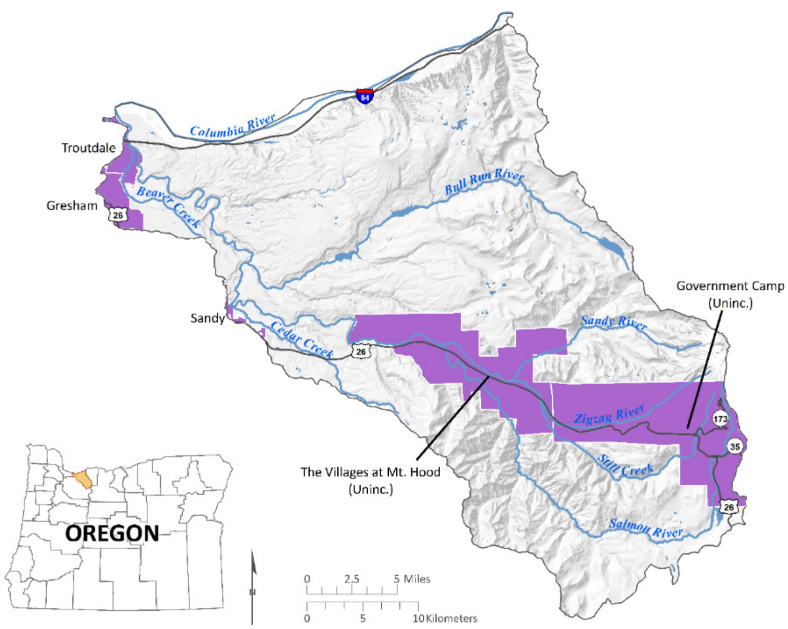
State of Oregon
Oregon Department of Geology and Mineral Industries
Brad Avy, State Geologist

OPEN-FILE REPORT O-20-06

NATURAL HAZARD RISK REPORT FOR THE LOWER COLUMBIA–SANDY WATERSHED, OREGON

INCLUDING THE CITIES OF GRESHAM, SANDY, AND TROUTDALE AND UNINCORPORATED COMMUNITIES OF GOVERNMENT CAMP AND THE VILLAGES AT MT. HOOD



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Cover image: Map shows the Lower Columbia–Sandy watershed study area and incorporated communities included in this report.

WHAT'S IN THIS REPORT?

This report describes the methods and results of natural hazard risk assessments for the communities in the Lower Columbia-Sandy watershed. The risk assessments can help communities better plan for disaster.

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GEOGRAPHIC INFORMATION SYSTEM (GIS) DATA

See the digital publication folder for files.
Geodatabase is Esri® version 10.2 format. Metadata is embedded in the geodatabase and is also provided as separate .xml format files.

Lower_ColumbiaSandy_Watershed Risk_Report_Data.gdb:

Feature dataset: Asset_Data
feature classes:
Building_footprints (polygon)
Communities (polygon)
UDF_points (points)
Raster data: Hazard_Data
FL_Depth_10
FL_Depth_50
FL_Depth_100
FL_Depth_500

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 the communities of the Lower Columbia–Sandy watershed in Oregon, with funding provided by the Federal Emergency Management Agency (FEMA). It describes the methods and results of the natural hazard risk assessments performed in 2017 by the Oregon Department of Geology and Mineral Industries (DOGAMI) within the study area. The purpose of this study is to provide communities within the study area a detailed risk assessment of the natural hazards that affect them to enable them to compare hazards and act to reduce their risk. The risk assessments contained in this study quantify the impacts of natural hazards to these communities and enhance the decision-making process in planning for disaster.

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

In the first task, we created a comprehensive asset database for the entire study area by synthesizing assessor data, U.S. Census information, 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. With these data we were able to represent accurate spatial location and vulnerability 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 some were produced using high-resolution lidar topographic data. While not all the data sources used in the report are countywide, each hazard dataset were the best available at the time of writing.

In the third task, we performed risk assessments using Esri® ArcGIS Desktop® software. We took two risk assessment approaches: (1) estimated loss (in dollars) to buildings from flood (recurrence intervals) and earthquake scenarios using FEMA Hazus®-MH methodology, and (2) calculated number of buildings, their value, and associated populations exposed to earthquake and flood, or susceptible to varying levels of hazard from landslides, wildfire, channel migration, and volcanic lahars.

The findings and conclusions of this report show the potential impacts of hazards in communities within the Lower Columbia–Sandy watershed. A Cascadia Subduction Zone (CSZ) earthquake will cause low to moderate damage and losses throughout the study area. Higher building losses are expected from a Mount Hood Fault Zone magnitude (M) 6.9 earthquake relative to a CSZ earthquake. We ran Hazus-MH earthquake simulations to illustrate the potential reduction in earthquake damage through seismic retrofits. Flooding is a minor threat for many communities in the study area and we quantify the number of elevated structures that are less vulnerable to flood hazard. Our analysis shows that landslide is a widespread hazard and is present for some communities within the study area. Exposure analysis shows that communities in the Villages at Mt. Hood are particularly vulnerable to channel migration hazard. The best data available at preparation of this report show that wildfire risk is moderate for the overall study area. Exposure analysis shows that buildings in the riverine valleys of the study area are vulnerable to volcanic lahar hazard. Our findings also indicate that some of the study area's critical facilities are at high risk from earthquake hazard. We also found that the two biggest causes of population displacement are a CSZ earthquake and a volcanic lahar hazard. Lastly, we demonstrate that this risk assessment can be a valuable tool to local decision-makers.

Results were broken out for the following geographic areas:

- Unincorporated Clackamas County (rural)
- City of Gresham
- City of Troutdale
- Communities of The Villages at Mt. Hood
- Unincorporated Multnomah County (rural)
- City of Sandy
- Community of Government Camp

Selected Study Area Results

Total buildings: 25,659

Total estimated building value: $8.1 billion

Cascadia Subduction Zone (CSZ) Magnitude 9.0 Earthquake
Red-tagged buildings[a]: 1,467
Yellow-tagged buildings[b]: 553
Loss Estimate: $558 million

100-year Flood Scenario
Number of buildings damaged: 295
Loss estimate: $6.8 million

Channel Migration Zone (High Risk)
Number of buildings exposed: 1,632
Exposed building value: $323 million

Lahar (Medium Scenario)
Number of buildings exposed: 953
Exposed building value: $144 million

Mount Hood Fault Zone (MHFZ) Magnitude 6.9 Earthquake
Red-tagged buildings[a]: 1,106
Yellow-tagged buildings[b]: 406
Loss Estimate: $462 million

Landslide (High and Very High-Susceptibility)
Number of buildings exposed: 1,205
Exposed building value: $295 million

Wildfire Results (High Risk)
Number of buildings exposed: 340
Exposed building value: $116 million

[a]Red-tagged buildings are considered to be uninhabitable due to complete damage.
[b]Yellow-tagged buildings are considered to be of limited habitability due to extensive damage.

1.0 INTRODUCTION

A natural hazard risk assessment analyzes how a hazard could affect the built environment, population, and local economy and identifies potential risk. In natural hazard mitigation planning, risk assessments are the basis for developing mitigation strategies and actions. A risk assessment enhances the decision-making process, so that steps can be taken to prepare for a potential hazard event.

Although this study is not the first multi-hazard risk assessment analyzing individual buildings and resident population in the study area, it is based on updated data and hazard information and is therefore the most detailed analysis to date of natural hazard risk for the region. In this report, we describe our assessment results, which quantify the various levels of risk that each hazard presents to the study area's communities.

The Lower Columbia–Sandy watershed, which extends from the High Cascades through the Western Cascades and into the Portland Basin, is subject to several significant natural hazards, including earthquake, flooding, landslides, wildfire, channel migration, and volcanic hazards. This region of the state is moderately developed in some parts and rural in other parts. Natural hazards that pose a potential threat to assets results in risk. The primary goal of this risk assessment is to inform communities of their vulnerability and risk to natural hazards and to be a resource for risk reduction actions.

1.1 Purpose

The purpose of this project is to help communities in the study area better understand their risk and increase resilience to natural hazards that are present in their community. This is accomplished by providing accurate, detailed, and best available information about these hazards and by measuring the number of people and buildings at risk.

The main objectives of this study are to:

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

The body of this report describes the methods and results for these objectives. Two primary methods (Hazus-MH or exposure), depending on the type of hazard, were used to assess risk. We describe the methods for creating the building and population information used in this project. Results for each hazard type are reported on a countywide basis within each hazard section, and community based results are reported in detail in **Appendix A: Community Risk Profiles**. **Appendix B** contains detailed risk assessment tables. **Appendix C** is a more detailed explanation of the Hazus-MH methodology. **Appendix D** lists acronyms and definitions of terms used in this report. **Appendix E** contains tabloid-size maps showing county-wide hazard maps

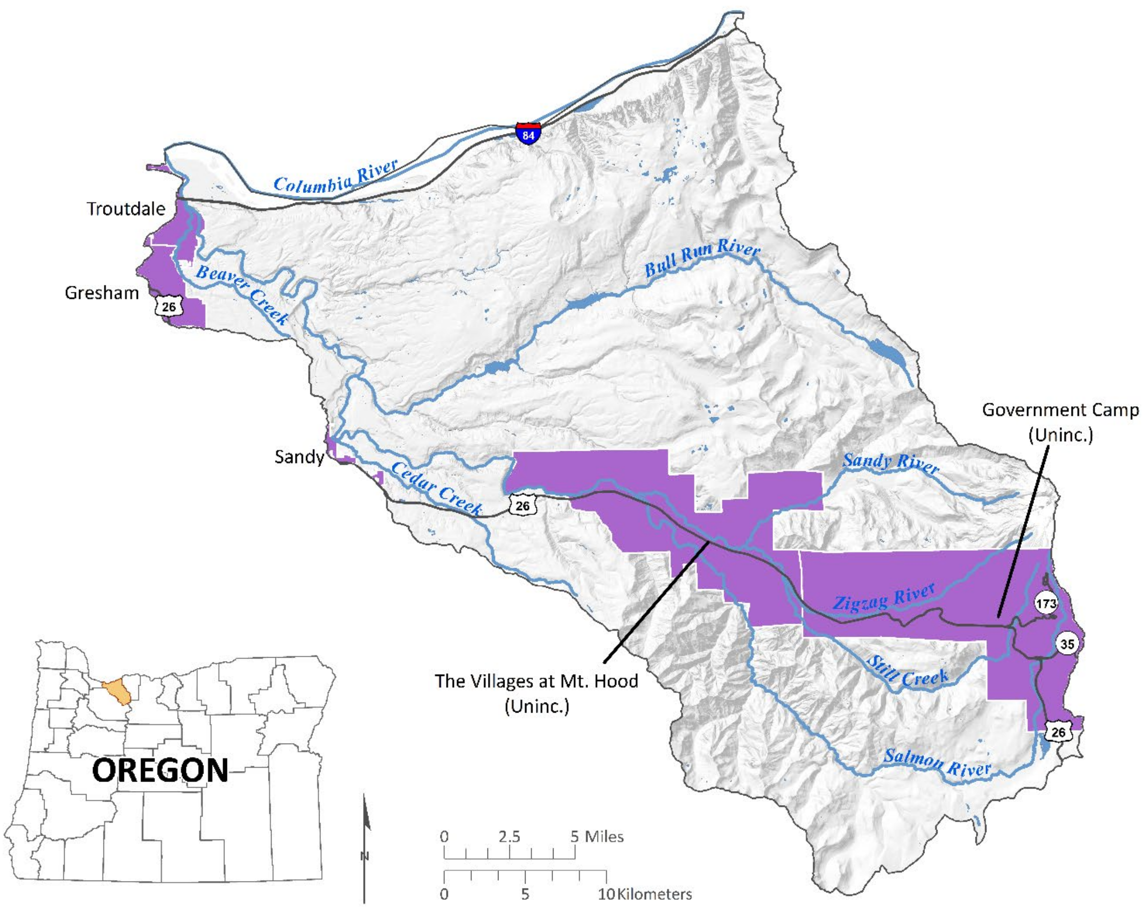
1.2 Study Area

The study area for this project is the portion of the Lower Columbia–Sandy watershed in Oregon (**Figure 1-1**). The Lower Columbia–Sandy watershed is in northwestern portion of Oregon and the southwestern portion of Washington at the western edge of the Columbia River Gorge. It covers portions of Clackamas

County and Multnomah County, Oregon. The study area is bordered by the Columbia River to the north. The eastern, western, and southern limits are defined by other drainages originating from Mount Hood, such as the Clackamas River watershed.

The geography consists of hilly terrain to some of the highest and steepest slopes in Oregon. The western slopes of Mount Hood define the eastern limit of the watershed; from there the terrain descends and land use transitions from heavily timbered forestland into inhabited farmland and suburbs. Where the Sandy River joins the Columbia River the study area is within the urban fringe of some of the densest urban areas of Oregon.

Figure 1-1. Study area: Lower Columbia–Sandy watershed with communities (in purple) identified.



The total population of the study area is 58,902 according to the 2010 U.S. Census (U.S. Census Bureau, 2010a). All communities in the study, incorporated and unincorporated, are located in the western portion of the study area. The study area's largest communities are only partially within the study area, so partial community population counts do not match official total population counts for the entire jurisdiction. The area with the largest concentration of residents in the study area is near the mouth of the Sandy River within communities of Troutdale and Gresham. The study area includes portions of the incorporated communities of Gresham, Sandy, and Troutdale (**Figure 1-1**) and the unincorporated communities of The Villages at Mt. Hood (Brightwood, Welches, Wimme, Zigzag, and Rhododendron) and Government Camp.

We selected these unincorporated communities based on population size and density, which make them distinct from the rural unincorporated counties' jurisdictions. The boundaries of the unincorporated communities are based on shapefiles provided to DOGAMI by Clackamas County Technology Services.

1.3 Project Scope

For this risk assessment, we applied a quantitative approach to buildings and population. The decision to limit the project scope to buildings and population was driven by data availability, strengths and limitations of the risk assessment methodology, and funding availability. We did not analyze impacts to the local economy, land values, or the environment. Depending on the natural hazard, we used one of two methodologies: loss estimation or exposure. Loss estimation was modeled using methodology from Hazus®-MH (Hazards U.S., Multi-Hazard), a tool developed by FEMA for calculating damage to buildings from flood and earthquake. Exposure is a simpler methodology, where buildings are categorized based on their location relative to various hazard zones. To account for impacts on population (permanent residents only), 2010 U.S. Census data (U.S. Census Bureau, 2010a) were associated with residential buildings.

A critical component of this risk assessment is a countywide building inventory developed from building footprint data and tax assessor databases from Multnomah and Clackamas Counties. 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 the risk assessment methodologies we used for each natural hazard. See **Table 1-1** for data sources.

for data sources.

Earthquake Risk Assessment

- Hazus-MH loss estimation from a CSZ magnitude 9.0 event
- Hazus-MH loss estimation from a MHFZ magnitude 6.9 event

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 (low to very high)

Wildfire Risk Assessment

- Exposure based on fire risk index (low to high)

Channel Migration Risk Assessment

- Exposure based on channel migration zone (exposed or not exposed)

Volcano Risk Assessment

- Exposure to four potential lahar scenarios (small to extra-large)

Table 1-1. Hazard data sources for this Lower Columbia–Sandy watershed study.

Hazard	Scenario or Classes	Scale/Level of Detail	Data Source
Earthquake	CSZ M9.0	regional	DOGAMI (Madin and Burns, 2013)
	Mount Hood Fault Zone (MHFZ) M6.9	Mount Hood	DOGAMI (Madin and others, 2017)
Flood	Depth grids: 10% (10-yr) 2% (50-yr) 1% (100-yr) 0.2% (500-yr)	watershed	DOGAMI; derived from FEMA (2016a, b) data included in GIS data for this report
Landslide*	Susceptibility (Low, Moderate, High, Very High)	state	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	Risk (Low, Moderate, High)	regional (Western United States)	Oregon Department of Forestry (Sanborn Map Company, Inc., 2013)
Lahar	Local source: Small — 10% (10-yr) Medium — 1% (100-yr) Large — 0.2–0.1% (500–1,000-yr) Extra-large — 0.001% (100,000-yr)	Mount Hood	DOGAMI (Burns and others, 2011)

CSZ M9.0 is Cascadia subduction zone magnitude 9 earthquake. MHFZ M6.9 is a crustal fault system located on the northern slope of Mount Hood.

*Landslide data comprise a composite dataset where the level of detail varies greatly from place to place within the state. Refer to section **3.4.1** or Burns and others (2016) for more information.

1.4 Previous Studies

DOGAMI conducted two previous risk assessments within or including the study area. Wang and Clark (1999) performed two general-level Hazus-MH earthquake analyses, a magnitude 8.5 CSZ earthquake and a 500-year probabilistic earthquake scenario, for the entire state of Oregon. In those analyses, the Lower Columbia–Sandy watershed area had higher loss ratios from the 500-year event than from the CSZ M8.5 event. In Wang and Clark analysis, the study area had a moderate loss ratio compared with all the counties in the state.

Burns and others (2011) conducted a multi-hazard risk study for Mount Hood region, which includes the study area. In that study, damage and losses for earthquake scenarios were analyzed in Hazus-MH; lahar hazard maps were developed using the GIS-based program LAHARZ (see section **3.7.1**, **Data sources**, for details); flood scenarios were run using the U.S. Army Corps of Engineers Hydrologic Engineering Centers River Analysis System (HEC-RAS) program; channel migration zones, published separately (English and others, 2013), were delineated and examined as a hazard based on exposure analysis; and landslide hazard was examined, with an emphasis on debris flows for the region. Building-level risk assessments were conducted using these hazard data sources for exposure analysis but were not used for Hazus-MH earthquake or flood analysis.

We did not compare the results of this project with the results of these previous studies because of limited time and funding.

