = Injuries will require hospitalization but are not life-threatening. Level 3 = Injuries will require hospitalization and can become life-threatening if not treated promptly. Level 4 = Deaths.*

| **Time** | **Level 1** | **Level 2** | **Level 3** | **Level 4** |
|---|---|---|---|---|
| 2 a.m. | 8 | 1 | 0 | 0 |
| 2 p.m. | 6 | 1 | 0 | 0 |
| 5 p.m. | 5 | 1 | 0 | 0 |

Table 8. *Building-related loss estimates from the 1993 Klamath Falls earthquake model*

| **Building loss (millions of dollars)** | | **Business interruption loss (millions of dollars)** | |
|---|---|---|---|
| Structural | 5.8 | Wage | 2.4 |
| Nonstructural | 20.1 | Income | 1.7 |
| Content | 10.1 | Rental | 1.8 |
| Inventory | 0.2 | Relocation | 4.3 |
| Subtotal | 36.2 | Subtotal | 10.2 |
| | | Total | 46.4 |

Table 9. *Injuries and building damages from three scenario earthquakes; n.d. = no data*

| Scenario | | Injuries and deaths | Building damage and loss: Damage (counts) | Building damage and loss: Loss (million dollars) |
|---|---|---|---|---|
| 500-year probabilistic hazard | 2 a.m. | 329 | n.d. | n.d. |
| | 2 p.m. | 356 | n.d. | n.d. |
| | 5 p.m. | 216 | 16,845 | 521.8 |
| Klamath Falls city center I (M 6.0) | 2 a.m. | 66 | n.d. | n.d. |
| | 2 p.m. | 70 | n.d. | n.d. |
| | 5 p.m. | 45 | 10,376 | 246.3 |
| Klamath Falls city center II (M 6.5) | 2 a.m. | 154 | n.d. | n.d. |
| | 2 p.m. | 166 | n.d. | n.d. |
| | 5 p.m. | 109 | 13,604 | 386.8 |

## CONCLUSION

Three relative seismic hazard maps for the individual hazards of ground motion amplification, liquefaction, and earthquake-induced landslides/rockslides, have been generated for Klamath County, based on the available data and limited geological, geophysical, and geotechnical investigations. These hazards exist due to the local geologic, hydrologic, and topographic conditions. The ground motion amplification map shows that the amplification hazards range from moderate to none (D to B soils). However, high amplification hazards (E and F soils) might exist in some areas in the county, especially along the rivers and lakes, but were not mapped due to limited field data and mapping scale. The liquefaction hazard potential in Klamath County is limited to a small number of areas with moderate liquefaction potential. However, the earthquake-induced landslide or rockfall hazard is considerable, ranging from low to very high. These maps, combined with the probabilistic and deterministic ground shaking hazard maps, provide a comprehensive earthquake hazard assessment for Klamath County.

The relative seismic hazard maps and the building and lifeline inventory in the HAZUS99 database were used in seismic risk analysis. The HAZUS99 database contains over 22,000 households with a total population of about 57,700 people in Klamath County and an estimated 23,000 buildings with a total square footage of 45,527,000 ft$^2$ and a building-replacement value of $3,134 million. The database also contains lifeline facilities, such as highways, bridges, and airports. The damage and loss estimates were modeled for four earthquake scenarios: the 1993 Klamath Falls earthquake, an earthquake of M 6.0 and another of M 6.5, both located at the Klamath Falls city center, and the 500-year probabilistic hazard scenario.

(1) The 1993 Klamath Falls earthquake scenario would cause damage to about 3,500 buildings, with losses of about $36 million, and several injuries (figures that are in the same magnitude as the reported damage and losses during the actual earthquake); also slight damage to 2 bridges.

(2) A scenario earthquake of M 6.0, located at the Klamath Falls city center, would cause damage to about 10,000 buildings, with losses of about $246 million and about 50 injuries and deaths, and slight damage to 3 bridges.

(3) A scenario earthquake of M 6.5, also located at the Klamath Falls city center, would cause damage to about 13,000 buildings, with losses of about $387 million and more than 100 injuries and deaths, slight to moderate damage to 8 bridges, and complete damage to 2 bridges.

(4) The 500-year probabilistic hazard scenario would cause damage to about 16,800 buildings, with losses of about $522 million and more than 200 injuries and deaths, and slight damage to 2 bridges.

In addition, a survey of 955 buildings was conducted by a team from the Oregon Institute of Technology (OIT) with a modified rapid visual screening based on

FEMA 154 methodology. This survey showed that the building inventory in the HAZUS99 database did not accurately reflect the actual building stock in Klamath County. This suggests that a thorough building investigation is needed in order to provide accurate seismic risk assessment.

The seismic risk to the surveyed buildings was also analyzed for the four earthquake scenarios as listed above. These four scenarios would cause damage to about 104, 393, 567, and 474 buildings, respectively.

This study indicates that HAZUS99 provides a reasonable estimate of damage and loss to the buildings, at the same magnitude as the reported damage and loss to the buildings during the actual 1993 Klamath Falls earthquake. But an improvement of the building inventory is needed in order to provide better estimates of damage and loss. Also, HAZUS99 is not sensitive to the risk posed by landslide/rockfall hazards. The risk posed by earthquake-induced landslide/rockfall along highways in Klamath County is of great concern. However, HAZUS99 modeling does not provide such information.

HAZUS99 was developed by FEMA and the National Institute of Building Sciences as a tool for developing reliable earthquake damage and loss estimates that are essential to good decision-making at the local, region, state, and national levels of government. These estimates can provide the basis for mitigation policy, developing and testing emergency preparedness and response plans, and planning for post-disaster relief and recovery.

The relative seismic hazard maps were developed based on the existing data and limited field investigations. They depict the relative ground motion amplification, liquefaction potential, and earthquake-induced landslide/rockslide potential due to local geologic conditions in Klamath County. They are not site-specific and should not be used in place of site-specific studies.

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# Appendix A. Geotechnical, geophysical, and water-well data

Location map of geotechnical, geophysical, and water-well data sites in Klamath County (Figure A-1) is in a separate .pdf file.

Table A-1. *Soil properties derived from the geotechnical, geophysical ,and water well data. Site names are keyed to location map Figure A–1 (.pdf file on CD). Data were taken from two layers at each site ("Soil–1" and "Soil–2"); correspondingly, two columns of data are listed on thickness ("Thick–1/–2"), shear wave velocity ("$V_s$–1/–2"), and standard penetration test numbers of blows per foot ("N–1/–2"). Listed zero values mean no data.*

| Site name | Soil–1 | Thick–1 | $V_S$–1 | N–1 | Soil–2 | Thick–2 | $V_S$–2 | N–2 |
|---|---|---|---|---|---|---|---|---|
| SR01 | Silt, sand, and gravel (Qal) | 3.25 | 120.00 | 0.00 | Diat. silt,clay&sand (Qs) | 0.00 | 421.00 | 0.00 |
| SR06 | Top soil | 8.00 | 177.00 | 0.00 | Diat. silt,clay&sand (Qs) | 0.00 | 300.00 | 0.00 |
| SR07 | Sand, silt & gravel (QTac) | 11.60 | 248.00 | 0.00 | Volcanic bedrock | 0.00 | 506.00 | 0.00 |
| SR08 | Top soil | 2.30 | 101.00 | 0.00 | Sand, silt & gravel (QTac) | 0.00 | 349.00 | 0.00 |
| SR09 | Sand, silt & gravel (QTac) | 8.30 | 244.00 | 0.00 | Volcanic bedrock | 0.00 | 668.00 | 0.00 |
| SR10 | Clay or silty clay (Qal) | 16.90 | 184.00 | 0.00 | Diat. silt,clay&sand (Qs) | 0.00 | 354.00 | 0.00 |
| SR03 | Top soil | 1.30 | 162.00 | 0.00 | Diat. silt,clay&sand (Qs) | 0.00 | 429.00 | 0.00 |
| SR04 | Top soil | 1.30 | 165.00 | 0.00 | Diat. silt,clay&sand (Qs) | 0.00 | 580.00 | 0.00 |
| SR05 | Sand, silt & gravel (QTac) | 4.60 | 393.00 | 0.00 | Volcanic bedrock | 0.00 | 559.00 | 0.00 |
| ODOT3 | Sandy silt & gravel (Qal) | 4.90 | 0.00 | 11.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 16.00 |
| ODOT1 | Top soil | 1.20 | 0.00 | 7.00 | Sand, silt & gravel (QTac) | 0.00 | 0.00 | 28.00 |
| ODOT2 | Silty/gravel sand (Qal) | 4.10 | 0.00 | 8.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 14.00 |
| ODOT4 | Silty Sand (Qal) | 1.00 | 0.00 | 8.00 | Gravel sand (Qs) | 0.00 | 0.00 | 50.00 |
| KCCH | Top soil | 2.30 | 0.00 | 15.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 27.00 |
| KF01 | Sand silt & gravel (Qal) | 8.00 | 139.00 | 6.00 | Diat. silt,clay&sand (Qs) | 0.00 | 274.00 | 17.00 |
| KF02 | Gravel sand & silt (Qal) | 3.00 | 173.00 | 18.00 | Diat. silt,clay&sand (Qs) | 0.00 | 312.00 | 17.00 |
| KF03 | Gravel sand (Qal) | 3.00 | 169.00 | 17.00 | Diat. silt,clay&sand (Qs) | 0.00 | 355.00 | 57.00 |
| KF04 | Sandy silt(top soil) | 1.00 | 165.00 | 0.00 | Diat. silt,clay&sand (Qs) | 0.00 | 300.00 | 19.00 |
| ODOTPC | Sand silt & gravel (Qal) | 5.00 | 0.00 | 8.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 16.00 |
| ODOT942 | Sand, silt &gravel (Qal) | 11.00 | 0.00 | 14.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 30.00 |
| ODOT981 | Sand, silt &gravel (Qal) | 3.00 | 0.00 | 8.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 20.00 |
| ODOT941 | Sand, silt &gravel (Qal) | 6.00 | 0.00 | 7.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 20.00 |
| ODOTMa | Sand, silt &gravel (Qal) | 6.00 | 0.00 | 7.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 20.00 |
| ODOTWi | Sand, silt &gravel (Qal) | 5.00 | 0.00 | 8.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 50.00 |
| ODOTAd | Sand, silt &gravel (Qal) | 6.00 | 0.00 | 7.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 17.00 |
| ODOTBo | Sand, silt &gravel (Qal) | 3.00 | 0.00 | 7.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 20.00 |
| KLAM-645 | Clay (Qal) | 4.00 | 0.00 | 0.00 | Lava | 0.00 | 0.00 | 0.00 |
| KLAM-791 | Top soil | 1.00 | 0.00 | 0.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 0.00 |
| KLAM-2031 | Top soil | 1.00 | 0.00 | 0.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 0.00 |
| KLAM-10793 | Clay & gravel (Qal) | 2.00 | 0.00 | 0.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 0.00 |
| KLAM-2236 | Sandy soil (Qal) | 6.00 | 0.00 | 0.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 0.00 |
| KLAM-483 | Pumice | 3.00 | 0.00 | 0.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 0.00 |
| KLAM-13852 | Pumice | 2.00 | 0.00 | 0.00 | Lava | 0.00 | 0.00 | 0.00 |
| KLAM-565 | Pumice | 12.00 | 0.00 | 0.00 | Basalt | 0.00 | 0.00 | 0.00 |

