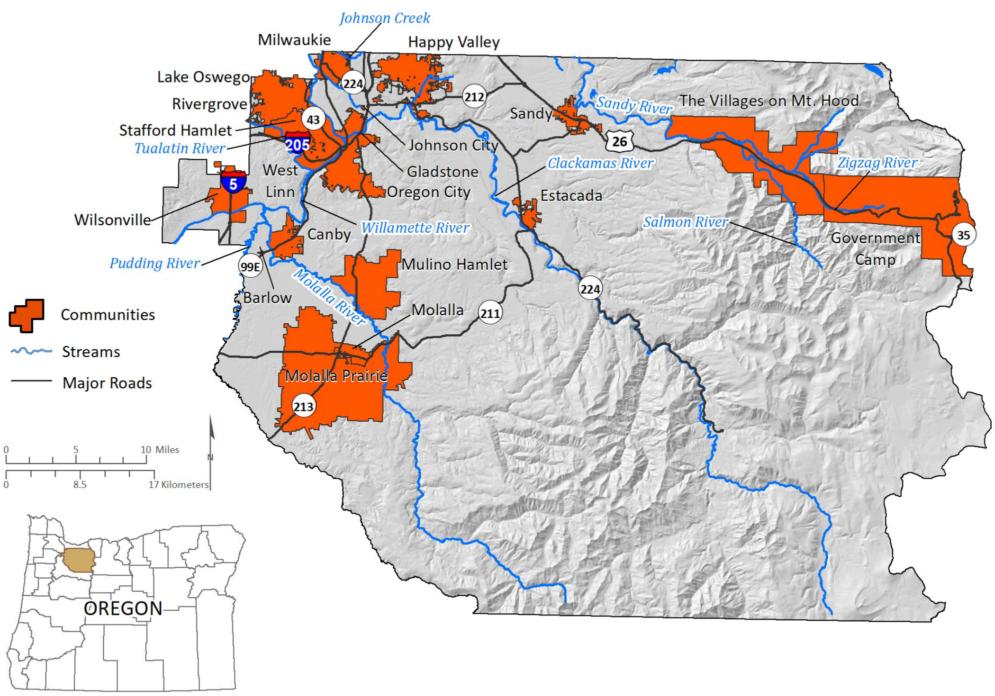
State of Oregon
Oregon Department of Geology and Mineral Industries
Ruarri J. Day-Stirrat, State Geologist

OPEN-FILE REPORT O-24-07

MULTI-HAZARD RISK REPORT FOR CLACKAMAS COUNTY, OREGON

INCLUDING THE CITIES OF BARLOW, CANBY, ESTACADA, GLADSTONE, HAPPY VALLEY, JOHNSON CITY, LAKE OSWEGO, MILWAUKIE, MOLALLA, OREGON CITY, RIVERGROVE, SANDY, WEST LINN, AND WILSONVILLE, AND THE UNINCORPORATED COMMUNITIES OF MOLALLA PRAIRIE, MULINO HAMLET, STAFFORD HAMLET, AND THE VILLAGES AT MOUNT HOOD



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2024

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Cover image: Study area of the Clackamas County Multi-Hazard Risk Report. Map depicts Clackamas County, Oregon and communities included in this report.

WHAT'S IN THIS REPORT?

This report describes the methods and results of a natural hazard risk assessment for communities in Clackamas County. The results quantify the impacts of natural hazards to each community and enhance the decision-making process in planning for disaster.

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See the digital publication folder for files.
Geodatabase is Esri® version 10.7 format. Metadata are embedded in the geodatabase and are also provided as separate .xml format files.

Clackamas_County_Risk_Report_Data.gdb

Feature dataset: Asset_Data

feature classes:

Building_footprints (polygons)
Communities (polygons)
UDF_points (points)

Raster data: Clackamas_County_Depth_Grids.gdb

FL_Depth_10 (GRID)
FL_Depth_50 (GRID)
FL_Depth_100 (GRID)
FL_Depth_500 (GRID)

Metadata in .xml file format:

Each dataset listed above has an associated, standalone .xml file containing metadata in the Federal Geographic Data Committee Content Standard for Digital Geospatial Metadata format.

EXECUTIVE SUMMARY

This report was prepared for communities in Clackamas County, Oregon, with funding provided by the University of Oregon's, Oregon Partnership for Disaster Resilience (OPDR). It describes the methods and results of a natural hazard risk assessment performed in 2023 by the Oregon Department of Geology and Mineral Industries (DOGAMI) within Clackamas County (herein referred to as the study area). The purpose of this project is to provide communities with a detailed assessment of the risks to people and the built environment that result from the natural hazards present in their community. This will enable them to better understand and compare hazards and act to reduce their risk. The risk assessment results quantify the consequences of natural hazards to each community and support the decision-making process in planning for disaster.

We arrived at our results and conclusions by completing three main tasks: compiling an asset database, identifying and using the best available hazard data, and performing a natural hazard risk assessment.

- In the first task, we created a comprehensive asset database for Clackamas County by synthesizing assessor data, Federal Emergency Management Agency (FEMA) Hazus®-MH general building stock information, and building footprint data. This work resulted in a single dataset of building points and their associated building characteristics (e.g., construction materials, number of floors, usage, etc.). Using these data, we were able to represent accurate spatial locations and vulnerabilities on a building-by-building basis.
- The second task was to identify and use the most current and appropriate hazard datasets for the study area. Most of the hazard datasets used in this report were created by DOGAMI and produced using peer-reviewed methods and with high-resolution, lidar topographic data. Although not all the data sources used in the report provide complete, countywide information, each hazard dataset used was the best available at the time of the analysis. Data sources and coverage are discussed in detail for each hazard in **Assessment Overview and Results.**
- In the third task, we analyzed risk using Esri® ArcGIS Desktop® software. We took two risk assessment approaches: (1) estimated loss (in dollars) to buildings from floods and earthquakes using the Hazus-MH methodology, and (2) calculated the number of buildings, their value, and associated populations exposed to earthquake, and flood scenarios, or susceptible to varying levels of hazard from landslides, channel migration, and wildfire. Details on recurrence intervals, susceptibility, hazard levels and other particulars are discussed in detail for each hazard in **Assessment Overview and Results.**

The findings and conclusions of this report show the wide range of potential impacts hazards could have on the communities of Clackamas County. A Mw 9.0 Cascadia Subduction Zone (CSZ) earthquake is expected to cause moderate to significant damage and losses throughout the county, with many of the critical facilities at High risk. A modeled Mw 6.8 earthquake on the Canby-Molalla Fault is expected to cause significant localized damages in the heavily populated areas in northwestern Clackamas County. We exhibit the potential for reduction in losses through simulating seismic retrofits of buildings using the Hazus-MH earthquake model. Roughly 40% to 60% of critical facilities are at risk from being nonfunctioning due to a CSZ or Canby-Molalla Fault earthquake. Flooding is identified as a very high-risk hazard for some communities in the county (e.g., Oregon City, Rivergrove, West Linn, and Mulino Hamlet) and we quantify the number of elevated structures in each community because they are more resilient to flood hazard. Our analysis shows that areas with moderate to steep slopes or at the base of steep slopes are at the greatest risk from landslide hazards, which are present in several communities (e.g., West Linn, Estacada, Oregon City, and the Villages at Mount Hood) and in rural parts of the county. More than 1,100 buildings along the Sandy River in the Village at Mount Hood were exposed to channel migration hazard. This is roughly 30% of the total community building stock. Wildfire exposure analysis shows a higher risk for buildings within the wildland-urban interface (WUI) and in the heavily forested areas in the eastern part of the county. More than 7% of the residents of Clackamas County are at risk from being displaced from either landslide or wildfire hazards. Volcanic lahar hazard could affect many buildings along the Sandy River in the Villages at Mount Hood. More than 70% of buildings in the Villages at Mount Hood are exposed to the Large lahar scenario.

Results were broken out for the following geographic areas:

- Unincorporated Clackamas County (rural)
- City of Canby
- City of Gladstone
- City of Johnson City
- City of Milwaukie
- City of Oregon City
- City of Sandy
- City of Wilsonville*
- Community of Molalla Prairie
- Community of Stafford Hamlet
- City of Barlow
- City of Estacada
- City of Happy Valley
- City of Lake Oswego*
- City of Molalla
- City of Rivergrove*
- City of West Linn
- Community of Government Camp
- Community of Mulino Hamlet
- Community of the Villages at Mt. Hood

*The portions of these cities that extend into adjacent counties are included in this report.

Selected countywide results Total buildings: 184,914 Total estimated building value: $79 billion	
Cascadia Subduction Zone Magnitude 9.0 Earthquake Scenario Red-tagged buildings[a]: 5,126 Yellow-tagged buildings[b]: 10,368 Loss estimate: $4.2 billion	**Canby-Molalla Fault Magnitude 6.8 Earthquake Scenario** Red-tagged buildings[a]: 6,392 Yellow-tagged buildings[b]: 14,917 Loss estimate: $9.3 billion
100-year Flood Scenario Number of buildings damaged: 1,452 Loss estimate: $222 million	**Landslide Exposure (High and Very High-Susceptibility)** Number of buildings exposed: 11,418 Exposed building value: $4.8 billion
Channel Migration Zone* (High Risk) Number of buildings exposed: 1,216 Exposed building value: $420 million	**Wildfire Exposure (High and Moderate Risk):** Number of buildings exposed: 15,461 Exposed building value: $4.8 billion
Volcanic Lahar Hazard (100-year Scenario):** Number of buildings exposed: 667 Exposed building value: $220 million	
[a]Red-tagged buildings are considered uninhabitable due to complete damage [b]Yellow-tagged buildings are considered limited habitability due to extensive damage *Results are limited to the study area of English and others (2013) and Abbe and others (2015), which covers the Sandy River. **Results are limited to the study area of Burns and others (2011), which covers the Sandy River watershed.	

The information presented in this report is designed to increase awareness of natural hazard risk, to support public outreach efforts, and to aid local decisionmakers in developing comprehensive plans and natural hazard mitigation plans. This study can help emergency managers identify vulnerable critical facilities and develop contingencies in their response plans. The results of this study are designed to be used to help communities identify and prioritize mitigation actions that will improve community resilience.

1.0 INTRODUCTION

A *natural hazard* is an environmental phenomenon that can have negative consequences for humans. Where natural hazards have the potential to damage assets or harm people, the result is natural hazard *risk*. A natural hazard risk assessment identifies the applicable hazards and analyzes their consequences on the built environment and population, including the cost of recovery. Risk assessments provide key foundational information that can be used to develop mitigation plans, strategies, and actions, so that steps can be taken to prepare for a potential hazard event.

Key Terms:

- *Vulnerability:* Characteristics that make people or assets more susceptible to a natural hazard.
- *Risk:* Likelihood of occurrence multiplied by consequence; the degree of probability that a loss or injury may occur as a result of a natural hazard.

This is a multi-hazard risk assessment analyzing the consequences to buildings and resident population in Clackamas County. It provides a detailed and comprehensive analysis of natural hazard risk and provides a comparative perspective not previously available. In this report, we describe our assessment results, which quantify the various levels of risk that each hazard presents to Clackamas County communities.

Clackamas County is located in the northwestern part of Oregon in the Willamette Valley. It is subject to a variety of natural hazards including: earthquakes, riverine flooding, landslides, channel migration, volcanic lahars, and wildfire. This region of Oregon ranges from sparsely to heavily developed, including dense urban areas transitioning to suburban development in unincorporated parts of the study. There are also large uninhabited areas where the county jurisdiction extends into the Cascade Range.

1.1 Purpose

The purpose of this project is to help communities in the study area better understand their natural hazards and risk, and increase resilience to earthquakes (including ground shaking, liquefaction and coseismic landslides), riverine flooding, landslides, channel migration, wildfire, and volcanic lahars. This is accomplished by using the best available, most accurate and detailed information about these hazards to assess the number of people and buildings at risk.

The main objectives of this study are to:

- compile a database of critical facilities, tax assessor data, buildings, and population distribution data,
- incorporate and use existing data from the most current geologic, hydrologic, and wildfire hazard studies,
- perform exposure and Hazus–based risk analyses, and
- share this report widely so that all interested parties have access to its information and data.

The body of this report describes our methods and results. Two primary methods (Hazus-MH loss estimation and exposure) were used to assess risk, depending on the type of hazard. These methods are described in the **Methods** section. Countywide results are reported for each hazard in **Community Risk Profiles**. Results for individual communities are detailed in **Appendix A: Community Risk Profiles**. **Appendix B** contains the detailed risk assessment tables used to generate the countywide results and community risk profiles. **Appendix C** provides additional explanation of the Hazus-MH methodology. **Appendix D** defines acronyms and other terms used in this report. **Appendix E** contains tabloid-size maps showing the spatial extent of the hazards, assets, and population across Clackamas County. These appendices can be helpful in clarifying the summarized results in each hazard section.

1.2 Study Area

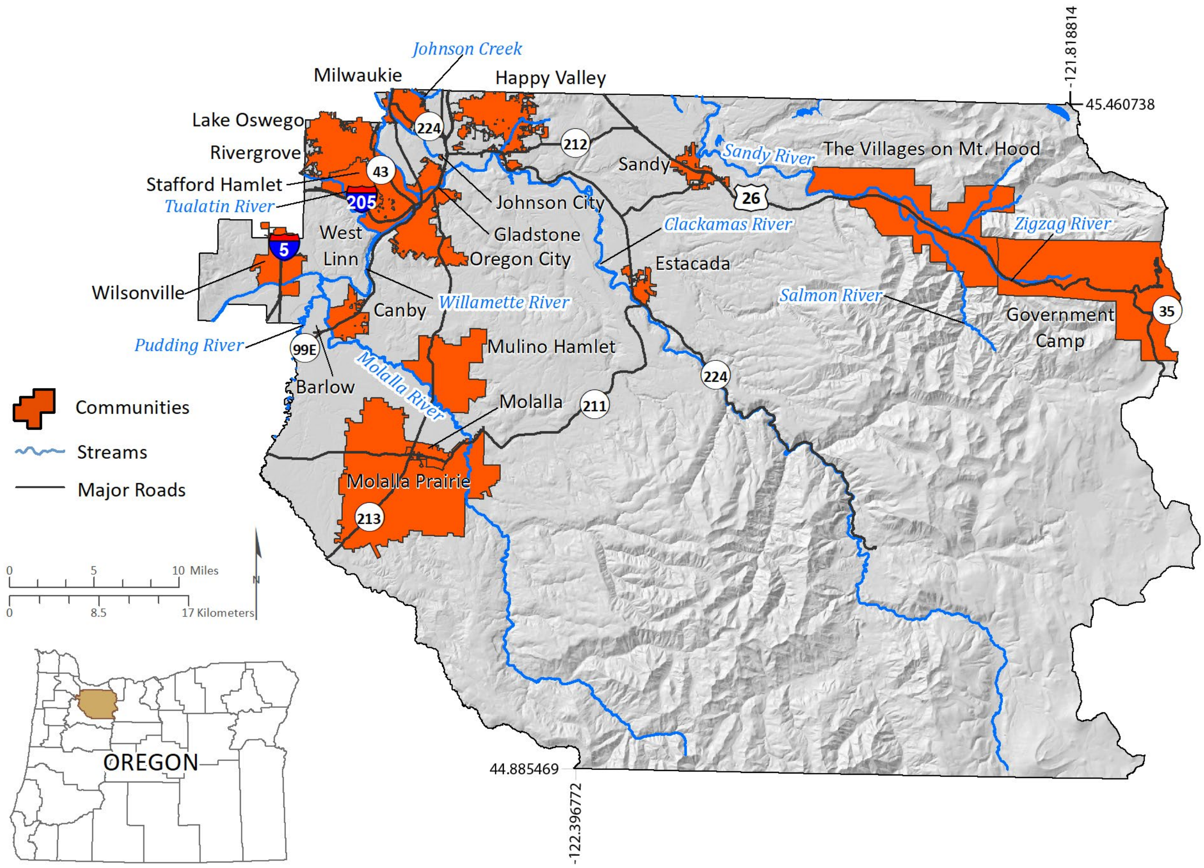
The study area for this project includes the entirety of Clackamas County, Oregon as well as portions of Lake Oswego, Rivergrove, and Wilsonville that are within Washington or Multnomah counties (**Figure 1-1**). Clackamas County is located in northwestern Oregon; the county is bordered by Multnomah County on the north, Hood River County and Wasco County on the east, Marion County on the south, and Yamhill County and Washington County on the west. The total area of Clackamas County is 1,882 mi^2 (4,875 km^2).

The geography of eastern Clackamas County consists of the heavily forested Cascade Range. Mount Hood, located at the eastern border of county with Hood River County, is the highest peak in Oregon at 11,249 ft (3,429 m). The Hood River National Forest makes up a significant portion of the county's eastern half. The western half of the county transitions from the heavily forested mountains to gently rolling farmland and then onto the heavily urbanized broad flat floor of the Willamette Valley.

Clackamas County is the third most populated county in Oregon, including approximately 430,000 people based on 2022 estimates from the Portland State University (PSU) Population Research Center.[1] Most residents reside in the northwestern part of the county. The City of Oregon City, which is the county seat, has a population of nearly 38,000. The City of Lake Oswego is the most populus in Clackamas County with a population of more than 38,000. Other incorporated communities of the study area are Barlow, Canby, Estacada, Gladstone, Happy Valley, Johnson City, Milwaukie, Molalla, Rivergrove, Sandy, West Linn, and Wilsonville (**Figure 1-1**). Portions of Portland and Tualatin that are within Clackamas County are included in this study and are aggregated into the unincorporated county jurisdiction. The unincorporated communities that were examined in this study were Molalla Prairie, Mulino Hamlet, Stafford Hamlet, and the Villages at Mount Hood.

[1] https://www.pdx.edu/population-research/population-estimate-reports

Figure 1-1. Study area: Clackamas County with communities in this study identified. Countywide results for each hazard are presented in Chapter 3.0. Individual community risk profiles are presented in Appendix A.



1.3 Project Scope

For this risk assessment, we limited the project scope to natural hazards affecting buildings and population because of data availability, the strengths and limitations of the risk assessment methodology, and funding availability. We did not directly analyze consequences to the local economy, community lifelines, stored hazardous materials, land values, socially vulnerable populations, infrastructure (e.g., transportation, power, water, gas, communication, and sewage), or the environment. Depending on the natural hazard, we used one of two methodologies: loss estimation or exposure. Loss estimation was modeled using Hazus®-MH (FEMA, 2012a, 2012b, 2012c), a tool developed by FEMA for calculating damage to buildings from flood and earthquake. Exposure is a simpler method, in which buildings are categorized based on their location relative to various hazard zones. City and county population numbers from the PSU Population Research Center data was used to distribute people into residential structures based on square footage (https://www.pdx.edu/population-research/population-estimate-reports).

A critical component of this risk assessment is a countywide building inventory developed from building footprint data and the Clackamas County tax assessor database (acquired 2022). The other key component is a suite of datasets that represent the currently best available science for a variety of natural hazards. The geologic hazard scenarios were selected by DOGAMI staff based on their expert knowledge of the datasets; most datasets are DOGAMI publications. In addition to geologic hazards, we included wildfire hazard in this risk assessment. The following is a list of hazards considered in this study and what risk assessment methodologies were applied. See **Table 1-1** for data sources.

Earthquake Risk Assessment

- Hazus-MH loss estimation from a CSZ earthquake magnitude (Mw) 9.0 scenario. Includes earthquake induced or "coseismic" liquefaction, soil amplification class, and landslides.
- Hazus-MH loss estimation from a Canby-Molalla Fault Mw 6.8 scenario. Includes coseismic liquefaction, soil amplification class, and landslides.

Flood Risk Assessment

- Hazus-MH loss estimation to four recurrence intervals (10%, 2%, 1%, and 0.2% annual chance)
- Exposure to 1% annual chance recurrence interval

Landslide Risk Assessment

- Exposure based on Landslide Susceptibility Index

Channel Migration Risk Assessment

- Exposure based on channel migration zone

Wildfire Risk Assessment

- Exposure based on Overall Wildfire Risk

Volcanic Lahar Risk Assessment

- Exposure based on S, M, L, XL Probability zones

Table 1-1. Hazard data sources for Clackamas County.

Hazard	Scenario or Classes	Spatial Extent	Data Source
Earthquake	CSZ Mw 9.0 Canby-Molalla Fault Mw 6.8	Regional Countywide	DOGAMI (Madin and others, 2021) USGS (Personius, 2002)
-Coseismic landslide	Susceptibility – wet (3-10 hazard classes)	Countywide	DOGAMI (Appleby and others, 2019)
-Coseismic liquefaction	Susceptibility (1-5 classes)	"	"
-Coseismic soil amplification class	National Earthquake Hazards Reduction Program (A-F classes)	"	"
Flood	Depth Grids: 10% (10-yr) 2% (50-yr) 1% (100-yr) 0.2% (500-yr)	Countywide	DOGAMI; derived from FEMA (2019) data included in GIS data for this report
Landslide	Susceptibility (Low, Moderate, High, Very High)	Statewide	DOGAMI (Burns and others, 2016)
Channel migration	Susceptibility (Not Exposed, Exposed)	portions of Sandy River within the study area	DOGAMI (English and others, 2013); Natural Systems Design (Abbe and others, 2015)
Wildfire	Overall Wildfire Risk (Low, Moderate, High)	Regional (Pacific Northwest, US)	ODF (Gilbertson-Day and others, 2018)
Lahar	Local source: S — 10% (10-yr) M — 1% (100-yr) L — 0.2–0.1% (500–1,000-yr) XL — 0.001% (100,000-yr)	Mount Hood	DOGAMI (Burns and others, 2011)

1.4 Previous Studies

One previous risk assessment was conducted that included the study area by DOGAMI. Wang (1998) used Hazus-MH to estimate the impacts from Mw 8.5 CSZ and 500-year probabilistic earthquake scenarios on the state of Oregon. The results of this study were arranged into individual counties. Clackamas County was estimated to have a 1.2% loss ratio in the Mw 8.5 CSZ scenario and approximately 8% in the 500-year probabilistic scenario. This study utilized a much lower level of detailed building information and site-specific earthquake hazard inputs; because of these differences, comparative analysis was not beneficial to the scope of this project.

DOGAMI Open-File Report O-11-16, Multi-Hazard and Risk Study for the Mount Hood Region, Multnomah, Clackamas, and Hood River counties, Oregon (Burns and others, 2011) is a study that examined the risk from volcano, landslide, flood, and earthquake to the communities on or near Mount Hood. The primary purpose of that study was to increase resilience for these communities from natural hazards. The report demonstrated how high-resolution lidar data is utilized to accurately map hazardous areas and identify assets (e.g., buildings and infrastructure).

DOGAMI Open-File Report O-13-08, Landslide Hazard and Risk Study of Northwestern Clackamas County, Oregon (Burns and others, 2013) was a study that examined the risk from landslide hazards for communities in the northwestern part of Clackamas County. The primary purpose of this study was to increase the understanding of landslide hazards in the area, so that steps to reduce risk could be taken. Using high-resolution lidar data, a landslide inventory database and landslide susceptibility maps were developed. Exposure analysis was performed to estimate the level of risk (i.e., interaction between assets and hazard) for the study area.

Bauer and others (2018) studied the impacts from a Mw 9.0 CSZ earthquake and a Portland Hills Fault Mw 6.8 earthquake for Clackamas, Multnomah, and Washington counties, within the Portland metropolitan area. The report discussed the findings from a Hazus-MH earthquake analysis using detailed building data and the best-available seismic and ground deformation information. These findings included scenarios of wet and dry landslide hazard, day and night casualties, and a seismic building code analysis. The report also discussed post-earthquake debris estimations and impacts to infrastructure.

Anthony and others (2020) conducted a multi-hazard risk assessment for the Lower Columbia-Sandy Watershed, which includes a portion of northeastern Clackamas County. Many of the methods, datasets, and report formatting, used here were derived from that report. Several of the hazard datasets (e.g., flood, landslide, channel migration zone (CMZ), and lahar) have not changed between Anthony and others (2020) and this report. New data, not available to Anthony and others (2020), such as building inventory, earthquake site-specific data (e.g., coseismic landslide, liquefaction, and National Earthquake Hazard Reduction Program (NEHRP)) and ground shaking and wildfire, are considered in this report. Significant differences that arose between Anthony and others (2020) and this report were due to the valuation of building stock applied. In Anthony and others (2020) the use of "real market value" was derived from the county assessor records versus estimated replacement costs based on square footage and building type in this report.

2.0 METHODS

Where natural hazards have the potential to damage assets or harm people, the result is natural hazard *risk*. We used a quantitative approach through two modes of analysis, Hazus-MH loss estimation and exposure, to assess the level of risk to assets and people from natural hazards.

2.1 Hazus-MH Loss Estimation

We used Hazus-MH version 5.0 (FEMA, 2021), which was the version available when we began this risk assessment study in 2022. According to FEMA (FEMA, 2012a, p. 1-1), "Hazus provides nationally applicable, standardized methodologies for estimating potential wind, flood, and earthquake losses on a regional basis. Hazus can be used to conduct loss estimation for floods and earthquakes [...]. The multi-hazard Hazus is intended for use by local, state, and regional officials and consultants to assist mitigation planning and emergency response and recovery preparedness. For some hazards, Hazus can also be used to prepare real-time estimates of damages during or following a disaster."

Key Terms:

- *Loss estimation:* Damage in terms of value that occurs to a building in an earthquake or flood scenario, as modeled with Hazus-MH methodology. This is measured as the cost to repair or replace the damaged building in US dollars.
- *Loss ratio:* Percentage of estimated loss relative to the total value.

Hazus-MH can be used in different modes depending on the level of detail required. Given the high spatial precision of the building inventory data and quality of the natural hazard data available for this study, we chose the user-defined facility (UDF) mode. This mode makes loss estimations for individual buildings relative to their "cost," which we then aggregate to the community level to report loss ratios. Costs used in this mode are associated with rebuilding using new materials, also known as replacement cost. Replacement cost is determined using a method called RSMeans valuation (Charest, 2017) and is calculated by multiplying the building area (in square feet) by a standard cost per square foot. These standard rates per square foot are in tables within the default Hazus-MH database.

Damage functions are at the core of Hazus-MH. The damage functions stored within the Hazus-MH data model were developed and calibrated from the observed results of past disasters. We estimated damage and loss by intersecting building locations with natural hazard layers and applying damage functions based on the hazard severity (e.g., depth of flooding) and building characteristics (e.g., first floor height). **Figure 2-1** illustrates the range of building loss estimates from a Hazus-MH flood analysis. In this example, most buildings within the 100-year flood zone are estimated to experience losses ranging from >0 to >15%. Buildings with a first-floor height above the level of flooding and those outside the flood zone are expected to experience no losses.

Figure 2-1. 100-year flood zone and building loss estimates example in the City of Gladstone, Oregon.

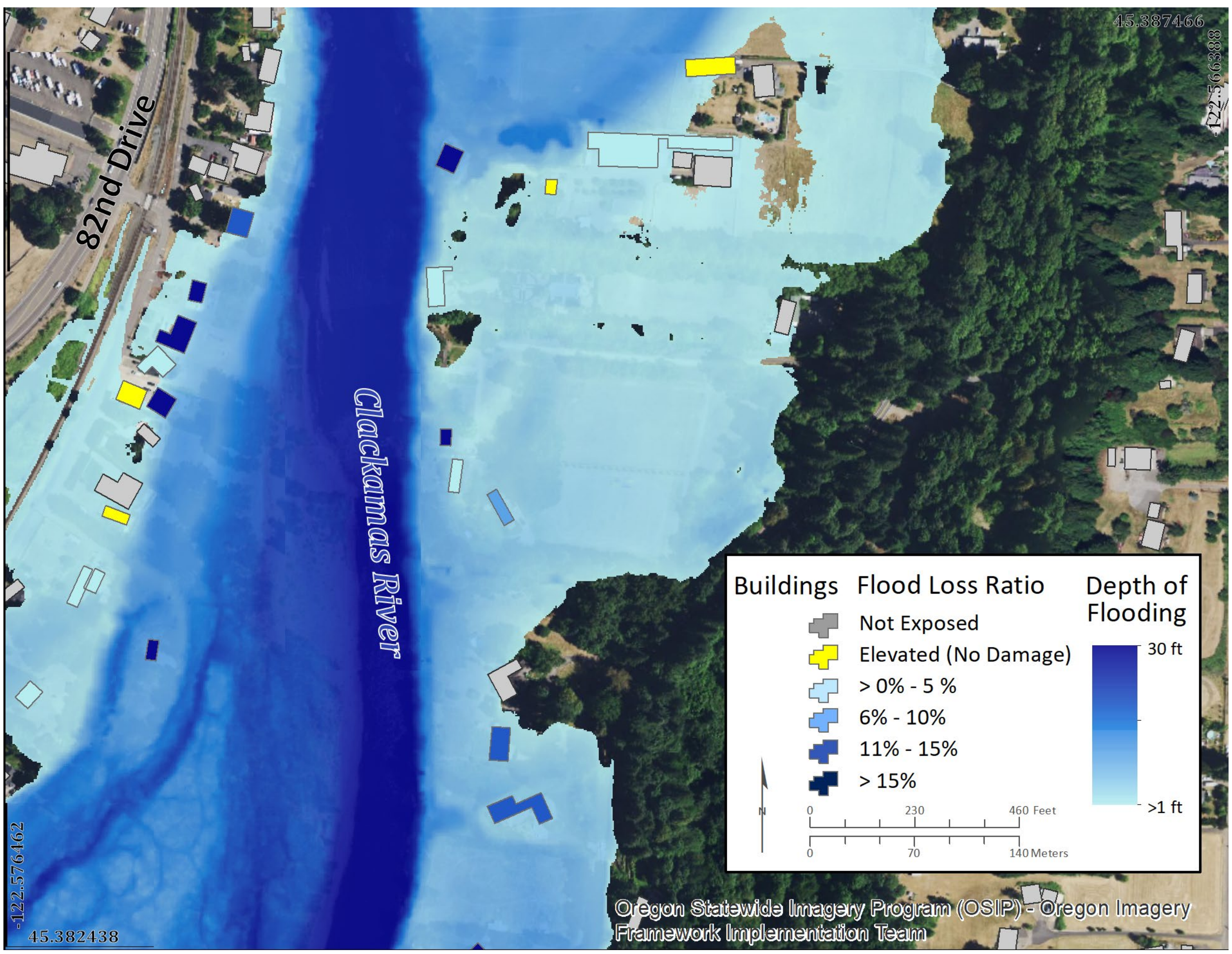


Image source: Oregon Statewide Imagery Program, 2018

Depth grid: Derived from the effective FEMA Flood Insurance Rate Map data for Clackamas County, 2019

2.2 Exposure

> **Key Terms:**
> - *Exposure:* Determination of whether a building is within or outside of a hazard zone. No loss estimation is modeled.
> - *Building value:* Total monetary value of a building. This term is used in the context of exposure.

Since loss estimation using Hazus-MH is not available for all types of natural hazards, we used exposure analysis to assess landslide, channel migration, and wildfire risk. Exposure methodology identifies the buildings and population that are within a particular natural hazard zone. This is an alternative to the more detailed loss estimation method for those natural hazards that do not have available damage models like in Hazus. It provides a way to easily quantify what is and is not threatened. Exposure results are communicated in terms of total building value exposed, rather than a loss estimate. For example, **Figure 2-2** shows buildings that are exposed to different levels of landslide susceptibility with building footprints colored based on what susceptibility zone the center of the building is within.

Exposure is used for landslide, wildfire, and channel migration hazards. For comparison with loss estimates, exposure is also used for the 1% annual chance flood (100-year flood).

Figure 2-2. Landslide susceptibility and building exposure example in Oregon City, Oregon.

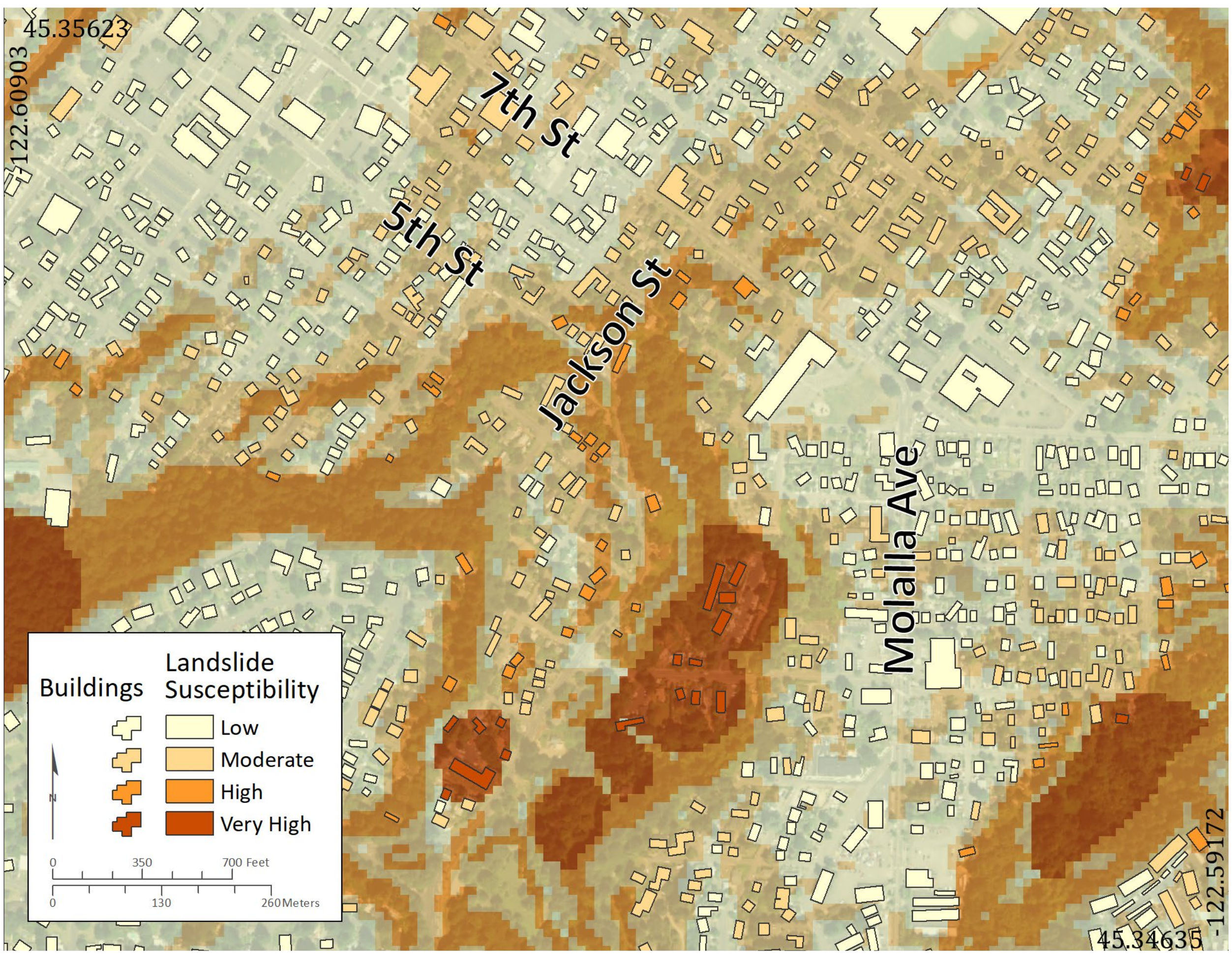


Image source: Oregon Statewide Imagery Program, 2018

Landslide data source: Landslide susceptibility overview map of Oregon, (Burns and others, 2016)

2.3 Building Inventory

A key piece of the risk assessment is the countywide building inventory. This inventory consists of all buildings larger than 100 ft^2 (9.3 m^2), as determined from existing building footprints (Williams, 2021). **Figure 2-3** shows an example of building inventory occupancy types used in the Hazus-MH and exposure analyses in Clackamas County. See also **Appendix B: Table B-1** and **Appendix E: Plate 1.**

To use the building inventory within Hazus-MH, we converted the building footprint polygons to points and migrated them into a UDF database with standardized field names and attribute domains. The UDF database formatting allows for the correct damage function to be applied to each building. Hazus-MH version 2.1 technical manuals (FEMA, 2012a, 2012b, 2012c) provide references for acceptable field names, field types, and attributes. The fields and attributes used in the UDF database (including building seismic codes) are discussed in more detail in **Appendix C.2.2**.

Figure 2-3. **Building occupancy types in the city of Molalla, Oregon.**

The number of buildings and total building value per community varies significantly in Clackamas County, with 60 buildings and $19 million for Barlow to 13,854 buildings and $8.5 billion for Lake Oswego (**Table 2-1**). A table detailing the occupancy class distribution by community is included in **Appendix B: Detailed Risk Assessment Tables**.

Table 2-1. Clackamas County building inventory.