2.0 METHODS

2.1 Hazus-MH Loss Estimation

> ***Key Terms:***
> - *Loss estimation:* Damage that occurs to a building in an earthquake or flood scenario, as modeled with Hazus-MH methodology.
> - *Loss ratio:* Percentage of estimated loss relative to the total value.

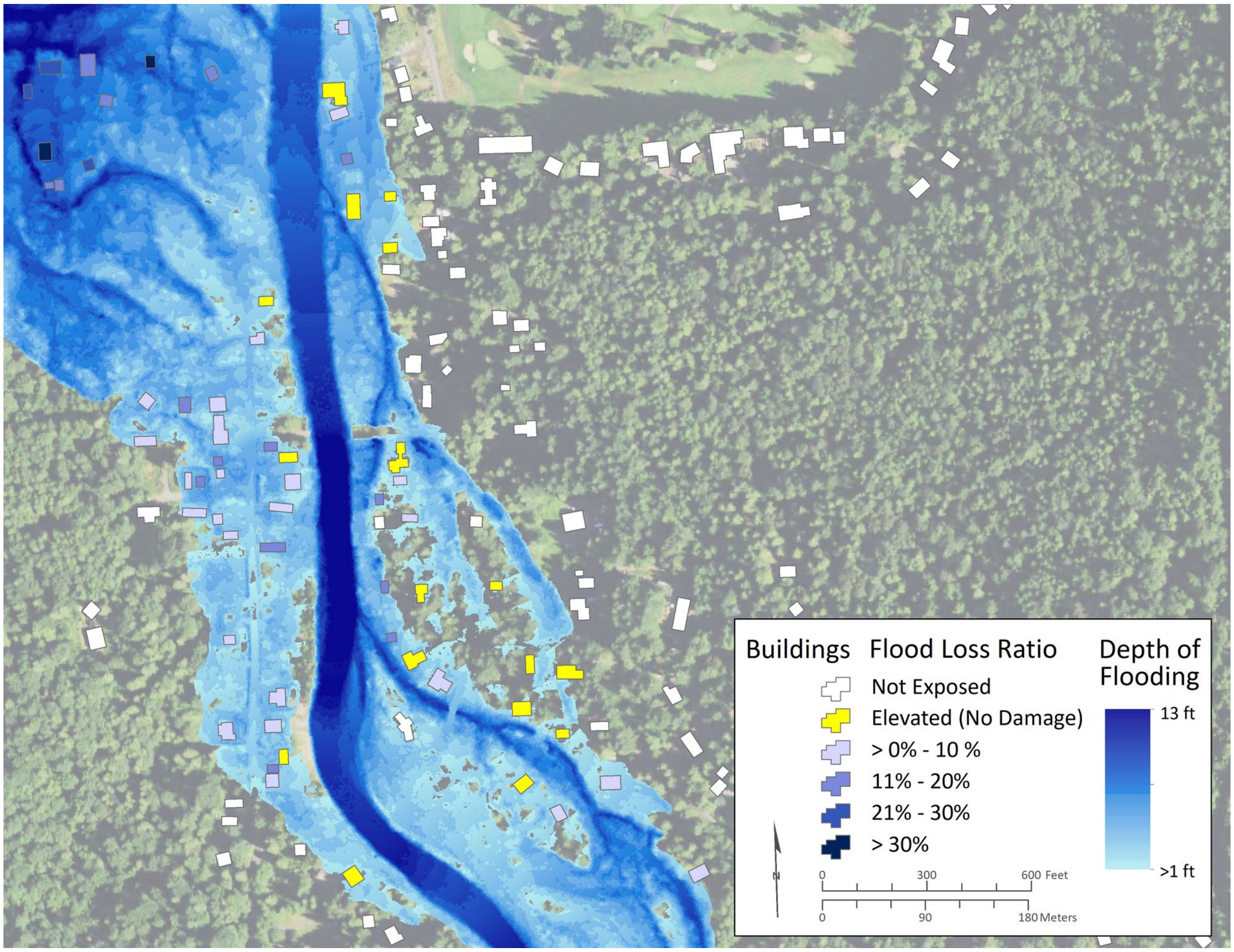
"Hazus provides nationally applicable, standardized methodologies for estimating potential wind, flood, and earthquake losses on a regional basis. Hazus can be used to conduct loss estimation for floods and earthquakes […]. The multi-hazard Hazus is intended for use by local, state, and regional officials 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" (FEMA, 2012a, p. 1-1).

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, DOGAMI chose the user-defined facility (UDF) mode. This mode makes loss estimations for individual buildings relative to their "cost," which DOGAMI then aggregates to the community level to report loss ratios. DOGAMI derives cost from the estimated building replacement cost. 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-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. Estimates of loss are made by intersecting building locations with natural hazard layers and applying damage functions based on the hazard severity and building characteristics. **Figure 2-1** illustrates the range of building loss estimates from Hazus-MH flood analysis.

DOGAMI used Hazus-MH version 3.0 (FEMA, 2015), which was the latest version available when we began this risk assessment.

Figure 2-1. 100-year flood zone and building loss estimates example in the study area.



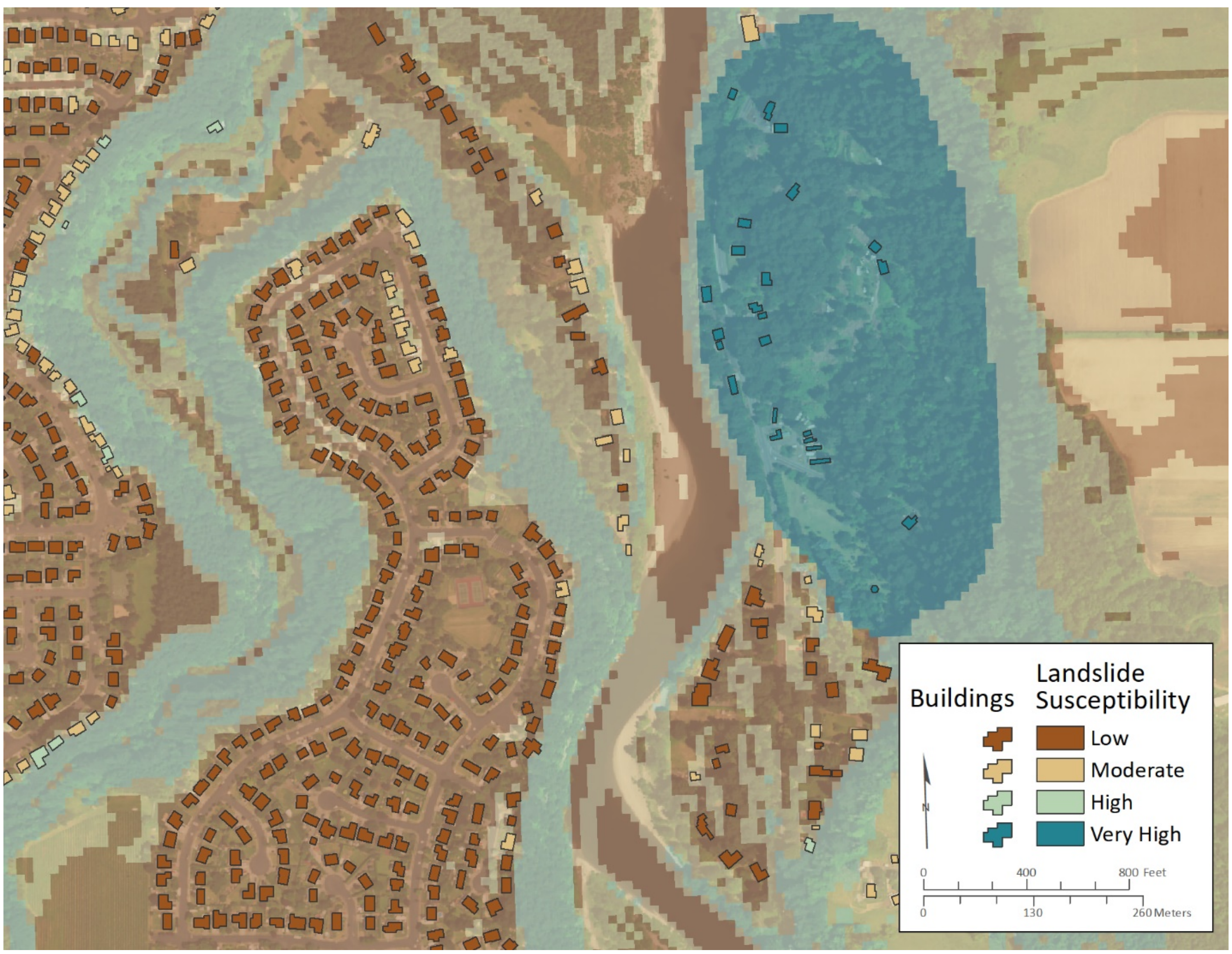
2.2 Exposure

> ***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.

Exposure methodology calculates the buildings and population within a natural hazard zone. This is an alternative methodology for natural hazards that do not have readily available damage functions and, therefore, loss estimation is not possible. 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 loss estimate, because the loss ratio is unknown. **Figure 2-2** shows buildings that are exposed to different landslide scenarios.

Exposure is used for landslide, wildfire, channel migration, and lahar to quantify buildings and residents at risk. For comparison with loss estimates, exposure is also used for the 1% annual chance flood.

Figure 2-2. Landslide susceptibility and building exposure example in the study area, portion of City of Troutdale.



2.3 Building Inventory

A key piece of the risk assessment is the building inventory of the study area. This inventory consists of all buildings larger than 500 square feet (152 square meters), as determined from existing building footprints (Burns and others, 2011) or tax assessor data. **Figure 2-3** shows an example of the building inventory occupancy types used in the Hazus-MH and exposure analyses in the study area. See also Appendix B, **Table B-1** and Appendix E, **Plate 1** and **Plate 2**.

Figure 2-3. Building footprints colored by occupancy type, portion of City of Gresham.

To use the building inventory within the Hazus-MH methodology, we converted building footprints 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, 2012b,c) 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.**

Table 2-1 shows the distribution of building count and value within the UDF database for the study area. A table detailing the occupancy class distribution by community is included in **Appendix B: Detailed Risk Assessment Tables.**

Table 2-1. Study area building inventory.

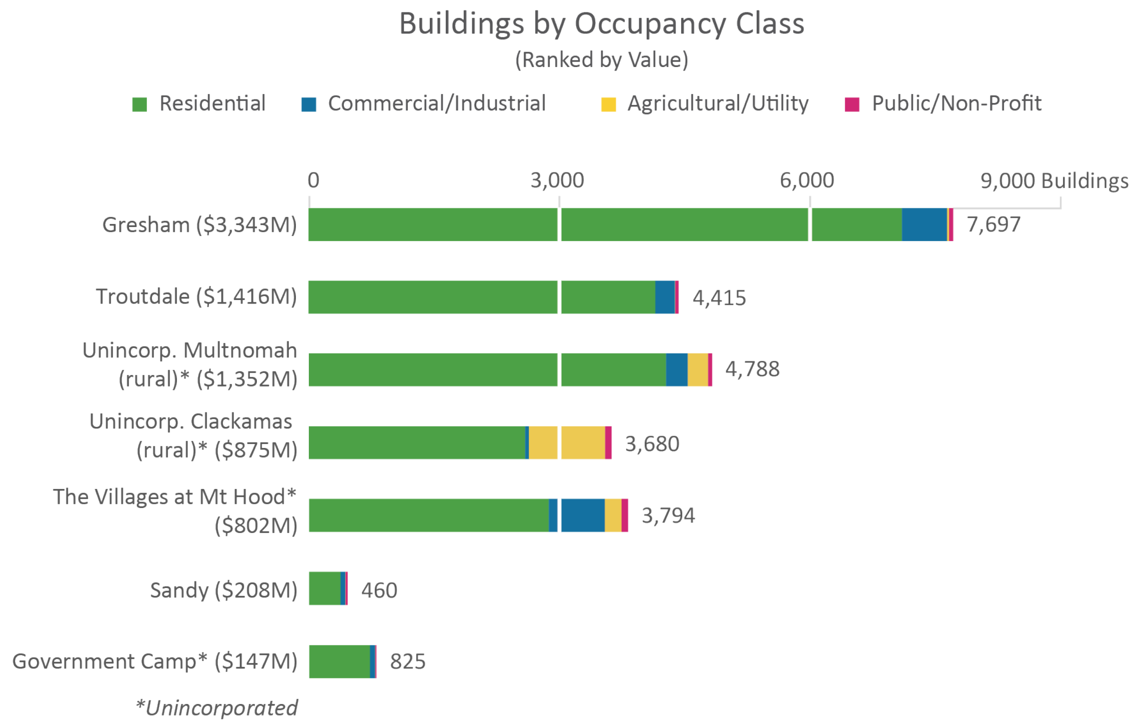
Community*	Total Number of Buildings	Percentage of Buildings of Study Area	Total Estimated Building Value ($)	Percentage of Building Value of Study Area
Unincorp. Clackamas County (rural)	4,788	19%	1,351,889,000	17%
Unincorp. Multnomah County (rural)	3,680	14%	874,879,000	11%
Government Camp	825	3.2%	147,179,000	1.8%
The Villages at Mt. Hood	3,794	15%	801,469,000	9.9%
Total Unincorporated Study Area	13,087	51%	3,175,415,000	39%
Gresham	7,697	30%	3,342,722,000	41%
Sandy	460	2%	207,451,000	3%
Troutdale	4,415	17%	1,410,884,000	17%
Total Study Area	25,659	100%	8,136,473,000	100%

*"Unincorp. Clackamas County (rural)" and "Unincorp. Multnomah County (rural)" exclude the incorporated communities, Government Camp, and The Villages at Mt. Hood. The study area contains only portions of the incorporated communities of Gresham, Sandy, and Troutdale.

The building footprint inventory was developed from Burns and others (2011) and was refined for use in loss estimation and exposure analyses. Additional building footprints were obtained from Portland Metro Regional Government. A database of Hazus-formatted building footprints for a significant portion of the study area was already available from a previous DOGAMI project (Bauer and others, 2018). Building footprints in the database were digitized from high-resolution lidar collected in 2009 (Hood to Coast 2009 project, DOGAMI [Oregon Lidar Consortium (OLC)]), and in 2014 (OLC Metro 2014 project, DOGAMI). The building footprints provide a spatial location and two-dimensional representation of a structure. The total number of buildings within the study area was 25,659.

Clackamas County and Multnomah County supplied assessor data (2016); the data were formatted by Bauer and others (2018) for use in risk assessments. The assessor data contain an array of information about each improvement (i.e., building). Taxlot data, which contain property boundaries and other information regarding the property, were obtained from the counties' assessors (Clackamas County Office of Assessment and Taxation, 2016; Multnomah County Office of Assessment and Taxation, 2016) and was used to link the buildings with assessor data. The linkage between the two datasets resulted in a database of UDF points that contain attributes for each building. These points are used in the risk assessments for both loss estimation and exposure analysis. **Figure 2-4** illustrates the variation of building value and occupancy across the communities of the study area.

Figure 2-4. Community building value in the study area by occupancy class.



Note that "Unincorp. Clackamas County (rural)" and "Unincorp. Multnomah County (rural)" exclude the incorporated communities, Government Camp, and The Villages at Mt. Hood. The study area contains portions of the incorporated communities of Gresham, Sandy, and Troutdale.

We attributed critical facilities in the UDF database so that 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™ data. The critical facilities we attributed include hospitals, schools, fire stations, police stations, emergency operations, and military facilities. In addition to these standard building types, we considered other building types based on local input or special considerations that are specific to the study area that would be essential during a natural hazard event, such as public works and water treatment facilities. Critical facilities are important to note because these facilities play a crucial role in emergency response efforts. 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.

Table 2-2 shows the critical facilities on a community basis. Critical facilities are listed for each community in **Appendix A: Community Risk Profiles**.

Table 2-2. Study area critical facilities inventory.

	Hospital & Clinic		School		Police/Fire		Emergency Services		Military		Other[2]		Total	
Community[1]	Count	Value ($)	Count	Value ($)	Count	Value ($)	Count	Value ($)	Count	Value ($)	Count	Value ($)	Count	Value ($)
(all dollar amounts in thousands)														
Unincorp. Clackamas County (rural)	—	—	2	58,999	3	1,400	—	—	—	—	—	—	5	60,399
Unincorp. Multnomah County (rural)	—	—	1	882	1	522	—	—	—	—	—	—	2	1,404
Government Camp	—	—	—	—	1	216	—	—	—	—	—	—	1	216
The Villages at Mt. Hood	—	—	2	11,681	2	2,638	—	—	—	—	—	—	4	14,319
Total Unincorp. Study Area	—	—	5	71,562	7	4,776	—	—	—	—	—	—	12	76,338
Gresham	1	41,961	4	46,958	1	449	—	—	—	—	1	139,588	7	288,956
Sandy	—	—	3	24,366	1	1,732	—	—	—	—	—	—	4	26,097
Troutdale	—	—	4	49,490	—	—	—	—	—	—	—	—	4	49,490
Total Study Area	1	41,961	16	192,375	9	6,956	—	—	—	—	1	139,588	27	380,882

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

[1]"Unincorp. Clackamas County (rural)" and "Unincorp. Multnomah County (rural)" exclude the incorporated communities, Government Camp, and The Villages at Mt. Hood. The study area contains only portions of the incorporated communities of Gresham, Sandy, and Troutdale.