Table A–1. *Continued*

| Site name | Soil–1 | Thick–1 | $V_S$–1 | N–1 | Soil–2 | Thick–2 | $V_S$–2 | N–2 |
|---|---|---|---|---|---|---|---|---|
| KLAM-660 | Pumice | 1.00 | 0.00 | 0.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 0.00 |
| KLAM-686 | Pumice | 12.00 | 0.00 | 0.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 0.00 |
| KLAM-10573 | Top soil | 2.00 | 0.00 | 0.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 0.00 |
| KLAM-435 | Top soil | 2.00 | 0.00 | 0.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 0.00 |
| KLAM-10845 | Top soil | 2.00 | 0.00 | 0.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 0.00 |
| KLAM-351 | Top soil | 1.00 | 0.00 | 0.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 0.00 |
| KLAM-465 | Top soil | 3.00 | 0.00 | 0.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 0.00 |
| KLAM-11753 | Top soil | 2.00 | 0.00 | 0.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 0.00 |
| KLAM-564 | Top soil | 2.00 | 0.00 | 0.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 0.00 |
| KLAM-10501 | Top soil | 3.00 | 0.00 | 0.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 0.00 |
| KLAM-1372 | Sand & gravel | 10.00 | 0.00 | 0.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 0.00 |
| KLAM-2277 | Sandy clay | 5.00 | 0.00 | 0.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 0.00 |
| KLAM-50340 | Top soil | 1.00 | 0.00 | 0.00 | Lava | 0.00 | 0.00 | 0.00 |
| KLAM-15129 | Clay | 6.00 | 0.00 | 0.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 0.00 |
| KLAM-15081 | Top Soil | 2.00 | 0.00 | 0.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 0.00 |
| KLAM-10565 | Top Soil | 2.00 | 0.00 | 0.00 | Lava | 0.00 | 0.00 | 0.00 |
| KLAM-14541 | Brown sand | 2.00 | 0.00 | 0.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 0.00 |
| KLAM-50166 | Top soil | 1.00 | 0.00 | 0.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 0.00 |
| KLAM-13744 | Top soil | 2.00 | 0.00 | 0.00 | Lava | 0.00 | 0.00 | 0.00 |
| KLAM-14912 | Top soil | 3.00 | 0.00 | 0.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 0.00 |
| KLAM-10263 | Sand & gravel (Qg) | 2.00 | 0.00 | 0.00 | Lava | 0.00 | 0.00 | 0.00 |
| KLAM-398 | Sand & gravel (Qg) | 2.00 | 0.00 | 0.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 0.00 |
| KLAM-1033 | Sand & gravel (Qg) | 3.00 | 0.00 | 0.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 0.00 |
| KLAM-1922 | Sand, silt & gravel (Qf) | 1.00 | 0.00 | 0.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 0.00 |
| KLAM-2084 | Sand, silt & gravel (Qf) | 1.00 | 0.00 | 0.00 | Diat. silt,clay&sand (Qs) | 0.00 | 0.00 | 0.00 |

# Appendix B.
# HAZUS99 inventory of buildings, critical facilities, and lifelines

Map of census tracts in Klamath County (Figure B-1) is shown on accompanying .pdf file on CD.

Table B-1. *Building inventory (general occupancy) in Klamath County, by building categories according to HAZUS99*

| Tract | Residential | Commercial | Industrial | Agricultural | Religious | Governmental | Educational | Total |
|---|---|---|---|---|---|---|---|---|
| 41035970100 | 1,617 | 9 | 1 | 1 | 0 | 1 | 1 | 1,630 |
| 41035970200 | 1,856 | 10 | 4 | 4 | 1 | 0 | 0 | 1,875 |
| 41035970300 | 1,472 | 8 | 3 | 1 | 0 | 0 | 0 | 1,484 |
| 41035970400 | 430 | 8 | 1 | 4 | 1 | 0 | 2 | 446 |
| 41035970500 | 670 | 3 | 1 | 2 | 4 | 1 | 1 | 682 |
| 41035970600 | 482 | 6 | 1 | 6 | 1 | 0 | 0 | 496 |
| 41035970700 | 780 | 13 | 1 | 4 | 1 | 0 | 1 | 800 |
| 41035970800 | 977 | 9 | 3 | 3 | 1 | 0 | 1 | 994 |
| 41035970900 | 1,297 | 10 | 3 | 1 | 2 | 0 | 1 | 1,314 |
| 41035971000 | 796 | 3 | 0 | 2 | 1 | 0 | 0 | 802 |
| 41035971100 | 1,507 | 11 | 1 | 1 | 3 | 0 | 1 | 1,524 |
| 41035971200 | 1,008 | 13 | 1 | 1 | 1 | 0 | 0 | 1,024 |
| 41035971300 | 1,613 | 17 | 7 | 1 | 2 | 0 | 1 | 1,641 |
| 41035971400 | 1,554 | 10 | 3 | 1 | 1 | 0 | 2 | 1,571 |
| 41035971500 | 1,649 | 62 | 9 | 2 | 3 | 0 | 1 | 1,726 |
| 41035971600 | 954 | 72 | 3 | 0 | 3 | 0 | 1 | 1,033 |
| 41035971700 | 1,026 | 13 | 1 | 0 | 4 | 0 | 1 | 1,045 |
| 41035971800 | 682 | 65 | 6 | 1 | 5 | 0 | 0 | 759 |
| 41035971900 | 1,090 | 18 | 4 | 2 | 7 | 1 | 1 | 1,123 |
| 41035972000 | 1,169 | 22 | 4 | 0 | 1 | 0 | 2 | 1,198 |
| Total | 22,629 | 382 | 57 | 37 | 42 | 3 | 17 | 23,167 |

Table B–2. *Building inventory (general building type) in Klamath County*

| Tract | Wood | Steel | Concrete | Precast concrete | Reinforced masonry | Unreinforced masonry | Mobile homes | Total |
|---|---|---|---|---|---|---|---|---|
| 41035970100 | 904 | 3 | 3 | 3 | 2 | 10 | 706 | 1,631 |
| 41035970200 | 1,126 | 4 | 3 | 4 | 3 | 13 | 723 | 1,876 |
| 41035970300 | 1,093 | 2 | 1 | 2 | 2 | 12 | 370 | 1,482 |
| 41035970400 | 262 | 3 | 2 | 3 | 3 | 4 | 169 | 446 |
| 41035970500 | 369 | 3 | 2 | 1 | 2 | 4 | 301 | 682 |
| 41035970600 | 383 | 3 | 1 | 2 | 2 | 5 | 98 | 494 |
| 41035970700 | 589 | 5 | 3 | 4 | 4 | 7 | 188 | 800 |
| 41035970800 | 759 | 3 | 2 | 4 | 3 | 9 | 214 | 994 |
| 41035970900 | 988 | 5 | 4 | 4 | 3 | 11 | 299 | 1,314 |
| 41035971000 | 603 | 0 | 1 | 1 | 1 | 7 | 188 | 801 |
| 41035971100 | 1,240 | 5 | 5 | 3 | 4 | 14 | 255 | 1,526 |
| 41035971200 | 728 | 5 | 4 | 3 | 3 | 9 | 274 | 1,026 |
| 41035971300 | 1,378 | 5 | 6 | 6 | 6 | 16 | 223 | 1,640 |
| 41035971400 | 1,409 | 4 | 3 | 3 | 3 | 15 | 134 | 1,571 |
| 41035971500 | 1,070 | 13 | 12 | 17 | 15 | 17 | 581 | 1,725 |
| 41035971600 | 894 | 15 | 16 | 13 | 18 | 15 | 61 | 1,032 |
| 41035971700 | 1,013 | 6 | 6 | 3 | 5 | 12 | 1 | 1,046 |
| 41035971800 | 679 | 13 | 17 | 16 | 17 | 13 | 2 | 757 |
| 41035971900 | 1,066 | 7 | 8 | 6 | 9 | 14 | 14 | 1,124 |
| 41035972000 | 1,045 | 9 | 8 | 3 | 8 | 13 | 113 | 1,199 |
| Total | 17,598 | 113 | 107 | 101 | 113 | 220 | 4,914 | 23,166 |

Table B–3. *Building value (thousands of dollars) per general occupancy in Klamath County*

| Tract | Residential | Commercial | Industrial | Agricultural | Religious | Governmental | Educational | Total |
|---|---|---|---|---|---|---|---|---|
| 41035970100 | 139,873 | 9,780 | 2,427 | 223 | 0 | 1,566 | 1,101 | 154,971 |
| 41035970200 | 162,461 | 11,465 | 5,468 | 795 | 1,408 | 550 | 640 | 182,786 |
| 41035970300 | 135,006 | 8,640 | 6,031 | 218 | 629 | 374 | 0 | 150,898 |
| 41035970400 | 37,849 | 8,351 | 1,227 | 880 | 1,587 | 169 | 2,898 | 52,961 |
| 41035970500 | 53,746 | 3,571 | 960 | 405 | 5,099 | 924 | 988 | 65,692 |
| 41035970600 | 48,073 | 6,922 | 2,237 | 1,291 | 1,108 | 213 | 688 | 60,532 |
| 41035970700 | 77,829 | 15,533 | 1,227 | 821 | 864 | 293 | 1,514 | 98,081 |
| 41035970800 | 91,433 | 10,286 | 5,066 | 553 | 1,399 | 242 | 2,283 | 111,262 |
| 41035970900 | 135,646 | 11,803 | 4,809 | 168 | 3,099 | 506 | 1,392 | 157,424 |
| 41035971000 | 77,850 | 4,111 | 1,060 | 343 | 901 | 315 | 0 | 84,580 |
| 41035971100 | 165,198 | 13,536 | 2,103 | 129 | 4,000 | 623 | 1,085 | 186,675 |
| 41035971200 | 105,070 | 15,161 | 1,495 | 198 | 1,127 | 388 | 0 | 123,439 |
| 41035971300 | 182,154 | 18,166 | 8,453 | 192 | 3,155 | 674 | 1,109 | 213,903 |
| 41035971400 | 161,964 | 10,646 | 3,420 | 277 | 1,559 | 682 | 3,263 | 181,810 |
| 41035971500 | 149,923 | 71,636 | 13,642 | 410 | 4,845 | 601 | 1,028 | 242,085 |
| 41035971600 | 147,929 | 73,096 | 3,459 | 68 | 4,817 | 418 | 1,101 | 230,888 |
| 41035971700 | 144,814 | 14,702 | 2,154 | 0 | 5,803 | 410 | 1,708 | 169,591 |
| 41035971800 | 130,960 | 90,503 | 8,503 | 101 | 6,376 | 381 | 777 | 237,601 |
| 41035971900 | 159,118 | 24,271 | 5,111 | 492 | 10,395 | 1,278 | 947 | 201,611 |
| 41035972000 | 154,240 | 58,899 | 8,905 | 78 | 817 | 550 | 3,759 | 227,247 |
| Total | 2,461,136 | 481,078 | 87,757 | 7,642 | 58,988 | 11,157 | 26,281 | 3,134,037 |