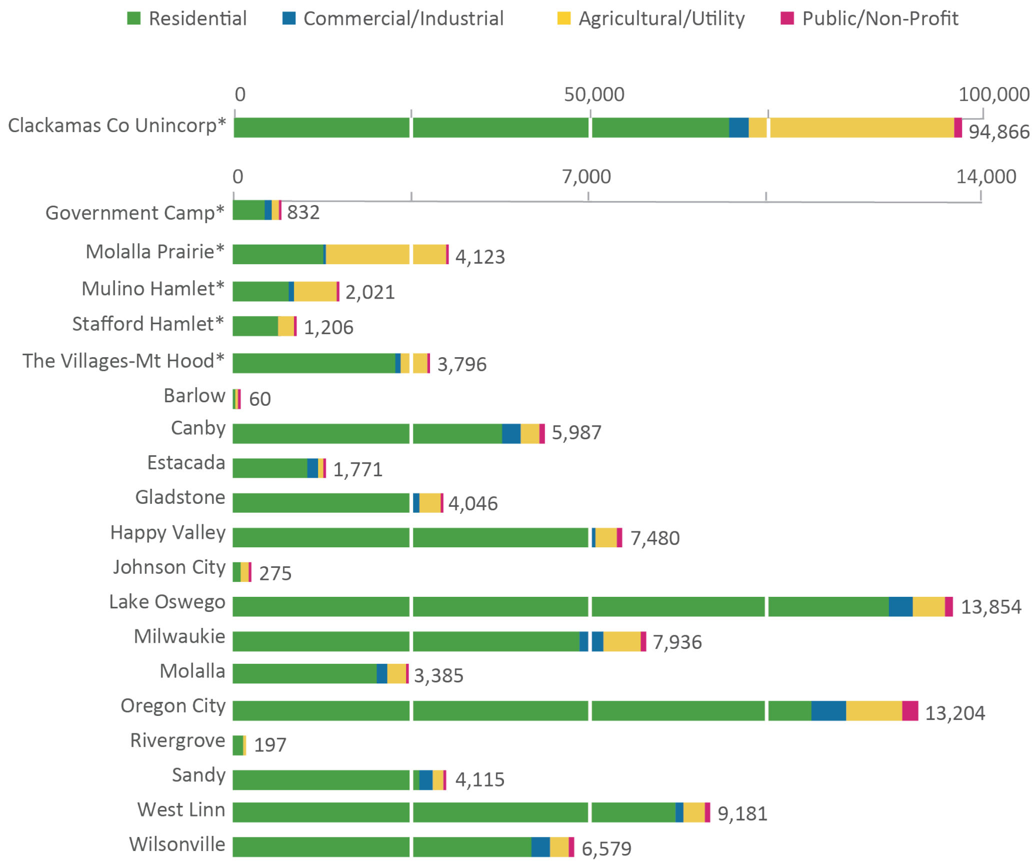
Community	Total Number of Buildings	Percentage of Total Buildings	Estimated Total Building Value ($)	Percentage of Total Building Value
Unincorp. Clackamas Co (rural)	94,866	52%	36,218,454,000	46%
Government Camp	832	0.4%	289,100,000	0.4%
Molalla Prairie	4,123	2.2%	1,313,253,000	1.7%
Mulino Hamlet	2,021	1.1%	584,353,000	0.7%
Stafford Hamlet	1,206	0.7%	564,063,000	0.7%
The Villages at Mt Hood	3,796	2.1%	1,297,133,000	1.6%
Total Unincorporated County	106,844	58%	40,266,356,000	51%
Barlow	60	0.0%	18,955,000	0.0%
Canby	5,987	3.2%	2,606,675,000	3.3%
Estacada	1,771	1.0%	671,792,000	0.8%
Gladstone	4,046	2.2%	1,447,740,000	1.8%
Happy Valley	7,480	4.0%	3,898,036,000	4.9%
Johnson City	275	0.1%	20,082,000	0.0%
Lake Oswego	13,854	7.5%	8,534,213,000	11%
Milwaukie	7,936	4.3%	3,656,357,000	4.6%
Molalla	3,385	1.8%	1,031,711,000	1.3%
Oregon City	13,204	7.1%	5,307,089,000	6.7%
Rivergrove	197	0.1%	95,954,000	0.1%
Sandy	4,115	2.2%	1,472,547,000	1.9%
West Linn	9,181	5.0%	4,479,107,000	5.7%
Wilsonville	6,579	3.6%	5,545,876,000	7.0%
Total Study Area	184,914	100%	79,052,489,000	100%

The building inventory was developed from a statewide building footprints dataset developed in 2021 called the Statewide Building Footprints for Oregon, release 1 (SBFO-1) (Williams, 2021). The SBFO-1 data of Clackamas County was modified from a building footprints dataset maintained by Metro Regional Land Information System[2]. The building footprints provide a spatial location and 2D representation of a structure. The total number of buildings within the study area was 184,914. We define buildings to be permanent structures with walls and a roof that can be occupied by people (Williams, 2021). Other structures, such as dams, water tanks/towers, sewage and water treatment tanks, tents, small garden sheds, hoop-houses or other plastic-covered greenhouses, and grain silos, were not considered buildings and were not included in this analysis.

The Clackamas County assessor data that was incorporated into building footprints was first developed for a report by Bauer and others (2018) to examine the impacts of earthquake hazard in Clackamas, Multnomah, and Washington counties. The assessor data contains an array of information about each improvement (e.g., building). We added and attributed additional buildings from current aerial imagery that were not included in the 2018 report. The building footprints were converted into points and were used in the risk assessment for both loss estimation and analyses. Lake Oswego and Oregon City are the communities with the highest total number of buildings and residential use is the most common countywide (**Figure 2-4**).

[2] http://rlisdiscovery.oregonmetro.gov/, downloaded June 2022

Figure 2-4. Community building value in Clackamas County by occupancy class.



**Unincorporated*

Some buildings are defined as critical facilities because they function in support of public safety, disaster recovery, relief efforts, and other emergency operations before, during, and after a natural disaster. Typical critical facilities include hospitals, schools, fire stations, police stations, emergency operations, and military facilities. Other critical infrastructure considered in this study include public works and water treatment facilities. We embedded identifying characteristics into the critical facilities in the UDF database so they could be highlighted in the results. Critical facilities data came from the DOGAMI Statewide Seismic Needs Assessment (SSNA; Lewis, 2007). We updated the SSNA data by reviewing Google Maps™. Communities that have critical facilities that can function during and immediately after a natural disaster are more resilient than those with critical facilities that are inoperable after a disaster. Critical facilities are present throughout the county with most in Lake Oswego and Oregon City (**Table 2-2**). Critical facilities are listed for each community in **Appendix A**.

Table 2-2. Clackamas County critical facilities inventory.

	Hospital & Clinic		School		Police/Fire		Emergency Services		Military		Other*		Total	
Community	Count	Value ($)	Count	Value ($)	Count	Value ($)	Count	Value ($)	Count	Value ($)	Count	Value ($)	Count	Value ($)
	(all dollar amounts in thousands)													
Unincorp. Clackamas Co (rural)	3	483,446	60	689,534	22	61,085	0	0	0	0	13	29,661	98	1,263,726
Government Camp	0	0	1	1,172	0	0	0	0	0	0	1	1,076	2	2,248
Molalla Prairie	0	0	3	14,804	0	0	0	0	0	0	0	0	3	14,804
Mulino Hamlet	0	0	1	5,213	1	1,046	0	0	0	0	0	0	2	6,259
Stafford Hamlet	0	0	3	47,388	0	0	0	0	0	0	0	0	3	47,388
The Villages at Mt Hood	0	0	2	13,503	3	3,727	0	0	0	0	1	942	6	18,172
Total Unincorp. County	3	483,446	70	771,614	26	65,859	0	0	0	0	15	31,679	114	1,352,597
Barlow	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Canby	2	4,448	7	194,406	2	18,334	0	0	0	0	2	7,248	13	224,435
Estacada	0	0	4	72,710	3	4,843	0	0	0	0	2	1,476	9	79,030
Gladstone	0	0	5	78,003	2	3,342	1	787	0	0	1	1,531	9	83,664
Happy Valley	1	2,627	10	146,341	6	10,079	1	5,327	0	0	0	0	18	164,374
Johnson City	0	0	0	0	0	0	1	170	0	0	0	0	1	170
Lake Oswego	2	14,273	25	319,198	5	11,098	0	0	1	2,732	2	1,851	35	349,152
Milwaukie	1	45,884	12	154,556	1	9,378	0	0	0	0	2	4,661	16	214,480
Molalla	1	2,001	4	70,618	2	3,972	0	0	0	0	2	2,654	9	79,245
Oregon City	3	73,928	16	315,563	8	22,422	0	0	1	1,126	3	32,432	31	445,472
Rivergrove	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sandy	1	1,477	3	144,080	3	6,889	0	0	0	0	0	0	7	152,446
West Linn	1	8,583	12	164,489	3	7,232	0	0	0	0	2	2,504	18	182,808
Wilsonville	1	2,354	8	140,836	2	7,077	1	4,707	0	0	2	2,982	14	157,956
Total Study Area	16	639,021	176	2,572,413	63	170,525	4	10,992	2	3,858	33	89,018	294	3,485,827

Note: Facilities with multiple buildings were consolidated into one building.

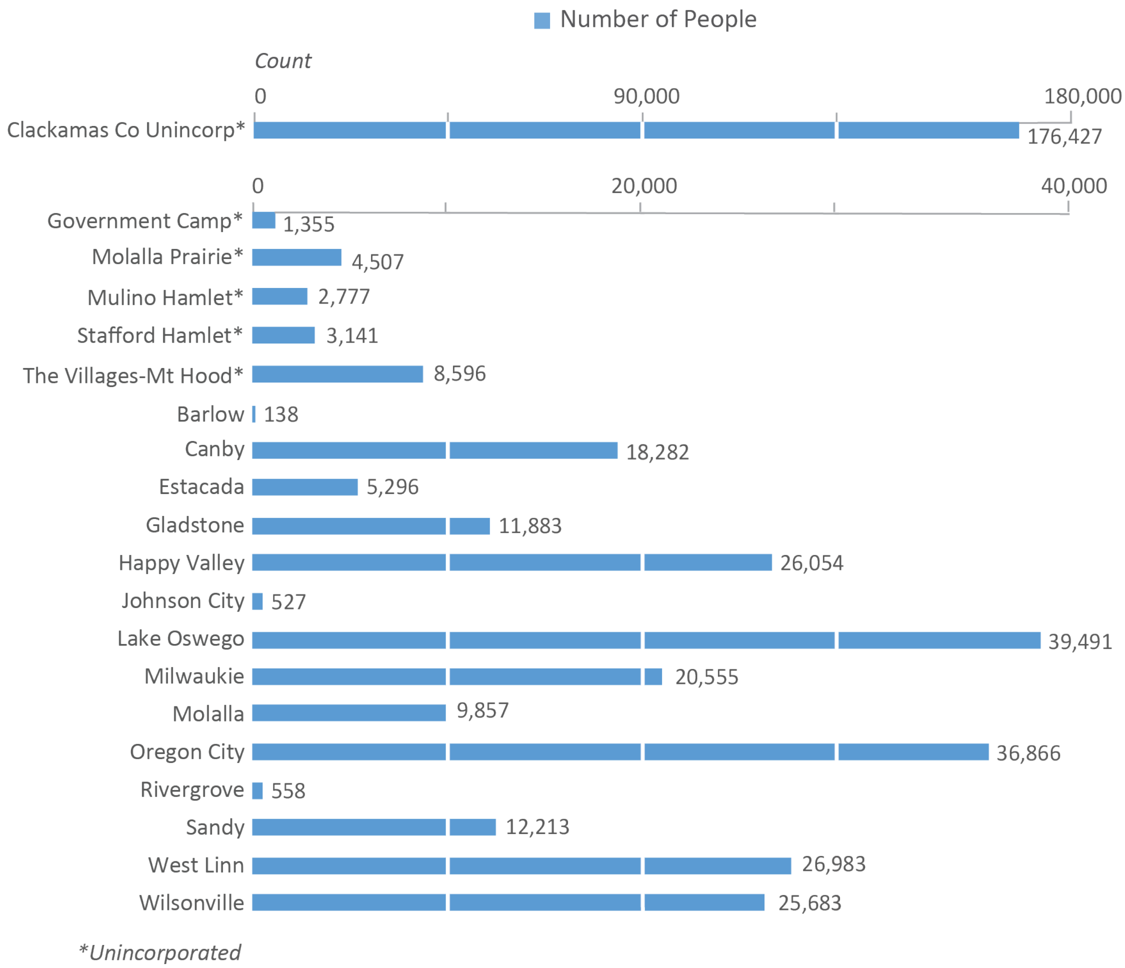
* Category includes buildings that are not traditional (emergency response) critical facilities but considered critical during an emergency based on input from local stakeholders (e.g., water treatment facilities or airports).

2.4 Population

One purpose of the UDF database design was so that we could estimate the number of people at risk from natural hazards. Within the UDF database, the PSU Population Research Center estimates of permanent residents were distributed proportionally among residential buildings based on building area. Estimates for every incorporated community, as well as the entire county, were available from the PSU data (**Figure 2-5**). We did not examine the impacts of natural hazards on non-permanent populations (e.g., tourists), whose total numbers fluctuate seasonally. Due to lack of information within the assessor database, we cannot distinguish between vacation homes and primary residences. Therefore, our method distributes some of the permanent residents into possible vacation homes.

From the PSU Population Research Center data, we assessed the risk of the 431,190 residents within the study area that could be affected by a natural hazard scenario. For each natural hazard, with the exception of the earthquake scenario, a simple exposure analysis was used to find the number of potentially displaced residents within a hazard zone. For the earthquake scenario the number of potentially displaced residents was based on residents in buildings estimated to be significantly damaged by the earthquake.

Figure 2-5. Population by Clackamas County community.



3.0 ASSESSMENT OVERVIEW AND RESULTS

In this risk assessment, we considered six natural hazards (earthquake, flood, landslide, channel migration, volcanic lahar, and wildfire) that pose a risk to Clackamas County. The assessment describes both localized vulnerabilities and the widespread challenges that affect all communities. While results of this risk assessment do not typically represent singular hazard events, they do quantify the potential overall level of risk present for assets and residents. The loss estimation and exposure results, as well as the rich datasets included with this report, can lead to greater understanding of the potential consequences of natural disasters. Communities can become more resilient to future disasters by utilizing the results in natural hazard mitigation plan (NHMP) updates and developing future action items for risk reduction.

In this section, results are presented for the entire study area. The study area includes all unincorporated areas and cities within Clackamas County. Individual community results are in **Appendix A: Community Risk Profiles.**

3.1 Earthquake

An earthquake is a sudden movement of rock along a fault in the earth's crust, which abruptly releases strain that has accumulated over time. This movement produces waves of shaking that spread in all directions. If an earthquake occurs near populated areas, it may cause casualties, economic disruption, and extensive property damage (Madin and Burns, 2013).

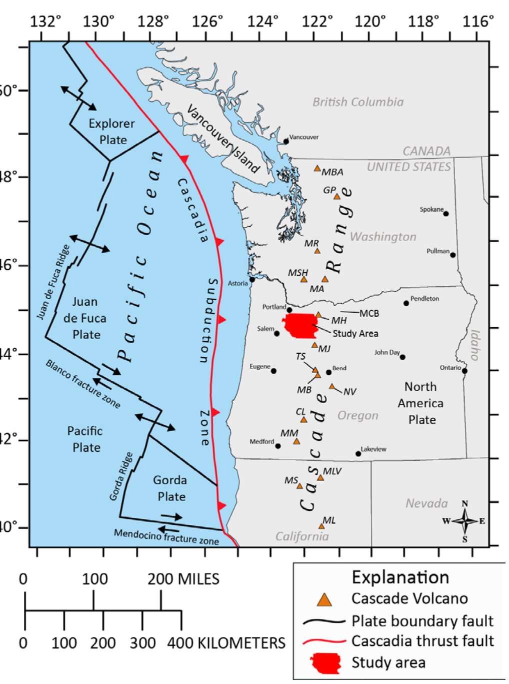
Two earthquake-induced hazards are liquefaction and landslides. Liquefaction occurs when saturated soils substantially lose bearing capacity due to ground shaking, causing the soil to behave like a liquid; this action can be a source of tremendous damage (Kramer, 1996). Coseismic landslides are mass movement of rock, debris, or soil induced by ground shaking. Both of these hazards are site specific and will only occur in locations where conditions permit. All earthquake losses in this report include damages derived from shaking as well as liquefaction and landslide factors.

Northwest Oregon is a seismically active area, with a history of several damaging earthquakes. For example, the Mount Angel Fault is an active fault located near the cities of Mount Angel, Woodburn, and Silverton. On March 25, 1993, a Mw 5.7 earthquake occurred with an epicenter approximately 3 mi (35 km) east of the City of Scotts Mills, Oregon. Many buildings were damaged from the event, including the Capitol building in Salem. Many unreinforced masonry buildings in the area were significantly damaged due to intense shaking. The preliminary damage estimate was $28.4 million ($50 million in 2022) (Black, 1996).

3.1.1 Scenarios: CSZ and Canby-Molalla Fault

Just off Oregon's coast, the Juan de Fuca tectonic plate slides under the North America Plate. Oregon (along with the rest of the Pacific Northwest and the nation) sits on the North America Plate. This area of interaction between the two plates is known as the CSZ. The pressure and friction created by this convergent motion builds potential energy at the plate boundary until the overriding plate (North America) suddenly slips, releasing energy that manifests as strong shaking spread over a wide area (**Figure 3-1**). Earthquakes as large as Mw 8 to Mw 9 occur along the CSZ on average every 230-540 years and scientists estimate a 16%-22% chance of one happening in the next 50 years (Goldfinger and others, 2012, 2017).

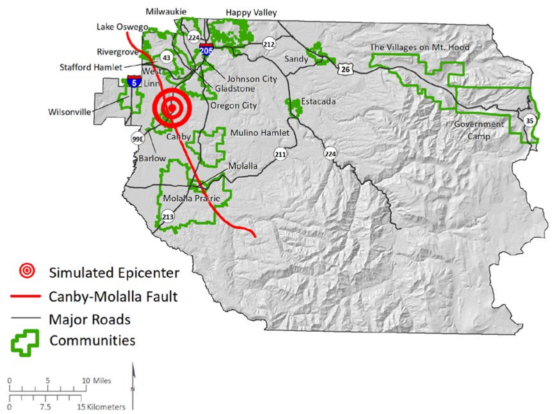
Figure 3-1. CSZ-plate interaction.



Unlike the CSZ, which is a tectonic plate boundary system and a source of very large earthquakes, crustal faults are the result of planar fractures within a single tectonic plate (i.e. intraplate). When blocks of crustal rock are displaced relative to one another, the released energy manifests as shaking spread over an area proportional to the earthquake rupture. Despite their comparatively small size, crustal earthquakes can cause significant damage due to their proximity to the surface and the built environment.

The other earthquake scenario examined for this report is the Canby-Molalla Fault (Personius, 2002), located in the western part of Clackamas County (**Figure 3-2**). While there are several identified active earthquake faults in the area, the Canby-Molalla Fault was selected for this risk assessment because other active faults were examined in recent studies (e.g., Portland Hills Fault in Bauer and others (2018)), the fault shows recent activity (i.e., late Quaternary), and its location is moderately constrained (Personius, 2002 and references cited therein). This is a Quaternary fault, mapped for 31 mi (50 km), estimated to slip less than 0.008 in/yr (0.2mm/yr) (Personius, 2002 and references cited therein). The estimated maximum fault displacement for the Canby-Molalla Fault could produce relatively large (Mw 6.8) earthquakes, enough to pose a significant hazard (Personius, 2002 and references cited therein). Although the damage produced from this fault would be far more localized than a CSZ event, it poses a serious seismic threat to the communities in the vicinity of the northwestern portion of Clackamas County.

Figure 3-2. Canby-Molalla fault location



The Hazus-MH earthquake analyses for this study indicate that the damages from the CSZ were consistent and widespread across the entire county, while damages from the Candy-Molalla Fault were concentrated and more severe in northwest Clackamas County. Earthquake shaking and ground failure (coseismic liquefaction and landslides) hazards were considered in both earthquake scenarios. The effects from either earthquake scenario present a challenge for planners preparing for hazard impacts.

3.1.2 Data sources: CSZ

Most of the earthquake hazard data used in our analysis come from the Oregon Seismic Hazard Database, release 1.0 (OSHD-1), which includes ground shaking (Madin and others, 2021) and site-specific earthquake data (Appleby and others, 2019) for a CSZ Mw 9.0 event. In recently published work, the USGS (Wirth and others, 2021) ran 30 CSZ Mw 9.0 simulations that represented the variability of shaking that Madin and others (2021) used to develop the ground shaking datasets in the OSHD-1.

Hazus-MH offers two scenario methods for estimating loss from earthquake: probabilistic and deterministic (FEMA, 2012b). A probabilistic scenario uses U.S. Geological Survey (USGS) National Seismic Hazard Maps, which are derived from seismic hazard curves calculated on a grid of sites across the United States that describe the annual frequency of exceeding a set of ground motions as a result of all possible earthquake sources (USGS, 2019). A deterministic scenario is based on a specific seismic event, which in this case is a CSZ Mw 9.0 event. We selected the deterministic scenario method because the CSZ event is the most likely large earthquake to impact this area (Goldfinger and others, 2012, 2017). We used the deterministic method along with the UDF database so that loss estimates could be calculated on a building-by-building basis.

The following hazard layers used for the loss estimation analysis come from OSHD-1: NEHRP soil classification, peak ground acceleration (PGA), peak ground velocity (PGV), spectral acceleration at 1.0 second period and 0.3 second period (SA10 and SA03), and liquefaction and landslide susceptibility. The liquefaction and landslide susceptibility layers together with PGA were used by the Hazus-MH tool to calculate probability and magnitude of permanent ground deformation.

3.1.3 Countywide results: CSZ

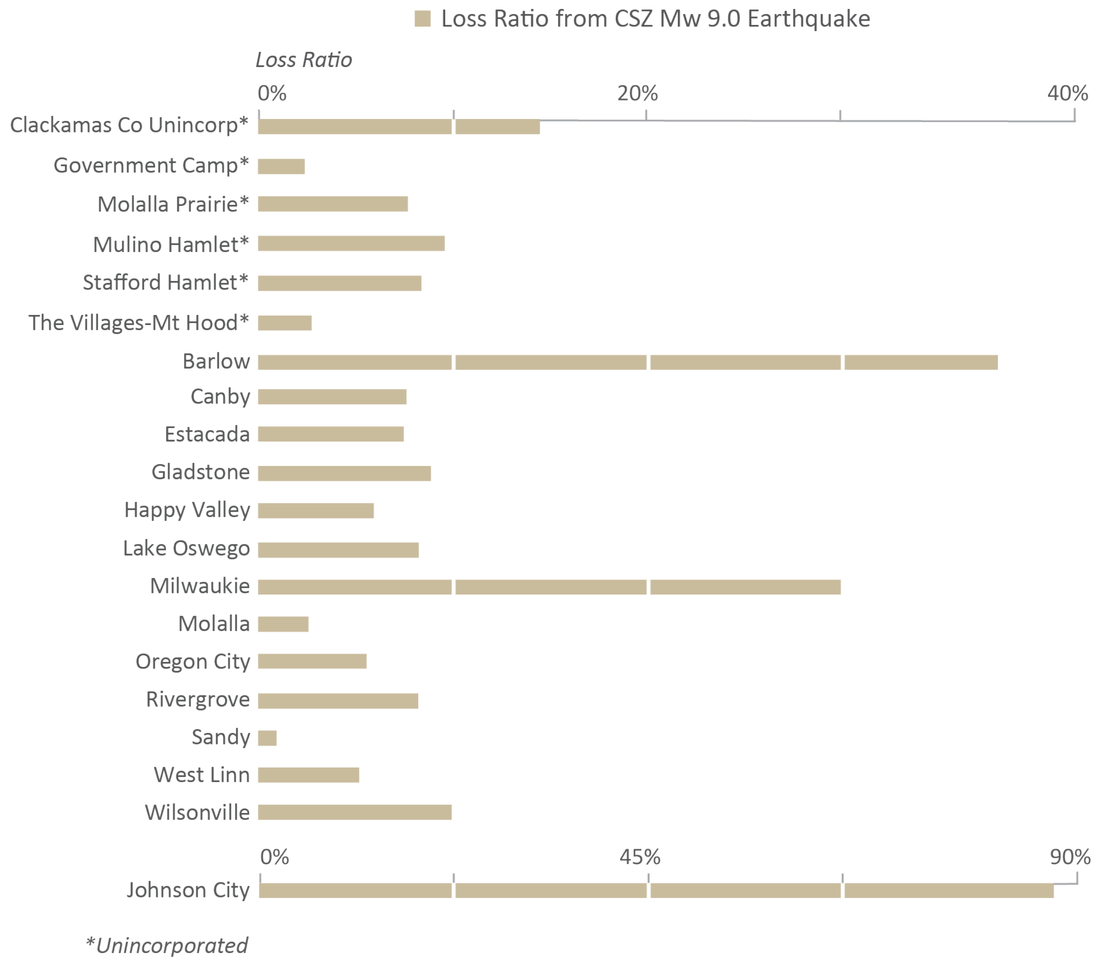
Because an earthquake can affect a wide area, every building in Clackamas County will be shaken by a CSZ Mw 9.0 earthquake. Hazus-MH loss estimates (see **Table B-2**) for each building are based on a formula where coefficients are multiplied by each of the five damage-state percentages (e.g., none, low, moderate, extensive, and complete). These damage states are correlated to loss ratios that are then multiplied by the total building replacement value to obtain a loss estimate (FEMA, 2012b). Loss ratio estimates from a CSZ earthquake scenario are presented in **Figure 3-3**.

In keeping with earthquake-damage reporting conventions, we used the Applied Technology Council (ATC)-20 post-earthquake building safety evaluation color-tagging system to represent damage states (Applied Technology Council, 2015). Red-tagged buildings correspond to a Hazus-MH damage state of “complete,” which means the building is uninhabitable. Yellow-tagged buildings are in the “extensive” damage state, indicating limited habitability. The number of red- or yellow-tagged buildings we report for each community is based on an aggregation of the probabilities for individual buildings (FEMA, 2012b).

Critical facilities were considered nonfunctioning if the Hazus-MH earthquake analysis showed that a building, or complex of buildings, had a greater than 50% chance of being at least moderately damaged (FEMA, 2012b). Because building-specific information is more readily available for critical facilities and also due to their importance after a disaster, we chose to report the results of these buildings individually.

The number of potentially displaced residents from our CSZ earthquake scenario was based on the formula (FEMA, 2012b): ([Number of Occupants] * [Probability of Complete Damage]) + (0.9 * [Number of Occupants] * [Probability of Extensive Damage]).

Figure 3-3. CSZ Mw 9.0 earthquake loss ratio by Clackamas County community.



The results indicate that Clackamas County could incur moderate to significant losses (11%) due to a CSZ Mw 9.0 earthquake. Most of the communities in Clackamas County can expect approximately 7% to 10% damage from a CSZ event. Much of the damage is due to soils that amplify seismic shaking. The floodplains of the many large rivers in the study area are composed of seismically reactive soils where the majority of the buildings in Clackamas County are located. Since these soils amplify ground shaking, the probability of earthquake damage is greater for structures built in these areas. The communities of Barlow and Milwaukie have very high estimated loss ratios due to the prevalence of this soil type.

Clackamas County CSZ Mw 9.0 earthquake results:

- Number of red-tagged buildings: 10,368
- Number of yellow-tagged buildings: 5,216
- Loss estimate: $8,975,495,000
- Loss ratio: 11%
- Nonfunctioning critical facilities: 178 of 294
- Potentially displaced population: 11,304

Although damage caused by coseismic landslides was not specifically looked at in this report, it likely contributes to the estimated damage from the earthquake hazard in Clackamas County. Landslide exposure in susceptibility zones show that 6% of buildings in Clackamas County are within a very high or high-susceptibility zone. We infer that a similar percentage of the total earthquake losses estimated in this study may be due to coseismic landslide.

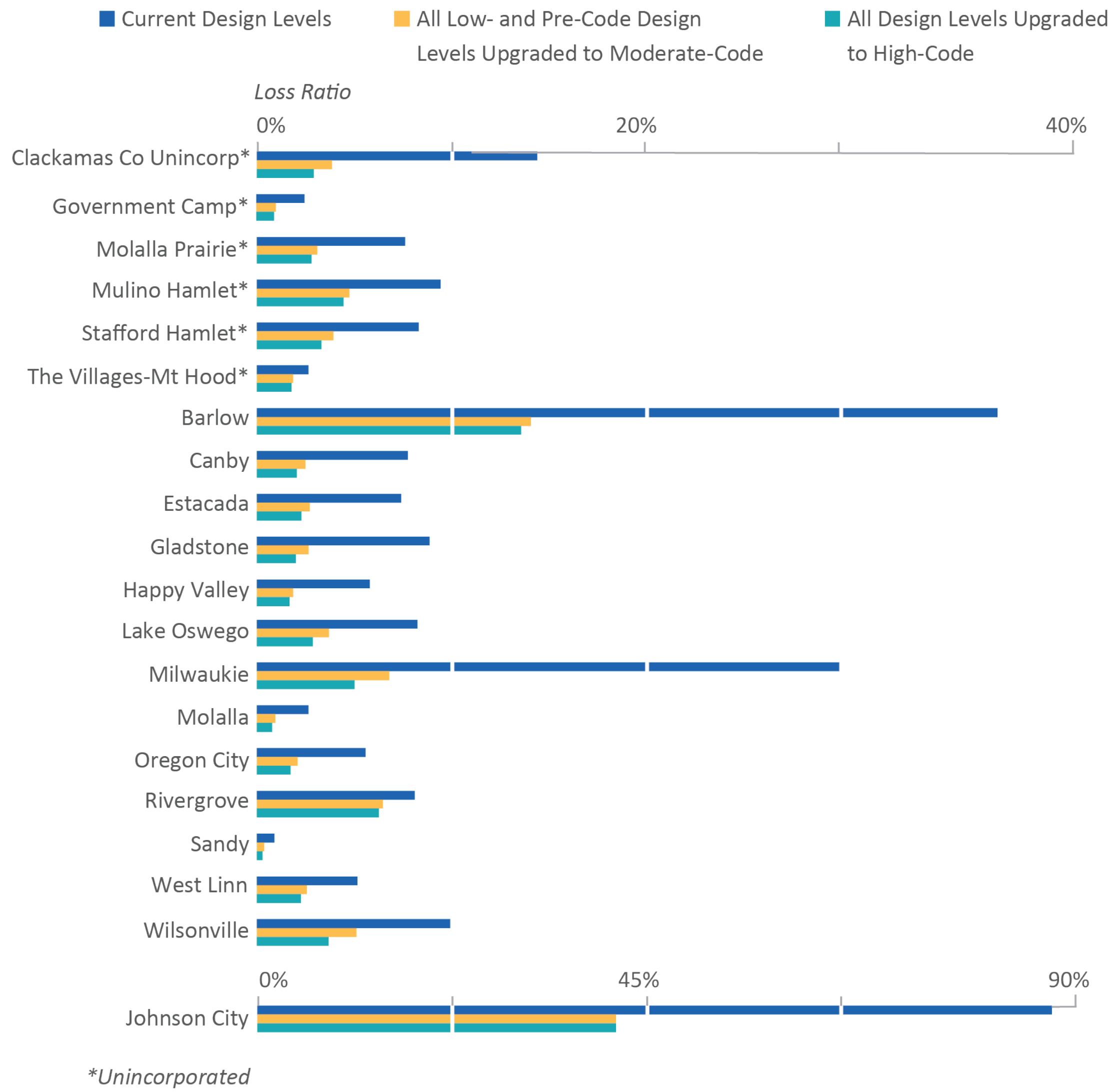
Building vulnerabilities, such as the age of the building stock and occupancy type, are also contributing factors in loss estimates. The first seismic building codes were implemented in Oregon in the 1970s (Judson, 2012) and by the 1990s, modern seismic building codes were being enforced. More than 70% of Clackamas County's buildings were built before the 1990s. In Hazus-MH, manufactured homes are one occupancy type that performs poorly in earthquake damage modeling. Communities that are composed of an older building stock and more vulnerable occupancy types are expected to experience more damage from earthquake than communities with fewer of these vulnerabilities. The very small community of Johnson City is nearly completely composed of manufactured housing, which is highly susceptible to earthquake shaking.

If pre- and low-code buildings could be seismically retrofitted to higher code standards, earthquake risk would be greatly reduced. In this study, a simulation in Hazus-MH earthquake analysis shows that loss ratios drop from 11% to 3.5%, when all pre- and low-code buildings are upgraded to at least moderate code level. While retrofits can decrease earthquake vulnerability, for areas of high landslide or liquefaction susceptibility, additional geotechnical mitigation may be necessary to have an effect on losses. Two simulations of a CSZ Mw 9.0 earthquake where all pre- and low-code buildings are upgraded to moderate code standards or to high code standards show significant reductions in loss estimates (**Figure 3-4**).

Key Terms:

- *Seismic retrofit:* Structural modification to a building that improves its resilience to earthquake.
- *Design level:* Hazus-MH terminology referring to the quality of a building's seismic building code (i. e. pre, low, moderate, and high). Refer to **Appendix C.2.3** for more information.

Figure 3-4. CSZ Mw 9.0 earthquake loss ratio in Clackamas County with simulated seismic building code upgrades.



3.1.4 Data sources: Canby-Molalla Fault scenario

The Mw 6.8 Canby-Molalla Fault deterministic scenario was selected as the most appropriate for communicating an alternative earthquake risk for Clackamas County. The default Hazus-MH faults database did not contain this fault, but Hazus-MH allows for custom earthquake scenarios. The parameters necessary for a custom scenario were sourced from the USGS Quaternary Fault and Fold Database.[3]

The epicenter was manually selected and was located at the closest proximity to the majority of buildings within the study area.

The following hazard layers used for our loss estimation are sourced from work conducted by Madin and others (2021): NEHRP soil classification, landslide susceptibility (wet), and liquefaction susceptibility. The liquefaction and landslide susceptibility layers were used in the Hazus-MH tool to

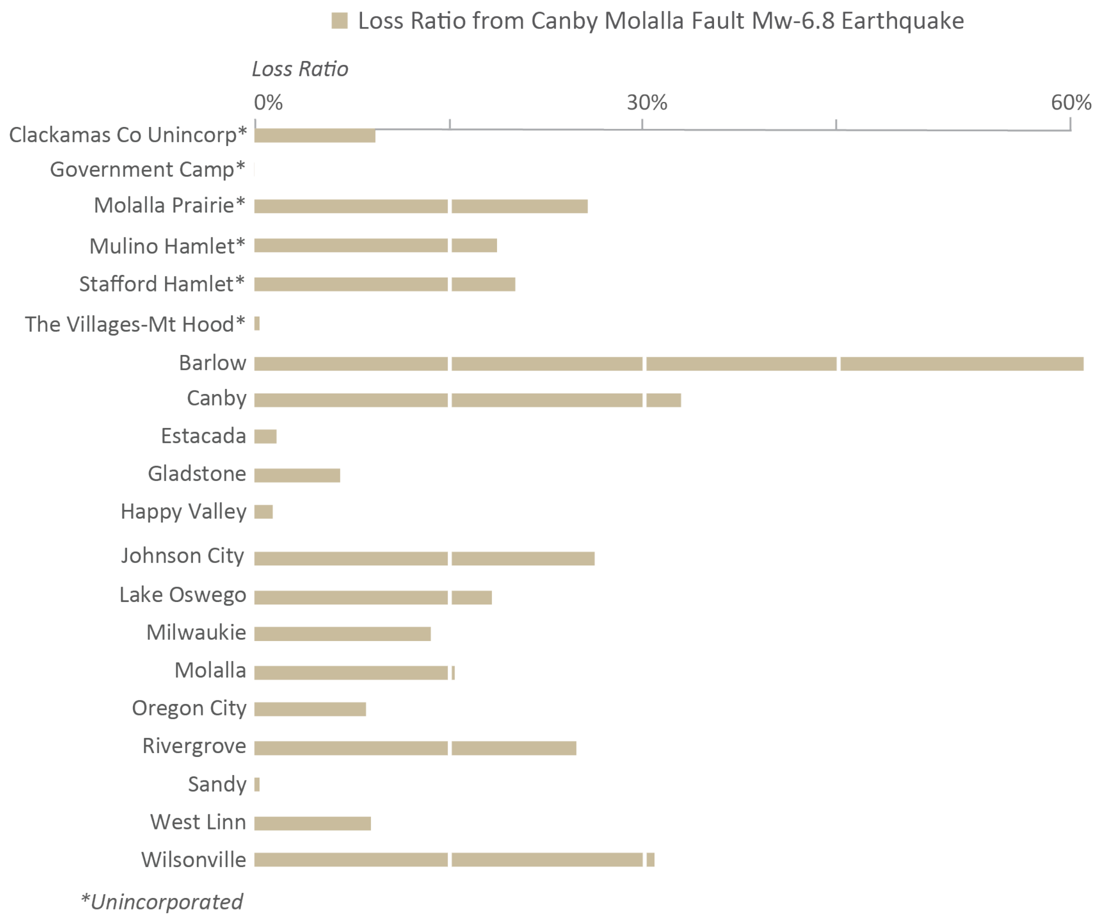
[3] https://www.usgs.gov/programs/earthquake-hazards/faults

calculate the probability and magnitude of permanent ground deformation caused by these factors. Hazus-MH uses a characteristic magnitude value to calculate the impacts of liquefaction and landslides. For this study, we followed the details provided in the default Hazus-MH database and used Mw 6.8 as the characteristic event.

3.1.5 Countywide results: Canby-Molalla Fault scenario

While a CSZ event will cause substantial widespread damage throughout the entire study area, our results indicate a Canby-Molalla Fault Mw 6.8 earthquake will cause significant damage (25%-30% in losses) in the communities in the northwestern portion of the county and more than 60% for the community of Barlow. Because an earthquake can affect a wide area, it will also cause damage in the other communities in Clackamas County, but to a lesser degree. Ground deformation (coseismic liquefaction and landslides) are also determining factors in damage results for this earthquake scenario. **Figure 3-5** shows loss ratios from this earthquake scenario for the communities of Clackamas County.

Figure 3-5. Earthquake loss ratio from Canby-Molalla Fault Mw 6.8 by Clackamas County community.