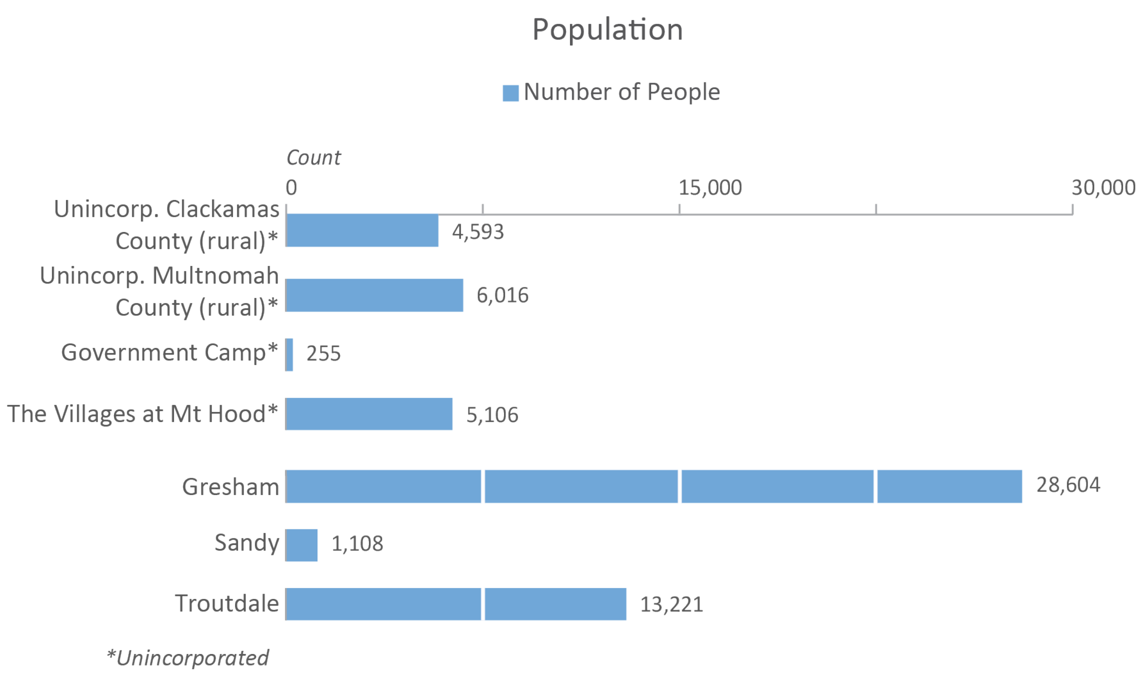
[2]Category includes buildings that are not traditional (emergency response) critical facilities but considered critical during an emergency based on input from local stakeholders (e.g., water treatment facilities or airports).

2.4 Population

Within the UDF database, the population of permanent residents reported per census block was distributed among residential buildings and pro-rated based on square footage (**Figure 2-5**). We did not examine for this report the impacts from natural hazards to non-permanent populations (e.g., tourists), whose total numbers fluctuate seasonally. We used census blocks to distribute population to buildings; however, because census blocks do not align with the study area boundary some buildings included in this report were outside of the study area. Due to lack of information within the assessor and census databases, this distribution also includes vacation homes, which in many of the communities make up a large portion of the total residential building stock. From information reported in the 2010 U.S. Census, American FactFinder regarding vacation rentals within the community of Government Camp, it is estimated that approximately 75% of residential buildings are vacation rentals (U.S. Census Bureau, 2010b).

Using this population distribution, DOGAMI analyzed the 58,903 residents within the study area who could be affected by a natural hazard scenario. For each natural hazard, with the exception of the CSZ magnitude 9.0 and MHFZ magnitude 6.9 earthquake scenarios, a simple exposure analysis was used to find the number of potentially displaced residents within a hazard zone. For the CSZ magnitude 9.0 and MHFZ magnitude 6.9 earthquake scenarios, the potentially displaced residents were based on the number of residents in buildings estimated to be significantly damaged by the earthquake.

Figure 2-5. Population by study area community.



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3.0 ASSESSMENT OVERVIEW AND RESULTS

This risk assessment considers six natural hazards (earthquake, flood, landslide, wildfire, channel migration, and lahar) that pose a risk to the study area. The assessment describes both localized vulnerabilities and the widespread challenges that impact all communities. The loss estimation and exposure results, as well as the rich dataset included with this report, can lead to greater understanding of the potential impact of disasters. Communities can use the results to update plans as part of the work toward becoming more resilient to future disasters.

3.1 Hazards and Study Area Results

In this section, results are presented for the study area. The study area includes all unincorporated areas, unincorporated communities, and cities within the Lower Columbia–Sandy watershed. Individual community results are in **Appendix A: Community Risk Profiles**.

3.2 Earthquake

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

Two potential 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.

3.2.1 Cascadia subduction zone and Mount Hood Fault Zone earthquake scenarios

Just off Oregon's coast, the Juan de Fuca tectonic plate slides under the North American plate. This area of interaction between the two plates is known as the Cascadia subduction zone (CSZ). The pressure and friction created by this convergent motion builds potential energy at the plate boundary until the overriding plate suddenly slips, releasing energy that manifests as strong shaking spread over a wide area. Earthquakes along the CSZ occur on average every 500 years and can be extremely large (Clague and others, 2000).

The other earthquake scenario examined for this report occurs in the Mount Hood Fault Zone (MHFZ), located on the northern and southern slopes of Mount Hood and trending northeast. This fault zone is a Holocene age active fault zone and is about 7.5 miles (12 km) long, 3 miles (4.5 km) wide, and a few hundred feet to 3 miles (5 km) deep. Madin and others (2017) estimated fault displacement could produce relatively large (magnitude 6.8 to 6.9) crustal earthquakes frequently enough to pose a significant hazard. Although the fault zone is distant from major population centers, it poses a serious seismic threat to the communities of Government Camp and The Villages at Mt. Hood.

We examined earthquake shaking and ground failure hazards produced from both earthquake scenarios. These two earthquake scenarios were analyzed in Hazus-MH because we observed, from the initial Hazus-MH analyses for this study, that buildings in the western portion of the study area were at higher risk to the CSZ M9.0 and buildings in the eastern portion were at higher risk to the MHFZ M6.9. The widespread effects from either earthquake scenario present a challenge for planners preparing for hazard impacts.

3.2.2 Data sources: Cascadia subduction zone scenario

Most of the hazard data inputs for our Hazus-MH earthquake analysis were originally created for the 2012 Oregon Resilience Plan (ORP) for Cascadia Subduction Zone Earthquakes (Madin and Burns, 2013). In conducting their vulnerability assessment, the ORP seismic workgroup chose an earthquake scenario of magnitude (M) 9.0 off the coast of Oregon along the subduction zone.

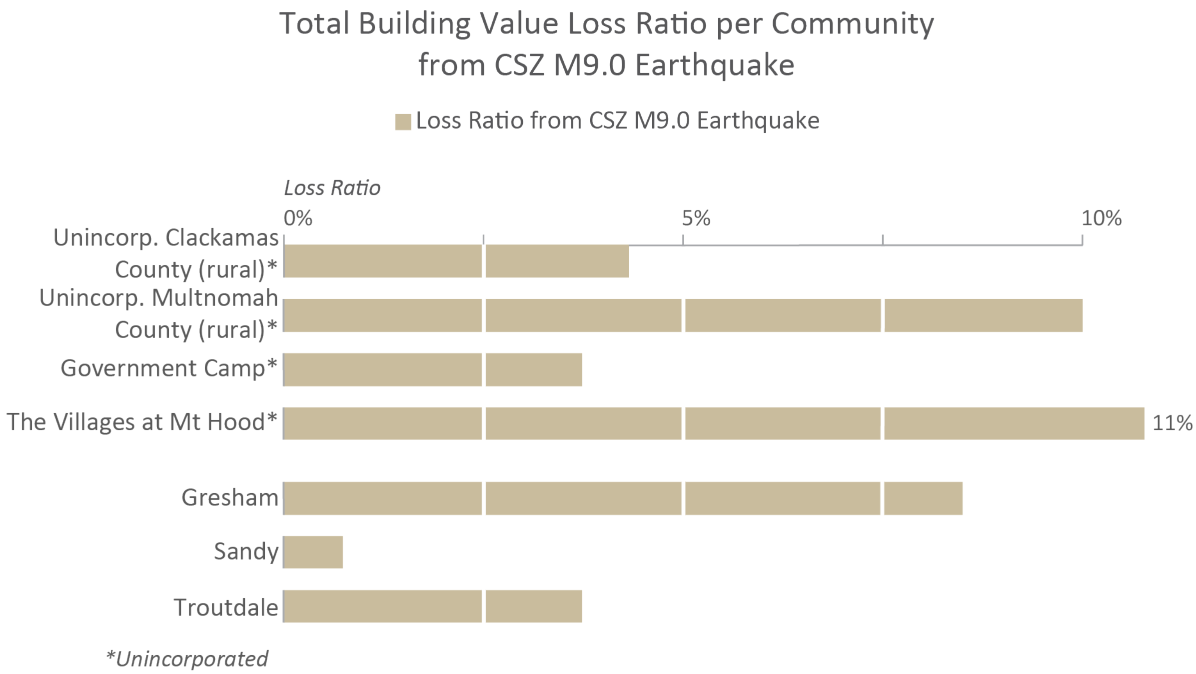
Hazus-MH offers two methods for estimating loss from earthquake, probabilistic and deterministic (FEMA, 2012b). A probabilistic scenario uses U.S. Geological Survey (USGS) National Seismic Hazard Maps which are derived from seismic hazard curves calculated on a grid of sites across the United States that describe the annual frequency of exceeding a set of ground motions as a result of all possible earthquake sources (USGS, 2017). A deterministic scenario is based on a specific seismic event, which in this case is the CSZ M9.0 event. We selected the deterministic scenario method because the CSZ event is the highest seismic risk to a portion of the study area (Clague and others, 2000). We used this 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 our loss estimation are derived from work conducted by Madin and Burns (2013): National Earthquake Hazard Reduction Program (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 susceptibility. We obtained landslide susceptibility data from the work of Appleby and others (2019). The more conservative "wet" landslide susceptibility scenario was used in this analysis (Appleby and others, 2019). The liquefaction and landslide susceptibility layers together with PGA were used by the Hazus-MH tool to calculate permanent ground deformation and associated probability.

3.2.3 Study area results: Cascadia subduction zone

Because an earthquake can affect a wide area, it is unlike other hazards in this report—every building in the study area, to some degree, will be affected by this hazard (see Appendix E, **Plate 3**). 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 (none, low, moderate, extensive, and complete). These damage states are correlated to loss ratios that are then multiplied by the building dollar value to obtain a loss estimate (FEMA, 2012b). **Figure 3-1** shows loss ratios from the CSZ event for the communities of the study area.

Figure 3-1. CSZ M9.0 earthquake loss ratio by study area community



Note that "Unincorp. Clackamas County (rural)" and "Unincorp. Multnomah County (rural)" exclude the incorporated communities, Government Camp, and The Villages at Mt. Hood. The study area contains portions of the incorporated communities of Gresham, Sandy, and Troutdale.

In keeping with earthquake damage reporting conventions, we used the ATC-20 post-earthquake building safety evaluation color-tagging system to represent damage states (Applied Technology Council, 1989). 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 buildings in each damage state is based on an aggregation of probabilities per community and does not represent individual buildings (FEMA, 2012b).

Critical facilities were considered non-functioning if the Hazus-MH earthquake analysis showed that a building or complex of buildings had a greater than 50-percent chance of being at least moderately damaged (FEMA, 2012b).

The number of potentially displaced residents from the CSZ M9.0 earthquake was based on the formula: ([Number of Occupants] * [Probability of Complete Damage]) + (0.9 * [Number of Occupants] * [Probability of Extensive Damage]). The probability of damage state was determined in the Hazus-MH earthquake analysis results.

Study area CSZ M9.0 earthquake results:

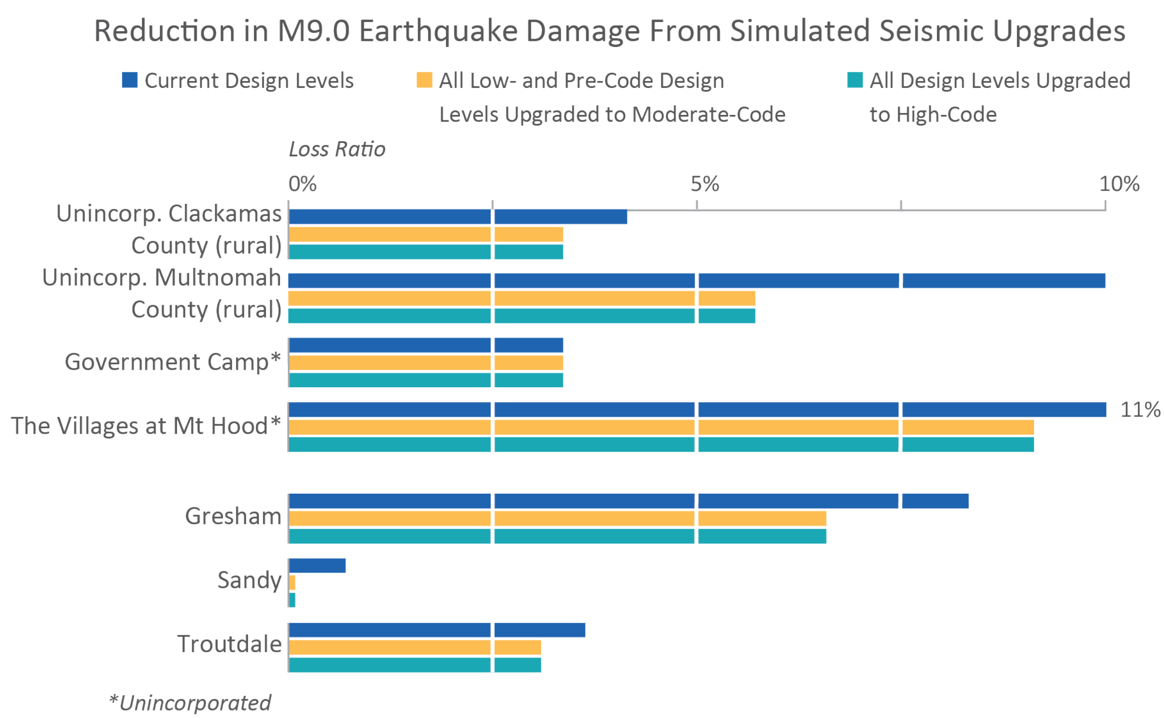
- Number of red-tagged buildings: 1,467
- Number of yellow-tagged buildings: 553
- Loss estimate: $557,829,000
- Loss ratio: 6.9%
- Non-functioning critical facilities: 4
- Potentially displaced population: 3,411

The results indicate that buildings in the western portion of the study area would incur more damage due to a CSZ M9.0 earthquake than would buildings in the eastern portion. This difference is primarily due to the proximity to the earthquake source.

Additionally, these results are influenced by the overall age of the building stock. Seismic building codes were implemented in Oregon in the 1970s (Judson, 2012); nearly 50% of buildings were built before "moderate" code enforcement. These estimated losses show that the age of the building stock is a primary metric of earthquake vulnerability for a community. Communities within the study area that are composed of an older building stock are expected to experience more damage from earthquake than are newer ones.

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 $558 million to $424 million (6.9% to 5.2%), when all buildings are upgraded to at least moderate code level. Although retrofits can decrease earthquake vulnerability, the benefits are minimized in landslide and liquefaction areas, where buildings would need additional geotechnical mitigation to have an effect on losses. **Figure 3-2** illustrates the reduction in loss estimates from a CSZ M9.0 earthquake through two simulations where all buildings are upgraded to at least moderate code standards and then all buildings to high code standards.

Figure 3-2. Cascadia subduction zone M9.0 earthquake loss ratio in the study area, with simulated seismic design upgrades.



Note that "Unincorp. Clackamas County (rural)" and "Unincorp. Multnomah County (rural)" exclude the incorporated communities, Government Camp, and The Villages at Mt. Hood. The study area contains portions of the incorporated communities of Gresham, Sandy, and Troutdale.

3.2.4 Data sources: Mount Hood Fault Zone (MHFZ) scenario

The hazard data inputs for the Mount Hood Fault Zone Hazus-MH analysis were based on findings reported by Madin and others (2017). The epicenter used in the Hazus-MH analysis was interpolated by measuring from the fault location at the surface, the depth of the earthquake, and the angle of the fault. This placed the epicenter about 6.2 miles (10 kilometers) below the unincorporated community of Welches. Ground shaking datasets were produced through Hazus-MH based on the scenario settings. Ground failure, liquefaction susceptibility, landslide susceptibility, and seismic soil data were obtained from DOGAMI (Madin and others, 2017).

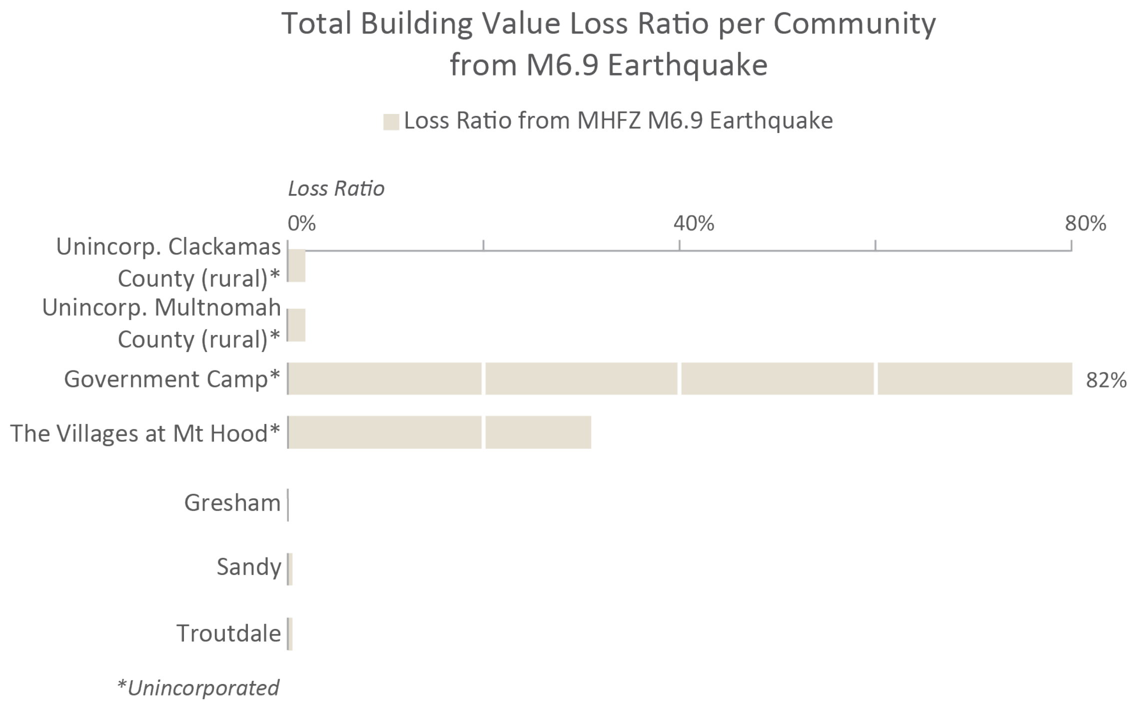
3.2.5 Study area results: Mount Hood Fault Zone

Although a CSZ event will cause some issues in the lower reaches of the watershed, our results indicate a MHFZ M6.9 earthquake will cause large-scale disruptions in the upper reaches of the watershed, especially in the communities of Government Camp and The Villages at Mt. Hood. Because an earthquake can affect a wide area, it is unique from other hazards described in this report—every building in the study area will experience some amount of shaking from a MHFZ M6.9 earthquake (Appendix E, **Plate 4**). **Figure 3-3** and **Table B-3** show loss ratios from this earthquake scenario for the communities of the Lower Columbia–Sandy watershed.