Table B–4. *Building value (thousands of dollars) per building type in Klamath County*

| Tract | Wood | Steel | Concrete | Precast concrete | Reinforced masonry | Unreinforced masonry | Mobile homes | Total |
|---|---|---|---|---|---|---|---|---|
| 41035970100 | 103,057 | 4,475 | 3,748 | 2,244 | 4,201 | 2,369 | 34,877 | 154,971 |
| 41035970200 | 126,460 | 5,165 | 4,340 | 3,629 | 4,526 | 2,821 | 35,846 | 182,786 |
| 41035970300 | 117,531 | 4,837 | 2,509 | 2,669 | 2,932 | 2,116 | 18,303 | 150,898 |
| 41035970400 | 31,610 | 2,864 | 2,971 | 2,569 | 3,129 | 1,374 | 8,443 | 52,961 |
| 41035970500 | 41,384 | 2,706 | 2,383 | 1,109 | 2,216 | 1,024 | 14,869 | 65,692 |
| 41035970600 | 44,633 | 2,931 | 2,087 | 2,368 | 2,302 | 1,187 | 5,023 | 60,532 |
| 41035970700 | 70,011 | 3,604 | 3,928 | 4,411 | 4,342 | 2,233 | 9,552 | 98,081 |
| 41035970800 | 84,069 | 4,142 | 3,263 | 3,683 | 3,446 | 1,985 | 10,674 | 111,262 |
| 41035970900 | 117,392 | 6,040 | 5,990 | 3,899 | 5,734 | 3,139 | 15,231 | 157,424 |
| 41035971000 | 67,693 | 1,668 | 1,686 | 1,128 | 1,658 | 1,275 | 9,472 | 84,580 |
| 41035971100 | 148,340 | 5,542 | 6,623 | 2,932 | 6,219 | 3,675 | 13,344 | 186,675 |
| 41035971200 | 90,766 | 4,282 | 4,175 | 2,821 | 4,683 | 2,545 | 14,168 | 123,439 |
| 41035971300 | 167,692 | 7,796 | 7,676 | 6,748 | 7,515 | 4,393 | 12,083 | 213,903 |
| 41035971400 | 156,331 | 4,335 | 4,017 | 2,895 | 4,256 | 2,974 | 7,002 | 181,810 |
| 41035971500 | 134,347 | 16,291 | 16,331 | 19,366 | 18,539 | 8,183 | 29,029 | 242,085 |
| 41035971600 | 145,938 | 17,762 | 19,044 | 13,378 | 21,223 | 8,706 | 4,837 | 230,888 |
| 41035971700 | 137,904 | 7,037 | 7,955 | 3,320 | 7,786 | 3,981 | 1,608 | 169,591 |
| 41035971800 | 132,300 | 20,662 | 25,343 | 20,024 | 25,942 | 10,973 | 2,357 | 237,601 |
| 41035971900 | 153,814 | 10,877 | 11,341 | 6,220 | 11,284 | 5,354 | 2,721 | 201,611 |
| 41035972000 | 146,190 | 19,152 | 20,435 | 6,490 | 22,902 | 5,946 | 6,131 | 227,247 |
| Total | 2,217,462 | 152,168 | 155,845 | 111,903 | 164,835 | 76,253 | 255,570 | 3,134,037 |

Table B–5. *Critical facility inventory*

| | |
|---|---|
| Hospital | 1 (239 beds) |
| School | 8 |
| Fire Station | 1 |
| Police Station | 3 |
| Emergency Operation | 1 |
| Dams | 47 |
| Hazardous Sites | 147 |

Table B–6. *Transportation system lifeline inventory*

| System | Component | Number of locations/segments | | Replacement value (million $) |
|---|---|---|---|---|
| Highway | Major roads | 48 | | 6,845 |
| | Bridges | 55 | | 131 |
| | Tunnels | 0 | | |
| | | | Subtotal | 6,976 |
| Railway | Tracks | 233 | | 886 |
| | Bridges | 0 | | 0 |
| | Tunnels | 0 | | 0 |
| | Facilities | 0 | | 0 |
| | | | Subtotal | 886 |
| Airport | Facilities | | | 74 |
| | Runways | | | 308 |
| | | | Subtotal | 382 |
| | | | Total | 8,245 |

Table B–7. *Utility system lifeline inventory*

| System | Component | Number of locations/segments | | Replacement value (million $) |
|---|---|---|---|---|
| Potable water | Pipeline | 0 | | 0 |
| | Facilities | 1 | | 30 |
| | | | Subtotal | 30 |
| Waste water | Pipeline | 0 | | 0 |
| | Facilities | 0 | | 0 |
| | | | Subtotal | 0 |
| Natural gas | Pipeline | 2 | | 32 |
| | Facilities | 0 | | 0 |
| | | | Subtotal | 2 |
| Oil system | Pipeline | 0 | | 0 |
| | Facilities | 0 | | 0 |
| | | | Subtotal | 0 |
| Electrical power | Facilities | 1 | | 100 |
| Communication | Facilities | 31 | | 62 |
| | | | Total | 224 |

# Appendix C. Data and damage estimates from a survey of 955 buildings in Klamath County

Map of census tracts in Klamath County (Figure B–1) is shown on .pdf file on CD. HAZUS building structural types were modified for this survey (Theodoropoulos and Wang, 2000): C1 = concrete moment frame; C2 = concrete shear walls; C3 = concrete frame with unreinforced masonry infill walls; PC1 = precast concrete tiltup walls; PC2 = precast concrete frames with concrete shear walls; RM1 = reinforced masonry bearing walls with wood or metal diaphragm; RM2 = reinforced masonry bearing walls with precast concrete diaphragm; S1 = steel moment frame; S2 = steel braced frame; S3 = steel light frame; S4 = steel frame with cast-in-place concrete shear walls; S5 = steel frame with unreinforced masonry infill walls; URM = unreinforced masonry bearing walls; W1 = wood, light frame, <5,000 $ft^2$; W2 = wood, commercial/industrial, >5,000 $ft^2$; UNK = unknown.

Table C–1. *Building survey data in Klamath County*

| Tract | C1 | C2 | C3 | PC1 | PC2 | RM1 | RM2 | S1 | S2 | S3 | S4 | S5 | URM | W1 | W2 | UNK | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 410359702 | - | - | - | - | - | 2 | - | - | - | 1 | - | - | 47 | 4 | - | - | 54 |
| 410359703 | - | - | - | - | - | - | - | 1 | - | - | - | - | - | - | - | - | 1 |
| 410359704 | - | 1 | - | - | - | 7 | - | - | 1 | - | - | | 3 | 2 | - | - | 14 |
| 410359706 | - | - | - | - | - | 5 | - | - | - | - | - | 1 | 10 | - | - | - | 16 |
| 410359707 | - | - | - | - | - | 1 | 3 | - | 1 | 3 | - | - | 10 | 11 | 1 | - | 30 |
| 410359708 | 1 | 8 | 1 | 3 | - | 5 | 2 | 5 | 15 | 18 | 3 | - | 4 | 8 | 9 | - | 82 |
| 410359709 | - | - | - | - | - | - | 1 | - | - | 1 | - | - | 16 | 1 | 1 | - | 20 |
| 410359710 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 2 | - | 2 |
| 410359711 | - | 1 | - | 1 | - | 16 | 8 | - | 3 | - | 1 | - | 11 | 39 | 3 | - | 83 |
| 410359712 | - | 2 | - | - | - | 18 | 3 | 3 | 2 | 1 | - | - | 13 | 16 | 3 | - | 61 |
| 410359713 | - | 1 | - | - | - | 5 | 4 | - | - | 4 | - | - | 4 | 21 | 4 | - | 43 |
| 410359714 | - | - | - | - | - | 5 | 1 | - | - | - | - | - | 8 | 4 | 4 | - | 22 |
| 410359715 | - | 2 | 1 | 1 | - | 13 | 8 | 1 | 6 | 6 | - | - | 17 | 6 | 4 | - | 65 |
| 410359716 | - | 1 | 4 | 3 | - | 17 | 2 | - | - | 1 | - | - | 49 | 27 | 14 | 1 | 119 |
| 410359717 | - | 2 | - | - | - | 5 | 4 | - | - | - | 1 | - | 38 | 3 | - | - | 53 |
| 410359718 | 1 | 2 | 7 | - | - | 14 | 6 | 2 | 3 | - | 1 | 1 | 103 | 9 | 11 | - | 160 |
| 410359719 | - | - | 1 | - | - | 7 | 11 | - | 1 | 1 | 1 | - | 28 | 12 | 6 | - | 68 |
| 410359720 | 3 | 3 | - | 2 | 4 | 19 | 3 | 5 | - | 1 | 1 | - | 9 | 6 | 6 | - | 62 |
| Total | 5 | 23 | 14 | 10 | 4 | 139 | 56 | 17 | 32 | 37 | 8 | 2 | 370 | 169 | 68 | 1 | 955 |

Table C–2. *Damages of 955 buildings from the 1993 Klamath Falls earthquake model*

| Tract | C1 | C2 | C3 | PC1 | PC2 | RM1 | RM2 | S1 | S2 | S3 | S4 | S5 | URM | W1 | W2 | UNK | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 410359702 | - | - | - | - | - | - | - | - | - | - | - | - | 1 | - | - | - | 1 |
| 410359703 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0 |
| 410359704 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0 |
| 410359706 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0 |
| 410359707 | - | - | - | - | - | - | - | - | - | - | - | - | 1 | 1 | - | - | 2 |
| 410359708 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0 |
| 410359709 | - | - | - | - | - | - | - | - | - | 1 | - | - | 6 | - | - | - | 7 |
| 410359710 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0 |
| 410359711 | - | - | - | - | - | 2 | - | - | - | - | - | - | 1 | 2 | - | - | 5 |
| 410359712 | - | - | - | - | - | 2 | 2 | - | - | - | - | - | 4 | 1 | - | - | 9 |
| 410359713 | - | - | - | - | - | - | - | - | - | 1 | - | - | 1 | 1 | - | - | 3 |
| 410359714 | | - | - | - | - | - | - | - | - | - | - | - | 1 | - | - | - | 1 |
| 410359715 | - | - | - | - | - | 3 | 2 | - | - | - | - | | 3 | - | 1 | - | 9 |
| 410359716 | - | - | 1 | 1 | - | 2 | - | - | - | - | - | - | 9 | 1 | 2 | - | 16 |
| 410359717 | - | - | - | - | - | 2 | - | - | - | - | - | - | 9 | 1 | - | - | 12 |
| 410359718 | - | - | 1 | - | - | - | - | - | - | - | - | - | 12 | - | - | - | 13 |
| 410359719 | - | - | - | - | - | - | 2 | - | - | - | - | - | 10 | - | 1 | - | 13 |
| 410359720 | 1 | - | - | 1 | 1 | 4 | 1 | - | - | - | - | - | 2 | 1 | 2 | - | 13 |
| Total | 1 | - | 2 | 2 | 1 | 15 | 7 | - | - | 2 | - | - | 60 | 8 | 6 | - | 104 |