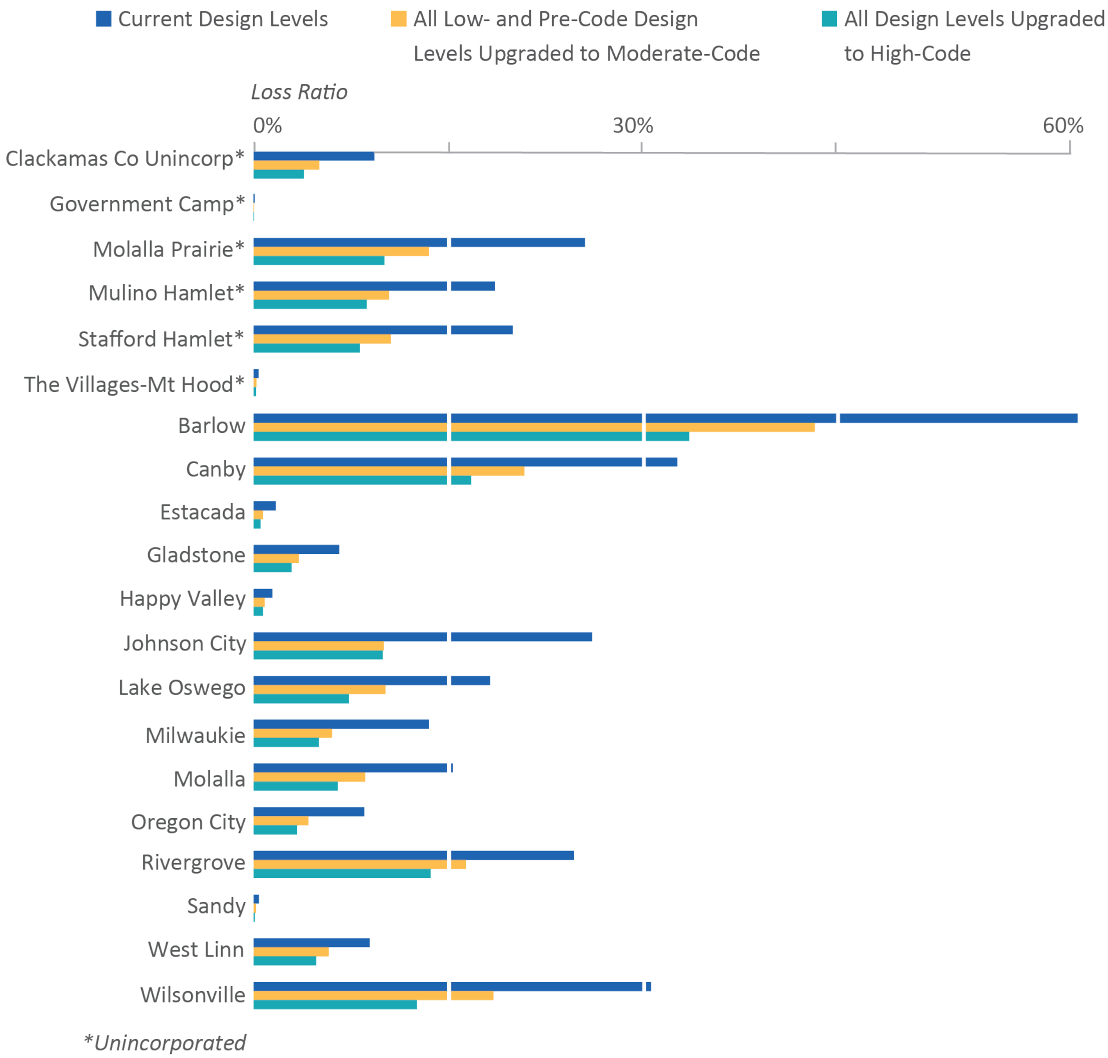
The results indicate that Clackamas County could incur losses of more than $9 billion, or 12% of their total building assets, from a Canby-Molalla Fault Mw 6.8 earthquake. These results are strongly influenced by the proximity of buildings to the epicenter of the simulated earthquake. Communities in the western portion of the county are not only close to the epicenter, but also are in areas of highly liquefiable soils. In addition to proximity, liquefaction would exacerbate the level of risk from this earthquake scenario for the communities in this part of the county. We observed that the Canby-Molalla Fault scenario produced a more variable loss ratio per community compared to the CSZ scenario where shaking intensity is reasonably constant across the county.

Clackamas County Canby-Molalla Fault Mw 6.8 earthquake results:

- Number of red-tagged buildings: 6,392
- Number of yellow-tagged buildings: 14,917
- Loss estimate: $ 9,320,783,000
- Loss ratio: 12%
- Nonfunctioning critical facilities: 127 of 294
- Potentially displaced population: 17,358

As with the CSZ earthquake hazard, if buildings could be seismically retrofitted to moderate- or high-code standards, the impact of this event would be greatly reduced. In a simulation by DOGAMI, Hazus-MH earthquake analysis shows that loss estimates drop from 12% to 6.6% when all buildings are brought up to at least moderate-code level. Although these upgrades can decrease earthquake vulnerability, the benefits are minimized in landslide and liquefaction areas, where buildings would need additional geotechnical mitigation to affect losses. **Figure 3-6** illustrates the reduction in loss estimates from a Canby-Molalla Fault Mw 6.8 earthquake through two simulations where all buildings are upgraded to at least moderate-code standards and then all buildings to high-code standards.

Figure 3-6. Canby-Molalla Fault Mw 6.8 earthquake loss ratio in Clackamas County with simulated seismic building code upgrades.



3.1.6 Areas of significant risk

We identified locations within the study area that are comparatively at greater risk to earthquake hazard:

- Areas near the epicenter of a Canby-Molalla Fault earthquake scenario are likely to incur a significant amount of damage. The communities of Barlow, Canby, and Wilsonville have the potential for significant losses if this scenario were to occur.
- Buildings in the floodplains of the Willamette, Molalla, Tualatin, and Clackamas rivers are at higher risk from earthquake damage due to significantly higher liquefaction susceptibility.
- The small community of Johnson City is composed of a high number of manufactured houses, which are vulnerable to earthquake shaking, and has a very high loss ratio (86%) from a CSZ event.
- Unreinforced masonry buildings in the older downtown portions of Oregon City and Milwaukie are more vulnerable to substantial damage during an earthquake, compared to other nearby structures built to modern standards.

- 178 of the 294 critical facilities in the study area are estimated to be nonfunctioning due to a CSZ earthquake like the one simulated in this study and 127 are estimated to be nonfunctioning due to a Canby-Molalla Fault earthquake.

3.2 Flooding

The frequency and severity of flooding may change over time due to changes in land use, including development, waterways, watershed management, precipitation patterns, and changes in climate. This study represents our current understanding of flood hazards and flood risk, but we recognize that flood models and risk assessments will need to be updated with changing conditions.

In its most basic form, a flood is an accumulation of water over normally dry areas, typically due to excessive rain or snowmelt. Floods become hazardous to people and property when they inundate an area where development has occurred, causing losses. Floods are a commonly occurring natural hazard in Clackamas County and have the potential to create public health hazards and public safety concerns, close and damage major highways, destroy railways, damage structures, and cause major economic disruption. More rare flood issues, such as flash flooding, ice jams, post-wildfire floods, and dam safety, were not examined in this report.

A typical method for determining flood risk is to identify the probability and impact of flooding. The annual probabilities calculated for flood hazard used in this report are 10%, 2%, 1%, and 0.2%, henceforth referred to as 10-year, 50-year, 100-year, and 500-year scenarios, respectively. The ability to assess the probability of a flood, and the level of accuracy of that assessment, is influenced by modeling advancements, better understanding of hydrologic factors, and longer periods of record for the stream or water body in question.

The major rivers and creeks within the county are the Clackamas, Pudding, Molalla, Salmon, Sandy, Tualatin, Willamette, and Zigzag rivers and Johnson and Mill creeks. In addition, there are several tributaries to these major streams that have mapped flood zones. All the mapped streams are subject to flooding and could cause damage to buildings in the floodplain.

Within the last 60 years there have been several major floods of note for Clackamas County, two of which affected large areas and many communities. In December of 1964 heavy rainfall on snow occurred, which caused flooding on the Willamette, Clackamas, Pudding, and Molalla rivers at 1-percent-annual-chance (100-year) levels. Flooding from these rivers caused damage in the communities of Oregon City, Clackamas, Barlow, Canby, Gladstone, and Milwaukie. A second recent historical flood occurred in 1996 for the Willamette and Tualatin rivers. The 1996 floods impacted the communities of Lake Oswego and Tualatin, with some of the highest flood levels in their history (FEMA, 2019).

The consequences of flooding are determined by adverse effects to human activities within the natural and built environment. These adverse conditions can be reduced through mitigation efforts, such as elevating structures above the expected level of flooding or removing structures through FEMA's property acquisition ("buyout") program.

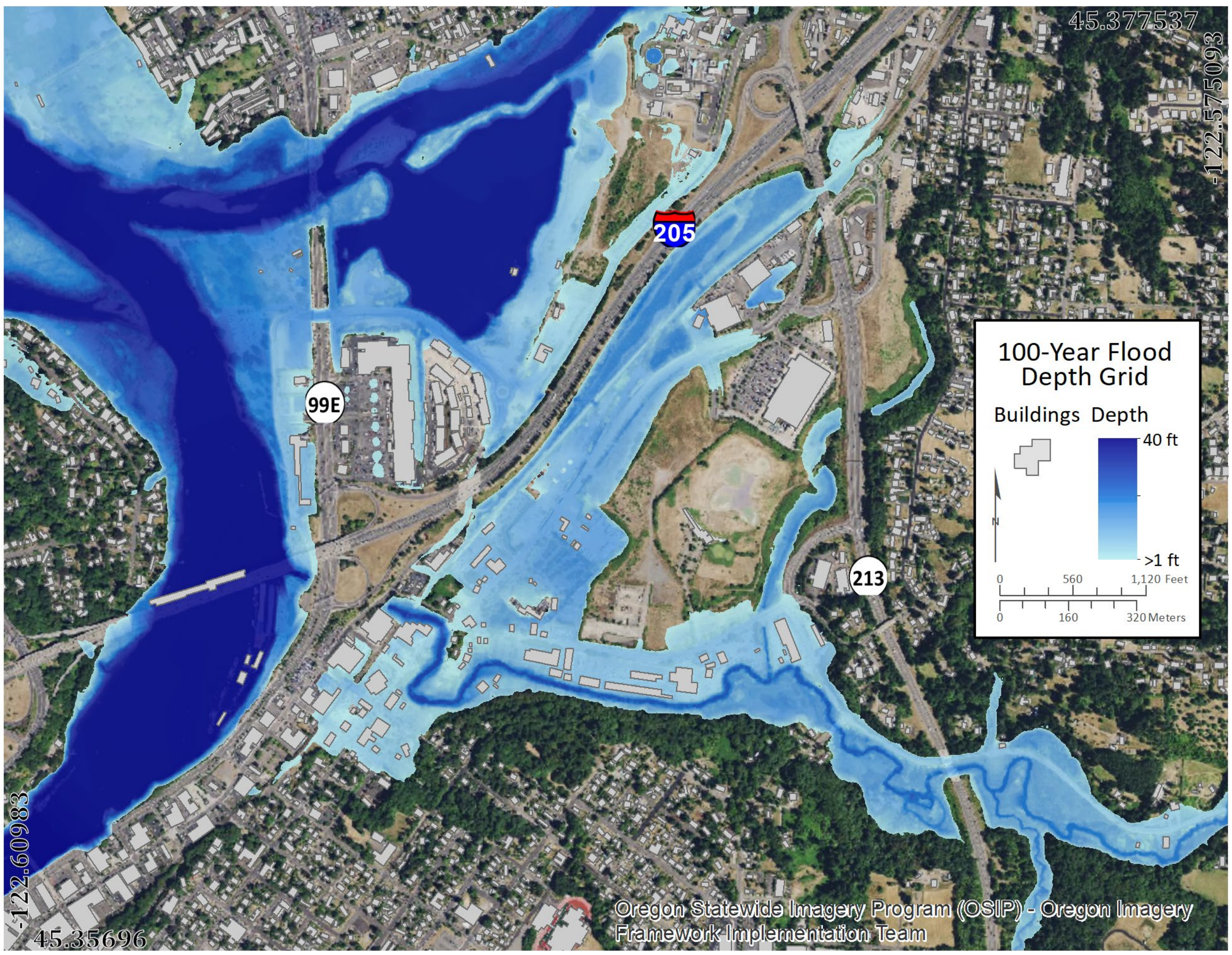
3.2.1 Data sources

The most recent Flood Insurance Study (FIS) and Flood Insurance Rate Maps (FIRMs) (FEMA, 2019) were used to assess flood risk in this study. Flooding inevitably occurs in areas outside of the detailed mapped areas, however due to limited data availability and variable data resolutions, no other data sources were used in this study. Further information regarding the National Flood Insurance Program (NFIP)-related statistics can be found at FEMA's website: https://nfipservices.floodsmart.gov/reports-flood-insurance-data.

DOGAMI developed the 10-, 50-, 100-, and 500-year depth grids from detailed stream information and high-resolution lidar collected in 2009, 2011, 2013, and 2014 (Hood to Coast 2009 project, Upper Sandy River 2011, Clackamol 2013, and Metro 2014 project - Oregon Lidar Consortium; see (https://www.oregon.gov/dogami/lidar/Pages/collectinglidar.aspx). The set of depth grids were used in this risk assessment to determine the level to which buildings are impacted by flooding.

Depth grids are raster GIS datasets in which each digital pixel value represents the depth of flooding at that location within the flood zone (**Figure 3-7**). Depth grids for four riverine flooding scenarios (10-, 50-, 100-, and 500-year) were used for loss estimations and, for comparative purposes, exposure analysis.

Figure 3-7. Flood depth grid example in the City of Oregon City, Oregon.



Building loss estimates are determined in Hazus-MH by overlaying building data on a depth grid. Hazus-MH uses individual building information, specifically the first-floor height above ground and the presence of a basement, to calculate the loss ratio from a particular depth of flood.

For Clackamas County, occupancy type and basement presence attributes were available from the assessor database for most buildings. Where individual building information was not available from assessor data, we used oblique imagery and street-level imagery to estimate these important building attributes. Only buildings in a flood zone or within 500 ft (152 m) of a flood zone were examined closely in this manner for more accurate information on first-floor height and basement presence. Because our analysis accounted for building first-floor height, buildings that have been elevated above the flood level were not given a loss estimate—but we did count residents in those structures as displaced. We did not look at the duration that residents would be displaced from their homes due to flooding. For information about structures exposed to flooding but not damaged, see the **Exposure analysis** section.

3.2.2 Countywide results

For this risk assessment, we imported the countywide UDF data and depth grids into Hazus-MH and ran a flood analysis for four flood scenarios (10-, 50-, 100-, and 500-year). We used the 100-year flood scenario as the primary scenario for reporting flood results (also see **Appendix E: Plate 7**). The 100-year flood has traditionally been used as a reference level for flooding and is the standard probability that FEMA uses for regulatory purposes. See **Appendix B: Table B-4** for multi-scenario cumulative results.

Clackamas Countywide 100-year flood loss:

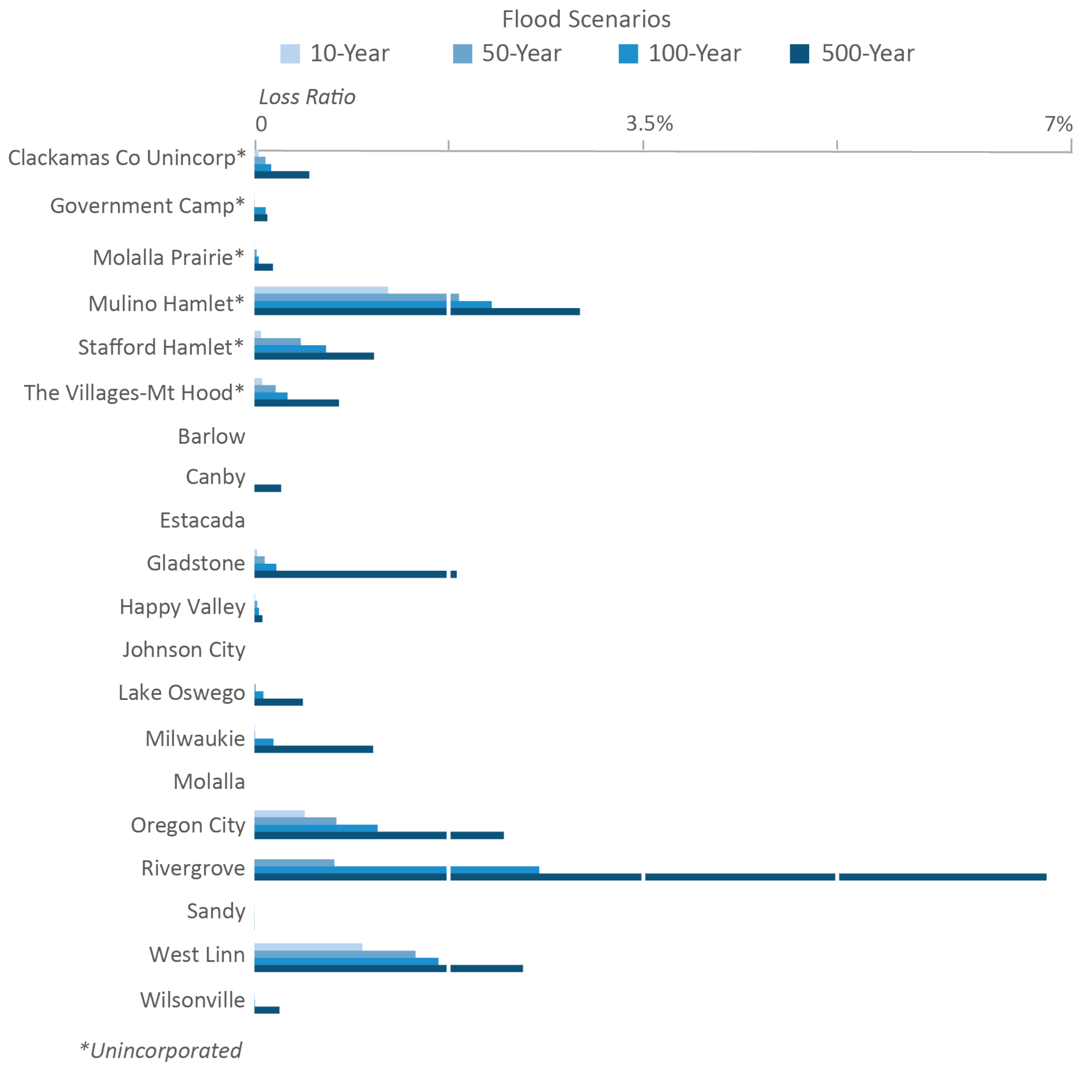
- Number of buildings damaged: 1,452
- Loss estimate: $222,037,000
- Loss ratio: 0.3%
- Damaged critical facilities: 2 of 294
- Potentially displaced population: 3,149

3.2.3 Hazus-MH analysis

The Hazus-MH loss estimate for the 100-year flood scenario for the entire county is more than $222 million. While the loss ratio of flood damage for the entirety of Clackamas County is quite low at 0.3%, the effects to areas of development near flood-prone streams is significant (**Figure 3-8**). In communities where most residents are not within flood-designated zones, the loss ratio may not be as helpful as the actual replacement cost and number of residents displaced in assessing the level of risk and consequences from flooding. The Hazus-MH analysis also provides useful information for individual communities so that planners can identify problems and consider which mitigation activities will provide the greatest resilience to flooding.

Based on the NFIP stream models, the main flooding problems within Clackamas County are primarily in the areas of Rivergrove, Mulino Hamlet, West Linn, Oregon City, Gladstone, and unincorporated areas outside of Barlow and Canby (**Figure 3-8**). There are several areas of concentrated flood risk in the study area. Most flood-exposed buildings in the study area are residential structures located in farmland and suburban areas outside of communities.

Figure 3-8. Ratio of flood loss estimates by Clackamas County community.



3.2.4 Exposure analysis

Separate from the Hazus-MH flood analysis, we did an exposure analysis by overlaying building locations on the 100-year flood extent. We did this to estimate the number of buildings that are elevated above the level of flooding and the number of displaced residents. This was done by comparing the number of nondamaged buildings from Hazus-MH with the number of exposed buildings in the flood zone. One percent of Clackamas County's buildings were found to be within designated flood zones. Of the 1,873 buildings that are exposed to flooding, we estimate that 421 are above the height of the 100-year flood. This evaluation also estimates that 3,149 residents might have mobility or access issues due to being surrounded and cut off by rising floodwaters. See **Appendix B: Table B-5** for individual community results of flood exposure.

3.2.5 Areas of significant risk

We identified locations within the study area that are comparatively at greater risk of flood hazard:

- Many farms and residential structures north of Barlow are built within the large floodplain of the Molalla River confluence with the Willamette River.
- Many buildings are at risk from flooding along Milk Creek in the community of Mulino Hamlet.
- Many residential buildings upstream of Oswego Lake in Lake Oswego and along the Tualatin River in Rivergrove are at risk from flood hazard.
- Many buildings along the Willamette River and the confluence of the Clackamas River in the cities of Gladstone, Oregon City, and West Linn are at risk from flood hazard.
- Many residential buildings along the Sandy River in the area of the Villages at Mount Hood are at risk from flood hazard.

3.3 Landslide Susceptibility

Landslides are mass movements of rock, debris, or soil down a slope. Landslides can occur in many sizes, at different depths, and with varying rates of movement. Generally, they are large, deep, and slow moving or small, shallow, and rapid. Factors that influence landslide type include slope steepness, water content, and underlying geology. Many triggers can cause a landslide: intense rainfall, earthquakes, or human-induced factors like water concentration, excavation along a landslide toe, or loading at the top. Landslides can cause severe damage to buildings and infrastructure. Fast-moving landslides may pose life safety risks and can occur throughout Oregon (Burns and others, 2016). The most common landslide types in Clackamas County are debris flows and shallow- and deep-seated landslides.

Because landslides are a site-specific hazard that occur over much smaller spatial extents than most other natural hazards, measuring the risk associated with future landslides for a large area can be difficult. Landslide susceptibility measures the likelihood that a given location will experience a landslide in the future based on a variety of factors, including slope, geology, soil type, and the presence of preexisting landslides.

This study represents our current understanding of landslide susceptibility to measure the risk of landsliding in Clackamas County. However, changing climate, precipitation patterns, land use, wildfire events, and land and forest management strategies may increase or decrease the susceptibility to landslides.

3.3.1 Data sources

We used the data from the Statewide Landslide Susceptibility Map (Burns and others, 2016), an analysis of multiple landslide datasets created using methods outlined in DOGAMI Special Paper Special Paper 42 (SP-42: Burns and Madin, 2009) for the landslide analysis.

Burns and others (2016) used the Statewide Landslide Information Database for Oregon (SLIDO) along with maps of generalized geology and slope to create a landslide susceptibility overview map of Oregon that shows zones of relative susceptibility: Very High, High, Moderate, and Low. Mapped landslides from SLIDO data directly define the Very High landslide susceptibility zone, while SLIDO data coupled with statistical results from generalized geology and slope maps define the other relative susceptibility zones (Burns and others, 2016).

SLIDO, release 3.2 (Burns and Watzig, 2014) was used in the Burns and others (2016) statewide susceptibility analysis, which preceded the new lidar-based inventory mapping of Hairston-Porter and others (2021) and thus, this newer mapping was not incorporated into the Statewide Landslide Susceptibility Map.

SLIDO is a compilation of past studies; some studies were completed very recently using new technologies like lidar-derived topography, and some studies were performed more than 50 years ago. Consequently, SLIDO data vary greatly in scale, scope, and focus and thus in accuracy and resolution across the state. Statewide landslide susceptibility map data have the inherent limitations of SLIDO and of the geology and slope maps used to create the map. Therefore, the statewide landslide susceptibility map varies significantly in scale and application across the state, depending on the details of the input datasets. Another limitation is that susceptibility mapping does not include some aspects of landslide hazard, such as runout, where the momentum of the landslide can carry debris beyond the zone deemed to be a high hazard area.

We used the data from the Statewide Landslide Susceptibility Map (Burns and others, 2016) in this report to identify the general level of susceptibility of a given area to landslide hazards, primarily shallow and deep landslides. We overlaid building and critical facilities data on landslide susceptibility zones to assess the exposure for each community (see **Appendix B: Table B-6**). The total dollar value of exposed buildings was summed for the study area and reported in **Section 3.3.2**. We also estimated the number of people threatened by landslides. Land value losses due to landslides and potentially hazardous unmapped areas that may pose real risk to communities were not examined for this report.

3.3.2 Countywide results

The communities in terrain with moderate to steep slopes or at the base of steep hillsides may have a high level of exposure to landslide hazard. Approximately 6% of the county's total building value lies within areas of high landslide susceptibility.

We combined High and Very High susceptibility areas as the primary scenario to provide a general sense of community risk for planning purposes (see **Appendix E, Plate 8**). These susceptibility zones represent areas most susceptible to landslides with the highest impact to the community.

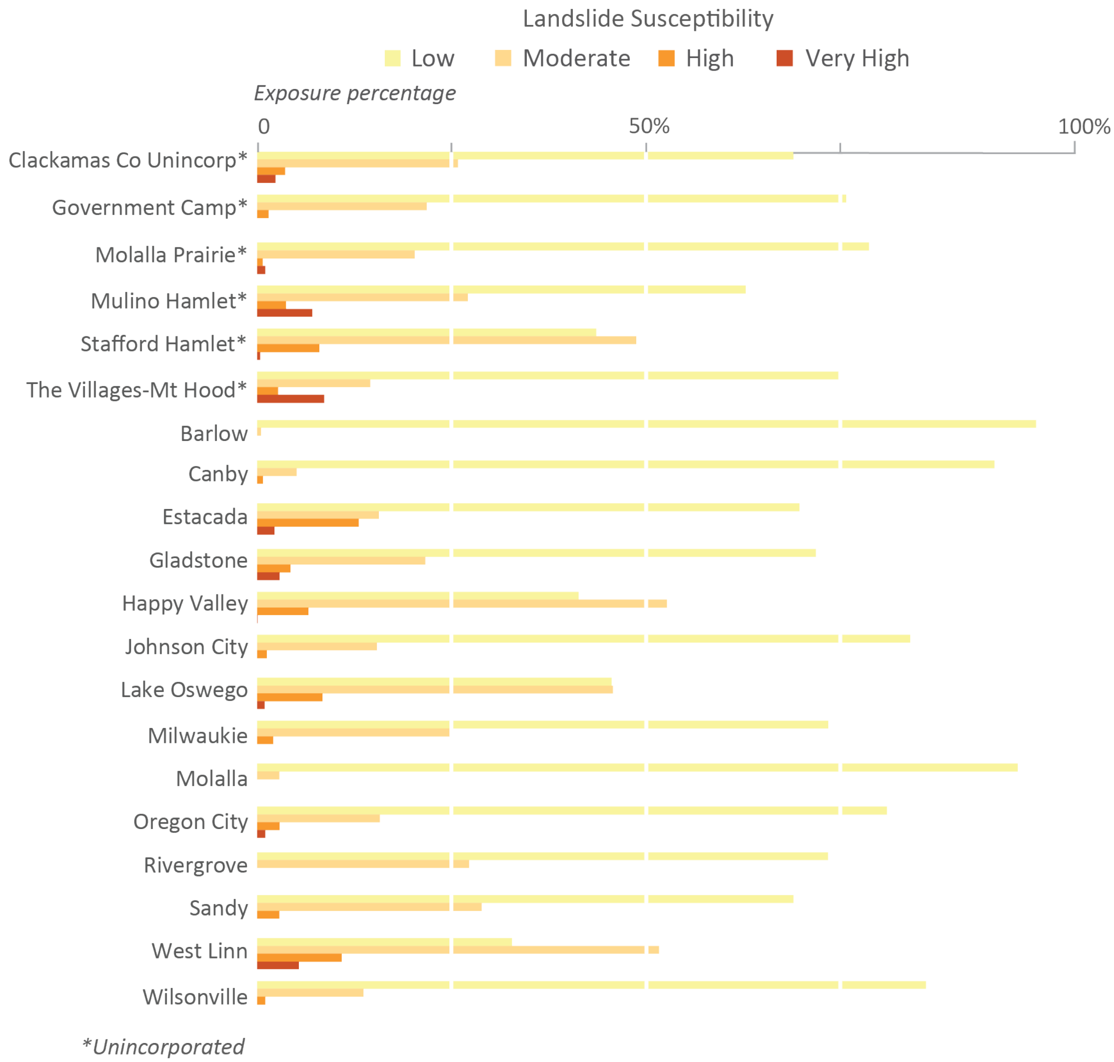
For this risk assessment we compared building locations to geographic extents of the landslide susceptibility zones (**Figure 3-9**). The exposure results are for the high and very high susceptibility zones. See **Appendix B: Detailed Risk Assessment Tables** for exposure analysis results of all susceptibility categories.

Clackamas countywide landslide exposure (High and Very High susceptibility):

- Number of buildings exposed: 11,418
- Value of buildings exposed to landslides: $4,784,804,000
- Percentage of total county value exposed to landslides: 6%
- Critical facilities exposed to landslides: 10 of 294
- Potentially displaced population: 31,912

With landslide hazard ubiquitous throughout most of the county, there are many areas where landslide risk is High. A high concentration of residential structures in West Linn, Gladstone, and Mulino Hamlet are built on existing landslides and are at Very High risk from landslide hazard. Developed areas along Highway 26, in Welches, and along the Sandy River at Zigzag are at Very High risk from landslide hazard within the larger community of the Villages at Mount Hood. Since landslide hazards are present throughout Clackamas County, it may present challenges for planning and mitigation efforts. Awareness of nearby areas of landslide hazard is beneficial to reducing risk for every community and rural area of Clackamas County.

Figure 3-9. Landslide susceptibility exposure by Clackamas County community.



3.3.3 Areas of significant risk

We identified locations within the study area that are comparatively at greater risk to landslide hazard:

- Concentrations of residentials structures in West Linn, Gladstone, Mulino Hamlet, and the Villages at Mount Hood are all in areas of existing landslides and are at Very High risk from landslide hazard.
- There is significant exposure to landslide hazard for the communities of West Linn, Estacada, Mulino Hamlet, the Villages at Mount Hood, and Lake Oswego.

3.4 Channel Migration

Channel migration is a dynamic process by which a stream's location changes over time. This process includes channel bed and bank erosion, sediment deposition, and channel avulsion, a process in which the stream abruptly moves to a new location on the floodplain. Many factors influence channel movement, including the local geology, size, and quantity of sediment within the river, and discharge of water, vegetation, channel shape, and slope. Human changes to the channel, such as the construction of dams and levees, also have a major impact on how a channel changes its course. In combination, these factors affect how a river's energy and erosive power is dispersed. Straight, steep streams have highly concentrated erosive power; by contrast, curving channels that flow across wide and flat floodplains allow a river to dissipate its energy and deposit sediment over a wider area (Rapp and Abbe, 2003).

The area in which a stream channel moves laterally over a given time is known as a CMZ. In places where development has occurred within the CMZ, structures are at risk for severe damage to foundations and infrastructure through erosion and flooding. The CMZ typically extends beyond the limits of the regulatory floodplain, but little consideration is given to this potential hazard. This factor contributes greatly to the level of risk that exists for many developed areas along streams (Rapp and Abbe, 2003).

The frequency and severity of channel migration may change over time due to changes in climate and precipitation patterns, land use, and how we manage our waterways. This study represents our current understanding of channel migration hazards and risk, but we recognize that channel migration mapping and risk assessments will need to be updated with time and changing conditions.

3.4.1 Data sources

The CMZ used for this report were developed by English and others (2013) and Abbe and others (2015) for portions of the Sandy River. DOGAMI's CMZ mapping considers areas of historical channel migration as well as, potential future erosion and channel avulsion. These areas are mapped based on geology, historical aerial imagery, lidar topography, limited field work, and measured rates of historical channel migration. The CMZ is subdivided into seven components: active channel, historical migration area, 30-year and 100-year erosion hazard areas, the avulsion hazard area, and flagged sections of streambank that are actively eroding or adjacent to landslides. The methodology for calculating each component and how they are combined are described in Rappe and Abbe (2003).

It is important to note that this study only evaluated the Sandy River for channel migration hazard. There are other waterways in Clackamas County that likely experience channel migration and structures built in proximity to these waterways are potentially at risk from channel migration hazard even if not within a studied hazard area. We suggest future CMZ studies on the other waterways of Clackamas County.

To assess the exposure within each community, we overlaid buildings and critical facilities within the CMZ. The following section presents the estimated total dollar value of exposed buildings and the number of people potentially displaced from the CMZ. Land value losses due to CMZ were not examined for this report.

3.4.2 Countywide results

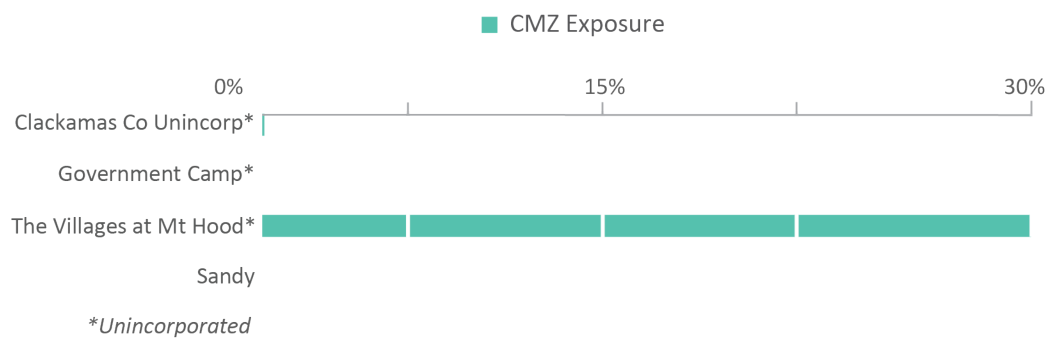
Mapped channel migration areas along the Sandy River show a very high level of risk from this hazard for many communities along this stream (English and others, 2013), (Abbe and others, 2015). To quantify risk, an exposure analysis was conducted by determining which buildings were within or outside of the CMZ (see **Appendix E: Plate 9**). Due to the frequency of shifting channel patterns in streams, channel migration can be a serious hazard in areas close to streams regardless of if they have been mapped as a hazard or not.

Clackamas County channel migration exposure:

- Number of buildings: 1,216
- Value of buildings exposed to channel migration: $420,518,000
- Percentage of study area value exposed to channel migration: 1.1%
- Critical facilities exposed to channel migration: 0 of 294
- Potentially displaced population: 3,282

A high number of buildings in the Villages at Mount Hood are built within areas where channel migration is likely to occur. Nearly one-third of the buildings in the Villages at Mount Hood are within the CMZ. **Figure 3-10** presents the estimated total building value at risk from channel migration for the communities of within the study area. See **Appendix B: Detailed Risk Assessment Tables** for complete analysis results.

Figure 3-10. **CMZ exposure by Clackamas County community within the study area of English and others (2013) and Abbe and others (2015).**



Note: Communities in figure limited to communities within the study area.

3.4.3 Areas of significant risk

We identified locations within the study area that are comparatively at greater risk to channel migration hazard:

- A significant portion (~30%) of the buildings in the Villages at Mount Hood are at risk from channel migration hazard from the Sandy River. We also estimate that 35% of residents within the community are exposed to this hazard.

3.5 Wildfire

Wildfires are a natural part of the ecosystem in Oregon. However, wildfires can present a substantial hazard to life and property in growing communities. The most common wildfire conditions include hot, dry, and windy weather; the inability of fire protection forces to contain or suppress the fire; the occurrence of multiple fires that overwhelm committed resources; and a large fuel load (dense vegetation). Once a fire has started, its behavior is influenced by numerous conditions, including fuel, topography, weather, drought, and development (Gilbertson-Day and others, 2018). Post-wildfire natural hazards can also present risk. These usually include flood, debris flows, and landslides. Post-wildfire geologic hazards, such as debris flows, were not evaluated in this project.

The 2018 Clackamas Community Wildfire Protection Plan (CCWPP) recommended that the county develop policies addressing fire restriction enforcement, WUI standards, and building code enforcement related to emergency access. Forests cover large portions of the county and play an important role in the local economy, but also surround homes and businesses (CCWPP, 2018). Contact the Clackamas County Planning Department for specific wildfire requirements.

In the Fall of 2020, very large wildfires occurred in the region, with the Beachie Creek and Riverside wildfires burning large portions of Clackamas County. These fires are termed “megafires” because they were greater than 100,000 acres (400 km^2) in size. The Beachie Creek wildfire burned nearly 194,000 acres (800 km^2) and the Riverside wildfire burned 138,000 acres (560 km^2) (Northwest Interagency Coordination Center website, accessed 3/6/2024). Evacuation orders, ranging from Level 1 to Level 3, were in place for the entire county during the emergency. The fires resulted in severe damage to the built and natural environment in Clackamas County with nearly 300 structures destroyed, including 62 homes according to the Oregon Department of Emergency Management.[4] This disaster directly demonstrates the degree of wildfire risk in the county.

The frequency, intensity, and severity of wildfires may change over time due to changes in climate, drought conditions, urbanization, and how we manage our forested lands. This study represents our current understanding of wildfire hazards and wildfire risk, but we recognize that wildfire models and risk assessments will need to be updated with time and changing conditions.

3.5.1 Data sources

The Pacific Northwest Quantitative Wildfire Risk Assessment (PNRA): Methods and Results (Gilbertson-Day and others, 2018) is a comprehensive report that includes a database of spatial information related to wildfire hazard developed by the United States Forest Service (USFS) for the states of Oregon and Washington. The steward of this database in Oregon is the Oregon Department of Forestry (ODF). The database was created to assess the level of risk residents and structures have to wildfire. For this project, the burn probability dataset, a dataset included in the PNRA database, was used to measure the risk to communities in Clackamas County.

Using guidance from ODF, we categorized the Overall Wildfire Risk dataset into low, moderate, and high-hazard zones for the wildfire exposure analysis. Overall Wildfire Risk was developed as a combination of burn probability and the presence of infrastructure and assets. The range of values in the risk dataset describe the level of potential impact and are characterized by negative values that indicate Very High risk to zero which indicates Low risk. The risk dataset also includes positive values that represent uninhabited areas that benefit from wildfire, but these were combined into the Low risk category (Gilbertson-Day and others, 2018).