Study area Mount Hood Fault Zone M6.9 earthquake results:

- Number of red-tagged buildings: 1,106
- Number of yellow-tagged buildings: 406
- Loss estimate: $462,032,000
- Loss ratio: 5.7%
- Non-functioning critical facilities: 3
- Potentially displaced population: 1,277

Figure 3-3. Mount Hood Fault Zone M6.9 earthquake loss ratio by study area community.



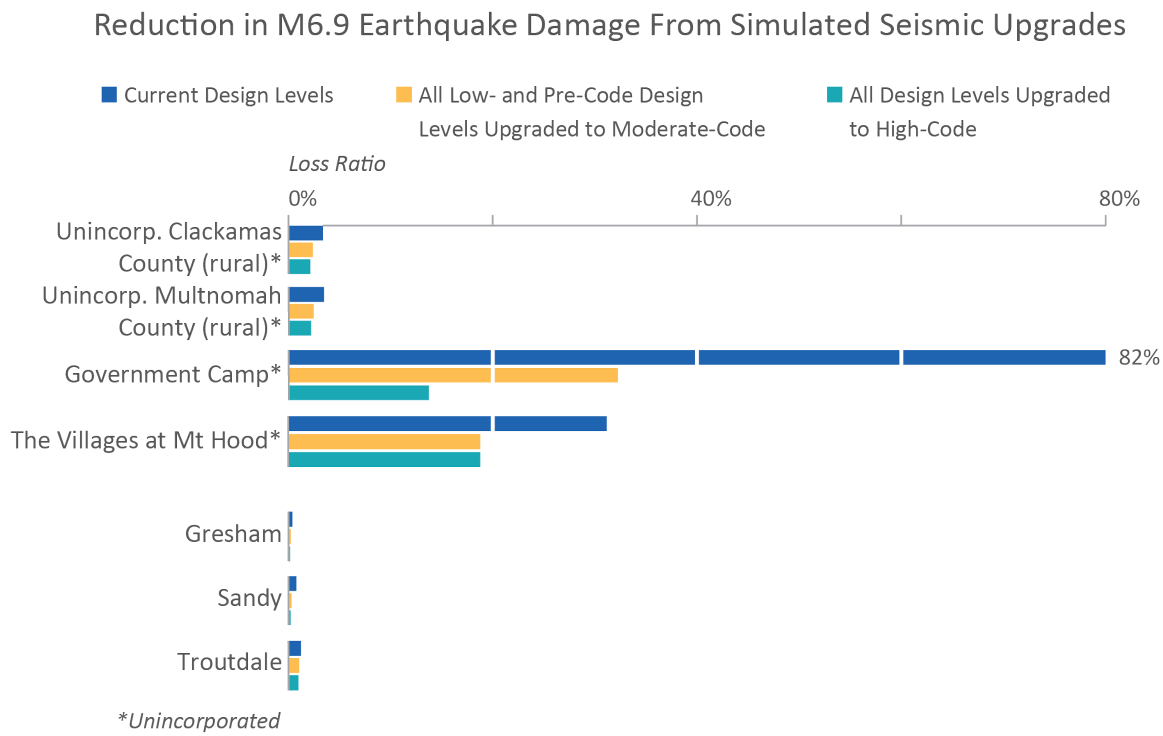
Note that “Unincorp. Clackamas County (rural)” and “Unincorp. Multnomah County (rural)” excludes the incorporated communities, Government Camp, and The Villages at Mt. Hood. The study area contains portions of the incorporated communities of Gresham, Sandy, and Troutdale.

Note that Government Camp’s most expensive buildings, Timberline Lodge and Ski Area, comprise the majority of the damage from this earthquake scenario at nearly 40%.

The results indicate that buildings in the upstream portion of the study area, would incur more damage due to a MHFZ magnitude 6.9 earthquake than would buildings lower in the study area due to the proximity to the earthquake source. The results of the crustal MHFZ scenario are significantly influenced by the seismic design level of the building. Seismic building codes were implemented in Oregon in the 1970s; nearly 50% of buildings were built before “moderate” code enforcement. This factor, along with areas of high landslide or liquefaction probability, results in the levels of damage.

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 4.1% to 3.2% 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 have an effect on losses. **Figure 3-4** illustrates the reduction in loss estimates from a MHFZ magnitude 6.9 earthquake through two simulations where all buildings are upgraded to at least moderate-code standards and then all buildings to high-code standards.

Figure 3-4. Mount Hood Fault Zone M6.9 earthquake loss ratio in the study area, with simulated seismic design upgrades.



Note that "Unincorp. Clackamas County (rural)" and "Unincorp. Multnomah County (rural)" exclude the incorporated communities, Government Camp, and The Villages at Mt. Hood. The study area contains portions of the incorporated communities of Gresham, Sandy, and Troutdale.

3.2.6 Areas of vulnerability or risk

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

We identified locations within the study area that are comparatively more vulnerable or at greater risk to CSZ M9.0 or MHFZ M6.9 earthquake hazard:

- High-liquefaction soils are found in the floodplain within the watershed. The lower reaches of the Sandy River at the confluence of the Columbia River, and The Villages at Mt. Hood area at the confluence of the Salmon River and Sandy River are more susceptible to liquefaction.
- The building inventories for the communities of Government Camp and The Villages at Mt. Hood are relatively older and may correlate to areas built to lower seismic building codes which contributes to the higher loss ratio for that region from both earthquake events.
- In the MHFZ M6.9 scenario, the community of Government Camp is estimated to sustain a very high loss ratio for building value (82%). Most of this damage is incurred from the community's most expensive buildings (e.g., Timberline Lodge) in this scenario. The percentage of red and yellow tagged buildings for Government Camp is near 40%.

3.3 Flooding

In its most basic form, a flood is an accumulation of water over normally dry areas. Floods become hazardous to people and property when they inundate an area where development has occurred, causing losses. Floods are a frequently occurring natural hazard in the study area, and have the potential to create public health hazards, public safety concerns, close and damage major highways, destroy railways, damage structures, and cause major economic disruption. A typical method for determining flood risk is to identify the probability of flooding and the impacts of flooding. The 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, respectively.

The primary drainage for the study area is the Sandy River. Most of the rivers within the study area flow into the Sandy River and eventually into the Columbia River. The major streams within the study area are the Sandy, Bull Run, Zig Zag, and Salmon Rivers, and the Beaver, Clear, and Still Creeks. All the listed rivers and creeks are subject to flooding and may cause damage to buildings within the floodplain.

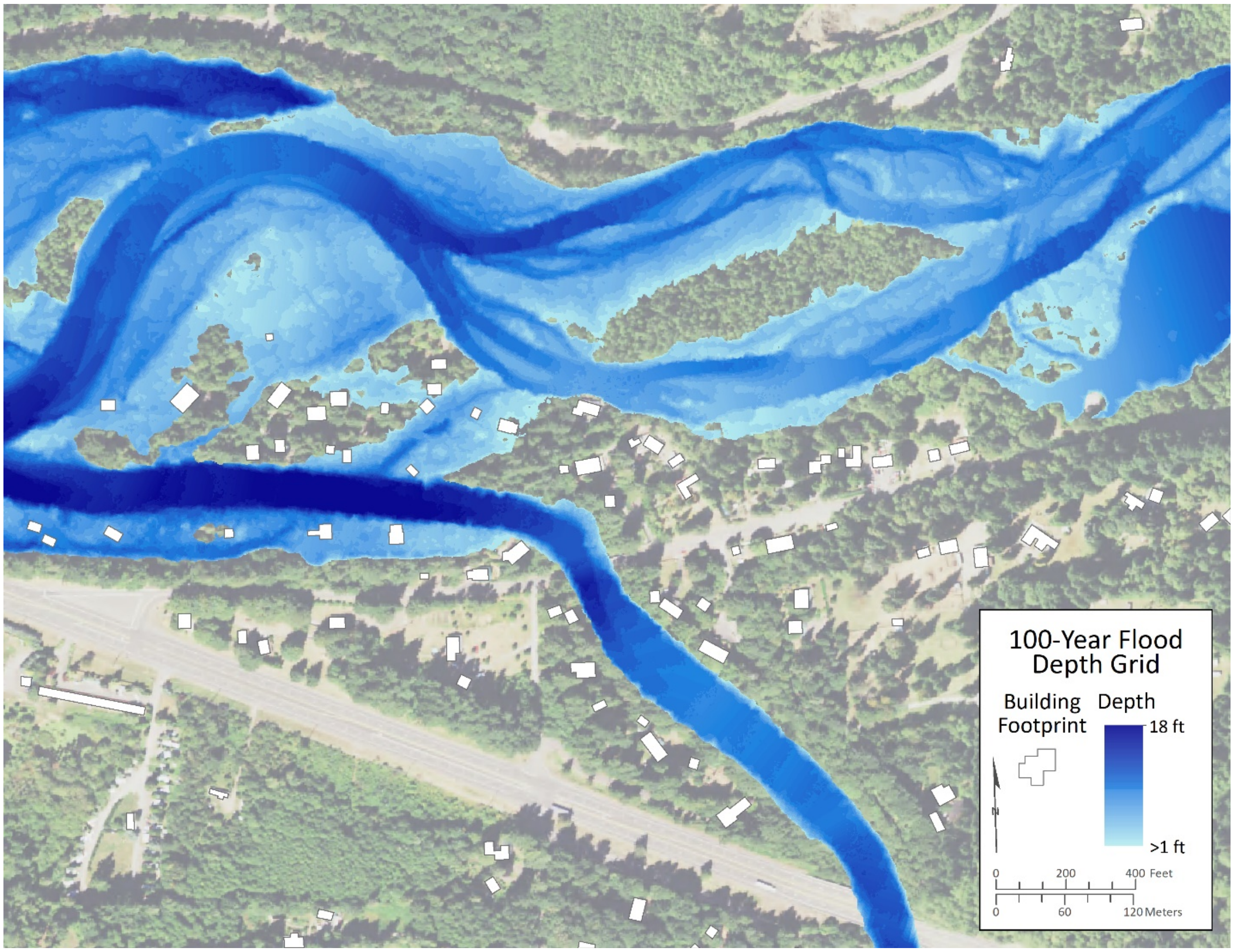
The ability to assess the probability of a flood and the level of accuracy of that assessment is influenced by modeling methodology advancements, better knowledge, and longer periods of record for the stream or water body in question. The impacts of flooding are determined by adverse effects to human activities within the area and the natural and built environment. Examples of common mitigating activities are to elevate structures above the expected level of flooding or to remove the structure through FEMA's property acquisition ("buyout") program. Flood issues like flash flooding, ice jams, post-wildfire floods, and dam safety were not examined in this report.

3.3.1 Data sources

Work on the Flood Insurance Study (FIS) and Flood Insurance Rate Maps (FIRMs) for the study area was conducted in 2013 (FEMA, 2016a,b); these were the primary data sources for the flood risk assessment. As of the completion of this report in 2018, the FIS and FIRMs were released as preliminary products. The currently effective FIS and FIRMs were adopted in 2008 for Clackamas County and 2009 for Multnomah County. Further information regarding the National Flood Insurance Program (NFIP) can be found on the FEMA website: https://www.fema.gov/flood-insurance.

Depth grids developed by DOGAMI in 2016 to revise the study area FIRMs were used in this risk assessment to determine the level to which buildings are impacted by flooding. Depth grids are raster GIS datasets where each digital pixel value represents the depth of flooding at that location within the flood zone (**Figure 3-5**). Though considered draft at the time of this analysis, the depth grid data are the best available flood hazard data. 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 3-5. Flood depth grid example, portion of The Villages at Mt. Hood. Sandy River (north) and Salmon River (south) shown.



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 the study area, 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 were used estimate these important building attributes. Only buildings in a flood zone or within 500 feet (152 meters) of a flood zone were examined closely to attribute buildings with more accurate information for 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 duration that residents would be displaced from their homes due to flooding. For information about structures exposed to flooding but not damaged, please see the **Exposure analysis** section below.

3.3.2 Study area results

For this risk assessment, we imported the study area UDF data and depth grids into Hazus-MH and ran a flood analysis for each of the four flood scenarios. We used the 100-year flood scenario as the primary scenario for reporting flood results (also see Appendix E, **Plate 5**). 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 (FEMA, 2013). See **Table B-4** for multi-scenario cumulative results.

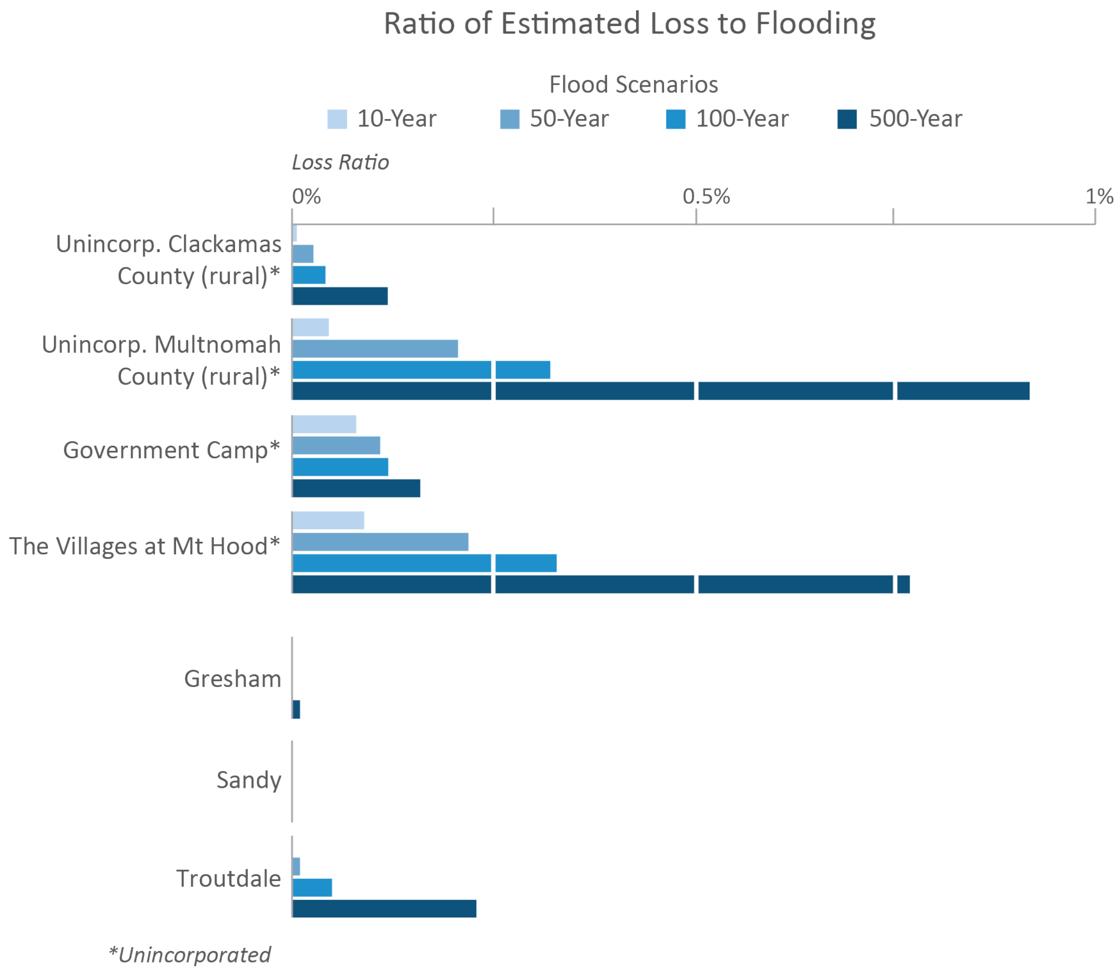
Study area 100-year flood loss:

- Number of buildings damaged: 295
- Loss estimate: $6,775,000
- Loss ratio: 0.1%
- Damaged critical facilities: 0
- Potentially displaced population: 669

3.3.3 Hazus-MH analysis

The Hazus-MH loss estimate for the 100-year flood scenario for the study area is about $6.7 million. Riverine flooding is estimated to have a minor impact to the study area (**Figure 3-6**). The Hazus-MH analysis also provides useful flood data on individual communities so that planners can identify problems and consider which mitigating activities will provide the greatest resilience to flooding.

Figure 3-6. Flood loss estimates by study area community.



Note that "Unincorp. Clackamas County (rural)" and "Unincorp. Multnomah County (rural)" exclude the incorporated communities, Government Camp, and The Villages at Mt. Hood. The study area contains portions of the incorporated communities of Gresham, Sandy, and Troutdale.