Table C–3. *Damages of 955 buildings from the 500-year hazard scenario*

| Tract | C1 | C2 | C3 | PC1 | PC2 | RM1 | RM2 | S1 | S2 | S3 | S4 | S5 | URM | W1 | W2 | UNK | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 410359702 | - | - | - | - | - | - | - | - | - | - | - | - | 10 | 1 | - | - | 11 |
| 410359703 | - | - | - | - | - | - | - | - | - | - | - | - | 0 | 0 | - | - | 0 |
| 410359704 | - | - | - | - | - | - | - | - | - | - | - | - | 0 | 0 | - | - | 0 |
| 410359706 | - | - | - | - | - | 3 | - | - | - | - | - | 1 | 5 | 0 | - | - | 9 |
| 410359707 | - | - | - | - | - | 0 | - | - | - | - | - | - | 5 | 7 | - | - | 12 |
| 410359708 | - | - | - | - | - | 2 | - | 2 | 8 | 7 | - | - | 0 | 0 | 5 | - | 24 |
| 410359709 | - | - | - | - | - | 0 | 1 | - | - | - | - | - | 11 | 0 | 0 | - | 12 |
| 410359710 | - | - | - | - | - | 0 | - | - | - | - | - | - | 0 | 0 | 1 | - | 1 |
| 410359711 | - | - | - | - | - | 11 | 1 | - | 2 | - | - | - | 5 | 13 | 2 | - | 34 |
| 410359712 | - | - | - | - | - | 14 | 2 | 1 | - | 1 | - | - | 10 | 7 | 2 | - | 37 |
| 410359713 | - | 1 | - | - | - | 2 | 2 | - | - | 3 | - | - | 4 | 4 | 2 | - | 18 |
| 410359714 | - | - | - | - | - | 5 | - | - | - | - | - | - | 5 | 2 | 2 | - | 14 |
| 410359715 | - | 1 | 1 | - | - | 9 | 4 | - | 1 | - | - | - | 10 | 0 | 2 | - | 28 |
| 410359716 | - | 1 | 3 | 2 | - | 9 | - | - | - | - | - | - | 29 | 8 | 9 | - | 61 |
| 410359717 | - | - | - | - | - | 5 | 1 | - | - | - | 1 | - | 29 | 2 | 0 | - | 38 |
| 410359718 | - | - | 3 | - | - | 5 | 2 | 1 | 2 | - | - | - | 80 | 4 | 5 | - | 102 |
| 410359719 | - | - | - | - | - | 1 | 5 | - | - | - | - | - | 20 | 3 | 5 | - | 34 |
| 410359720 | 2 | 1 | - | 2 | 3 | 12 | 2 | 3 | - | - | - | - | 5 | 5 | 4 | - | 39 |
| Total | 2 | 4 | 7 | 4 | 3 | 78 | 20 | 7 | 13 | 11 | 1 | 1 | 228 | 56 | 39 | - | 474 |

Table C–4. *Damages of 955 buildings from the Klamath Falls city center scenario I*

| Tract | C1 | C2 | C3 | PC1 | PC2 | RM1 | RM2 | S1 | S2 | S3 | S4 | S5 | URM | W1 | W2 | UNK | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 410359702 | - | - | - | - | - | - | - | - | - | - | - | - | 1 | - | - | - | 1 |
| 410359703 | - | - | - | - | - | - | - | - | - | - | - | - | 0 | 0 | - | - | 0 |
| 410359704 | - | - | - | - | - | - | - | - | - | - | - | - | 0 | 0 | - | - | 0 |
| 410359706 | - | - | - | - | - | 0 | - | - | - | - | - | - | 1 | 0 | - | - | 1 |
| 410359707 | - | - | - | - | - | 0 | - | - | - | - | - | - | 3 | 4 | - | - | 7 |
| 410359708 | - | - | - | - | - | 1 | - | 1 | 4 | 6 | - | - | 0 | 0 | 5 | - | 17 |
| 410359709 | - | - | - | - | - | 0 | 1 | - | - | 1 | - | - | 10 | 0 | 0 | - | 12 |
| 410359710 | - | - | - | - | - | 0 | - | - | - | - | - | - | 0 | 0 | 0 | - | 0 |
| 410359711 | - | - | - | - | - | 9 | 1 | - | 2 | - | - | - | 5 | 12 | 1 | - | 30 |
| 410359712 | - | - | - | - | - | 10 | 2 | 1 | - | 1 | - | - | 10 | 6 | 2 | - | 32 |
| 410359713 | - | 1 | - | - | - | 2 | 2 | - | - | 3 | - | - | 3 | 3 | 2 | - | 16 |
| 410359714 | | - | - | - | - | 4 | - | - | - | - | - | - | 5 | 1 | 2 | - | 12 |
| 410359715 | - | 1 | 1 | - | - | 7 | 4 | - | 2 | 2 | - | - | 8 | 0 | 3 | - | 28 |
| 410359716 | - | 1 | 3 | 2 | - | 7 | - | - | - | - | - | - | 26 | 7 | 9 | - | 55 |
| 410359717 | - | - | - | - | - | 2 | 1 | - | - | - | - | - | 26 | 2 | 0 | - | 31 |
| 410359718 | - | - | 3 | - | - | 4 | 2 | 1 | 2 | - | - | - | 65 | 1 | 4 | - | 82 |
| 410359719 | - | - | - | - | - | 1 | 4 | - | - | - | - | - | 21 | 2 | 4 | - | 32 |
| 410359720 | 1 | 2 | - | 1 | 3 | 12 | 2 | 2 | - | - | - | - | 6 | 4 | 4 | - | 37 |
| Total | 1 | 5 | 7 | 3 | 3 | 59 | 19 | 5 | 10 | 13 | - | - | 190 | 42 | 36 | - | 393 |

Table C–5. *Damages of 955 buildings from the Klamath Falls city center scenario II*

| Tract | C1 | C2 | C3 | PC1 | PC2 | RM1 | RM2 | S1 | S2 | S3 | S4 | S5 | URM | W1 | W2 | UNK | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 410359702 | - | - | - | - | - | - | - | - | - | - | - | - | 3 | 0 | - | - | 3 |
| 410359703 | - | - | - | - | - | - | - | - | - | - | - | - | 0 | 0 | - | - | 0 |
| 410359704 | - | - | - | - | - | - | - | - | - | - | - | - | 0 | 0 | - | - | 0 |
| 410359706 | - | - | - | - | - | 2 | - | - | - | - | - | - | 3 | 0 | - | - | 5 |
| 410359707 | - | - | - | - | - | 0 | - | - | - | - | - | - | 5 | 9 | - | - | 14 |
| 410359708 | - | - | - | - | - | 2 | - | 2 | 9 | 6 | - | - | 0 | 0 | 8 | - | 27 |
| 410359709 | - | - | - | - | - | 0 | 1 | - | - | 1 | - | - | 14 | 0 | 0 | - | 16 |
| 410359710 | - | - | - | - | - | 0 | - | - | - | - | - | - | 0 | 0 | 1 | - | 1 |
| 410359711 | - | - | - | - | - | 12 | 6 | - | 2 | - | - | - | 5 | 16 | 2 | - | 43 |
| 410359712 | - | - | - | - | - | 12 | 2 | 2 | - | 1 | - | - | 11 | 10 | 2 | - | 40 |
| 410359713 | - | 1 | - | - | - | 4 | 3 | - | - | 3 | - | - | 4 | 14 | 3 | - | 32 |
| 410359714 | | - | - | - | - | 5 | - | - | - | - | - | - | 7 | 3 | 3 | - | 18 |
| 410359715 | - | 1 | 1 | - | - | 8 | 7 | - | 3 | 2 | - | - | 10 | 0 | 3 | - | 35 |
| 410359716 | - | 1 | 4 | 2 | - | 14 | - | - | - | - | - | - | 31 | 10 | 12 | - | 74 |
| 410359717 | - | - | - | - | - | 4 | 2 | - | - | - | 1 | - | 31 | 2 | 0 | - | 40 |
| 410359718 | 1 | - | 5 | - | - | 8 | 3 | 1 | 1 | - | - | - | 94 | 4 | 6 | - | 123 |
| 410359719 | - | - | - | - | - | 2 | 7 | - | - | - | - | - | 27 | 4 | 6 | - | 46 |
| 410359720 | 2 | 2 | - | 2 | 3 | 17 | 2 | 5 | - | - | - | - | 7 | 5 | 5 | - | 50 |
| Total | 3 | 5 | 10 | 4 | 3 | 90 | 33 | 10 | 15 | 13 | 1 | - | 252 | 77 | 51 | - | 567 |

# Appendix D. Damage and loss estimates for three earthquake models

Of the four earthquake models used in this study (Table 6), this includes the probabilistic 500-year-interval scenario and the Klamath Falls city center scenarios I and II.

## Appendix D1. Damages and losses from the 500-year probabilistic hazard scenario

Table D1–1. *Expected building damage by occupancy*

| Occupancy | None | Slight | Moderate | Extensive | Complete | Total |
|---|---|---|---|---|---|---|
| Agriculture | 14 | 4 | 7 | 2 | 1 | 28 |
| Commercial | 69 | 51 | 91 | 71 | 55 | 337 |
| Education | 4 | 0 | 1 | 0 | 0 | 5 |
| Government | 2 | 0 | 0 | 0 | 0 | 2 |
| Industrial | 11 | 2 | 8 | 9 | 6 | 36 |
| Religion | 10 | 6 | 7 | 6 | 4 | 33 |
| Residential | 6,211 | 6,754 | 6,371 | 2,025 | 1,364 | 22,725 |
| Total | 6,321 | 6,817 | 6,485 | 2,113 | 1,430 | 23,166 |

Table D1–2. *Expected building damage by building type*

| Building type | None | Slight | Moderate | Extensive | Complete | Total |
|---|---|---|---|---|---|---|
| Concrete | 28 | 13 | 30 | 21 | 15 | 107 |
| Mobile home | 544 | 809 | 1,524 | 1,150 | 887 | 4,914 |
| Precast concrete | 21 | 5 | 26 | 28 | 21 | 101 |
| Reinforced masonry bearings walls | 25 | 12 | 30 | 27 | 19 | 113 |
| Steel | 53 | 4 | 14 | 22 | 20 | 113 |
| Unreinforced masonry bearing walls | 21 | 33 | 61 | 53 | 52 | 220 |
| Wood | 5,629 | 5,941 | 4,800 | 812 | 416 | 17,598 |
| Total | 6,321 | 6,817 | 6,485 | 2,113 | 1,430 | 23,166 |

Table D1–3. *Expected damage to essential facilities*

| Classification | Total | Number of facilities with at least moderate damage | with complete damage | with functionality >50% at day 1 |
|---|---|---|---|---|
| Hospitals | 1 | 1 | 0 | 0 |
| Schools | 8 | 8 | 0 | 1 |
| Emergency operation centers | 1 | 1 | 0 | 0 |
| Police stations | 3 | 3 | 0 | 3 |
| Fire stations | 1 | 1 | 0 | 1 |