Overall Wildfire Risk values were grouped into three categories:

- Low wildfire risk (-0.000011 to 0.005)
- Moderate wildfire risk (-0.000119 to -0.000011)
- High wildfire risk (-0.203 to -0.000119)

We overlaid the buildings layer and critical facilities on each of the wildfire hazard zones to determine exposure. In certain areas, no wildfire data is present, which indicates areas that have minimal risk to wildfire hazard (see **Appendix B: Table B-8**). The total dollar value of exposed buildings in the study area

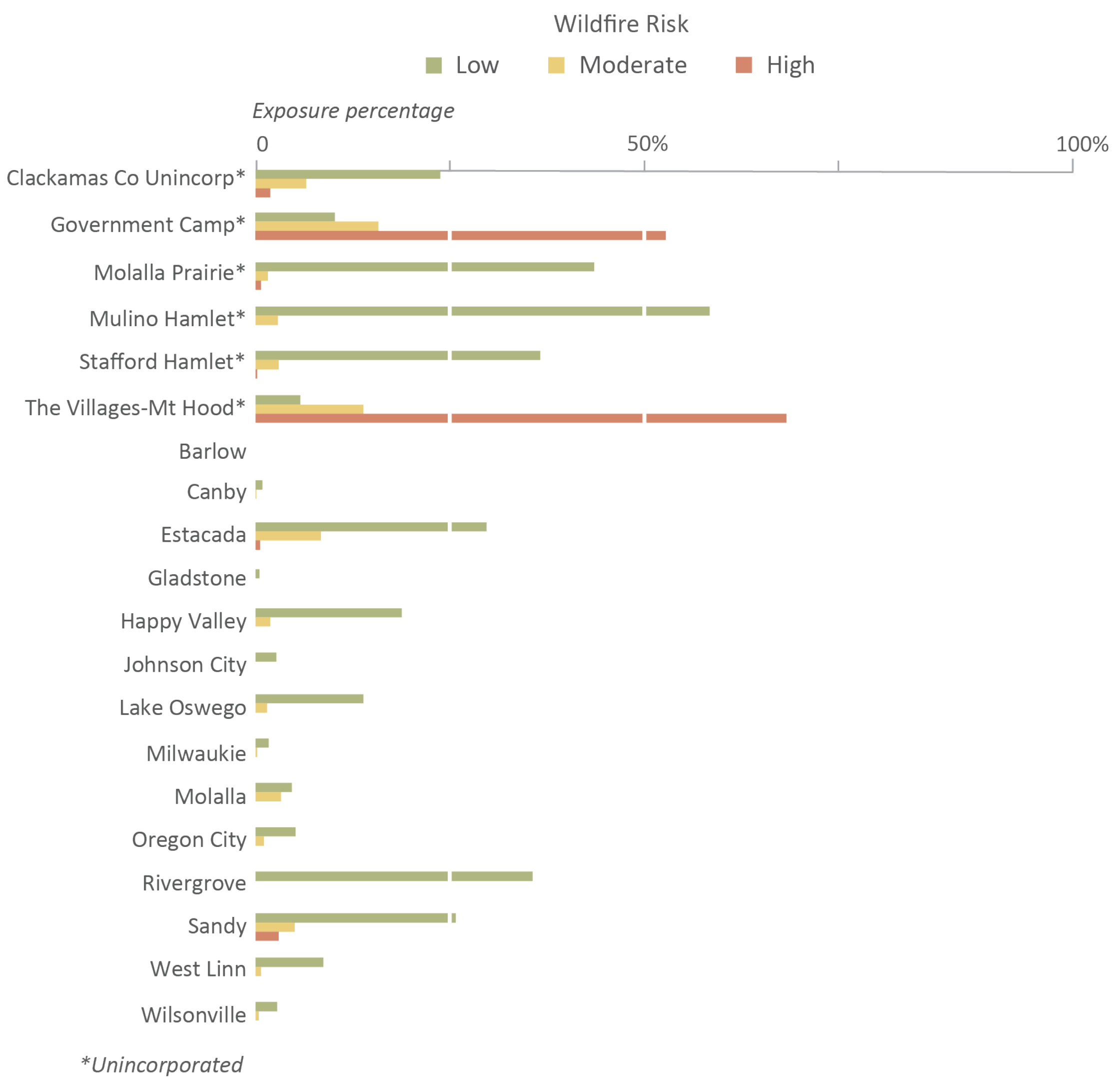
[4] https://storymaps.arcgis.com/stories/6e1e42989d1b4beb809223d5430a3750

is reported in the following section. We also estimated the number of people threatened by wildfire. Land value losses and, infrastructure, and environmental impacts due to wildfire were not examined for this project.

3.5.2 Countywide results

The combined High and Moderate risk categories were chosen as the scenarios that represent areas that have the highest potential for losses. However, Low risk is not the same as no risk. Moderate wildfire risk is included with High risk in the assessment of exposure, because under certain conditions moderate risk zones can be very susceptible to burn. In combining the High and Moderate risk categories within Clackamas County, we can emphasize areas where lives and property are most at risk (**Figure 3-11**).

Figure 3-11. Exposure to wildfire hazard by Clackamas County community.



Clackamas Countywide wildfire exposure (High or Moderate risk):
- Number of buildings: 15,461
- Value of buildings exposed to wildfire: $4,780,928,000
- Percentage of total county value exposed to wildfire: 6.1%
- Critical facilities exposed to wildfire: 12 of 294
- Potentially displaced population: 30,697

For this risk assessment, the building locations were compared to the geographic extent of the wildfire risk categories. Hundreds of buildings in the heavily forested unincorporated parts of eastern Clackamas County are exposed to High or Moderate wildfire risk (see **Appendix E: Plate 10**). There is a very High risk from wildfire in the communities of Government Camp, the Villages at Mount Hood, and Estacada. The WUI in nearly every community in Clackamas County has at least some risk to wildfire. See **Appendix B: Detailed Risk Assessment Tables** for multi-scenario analysis results.

3.5.3 Areas of significant risk

We identified locations within the study area that are comparatively at greater risk to wildfire hazard:

- The WUI for nearly every community in Clackamas County has exposure to wildfire risk, including nearly 9% of buildings in Estacada that are exposed to Moderate to High wildfire risk.
- High risk of wildfire exists for the unincorporated communities of the Villages at Mount Hood and Government Camp. Most of the heavily forested eastern parts of the unincorporated county are also at High risk from wildfire hazard.

3.6 Volcanic Hazard – Lahar

A lahar is a water-saturated mixture of muddy debris and rock fragments that originates from a volcano and flows down channels at a rapid speed (exceeding 120 mi/hr [200 km/hr]). Lahars can occur on the flanks of a volcano with or without a volcanic eruption; noneruption-related lahars can be initiated during heavy rains or by a sudden outburst of glacial melt where a volcano is covered with heavy loads of snow and ice. When this sudden, large volume of water mixes with volcanic sediments and moves downslope, a lahar is produced.

Distal volcanic hazard zones, as opposed to proximal volcanic hazard zones, are hazard types that affect outer areas, away from the center of volcanic activity. Lahars are considered a distal volcanic hazard, because they can travel large distances, causing damage to anything in their path even tens of miles away from its source. Because lahars have high drag and buoyancy forces resulting from the high sediment content of the flow, they are capable of moving large objects, such as trees and vehicles, and destroying infrastructure, such as houses and bridges. They also can influence water quality, depending on the water sources used by affected communities.

Mount Hood has had several notable eruptions in the past 30,000 years. Extensive lahars were created by both the Polallie eruptive period, which occurred 13,000-20,000 years ago, and the Timberline eruptive period, which occurred 1,500 years ago (Pierson and others, 2009). The Old Maid eruptive period is the most recent source of lahar exposure in the region, occurring approximately 200 years ago (Madin and others, 2017). Lahars inundated the Sandy, Zigzag, Salmon, and White River valleys. These lahar deposits tend to exacerbate flooding and channel migration risk in the Upper Sandy River region due to the heavy debris remaining after an event and the huge amounts of sediment deposited.

3.6.1 Data sources

The lahar zones used in this report were created by DOGAMI using the software application LAHARZ (Iverson and others, 1998). The LAHARZ software is a GIS-based application that calculates the area expected to be within the volcanic debris flow, based on certain inputs. The data parameters necessary to run the model are the starting location, a volume of debris material, and a digital elevation model (DEM). The starting locations for modeled runs were placed at points where the total upstream drainage area was greater than 10,700 ft^2 (994 m^2). This was based on recommendations provided from Griswold and Iverson (2008). Lahar volume amounts used in the model were based on recommendations from Scott and others (1997) and Iverson and others (1998). The different volume amounts used in the final analysis are related to annual probability and recurrence intervals.

The recurrence interval associated with the lahar exposure scenarios are as follows (Burns and others, 2011):

- XL: 100,000-year recurrence interval
- L: 500-1,000-year recurrence interval
- M: 100-year recurrence interval
- Sm: 10-year recurrence interval

For this risk assessment, DOGAMI compared the location of buildings and critical facilities to the geographic extent of the lahar inundation zones to assess the exposure for each community. The exposure results shown below are for only the Medium (M) scenario. The total dollar value of exposed buildings was summed for the study area and reported below. We were also able to estimate the number of people at risk from lahar hazard. Refer to **Figure 3-12** to view the cumulative multi-scenario analysis results.

3.6.2 County results

It is important to understand how volcanic hazards differ from earthquake or flood hazards. Earthquakes and floods tend to happen over relatively short windows of time, from minutes to hours, and recovery can usually begin days or weeks after the event. By contrast, volcanic hazards can last days to decades, delaying a region's ability to recover. The aftermath of a volcanic event can lead to periods of localized channel transport of lahar material, precipitation patterns for the region can also lead to increased debris flows due to increased discharge in the riverine environment. Results of this study examine a single volcanic event, not the cumulative effects of hazards from a volcanic eruption (Burns and others 2011).

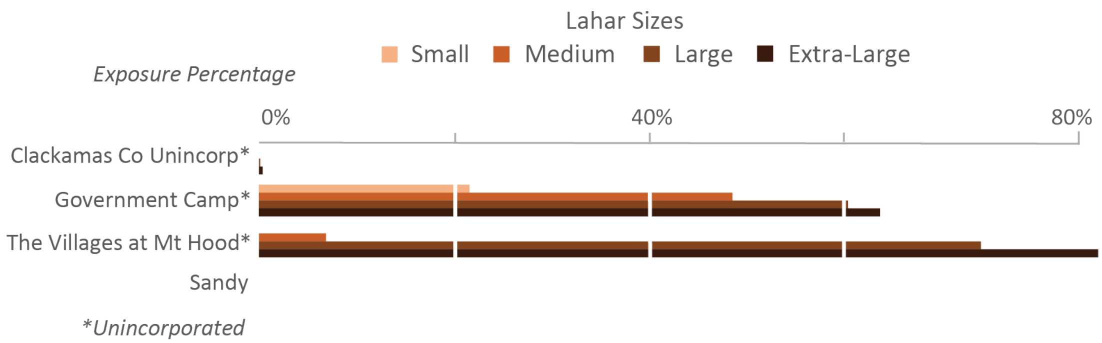
For this risk assessment, the results of the exposure analysis were limited to the communities included in the report by Burns and others (2011) that fall within the study area, which are those communities along the Sandy River and the unincorporated portions of Clackamas County. See **Appendix B: Detailed Risk Assessment Tables** to view the multi-scenario analysis results.

Clackamas County study area volcanic lahar exposure (1% annual chance):

- Number of buildings: 667
- Value of buildings exposed to volcanic lahar: $219,801,000
- Percentage of total county value exposed to volcanic lahar: 0.6%
- Critical facilities exposed to volcanic lahar: 0 of 294
- Potentially displaced population: 1,580

Lahar hazard is not a concern for residents in Clackamas County living outside the lahar hazard zone as defined by the USGS Mount Hood Volcano hazards zonation map (Scott and others, 1997). However, developed areas along Highway 26 on the western slope of Mount Hood have a high exposure to volcanic lahar hazard. Buildings that are located outside of the riverine valleys of Mount Hood are at much lower risk from lahar hazard. The communities with the highest risk from a volcanic eruption and lahar event are Government Camp and the Villages at Mount Hood.

Figure 3-12. Lahar risk exposure by Clackamas County community.



Note: Communities in figure are limited to communities within the study area of Burns and others (2011).

3.6.3 Areas of concern

- Lahar risk is confined to river valley channels and is a higher risk for communities and properties closer to Mount Hood and communities in proximity to rivers and streams draining the volcano.
- The 500-year recurrence interval is the most concerning for residents near the volcano with 61% exposure risk for Government Camp, and 71% exposure risk for the Villages at Mount Hood.

4.0 CONCLUSIONS

The purpose of this study is to provide a better understanding of potential impacts from multiple natural hazards at the community scale. We accomplished this by using the most up-to-date natural hazard mapping and loss estimation tools or exposure analysis to quantify risk to assets and potential to displace or harm people. This detailed approach provides new context for the county's risk-reduction efforts. We note several important findings based on the results of this study:

- **Moderate to significant damage and losses for most areas in Clackamas County can occur from a CSZ Mw 9.0 earthquake—**Based on the results of the CSZ Mw 9.0 earthquake scenario, communities in the western part of the county will experience significant impact and disruption from such an event. Results show that this earthquake could cause building value losses ranging from 10% to 30% in the more densely populated parts of the county. Many buildings along the Clackamas, Molalla, Tualatin, and Willamette rivers are at higher risk from earthquake damage due to ground deformation related to liquefaction. High vulnerability within the building inventory (primarily unreinforced masonry) also contributed to modeled losses in the county.
- **Significant damage and losses for some areas in Clackamas County can occur from a Canby-Molalla Fault earthquake** — Based on the results of a Canby-Molalla fault Mw 6.8 earthquake scenario, some communities in Clackamas County will experience significant impact and disruption. Results show that an earthquake focused on the Canby-Molalla Fault can cause building losses ranging from 15% to 30% for buildings in the northwestern part of Clackamas County. Some communities like Barlow, Canby, and Wilsonville can expect earthquake damage due to proximity to the epicenter (i.e., severe shaking) and ground deformation related to liquefaction. High vulnerability within the building inventory (primarily unreinforced masonry) also contributed to modeled losses in the county.
- **Retrofitting buildings to modern seismic building codes can reduce damages and losses from earthquake shaking—**Seismic building codes have a major influence on earthquake-shaking damage estimated in this study. We found that retrofitting to at least moderate code was the most efficient mitigation strategy because the additional benefit from retrofitting to high code was minimal. In our simulation of upgrading buildings to at least moderate code, the estimated loss for the entire study area was reduced from 11% to 3.5% for a CSZ event and 12% to 6.6% for a Canby-Molalla Fault event. Communities with older buildings, that were constructed below the moderate seismic code standards are both the most vulnerable and have the greatest potential for risk reduction. For example, the City of Milwaukie could reduce losses from 30% to 6.8% for a CSZ event and 13% to 5.8% for a Canby-Molalla Fault event by retrofitting all buildings to at least moderate code. While seismic retrofits are an effective strategy for reducing earthquake-shaking damage, it should be noted that earthquake-induced liquefaction hazards will also be present in areas along the Clackamas, Molalla, Tualatin, and Willamette rivers and these hazards require different geotechnical mitigation strategies.
- **Some communities in the study area are at Very High risk from flooding—**Many buildings within the floodplain are vulnerable to significant damage from flooding. At first glance, Hazus-MH flood loss estimates may give a false impression of lower risk because they show lower damages within individual communities relative to other hazards we examined. This is likely due to the difference between the type of results from loss estimation and exposure analysis, as well

as the limited area impacted by flooding. Flooding is one of the most frequently occurring natural hazards and thus, commonly has repetitive losses that occur with recurrence intervals of tens to hundreds of years versus earthquake hazards with recurrence intervals of hundreds to thousands of years. We estimate that an average of 20% building value loss occurs for buildings within the 100-year flood zone. Areas most vulnerable to flood hazard within the study are the confluence of the Clackamas River with the Willamette River, the confluence of the Molalla River with the Willamette River, along Milk Creek in Mulino Hamlet, and the Tualatin River in the community of Rivergrove.

- **Elevating structures in the flood zone reduces vulnerability**—We used flood exposure analysis in addition to Hazus-MH loss estimation to identify buildings that were not damaged but were within the area expected to experience a 100-year flood. By using both analyses in this way, the number of elevated structures within the flood zone could be quantified. This showed possible mitigation opportunities in flood loss prevention and the effectiveness of past activities. For example, in the City of Lake Oswego an estimated 32 buildings exposed to flooding are elevated above the base flood elevation (BFE). Based on the number of buildings exposed to flooding throughout the county, many would benefit from elevating structures above the level of flooding.
- **Landslide risk is significant for steeper areas in the county**—The landslide mapping used in this study was created using lidar and modern mapping methods to develop very accurate landslide hazard maps. We used an exposure analysis to assess the threat from landslide hazards. The developed areas along Highway 26, in Welches, and along the Sandy River at Zigzag are at Very High risk from landslide hazard within the community of the Villages at Mount Hood. Approximately 15% of the buildings in Estacada and West Linn are exposed to Very High or High landslide hazard.
- **Exposure analysis shows that buildings along the Sandy River are at risk from channel migration hazard**—Exposure analysis shows that channel migration hazard is a threat to communities and buildings along the Sandy River. The Villages at Mount Hood have Very High risk from channel migration hazard, with approximately one-third of the buildings exposed to the hazard.
- **Volcanic lahar hazard is a threat for buildings along the Sandy River in the Villages at Mount Hood**—We used exposure analysis to estimate the level of risk from volcanic lahar hazard. Developed areas within the river valleys along Highway 26 on the western slope of Mount Hood have a High exposure to volcanic lahar hazard. Government Camp and the Villages at Mount Hood have a Very High risk from volcanic lahar hazard, with 61% exposure for Government Camp and 71% for the Villages at Mount Hood.
- **Wildfire risk is higher in the wildland-urban interface portions of the county**—Exposure analysis shows that buildings located in the heavily forested portions of western Clackamas County are at higher risk from wildfire than other areas in the county. The communities at highest risk from wildfire are Government Camp, the Villages at Mount Hood, and Estacada. In general, the WUI in nearly every community has at least some risk from wildfire. This is especially true for eastern portions of the county.
- **Most of the study area's critical facilities are at greatest risk from earthquake hazard, relative to other hazards in the study area**— Because of their importance during and after a natural disaster, we identified and examined critical facilities. We have estimated that 61% (178 of 294) of Clackamas County's critical facilities will be nonfunctioning after a CSZ Mw 9.0 earthquake and 43% (127 of 294) will be nonfunctioning after a Canby-Molalla Fault Mw 6.8

earthquake. We found that a small number of critical facilities are exposed to flood (10) and wildfire (12) hazards.

- **The biggest causes of displacement of population are landslide hazard and wildfire hazard**—Potential displacement of permanent residents from natural hazards was estimated within this report. We estimated that there is risk to 7.4% of the population in the county from landslide hazard and 7.1% are exposed to High or Moderate wildfire risk. A CSZ earthquake is estimated to displace 2.6% of the county's population and the Canby-Molalla Fault is estimated to displace 4% of the permanent population. A small percentage of residents are vulnerable to displacement from flood, channel migration, and volcanic lahar hazards.
- **The results allow communities to compare across hazards and prioritize their needs**—Each community within the study area was assessed for natural hazard exposure and loss. This allowed for comparison of risk for a specific hazard between communities. It also allows for a comparison between different hazards, though care must be taken to distinguish loss estimates and exposure results. The loss estimates and exposure analyses can assist in developing plans that address the concerns of those individual communities.

5.0 LIMITATIONS

There are several limitations to keep in mind when interpreting the results of this risk assessment.

- **Spatial and temporal variability of natural hazard occurrence** – With the exception of earthquakes, other hazards like flood, landslide, channel migration, volcanic lahar, and wildfire are extremely unlikely to occur across the fully mapped extent of the hazard zones. For example, areas mapped in the 100-year flood zone will be prone to flooding on occasion in certain watersheds during specific events, but not all at once throughout the entire county or even an entire community. While we report the overall impacts of a given hazard scenario, the losses from a single hazard event probably will not be as severe and widespread.
- **Loss estimation for individual buildings** – Hazus-MH is a model, not reality, which is an important factor when considering the loss ratio of an individual building. On-the-ground mitigation, such as elevation of buildings to avoid flood loss, has been only minimally captured. Also, due to a lack of building material information, assumptions were made about the distribution of wood, steel, and unreinforced masonry buildings. Loss estimation is most insightful when individual building results are aggregated to the community level because it reduces the impact of data outliers.
- **Loss estimation versus exposure** – We recommend careful interpretation of exposure results. This is due to the spatial and temporal variability of natural hazards (described above) and the inability to perform loss estimations due to the lack of Hazus-MH damage functions. Exposure is reported in terms of total building value, which could imply a total loss of the buildings in a particular hazard zone, but this is not the case. Exposure is simply a calculation of the number of buildings and their value and does not make estimates about the level to which an individual building could be damaged.
- **Population variability** – Some of the communities in Clackamas County have vacation homes and rentals, which are typically occupied during the summer. Our estimates of potentially displaced people rely on permanent populations published in the PSU Population Research Center

estimates of permanent residents. As a result, we are slightly underestimating the number of people that may be in harm's way on a summer weekend.

- **Data accuracy and completeness** – Some datasets in our risk assessment had incomplete coverage or lacked high-resolution data within the study area. We used lower-resolution data where there was incomplete coverage or where high-resolution data was not available. We made assumptions to amend areas of incomplete data coverage based on reasonable methods described within this report. Data layers in which assumptions were made to fill gaps are building footprints, population, some building specific attributes, and landslide susceptibility. Many of the datasets included known or suspected artifacts, omissions, and errors, however repairing these problems was beyond the scope of the project and are areas needing additional research. We are aware that some uncertainty has been introduced from these data amendments at an individual building scale, but at community-wide scales the effects of the uncertainties are slight.
- **Changing Conditions** – This assessment did not account for potential changes in climate, land use, or population; it is a snapshot of Clackamas County's current risk from natural hazards. Human-induced climate change poses a significant and widespread risk to people around the world. In Oregon, climate change is expected to increase the frequency and intensity of floods, wildfires, and landslides, but quantifying this change was beyond the scope of this study.

6.0 RECOMMENDATIONS

The following actions are needed to better understand hazards and reduce risk to natural hazard through mitigation planning. These implementation areas, while not comprehensive, touch on all phases of risk management and focus on awareness and preparation, planning, emergency response, mitigation funding opportunities, and hazard-specific risk reduction activities.

6.1 Awareness and Preparation

Natural hazard awareness is crucial to lowering risk and lessening the impacts of natural hazards. When community members understand their risk and know the role that they play in preparedness, the community will become a much safer place to live. Awareness and preparation not only reduce the initial impact from natural hazards, but they also reduce the time a community needs to recover from a disaster, commonly referred to as "resilience."

This report is intended to provide local officials with a comprehensive and authoritative profile of natural hazard risk to underpin their public outreach efforts.

Messaging can be tailored to stakeholder groups. For example, outreach to homeowners could focus on actions they can take to reduce risk to their property. The DOGAMI Homeowners Guide to Landslides[5] provides a variety of risk reduction options for homeowners who live in high landslide susceptibility areas. This guide is one of many existing resources. Agencies partnering with local officials in the development of additional effective resources could help reach a broader community and user groups.

[5] https://www.oregon.gov/dogami/Landslide/Documents/Landslide_Hazards_Land_Use_Guide_2019.pdf

6.2 Planning

This report can help local decisionmakers develop their local plans by identifying geohazards and associated risks to the community. The primary framework for accomplishing this is through the comprehensive planning process. The comprehensive plan sets the long-term trajectory of capital improvements, zoning, and urban growth boundary expansion, all of which are planning tools that can be used to reduce natural hazard risk.

Another framework is the NHMP process. NHMP plans focus on characterizing natural hazard risk and identifying actions to reduce risk. Additionally, the information presented here can be a resource when updating the mitigation actions and inform the vulnerability assessment section of the NHMP plan.

While there are many similarities between this report and an NHMP, the primary difference is that the risk assessment is not a planning document. Additional differences can be the hazards or critical facilities examined in each report. Differences between the reports may be due to data availability or limited methodologies for specific hazards. The critical facilities considered in this report may not be identical to those listed in a typical NHMP due to the lack of damage functions in Hazus-MH for non-building structures and to different considerations about emergency response during and after a disaster.

6.3 Emergency Response

Critical facilities will play a major role during and immediately after a natural disaster. This study can help emergency managers identify vulnerable critical facilities and develop contingency plans. Additionally, detailed mapping of potentially displaced residents can be used to re-evaluate evacuation routes and identify vulnerable populations to target for early warning.

The building database that accompanies this report presents many opportunities for future pre-disaster mitigation, emergency response, and community resilience improvements. Vulnerable areas can be identified and targeted for awareness campaigns. These campaigns can be aimed at pre-disaster mitigation through, for example, improvements of the structural connection of a building's frame to its foundation. Emergency response entities can benefit from the use of the building dataset through identification of potential hazards and populated buildings before and during a disaster. Both reduction of the magnitude of the disaster and a decrease in the response time contribute to a community's overall resilience.

6.4 Mitigation Funding Opportunities

Several state and federal funding options are available to communities that are susceptible to natural hazards and have specific cost-effective mitigation projects they wish to accomplish. The Oregon Office of Emergency Management (OEM) State Hazard Mitigation Officer (SHMO) can provide communities assistance in determining eligibility, finding mitigation grants, and navigating the mitigation grant application process. OEM has produced a document that can assist local officials in applying for mitigation funds[6].

At the time of writing this report, FEMA has five programs that assist with mitigation funding for natural hazards: Hazard Mitigation Grant Program (HMGP), HMGP Post-Fire Assistance, Pre-Disaster Mitigation (PDM) Grant Program, Building Resilient Infrastructure and Communities (BRIC) grant

[6] https://www.oregon.gov/OEM/Documents/Oregon_Hazard_Mitigation_Grant_Program_Handbook.pdf

program, and Flood Mitigation Assistance (FMA)[7]. The SHMO can help with finding further opportunities for earthquake and tsunami assistance and funding.

6.5 Hazard-Specific Risk Reduction Actions

6.5.1 Earthquake

- Evaluate critical facilities for seismic preparedness by identifying structural deficiencies and vulnerabilities to dependent systems (e.g., water, fuel, power).
- Evaluate vulnerabilities of critical facilities. We estimate that 61% of critical facilities be damaged by a CSZ earthquake scenario described in this report, which will have many direct and indirect negative effects on first-response and recovery efforts.
- Identify communities and buildings that would benefit from seismic upgrades.

6.5.2 Flood

- Map areas of potential flood water storage areas.
- Identify structures that have repeatedly flooded in the past and would be eligible for FEMA's "buyout" program.
- Additional risk reduction strategies may be found on FEMA's website at https://www.ready.gov/floods.

6.5.3 Landslide

- Create modern landslide inventory and susceptibility maps.
- Monitor ground movement in high susceptibility areas.
- Evaluate risks to transportation networks and land value losses due to landslides in future risk assessments.
- Study the risk from landslides that are experience channel erosion at the toe of the landslide.
- Additional risk reduction strategies may be found on FEMA's website at https://www.ready.gov/landslides-debris-flow.

6.5.4 Channel migration

- Future development in areas with the largest CMZs, particularly Sandy River, could incorporate CMZ mitigation strategies into plans and designs.
- Evaluate the losses in land value or productivity due to channel migration.
- Evaluate risks to transportation networks and bridges due to channel migration.
- Identify areas suitable for conservation corridors along rivers that are at risk from channel migration. These can be multi-purpose including areas that provide or improve flood water storage, riparian and aquatic habitat restoration, climate change resilience, and water quality.

6.5.5 Wildfire-related geologic hazards

- Evaluate post-wildfire geologic hazards including flood, debris flows, and landslides.
- Additional risk reduction strategies may be found on FEMA's website at https://www.ready.gov/wildfires.

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[7] https://www.fema.gov/grants/mitigation

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9.0 APPENDICES

APPENDIX A. COMMUNITY RISK PROFILES

A risk analysis summary for each community is provided in this section to encourage ideas for natural hazard risk reduction. Increasing disaster preparedness, public hazards communication, and education, ensuring functionality of emergency services, and ensuring access to evacuation routes are actions that every community can take to reduce their risk. This appendix contains community specific data to provide an overview of the community and the level of risk from each natural hazard analyzed. In addition, for each community a list of critical facilities and assumed impact from individual hazards is provided.

A.1 Unincorporated Clackamas County (Rural)

Table A-1. Unincorporated Clackamas County (rural) hazard profile.

Community Overview				
Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)
Unincorporated Clackamas County (rural)	176,427	94,866	100	36,478,644,000

Hazus-MH Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Damaged Buildings	Damaged Critical Facilities	Loss Estimate ($)	Loss Ratio
Flood[2]	1% Annual Chance	1,532	0.9%	713	0	53,332,000	0.1%
Earthquake	CSZ Mw 9.0 Deterministic	5,497	3.1%	9,616	59	5,175,264,000	14%
Earthquake	Canby-Molalla Fault Mw 6.8 Deterministic	4020	2.3%	9481	22	3,236,598,000	8.9%

Exposure Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Exposure Ratio
Landslide	High and Very High Susceptibility	12,965	7.3%	5,956	7	2,135,109,000	5.9%
Channel Migration	Channel Migration Zone	279	0.2%	99	0	35,754,000	0.1%
Wildfire	High and Moderate Risk	16,526	9.4%	9,833	10	2,906,461,000	8.0%
Volcanic Lahar	1% Annual Chance	0	0%	0	0	0	0%

[1]Facilities with multiple buildings were consolidated into one building complex.

[2]No damage is estimated for exposed structures with "First floor height" above the level of flooding (base flood elevation).

Table A-2. Unincorporated Clackamas County (rural) critical facilities.

	Flood 1% Annual Chance	CSZ 9.0 Earthquake Moderate to Complete Damage	Canby-Molalla Fault Mw 6.8 Moderate to Complete Damage	Landslide High and Very High Susceptibility	Channel Migration Zone	Wildfire High or Moderate Risk	Volcanic Lahar - 1% Annual Chance
Critical Facilities by Community	**Exposed**	**>50% Prob.**	**>50% Prob.**	**Exposed**	**Exposed**	**Exposed**	**Exposed**
Alder Creek Middle School	-	X	X	-	-	-	-
Beavercreek Elementary	-	X	-	-	-	-	-
Bilquist Elementary	-	X	X	-	-	-	-
Boring Middle School	-	X	-	-	-	-	-
Boring STP	-	-	-	-	-	-	-
Bridgeport Elementary School	-	X	X	-	-	-	-
Bull Run Power Plant	-	-	-	X	-	X	-
Butte Creek Elementary School	-	X	X	-	-	-	-
Canby Fire District 65	-	X	X	-	-	-	-
Candy Lane Elementary School	-	X	-	-	-	-	-

Critical Facilities by Community	Flood 1% Annual Chance	CSZ 9.0 Earthquake Moderate to Complete Damage	Canby-Molalla Fault Mw 6.8 Moderate to Complete Damage	Landslide High and Very High Susceptibility	Channel Migration Zone	Wildfire High or Moderate Risk	Volcanic Lahar - 1% Annual Chance
	Exposed	>50% Prob.	>50% Prob.	Exposed	Exposed	Exposed	Exposed
Carus School	-	X	-	-	-	-	-
Carver School	-	X	-	X	-	-	-
Cascade Heights Public Charter School	-	X	X	-	-	-	-
CHRIST THE KING PARISH SCHOOL	-	X	-	-	-	-	-
Christa McAuliffe Academy - School of Arts and Sciences	-	X	X	-	-	-	-
Clackamas County Sheriffs Office	-	X	-	-	-	-	-
Clackamas County Sheriffs Office - North Station	-	X	-	-	-	-	-
Clackamas County Sheriffs Office - Public Safety Training Center	-	-	-	-	-	-	-
Clackamas Day School	-	X	-	-	-	-	-
Clackamas Fire District #1 - Station 1	-	X	-	-	-	-	-
Clackamas Fire District #1 - Station 10	-	-	-	-	-	-	-
Clackamas Fire District #1 - Station 11	-	-	-	-	-	-	-
Clackamas Fire District #1 - Station 12	-	X	-	-	-	-	-
Clackamas Fire District #1 - Station 13	-	-	-	-	-	-	-
Clackamas Fire District #1 - Station 14	-	X	-	-	-	-	-
Clackamas Fire District #1 - Station 18	-	-	-	-	-	-	-
Clackamas Fire District #1 - Station 19	-	-	-	-	-	-	-
Clackamas Fire District #1 - Station 20	-	-	-	-	-	-	-
Clackamas Fire District #1 - Station 21	-	-	-	-	-	-	-
Clackamas Fire District #1 - Station 3	-	-	-	-	-	-	-
Clackamas Fire District #1 - Station 4	-	-	-	-	-	-	-
Clackamas High School	-	X	-	-	-	-	-
CLACKAMAS MIDDLE COLLEGE	-	X	-	-	-	-	-
Clackamas River Water	-	X	-	-	-	-	-
Clackamas Web Academy	-	X	X	-	-	-	-
Clarkes Elementary School	-	-	-	-	-	-	-
Colton Elementary	-	-	-	-	-	-	-
Colton High School	-	-	-	-	-	X	-
Colton Middle School	-	-	-	-	-	-	-
Colton RFPD and Water District	-	-	-	-	-	-	-
Colton Solar	-	-	-	-	-	-	-
Colton Water Treatment	-	-	-	-	-	-	-
Concord Elementary School	-	-	-	-	-	-	-
Damascus Christian School	-	X	-	-	-	-	-
Damascus Middle School	-	X	-	-	-	-	-
Deep Creek Elementary School	-	X	-	-	-	-	-
Elliott Prairie Christian School	-	X	X	-	-	-	-
Estacada RFPD Fire Station 333	-	-	-	-	-	X	-
Firwood Elementary	-	-	-	-	-	X	-
Good Shepherd School	-	-	-	-	-	-	-

Critical Facilities by Community	Flood 1% Annual Chance	CSZ 9.0 Earthquake Moderate to Complete Damage	Canby-Molalla Fault Mw 6.8 Moderate to Complete Damage	Landslide High and Very High Susceptibility	Channel Migration Zone	Wildfire High or Moderate Risk	Volcanic Lahar - 1% Annual Chance
	Exposed	>50% Prob.	>50% Prob.	Exposed	Exposed	Exposed	Exposed
HAPPY VALLEY MONTESSORI SCHOOL	-	X	-	-	-	-	-
Hood View Junior Academy	-	X	-	-	-	-	-
Jennings Lodge Elementary School	-	X	-	-	-	-	-
Kaiser Sunnyside Medical Center	-	X	-	X	-	-	-
Kelso Elementary School	-	-	-	-	-	-	-
La Salle Catholic College Preparatory	-	X	X	-	-	-	-
Legacy Meridian Park Hospital	-	X	X	-	-	-	-
LEWIS AND CLARK MONTESSORI CHARTER SCHOOL	-	X	-	-	-	-	-
Molalla RFPD 73 - Station 3	-	-	-	-	-	-	-
Mount Scott Elementary School	-	X	-	-	-	-	-
Naas Elementary School	-	-	-	-	-	-	-
New Urban High School	-	-	X	-	-	-	-
Ninety-One School	-	X	-	-	-	-	-
NORTHWEST COLLEGE-CLACKAMAS	-	X	-	-	-	-	-
Oak Grove Elementary School	-	X	-	-	-	-	-
Oak Grove Learning Tree Day School	-	-	-	-	-	-	-
Oak Grove Power Plant	-	-	-	X	-	X	-
Oak Lodge Sanitary District	-	X	X	-	-	-	-
Ogden Middle School	-	X	X	-	-	-	-
OREGON TRAIL ACADEMY	-	-	-	-	-	-	-
Oregon Trail Elementary School	-	X	-	-	-	-	-
PGE Hydro Plant - Faraday	-	X	X	-	-	-	-
Powerhouse Plant - Bull Run 2	-	X	-	X	-	X	-
Providence Medical Group - Sunnyside	-	X	-	-	-	-	-
Redland Elementary School	-	X	-	-	-	-	-
Renaissance Public Academy	-	-	-	-	-	X	-
Rex Putnam High School	-	X	-	-	-	-	-
River Mill Power Plant	-	-	-	-	-	-	-
Riverside Elementary School	-	X	X	-	-	-	-
Sandy RFPD 72 - Dover Station	-	-	-	-	-	-	-
Sandy RFPD 72 - Roslyn Station	-	-	-	-	-	-	-
Sandy WWTP	-	-	-	X	-	-	-
School Building	-	X	X	-	-	-	-
SPRING MOUNTAIN CHRISTIAN ACADEMY	-	-	-	-	-	-	-
Springwater Environmental Sciences	-	X	-	-	-	-	-
Stafford Academy	-	X	X	-	-	-	-
Stone Creek Hydroelectric	-	-	-	-	-	X	-
SUMMIT LEARNING CHARTER	-	X	-	-	-	-	-
Sunnyside Elementary School	-	X	-	-	-	-	-
Sunrise Middle School	-	-	-	-	-	-	-

	Flood 1% Annual Chance	CSZ 9.0 Earthquake Moderate to Complete Damage	Canby-Molalla Fault Mw 6.8 Moderate to Complete Damage	Landslide High and Very High Susceptibility	Channel Migration Zone	Wildfire High or Moderate Risk	Volcanic Lahar - 1% Annual Chance
Critical Facilities by Community	**Exposed**	**>50% Prob.**	**>50% Prob.**	**Exposed**	**Exposed**	**Exposed**	**Exposed**
The Childrens Hour Academy	-	X	X	-	-	-	-
Timothy Lake Power Plant	-	-	-	-	-	-	-
Trinity Luthern Church and School	-	X	-	-	-	-	-
Tualatin Valley Fire and Rescue - Station 57	-	-	X	-	-	-	-
USFS – Mt. Hood National Forest	-	-	-	X	-	X	-
USFW - Eagle Creek National Fish Hatchery	-	X	-	-	-	-	-
View Acres Elementary School	-	X	-	-	-	-	-
West Lake Montessori School	-	X	X	-	-	-	-
Whitcomb Elementary School	-	X	X	-	-	-	-
Wichita Elementary School	-	X	-	-	-	-	-

A.2 Unincorporated Community of Government Camp

Table A-3. Unincorporated community of Government Camp hazard profile.

Community Overview					
Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)	
Government Camp	1,355	832	2	289,100,000	

Hazus-MH Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Damaged Buildings	Damaged Critical Facilities	Loss Estimate ($)	Loss Ratio
Flood[2]	1% Annual Chance	10	0.7%	15	0	177,000	0.1%
Earthquake	CSZ Mw 9.0 Deterministic	4	0.3%	5	0	5,706,000	2.0%
Earthquake	Canby-Molalla Fault Mw 6.8 Deterministic	0	0	0	0	510,000	0.2%

Exposure Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Exposure Ratio
Landslide	High and Very High Susceptibility	225	17%	28	0	3,635,000	1.3%
Channel Migration	Channel Migration Zone	0	0%	0	0	0	0%
Wildfire	High and Moderate Risk	1,046	77%	675	0	192,249,000	66%
Volcanic Lahar	1% Annual Chance	958	71%	412	0	140,344,000	49%

[1]Facilities with multiple buildings were consolidated into one building complex.

[2]No damage is estimated for exposed structures with "First floor height" above the level of flooding (base flood elevation).

Table A-4. Unincorporated community of the Government Camp critical facilities.

	Flood 1% Annual Chance	**CSZ 9.0 Earthquake Moderate to Complete Damage**	**Canby-Molalla Fault Mw 6.8 Moderate to Complete Damage**	**Landslide High and Very High Susceptibility**	**Channel Migration Zone**	**Wildfire High or Moderate Risk**	**Volcanic Lahar 100-year**
Critical Facilities by Community	**Exposed**	**>50% Prob.**	**>50% Prob.**	**Exposed**	**Exposed**	**Exposed**	**Exposed**
Mount Hood Academy	-	-	-	-	-	-	-
Government Camp STP	-	-	-	-	-	-	-

A.3 Unincorporated Community of Molalla Prairie

Table A-5. Unincorporated community of Molalla Prairie hazard profile.