3.3.4 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 found that nearly 2% of the buildings in the study area were within designated flood zones. By comparing the number of non-damaged buildings from Hazus-MH with exposed buildings in the flood zone, we can estimate the number of buildings that could be elevated above the level of flooding. Of the 427 buildings exposed to flooding, we estimate that 134 are above the height of the 100-year flood. Elevating more of these exposed structures would further reduce the potential damages sustained from flooding. This evaluation also estimates that 669 residents might have mobility or access issues due to surrounding water. See **Table B-5** for community-based results of flood exposure.

3.3.5 Areas of vulnerability or risk

We identified locations within the study area that are comparatively more vulnerable or at greater risk to flood hazard:

- Developed areas in The Villages at Mt. Hood are exposed to the 100-year flood along the Sandy River and the Salmon River.
- Flooding in the City of Troutdale, portion of the city within the study area, comes from the floodplains created by the confluence of Beaver Creek and Sandy River: 1% of the buildings are exposed to flood hazard, with 27% of those buildings elevated above the 100-year flood. All buildings at the confluence are exposed to the 500-year flood recurrence.

3.4 Landslide Susceptibility

Landslides are mass movements of rock, debris, or soil most commonly downhill. There are many different types of landslides in Oregon. In the study area, the most common are debris flows and shallow- and deep-seated landslides. 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. Some factors that influence landslide type are hillside slope, water content, and geology. Many triggers can cause a landslide: intense rainfall, earthquakes, or human-induced factors like 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).

3.4.1 Data sources

The Statewide Landslide Information Layer for Oregon (SLIDO, release 3.2 [Burns and Watzig, 2014]) is an inventory of mapped landslides in the state of Oregon. 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.

Burns and others (2016) used SLIDO inventory data 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. 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). Statewide landslide susceptibility map data have the inherent limitations of SLIDO and of the generalized geology and slope maps used to create the map. Therefore, the statewide landslide susceptibility map varies significantly in quality across the state, depending on the quality 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.

The landslide susceptibility map also varies significantly in quality across the state depending on the quality of the input datasets. Quality of mapping within the study area varies in accuracy from high-quality lidar-derived inventory for the lower watershed near the confluence of the Columbia River and Sandy River as discussed in DOGAMI Special Paper 42 (SP-42: Burns and Madin, 2009), to limited partial SP-42 mapping on Mount Hood and down the Sandy River to just east of the City of Sandy. While much of the unincorporated portions of the study area were mapped using older techniques and would benefit from newer mapping methods outlined in SP-42, less than 6% of the unincorporated study area building inventory was mapped using the older techniques.

Highly detailed mapping in the Bull Run Watershed (Burns and others, 2015) fell within the study area, but this area is nearly completely uninhabited so had no bearing on the results of the analysis. The Bull

Run Watershed is critical in that it supplies water to hundreds of thousands of residents in the Portland Metro area; however, the effects of landslide hazard on the watershed was not examined in this report.

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 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 **Table B-6**). The total dollar value of exposed buildings was summed for the study area and is reported below. We also estimated the number of people threatened by landslides. Land value losses due to landslides were not examined for this report.

3.4.2 Study area results

All the study area's communities have some exposure to landslide hazard. Communities that developed in terrain with moderate to steep slopes or at the base of steep hillsides may be at risk to landslides. The Cascade Mountain Range runs through the eastern portion of the study area, so much of that area is steep and landslide prone. The combination of rugged terrain, historically active landslides, and large amounts of rainfall, and frequent large earthquakes make landslide hazard a serious threat.

We combined high and very high susceptibility categories as the primary scenarios to provide a general sense of community risk for planning purposes (see Appendix E, **Plate 6**). It was useful to combine exposure for both susceptibility categories to accurately depict the level of landslide risk to communities. These susceptibility categories represent areas most prone to landslides with the highest impact to the community.

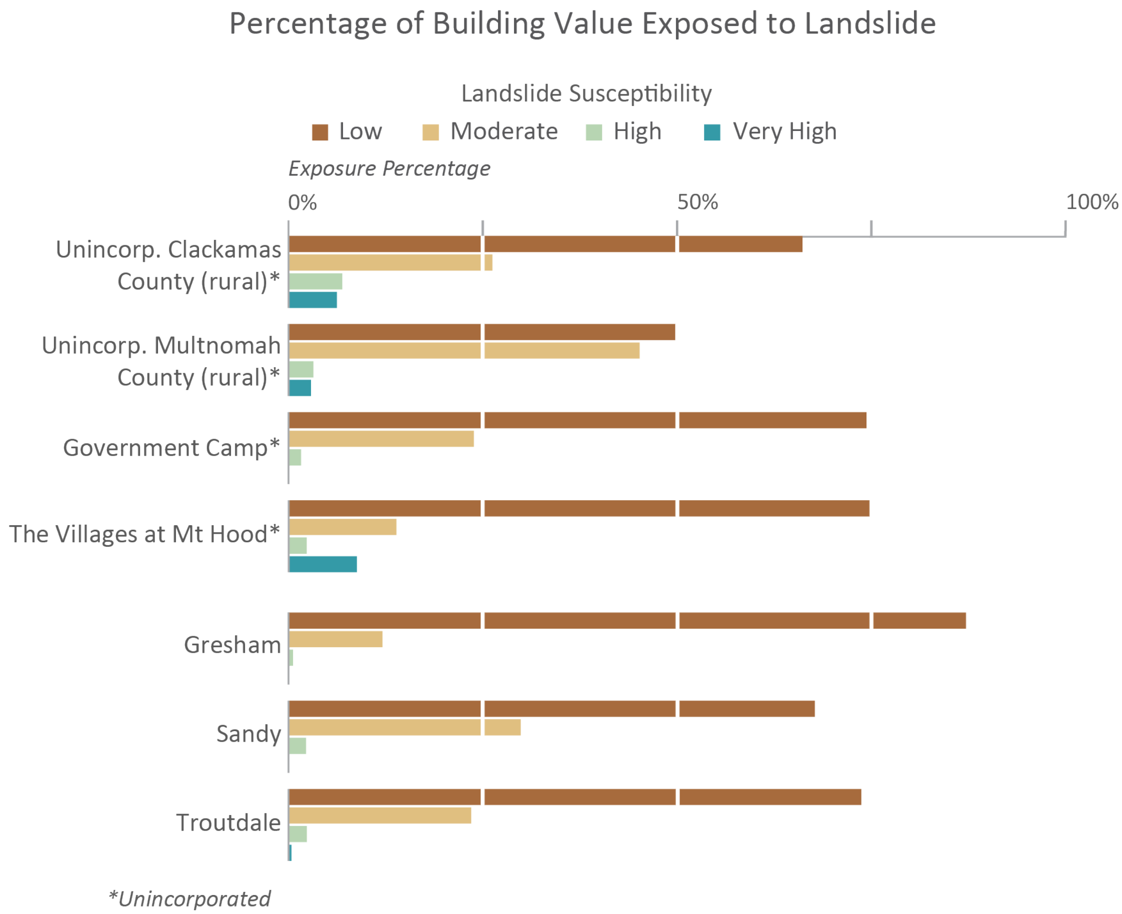
For this risk assessment we compared building locations to geographic extents of the landslide susceptibility zones (**Figure 3-7**). The exposure results shown below are for the high and very high susceptibility zones. See **Appendix B: Detailed Risk Assessment Tables** for multi-scenario analysis results.

Study area landslide exposure (High and Very High susceptibility):

- Number of buildings: 1,205
- Exposure value: $295,214,000
- Percentage of exposure value: 3.7%
- Critical facilities exposed: 0
- Potentially displaced population: 1,807

The percentage of building exposure to very high and high landslide susceptibility is less than 5% for the study area. While the percentage for the entire study area is less than 5%, the landslide hazard is considered relatively high with most of the areas at risk built on existing landslide deposits. Landslide hazard is ubiquitous in a large percentage of undeveloped land and may present challenges for future planning and mitigation efforts. Awareness of nearby areas of landslide hazard and when there are periods of heightened potential for landslides is beneficial to reducing risk for every community and rural area of the study area.

Figure 3-7. Landslide susceptibility exposure by study area community.



Note that “Unincorp. Clackamas County (rural)” and “Unincorp. Multnomah County (rural)” exclude the incorporated communities, Government Camp, and The Villages at Mt. Hood. The study area contains portions of the incorporated communities of Gresham, Sandy, and Troutdale.

3.4.3 Areas of vulnerability or risk

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

- The Villages at Mt. Hood have the highest exposure to landslide risk in the watershed; most of the buildings at risk from exposure are built on existing landslides that had not been identified prior to the detailed mapping techniques of Burns and Madin (2009).

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, because commonly development occurs in the wildland-urban interface (WUI) (Sanborn Map Company, Inc., 2013). 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 (Sanborn Map Company, Inc., 2013). Post-wildfire geologic hazards can also present risk. These usually include flooding, debris flows, and landslides. Post-wildfire geologic hazards were not evaluated in this project.

There is potential for losses due to WUI fires in the study area. Forests cover most of the undeveloped land in the study area. In an effort to limit exposure to wildfire, Clackamas County adopted a Community Wildfire Protection Plan in 2007 and Multnomah County adopted a Community Wildfire Protection Plan in 2011 that provides guidance on reducing risk to wildfire. Contact Clackamas County or Multnomah County Emergency Management for specific requirements related to the counties' comprehensive plans.

3.5.1 Data sources

The West Wide Wildfire Risk Assessment (WWA; Sanborn Map Company, 2013) is a comprehensive report that includes a database developed over the course of several years for 17 Western states and some Pacific Islands. 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 Fire Risk Index (FRI) dataset, a dataset included in the WWA database, was used to measure the level of risk to communities in the study area.

Using guidance from ODF, we categorized the FRI into low, moderate, and high hazard zones for the wildfire exposure analysis. The hazard zones are based on a combination of the impacts of wildfire (Fire Effects Index) and the probability of wildfire (Fire Threat Index). Both indices are the result of an integration of several input datasets. Broadly, the Fire Effects Index is based on potentially impacted assets and the difficulty of suppression. The components that make up the Fire Threat Index are fire occurrence, fire behavior, and fire suppression effectiveness (Sanborn Map Company, Inc., 2013).

We overlaid the buildings layer and critical facilities on each of the fire hazard zones to determine exposure. In certain areas no wildfire data are present which indicates areas that have minimal risk to wildfire hazard (see **Table B-7**). The total dollar value of exposed buildings in the study area is $116,224,000. We also estimated the number of people threatened by wildfire. Land value losses due to wildfire were not examined for this project.

3.5.2 Study area results

The high-risk category was chosen as the primary scenario for this report because that category represents areas that have the highest potential for losses. However, a large amount of loss would occur if the moderate risk areas were to burn, as some of the communities have ~60–70% of exposure to moderate wildfire risk. Still, the focus of this section is on high-hazard areas within the study area to emphasize the areas where lives and property are most threatened.

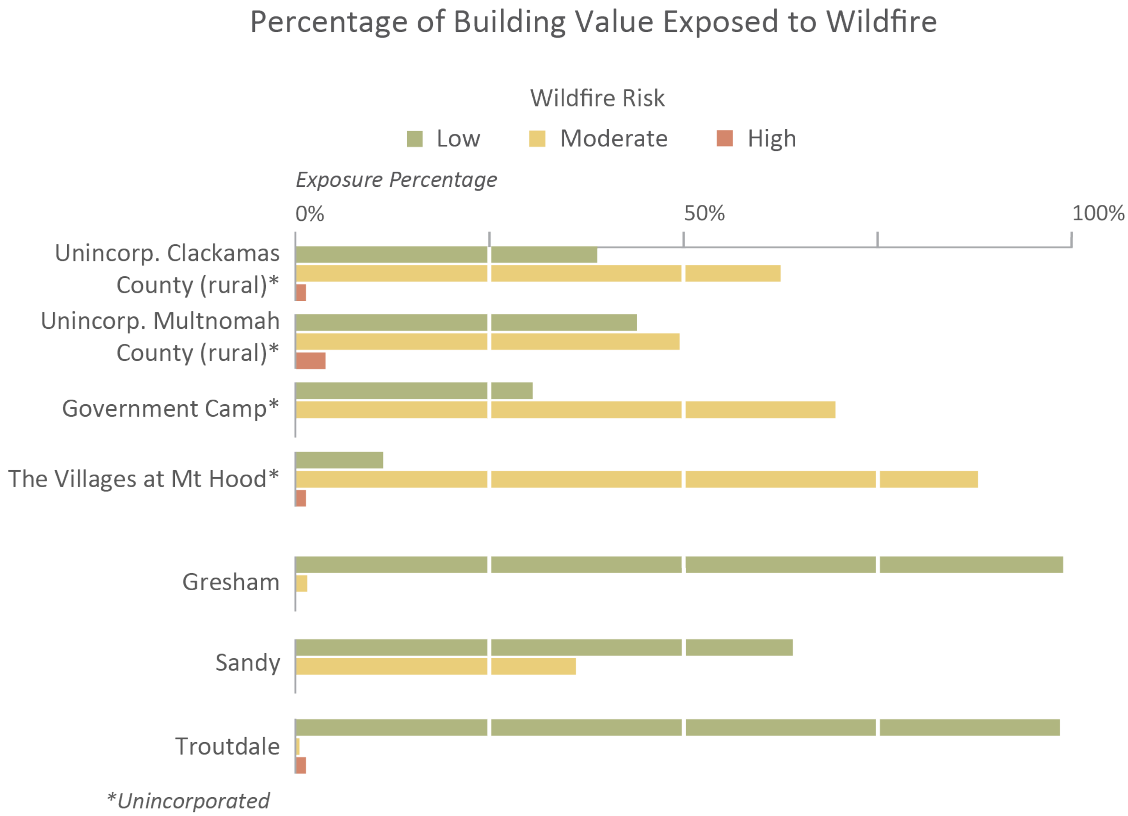
Study area wildfire exposure (High risk):

- Number of buildings: 340
- Exposure value: $116,224,000
- Percentage of exposure value: 1.5%
- Critical facilities exposed: 0
- Potentially displaced population: 429

For this risk assessment, the building locations were compared to the geographic extent of the wildfire risk categories. We found that most communities in the study area do not have high risk exposure to wildfire. The primary areas of exposure to this hazard are in the forested unincorporated areas of the study area (see Appendix E, **Plate 7**). The unincorporated communities Government Camp and The

Villages at Mt. Hood are at a higher risk to wildfire than other communities in the study area. **Figure 3-8** illustrates the distribution of losses due to wildfire with the different communities of the study area. See **Appendix B: Detailed Risk Assessment Tables** for multi-scenario cumulative results.

Figure 3-8. Wildfire risk exposure by study area community.



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3.5.3 Areas of vulnerability or risk

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

- Wildfire risk is high for hundreds of homes in the forested areas in the eastern portion of Lower Columbia–Sandy (rural).
- The unincorporated communities Government Camp and The Villages at Mt Hood are at a higher risk to wildfire than other communities in the study area.
- The 2017 Eagle Creek Fire was a large wildfire in the study area. This wildfire was not specifically examined in this report, but areas near the burn are at risk to indirect hazards such as post-wildfire debris flows, rock falls, and flash flooding.

3.6 Channel Migration

Channel migration is a dynamic process by which a stream's course changes over time due to bank erosion and stream deposition. Many factors determine stream channel volatility. The steepness of terrain, sensitivity to erosion, channel shape, water volume, and the size and shape of the floodplain are the primary determining factors for how a channel changes its course. These factors affect how energy is dispersed from high water flows. Straight and confined streams have high erosive power, while wide and flat floodplains slow the flow, deposit sediments, and allow a channel to meander and create secondary channels (Rapp and Abbe, 2003).

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

3.6.1 Data sources

The channel migration zones used for this report were developed for portions of the Sandy River by English and others (2013) and Abbe and others (2015). The approach used to define the CMZ is based on methods developed by Rapp and Abbe (2003) and combines several related zones which when taken together encompass the area a stream channel is expected to move. CMZ exposure combines areas of know migration, historical channel position, and erosion potential within the floodplain (Rapp and Abbe, 2003). An analysis includes the geology of the region because some rock types, deposits, and soils influence the mutability of the channel.

To assess the exposure for each community, we overlaid buildings and critical facilities on the CMZ. The total dollar value of exposed buildings was summed for the study area and is reported below. We were also able to estimate the number of people potentially displaced from the CMZ. Land value losses due to CMZ were not examined for this report.

3.6.2 Study area results

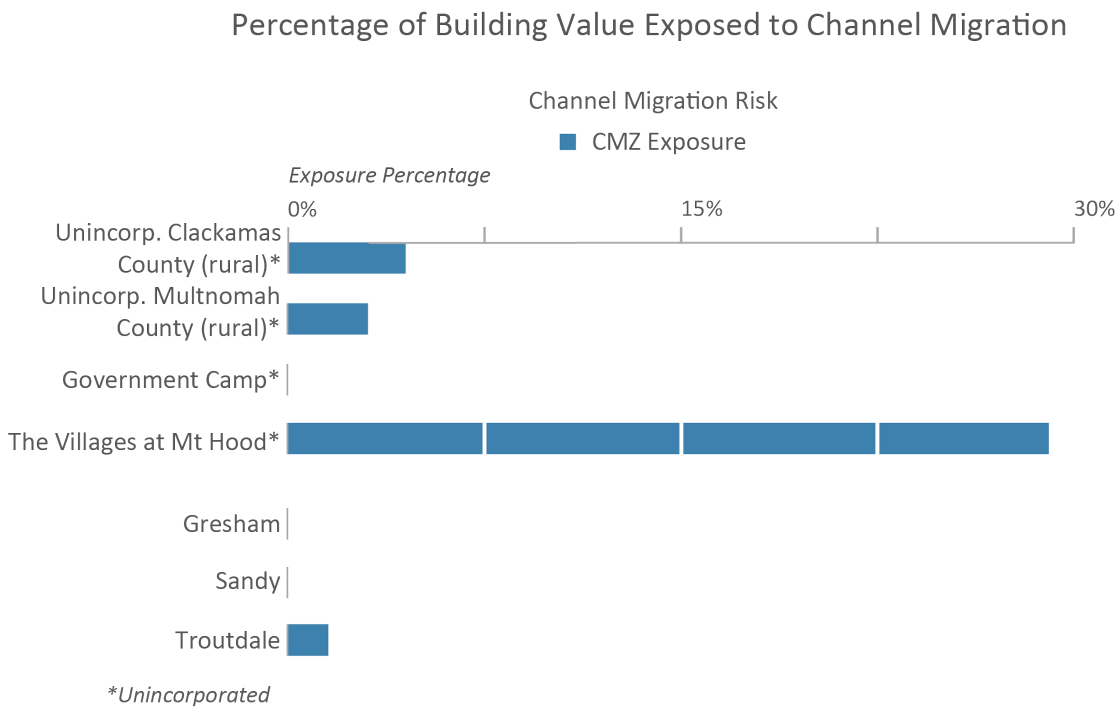
Riverine communities in the study area all have some level of exposure to channel migration. Development along the river and within floodplains has greatly increased the exposure of property owners to flood and erosion hazards (see Appendix B, **Table B-8** and Appendix E, **Plate 8**).