Table D1–4. *Expected damage to the transportation systems*

| System | Component | Number of locations/segments | Number of locations: with at least moderate damage | with complete damage | with functionality >50% after day 1 | after day 7 |
|---|---|---|---|---|---|---|
| Highway | Roads | 48 | 0 | 0 | 48 | 48 |
| | Bridges | 55 | 2 | 0 | 55 | 55 |
| | Tunnels | 0 | 0 | 0 | 0 | 0 |
| Railways | Tracks | 0 | - | 0 | 233 | 233 |
| | Bridges | 0 | 0 | 0 | 0 | 0 |
| | Tunnels | 0 | 0 | 0 | 0 | 0 |
| | Facilities | 0 | 0 | 0 | 0 | 0 |
| Airport | Facilities | 10 | 3 | 0 | 10 | 10 |
| | Runways | 11 | 0 | 0 | 11 | 11 |

Table D1--5. *Expected utility system facility damage*

| System | Total number of locations/segments | Number of locations: with at least moderate damage | with complete damage | with functionality >50% after day 1 | after day 7 |
|---|---|---|---|---|---|
| Potable water | 1 | 0 | 0 | 1 | 1 |
| Waste water | 0 | 0 | 0 | 0 | 0 |
| Natural gas | 0 | 0 | 0 | 0 | 0 |
| Oil systems | 0 | 0 | 0 | 0 | 0 |
| Electrical power | 1 | 1 | 0 | 0 | 1 |
| Communication | 31 | 14 | 0 | 31 | 31 |
| Total | 33 | 15 | 0 | 32 | 33 |

Table D1–6. *Expected utility system pipeline damage*

| System | Total pipeline length (km) | Number of leaks | Number of breaks |
|---|---|---|---|
| Potable water | 0 | 0 | 0 |
| Waste water | 0 | 0 | 0 |
| Natural gas | 193 | 26 | 7 |
| Oil | 0 | 0 | 0 |
| Total | 193 | 26 | 7 |

Table D1–7. *Expected potable water and electrical power system performance*

| | Total number of households | Number of households without service: At day 1 | At day 3 | At day 7 | At day 30 | At day 90 |
|---|---|---|---|---|---|---|
| Potable water | 22,414 | 0 | 0 | 0 | 0 | 0 |
| Electrical power | 22,414 | 16,152 | 10,714 | 4,769 | 325 | 0 |

Table D1–8. *Casualty estimates; severity levels as in Table 7*

| | Total casualties – 2am | | | | Total casualties – 2pm | | | | Total casualties – 5pm | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | At home | At work | Commute | Total | At home | At work | Commute | Total | At home | At work | Commute | Total |
| Severity 1: | 272 | 3 | 0 | 275 | 96 | 194 | 0 | 290 | 114 | 64 | 0 | 178 |
| Severity 2: | 48 | 1 | 0 | 48 | 17 | 37 | 0 | 54 | 20 | 12 | 0 | 32 |
| Severity 3: | 3 | 0 | 0 | 3 | 1 | 5 | 0 | 6 | 1 | 2 | 0 | 3 |
| Severity 4: | 3 | 0 | 0 | 3 | 1 | 5 | 0 | 6 | 1 | 2 | 0 | 3 |
| Total: | 326 | 4 | 0 | 329 | 115 | 240 | 0 | 356 | 137 | 79 | 0 | 216 |

Table D1–9. *Building-related economic loss estimates (millions of dollars)*

| Capital stock losses | | | | | Business losses | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Structural | Nonstructural | Contents | Inventory | Loss ratio (%) | Relocation | Income | Wages | Rental | Total |
| 102.7 | 319.0 | 98.8 | 1.5 | 13.5 | 69.9 | 44.3 | 45.0 | 32.3 | 713.4 |

Table D1–10. *Expected damage to the transportation systems (millions of dollars)*

| System | Component | Inventory value | Economic loss | Loss ratio (%) |
|---|---|---|---|---|
| Highways | Roads | 6,845.4 | 0 | 0 |
| | Bridges | 131.0 | 0.4 | 0 |
| | Tunnels | 0 | 0 | 0 |
| Railways | Tracks | 886.2 | 0 | 0 |
| | Bridges | 0 | 0 | 0 |
| | Tunnels | 0 | 0 | 0 |
| | Facilities | 0 | 0 | 0 |
| Airport | Facilities | 74.0 | 14.3 | 5.2 |
| | Runways | 308.0 | 0 | 0 |

Table D1–11. *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 | 30.0 | 8.1 | 27.1 |
| | Subtotal | 30.0 | 8.1 | 27.1 |
| Natural gas | Pipelines | 32.1 | 0.0 | 0.0 |
| | Facilities | 0.0 | 0.0 | 0.0 |
| | Subtotal | 32.1 | 0.0 | 0.0 |
| Electrical power | Facilities | 1,437.3 | 6.0 | 6.0 |
| Communication | Facilities | 62.0 | 15.1 | 24.4 |

Table D1–12. *Indirect economic impact (numbers of employees and millions of dollars)*

| | Employment | | Income | |
|---|---|---|---|---|
| Elapsed time | Employee change | Rate of change (%) | Income change | Rate of change (%) |
| Year 1 | 0.00 | 0.00 | –10.30 | –0.08 |
| Year 2 | 0.00 | 0.00 | –18.00 | –0.21 |
| Year 3 | 0.00 | 0.00 | –20.61 | –2.86 |
| Year 4 | 0.00 | 0.00 | –20.61 | –2.86 |
| Year 5 | 0.00 | 0.00 | –20.61 | –2.86 |

## Appendix D2. Damages and losses from the Klamath Falls city center earthquake scenario I

Table D2–1. *Expected building damage by occupancy*

| Occupancy | None | Slight | Moderate | Extensive | Complete | Total |
|---|---|---|---|---|---|---|
| Agriculture | 27 | 2 | 2 | 0 | 0 | 31 |
| Commercial | 170 | 56 | 87 | 35 | 2 | 350 |
| Education | 6 | 0 | 0 | 0 | 0 | 6 |
| Government | 2 | 0 | 0 | 0 | 0 | 2 |
| Industrial | 30 | 3 | 11 | 3 | 0 | 47 |
| Religion | 24 | 7 | 9 | 1 | 0 | 41 |
| Residential | 12,530 | 5598 | 3,604 | 882 | 74 | 22,688 |
| Total | 12,789 | 5666 | 3,713 | 921 | 76 | 23,165 |

Table D2–2. *Expected building damage by building type*

| Building type | None | Slight | Moderate | Extensive | Complete | Total |
|---|---|---|---|---|---|---|
| Concrete | 54 | 17 | 25 | 11 | 0 | 107 |
| Mobile home | 2,611 | 784 | 1,067 | 396 | 56 | 4,914 |
| Precast concrete | 47 | 8 | 25 | 19 | 2 | 101 |
| Reinforced masonry bearings walls | 58 | 12 | 27 | 16 | 0 | 113 |
| Steel | 74 | 8 | 25 | 6 | 0 | 113 |
| Unreinforced masonry bearing walls | 74 | 41 | 53 | 33 | 19 | 220 |
| Wood | 9,871 | 4,796 | 2,491 | 440 | 0 | 17,598 |
| Total | 12789 | 5,666 | 3,713 | 921 | 77 | 23,166 |

Table D2–3. *Expected damage to essential facilities*

| | | Number of facilities | | |
|---|---|---|---|---|
| Classification | Total | with at least moderate damage | with complete damage | with functionality >50% at day 1 |
| Hospitals | 1 | 1 | 0 | 0 |
| Schools | 8 | 7 | 0 | 4 |
| Emergency operation centers | 1 | 1 | 0 | 0 |
| Police stations | 3 | 2 | 0 | 3 |
| Fire stations | 1 | 1 | 0 | 1 |

Table D2–4. *Expected damage to the transportation systems*

| | | | Number of locations | | | |
|---|---|---|---|---|---|---|
| | | | | | with functionality >50% | |
| System | Component | Number of locations/segments | with at least moderate damage | with complete damage | after day 1 | after day 7 |
| Highway | Roads | 48 | 0 | 0 | 48 | 48 |
| | Bridges | 55 | 3 | 0 | 54 | 55 |
| | Tunnels | 0 | 0 | 0 | 0 | 0 |
| Railways | Tracks | 0 | - | 0 | 233 | 233 |
| | Bridges | 0 | 0 | 0 | 0 | 0 |
| | Tunnels | 0 | 0 | 0 | 0 | 0 |
| | Facilities | 0 | 0 | 0 | 0 | 0 |
| Airport | Facilities | 10 | 1 | 0 | 10 | 10 |
| | Runways | 11 | 0 | 0 | 11 | 11 |

Table D2--5. *Expected utility system facility damage*

| System | Total number of locations/segments | Number of locations: with at least moderate damage | with complete damage | with functionality >50% after day 1 | with functionality >50% after day 7 |
|---|---|---|---|---|---|
| Potable water | 1 | 0 | 0 | 1 | 1 |
| Waste water | 0 | 0 | 0 | 0 | 0 |
| Natural gas | 0 | 0 | 0 | 0 | 0 |
| Oil systems | 0 | 0 | 0 | 0 | 0 |
| Electrical power | 1 | 0 | 0 | 1 | 1 |
| Communication | 31 | 12 | 0 | 31 | 31 |
| Total | 33 | 12 | 0 | 33 | 33 |

Table D2–6. *Expected utility system pipeline damage*

| System | Total pipeline length (km) | Number of leaks | Number of breaks |
|---|---|---|---|
| Potable water | 0 | 0 | 0 |
| Waste water | 0 | 0 | 0 |
| Natural gas | 193 | 0 | 0 |
| Oil | 0 | 0 | 0 |
| Total | 193 | 0 | 0 |

Table D2–7. *Expected potable water and electrical power system performance*

| | Total number of households | Number of households without service: At day 1 | At day 3 | At day 7 | At day 30 | At day 90 |
|---|---|---|---|---|---|---|
| Potable water | 22,414 | 0 | 0 | 0 | 0 | 0 |
| Electrical power | 22,414 | 14,219 | 9,990 | 4,819 | 425 | 0 |

Table D2–8. *Casualty estimates; severity levels as in Table 7*

| | Total casualties – 2am | | | | Total casualties – 2pm | | | | Total casualties – 5pm | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | At home | At work | Commute | Total | At home | At work | Commute | Total | At home | At work | Commute | Total |
| Severity 1: | 57 | 1 | 0 | 58 | 20 | 39 | 0 | 59 | 23 | 13 | 0 | 36 |
| Severity 2: | 8 | 0 | 0 | 8 | 3 | 7 | 0 | 10 | 3 | 2 | 0 | 5 |
| Severity 3: | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 |
| Severity 4: | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 |
| Total: | 65 | 1 | 0 | 66 | 23 | 48 | 0 | 71 | 26 | 16 | 1 | 43 |

Table D2–9. *Building-related economic loss estimates (millions of dollars)*

| Capital stock losses | | | | | Business losses | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Structural | Nonstructural | Contents | Inventory | Loss ratio (%) | Relocation | Income | Wages | Rental | Total |
| 35.7 | 144.9 | 64.7 | 1.0 | 5.8 | 28.8 | 12.6 | 16.9 | 12.9 | 316.7 |