Community Overview				
Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)
Molalla Prairie	4,507	4,123	3	1,313,253,000

Hazus-MH Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Damaged Buildings	Damaged Critical Facilities	Loss Estimate ($)	Loss Ratio
Flood[2]	1% Annual Chance	41	0.9%	38	0	471,000	0.0%
Earthquake	CSZ Mw 9.0 Deterministic	27	0.6%	361	1	92,746,000	7.1%
Earthquake	Canby-Molalla Fault Mw 6.8 Deterministic	217	4.8%	1275	3	319,440,000	24%

Exposure Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Exposure Ratio
Landslide	High and Very High Susceptibility	89	2.0%	86	0	22,229,000	1.7%
Wildfire	High and Moderate Risk	219	4.9%	161	0	30,032,000	2.3%

[1]Facilities with multiple buildings were consolidated into one building complex.

[2]No damage is estimated for exposed structures with "First floor height" above the level of flooding (base flood elevation).

Table A-6. Unincorporated community of Molalla Prairie critical facilities.

Critical Facilities by Community	Flood 1% Annual Chance	CSZ 9.0 Earthquake Moderate to Complete Damage	Canby-Molalla Fault Mw 6.8 Moderate to Complete Damage	Landslide High and Very High Susceptibility	Wildfire High or Moderate Risk
	Exposed	**>50% Prob.**	**>50% Prob.**	**Exposed**	**Exposed**
Country Christian School	-	-	X	-	-
Molalla River Academy	-	X	X	-	-
Rural Dell Elementary	-	-	X	-	-

A.4 Unincorporated Community of Mulino Hamlet

Table A-7. Unincorporated community of Mulino Hamlet hazard profile.

Community Overview				
Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)
Mulino Hamlet	2,777	2,021	2	584,353,000

Hazus-MH Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Damaged Buildings	Damaged Critical Facilities	Loss Estimate ($)	Loss Ratio
Flood[2]	1% Annual Chance	194	7.0%	167	0	12,113,000	2.1%
Earthquake	CSZ Mw 9.0 Deterministic	39	1.4%	253	2	56,845,000	9.7%
Earthquake	Canby-Molalla Fault Mw 6.8 Deterministic	98	3.5	460	2	103,543,000	18%

Exposure Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Exposure Ratio
Landslide	High and Very High Susceptibility	307	11.0%	236	0	62,544,000	10.7%
Wildfire	High and Moderate Risk	100	3.6%	59	0	17,077,000	2.9%

[1]Facilities with multiple buildings were consolidated into one building complex.

[2]No damage is estimated for exposed structures with "First floor height" above the level of flooding (base flood elevation).

Table A-8. Unincorporated community of Mulino Hamlet critical facilities.

	Flood 1% Annual Chance	CSZ 9.0 Earthquake Moderate to Complete Damage	Canby-Molalla Fault Mw 6.8 Moderate to Complete Damage	Landslide High and Very High Susceptibility	Wildfire High or Moderate Risk
Critical Facilities by Community	**Exposed**	**>50% Prob.**	**>50% Prob.**	**Exposed**	**Exposed**
Molalla RFPD 73 - Station 2	-	X	X	-	-
Mulino Elementary	-	X	X	-	-

A.5 Unincorporated Community of Stafford Hamlet

Table A-9. Unincorporated community of Stafford Hamlet hazard profile.

Community Overview				
Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)
Stafford Hamlet	3,141	1,206	3	564,063,000

Hazus-MH Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Damaged Buildings	Damaged Critical Facilities	Loss Estimate ($)	Loss Ratio
Flood[2]	1% Annual Chance	106	3.4%	40	0	3,531,000	0.6%
Earthquake	CSZ Mw 9.0 Deterministic	41	1.3%	108	3	46,586,000	8.3%
Earthquake	Canby-Molalla Fault Mw 6.8 Deterministic	151	4.8%	262	3	107,325,000	19%

Exposure Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Exposure Ratio
Landslide	High and Very High Susceptibility	298	9.5%	102	0	46,730,000	8.3%
Wildfire	High and Moderate Risk	134	4.3%	37	0	17,872,000	3.2%

[1]Facilities with multiple buildings were consolidated into one building complex.

[2]No damage is estimated for exposed structures with “First floor height” above the level of flooding (base flood elevation).

Table A-10. Unincorporated community of Stafford Hamlet critical facilities.

	Flood 1% Annual Chance	**CSZ 9.0 Earthquake Moderate to Complete Damage**	**Canby-Molalla Fault Mw 6.8 Moderate to Complete Damage**	**Landslide High and Very High Susceptibility**	**Wildfire High or Moderate Risk**
Critical Facilities by Community	**Exposed**	**>50% Prob.**	**>50% Prob.**	**Exposed**	**Exposed**
Arbor School of Arts and Sciences	-	X	X	-	-
Athey Creek Middle	-	X	X	-	-
Stafford Primary School	-	X	X	-	-

A.6 Unincorporated Community of the Villages at Mount Hood

Table A-11. Unincorporated community of the Villages at Mount Hood hazard profile.

Community Overview					
Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)	
The Villages at Mount Hood	8,596	3,796	6	1,297,133,000	

Hazus-MH Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Damaged Buildings	Damaged Critical Facilities	Loss Estimate ($)	Loss Ratio
Flood[2]	1% Annual Chance	338	3.9%	117	0	3,739,000	0.3%
Earthquake	CSZ Mw 9.0 Deterministic	74	0.9%	183	1	44,545,000	3.4%
Earthquake	Canby-Molalla Fault Mw 6.8 Deterministic	4	0%	12	0	4,824,000	0.4%

Exposure Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Exposure Ratio
Landslide	High and Very High Susceptibility	1,047	12%	420	0	144,822,000	11.2%
Channel Migration	Channel Migration Zone	3,003	35%	1,117	0	384,764,000	30%
Wildfire	High and Moderate Risk	7,460	87%	3,197	2	1,075,757,000	83%
Volcanic Lahar	1% Annual Chance	622	7.2%	255	0	79,457,000	6.1%

[1]Facilities with multiple buildings were consolidated into one building complex.

[2]No damage is estimated for exposed structures with "First floor height" above the level of flooding (base flood elevation).

Table A-12. Unincorporated community of the Villages at Mount Hood critical facilities.

	Flood 1% Annual Chance	**CSZ 9.0 Earthquake Moderate to Complete Damage**	**Canby-Molalla Fault Mw 6.8 Moderate to Complete Damage**	**Landslide High and Very High Susceptibility**	**Channel Migration Zone**	**Wildfire High or Moderate Risk**	**Volcanic Lahar 100-year**
Critical Facilities by Community	**Exposed**	**>50% Prob.**	**>50% Prob.**	**Exposed**	**Exposed**	**Exposed**	**Exposed**
Hoodland RFPD 74	-	-	-	-	-	-	-
Hoodland RFPD 74 - Station 252	-	X	-	-	-	-	-
Hoodland STP	-	-	-	-	-	X	-
Mt Hood National Forest – Zigzag Ranger Station	-	-	-	-	-	X	-
Welches Elementary School	-	-	-	-	-	-	-
Welches Middle School	-	-	-	-	-	-	-

A.7 City of Barlow

Table A-13. City of Barlow hazard profile.

Community Overview				
Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)
Barlow	138	60	0	18,955,000

Hazus-MH Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Damaged Buildings	Damaged Critical Facilities	Loss Estimate ($)	Loss Ratio
Flood[2]	1% Annual Chance	0	0.0%	0	0	0	0.0%
Earthquake	CSZ Mw 9.0 Deterministic	7	5.0%	20	0	6,908,000	36%
Earthquake	Canby-Molalla Fault Mw 6.8 Deterministic	23	17%	35	0	11,469,000	61%

Exposure Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Exposure Ratio
Landslide	High and Very High Susceptibility	0	0%	0	0	0	0%
Wildfire	High and Moderate Risk	0	0%	0	0	0	0%

[1]Facilities with multiple buildings were consolidated into one building complex.

[2]No damage is estimated for exposed structures with “First floor height” above the level of flooding (base flood elevation).

A.8 City of Canby

Table A-14. City of Canby hazard profile.

Community Overview					
Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)
Canby	18,282	5,987	13	2,606,675,000

Hazus-MH Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Damaged Buildings	Damaged Critical Facilities	Loss Estimate ($)	Loss Ratio
Flood[2]	1% Annual Chance	3	0.0%	0	0	0	0.0%
Earthquake	CSZ Mw 9.0 Deterministic	516	2.8%	477	8	185,609,000	7.1%
Earthquake	Canby-Molalla Fault Mw 6.8 Deterministic	3,017	17%	2,210	12	811,347,000	31%

Exposure Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Exposure Ratio
Landslide	High and Very High Susceptibility	20	0.1%	11	1	19,528,000	0.7%
Wildfire	High and Moderate Risk	8	0.04%	9	0	2,924,000	0.1%

[1]Facilities with multiple buildings were consolidated into one building complex.

[2]No damage is estimated for exposed structures with "First floor height" above the level of flooding (base flood elevation).

Table A-15. City of Canby critical facilities.

	Flood 1% Annual Chance	CSZ 9.0 Earthquake Moderate to Complete Damage	Canby-Molalla Fault Mw 6.8 Moderate to Complete Damage	Landslide High and Very High Susceptibility	Wildfire High or Moderate Risk
Critical Facilities by Community	**Exposed**	**>50% Prob.**	**>50% Prob.**	**Exposed**	**Exposed**
Ackerman Middle School	-	X	X	-	-
Baker Prairie Middle School	-	X	X	-	-
Canby Fire District 62	-	-	X	-	-
Canby High School	-	X	X	-	-
Canby Police Department	-	-	-	X	-
Canby Public Works	-	X	X	-	-
Canby Sewage Treatment	-	X	X	-	-
Cecile Trost Elementary School	-	-	X	-	-
Howard Eccles Elementary School	-	X	X	-	-
Legacy Medical Group - Canby	-	X	X	-	-
Philander Lee Elementary School	-	X	X	-	-
Willamette Falls Health Center	-	-	X	-	-
William Knight Elementary School	-	-	X	-	-

A.9 City of Estacada

Table A-16. City of Estacada hazard profile.

Community Overview							
Community Name		Population	Number of Buildings		Critical Facilities[1]		Total Building Value ($)
Estacada		5,296	1,771		13		671,792,000
Hazus-MH Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Damaged Buildings	Damaged Critical Facilities	Loss Estimate ($)	Loss Ratio
Flood[2]	1% Annual Chance	0	0.0%	0	0	0	0.0%
Earthquake	CSZ Mw 9.0 Deterministic	39	0.7%	104	11	47,644,000	7.1%
Earthquake	Canby-Molalla Fault Mw 6.8 Deterministic	6	0.1%	18	1	10,934,000	1.6%
Exposure Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Exposure Ratio
Landslide	High and Very High Susceptibility	1,386	26.2%	371	0	101,977,000	15.2%
Wildfire	High and Moderate Risk	826	16%	212	0	60,822,000	9.1%

[1]Facilities with multiple buildings were consolidated into one building complex.

[2]No damage is estimated for exposed structures with "First floor height" above the level of flooding (base flood elevation).

Table A-17. City of Estacada critical facilities.

	Flood 1% Annual Chance	CSZ 9.0 Earthquake Moderate to Complete Damage	Canby-Molalla Fault Mw 6.8 Moderate to Complete Damage	Landslide High and Very High Susceptibility	Wildfire High or Moderate Risk
Critical Facilities by Community	**Exposed**	**>50% Prob.**	**>50% Prob.**	**Exposed**	**Exposed**
Adventist Health Urgent Care	-	X	-	-	-
Clackamas River Elementary School	-	-	-	-	-
Estacada City Hall	-	X	-	-	-
Estacada Community Center	-	X	-	-	-
Estacada High School	-	X	-	-	-
Estacada Junior High School	-	X	-	-	-
Estacada Public Works	-	-	-	-	-
Estacada RFPD No. 69	-	X	-	-	-
Estacada RFPD No. 69 - Administration	-	X	-	-	-
Estacada STP	-	X	-	-	-
Mount Hood National Forest - Clackamas River Ranger District - Estacada	-	X	-	-	-
Orchid Health Wade Creek Clinic	-	X	X	-	-
River Mill Elementary School	-	X	-	-	-

A.10 City of Gladstone

Table A-18. City of Gladstone hazard profile.

Community Overview					
Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)	
Gladstone	11,883	4,046	9	1,447,740,000	

Hazus-MH Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Damaged Buildings	Damaged Critical Facilities	Loss Estimate ($)	Loss Ratio
Flood[2]	1% Annual Chance	110	0.9%	29	0	2,756,000	0.2%
Earthquake	CSZ Mw 9.0 Deterministic	263	2.2%	369	7	120,946,000	8.4%
Earthquake	Canby-Molalla Fault Mw 6.8 Deterministic	241	2.0%	348	5	90,881,000	6.2%

Exposure Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Exposure Ratio
Landslide	High and Very High Susceptibility	974	8.2%	244	0	103,197,000	7.1%
Wildfire	High and Moderate Risk	0	0%	0	0	0	0%

[1]Facilities with multiple buildings were consolidated into one building complex.

[2]No damage is estimated for exposed structures with "First floor height" above the level of flooding (base flood elevation).

Table A-19. City of Gladstone critical facilities.

Critical Facilities by Community	Flood 1% Annual Chance	CSZ 9.0 Earthquake Moderate to Complete Damage	Canby-Molalla Fault Mw 6.8 Moderate to Complete Damage	Landslide High and Very High Susceptibility	Wildfire High or Moderate Risk
	Exposed	>50% Prob.	>50% Prob.	Exposed	Exposed
Gladstone Emergency Operations Center	-	X	-	-	-
Gladstone Fire Department	-	-	-	-	-
Gladstone High School	-	X	X	-	-
Gladstone Police Department	-	X	X	-	-
Gladstone Public Works	-	X	X	-	-
Grace Christian School	-	-	-	-	-
John Wetten Elementary School	-	X	X	-	-
Rivergate SDA School	-	X	X	-	-
Walter L Kraxberger Middle School	-	X	-	-	-

A.11 City of Happy Valley

Table A-20. City of Happy Valley hazard profile.

Community Overview				
Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)
Happy Valley	26,054	7,480	18	3,898,036,000

Hazus-MH Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Damaged Buildings	Damaged Critical Facilities	Loss Estimate ($)	Loss Ratio
Flood[2]	1% Annual Chance	68	0.3%	40	0	1,532,000	0.0%
Earthquake	CSZ Mw 9.0 Deterministic	396	1.5%	327	10	253,627,000	6.5%
Earthquake	Canby-Molalla Fault Mw 6.8 Deterministic	66	0.3%	77	0	53,400,000	1.4%

Exposure Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Exposure Ratio
Landslide	High and Very High Susceptibility	1,901	7.3%	428	0	255,501,000	6.6%
Wildfire	High and Moderate Risk	603	2.3%	188	0	76,503,000	1.9%

[1]Facilities with multiple buildings were consolidated into one building complex.

[2]No damage is estimated for exposed structures with "First floor height" above the level of flooding (base flood elevation).

Table A-21. City of Happy Valley critical facilities.

	Flood 1% Annual Chance	CSZ 9.0 Earthquake Moderate to Complete Damage	Canby-Molalla Fault Mw 6.8 Moderate to Complete Damage	Landslide High and Very High Susceptibility	Wildfire High or Moderate Risk
Critical Facilities by Community	**Exposed**	**>50% Prob.**	**>50% Prob.**	**Exposed**	**Exposed**
Academy for Kids	-	-	-	-	-
BEATRICE MORROW CANNADY ELEMENTARY	-	-	-	-	-
Clackamas Fire District #1 - Station 5	-	X	-	-	-
Clackamas Fire District #1 - Station 6	-	X	-	-	-
Clackamas Fire District #1 - Station 7	-	X	-	-	-
Clackamas Fire District #1 - Station 8	-	X	-	-	-
Clackamas Fire District #1 - Training Center	-	-	-	-	-
Happy Valley Emergency Operations Center	-	-	-	-	-
Happy Valley Public Works	-	-	-	-	-
Happy Valley Middle School	-	X	-	-	-
Happy Valley Police Department	-	-	-	-	-
Providence Medical Group - Happy Valley	-	X	-	-	-
Rock Creek Middle School	-	X	-	-	-
Scouters Mountain Elementary	-	X	-	-	-
Spring Mountain Elementary School	-	-	-	-	-
Sunnyside Montessori House	-	-	-	-	-
The Goddard School - Clackamas	-	-	-	-	-
VALLEY VIEW DAYSCHOOL	-	X	-	-	-
Verne A. Duncan Elementary	-	X	-	-	-

A.12 City of Johnson City

Table A-22. City of Johnson City hazard profile.

Community Overview					
Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)	
Johnson City	527	275	1	20,082,000	

Hazus-MH Analysis Summary

Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Damaged Buildings	Damaged Critical Facilities	Loss Estimate ($)	Loss Ratio
Flood[2]	1% Annual Chance	0	0.0%	0	0	0	0.0%
Earthquake*	CSZ Mw 9.0 Deterministic	415	78.7%	273	0	17,344,000	86%
Earthquake*	Canby-Molalla Fault Mw 6.8 Deterministic	44	8.4%	109	0	4,990,000	25%

Exposure Analysis Summary

Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Exposure Ratio
Landslide	High and Very High Susceptibility	8	1.6%	2	0	246,000	1.2%
Wildfire	High and Moderate Risk	0	0%	0	0	0	0%

[1]Facilities with multiple buildings were consolidated into one building complex.

[2]No damage is estimated for exposed structures with "First floor height" above the level of flooding (base flood elevation).

Table A-23. City of Johnson City critical facilities.

	Flood 1% Annual Chance	**CSZ 9.0 Earthquake Moderate to Complete Damage**	**Canby-Molalla Fault Mw 6.8 Moderate to Complete Damage**	**Landslide High and Very High Susceptibility**	**Wildfire High or Moderate Risk**
Critical Facilities by Community	**Exposed**	**>50% Prob.**	**>50% Prob.**	**Exposed**	**Exposed**
Johnson City Emergency Operations Center	-	-	-	-	-

A.13 City of Lake Oswego

Table A-24. City of Lake Oswego hazard profile.

Community Overview				
Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)
Lake Oswego	39,491	13,854	37	8,534,213,000

Hazus-MH Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Damaged Buildings	Damaged Critical Facilities	Loss Estimate ($)	Loss Ratio
Flood[2]	1% Annual Chance	224	0.6%	82	0	6,660,000	0.1%
Earthquake*	CSZ Mw 9.0 Deterministic	1,012	2.6%	752	16	664,983,000	7.8%
Earthquake*	Canby-Molalla Fault Mw 6.8 Deterministic	2,654	6.7%	2,353	24	1,481,727,000	17%

Exposure Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Exposure Ratio
Landslide	High and Very High Susceptibility	4,461	11.3%	1,305	0	791,483,000	9.3%
Wildfire	High and Moderate Risk	765	1.9%	233	0	124,835,000	1.5%

[1]Facilities with multiple buildings were consolidated into one building complex.

[2]No damage is estimated for exposed structures with “First floor height” above the level of flooding (base flood elevation).

Table A-25. City of Lake Oswego critical facilities.

Critical Facilities by Community	Flood 1% Annual Chance Exposed	CSZ 9.0 Earthquake Moderate to Complete Damage >50% Prob.	Canby-Molalla Fault Mw 6.8 Moderate to Complete Damage >50% Prob.	Landslide High and Very High Susceptibility Exposed	Wildfire High or Moderate Risk Exposed
Bethlehem Christian Preschool	-	-	X	-	-
Bryant Elementary and Waluga Jr High	-	X	X	-	-
CHINESE AMERICAN INTERNATIONAL SCHOOL	-	-	-	-	-
Forest Hills Elementary School	-	X	X	-	-
Hallinan Elementary School	-	-	X	-	-
HARMONY ACADEMY	-	X	X	-	-
INTERNATIONAL LEADERSHIP ACADEMY	-	X	X	-	-
Lake Grove Elementary School	-	-	X	-	-
Lake Oswego Armory	-	-	X	-	-
Lake Oswego Fire Department - Station 210	-	-	-	-	-
Lake Oswego Fire Department - Station 211	-	X	X	-	-
Lake Oswego Fire Department - Station 212	-	-	-	-	-
Lake Oswego City Hall	-	-	-	-	-
Lake Oswego Emergency Operations Center	-	-	X	-	-
Lake Oswego Fire Department - Station 214	-	-	-	-	-
Lake Oswego Junior High School	-	-	-	-	-
Lake Oswego Police Department	-	X	X	-	-
Lake Oswego Public Works	-	X	X	-	-
Lake Oswego Senior High School	-	X	X	-	-
Lakeridge High School	-	X	X	-	-
LAKERIDGE MIDDLE SCHOOL	-	X	X	-	-
Legacy Medical Group - Lake Oswego	-	-	-	-	-
Mountain Park Kindercare	-	-	-	-	-
Oak Creek Elementary School	-	-	-	-	-
Our Lady of the Lake School	-	X	X	-	-
Palisades Elementary School	-	-	X	-	-
Park Academy	-	X	X	-	-
Portland - Tryon Creek WWTP	-	X	X	-	-
Providence Medical Group - Mercantile	-	X	X	-	-
River Grove Elementary School	-	X	X	-	-
Sonshine Express Preschool	-	-	-	-	-
Touchstone Elementary School	-	-	-	-	-
Uplands Elementary School	-	-	X	-	-
VILLAGE MONTESSORI OF LAKE OSWEGO	-	-	-	-	-
West Hills Montessori School - Lake Oswego Campus	-	X	X	-	-
Westridge Elementary School	-	-	X	-	-
St. Stephens Academy	-	-	-	-	-

A.14 City of Milwaukie

Table A-26. City of Milwaukie hazard profile.

Community Overview					
Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)	
Milwaukie	20,555	7,936	16	3,656,357,000	

Hazus-MH Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Damaged Buildings	Damaged Critical Facilities	Loss Estimate ($)	Loss Ratio
Flood[2]	1% Annual Chance	130	0.6%	20	0	6,057,000	0.2%
Earthquake*	CSZ Mw 9.0 Deterministic	1,115	5.4%	1,045	16	1,090,161,000	30%
Earthquake*	Canby-Molalla Fault Mw 6.8 Deterministic	558	2.7%	745	13	471,364,000	13%

Exposure Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Exposure Ratio
Landslide	High and Very High Susceptibility	568	2.8%	102	0	73,838,000	2.0%
Wildfire	High and Moderate Risk	59	0.3%	10	0	5,567,000	0.2%

[1]Facilities with multiple buildings were consolidated into one building complex.

[2]No damage is estimated for exposed structures with "First floor height" above the level of flooding (base flood elevation).

Table A-27. City of Milwaukie critical facilities.

	Flood 1% Annual Chance	CSZ 9.0 Earthquake Moderate to Complete Damage	Canby-Molalla Fault Mw 6.8 Moderate to Complete Damage	Landslide High and Very High Susceptibility	Wildfire High or Moderate Risk
Critical Facilities by Community	**Exposed**	**>50% Prob.**	**>50% Prob.**	**Exposed**	**Exposed**
Ardenwald Elementary School	-	X	X	-	-
Campbell Elementary School	-	X	X	-	-
Clackamas Fire District #1 - Station 2	-	X	-	-	-
Kellogg Creek WWTP	-	X	X	-	-
Lewelling Elementary School	-	X	-	-	-
MILWAUKIE ACADEMY OF THE ARTS	-	X	X	-	-
Milwaukie Covenant Preschool	-	X	-	-	-
Milwaukie El Puente Elementary	-	X	X	-	-
Milwaukie Elementary School	-	X	X	-	-
Milwaukie High School	-	X	X	-	-
Milwaukie Public Works	-	X	X	-	-
Portland Waldorf School	-	X	X	-	-
Providence Milwaukie Hospital	-	X	X	-	-
Rowe Middle School	-	X	X	-	-

A.15 City of Molalla

Table A-28. City of Molalla hazard profile.

Community Overview							
Community Name		Population	Number of Buildings		Critical Facilities[1]	Total Building Value ($)	
Molalla		9,857	3,385		9	1,031,711,000	
Hazus-MH Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Damaged Buildings	Damaged Critical Facilities	Loss Estimate ($)	Loss Ratio
Flood[2]	1% Annual Chance	0	0.0%	0	0	0	0.0%
Earthquake*	CSZ Mw 9.0 Deterministic	10	0.1%	47	3	27,620,000	2.7%
Earthquake*	Canby-Molalla Fault Mw 6.8 Deterministic	409	4.1%	528	8	150,833,000	15%
Exposure Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Exposure Ratio
Landslide	High and Very High Susceptibility	0	0.0%	0	0	0	0.0%
Wildfire	High and Moderate Risk	505	5.1%	147	0	34,560,000	3.3%

[1]Facilities with multiple buildings were consolidated into one building complex.

[2]No damage is estimated for exposed structures with "First floor height" above the level of flooding (base flood elevation).

Table A-29. City of Molalla critical facilities.

	Flood 1% Annual Chance	**CSZ 9.0 Earthquake Moderate to Complete Damage**	**Canby-Molalla Fault Mw 6.8 Moderate to Complete Damage**	**Landslide High and Very High Susceptibility**	**Wildfire High or Moderate Risk**
Critical Facilities by Community	**Exposed**	**>50% Prob.**	**>50% Prob.**	**Exposed**	**Exposed**
Far Horizons Academy	-	-	-	-	-
Molalla Elementary School	-	-	X	-	-
Molalla High School	-	-	X	-	-
Molalla Police Department	-	-	X	-	-
Molalla Public Works	-	-	X	-	-
Molalla RFPD 73 - Station 1	-	-	X	-	-
Molalla River Middle School	-	X	X	-	-
Molalla STP	-	X	X	-	-
Molalla Urgent Care	-	X	X	-	-

A.16 City of Oregon City

Table A-30. City of Oregon City hazard profile.

Community Overview				
Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)
Oregon City	36,866	13,204	31	5,307,089,000

Hazus-MH Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Damaged Buildings	Damaged Critical Facilities	Loss Estimate ($)	Loss Ratio
Flood[2]	1% Annual Chance	44	0.1%	103	2	57,075,000	1.1%
Earthquake*	CSZ Mw 9.0 Deterministic	213	0.6%	477	24	340,167,000	6.4%
Earthquake*	Canby-Molalla Fault Mw 6.8 Deterministic	415	1.1%	696	12	431,898,000	0.8%

Exposure Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Exposure Ratio
Landslide	High and Very High Susceptibility	1,778	4.8%	533	0	205,419,000	3.9%
Wildfire	High and Moderate Risk	599	1.6%	173	0	60,071,000	1.1%

[1]Facilities with multiple buildings were consolidated into one building complex.

[2]No damage is estimated for exposed structures with "First floor height" above the level of flooding (base flood elevation).

Table A-31. City of Oregon City critical facilities.

Critical Facilities by Community	Flood 1% Annual Chance Exposed	CSZ 9.0 Earthquake Moderate to Complete Damage >50% Prob.	Canby-Molalla Fault Mw 6.8 Moderate to Complete Damage >50% Prob.	Landslide High and Very High Susceptibility Exposed	Wildfire High or Moderate Risk Exposed
Alliance Charter Academy	-	X	-	-	-
CLACKAMAS ACADEMY OF INDUSTRIAL SCIENCES	-	X	X	-	-
CLACKAMAS COMMUNITY COLLEGE	-	X	-	-	-
Clackamas Community College - Public Safety	-	-	-	-	-
Clackamas County Jail	-	X	X	-	-
Clackamas County Public Works	X	X	X	-	-
Clackamas County Sheriff's Lot	X	X	X	-	-
Clackamas County Sheriffs Office - South Station	-	-	-	-	-
Clackamas Fire District #1 - Station 15	-	X	X	-	-
Clackamas Fire District #1 - Station 16	-	X	-	-	-
Clackamas Fire District #1 - Station 17	-	-	-	-	-
Clackamas Fire District #1 - Station 9	-	-	-	-	-
Clackamas Middle School	-	-	-	-	-
Eye Health Northwest	-	X	-	-	-
Gaffney Lane Elementary School	-	X	-	-	-
Gardiner Middle School	-	X	-	-	-
Holcomb Elementary School	-	X	-	-	-
Jackson Building	-	X	X	-	-
John McLoughlin Elementary School	-	X	X	-	-
Kings Academy	-	X	X	-	-
Mt Pleasant Elementary School	-	X	-	-	-
North Clackamas Christian School	-	X	-	-	-
Oregon City Armory	-	X	-	-	-
Oregon City Police Department	-	X	-	-	-
Oregon City Senior High School	-	X	-	-	-
OREGON CITY SERVICE LEARNING ACADEMY	-	X	X	-	-
Providence Williamette Falls Hospital	-	X	X	-	-
St John the Apostle School	-	-	-	-	-
THE MARYLHURST SCHOOL	-	X	-	-	-
TRI-CITY SERVICE DISTRICT	-	-	X	-	-
Williamette Falls Hospital	-	X	X	-	-

A.17 City of Rivergrove

Table A-32. City of Rivergrove hazard profile.

Community Overview							
Community Name		Population	Number of Buildings		Critical Facilities[1]	Total Building Value ($)	
Rivergrove		558	197		0	95,954,000	
Hazus-MH Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Damaged Buildings	Damaged Critical Facilities	Loss Estimate ($)	Loss Ratio
Flood[2]	1% Annual Chance	141	25.3%	34	0	2,387,000	2.5%
Earthquake*	CSZ Mw 9.0 Deterministic	13	2.3%	23	0	7,818,000	8.1%
Earthquake*	Canby-Molalla Fault Mw 6.8 Deterministic	65	12%	65	0	22,557,000	24%
Exposure Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Exposure Ratio
Landslide	High and Very High Susceptibility	0	0.0%	0	0	0	0.0%
Wildfire	High and Moderate Risk	0	0.0%	0	0	0	0.0%

[1]Facilities with multiple buildings were consolidated into one building complex.

[2]No damage is estimated for exposed structures with “First floor height” above the level of flooding (base flood elevation).

A.18 City of Sandy

Table A-33. City of Sandy hazard profile.

Community Overview							
Community Name		Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)		
Sandy		12,213	4,115	8	1,472,547,000		
Hazus-MH Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Damaged Buildings	Damaged Critical Facilities	Loss Estimate ($)	Loss Ratio
Flood[2]	1% Annual Chance	6	0.1%	1	0	2,000	0.0%
Earthquake*	CSZ Mw 9.0 Deterministic	4	0.0%	16	1	17,258,000	1.2%
Earthquake*	Canby-Molalla Fault Mw 6.8 Deterministic	1	0.0%	6	0	5,619,000	0.4%
Exposure Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Exposure Ratio
Landslide	High and Very High Susceptibility	492	4.0%	127	0	41,371,000	2.8%
Channel Migration	Channel Migration Zone	0	0%	0	0	0	0%
Wildfire	High and Moderate Risk	1,386	11%	404	0	118,157,000	8.1%
Volcanic Lahard	1% Annual Chance	0	0%	0	0	0	0%

[1]Facilities with multiple buildings were consolidated into one building complex.

[2]No damage is estimated for exposed structures with "First floor height" above the level of flooding (base flood elevation).

Table A-34. City of Sandy critical facilities.

	Flood 1% Annual Chance	CSZ 9.0 Earthquake Moderate to Complete Damage	Canby-Molalla Fault Mw 6.8 Moderate to Complete Damage	Landslide High and Very High Susceptibility	Channel Migration Zone	Wildfire High or Moderate Risk	Volcanic Lahar
Critical Facilities by Community	**Exposed**	**>50% Prob.**	**>50% Prob.**	**Exposed**	**Exposed**	**Exposed**	**Exposed**
Cedar Ridge Middle School	-	X	-	-	-	-	-
Legacy Medical Group – Firwood	-	-	-	-	-	-	-
Mount Hood National Forest - Headquarters	-	-	-	-	-	-	-
Sandy Grade School	-	-	-	-	-	-	-
Sandy High School	-	-	-	-	-	-	-
Sandy Police Department	-	-	-	-	-	-	-
Sandy RFPD 72 - Main Station	-	-	-	-	-	-	-
Sandy Transit Operations Center	-	-	-	-	-	-	-

A.19 City of West Linn

Table A-35. City of West Linn hazard profile.

Community Overview				
Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)
West Linn	26,983	9,181	18	4,479,107,000

Hazus-MH Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Damaged Buildings	Damaged Critical Facilities	Loss Estimate ($)	Loss Ratio
Flood[2]	1% Annual Chance	165	0.6%	48	0	72,005,000	1.6%
Earthquake*	CSZ Mw 9.0 Deterministic	332	1.2%	422	15	235,282,000	5.3%
Earthquake*	Canby-Molalla Fault Mw 6.8 Deterministic	771	2.9%	926	13	382,272,000	8.5%

Exposure Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Exposure Ratio
Landslide	High and Very High Susceptibility	4,882	18.1%	1,376	2	721,697,000	16.1%
Wildfire	High and Moderate Risk	228	0.8%	74	0	32,427,000	0.7%

[1]Facilities with multiple buildings were consolidated into one building complex.

[2]No damage is estimated for exposed structures with "First floor height" above the level of flooding (base flood elevation).

Table A-36. City of West Linn critical facilities.

	Flood 1% Annual Chance	CSZ 9.0 Earthquake Moderate to Complete Damage	Canby-Molalla Fault Mw 6.8 Moderate to Complete Damage	Landslide High and Very High Susceptibility	Wildfire High or Moderate Risk
Critical Facilities by Community	**Exposed**	**>50% Prob.**	**>50% Prob.**	**Exposed**	**Exposed**
Bolton Primary School	-	X	X	-	-
Cedaroak Park Primary School	-	X	X	-	-
Columbia Academy	-	X	X	-	-
Legacy Medical Group - West Linn	-	X	X	-	-
Rosemont Ridge Middle School	-	-	-	-	-
Sullivan substation	-	X	X	-	-
SUNGARDEN MONTESSORI CENTER	-	X	X	-	-
Sunset Primary School	-	X	X	-	-
Three Rivers Charter School	-	-	-	X	-
Trillium Creek Primary School	-	-	-	-	-
Tualatin Valley Fire and Rescue - Station 58	-	X	X	-	-
Tualatin Valley Fire and Rescue - Station 59	-	X	X	-	-
West Linn High School	-	X	X	-	-
West Linn Kindercare	-	X	-	-	-
West Linn Montessori School	-	X	-	X	-
West Linn Police Department	-	X	X	-	-
West Linn Public Works	-	X	X	-	-
Willamette Primary School	-	X	X	-	-

A.20 City of Wilsonville

Table A-37. City of Wilsonville hazard profile.

Community Overview					
Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)	
Wilsonville	25,683	6,579	14	5,545,876,000	

Hazus-MH Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Damaged Buildings	Damaged Critical Facilities	Loss Estimate ($)	Loss Ratio
Flood[2]	1% Annual Chance	37	0.1%	5	0	201,000	0.0%
Earthquake*	CSZ Mw 9.0 Deterministic	1,285	5.0%	619	6	538,438,000	9.7%
Earthquake*	Canby-Molalla Fault Mw 6.8 Deterministic	4,597	18%	1,704	11	1,619,252,000	29%

Exposure Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Exposure Ratio
Landslide	High and Very High Susceptibility	512	2.0%	91	0	55,477,000	1.0%
Wildfire	High and Moderate Risk	235	0.9%	49	0	25,614,000	0.4%

[1]Facilities with multiple buildings were consolidated into one building complex.

[2]No damage is estimated for exposed structures with "First floor height" above the level of flooding (base flood elevation).

Table A-38. City of Wilsonville critical facilities.

Critical Facilities by Community	Flood 1% Annual Chance	CSZ 9.0 Earthquake Moderate to Complete Damage	Canby-Molalla Fault Mw 6.8 Moderate to Complete Damage	Landslide High and Very High Susceptibility	Wildfire High or Moderate Risk
	Exposed	>50% Prob.	>50% Prob.	Exposed	Exposed
Arts and Technology School	-	-	X	-	-
Boeckman Creek Primary School	-	X	X	-	-
Boones Ferry Primary School	-	-	-	-	-
Geneva Health Center and Urgent Care	-	-	X	-	-
Inza R. Wood Middle School	-	X	X	-	-
Lowrie Primary	-	-	-	-	-
Meridian Creek Middle	-	-	-	-	-
Tualatin Valley Fire and Rescue - Station 52	-	-	X	-	-
Tualatin Valley Fire and Rescue - Station 56	-	-	X	-	-
Victory Academy	-	X	X	-	-
Wilsonville Emergency Operations Center	-	X	X	-	-
Wilsonville High School	-	X	X	-	-
Wilsonville Public Works	-	-	X	-	-
Wilsonville Sewage Treatment	-	X	X	-	-

APPENDIX B. DETAILED RISK ASSESSMENT TABLES

Table B-1. Clackamas County building inventory.