Study area channel migration exposure (High risk):

- Number of buildings: 1,632
- Exposure value: $322,951,000
- Percentage of exposure value: 4%
- Critical facilities exposed: 0
- Potentially displaced population: 2,315

The riverine communities of the study area have exposure to channel migration hazard. The Villages at Mt. Hood have the highest risk from this hazard (29%). The findings for the Upper and Lower Sandy River, as well as the Zigzag River and Salmon River can help inform long-term community planning for these areas. **Figure 3-9** illustrates the building exposure value due to channel migration for the different communities of the study area.

Figure 3-9. Channel migration exposure by study area community.



Note that "Unincorp. Clackamas County (rural)" and "Unincorp. Multnomah County (rural)" exclude the incorporated communities, Government Camp, and The Villages at Mt. Hood. The study area contains portions of the incorporated communities of Gresham, Sandy, and Troutdale.

3.6.3 Areas of vulnerability or risk

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

- Channel migration exposure is a significant concern for The Villages at Mt. Hood.
- Along the Sandy River a small portion of the unincorporated study area, and Troutdale are exposed to channel migration risk.

3.7 Volcano 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. Lahars are typically generated from a volcanic eruption but can be initiated during heavy rains or by a sudden outburst of glacial melt. They are most common when a volcano that is covered with heavy loads of snow and ice erupts. When water mixes with materials from eruptions and lahars, a volcanic debris flow can occur (Driedger and Scott, 2002).

Distal volcanic hazards, as opposed to proximal volcanic hazards affect areas away from the center of geologic activity. A lahar is considered a distal volcanic hazard, because a lahar is capable of traveling long distances and causing damage (Burns and others, 2011). Because a lahar moves like flowing concrete, it has the capacity to destroy most things in its path. Lahar deposits tend to exacerbate flooding and channel migration risk in the river valleys they affect (Driedger and Scott, 2002).

Mount Hood has had several notable eruptions in the past 30,000 years, from which many extensive lahars have been created. The Old Maid eruptive period, which occurred about 200 years ago, is the most recent in the region and impacted several streams flowing from Mount Hood (Burns and others, 2011).

3.7.1 Data sources

The lahar zones used in this report were created by Burns and others (2011) 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 a 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 square feet (994 square meters). 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 intervals associated with the lahar exposure scenarios are as follows (Burns and others, 2011): Extra-large: 100,000 years; Large: 500–1,000 years; Medium: 100 years; and Small: 10 years.

For this risk assessment, we compared the locations of buildings and critical facilities to the geographic extent of the lahar inundation zones to assess the exposure for each community (see Appendix B, **Table B-9**, and Appendix E, **Plate 9**). The exposure results shown below are for only the Medium scenario. We also estimated the number of people at risk from lahar hazard.

3.7.2 Study area results

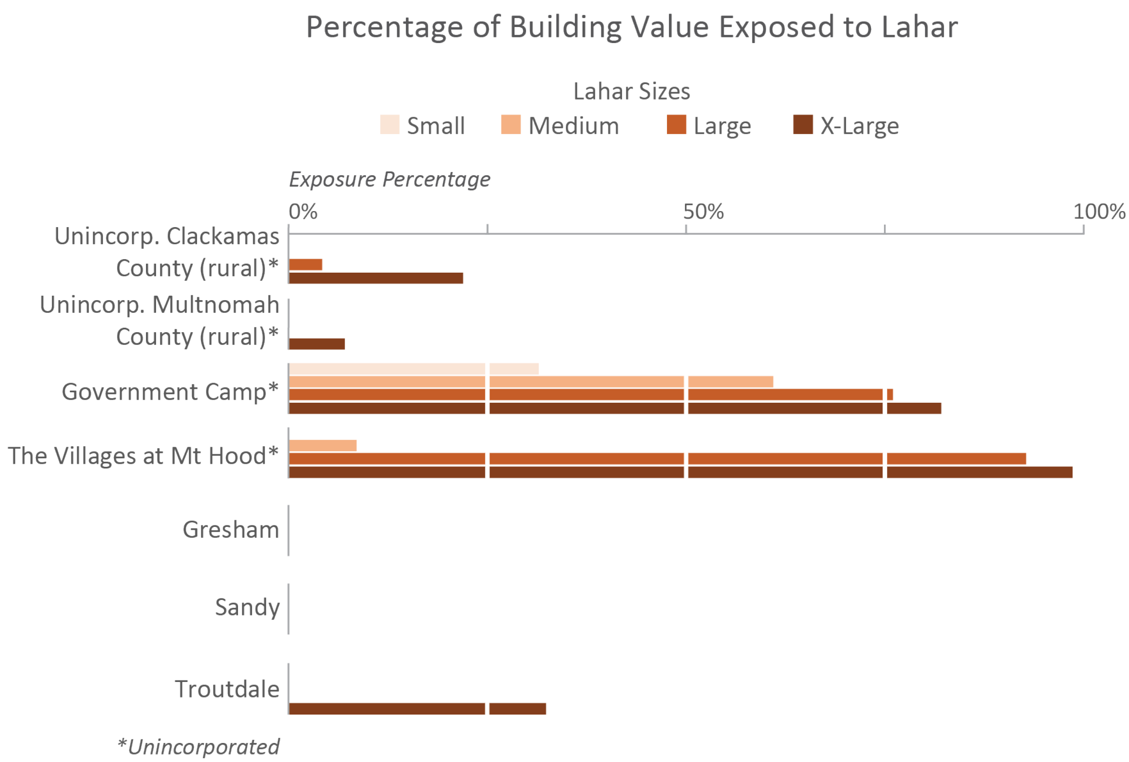
Most of the 60,000 residents in the study area are not exposed to lahar hazard, but the hazard poses significant concerns for those closer to Mount Hood and those within distal riverine valleys.

Study area lahar exposure (Medium):

- Number of buildings: 953
- Exposure value: $143,815,000
- Percentage of exposure value: 1.8%
- Critical facilities exposed: 1
- Potentially displaced population: 381

The total dollar value of exposed buildings was summed for the study area and is shown in **Figure 3-10**. The communities most threatened from a volcanic eruption and lahar event are Government Camp and The Villages at Mt. Hood. See **Appendix B: Detailed Risk Assessment Tables** for cumulative multi-scenario analysis results.

Figure 3-10.Lahar exposure by study area community.



Note that "Unincorp. Clackamas County (rural)" and "Unincorp. Multnomah County (rural)" exclude the incorporated communities, Government Camp, and The Villages at Mt. Hood. The study area contains portions of the incorporated communities of Gresham, Sandy, and Troutdale.

3.7.3 Areas of vulnerability or risk

We identified locations within the study area that are comparatively more vulnerable or at greater risk to lahar hazard:

- Lahar risk is mostly confined to the river valley channels and is a higher risk for communities and properties closer to Mount Hood.
- The 500–1,000-year return interval is a significant threat for residents near Mount Hood. Government Camp has 77% exposure and The Villages at Mt. Hood has 81% exposure to this hazard.

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 accomplish this by using the latest natural hazard mapping and loss estimation tools to quantify expected damage to buildings and potential displacement of permanent residents. The comprehensive and fine-grained approach to the analysis provides new context for the study area's risk reduction efforts. From the results of this study we note several important findings:

- **Low to moderate overall damage and losses are expected from a Cascadia M9.0 earthquake**—The study area is close enough to the Cascadia Subduction Zone (CSZ) that it will experience some impact and disruption from a CSZ magnitude 9.0 (M9.0) earthquake event. Results show that a CSZ M9.0 event will cause building losses of nearly 7% across the study area. The distance from the CSZ is the primary reason for the lack of extensive damage for communities within the study area. The small variation in damage across the study area is primarily due to the age of the building inventories.
- **Higher building losses are expected from the Mount Hood Fault Zone (MHFZ) magnitude 6.9 event relative to the CSZ event**—The upper reaches of the watershed would experience very little impact from the CSZ M9.0, but these areas would experience more significant impact and disruption from a Mount Hood Fault Zone (MHFZ) magnitude 6.9 event. The impact of the MHFZ varies in the study area; communities near the epicenter sustain more damage. Results show that such an event would cause building losses of over 80% in the Government Camp area. Most of this damage is incurred from the community's most expensive buildings (e.g., Timberline Lodge) in this scenario. The percentage of red and yellow tagged buildings for Government Camp is near 40%. Building value loss ratio is close to 32% for the community of The Villages at Mt. Hood. Damages for the rest of the study area from the MHFZ M6.9 were much lower.
- **Retrofitting buildings to modern seismic building codes can reduce damage and losses from earthquake**—Seismic building codes have a major influence on earthquake shaking damage estimated by Hazus-MH, a software tool developed by the Federal Emergency Management Agency (FEMA) for calculating loss from natural hazards. We examined potential loss reduction from seismic retrofits (modifications that improve a building's seismic resilience) in simulations by using Hazus-MH building code "design level" attributes of pre, low, moderate, and high (FEMA, 2012b) in each of the earthquake scenarios. The simulations were accomplished by upgrading every pre (non-existent) and low seismic code building to moderate seismic code levels in one scenario, and then by further upgrading all buildings to high (current) code in another scenario. We found that retrofitting to at least moderate code was the most cost-effective 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 6.9% to 5.2% for a CSZ event, and from 5.7% to 3.2% for a MHFZ event. Communities with older building stock constructed at pre or low code seismic building code standards would attain greater loss reduction than the study area as a whole. An example is Government Camp, where an enormous loss reduction (from 82% to 34%) could occur by upgrading to at least moderate code. This stands in contrast to a CSZ event for the same community, where no significant change to loss ratios from the upgrade are expected. Although seismic retrofits are an effective strategy for reducing earthquake shaking damage, it should be noted that earthquake-induced landslide and liquefaction hazards will also be present in some areas, and these hazards require different geotechnical mitigation strategies.

- **Flooding is a minor threat for most of the communities in the study area**—Every community is estimated to experience less than 1% of total building value loss from the 100-year flood. At first glance, Hazus-MH flood loss estimates may give a false impression of risk because they show fairly low damages for a community relative to other hazards we examined. This is due to the difference between loss estimation and exposure results, as well as the limited area impacted from flooding. Residents and buildings located along the Sandy River and its tributaries are at a greater risk from flood than are residents and buildings at other locations within the study area. The Villages at Mt. Hood have the most damage and exposure to flooding along the Upper Sandy River region, but losses from flooding were still less than 1% of the total building value.
- **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 needs in flood loss prevention and the effectiveness of past activities. For example, The Villages at Mt. Hood communities have 74 buildings (valued at $11.9 million) elevated above the level of flooding; more elevated structures can further reduce estimated damages.
- **Landslide is a widespread hazard and is present for some communities within the study area**—Landslide hazard mapping using lidar was recently done for portions of the lower study area using lidar. Lidar based mapping greatly increases the accuracy of the hazard maps. We used exposure analysis to assess the threat from landslide hazard. The communities of The Villages at Mt. Hood and portions of the unincorporated areas in Clackamas County have the highest exposure to risk, mostly attributed to structures being built on existing slides.
- **Exposure analysis shows that communities in The Villages at Mt. Hood area are particularly vulnerable to channel migration hazard**—30% of The Villages at Mt. Hood total building value is exposed to channel migration hazard.
- **Wildfire risk is moderate for the overall study area**—Exposure analysis shows that buildings in the eastern part of the study area are vulnerable to wildfire hazard; most of the exposure falls within the unincorporated portion of the study area. High wildfire hazard is mostly limited to a few heavily forested rural areas. However, moderate wildfire hazard is present throughout the county and so is a potential threat to communities.
- **Exposure analysis show that buildings in the riverine valleys of the study area are vulnerable to volcanic lahar hazard**—The communities of Government Camp and The Villages at Mt. Hood areas are particularly at risk to lahar hazard. Government Camp has 63% of its building value exposed in the Medium scenario (100-year event). Lower portions of the watershed are at risk only from the least likely (100,000-year [Extra-large]) scenario; the City of Troutdale has a 37% exposure from that recurrence interval.
- **Some of the study area's critical facilities are at high risk to an earthquake**—Critical facilities were identified and were specifically examined within this report. We estimate that 15% the 27 critical facilities in the study area will be non-functioning after a CSZ event and 7% will be non-functioning after a MHFZ event. For comparative purposes, 4% of critical facilities are vulnerable to 100-year lahar event, and no other hazards within the region affect critical facilities.
- **The two biggest causes of displacement to population are a CSZ earthquake and lahar**—Displacement of permanent residents from natural hazards was quantified within this report. We estimate that 5.7% of the population in the study area would be displaced due to a CSZ earthquake and 2.2% of the population would be displaced due to a MHFZ earthquake. Landslide hazard is a

potential threat to 3.1% of permanent residents, and flood hazard makes 1.1% vulnerable to displacement. The lahar hazard poses a potential threat to 0.7% of permanent residents. A small percentage of residents is at risk to displacement from wildfire and channel migration.

- **The results allow communities the ability 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 between communities and impacts from each natural hazard. The Hazus-MH and exposure analysis results can assist in developing plans that address concerns for 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** – Flood, landslide, channel migration, and wildfire are unlikely to occur at one time to the fully mapped extent of the hazard zones. For instance, areas mapped in the 1% annual chance flood zone will be prone to flooding on occasion in certain portions of the watershed during specific events, but not all at once throughout the entire study area or even the 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. An exception to this is earthquake ground shaking; this is expected to impact the entire study area and loss estimates are based on a single event.
- **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. Hazus-MH does not provide a site-specific analysis. 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, smoothing out the noise.
- **Loss estimation versus exposure** – Interpretation of exposure results should consider 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 communities in Lower Columbia–Sandy watershed are considered vacation destinations particularly during the summer. Our estimates of potentially displaced people rely on permanent populations published in the 2010 U.S. Census (United States Census Bureau, 2010a). As a result, we are underestimating the number of people that may be at risk to hazards, especially during periods of high temporary population.
- **Data accuracy and completeness** – Some datasets in our risk assessments had incomplete coverage or no high-resolution data within the study area. We used lower-resolution data to fill gaps where there was incomplete coverage or where high-resolution data were not available. Assumptions to amend areas of incomplete data coverage were made based on reasonable methods described within this report. However, we are aware that some uncertainty has been introduced from these data amendments at an individual building scale. At community-wide scales the effects of the uncertainties are slight. Data layers in which assumptions were made to

fill gaps are: building footprints, population, some attributes derived from the assessor database, and landslide susceptibility. Many of the datasets included known or suspected artifacts, omissions and errors. Identifying or repairing these problems was beyond the scope of the project and are areas needing additional research.

6.0 RECOMMENDATIONS

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

6.1 Awareness and Preparation

Awareness is crucial to lowering risk and lessening the impacts of natural hazards. When community members understand their risk and know the role they play in preparedness, the community in general is a much safer place to live. Awareness and preparation not only reduce the initial impact from natural hazards, they also reduce the amount of recovery time for a community to bounce back from a disaster—this ability is commonly referred to as "resilience."

This report is intended to provide local officials 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. A Homeowner's Guide to Landslides for Washington and Oregon (https://www.oregongeology.org/Landslide/ger_homeowners_guide_landslides.pdf) 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.

6.2 Planning

Information presented here can help identify geohazards and associated risks to communities and help local decision-makers develop their plans. 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 natural hazard mitigation plan (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 mitigation actions and can inform the vulnerability assessment section of the NHMP plan.

While there are many similarities between this report and an NHMP, the hazards or critical facilities in the two reports can vary. 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 due 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. The results of this study can help emergency managers identify vulnerable critical facilities and develop contingencies in response 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 structural connections of building frames to foundations. 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 increase in response time contribute to a community's overall resilience.

6.4 Mitigation Funding Opportunities

Several funding options are available to communities susceptible to natural hazards. State and federal funds are available for specific mitigation projects that demonstrate cost effective natural hazard risk reduction. 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.

At the time of authoring this report, FEMA has two programs that assist with mitigation funding for natural hazards: Hazard Mitigation Grant Program (HMGP) and Pre-Disaster Mitigation (PDM) Grant Program. FEMA also has a grant program specifically for flooding called Flood Mitigation Assistance (FMA). The SHMO can help find further opportunities for earthquake 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 15% of critical facilities will be damaged by the CSZ event and that 7% of critical facilities will be damaged by the MHFZ event; damage to critical facilities 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.

6.5.3 Landslide

- Create modern landslide inventory and susceptibility maps.

- Monitor ground movement in high susceptibility areas.
- Consider land value losses due to landslide in future risk assessments.

6.5.4 Wildfire related to geologic hazards

- Evaluate post-wildfire geologic hazards including flood, debris flows, and landslides.

6.5.5 Channel migration

- Create modern channel migration hazard maps.
- Consider land value losses due to channel migration in future risk assessments.