Table D2–10. *Expected damage to the transportation systems (millions of dollars)*

| System | Component | Inventory value | Economic loss | Loss ratio (%) |
|---|---|---|---|---|
| Highways | Roads | 6,845.4 | 0 | 0 |
| | Bridges | 131.0 | 0.8 | 0 |
| | Tunnels | 0 | 0 | 0 |
| Railways | Tracks | 886.2 | 0 | 0 |
| | Bridges | 0 | 0 | 0 |
| | Tunnels | 0 | 0 | 0 |
| | Facilities | 0 | 0 | 0 |
| Airport | Facilities | 74.0 | 4.6 | 16.2 |
| | Runways | 308.0 | 0 | 0 |

Table D2–11. *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 | 30.0 | 0.6 | 1.9 |
| | Subtotal | 30.0 | 0.6 | 1.9 |
| Natural gas | Pipelines | 32.1 | 0.0 | 0.0 |
| | Facilities | 0.0 | 0.0 | 0.0 |
| | Subtotal | 32.1 | 0.0 | 0.0 |
| Electrical power | Facilities | 1,437.3 | 0.3 | 0.3 |
| Communication | Facilities | 62.0 | 12.5 | 20.2 |

Table D2–12. *Indirect economic impact (numbers of employees and millions of dollars)*

| | Employment | | Income | |
|---|---|---|---|---|
| Elapsed time | Employee change | Rate of change (%) | Income change | Rate of change (%) |
| Year 1 | 0.00 | 0.00 | –4.44 | –0.03 |
| Year 2 | 0.00 | 0.00 | –7.71 | –0.09 |
| Year 3 | 0.00 | 0.00 | –8.83 | –1.22 |
| Year 4 | 0.00 | 0.00 | –8.83 | –1.22 |
| Year 5 | 0.00 | 0.00 | –8.83 | –1.22 |

## Appendix D3. Damages and losses from the Klamath Falls city center earthquake scenario II

Table D3–1. *Expected building damage by occupancy*

| Occupancy | None | Slight | Moderate | Extensive | Complete | Total |
|---|---|---|---|---|---|---|
| Agriculture | 21 | 3 | 6 | 0 | 0 | 30 |
| Commercial | 108 | 48 | 117 | 59 | 13 | 345 |
| Education | 4 | 0 | 0 | 0 | 0 | 4 |
| Government | 2 | 0 | 0 | 0 | 0 | 2 |
| Industrial | 20 | 2 | 12 | 8 | 0 | 42 |
| Religion | 16 | 6 | 12 | 6 | 0 | 40 |
| Residential | 9,389 | 6,144 | 5,076 | 1,721 | 371 | 22,701 |
| Total | 9,560 | 6,203 | 5,223 | 1,794 | 384 | 23,164 |

Table D3–2. *Expected building damage by building type*

| Building type | None | Slight | Moderate | Extensive | Complete | Total |
|---|---|---|---|---|---|---|
| Concrete | 37 | 15 | 31 | 21 | 3 | 107 |
| Mobile home | 1,968 | 731 | 1,208 | 794 | 213 | 4,914 |
| Precast concrete | 31 | 6 | 33 | 25 | 6 | 101 |
| Reinforced masonry bearings walls | 41 | 13 | 30 | 26 | 3 | 113 |
| Steel | 54 | 5 | 38 | 14 | 2 | 113 |
| Unreinforced masonry bearing walls | 49 | 35 | 55 | 45 | 36 | 220 |
| Wood | 7,380 | 5,398 | 3,828 | 869 | 123 | 17,598 |
| Total | 9,560 | 6,203 | 5,223 | 1,794 | 386 | 23,166 |

Table D3–3. *Expected damage to essential facilities*

| | | Number of facilities | | |
|---|---|---|---|---|
| Classification | Total | with at least moderate damage | with complete damage | with functionality >50% at day 1 |
| Hospitals | 1 | 1 | 0 | 0 |
| Schools | 8 | 7 | 0 | 4 |
| Emergency operation centers | 1 | 1 | 0 | 0 |
| Police stations | 3 | 2 | 0 | 1 |
| Fire stations | 1 | 1 | 0 | 1 |

Table D3–4. *Expected damage to the transportation systems*

| System | Component | Number of locations/segments | Number of locations with at least moderate damage | with complete damage | with functionality >50% after day 1 | after day 7 |
|---|---|---|---|---|---|---|
| Highway | Roads | 48 | 0 | 0 | 48 | 48 |
| | Bridges | 55 | 8 | 2 | 48 | 50 |
| | Tunnels | 0 | 0 | 0 | 0 | 0 |
| Railways | Tracks | 0 | - | 0 | 233 | 233 |
| | Bridges | 0 | 0 | 0 | 0 | 0 |
| | Tunnels | 0 | 0 | 0 | 0 | 0 |
| | Facilities | 0 | 0 | 0 | 0 | 0 |
| Airport | Facilities | 10 | 2 | 0 | 10 | 10 |
| | Runways | 11 | 0 | 0 | 11 | 11 |

Table D3--5. *Expected utility system facility damage*

| System | Total number of locations/segments | Number of locations with at least moderate damage | with complete damage | with functionality >50% after day 1 | after day 7 |
|---|---|---|---|---|---|
| Potable water | 1 | 0 | 0 | 1 | 1 |
| Waste water | 0 | 0 | 0 | 0 | 0 |
| Natural gas | 0 | 0 | 0 | 0 | 0 |
| Oil systems | 0 | 0 | 0 | 0 | 0 |
| Electrical power | 1 | 0 | 0 | 1 | 1 |
| Communication | 31 | 17 | 1 | 31 | 31 |
| Total | 33 | 17 | 1 | 33 | 33 |

Table D3–6. *Expected utility system pipeline damage*

| System | Total pipeline length (km) | Number of leaks | Number of breaks |
|---|---|---|---|
| Potable water | 0 | 0 | 0 |
| Waste water | 0 | 0 | 0 |
| Natural gas | 193 | 2 | 0 |
| Oil | 0 | 0 | 0 |
| Total | 193 | 2 | 0 |

Table D3–7. *Expected potable water and electrical power system performance*

| | Total number of households | Number of households without service At day 1 | At day 3 | At day 7 | At day 30 | At day 90 |
|---|---|---|---|---|---|---|
| Potable water | 22,414 | 0 | 0 | 0 | 0 | 0 |
| Electrical power | 22,414 | 16,095 | 12,453 | 6,849 | 931 | 0 |

Table D3–8. *Casualty estimates; severity levels as in Table 7*

| | Total casualties – 2am | | | | Total casualties – 2pm | | | | Total casualties – 5pm | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | At home | At work | Commute | Total | At home | At work | Commute | Total | At home | At work | Commute | Total |
| Severity 1: | 130 | 1 | 0 | 131 | 45 | 90 | 1 | 136 | 54 | 30 | 2 | 86 |
| Severity 2: | 20 | 0 | 0 | 20 | 7 | 16 | 1 | 24 | 8 | 5 | 2 | 15 |
| Severity 3: | 1 | 0 | 0 | 1 | 0 | 2 | 1 | 3 | 0 | 1 | 4 | 5 |
| Severity 4: | 1 | 0 | 0 | 1 | 0 | 2 | 0 | 2 | 0 | 1 | 1 | 2 |
| Total: | 152 | 1 | 0 | 153 | 52 | 110 | 3 | 165 | 62 | 37 | 9 | 108 |

Table D3–9. *Building-related economic loss estimates (millions of dollars)*

| Capital stock losses | | | | | Business losses | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Structural** | **Nonstructural** | **Contents** | **Inventory** | **Loss ratio (%)** | **Relocation** | **Income** | **Wages** | **Rental** | **Total** |
| 65.3 | 231.6 | 88.5 | 1.4 | 9.5 | 50.0 | 24.3 | 28.1 | 22.9 | 512.1 |

Table D3–10. *Expected damage to the transportation systems (millions of dollars)*

| System | Component | Inventory value | Economic loss | Loss ratio (%) |
|---|---|---|---|---|
| Highways | Roads | 6,845.4 | 0 | 0 |
| | Bridges | 131.0 | 2.8 | 0 |
| | Tunnels | 0 | 0 | 0 |
| Railways | Tracks | 886.2 | 0 | 0 |
| | Bridges | 0 | 0 | 0 |
| | Tunnels | 0 | 0 | 0 |
| | Facilities | 0 | 0 | 0 |
| Airport | Facilities | 74.0 | 8.4 | 8.8 |
| | Runways | 308.0 | 0 | 0 |

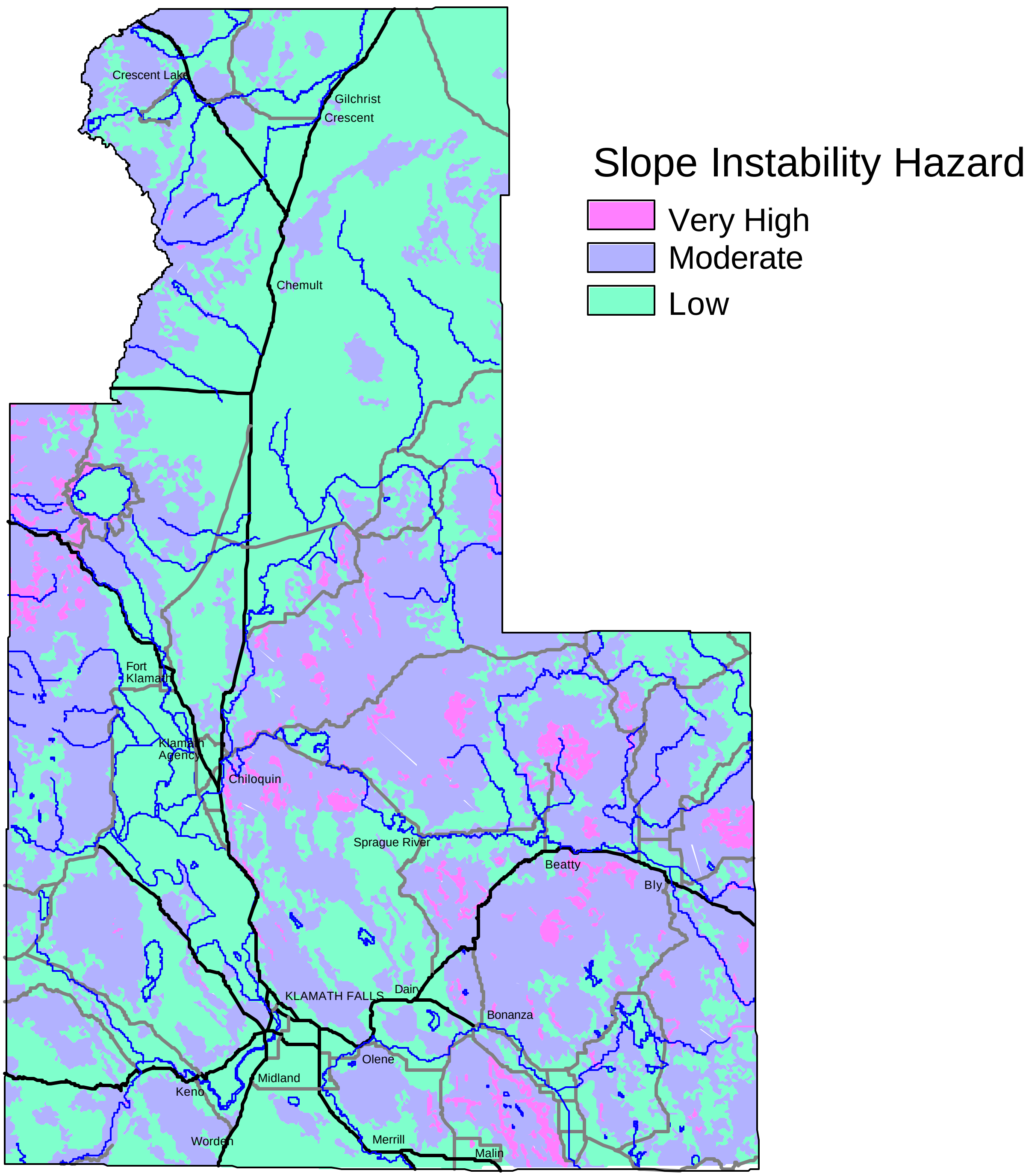
Table D3–11. *Utility system economic losses (millions of dollars)*