(all dollar amounts in thousands)

	Residential			Commercial and Industrial			Agricultural			Public and Non-Profit			All Buildings			
Community	**Number of Buildings**	**Building Value ($)**	**Building Value per Community Total**	**Number of Buildings**	**Building Value ($)**	**Building Value per Community Total**	**Number of Buildings**	**Building Value ($)**	**Building Value per Community Total**	**Number of Buildings**	**Building Value ($)**	**Building Value per Community Total**	**Number of Buildings**	**Number of Buildings per Study Area Total**	**Building Value ($)**	**Value of Buildings per Study Area Total**
Unincorp. Clackamas Co (rural)	64,528	22,934,889	63%	2,498	6,018,705	16%	26,822	5,797,978	16%	1,018	1,466,883	4%	94,866	52%	36,218,454	46%
Government Camp	570	208,960	72%	53	45,888	16%	183	13,754	4.8%	26	20,497	7%	832	0.4%	289,100	0.4%
Molalla Prairie	1,712	567,720	43%	56	58,740	4.5%	2,319	657,563	50%	36	29,230	2.2%	4,123	2.2%	1,313,253	1.7%
Mulino Hamlet	1,079	355,559	61%	60	31,251	5.3%	855	168,567	28.8%	27	28,976	5.0%	2,021	1.1%	584,353	0.7%
Stafford Hamlet	839	407,848	72%	16	8,631	1.5%	294	59,950	10.6%	57	87,633	15.5%	1,206	0.7%	564,063	0.7%
The Villages at Mt Hood	3,090	1,129,292	87%	104	60,442	5%	536	59,694	4.6%	66	47,705	3.7%	3,796	2.1%	1,297,133	1.6%
Total Unincorporated County	71,818	25,604,268	64%	2,787	6,223,658	15.5%	31,009	6,757,507	16.8%	1,230	1,680,924	4.2%	106,844	58%	40,266,356	51%
Barlow	39	9,431	50%	5	6,193	32.7%	12	723	3.8%	4	2,607	14%	60	0.0%	18,955	0.0%
Canby	5,190	1,586,962	61%	343	683,398	26%	334	33,105	1%	120	303,210	12%	5,987	3.2%	2,606,675	3.3%
Estacada	1,430	388,177	58%	173	167,433	25%	110	11,008	1.6%	58	105,174	16%	1,771	1.0%	671,792	0.8%
Gladstone	3,418	1,159,859	80%	153	131,611	9%	410	29,264	2%	65	127,006	9%	4,046	2.2%	1,447,740	1.8%
Happy Valley	6,842	3,392,568	87%	109	99,650	3%	414	64,563	2%	115	341,254	8.8%	7,480	4.0%	3,898,036	4.9%
Johnson City	154	10,839	54%	0	0	0%	120	9,073	45%	1	170	1%	275	0%	20,082	0%
Lake Oswego	12,640	6,853,985	80%	469	1,109,392	13%	587	46,476	1%	158	524,359	6.1%	13,854	7%	8,534,213	11%
Milwaukie	6,685	2,010,339	55%	414	1,264,672	35%	720	51,398	1%	117	329,947	9%	7,936	4%	3,656,357	5%
Molalla	2,737	683,498	66%	204	174,605	17%	363	29,727	3%	81	143,880	14%	3,385	2%	1,031,711	1%
Oregon City	11,137	3,630,849	68%	664	929,298	4%	1,097	83,178	2%	306	663,766	13%	13,204	7%	5,307,089	7%
Rivergrove	190	95,437	99%	0	0	0%	7	516	1%	0	0	0%	197	0%	95,954	0%
Sandy	3,567	1,014,545	69%	250	248,170	17%	217	19,792	1%	81	190,039	13%	4,115	2%	1,472,547	2%
West Linn	8,529	3,912,635	87%	162	324,511	7%	394	27,498	1%	96	214,463	5%	9,181	5%	4,479,107	6%
Wilsonville	5,740	2,840,643	51%	377	2,297,839	41%	348	26,426	0%	114	380,969	7%	6,579	4%	5,545,876	7%
Total Study Area	140,116	53,194,037	67%	6,110	13,660,428	17%	36,142	7,190,255	9%	2,546	5,007,769	6%	184,914	100%	79,052,489	100%

Table B-2. CSZ Mw 9.0 Earthquake loss estimates.

(all dollar amounts in thousands)

	Total Number of Buildings	Total Estimated Building Value ($)	Total Earthquake Damage: Buildings Damaged: Yellow-Tagged Buildings	Red-Tagged Buildings	Sum of Economic Loss	Loss Ratio	Total Earthquake Damage: All Buildings Changed to At Least Moderate Code: Yellow-Tagged Buildings	Red-Tagged Buildings	Sum of Economic Loss	Loss Ratio
Unincorp. Clackamas Co (rural)	94,866	36,218,454	6,016	3,599	5,175,264	14%	3,670	743	1,371,606	3.8%
Government Camp	832	289,100	5	1	5,706	2.0%	3	1	1,999	0.7%
Molalla Prairie	4,123	1,313,253	300	61	92,746	7.1%	118	25	38,737	2.9%
Mulino Hamlet	2,021	584,353	200	53	56,845	9.7%	126	30	28,737	4.9%
Stafford Hamlet	1,206	564,063	87	21	46,586	8.3%	50	11	21,852	3.9%
The Villages at Mt Hood	3,796	1,297,133	154	29	44,545	3.4%	116	28	31,192	2.4%
Total Unincorporated County	106,844	40,266,356	6,761	3,765	5,421,691	14%	4,083	839	1,494,124	3.7%
Barlow	60	18,955	13	7	6,908	36%	12	3	2,562	14%
Canby	5,987	2,606,675	363	114	185,609	7.1%	87	11	61,171	2.3%
Estacada	1,771	671,792	92	12	47,644	7.1%	33	6	17,184	2.6%
Gladstone	4,046	1,447,740	279	90	120,946	8.4%	122	18	36,130	2.5%
Happy Valley	7,480	3,898,036	194	133	253,627	6.5%	115	26	83,359	2.1%
Johnson City	275	20,082	57	216	17,344	86%	169	34	7,878	39%
Lake Oswego	13,854	8,534,213	617	134	664,983	7.8%	382	90	296,873	3.5%
Milwaukie	7,936	3,656,357	682	364	1,090,161	30%	462	114	248,182	6.8%
Molalla	3,385	1,031,711	46	1	27,620	2.7%	5	0	9,963	1.0%
Oregon City	13,204	5,307,089	392	84	340,167	6.4%	167	36	125,635	2.4%
Rivergrove	197	95,954	18	4	7,818	8.1%	17	4	6,210	6.5%
Sandy	4,115	1,472,547	15	1	17,258	1.2%	3	0	7,087	0.5%
West Linn	9,181	4,479,107	343	79	235,282	5.3%	253	62	116,408	2.6%
Wilsonville	6,579	5,545,876	495	124	538,438	9.7%	333	71	275,431	5.0%
Total Study Area	184,914	79,052,489	10,368	5,126	8,975,495	11%	6,244	1,314	2,788,197	3.5%

Table B-3. Canby-Molalla Fault Mw 6.8 Earthquake loss estimates.

(all dollar amounts in thousands)

			Total Earthquake Damage							
			Buildings Damaged				All Buildings Changed to At Least Moderate Code			
	Total Number of Buildings	Total Estimated Building Value ($)	Yellow-Tagged Buildings	Red-Tagged Buildings	Sum of Economic Loss	Loss Ratio	Yellow-Tagged Buildings	Red-Tagged Buildings	Sum of Economic Loss	Loss Ratio
Unincorp. Clackamas Co (rural)	94,866	36,218,454	6,579	2,903	3,236,598	8.9%	4,279	1,237	1,756,530	4.8%
Government Camp	832	289,100	0	0	510	0.2%	0	0	169	0.7%
Molalla Prairie	4,123	1,313,253	802	473	319,440	24%	520	163	169,335	13%
Mulino Hamlet	2,021	584,353	309	152	103,543	18%	230	63	58,171	10%
Stafford Hamlet	1,206	564,063	185	77	107,325	19%	120	35	56,738	10%
The Villages at Mt Hood	3,796	1,297,133	10	2	4,824	0.4%	7	2	2,791	0.2%
Total Unincorporated County	106,844	40,266,356	7,885	3,606	3,772,239	9.4%	5,157	1,500	2,043,906	5.1%
Barlow	60	18,955	19	14	11,469	61%	16	8	7,810	41%
Canby	5,987	2,606,675	1,314	897	811,347	31%	1,028	445	518,513	20%
Estacada	1,771	671,792	17	2	10,934	1.6%	6	1	4,717	0.7%
Gladstone	4,046	1,447,740	275	73	90,881	6.3%	153	32	48,109	3.3%
Happy Valley	7,480	3,898,036	61	16	53,400	1.4%	36	8	32,255	0.8%
Johnson City	275	20,082	86	23	4,990	25%	33	4	1,918	9.6%
Lake Oswego	13,854	8,534,213	1,773	580	1,481,727	17%	1,131	296	827,006	9.7%
Milwaukie	7,936	3,656,357	608	137	471,364	13%	388	94	210,524	5.8%
Molalla	3,385	1,031,711	385	143	150,833	15%	234	60	84,457	8.2%
Oregon City	13,204	5,307,089	539	157	431,898	8.1%	300	69	214,000	4.0%
Rivergrove	197	95,954	47	18	22,557	24%	36	10	14,968	16%
Sandy	4,115	1,472,547	5	0	5,619	0.4%	2	0	2,692	0.2%
West Linn	9,181	4,479,107	737	189	382,272	8.5%	518	132	247,390	5.5%
Wilsonville	6,579	5,545,876	1,167	537	1,619,252	29%	991	294	977,179	18%
Total Study Area	184,914	79,052,489	14,917	6,392	9,320,783	12%	10,030	2,951	5,235,446	6.6%

Table B-4. Flood loss estimates.

			(all dollar amounts in thousands)											
			10% (10-yr)			**2% (50-yr)**			**1% (100-yr)**			**0.2% (500-yr)**		
Community	**Total Number of Buildings**	**Total Estimated Building Value ($)**	**Number of Buildings**	**Loss Estimate**	**Loss Ratio**	**Number of Buildings**	**Loss Estimate**	**Loss Ratio**	**Number of Buildings**	**Loss Estimate**	**Loss Ratio**	**Number of Buildings**	**Loss Estimate**	**Loss Ratio**
Unincorp. Clackamas Co (rural)	94,866	36,218,454	237	12,729	0.0%	509	34,749	0.1%	713	53,332	0.1%	1,584	174,497	0.5%
Government Camp	832	289,100	11	123	0.0%	13	160	0.0%	15	177	0.1%	17	225	0.1%
Molalla Prairie	4,123	1,313,253	4	13	0.0%	25	234	0.0%	38	471	0.0%	90	2,125	0.2%
Mulino Hamlet	2,021	584,353	137	6,815	1.2%	164	10,429	1.8%	167	12,113	2.1%	180	16,600	2.8%
Stafford Hamlet	1,206	564,063	14	316	0.1%	33	2,275	0.4%	40	3,531	0.6%	48	5,884	1.0%
The Villages at Mt Hood	3,796	1,297,133	34	883	0.1%	80	2,397	0.2%	117	3,739	0.3%	207	9,585	0.7%
Total Unincorporated County	106,844	40,266,356	437	20,879	0.1%	824	50,245	0.1%	1,090	73,362	0.2%	2,126	208,917	0.5%
Barlow	60	18,955	0	0	0.0%	0	0	0.0%	0	0	0.0%	0	0	0.0%
Canby	5,987	2,606,675	0	0	0.0%	0	0	0.0%	0	0	0.0%	82	6,051	0.2%
Estacada	1,771	671,792	0	0	0.0%	0	0	0.0%	0	0	0.0%	0	0	0.0%
Gladstone	4,046	1,447,740	6	316	0.0%	17	1,302	0.1%	29	2,756	0.2%	293	25,553	1.8%
Happy Valley	7,480	3,898,036	9	165	0.0%	32	981	0.0%	40	1,532	0.04%	41	2,721	0.1%
Johnson City	275	20,082	0	0	0.0%	0	0	0.0%	0	0	0.0%	0	0	0.0%
Lake Oswego	13,854	8,534,213	2	73	0.0%	26	964	0.0%	82	6,660	0.1%	247	35,956	0.4%
Milwaukie	7,936	3,656,357	7	89	0.0%	12	179	0.0%	20	6,057	0.2%	78	37,870	1.0%
Molalla	3,385	1,031,711	0	0	0.0%	0	0	0.0%	0	0	0.0%	0	0	0.0%
Oregon City	13,204	5,307,089	19	23,191	0.4%	73	37,990	0.7%	103	57,075	1.1%	209	115,573	2.2%
Rivergrove	197	95,954	0	0	0.0%	15	670	0.7%	34	2,387	2.5%	51	6,638	6.9%
Sandy	4,115	1,472,547	1	2	0.0%	1	2	0.0%	1	2	0.0%	1	2	0.0%
West Linn	9,181	4,479,107	6	42,193	0.9%	22	62,920	1.4%	48	72,005	1.6%	185	104,983	2.3%
Wilsonville	6,579	5,545,876	0	0	0.0%	1	18	0.0%	5	201	0.0%	125	12,088	0.2%
Total Study Area	184,914	79,052,489	487	86,908	0.1%	1,023	155,272	0.2%	1,452	222,037	0.3%	3,438	556,351	0.7%

Table B-5. Flood exposure.

Community	Total Number of Buildings	Total Population	1% (100-yr) Potentially Displaced Residents from Flood Exposure	% Potentially Displaced Residents from flood Exposure	Number of Flood Exposed Buildings	% of Flood Exposed Buildings	Number of Flood Exposed Buildings Without Damage
Unincorp. Clackamas Co (rural)	94,866	176,427	1,532	0.9%	965	1.0%	245
Government Camp	832	1,355	10	0.7%	15	1.8%	7
Molalla Prairie	4,123	4,507	41	0.9%	50	1.2%	12
Mulino Hamlet	2,021	2,777	194	7.0%	176	8.7%	9
Stafford Hamlet	1,206	3,141	106	3.4%	46	3.8%	6
The Villages at Mt Hood	3,796	8,596	338	3.9%	169	4.5%	52
Total Unincorporated County	106,844	196,803	2,221	1.1%	1,421	1.3%	331
Barlow	60	138	0	0.0%	0	0.0%	0
Canby	5,987	18,282	3	0.0%	1	0.0%	1
Estacada	1,771	5,296	0	0.0%	0	0.0%	0
Gladstone	4,046	11,883	110	0.9%	35	0.9%	6
Happy Valley	7,480	26,054	68	0.3%	41	0.5%	1
Johnson City	275	527	0	0.0%	0	0.0%	0
Lake Oswego	13,854	39,491	224	0.6%	114	0.8%	32
Milwaukie	7,936	20,555	130	0.6%	34	0.4%	14
Molalla	3,385	9,857	0	0.0%	0	0.0%	0
Oregon City	13,204	36,866	44	0.1%	105	0.8%	2
Rivergrove	197	558	141	25%	44	22%	10
Sandy	4,115	12,213	6	0.1%	2	0.0%	1
West Linn	9,181	26,983	165	0.6%	68	0.7%	20
Wilsonville	6,579	25,683	37	0.1%	8	0.1%	3
Total Study Area	184,914	431,190	3,149	0.7%	1,873	1.0%	421

Table B-6. Landslide exposure.

(all dollar amounts in thousands)

Community	Total Number of Buildings	Total Estimated Building Value ($)	Very High Susceptibility: Number of Buildings	Very High Susceptibility: Building Value ($)	Very High Susceptibility: Percent of Building Value Exposed	High Susceptibility: Number of Buildings	High Susceptibility: Building Value ($)	High Susceptibility: Percent of Building Value Exposed	Moderate Susceptibility: Number of Buildings	Moderate Susceptibility: Building Value ($)	Moderate Susceptibility: Percent of Building Value Exposed
Unincorp. Clackamas Co (rural)	94,866	36,218,454	2,300	847,979	2.3%	3,656	1,287,130	3.5%	26,028	9,293,184	26%
Government Camp	832	289,100	0	0	0%	28	3,635	1.3%	209	63,170	22%
Molalla Prairie	4,123	1,313,253	49	13,179	1.0%	37	9,050	0.7%	989	264,219	20%
Mulino Hamlet	2,021	584,353	153	41,146	7.0%	83	21,398	3.7%	569	157,164	27%
Stafford Hamlet	1,206	564,063	8	2,103	0.4%	94	44,627	7.9%	624	273,098	48%
The Villages at Mt Hood	3,796	1,297,133	316	110,617	8.5%	104	34,205	2.6%	593	187,242	14%
Total Unincorporated County	106,844	40,266,356	2,826	1,015,024	2.5%	4,002	1,400,045	3.5%	29,012	10,238,077	25%
Barlow	60	18,955	0	0	0.0%	0	0	0.0%	1	94	0%
Canby	5,987	2,606,675	0	0	0.0%	11	19,528	0.7%	299	131,290	5%
Estacada	1,771	671,792	55	14,846	2.2%	316	87,131	13%	309	104,356	16%
Gladstone	4,046	1,447,740	130	41,500	3%	114	61,697	4.3%	802	311,029	21%
Happy Valley	7,480	3,898,036	3	973	0.0%	425	254,528	6.5%	3,960	2,041,316	52%
Johnson City	275	20,082	0	0	0.0%	2	246	1.2%	45	3,075	15%
Lake Oswego	13,854	8,534,213	159	80,225	0.9%	1,146	711,258	8.3%	6,843	3,878,851	45%
Milwaukie	7,936	3,656,357	0	0	0.0%	102	73,838	2.0%	2,256	914,388	25%
Molalla	3,385	1,031,711	0	0	0.0%	0	0	0.0%	68	28,868	2.8%
Oregon City	13,204	5,307,089	129	54,781	1.0%	404	150,638	2.8%	2,009	831,414	16%
Rivergrove	197	95,954	0	0	0.0%	0	0	0.0%	53	25,986	27%
Sandy	4,115	1,472,547	0	0	0.0%	127	41,371	2.8%	1,340	422,229	29%
West Linn	9,181	4,479,107	462	238,082	5.3%	914	483,615	11%	4,928	2,299,050	51%
Wilsonville	6,579	5,545,876	0	0	0.0%	91	55,477	1.0%	1,441	752,100	14%
Total Study Area	184,914	79,052,489	3,764	1,445,432	1.8%	7,654	3,339,372	4.2%	53,366	21,982,122	28%

Table B-7. Channel migration exposure

(all dollar amounts in thousands)

				Channel Migration Hazard				
Community*	**Total Number of Buildings**	**Total Population**	**Total Estimated Building Value ($)**	**Potentially Displaced Residents from channel migration Exposure**	**% Potentially Displaced Residents from channel migration Exposure**	**Number of Buildings Exposed**	**Building Value ($)**	**Ratio of Exposure Value**
Unincorp. Clackamas Co (rural)	94,866	176,427	36,218,454	279	0.2%	99	35,754	0.1%
Government Camp	832	1,355	289,100	0	0%	0	0	0%
The Villages at Mount Hood	3,796	8,596	1,297,133	3,003	35%	1,117	384,764	30%
Sandy	4,115	12,213	1,472,547	0	0%	0	0	0%
Total Study Area	103,609	198,591	39,277,234	3,282	1.7%	1,216	420,518	1.1%

*Communities in table limited to communities within the study area of English and others (2013) and Abbe and others (2015).

Table B-8. Wildfire exposure.

			(all dollar amounts in thousands)								
			High Hazard			Moderate Hazard			Low Hazard		
Community	Total Number of Buildings	Total Estimated Building Value ($)	Number of Buildings	Building Value ($)	Percent of Building Value Exposed	Number of Buildings	Building Value ($)	Percent of Building Value Exposed	Number of Buildings	Building Value ($)	Percent of Building Value Exposed
Unincorp. Clackamas Co (rural)	94,866	36,218,454	1726	527,730	1.5%	8,107	2,378,730	6.6%	27,436	8,808,468	24%
Government Camp	832	289,100	557	150,152	52%	118	42,098	15%	52	27,765	9.6%
Molalla Prairie	4,123	1,313,253	65	8,857	0.7%	96	21,175	1.6%	2,136	573,916	44%
Mulino Hamlet	2,021	584,353	0	0	0.0%	59	17,077	2.9%	1,259	342,453	59%
Stafford Hamlet	1,206	564,063	4	985	0.2%	33	16,887	3.0%	491	206,747	37%
The Villages at Mt Hood	3,796	1,297,133	2,657	899,859	69%	540	175,898	14%	244	74,962	5.8%
Total Unincorporated County	106,844	40,266,356	5,009	1,587,583	3.9%	8,953	2,651,865	6.6%	31,618	10,034,311	25%
Barlow	60	18,955	0	0	0.0%	0	0	0.0%	0	0	0.0%
Canby	5,987	2,606,675	0	0	0.0%	9	2,924	0.1%	83	24,705	0.9%
Estacada	1,771	671,792	14	3,830	0.6%	198	56,992	8.5%	607	202,698	30%
Gladstone	4,046	1,447,740	0	0	0.0%	0	0	0.0%	19	7465	0.5%
Happy Valley	7,480	3,898,036	5	805	0.0%	183	75,698	1.9%	1,578	747,448	19%
Johnson City	275	20,082	0	0	0.0%	0	0	0.0%	8	551	2.7%
Lake Oswego	13,854	8,534,213	0	0	0.0%	233	124,835	1.5%	2,077	1,168,861	14%
Milwaukie	7,936	3,656,357	0	0	0.0%	10	5,567	0.2%	109	63,727	1.7%
Molalla	3,385	1,031,711	0	0	0.0%	147	34,560	3.3%	135	48,814	4.7%
Oregon City	13,204	5,307,089	0	0	0.0%	173	60,071	1.1%	682	273,337	5.2%
Rivergrove	197	95,954	0	0	0.0%	0	0	0.0%	64	34,537	36%
Sandy	4,115	1,472,547	146	43,558	3.0%	258	74,599	5.1%	913	383,259	26%
West Linn	9,181	4,479,107	0	0	0.0%	74	32,427	0.7%	837	394,466	8.8%
Wilsonville	6,579	5,545,876	1	1,700	0.0%	48	23,914	0.4%	187	156,174	2.8%
Total Study Area	184,914	79,052,489	5,175	1,637,476	2.1%	10,286	3,143,452	4.0%	38,917	13,540,353	17%

Table B-9. Volcanic lahar hazard exposure.

			(all dollar amounts in thousands)											
			Small: 10% (10-yr)			**Medium: 1% (100-yr)**			**Large: 0.2-0.1% (500 to 1000-yr)**			**Extra Large: 0.001% (100,000-yr)**		
Community*	**Total Number of Buildings**	**Total Estimated Building Value ($)**	**Number of Buildings**	**Loss Estimate**	**Percent of Building Value Exposed**	**Number of Buildings**	**Loss Estimate**	**Percent of Building Value Exposed**	**Number of Buildings**	**Loss Estimate**	**Percent of Building Value Exposed**	**Number of Buildings**	**Loss Estimate**	**Percent of Building Value Exposed**
Unincorp. Clackamas County	94,866	36,218,454	0	0	0%	0	0	0%	137	39,809	0.1%	501	163,830	0.5%
Government Camp	832	289,100	153	64,606	22%	412	140,344	49%	525	175,940	61%	537	184,184	64%
The Villages at Mt. Hood	3,797	1,297,133	0	0	0%	255	79,457	6.1%	2,534	922,093	71%	2,960	1,073,088	83%
Sandy	4,115	1,472,547	0	0	0%	0	0	0%	0	0	0%	0	0	0%
Total	99,495	37,804,687	153	64,606	0.2%	667	219,801	0.6%	3,196	1,137,842	3%	3,998	1,421,102	3.8%

*Communities in table limited to communities within the study area of Burns and others (2011).

APPENDIX C. HAZUS-MH METHODOLOGY

C.1 Software

We performed all loss estimations using Hazus®-MH 6.0 and ArcGIS® Desktop® 10.7.1.

C.2 User-Defined Facilities (UDF) Database

A UDF database was compiled for all buildings in Clackamas County for use in both the flood and earthquake modules of Hazus-MH. The Clackamas County assessor database (acquired in 2018) was used to determine which taxlots had improvements (i.e., buildings) should be included in the UDF database.

C.2.1 Locating buildings points

The Oregon Department of Geology and Mineral Industries (DOGAMI) used the SBFO-1 (Williams, 2021) dataset to help precisely locate the centroid of each building. Extra effort was spent to locate building points along the 1% and 0.2% annual chance inundation fringe. When buildings were partially within the inundation zone, the building point was moved to the centroid of the portion of the building within the inundation zone. An iterative approach was used to further refine locations of building points for the flood module by generating results, reviewing the highest value buildings, and moving the building point over a representative elevation on the lidar digital elevation model to ensure an accurate first floor height.

C.2.2 Attributing building points

Populating the required attributes for Hazus-MH was achieved through a variety of approaches. The Clackamas County assessor database was used whenever possible, but in many cases that database did not provide the necessary information. The following is list of attributes and their sources:

- **Longitude** and **Latitude** – Location information that provides Hazus-MH the x and y-position of the UDF point. This allows for an overlay to occur between the UDF point and the flood or earthquake input data layers. The hazard model uses this spatial overlay to determine the correct hazard risk level that will be applied to the UDF point. The format of the attribute must be in decimal degrees. A simple geometric calculation using GIS software is done on the point to derive this value.
- **Occupancy class** – An alphanumeric attribute that indicates the use of the UDF (e.g. 'RES1' is a single family dwelling). The alphanumeric code is composed of seven broad occupancy types (RES = residential, COM = commercial, IND = industrial, AGR = agricultural, GOV = public, REL = non-profit/religious, EDU = education) and various suffixes that indicate more specific types. This code determines the damage function to be used for flood analysis. It is also used to attribute the Building Type field, discussed below, for the earthquake analysis. The code was interpreted from "Stat Class" or "Description" data found in the Clackamas County assessor database. When data was not available, the default value of RES1 was applied throughout.
- **Cost** – The replacement cost of an individual UDF. Loss ratio is derived from this value. Replacement cost is based on a method called RSMeans valuation (Charest, 2017) and is calculated by multiplying the building square footage by a standard cost per square foot. These standard rates per square foot are in tables within the default Hazus database.

- **Year built** – The year of construction that is used to attribute the Building Design Level field for the earthquake analysis (see "Building Design" below). The year a UDF was built is obtained from Clackamas County assessor database. When not available, the year of "1970" was applied.
- **Square feet** – The size of the UDF is used to pro-rate the total improvement value for taxlots with multiple UDFs. The value distribution method will ensure that UDFs with the highest square footage will be the most expensive on a given taxlot. This value is also used to pro-rate the **Number of People** field for Residential UDFs. The value was obtained from PSU Population Research Center estimates for Clackamas County and incorporated communities, where number of people are distributed based on square footage.
- **Number of stories** – The number of stories for an individual UDF, along with Occupancy Class, determines the applied damage function for flood analysis. The value was obtained from the Clackamas County assessor database when available. For UDFs without assessor information for number of stories that are within the flood zone, closer inspection using Google Street View™ or available oblique imagery was used for attribution.
- **Foundation type** – The UDF foundation type correlates with First Floor Height values in feet (see Table 3.11 in the Hazus-MH Technical Manual for the Flood Model [FEMA, 2012a]). It also functions within the flood model by indicating if a basement exists or not. UDFs with a basement have a different damage function from UDFs that do not have one. The value was obtained from the Clackamas County assessor database when available. For UDFs without assessor information for basements that are within the flood zone, closer inspection using Google Street View™ or available oblique imagery was used to ascertain if one exists or not.
- **First floor height** – The height in feet above grade for the lowest habitable floor. The height is factored during the depth of flooding analysis. The value is used directly by Hazus-MH, where Hazus-MH overlays a UDF location on a depth grid and using the **first floor height** determines the level of flooding occurring to a building. It is derived from the Foundation Type attribute or observation via oblique imagery or Google Street View™ mapping service.
- **Building type** – This attribute determines the construction material and structural integrity of an individual UDF. It is used by Hazus-MH for estimating earthquake losses by determining which damage function will be applied. This information was unavailable from the Clackamas County assessor data, so instead it was derived from a statistical distribution based on **Occupancy class**.
- **Building design level** – This attribute determines the seismic building code for an individual UDF. It is used by Hazus-MH for estimating earthquake losses by determining which damage function will be applied. This information is derived from the **Year Built** attribute (Clackamas County Assessor) and state/regional Seismic Building Code benchmark years.
- **Number of people** – The estimated number of permanent residents living within an individual residential structure. It is used in the post-analysis phase to determine the amount of people affected by a given hazard. This attribute is derived from PSU Population Research Center estimates for Clackamas County and incorporated communities, where number of people are distributed based on square footage.
- **Community** – The community that a UDF is within. These areas are used in the post-analysis for reporting results. The communities were based on incorporated area boundaries; unincorporated community areas were based on building density.

C.2.3 Seismic building codes

Oregon initially adopted seismic building codes in the mid-1970s (Judson, 2012). The established benchmark years of code enforcement are used in determining a "design level" for individual buildings. The design level attributes (pre code, low code, moderate code, and high code) are used in the Hazus-MH earthquake model to determine what damage functions are applied to a given building (FEMA, 2012b). The year built or the year of the most recent seismic retrofit are the main considerations for an individual design level attribute. Seismic retrofitting information for structures would be ideal for this analysis but was not available for Clackamas County. **Table C-1** outlines the benchmark years that apply to buildings within Clackamas County.

Table C-1. Clackamas County seismic design level benchmark years.

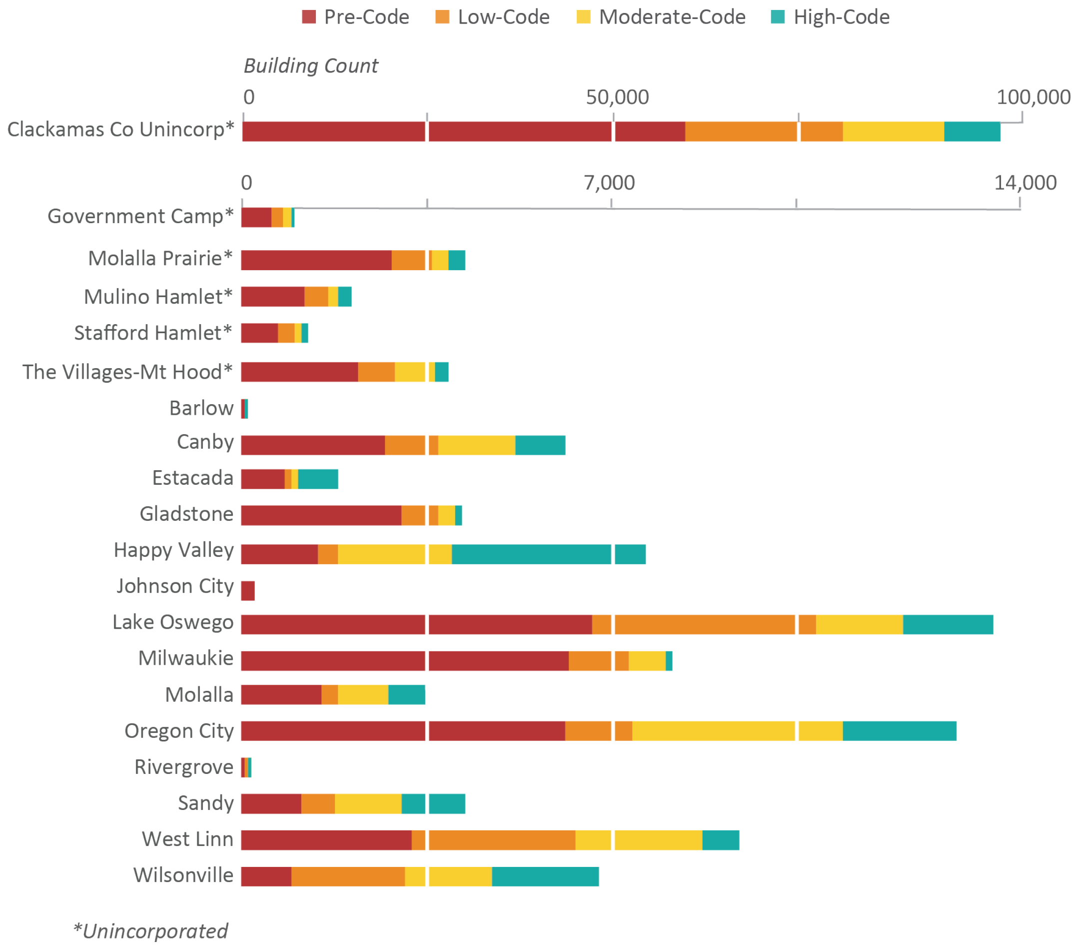
Building Type	Year Built	Design Level	Basis
Single-Family Dwelling (includes Duplexes)	prior to 1976	Pre Code	Interpretation of Judson (Judson, 2012)
	1976–1991	Low Code	
	1992–2003	Moderate Code	
	2004–2016	High Code	
Manufactured Housing	prior to 2003	Pre Code	Interpretation of OR BCD 2002 Manufactured Dwelling Special Codes (Oregon Building Codes Division, 2002)
	2003–2010	Low Code	
	2011–2016	Moderate Code	Interpretation of OR BCD 2010 Manufactured Dwelling Special Codes Update (Oregon Building Codes Division, 2010)
All other buildings	prior to 1976	Pre Code	Business Oregon 2022 Oregon Benefit-Cost Analysis Tool, p. 24 (Business Oregon, 2022)
	1976–1990	Low Code	
	1991–2016	Moderate Code	

Table C-2 and corresponding **Figure C-1** illustrate the current state of seismic building codes for the county.

Table C-2. Seismic design level in Clackamas County.

		Pre Code		Low Code		Moderate Code		High Code	
Community	Total Number of Buildings	Number of Buildings	Percentage of Buildings	Number of Buildings	Percentage of Buildings	Number of Buildings	Percentage of Buildings	Number of Buildings	Percentage of Buildings
Unincorp. Clackamas Co (rural)	95,698	55,854	58%	19,959	21%	12,763	13%	7,122	7.4%
Government Camp	832	604	73%	95	11%	79	9.5%	54	6.5%
Molalla Prairie	4,123	2,752	67%	734	18%	365	8.9%	272	6.6%
Mulino Hamlet	2,021	1,154	57%	437	22%	225	11%	205	10%
Stafford Hamlet	1,206	691	57%	281	23%	141	12%	93	7.7%
The Villages-Mt Hood	3,796	2,156	57%	711	19%	698	18%	231	6.1%
Total Unincorp. County	106,844	62,607	59%	22,122	21%	14,192	13%	7,923	7.4%
Barlow	60	55	92%	1	1.7%	3	5.0%	1	1.7%
Canby	5,987	2,633	44%	1,005	17%	1,400	23%	949	16%
Estacada	1,771	778	44%	141	8.0%	143	8.1%	709	40%
Gladstone	4,046	2,950	73%	671	17%	328	8.1%	97	2.4%
Happy Valley	7,480	1,404	19%	410	5.5%	2,086	28%	3,580	48%
Johnson City	275	275	100%	0	0.0%	0	0.0%	0	0%
Lake Oswego	13,854	6,455	47%	4,164	30%	1,621	12%	1,614	12%
Milwaukie	7,936	6,040	76%	1,127	14%	645	8.1%	124	1.6%
Molalla	3,385	1,509	45%	293	8.7%	925	27%	658	19%
Oregon City	13,204	5,999	45%	1,199	9.1%	3,894	29%	2,112	16%
Rivergrove	197	90	46%	16	8.1%	26	13%	65	33%
Sandy	4,115	1,127	27%	625	15%	1,194	29%	1,169	28%
West Linn	9,181	3,130	34%	3,049	33%	2,336	25%	666	7.3%
Wilsonville	6,579	909	14%	2,113	32%	1,594	24%	1,963	30%
Total Study Area	184,914	95,961	52%	36,936	20%	30,387	16%	21,630	12%

Figure C-1. Seismic design level by Clackamas County community.



C.3 Flood Hazard Data

DOGAMI developed depth grids from detailed stream model information within the study area. These depth grids were used in this risk assessment to determine the level to which buildings are impacted by flooding.

A study area-wide, 2-meter, lidar-based depth grid was developed for each of the 10-, 50-, 100-, and 500-year annual chance flood events. The depth grids were imported into Hazus-MH for determining the depth of flooding for areas within the FEMA flood zones.

Once the UDF database was developed into a Hazus-compliant format, the Hazus-MH methodology was applied using a Python (programming language) script developed by DOGAMI (Bauer, 2018). The analysis was then run for a given flood event, and the script cross-referenced a UDF location with the depth grid to find the depth of flooding. The script then applied a specific damage function, based on a UDF's Occupancy Class [OccCls], which was used to determine the loss ratio for a given amount of flood depth, relative to the UDF's first-floor height.

C.4 Earthquake Hazard Data

The following hazard layers used for our loss estimation are derived from work conducted by Madin and others (2021): National Earthquake Hazard Reduction Program (NEHRP) soil classification, liquefaction susceptibility and wet landslide susceptibility. The liquefaction and landslide susceptibility layers together with NEHRP were used by the Hazus-MH tool to calculate ground motion layers and permanent ground deformation and associated probability. The default value of 5 feet was used for the water table depth value.

During the Hazus-MH earthquake analysis, each UDF was analyzed given its site-specific parameters (ground deformation) and evaluated for loss, expressed as a probability of a damage state. Specific damage functions based on Building type and Building design level were used to calculate the damage states given the site-specific parameters for each UDF. The output provided probabilities of the five damage states (None, Slight, Moderate, Extensive, Complete) from which losses in dollar amounts were derived.

C.5 Post-Analysis Quality Control

Ensuring the quality of the results from Hazus-MH flood and earthquake modules is an essential part of the process. A primary characteristic of the process is that it is iterative. A UDF database without errors is highly unlikely, so this part of the process is intended to limit and reduce the influence these errors have on the final outcome. Before applying the Hazus-MH methodology, closely examining the top 10 largest area UDFs and the top 10 most expensive UDFs is advisable. Special consideration can also be given to critical facilities due to their importance to communities.

Identifying, verifying, and correcting (if needed) the outliers in the results is the most efficient way to improve the UDF database. This can be done by sorting the results based on the loss estimates and closely scrutinizing the top 10 to 15 records. If corrections are made, then subsequent iterations are necessary. We continued checking the "loss leaders" until no more corrections were needed.

Finding anomalies and investigating possible sources of error are crucial in making corrections to the data. A wide range of corrections might be required to produce a better outcome. For example, floating homes may need to have a first-floor height adjustment or a UDF point position might need to be moved due to issues with the depth grid. Incorrect basement or occupancy type attribution could be the cause of a problem. Commonly, inconsistencies between assessor data and taxlot geometry can be the source of an error. These are just a few of the many types of problems addressed in the quality control process.

APPENDIX D. ACRONYMS AND DEFINITIONS

D.1 Acronyms

CRS	Community Rating System
CSZ	Cascadia subduction zone
DLCD	Oregon Department of Land Conservation and Development
DOGAMI	Department of Geology and Mineral Industries (State of Oregon)
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study
FRI	Fire Risk Index
GIS	Geographic Information System
NFIP	National Flood Insurance Program
NHMP	Natural hazard mitigation plan
NOAA	National Oceanic and Atmospheric Administration
ODF	Oregon Department of Forestry
OEM	Oregon Emergency Management
OFR	Open-File Report
OPDR	Oregon Partnership for Disaster Resilience
PGA	Peak ground acceleration
PGD	Permanent ground deformation
PGV	Peak ground velocity
Risk MAP	Risk Mapping, Assessment, and Planning
SHMO	State Hazard Mitigation Officer
SLIDO	State Landslide Information Layer for Oregon
UDF	User-defined facilities
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
WUI	Wildland-urban interface
WWA	West Wide Wildfire Risk Assessment

D.2 Definitions

1% annual chance flood – The flood elevation that has a 1-percent chance of being equaled or exceeded each year. Sometimes referred to as the 100-year flood.

0.2% annual chance flood – The flood elevation that has a 0.2-percent chance of being equaled or exceeded each year. Sometimes referred to as the 500-year flood.