6.5.6 Volcanic hazard — lahar

- Create volcanic lahar hazard maps based on best practices and updated lidar information.

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9.0 APPENDICES

APPENDIX A. COMMUNITY RISK PROFILES

A hazard 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 access to evacuation routes are actions that every community can take to reduce its 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)*	4,593	3,680	2	874,879,000

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	138	3%	74	0	2,988,000	0.3%
Earthquake	CSZ M9.0 Deterministic[3]	133	2.9%	143	0	37,763,000	4.3%
Earthquake	Mount Hood M6.9 Probabilistic[3]	77	1.7%	81	0	23,671,000	2.7%

Exposure Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Percent of Exposure
Landslide	High and Very High Susceptibility	380	8%	311	0	91,139,000	10%
Wildfire	High Risk	44	0.1%	31	0	9,036,000	1%
Channel migration	High Hazard	178	4%	145	0	33,781,000	4%
Lahar	Medium (1% Annual Chance)	0	0%	0	0	0	0%

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

[2]No loss is estimated for exposed structures with "First Floor Heights" above the level of flooding (base flood elevation).

[3]CSZ M9.0 is Cascadia subduction zone magnitude 9.0 earthquake scenario; Mount Hood M6.9 is Mount Hood Fault Zone magnitude 6.9 earthquake scenario.

*Information only for portions of community within the study area.

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

	Flood 1% Annual Chance	Earthquake Moderate to Complete Damage	Landslide High and Very High Susceptibility	Wildfire High Risk	Channel Migration High Hazard	Lahar 1% Annual Chance
Critical Facilities by Community	**Exposed**	**>50% Prob.**	**Exposed**	**Exposed**	**Exposed**	**Exposed**
Firwood Elementary School	—	—	—	—	—	—
Sandy FFPD #72	—	—	—	—	—	—

A.2 Unincorporated Multnomah County (rural)

Table A-3. Unincorporated Multnomah County (rural) hazard profile.

Community Overview				
Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)
Unincorporated Multnomah County (rural)*	6,016	4,788	5	1,351,889,000

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	12	0.2%	9	0	218,000	0%
Earthquake	CSZ M9.0 Deterministic[3]	396	6.6%	534	2	129,429,000	9.6%
Earthquake	Mount Hood M6.9 Probabilistic[3]	69	1.1%	129	0	40,903,000	3.0%

Exposure Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Percent of Exposure
Landslide	High and Very High Susceptibility	302	5%	251	0	55,608,000	4.1%
Wildfire	High Risk	247	4%	202	0	74,668,000	5.5%
Channel migration	High Hazard	139	2%	114	0	33,900,000	3%
Lahar	Medium (1% Annual Chance)	0	0%	0	0	0	0%

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

[2]No loss is estimated for exposed structures with "First Floor Heights" above the level of flooding (base flood elevation).

[3]CSZ M9.0 is Cascadia subduction zone magnitude 9.0 earthquake scenario; Mount Hood M6.9 is Mount Hood Fault Zone magnitude 6.9 earthquake scenario.

*Information only for portions of community within the study area.

Table A-4. Unincorporated Multnomah County (rural) critical facilities.

Critical Facilities by Community	Flood 1% Annual Chance Exposed	Earthquake Moderate to Complete Damage >50% Prob.	Landslide High and Very High Susceptibility Exposed	Wildfire High Risk Exposed	Channel Migration High Hazard Exposed	Lahar 1% Annual Chance Exposed
Corbett Grade School	—	—	—	—	—	—
Gresham Fire Station #76	—	—	—	—	—	—
Multnomah County RFPD 14 Aims Station #63	—	—	—	—	—	—
Multnomah County RFPD 14 Corbett Station #62	—	X (CSZ)	—	—	—	—
Sam Barlow High School	—	X (CSZ)	—	—	—	—

CSZ is Cascadia subduction zone magnitude 9.0 earthquake scenario.

A.3 Unincorporated Community of Government Camp

Table A-5. Unincorporated community Government Camp hazard profile.

Community Overview

Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)
Government Camp	255	825	1	147,179,000

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	4	1.5%	12	0	182,000	0.1%
Earthquake	CSZ M9.0 Deterministic[3]	6	2.3%	15	0	4,758,000	3.2%
Earthquake	Mount Hood M6.9 Probabilistic[3]	100	39%	348	1	120,951,000[4]	82.2%[4]

Exposure Analysis Summary

Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Percent of Exposure
Landslide	High and Very High Susceptibility	8	2.9%	27	0	2,295,000	1.6%
Wildfire	High Risk	1	0.2%	2	0	533,000	0.4%
Channel migration	High Hazard	0	0%	0	0	0	0%
Lahar	Medium (1% Annual Chance)	163	64%	611	1	92,477,000	63%

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

[2]No loss is estimated for exposed structures with "First Floor Heights" above the level of flooding (base flood elevation).

[3]CSZ M9.0 is Cascadia subduction zone magnitude 9.0 earthquake scenario; Mount Hood M6.9 is Mount Hood Fault Zone magnitude 6.9 earthquake scenario.

[4]Most of this damage is incurred from the community's most expensive buildings (e.g., Timberline Lodge) in this scenario. The percentage of red and yellow tagged buildings for Government Camp is near 40%.

Table A-6. Unincorporated community Government Camp critical facilities.

	Flood 1% Annual Chance	**Earthquake Moderate to Complete Damage**	**Landslide High and Very High Susceptibility**	**Wildfire High Risk**	**Channel Migration High Hazard**	**Lahar 1% Annual Chance**
Critical Facilities by Community	**Exposed**	**>50% Prob.**	**Exposed**	**Exposed**	**Exposed**	**Exposed**
Hoodland RFPD #74 – Government Camp	—	X (MHFZ)	—	—	—	X

MHFZ is Mount Hood Fault Zone magnitude 6.9 earthquake scenario.

A.4 Unincorporated Communities of The Villages at Mt. Hood

Table A-7. Unincorporated communities of The Villages at Mt. Hood hazard profile.

Community Overview					
Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)	
The Villages at Mt. Hood	5,106	3,794	4	801,469,000	

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	285	5.6%	161	0	2,628,000	0.3%
Earthquake	CSZ M9.0 Deterministic[3]	408	8.0%	304	1	85,915,000	11%
Earthquake	Mount Hood M6.9 Probabilistic[3]	993	20%	923	2	255,190,000	32%

Exposure Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Percent of Exposure
Landslide	High and Very High Susceptibility	524	10%	420	0	88,719,000	11%
Wildfire	High Risk	53	1%	47	0	9,855,000	1.2%
Channel migration	High Hazard	1,855	36%	1,307	0	233,667,000	29%
Lahar	Medium (1% Annual Chance)	218	4%	342	0	51,338,000	9%

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

[2]No loss is estimated for exposed structures with "First Floor Heights" above the level of flooding (base flood elevation).

[3]CSZ M9.0 is Cascadia subduction zone magnitude 9.0 earthquake scenario; Mount Hood M6.9 is Mount Hood Fault Zone magnitude 6.9 earthquake scenario.

Table A-8. Unincorporated communities of The Villages at Mt. Hood critical facilities.

Critical Facilities by Community	Flood 1% Annual Chance	Earthquake Moderate to Complete Damage	Landslide High and Very High Susceptibility	Wildfire High Risk	Channel Migration High Hazard	Lahar 1% Annual Chance
	Exposed	>50% Prob.	Exposed	Exposed	Exposed	Exposed
Hoodland RFPD #74 - Brightwood	—	—	—	—	—	—
Hoodland RFPD #74 - Welches	—	X (MHFZ)	—	—	—	—
Welches Elementary School	—	X (CSZ): X (MHFZ)	—	—	—	—
Welches Middle School	—	—	—	—	—	—

CSZ is Cascadia subduction zone magnitude 9.0 earthquake scenario. MHFZ is Mount Hood Fault Zone magnitude 6.9 earthquake scenario.

A.5 City of Gresham

Table A-9. City of Gresham hazard profile.

Community Overview					
Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)	
Gresham*	28,604	7,697	7	3,342,722,000	

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	102	0.4%	6	0	119,000	0%
Earthquake	CSZ M9.0 Deterministic[3]	2,244	7.8%	912	1	251,378,000	7.5%
Earthquake	Mount Hood M6.9 Probabilistic[3]	9	0.0%	9	0	8,959,000	0.3%

Exposure Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Percent of Exposure
Landslide	High and Very High Susceptibility	123	0.4%	40	0	16,338,000	0.5%
Wildfire	High Risk	6	0%	4	0	1,163,000	0%
Channel migration	High Hazard	0	0%	0	0	0	0%
Lahar	Medium (1% Annual Chance)	0	0%	0	0	0	0%

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

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

[3]CSZ M9.0 is Cascadia subduction zone magnitude 9.0 earthquake scenario; Mount Hood M6.9 is Mount Hood Fault Zone magnitude 6.9 earthquake scenario.

*Information only for portions of community within the study area.

Table A-10. City of Gresham critical facilities.

Critical Facilities by Community	Flood 1% Annual Chance	Earthquake Moderate to Complete Damage	Landslide High and Very High Susceptibility	Wildfire High Risk	Channel Migration High Hazard	Lahar 1% Annual Chance
	Exposed	>50% Prob.	Exposed	Exposed	Exposed	Exposed
Gordon Russell Middle School	—	—	—	—	—	—
Gresham Fire Station 72 - Kane Road	—	—	—	—	—	—
Hall Elementary School	—	—	—	—	—	—
Kelly Creek Elementary School	—	—	—	—	—	—
Legacy Mt. Hood Medical Center	—	—	—	—	—	—
Mt Hood CC Academic Center	—	—	—	—	—	—
Powell Valley Elementary School	—	X (CSZ)	—	—	—	—

CSZ is Cascadia subduction zone magnitude 9.0 earthquake scenario.

A.6 City of Sandy

Table A-11. City of Sandy hazard profile.

Community Overview							
Community Name		Population	Number of Buildings		Critical Facilities[1]		Total Building Value ($)
Sandy*		1,108	460		4		207,451,000
Hazus-MH Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Damaged Buildings	Damaged Critical Facilities	Loss Estimate ($)	Loss Ratio
Flood[2]	1% Annual Chance	0	0%	0	0	0	0%
Earthquake	CSZ M9.0 Deterministic[3]	0	0.0%	1	0	1,722,000	0.8%
Earthquake	Mount Hood M6.9 Probabilistic[3]	0	0.0%	1	0	1,363,000	0.7%
Exposure Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Percent of Exposure
Landslide	High and Very High Susceptibility	53	4.8%	18	0	4,488,000	2.2%
Wildfire	High Risk	4	0.4%	2	0	535,000	0.3%
Channel migration	High Hazard	0	0%	0	0	0	0%
Lahar	Medium (1% Annual Chance)	0	0%	0	0	0	0%

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

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

[3]CSZ M9.0 is Cascadia subduction zone magnitude 9.0 earthquake scenario; Mount Hood M6.9 is Mount Hood Fault Zone magnitude 6.9 earthquake scenario.

*Information only for portions of community within the study area.

Table A-12. City of Sandy critical facilities.

	Flood 1% Annual Chance	Earthquake Moderate to Complete Damage	Landslide High and Very High Susceptibility	Wildfire High Risk	Channel Migration High Hazard	Lahar 1% Annual Chance
Critical Facilities by Community	**Exposed**	**>50% Prob.**	**Exposed**	**Exposed**	**Exposed**	**Exposed**
Cedar Ridge Middle School	—	—	—	—	—	—
Sandy Grade School	—	—	—	—	—	—
Sandy High School - Frazier	—	—	—	—	—	—
Sandy Police Department	—	—	—	—	—	—

A.7 City of Troutdale

Table A-13. City of Troutdale hazard profile.

Community Overview							
Community Name		Population	Number of Buildings		Critical Facilities[1]		Total Building Value ($)
Troutdale*		13,221	4,415		4		1,410,884,000
Hazus-MH Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Damaged Buildings	Damaged Critical Facilities	Loss Estimate ($)	Loss Ratio
Flood[2]	1% Annual Chance	128	1%	33	0	640,000	0%
Earthquake	CSZ M9.0 Deterministic[3]	224	1.7%	111	0	46,865,000	3.3%
Earthquake	Mount Hood M6.9 Probabilistic[3]	29	0.2%	19	0	10,994,000	0.8%
Exposure Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Percent of Exposure
Landslide	High and Very High Susceptibility	417	3.2%	138	0	36,627,000	2.6%
Wildfire	High Risk	73	0.6%	52	0	20,433,000	1.4%
Channel migration	High Hazard	143	1%	66	0	21,603,000	2%
Lahar	Medium (1% Annual Chance)	0	0%	0	0	0	0%

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

[2]No loss is estimated for exposed structures with "First Floor Heights" above the level of flooding (base flood elevation).

[3]CSZ M9.0 is Cascadia subduction zone magnitude 9.0 earthquake scenario; Mount Hood M6.9 is Mount Hood Fault Zone magnitude 6.9 earthquake scenario.

*Information only for portions of community within the study area.

Table A-14. City of Troutdale critical facilities.

	Flood 1% Annual Chance	Earthquake Moderate to Complete Damage	Landslide High and Very High Susceptibility	Wildfire High Risk	Channel Migration High Hazard	Lahar 1% Annual Chance
Critical Facilities by Community	**Exposed**	**>50% Prob.**	**Exposed**	**Exposed**	**Exposed**	**Exposed**
Reynolds High School	—	—	—	—	—	—
Sweetbriar Elementary School	—	—	—	—	—	—
Troutdale Elementary School	—	—	—	—	—	—
Walt Morey Middle School	—	—	—	—	—	—

APPENDIX B. DETAILED RISK ASSESSMENT TABLES

Table B-1. Lower Columbia–Sandy watershed building inventory.

(all dollar amounts in thousands)

	Residential			Commercial and Industrial			Agricultural			Public and Non-Profit			All Buildings			
Community[1]	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 ($)	Building Value per Study Area Total
Unincorp. Clackamas County (rural)	2,630	649,794	74%	44	22,070	3%	927	166,313	19%	79	36,702	4%	3,680	14%	874,879	11%
Unincorp. Multnomah County (rural)	4,241	1,034,069	77%	259	152,869	11%	240	42,829	3%	48	122,123	9%	4,788	19%	1,351,889	17%
Government Camp	741	107,437	73%	66	29,051	20%	1	482	0.5%	17	10,208	7%	825	3%	147,179	2%
The Villages at Mt. Hood	2,865	538,569	67%	669	200,484	25%	184	23,176	3%	76	39,239	5%	3,794	15%	801,469	10%
Total Unincorp. Study Area	10,477	2,329,869	73%	1,038	404,474	13%	1,352	232,800	7%	220	208,272	7%	13,087	51%	3,175,415	39%
Gresham	7,163	2,454,677	73%	468	607,022	18%	16	2,929	0%	50	278,095	8%	7,697	30%	3,342,722	41%
Sandy	378	99,540	48%	55	42,845	21%	1	282	0.3%	26	64,785	31%	460	2%	207,451	3%
Troutdale	4,174	1,075,688	76%	199	234,382	17%	4	1,116	0%	38	99,698	7%	4,415	17%	1,410,884	17%
Total Study Area	22,192	5,959,774	73%	1,760	1,288,723	16%	1,373	237,127	4%	334	650,850	8%	25,659	100%	8,136,473	100%

[1]"Unincorp. Clackamas County (rural)" and "Unincorp. Multnomah County (rural)" exclude the incorporated communities, Government Camp, and The Villages at Mt. Hood. The study area contains only portions of the incorporated communities of Gresham, Sandy, and Troutdale.

Table B-2. Cascadia subduction zone earthquake loss estimates.

(all dollar amounts in thousands)

Community[1]	Total Number of Buildings	Total Estimated Building Value ($)	Buildings Damaged: Yellow-Tagged Buildings	Buildings Damaged: Red-Tagged Buildings	Buildings Damaged: Sum of Economic Loss	Buildings Damaged: Loss Ratio	All Buildings Changed to At Least Moderate Code: Yellow-Tagged Buildings	All Buildings Changed to At Least Moderate Code: Red-Tagged Buildings	All Buildings Changed to At Least Moderate Code: Sum of Economic Loss	All Buildings Changed to At Least Moderate Code: Loss Ratio
Unincorp. Clackamas County (rural)	3,680	874,879	48	95	37,763	4.3%	5	85	24,602	2.8%
Unincorp. Multnomah County (rural)	4,788	1,351,889	220	314	129,429	10%	16	271	87,524	6.5%
Government Camp	825	147,179	1	13	4,758	3.2%	1	13	3,985	2.7%
The Villages at Mt. Hood	3,794	801,469	38	266	85,915	11%	8	259	72,316	9.0%
Total Unincorp. Study Area	13,087	3,175,415	307	688	257,864	8.1%	30	628	188,427	5.9%
Gresham	7,697	3,342,722	233	680	251,378	7.5%	5	638	198,168	5.9%
Sandy	460	207,451	1	0	1,722	0.8%	0	0	197	0.1%
Troutdale	4,415	1,410,884	12	99	46,865	3.3%	5	91	37,155	2.6%
Total Study Area	25,659	8,136,473	533	1,467	557,829	6.9%	40	1,357	423,947	5.2%

[1]"Unincorp. Clackamas County (rural)" and "Unincorp. Multnomah County (rural)" exclude the incorporated communities, Government Camp, and The Villages at Mt. Hood. The study area contains only portions of the incorporated communities of Gresham, Sandy, and Troutdale.

Table B-3. Mount Hood Fault Zone earthquake loss estimates.