| System | Component | Inventory value | Economic loss | Loss ratio (%) |
|---|---|---|---|---|
| Potable water | Pipelines | 0.0 | 0.0 | 0.0 |
| | Facilities | 30.0 | 2.8 | 9.2 |
| | Subtotal | 30.0 | 2.8 | 9.2 |
| Natural gas | Pipelines | 32.1 | 0.0 | 0.0 |
| | Facilities | 0.0 | 0.0 | 0.0 |
| | Subtotal | 32.1 | 0.0 | 0.0 |
| Electrical power | Facilities | 1,437.3 | 1.1 | 1.1 |
| Communication | Facilities | 62.0 | 18.0 | 29.0 |

Table D3–12. *Indirect economic impact (numbers of employees and millions of dollars)*

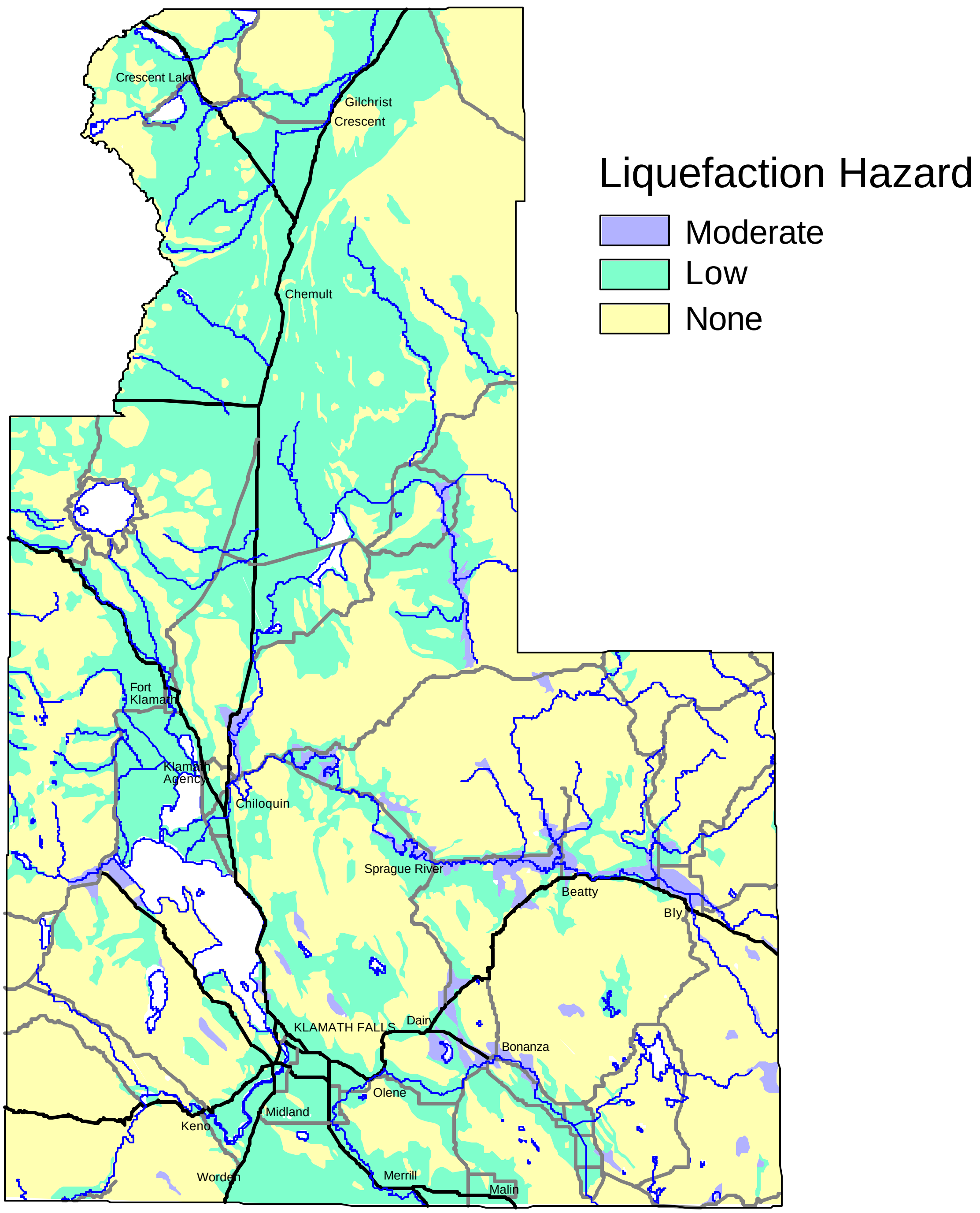
| | Employment | | Income | |
|---|---|---|---|---|
| **Elapsed time** | **Employee change** | **Rate of change (%)** | **Income change** | **Rate of change (%)** |
| Year 1 | 0.00 | 0.00 | –4.44 | –0.03 |
| Year 2 | 0.00 | 0.00 | –7.71 | –0.09 |
| Year 3 | 0.00 | 0.00 | –8.83 | –1.22 |
| Year 4 | 0.00 | 0.00 | –8.83 | –1.22 |
| Year 5 | 0.00 | 0.00 | –8.83 | –1.22 |

# Relative Slope Hazard Map



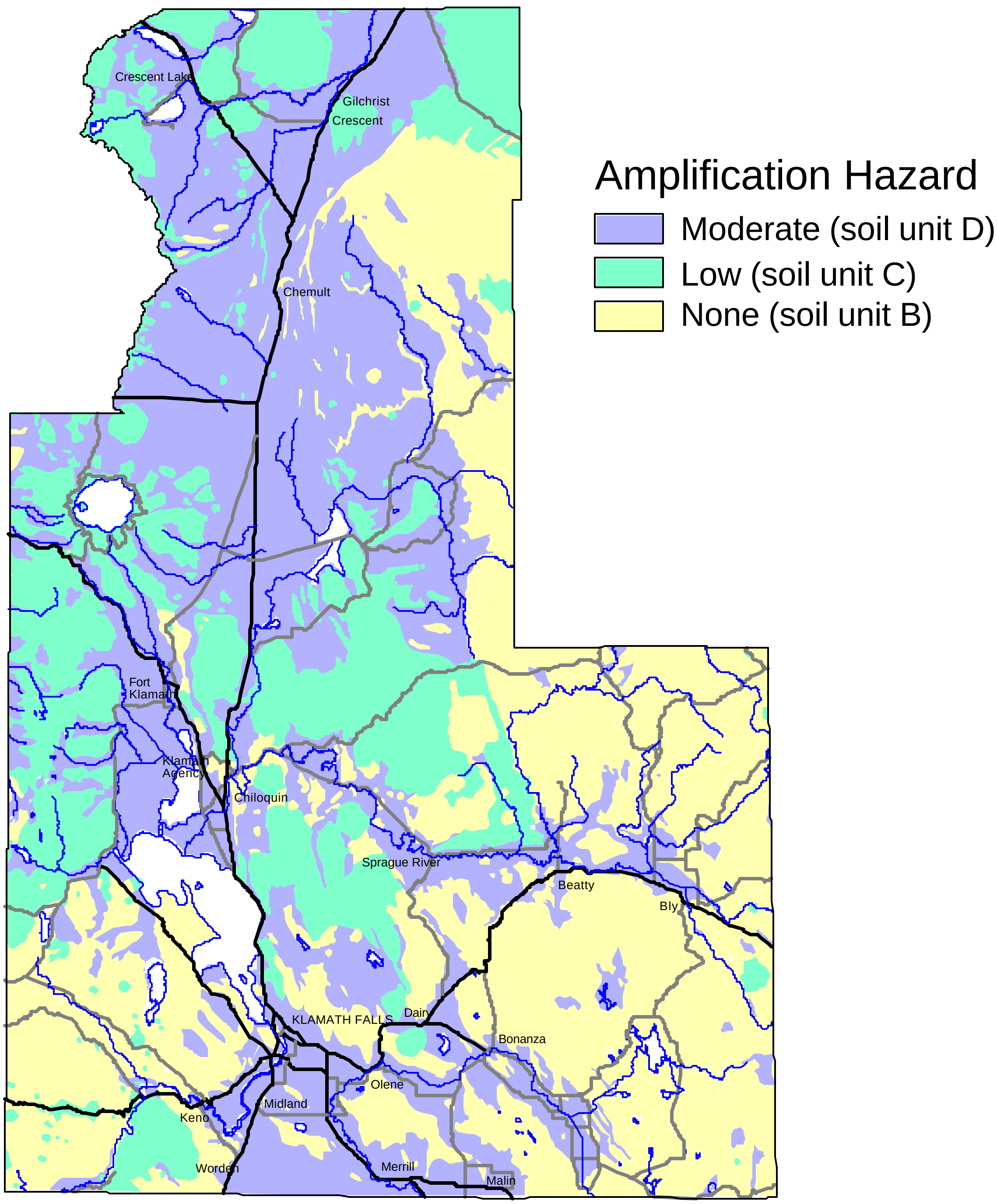

See accompanying text for an explanation of how these ratings were defined and what the various levels of hazard mean.

# Relative Liquefaction Susceptibility Map




See accompanying text for an explanation of how these ratings were defined and what the various levels of hazard mean.

# Relative Ground Motion Amplification Map




See accompanying text for an explanation of how these ratings were defined and what the various levels of hazard mean.

Figure 1. Maximum peak ground acceleration (PGA, in percent g) expected in Klamath County from earthquakes with a frequency of occurrence of once in 500 years, after Frankel and others (1996).