Base flood elevation (BFE) – Elevation of the 1-percent-annual-chance flood. This elevation is the basis of the insurance and floodplain management requirements of the NFIP.

Critical facilities – Facilities that, if damaged, would present an immediate threat to life, public health, and safety. As categorized in HAZUS-MH, critical facilities include hospitals, emergency operations centers, police stations, fire stations and schools.

Exposure – Determination of whether a building is within or outside of a hazard zone. No loss estimation is modeled.

Flood Insurance Rate Map (FIRM) – An official map of a community, on which FEMA has delineated both the SFHAs and the risk premium zones applicable to the community.

Flood Insurance Study (FIS) – Contains an examination, evaluation, and determination of the flood hazards of a community and, if appropriate, the corresponding water-surface elevations.

Hazus-MH – A GIS-based risk assessment methodology and software application created by FEMA and the National Institute of Building Sciences for analyzing potential losses from floods, hurricane winds, and earthquakes.

Lidar – A remote sensing technology that measures distance by illuminating a target with a laser and analyzing the reflected light. Lidar is popularly used as a technology to make high-resolution maps.

Liquefaction – Describes a phenomenon whereby a saturated soil substantially loses strength and stiffness in response to an applied stress, usually an earthquake, causing it to behave like liquid.

Loss Ratio – The expression of loss as a fraction of the value of the local inventory (total value/loss).

Magnitude – A scale used by seismologists to measure the size of earthquakes in terms of energy released.

Risk – Probability multiplied by consequence; the degree of probability that a loss or injury may occur as a result of a natural hazard. Sometimes referred to as vulnerability.

Risk MAP – The vision of this FEMA strategy is to work collaboratively with State, local, and tribal entities to deliver quality flood data that increases public awareness and leads to action that reduces risk to life and property.

Riverine – Of or produced by a river. Riverine floodplains have readily identifiable channels.

Susceptibility – Degree of proneness to natural hazards that is determined based on physical characteristics that are present.

Vulnerability – Characteristics that make people or assets more susceptible to a natural hazard.

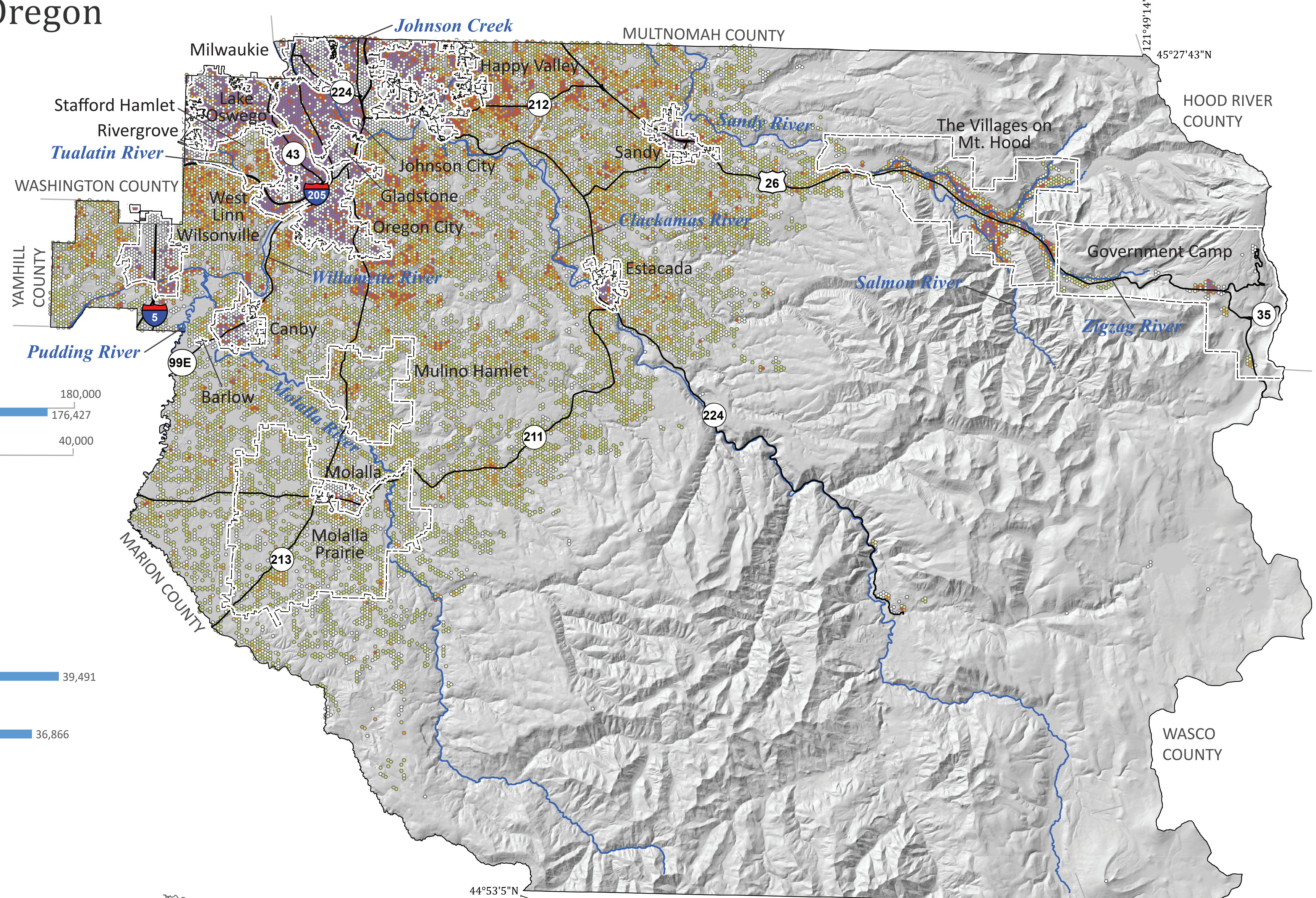
APPENDIX E. MAP PLATES

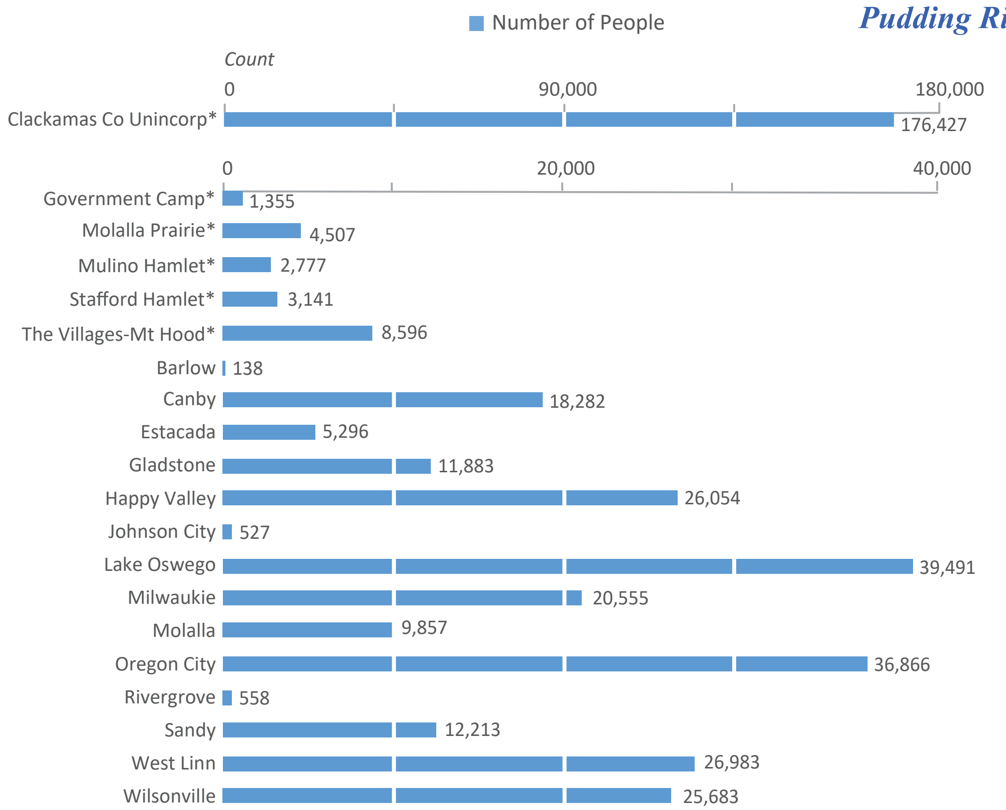
See appendix folder for individual map PDFs.

Population Density Map of Clackamas County, Oregon

People per 120 acres

- Building(s) present no permanent residents
- 1 - 5
- 5 - 10
- 10 - 20
- 20 - 40
- 40 +





*Unincorporated

Data Sources:
Population data: PSU Population Research Center (2021)
Roads: Oregon Department of Transportation Signed Routes (2013)
Place names: U.S. Geological Survey Geographic Names Information System (2015)
City limits: Oregon Department of Transportation (2014)
Basemap: Oregon Lidar Consortium (2014)
Hydrography: U.S. Geological Survey National Hydrography Dataset (2017)

Projection: NAD 1983 HARN Oregon Statewide Lambert
Software: Esri® ArcMap 10, Adobe® Illustrator CC

Cartography by: Matt C. Williams, 2024

Study Location Map

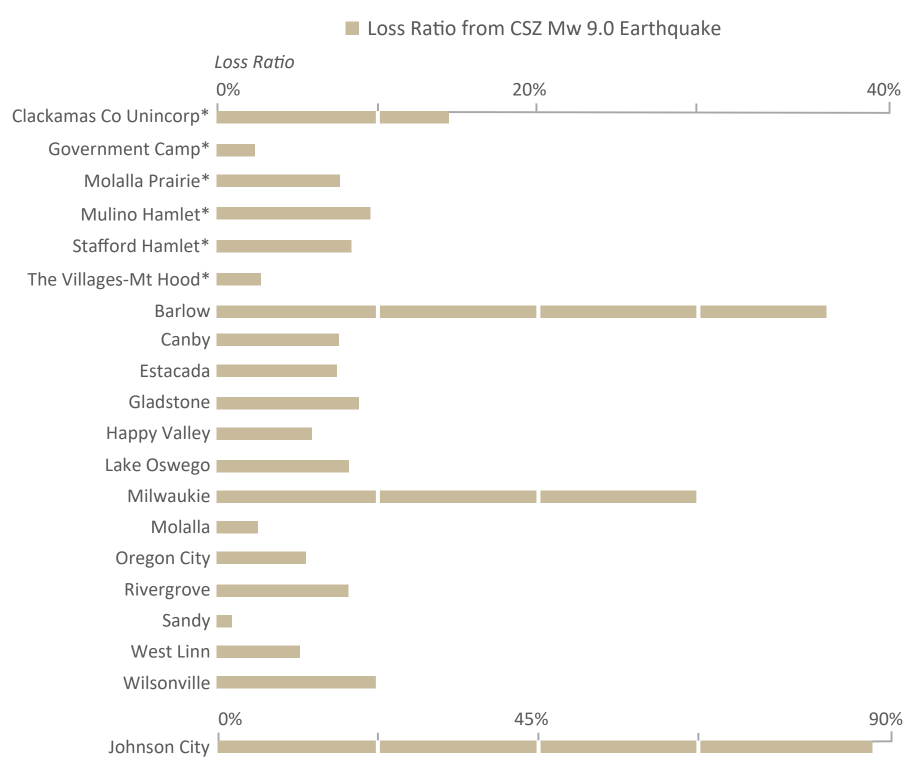
0 3 6 Miles
0 5 10 Kilometers
N

This map is an overview map and not intended to provide details at the community scale. The GIS data that are published with the Clackamas County Multi-Hazard Risk Assessment can be used to inform regarding queries at the community scale.

Disclaimer: This product is for informational purposes and may not have been prepared for or be suitable for legal, engineering, or surveying purposes. Users of this information should review or consult the primary data and information sources to ascertain the usability of the information. This publication cannot substitute for site-specific investigations by qualified practitioners. Site-specific data may give results that differ from the results shown in the publication. See the accompanying text report for more details on the limitations of the methods and data used to prepare this publication.

CSZ Magnitude-9.0 Earthquake Shaking Map of Clackamas County, Oregon

Modified Mercalli	Perceived Shaking	Potential Damage	Peak Ground Acceleration (g)
I	Not felt	None	< 0.000464
II	Weak	None	0.000464 - 0.00297
III	Weak	None	0.000464 - 0.00297
IV	Light	None	0.00297 - 0.0276
V	Moderate	Very Light	0.0276 - 0.115
VI	Strong	Light	0.115 - 0.215
VII	Very Strong	Moderate	0.215 - 0.401
VIII	Severe	Mod./Heavy	0.401 - 0.747
IX	Violent	Heavy	0.747 - 1.39
X	Extreme	Very Heavy	> 1.39



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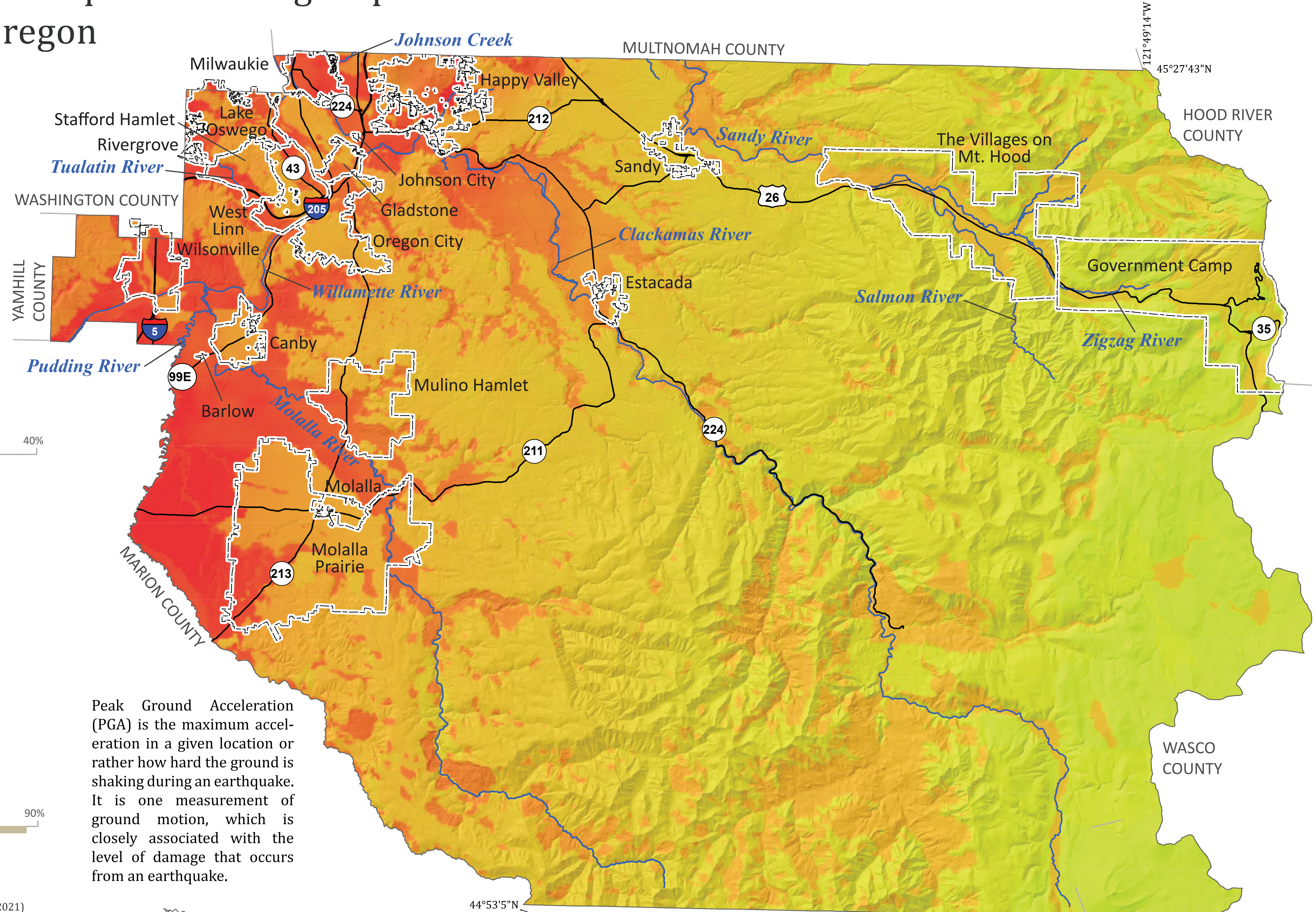

Peak Ground Acceleration (PGA) is the maximum acceleration in a given location or rather how hard the ground is shaking during an earthquake. It is one measurement of ground motion, which is closely associated with the level of damage that occurs from an earthquake.

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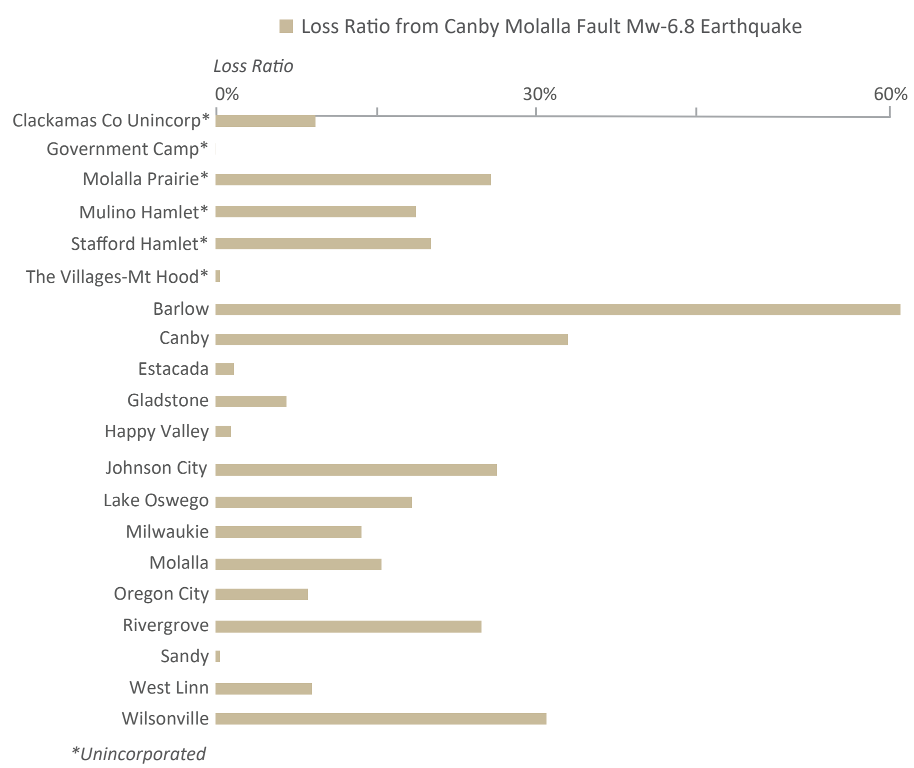
Data Sources:
Earthquake peak ground acceleration: Oregon Department of Geology and Mineral Industries (2021)
Roads: Oregon Department of Transportation Signed Routes (2013)
Place names: U.S. Geological Survey Geographic Names Information System (2015)
City limits: Oregon Department of Transportation (2014)
Basemap: Oregon Lidar Consortium (2014)
Hydrography: U.S. Geological Survey National Hydrography Dataset (2017)

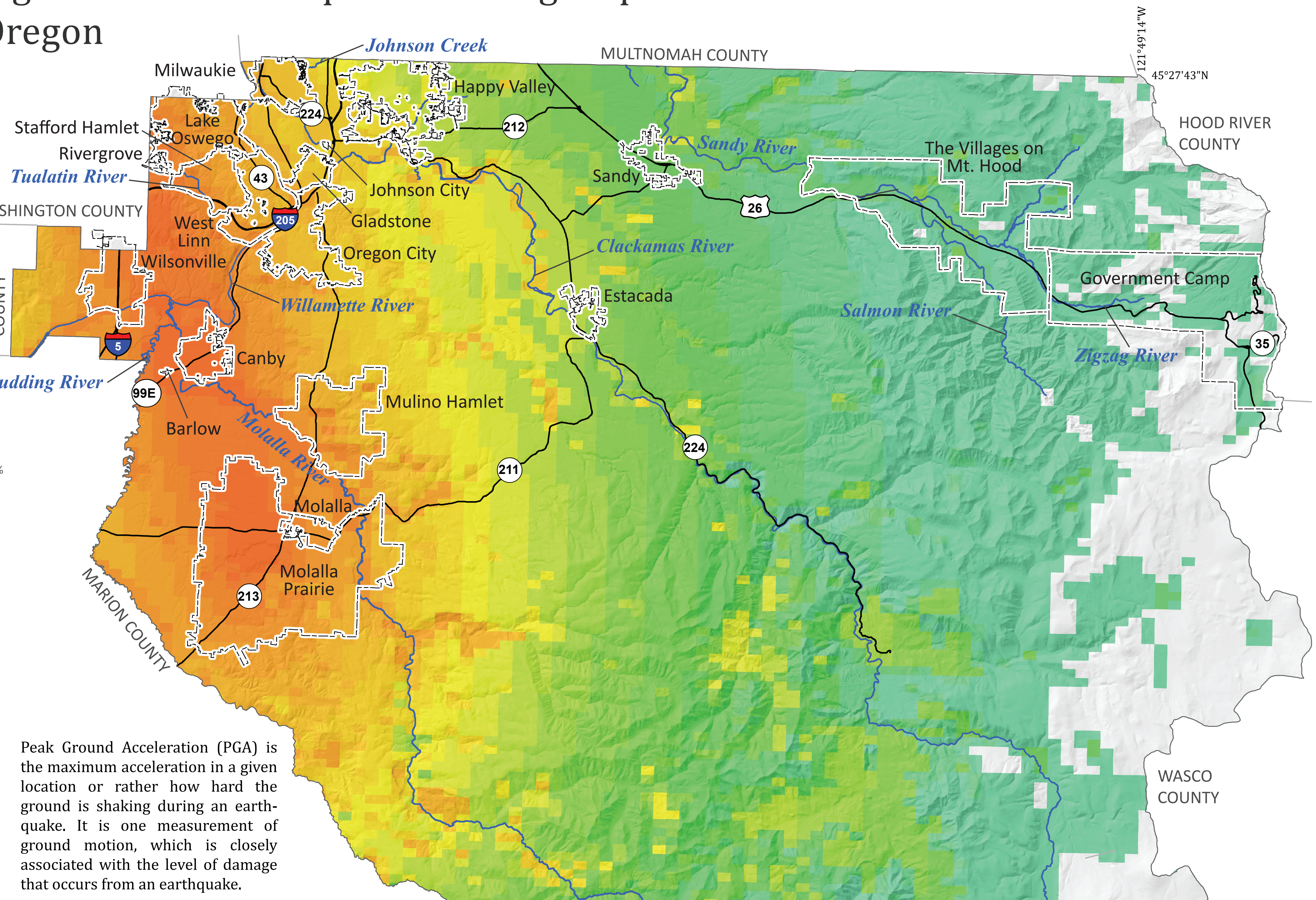
Projection: NAD 1983 HARN Oregon Statewide Lambert
Software: Esri® ArcMap 10, Adobe® Illustrator CC

Cartography by: Matt C. Williams, 2024

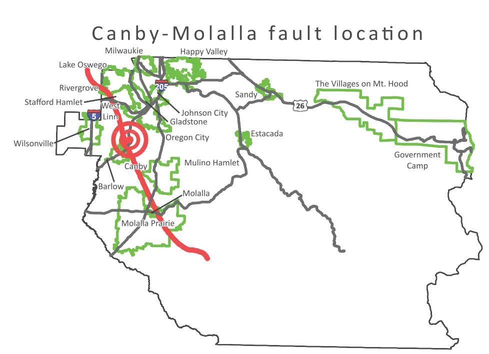
Canby-Molalla Fault Magnitude-6.8 Earthquake Shaking Map of Clackamas County, Oregon

Modified Mercalli	Perceived Shaking	Potential Damage	Peak Ground Acceleration (g)
I	Not felt	None	< 0.000464
II	Weak	None	0.000464 - 0.00297
III	Weak	None	0.000464 - 0.00297
IV	Light	None	0.00297 - 0.0276
V	Moderate	Very Light	0.0276 - 0.115
VI	Strong	Light	0.115 - 0.215
VII	Very Strong	Moderate	0.215 - 0.401
VIII	Severe	Mod./Heavy	0.401 - 0.747
IX	Violent	Heavy	0.747 - 1.39
X	Extreme	Very Heavy	> 1.39





Peak Ground Acceleration (PGA) is the maximum acceleration in a given location or rather how hard the ground is shaking during an earthquake. It is one measurement of ground motion, which is closely associated with the level of damage that occurs from an earthquake.



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Data Sources:
Earthquake peak ground acceleration: Generated from Hazus 5.0 earthquake analysis (2023)
Roads: Oregon Department of Transportation Signed Routes (2013)
Place names: U.S. Geological Survey Geographic Names Information System (2015)
City limits: Oregon Department of Transportation (2014)
Basemap: Oregon Lidar Consortium (2014)
Hydrography: U.S. Geological Survey National Hydrography Dataset (2017)

Projection: NAD 1983 HARN Oregon Statewide Lambert
Software: Esri® ArcMap 10, Adobe® Illustrator CC

Cartography by: Matt C. Williams, 2024

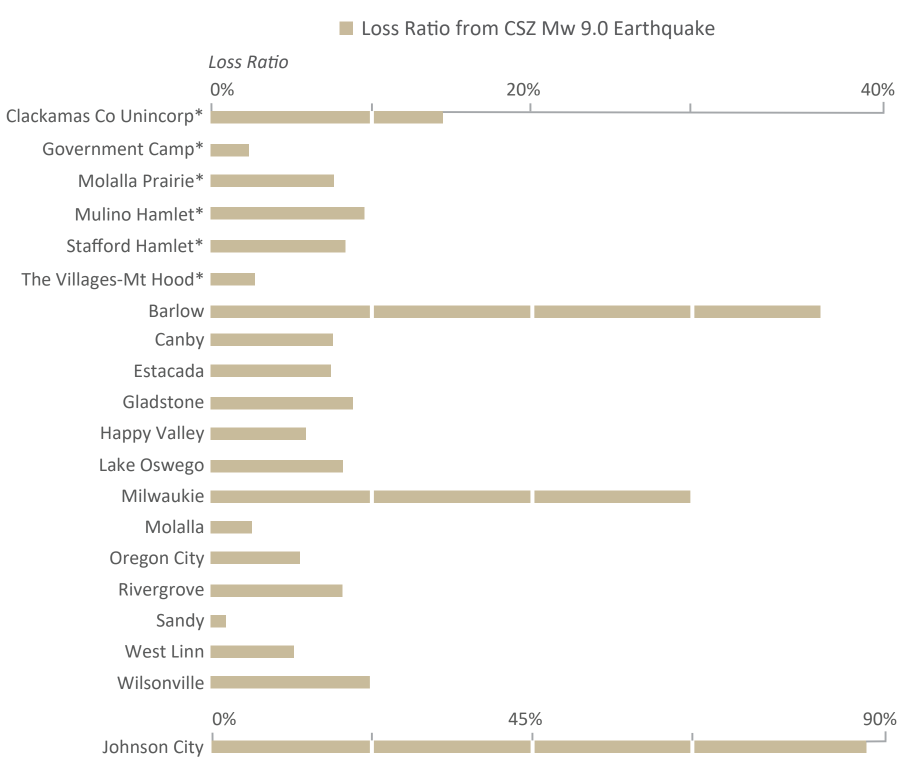
PLATE 4

Coseismic Landslide Susceptibility (Wet) Map of Clackamas County, Oregon

Coseismic landslide is a type of ground deformation that occurs during an earthquake where slope failure creates a mass movement of rock and debris. Saturated ground increases the susceptibility of a landslide occuring from seismic shaking. Coseismic landslides are a significant factor in the risk from earthquake hazard.

Coseismic Landslide Susceptibility (Wet)

0 (None) — 9 (High)



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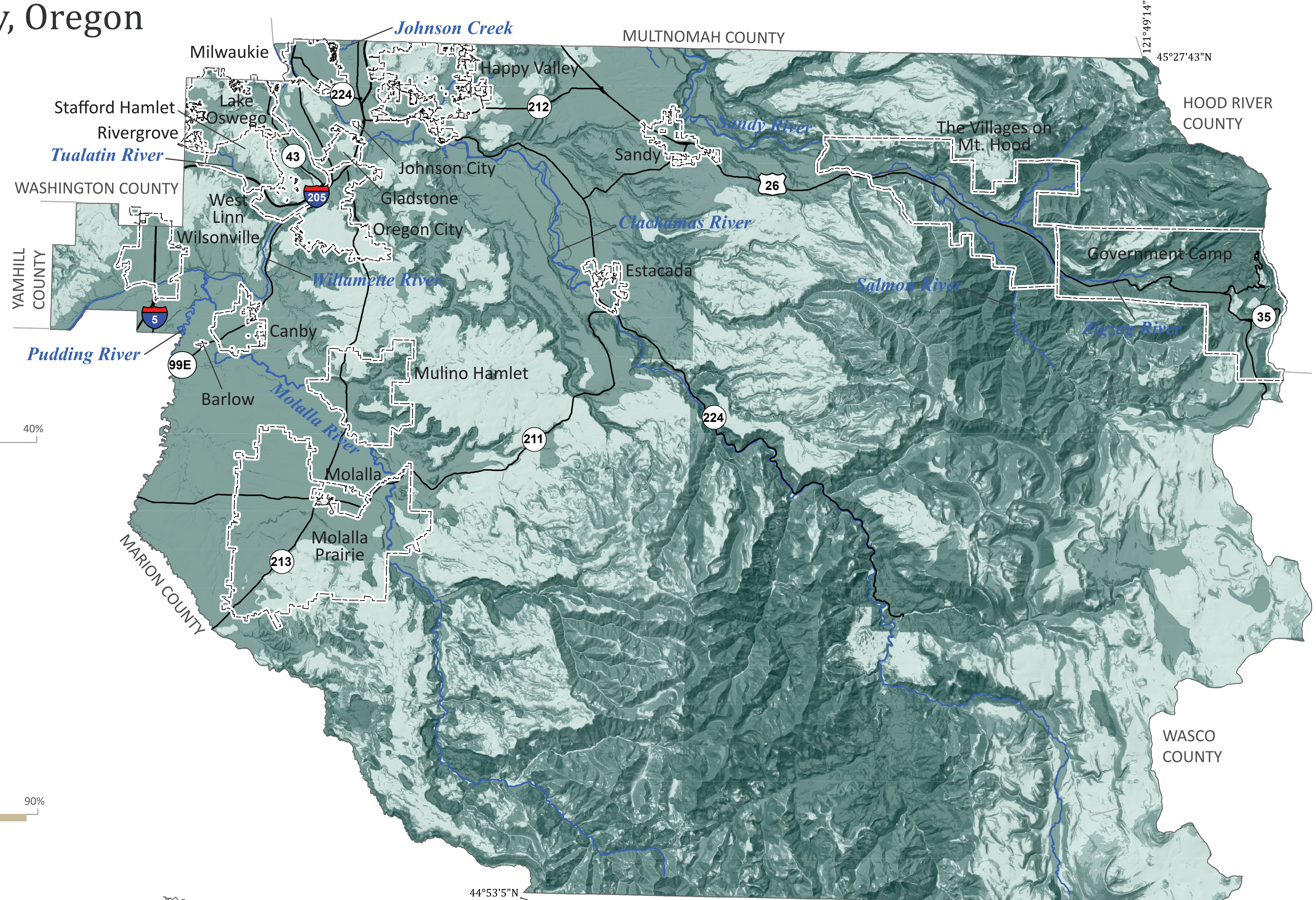

0 3 6 Miles
0 5 10 Kilometers
N

Data Sources:
Coseismic Landslide (wet): Oregon Department of Geology and Mineral Industries (2021)
Roads: Oregon Department of Transportation Signed Routes (2013)
Place names: U.S. Geological Survey Geographic Names Information System (2015)
City limits: Oregon Department of Transportation (2014)
Basemap: Oregon Lidar Consortium (2014)
Hydrography: U.S. Geological Survey National Hydrography Dataset (2017)

Projection: NAD 1983 HARN Oregon Statewide Lambert
Software: Esri® ArcMap 10, Adobe® Illustrator CC

Cartography by: Matt C. Williams, 2024

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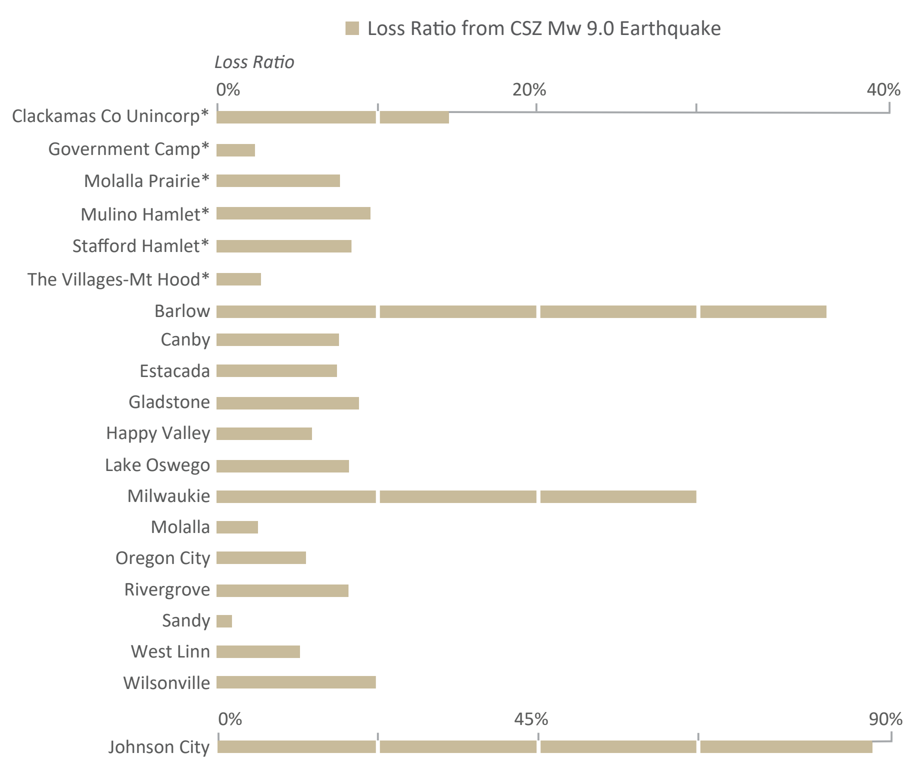
Liquefaction Susceptibility Map of Clackamas County, Oregon

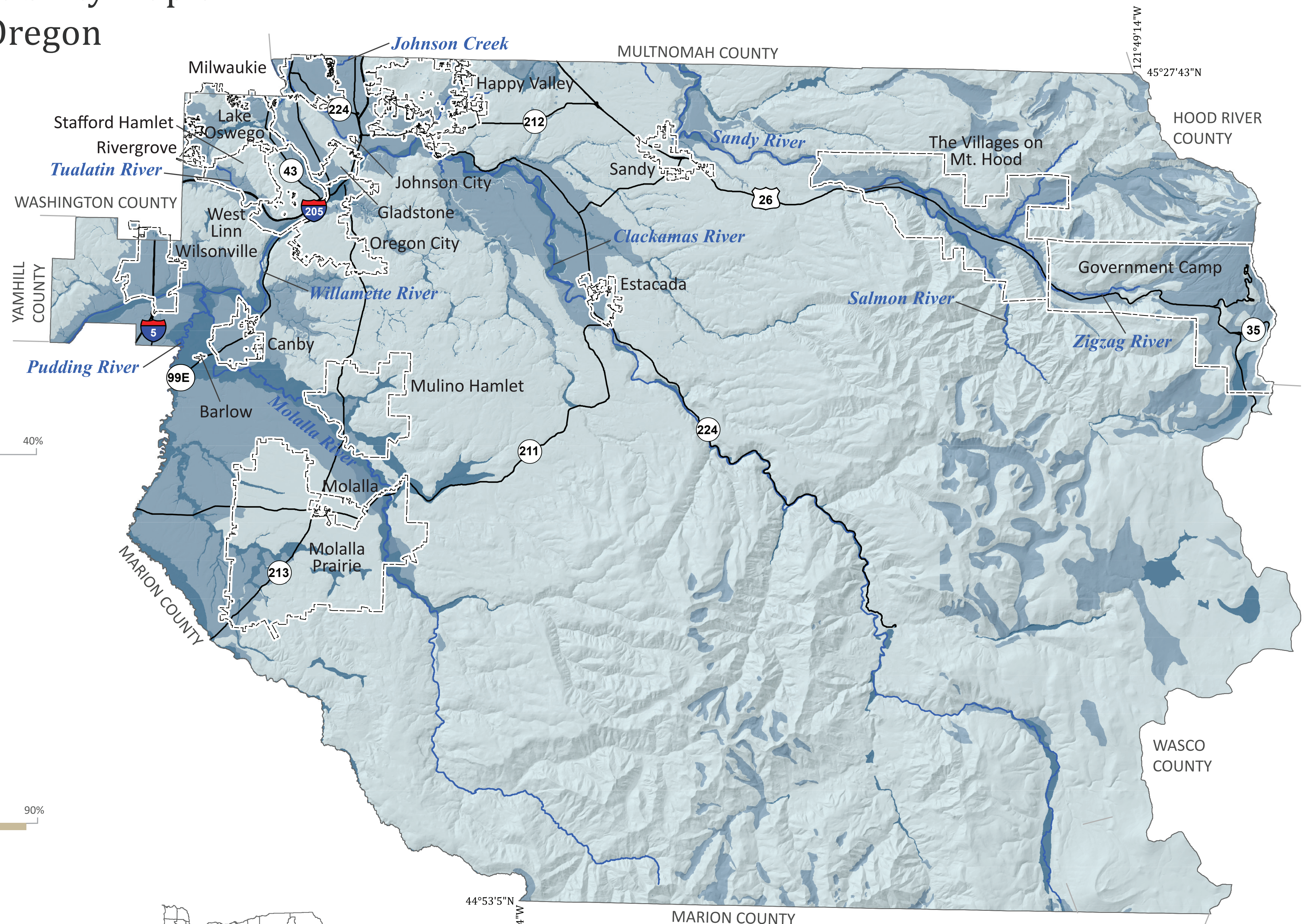
Liquefaction is a type of ground deformation that occurs during an earthquake where saturated, non-cohesive soil contracts and liquefies. The ground that becomes liquefied can no longer support heavy structures that are built on top of it. Liquefaction is a significant factor in the risk from earthquake hazard.