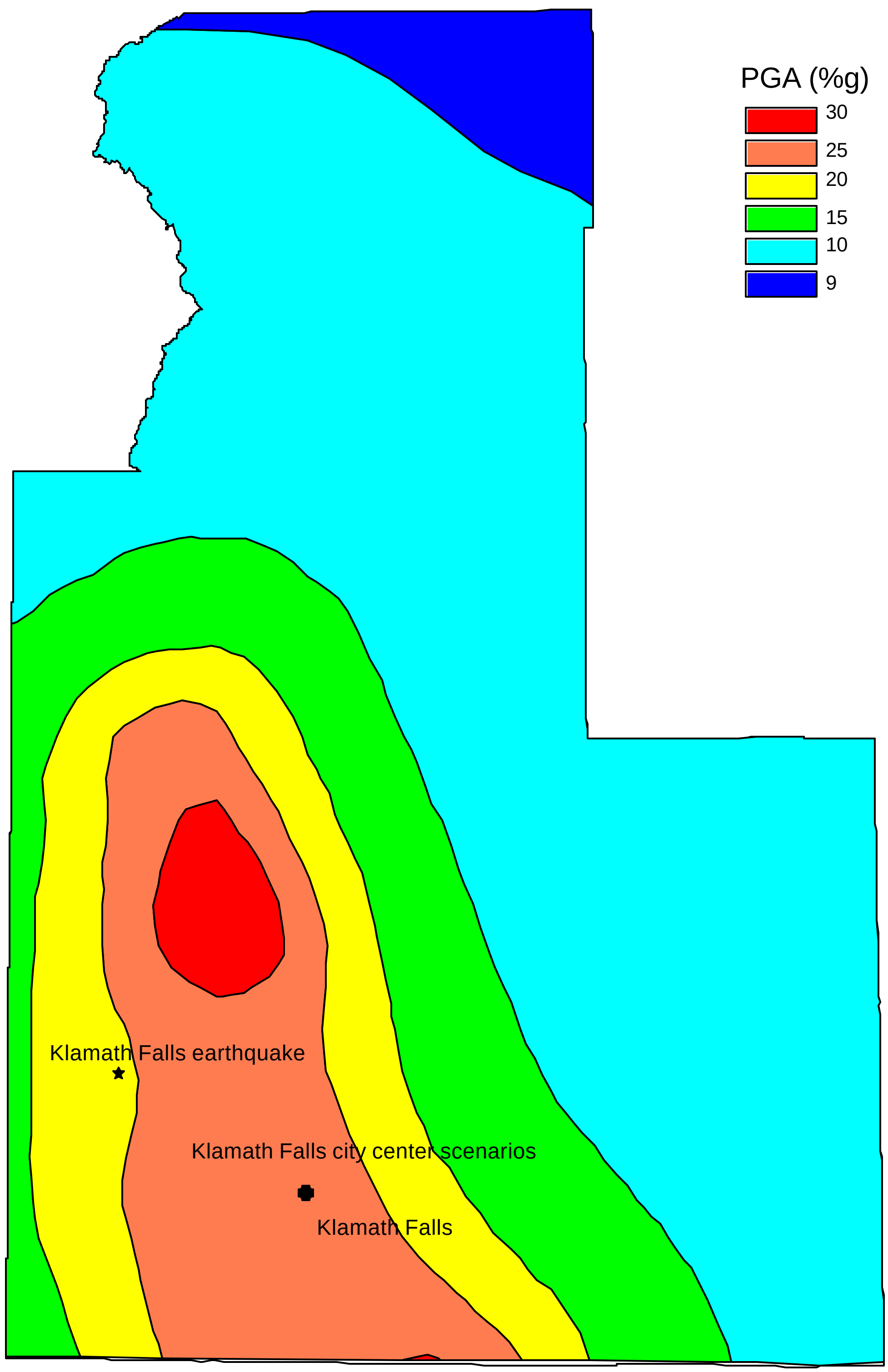


Figure 2. Simplified geologic map of Klamath County after Walker and MacLeod (1991). See unit descriptions in Table 2 of the accompanying text.

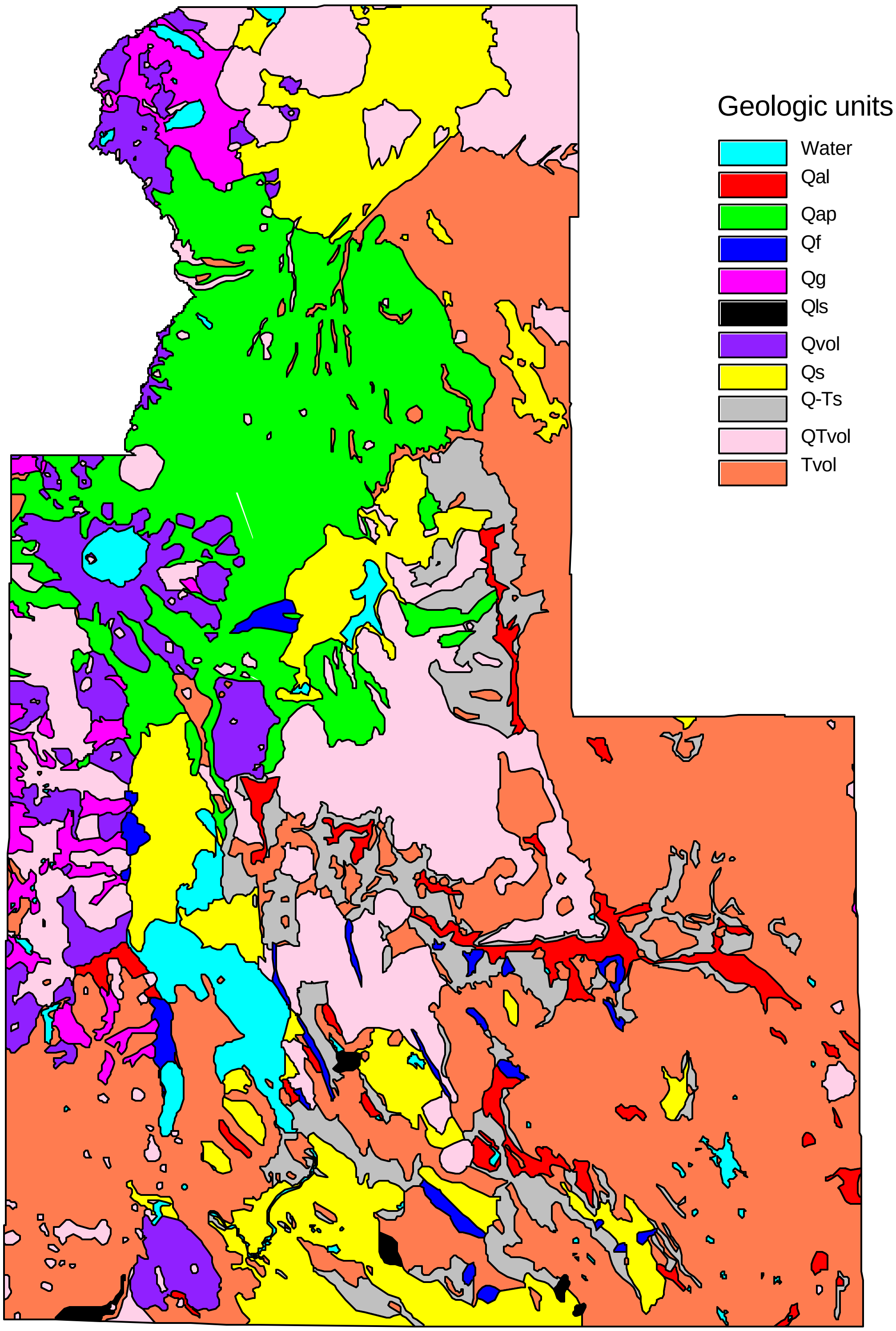


Figure A-1. Location map of data point sites in Klamath County as listed in Table A-1 of the accompanying text.

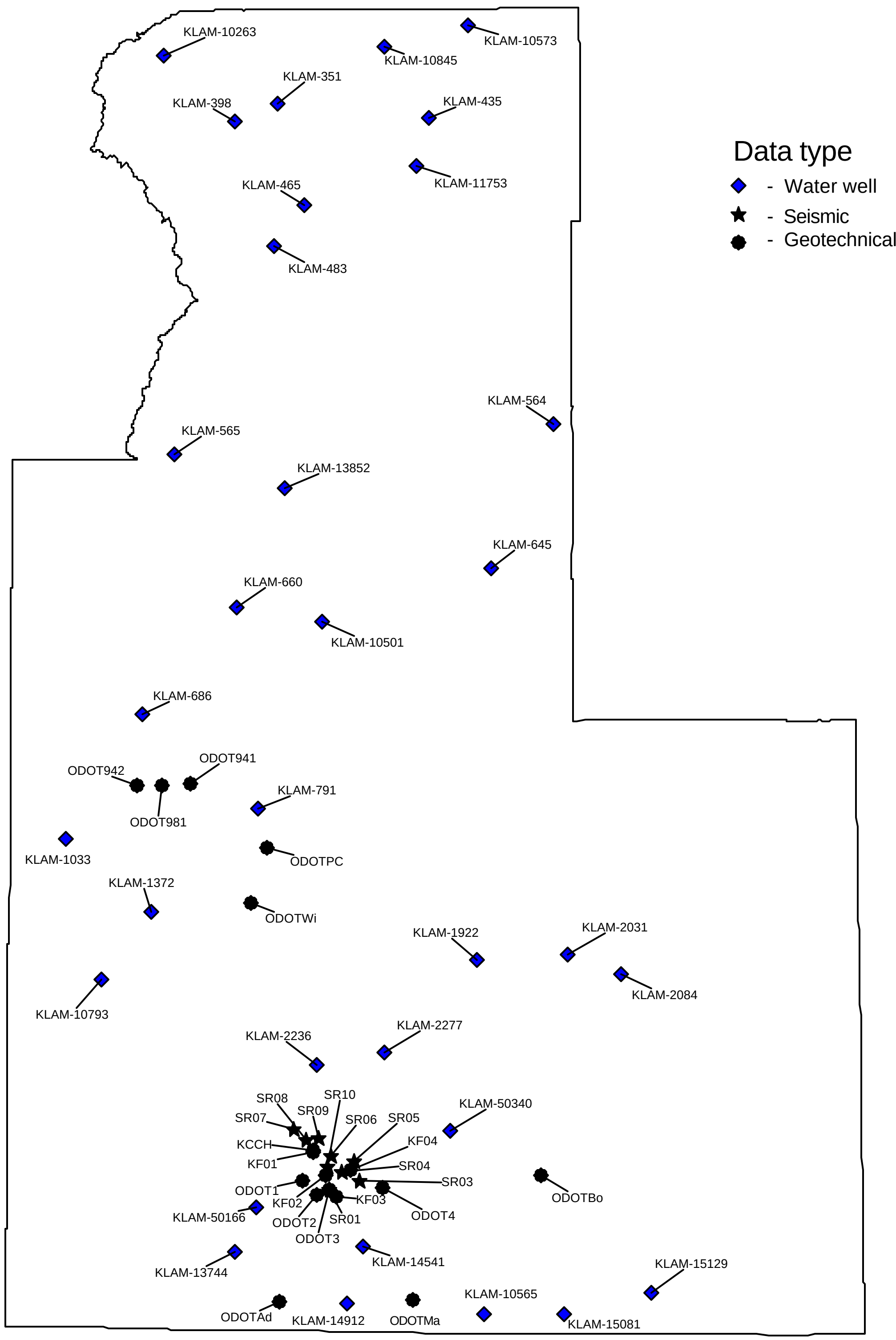


Figure B-1. Map of census tracts in Klamath County as used in Appendix B of the accompanying text.