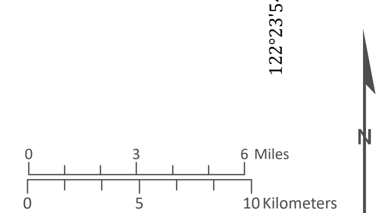
Liquefaction Susceptibility

- Low or None
- Moderate
- High
- Very High



*Unincorporated





Study Location Map

Data Sources:
Liquefaction susceptibility: Oregon Department of Geology and Mineral Industries (2021)
Roads: Oregon Department of Transportation Signed Routes (2013)
Place names: U.S. Geological Survey Geographic Names Information System (2015)
City limits: Oregon Department of Transportation (2014)
Basemap: Oregon Lidar Consortium (2014)
Hydrography: U.S. Geological Survey National Hydrography Dataset (2017)

Projection: NAD 1983 HARN Oregon Statewide Lambert
Software: Esri® ArcMap 10, Adobe® Illustrator CC

Cartography by: Matt C. Williams, 2024

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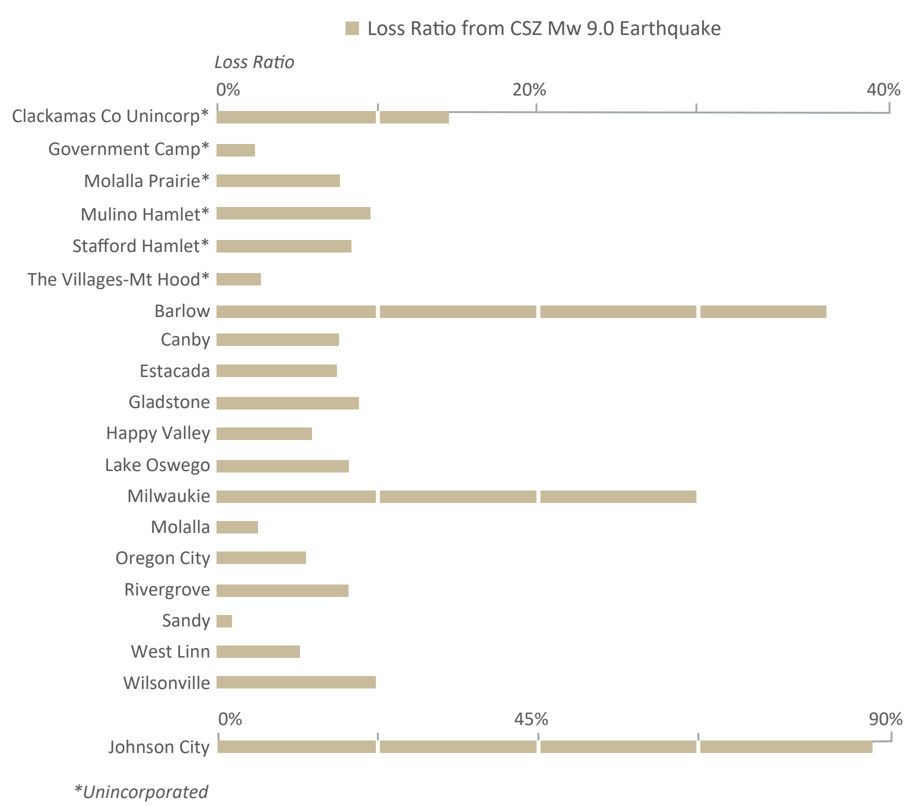
Site Amplification Class Map of Clackamas County, Oregon

Site Amplification is the degree to which soil types attenuate (weaken) or amplify (strengthen) seismic waves produced from an earthquake. The National Earthquake Hazards Reduction Program (NEHRP) classifies these geologic units into soft rock (B), dense soil or soft rock (C), stiff soil (D), and soft clay or soil (E, F). NEHRP soils can significantly affect the level of shaking and amount of damage that occurs at a specific location during an earthquake

NEHRP Class

- B
- C
- D
- E, F



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Data Sources:
Soil amplification: Oregon Department of Geology and Mineral Industries (2021)
Roads: Oregon Department of Transportation Signed Routes (2013)
Place names: U.S. Geological Survey Geographic Names Information System (2015)
City limits: Oregon Department of Transportation (2014)
Basemap: Oregon Lidar Consortium (2014)
Hydrography: U.S. Geological Survey National Hydrography Dataset (2017)

Projection: NAD 1983 HARN Oregon Statewide Lambert
Software: Esri® ArcMap 10, Adobe® Illustrator CC

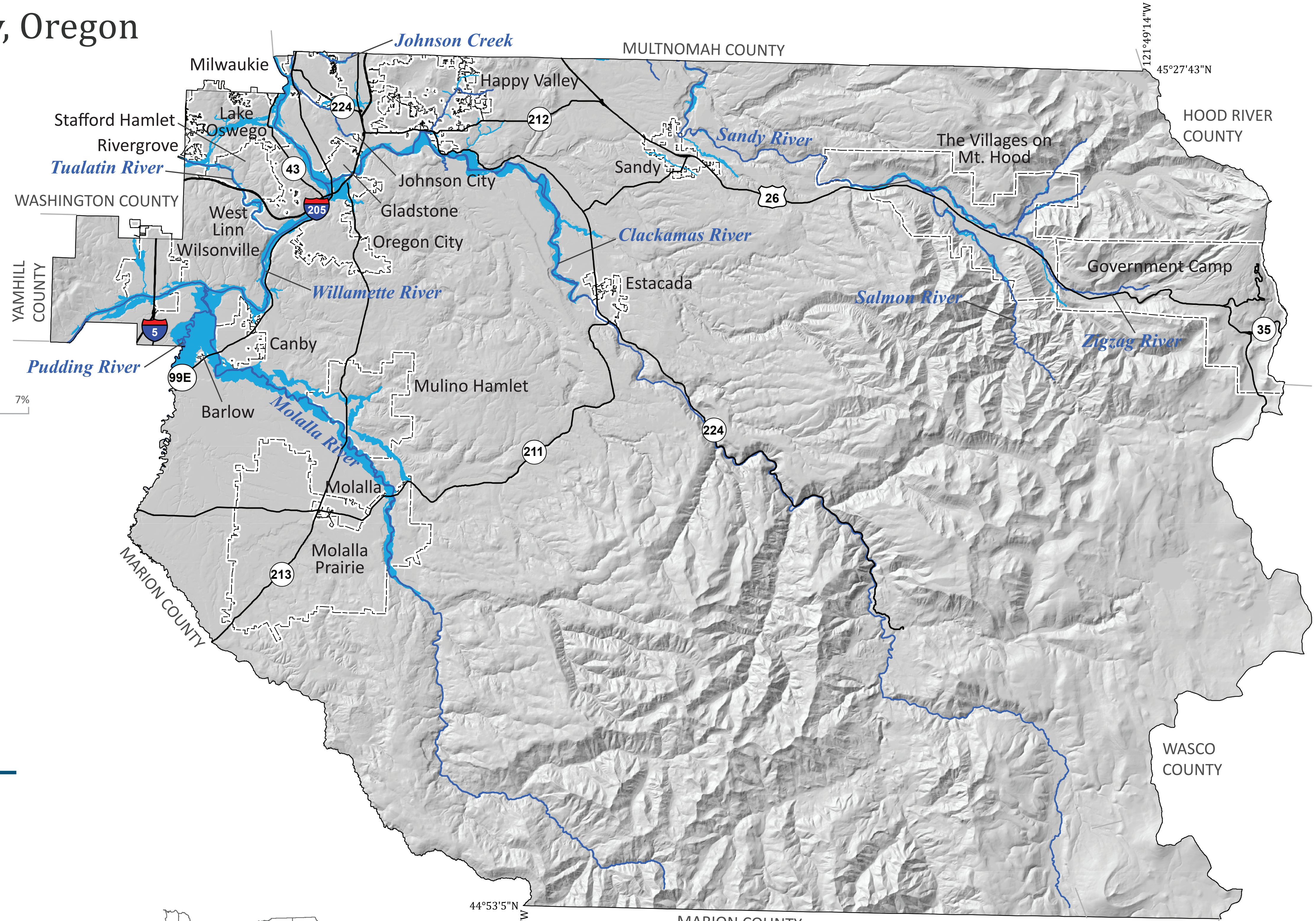
Cartography by: Matt C. Williams, 2024

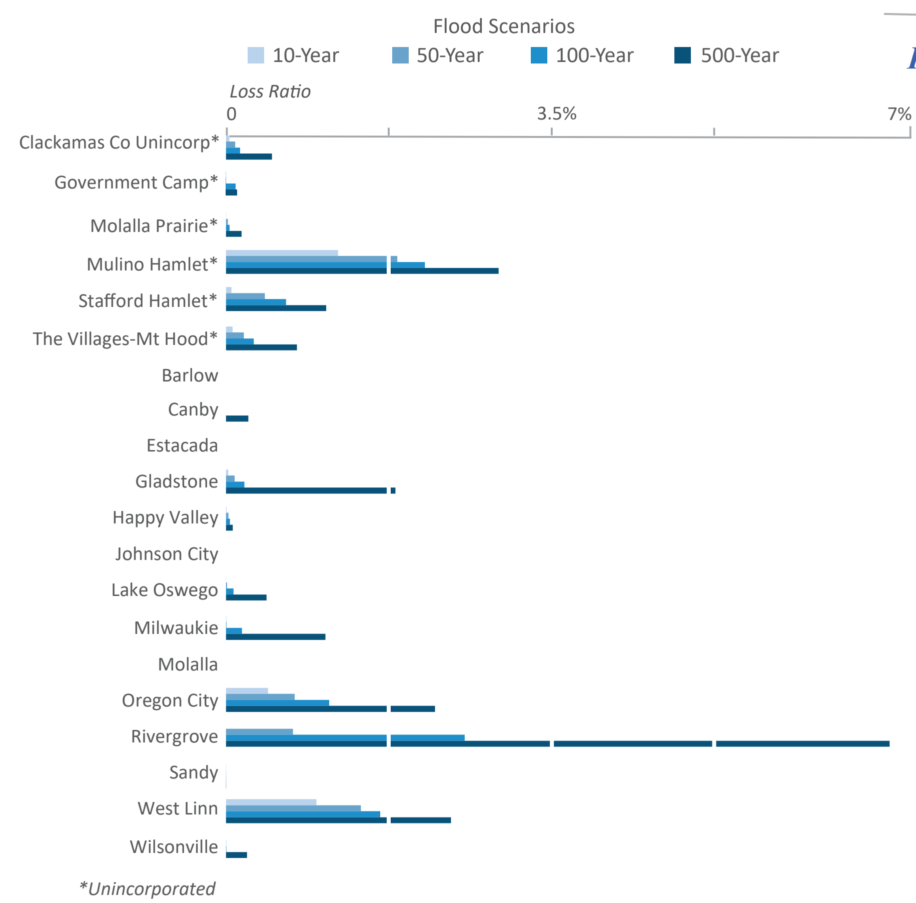
Flood Hazard Map of Clackamas County, Oregon

The flood hazard data show areas expected to be inundated during a 100-year flood event. Flooding sources include riverine. Areas are consistent with the regulatory flood zones depicted in Clackamas County's Digital Flood Insurance Rate Maps.

Flood Hazard Zone

100-Year Flood (1% annual chance)





Data Sources:
Flood hazard zone (100-year): Polk County Flood Insurance Rate Map (2006)
Roads: Oregon Department of Transportation Signed Routes (2013)
Place names: U.S. Geological Survey Geographic Names Information System (2015)
City limits: Oregon Department of Transportation (2014)
Basemap: Oregon Lidar Consortium (2014)
Hydrography: U.S. Geological Survey National Hydrography Dataset (2017)

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0 3 6 Miles
0 5 10 Kilometers
N

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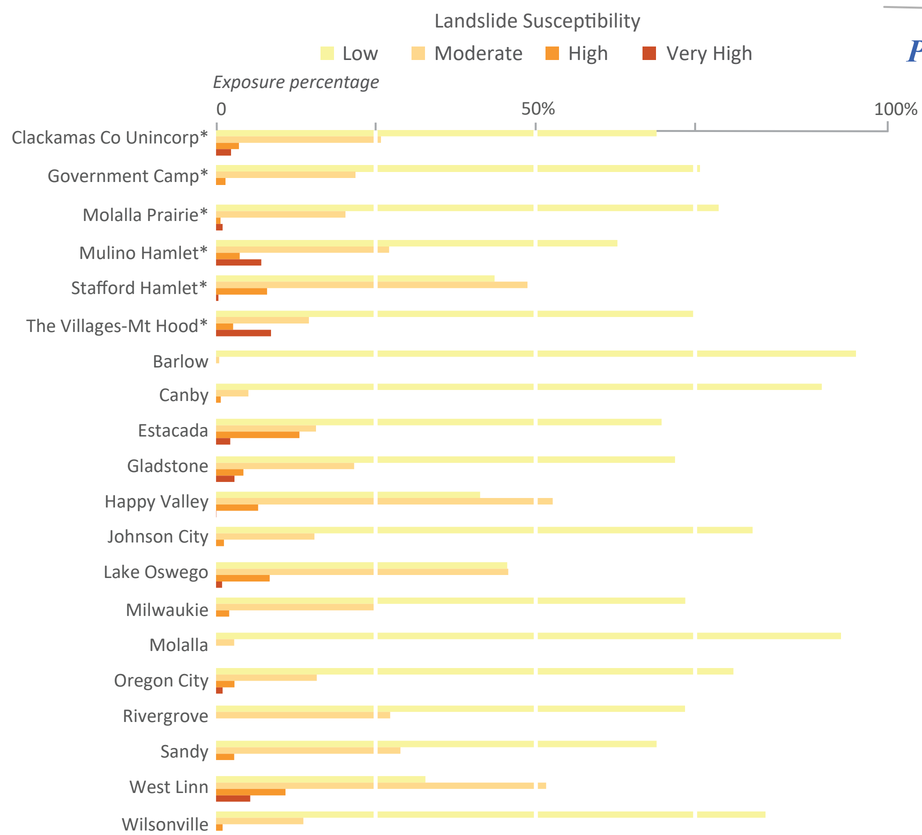
Landslide Susceptibility Map of Clackamas County, Oregon

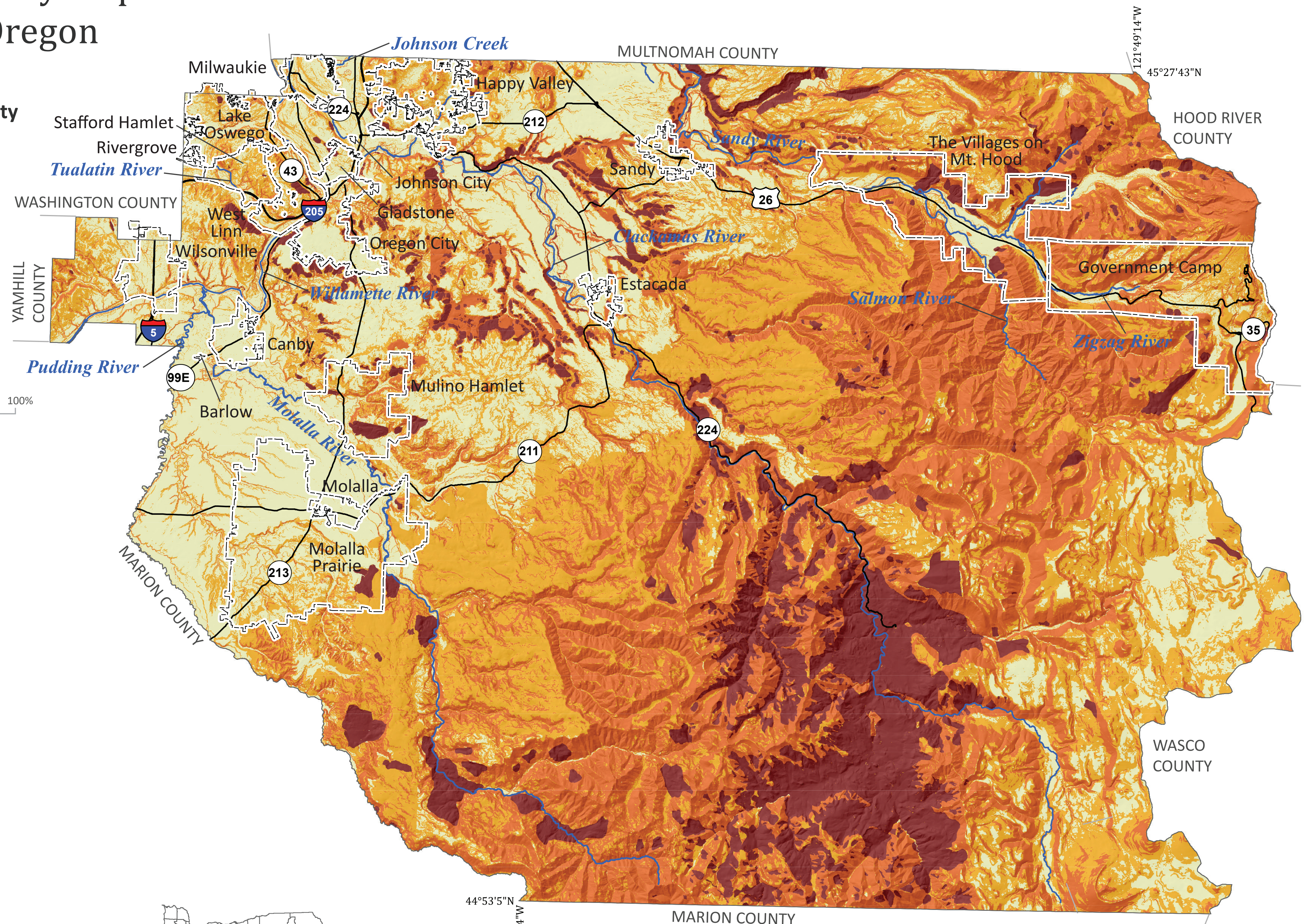
Landslide susceptibility is categorized as Low, Moderate, High, and Very High which describes the general level of susceptibility to landslide hazard. The dataset is an aggregation of three primary sources: landslide inventory (SLIDO), generalized geology, and slope.

Landslide Susceptibility

- Low
- Moderate
- High
- Very High



*Unincorporated



Data Sources:
Landslide susceptibility: Oregon Department of Geology and Mineral Industries, Burns and others (2016)
Roads: Oregon Department of Transportation Signed Routes (2013)
Place names: U.S. Geological Survey Geographic Names Information System (2015)
City limits: Oregon Department of Transportation (2014)
Basemap: Oregon Lidar Consortium (2014)
Hydrography: U.S. Geological Survey National Hydrography Dataset (2017)

Projection: NAD 1983 HARN Oregon Statewide Lambert
Software: Esri® ArcMap 10, Adobe® Illustrator CC

Cartography by: Matt C. Williams, 2024

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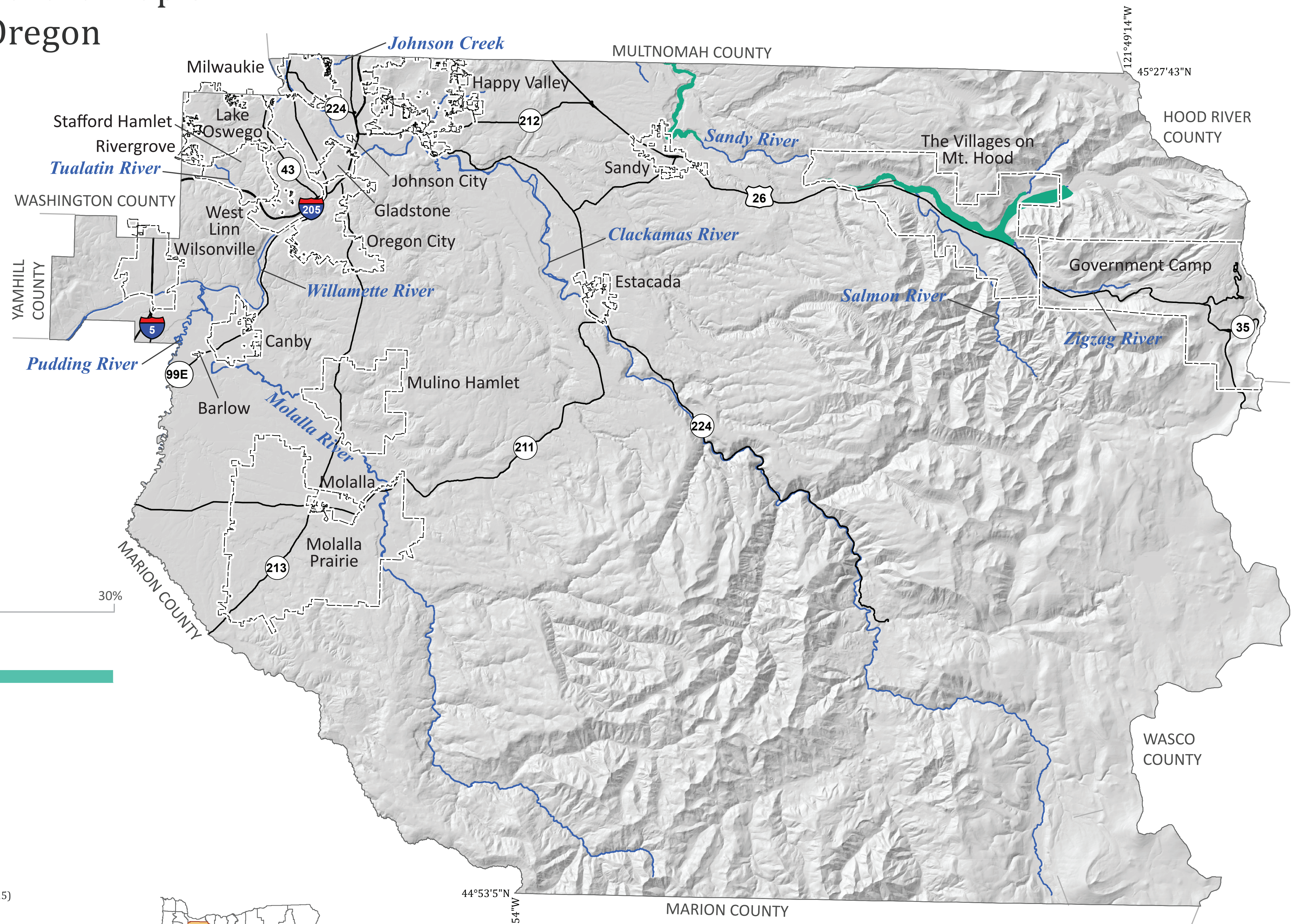
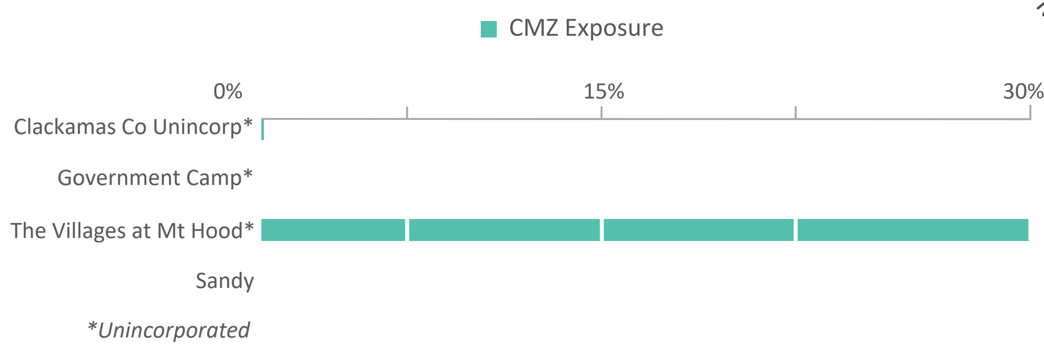
Channel Migration Hazard Map of Clackamas County, Oregon

Channel migration is a process by which a stream's course changes over time due to bank erosion and stream deposition. The channel migration zone is defined by the 100-year Erosion Hazard Area (EHA). Shown are the 100-year EHA in Clackamas County. Buildings within these areas are at greater risk to channel migration hazard than other areas.



Channel Migration Hazard Zone

100-Year Erosion



Data Sources:
Channel migration zone (100-year): DOGAMI (English and others, 2013); (Abbe and others, 2015)
Roads: Oregon Department of Transportation Signed Routes (2013)
Place names: U.S. Geological Survey Geographic Names Information System (2015)
City limits: Oregon Department of Transportation (2014)
Basemap: Oregon Lidar Consortium (2014)
Hydrography: U.S. Geological Survey National Hydrography Dataset (2017)

Projection: NAD 1983 UTM Zone 10N
Software: Esri® ArcMap 10, Adobe® Illustrator CC

Cartography by:Matt C. Williams, 2024

Study Location Map

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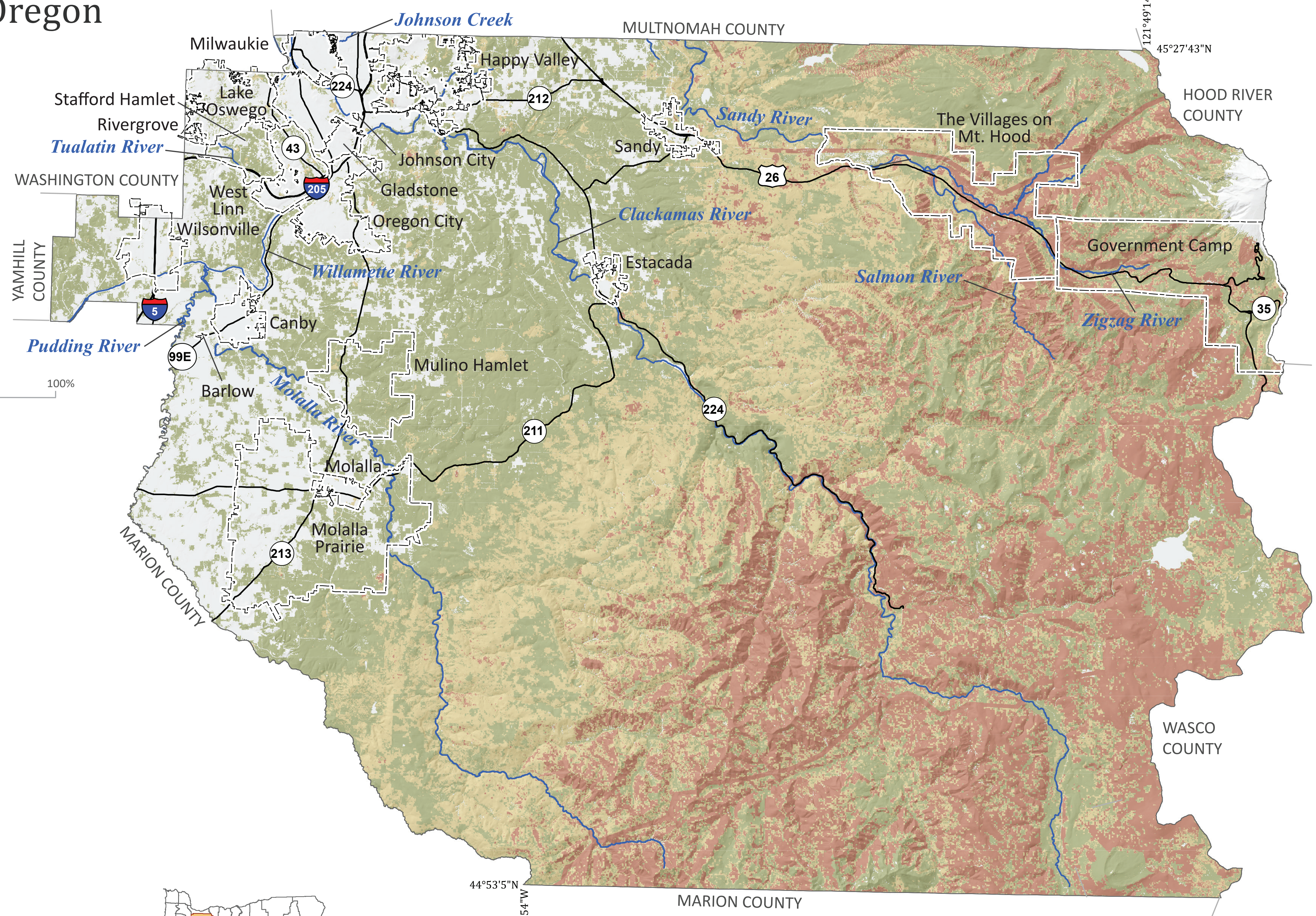
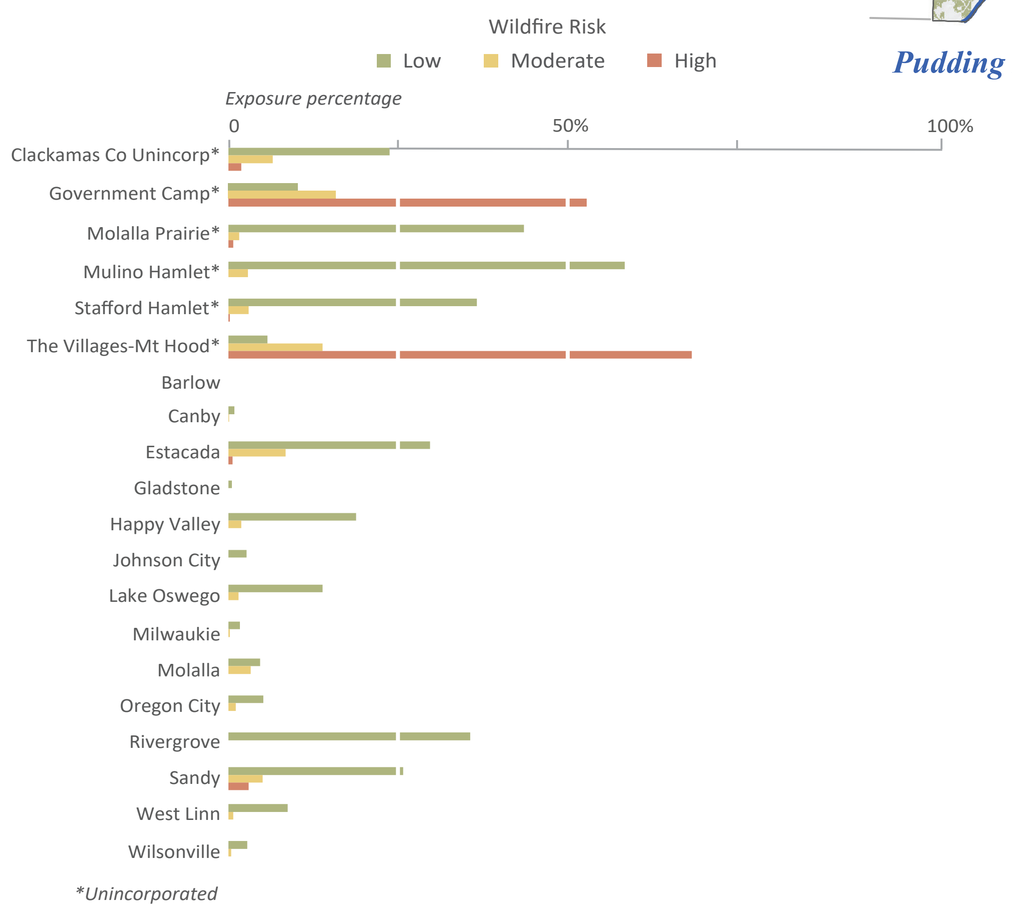
Wildfire Risk Map of Clackamas County, Oregon

Wildfire Risk is categorized as Low, Moderate, and High and indicates the level of risk a location has to wildfire hazard. The Wildfire Risk data layer is derived from a combination of the burn probability (fire history and behavior) and conditional flame length data.





Data Sources:
Wildfire risk data: Oregon Department of Forestry, Pyrologix, LCC. (2018)
Roads: Oregon Department of Transportation Signed Routes (2013)
Place names: U.S. Geological Survey Geographic Names Information System (2015)
City limits: Oregon Department of Transportation (2014)
Basemap: Oregon Lidar Consortium (2014)
Hydrography: U.S. Geological Survey National Hydrography Dataset (2017)

Projection: NAD 1983 HARN Oregon Statewide Lambert
Software: Esri® ArcMap 10, Adobe® Illustrator CC

Cartography by: Matt C. Williams, 2024

Study Location Map

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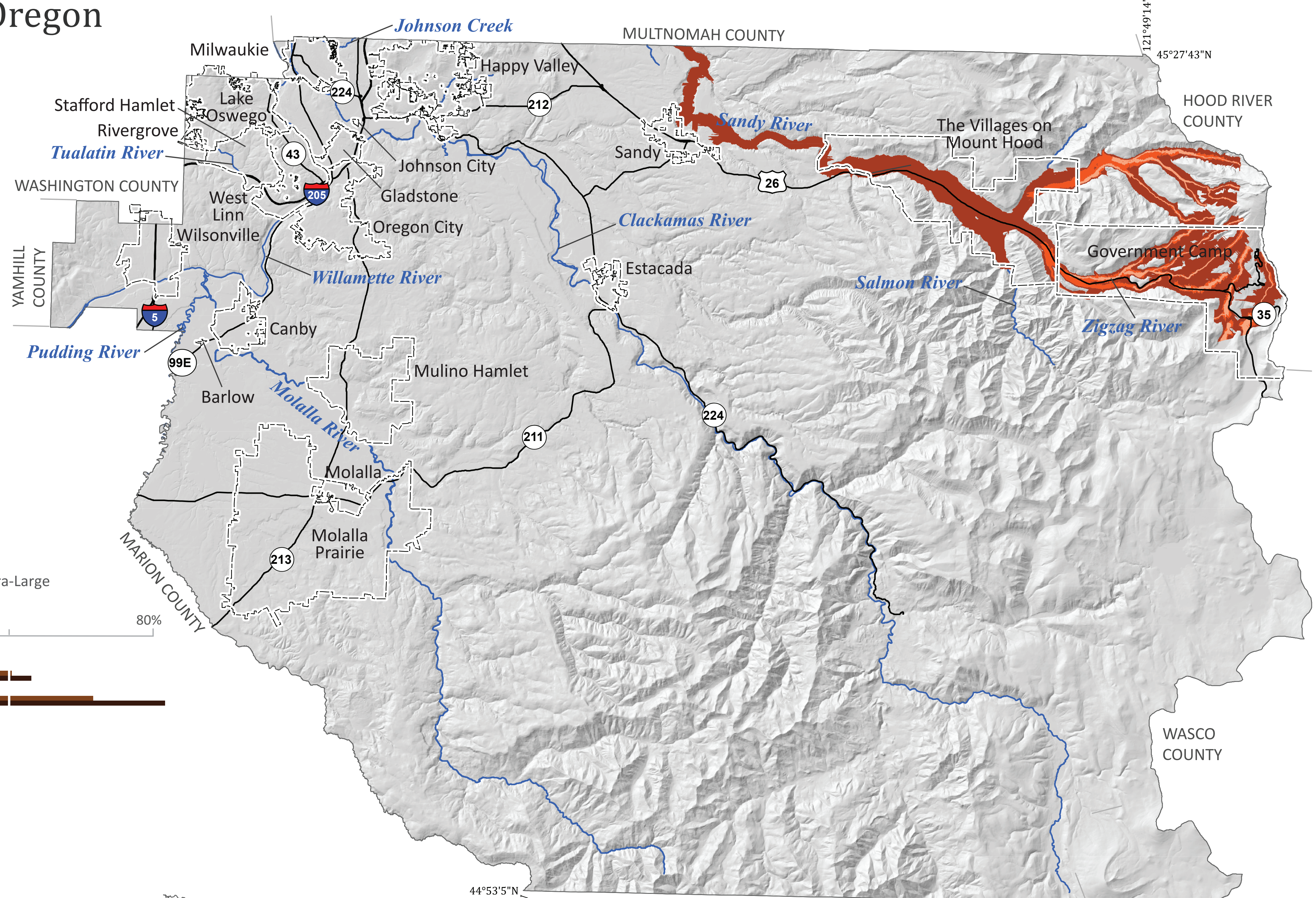
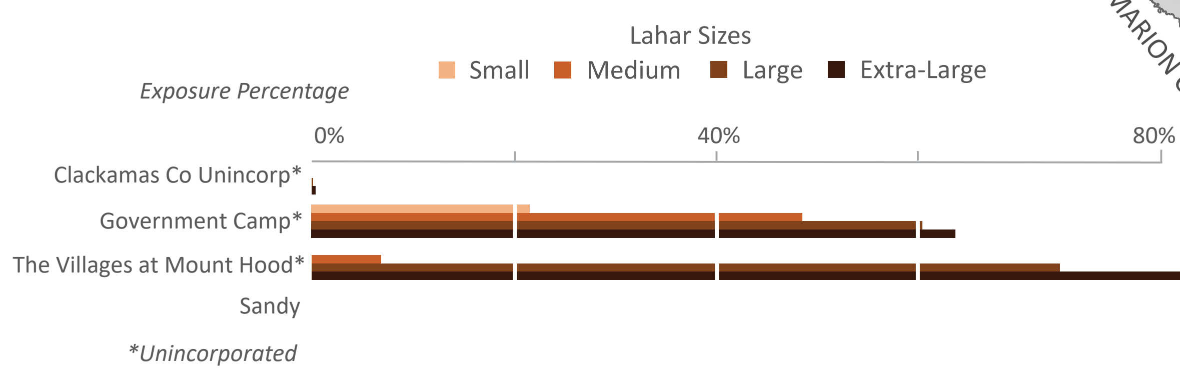
Lahar Exposure Map of Clackamas County, Oregon

The lahar hazard data show areas of expected exposure from several local lahar scenarios produced from a volcanic event on Mount Hood. The scenarios were categorized based on three sizes, ranging from Small to Large.

Lahar Hazard Zone

- Small
- Medium
- Large





Data Sources:
Mount Hood lahar zones: DOGAMI (Burns and others, 2011)
Roads: Oregon Department of Transportation Signed Routes (2013)
Place names: U.S. Geological Survey Geographic Names Information System (2015)
City limits: Oregon Department of Transportation (2014)
Basemap: Oregon Lidar Consortium (2014)
Hydrography: U.S. Geological Survey National Hydrography Dataset (2017)

Projection: NAD 1983 UTM Zone 10N
Software: Esri® ArcMap 10, Adobe® Illustrator CC

Cartography by:Matt C. Williams, 2024

Study Location Map

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