(all dollar amounts in thousands)

Community[1]	Total Number of Buildings	Total Estimated Building Value ($)	Buildings Damaged: Yellow-Tagged Buildings	Buildings Damaged: Red-Tagged Buildings	Buildings Damaged: Sum of Economic Loss	Buildings Damaged: Loss Ratio	All Buildings Changed to at Least Moderate Code: Yellow-Tagged Buildings	All Buildings Changed to at Least Moderate Code: Red-Tagged Buildings	All Buildings Changed to at Least Moderate Code: Sum of Economic Loss	All Buildings Changed to at Least Moderate Code: Loss Ratio
Unincorp. Clackamas County (rural)	3,680	874,879	25	56	23,671	2.7%	7	54	17,140	2%
Unincorp. Multnomah County (rural)	4,788	1,351,889	48	81	40,903	3.0%	19	64	27,948	2.1%
Government Camp	825	147,179	92	256	120,951	82%	31	221	49,594	34%
The Villages at Mt. Hood	3,794	801,469	226	697	255,190	32%	107	657	151,038	19%
Total Unincorp. Study Area	13,087	3,175,415	392	1,090	440,715	14%	164	996	245,720	7.7%
Gresham	7,697	3,342,722	8	1	8,959	0.3%	3	1	5,655	0.2%
Sandy	460	207,451	1	0	1,363	0.7%	0	0	541	0.3%
Troutdale	4,415	1,410,884	5	14	10,994	0.8%	2	14	11,198	0.8%
Total Study Area	25,659	8,136,473	406	1,106	462,032	5.7%	170	1,011	263,114	3.2%

[1]"Unincorp. Clackamas County (rural)" and "Unincorp. Multnomah County (rural)" exclude the incorporated communities, Government Camp, and The Villages at Mt. Hood. The study area contains only portions of the incorporated communities of Gresham, Sandy, and Troutdale.

Table B-4. Flood loss estimates.

(all dollar amounts in thousands)

Community[1]	Total Number of Buildings	Total Estimated Building Value ($)	10% (10-yr)			2% (50-yr)			1% (100-yr)			0.2% (500-yr)		
			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 County (rural)	3,680	874,879	24	455	0%	59	1,857	0.2%	74	2,988	0.3%	153	7,532	0.9%
Unincorp. Multnomah County (rural)	4,788	1,351,889	2	28	0%	7	105	0%	9	218	0%	29	1,314	0%
Government Camp	825	147,179	11	114	0.1%	11	163	0.1%	12	182	0.1%	14	232	0.2%
The Villages at Mt. Hood	3,794	801,469	50	709	0.1%	118	1,763	0.2%	161	2,628	0.3%	275	6,187	0.8%
Total Unincorp. Study Area	13,087	3,175,416	87	1,306	0%	195	3,888	0.1%	256	6,016	0.2%	471	15,265	0.5%
Gresham	7,697	3,342,722	1	16	0%	5	94	0%	6	119	0%	10	380	0%
Sandy	460	207,451	0	0	0%	0	0	0%	0	0	0%	0	0	0%
Troutdale	4,415	1,410,884	1	10	0%	8	87	0%	33	640	0%	67	3,262	0.6%
Total Study Area	25,659	8,136,473	89	1,332	0%	208	4,069	0%	295	6,775	0%	548	18,907	0.2%

[1]"Unincorp. Clackamas County (rural)" and "Unincorp. Multnomah County (rural)" exclude the incorporated communities, Government Camp, and The Villages at Mt. Hood. The study area contains only portions of the incorporated communities of Gresham, Sandy, and Troutdale.

Table B-5. Flood exposure.

	1% (100-yr)						
Community[1]	**Total Number of Buildings**	**Total Population**	**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 County (rural)	3,680	4,593	138	3%	106	2.9%	32
Unincorp. Multnomah County (rural)	4,788	6,016	12	0.2%	11	0.2%	2
Government Camp	825	255	4	1.5%	15	1.8%	3
The Villages at Mt. Hood	3,794	5,106	285	5.6%	233	6.2%	74
Total Unincorp. Study Area	13,087	15,970	439	2.7%	365	2.8%	111
Gresham	7,697	28,604	102	0.4%	17	0.2%	11
Sandy	460	1,108	0	0%	0	0%	0
Troutdale	4,415	13,221	128	1%	45	1%	12
Total Study Area	25,659	58,902	669	1%	427	1.7%	134

[1]"Unincorp. Clackamas County (rural)" and "Unincorp. Multnomah County (rural)" exclude the incorporated communities, Government Camp, and The Villages at Mt. Hood. The study area contains only portions of the incorporated communities of Gresham, Sandy, and Troutdale.

Table B-6. Landslide exposure.

(all dollar amounts in thousands)

Community[1]	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 County (rural)	3,680	874,879	129	43,330	4.9%	182	47,809	5.5%	964	220,432	25%
Unincorp. Multnomah County (rural)	4,788	1,351,889	105	25,808	1.9%	146	29,800	2.2%	2,324	622,311	46%
Government Camp	825	147,179	0	0	0%	27	2,295	1.6%	208	35,117	24%
The Villages at Mt. Hood	3,794	801,469	315	70,305	9%	105	18,414	2.3%	598	111,198	14%
Total Unincorp. Study Area	13,087	3,175,415	549	139,443	4.4%	460	98,318	3.1%	4,094	989,058	31%
Gresham	7,697	3,342,722	0	0	0%	40	16,338	0.5%	1,044	403,469	12%
Sandy	460	207,451	0	0	0%	18	4,448	2.2%	141	62,065	30%
Troutdale	4,415	1,410,884	24	4,327	0.3%	114	32,299	2.3%	1,123	331,566	24%
Total Study Area	25,659	8,136,473	573	143,770	1.8%	632	151,444	1.9%	6,402	1,786,158	22%

[1]"Unincorp. Clackamas County (rural)" and "Unincorp. Multnomah County (rural)" exclude the incorporated communities, Government Camp, and The Villages at Mt. Hood. The study area contains only portions of the incorporated communities of Gresham, Sandy, and Troutdale.

Table B-7. Wildfire exposure.

			(all dollar amounts in thousands)					
			High Risk			**Moderate Risk**		
Community[1]	**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**
Unincorp. Watershed (rural) Clackamas County	3,680	874,879	31	9,036	1%	2,419	542,025	62%
Unincorp. Watershed (rural) Multnomah County	4,788	1,351,889	202	74,668	5.7%	2,494	660,495	49%
Government Camp	825	147,179	2	533	0.4%	618	101,979	69%
The Villages at Mt. Hood	3,794	801,469	47	9,855	1.2%	3,344	702,094	88%
Total Unincorp. Study Area	13,087	3,175,415	282	94,093	3.1%	8,875	2,006,593	64%
Gresham	7,697	3,342,722	4	1,163	0.03%	172	47,068	1.4%
Sandy	460	207,451	2	535	0.3%	217	74,574	36%
Troutdale	4,415	1,410,884	52	20,433	1.4%	24	5,850	0.4%
Total Study Area	25,659	8,136,473	340	116,224	1.5%	9,288	2,134,084	27%

[1]"Unincorp. Clackamas County (rural)" and "Unincorp. Multnomah County (rural)" exclude the incorporated communities, Government Camp, and The Villages at Mt. Hood. The study area contains only portions of the incorporated communities of Gresham, Sandy, and Troutdale.

Table B-8. Channel migration exposure.

Community[1]	Total Number of Buildings	Total Population	Total Estimated Building Value ($)	*(all dollar amounts in thousands)* Channel Migration Hazard: Potentially Displaced Residents from Channel Migration Exposure	% Potentially Displaced Residents from Channel Migration Exposure	Number of Buildings Exposed	Building Value ($)	Percent of Building Value Exposed
Unincorp. Clackamas County (rural)	3,680	4,593	874,879	178	3.9%	145	33,780	3.9%
Unincorp. Multnomah County (rural)	4,788	6,016	1,351,889	139	2.3%	114	33,900	2.5%
Government Camp	825	255	147,179	0	0%	0	0	0%
The Villages at Mt. Hood	3,794	5,106	801,469	1,855	36%	1,307	233,667	29%
Total Unincorp. Study Area	13,087	15,970	3,175,415	2,172	14%	1,566	301,347	9.5%
Gresham	7,697	28,604	3,342,722	0	0%	0	0	0%
Sandy	460	1,108	207,451	0	0%	0	0	0%
Troutdale	4,415	13,221	1,410,884	143	1%	66	21,603	1.5%
Total Study Area	25,659	58,903	8,136,473	2,315	3.9%	1,632	322,951	4%

[1]"Unincorp. Clackamas County (rural)" and "Unincorp. Multnomah County (rural)" exclude the incorporated communities, Government Camp, and The Villages at Mt. Hood. The study area contains only portions of the incorporated communities of Gresham, Sandy, and Troutdale.

Table B-9. Volcano hazard – lahar 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[1]	**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 (rural)	3,680	874,879	0	0	0%	0	0	0%	180	28,274	3.2%	747	177,587	20%
Unincorp. Multnomah County (rural)	4,788	1,351,889	0	0	0%	0	0	0%	0	0	0%	228	75,738	5.6%
Government Camp	825	147,179	235	43,764	30%	611	92,477	63%	748	113,643	77%	776	122,358	83%
The Villages at Mt. Hood	3,794	801,469	0	0	0%	342	51,338	6.4%	3,131	644,900	81%	3,649	768,442	96%
Total Unincorp. Study Area	13,087	3,175,415	235	43,764	1.4%	953	143,815	4.5%	4,059	786,817	25%	5,400	1,144,575	36%
Gresham	7,697	3,342,722	0	0	0%	0	0	0%	0	0	0%	1	319	0%
Sandy	460	207,451	0	0	0%	0	0	0%	0	0	0%	0	0	0%
Troutdale	4,415	1,410,884	0	0	0%	0	0	0%	0	0	0%	1,588	522,890	37%
Total Study Area	25,659	8,136,473	235	43,764	0.5%	953	143,815	1.8%	4,059	786,817	9.7%	6,989	1,667,784	21%

[1]"Unincorp. Clackamas County (rural)" and "Unincorp. Multnomah County (rural)" exclude the incorporated communities, Government Camp, and The Villages at Mt. Hood. The study area contains only portions of the incorporated communities of Gresham, Sandy, and Troutdale.

APPENDIX C. HAZUS-MH METHODOLOGY

C.1 Software

We performed all loss estimations using Hazus®-MH 3.0 and ArcGIS® Desktop® 10.2.2.

C.2 User-Defined Facilities (UDF) Database

We complied a UDF database for all buildings in Lower Columbia–Sandy watershed for use in both the flood and earthquake modules of Hazus-MH. We used the Multnomah County assessor database and Clackamas County assessor database (both acquired in 2016) to determine which taxlots had improvements (i.e., buildings) and how many building points should be included in the UDF database.

C.2.1 Locating buildings points

We used the existing DOGAMI dataset of building footprints from Oregon Metro GIS and digitized by DOGAMI from lidar to help precisely locate the centroid of each building. Where the building footprint dataset lacked coverage in the eastern portion of the county, we used the centroid of the taxlot; for taxlots larger than 10 acres the building centroid was corrected by using orthoimagery. Extra effort was spent to locate building points along the 1% and 0.2% annual chance inundation fringe. For buildings partially within the inundation zone, we moved the building point to the centroid of the portion of the building within the inundation zone. We used an iterative approach 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

We populated the required attributes for Hazus-MH through a variety of approaches. We used databases from Clackamas County and Multnomah County assessors whenever possible, but in many cases those databases 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 one 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 and Multnomah County assessor databases. Where data were not available, the default value of RES1 was applied throughout.

- **Cost** –The 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-MH 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 and Multnomah County assessor databases. Where not available (>1%), the year "1900" 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 ensures 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 within a census block. The value was obtained from DOGAMI's building footprints; where (RES) footprints were not available, we used Clackamas County and Multnomah County assessor database values.
- **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 Clackamas County and Multnomah County assessor databases where available. For UDFs without assessor information for number of stories that are within the flood zone, closer inspection using the Google Street View™ mapping service or available oblique imagery was used for attribution.
- **Foundation type** – The UDF foundation type correlates with the **First floor height** value in feet (see Table 3.11 in the Hazus-MH Technical Manual for the Flood Model [FEMA Hazus-MH, 2012c]). 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. The value was obtained from Clackamas County and Multnomah County assessor databases where 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: Hazus-MH overlays a UDF location on a depth grid and by using the **First floor height** determines the level of flooding occurring to a building. The **First floor height** is derived from the **Foundation type** attribute (Clackamas/Multnomah assessor data) or observation via oblique imagery or Google Street Maps.
- **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 not in the Clackamas County and Multnomah County assessor data, so instead Building type 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 (see "Seismic Building Codes" section below for further information). This information is derived from the **Year built** attribute (Clackamas/Multnomah 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 default Hazus-MH database (U.S. Census Bureau, 2010a) of population per census block and distributed across residential UDFs.

- **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 boundaries and for unincorporated areas, 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 is the main consideration for an individual design level attribute. Seismic retrofitting information for structures would be ideal for this analysis but was not available for Clackamas County and Multnomah County. **Table C-1** outlines the benchmark years that apply to buildings within Clackamas County and Multnomah County.

Table C-1. Study area 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 (2012)
	1976–1990	Low Code	
	1991–2004	Moderate Code	
	2005 - 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–Present	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 2014-0311 Oregon Benefit-Cost Analysis Tool, p. 24 (Business Oregon, 2015)
	1976–1990	Low Code	
	1991 - Present	Moderate Code	

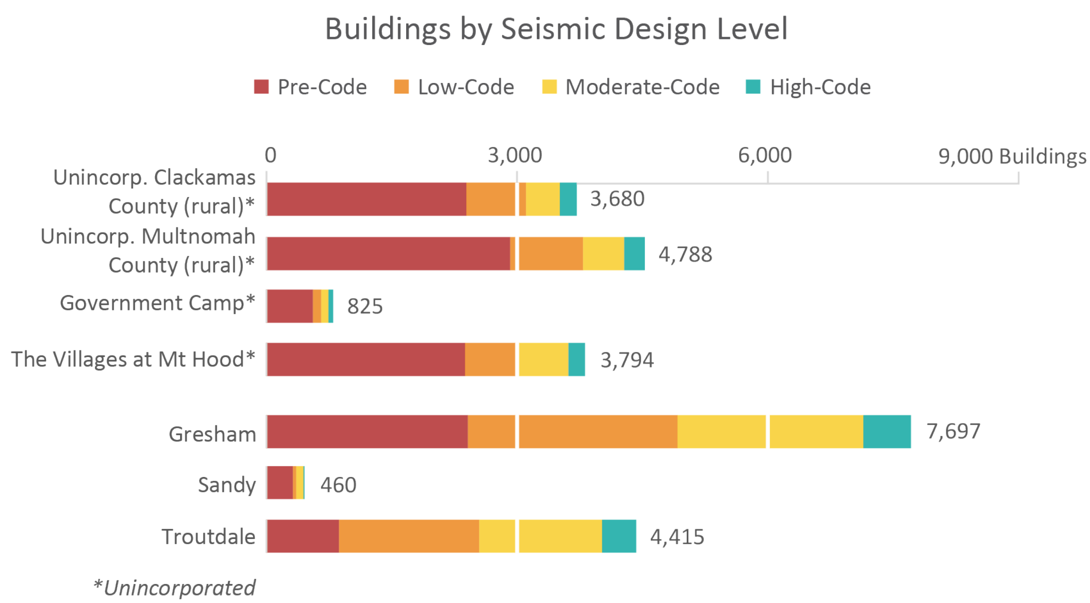
Table C-2 and corresponding **Figure C-1** illustrate the current state of seismic building codes for the study area.

Table C-2. Seismic design level in the study area.

		Pre-Code		Low-Code		Moderate-Code		High-Code	
Community[1]	**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 County (rural)	3,680	2,448	67%	608	17%	356	9.7%	268	7.3%
Unincorp. Multnomah County (rural)	4,788	3,010	63%	1,019	21%	566	12%	193	4.0%
Government Camp	825	578	70%	101	12%	87	11%	59	7%
The Villages at Mt. Hood	3,794	2,367	62%	638	17%	593	16%	196	5%
Total Unincorp. Study Area	13,087	8,403	64%	2,366	18%	1,602	12%	716	5%
Gresham	7,697	2,410	31%	2,501	32%	2,218	29%	568	7%
Sandy	460	323	70%	40	9%	84	18%	13	3%
Troutdale	4,415	872	20%	1,672	38%	1,464	33%	407	9%
Total Study Area	25,659	12,008	47%	6,579	26%	5,368	21%	1,704	7%

[1]"Unincorp. Clackamas County (rural)" and "Unincorp. Multnomah County (rural)" exclude the incorporated communities, Government Camp, and The Villages at Mt. Hood. The study area contains only portions of the incorporated communities of Gresham, Sandy, and Troutdale.

Figure C-1. Seismic design level by Lower Columbia–Sandy watershed community.



Note that "Unincorp. Clackamas County (rural)" and "Unincorp. Multnomah County (rural)" exclude the incorporated communities, Government Camp, and The Villages at Mt. Hood. The study area contains portions of the incorporated communities of Gresham, Sandy, and Troutdale.

C.3 Flood Hazard Data

DOGAMI developed flood hazard data in 2013 for a revision of the Lower Columbia–Sandy watershed FEMA Flood Insurance Study (FEMA, 2016a, b). The hazard data were based on a combination of previous flood studies and new riverine hydrologic and hydraulic analyses. For riverine areas, the flood elevations for the 10-, 50-, 100-, and 500-year events for each stream cross-section were used to develop depth of flooding raster datasets or "depth grids."

A watershed-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. 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

Several data layers were used for the deterministic analysis conducted for this report. Data layers created for the Oregon Resilience Plan (ORP; Madin and Burns, 2013) provided most of the earthquake inputs for the CSZ magnitude 9.0 event modeled in Hazus-MH. Liquefaction susceptibility data came directly from the ORP, but site ground motion data (PGA: peak ground acceleration; PGV: peak ground velocity; SA10 and SA03: spectral acceleration at 1.0 second period and 0.3 second period) were derived from NEHRP site class soil data. The GIS procedure used to amplify the site ground motion data from NEHRP soil data are described in Appendix B of Bauer and others (2018). We obtained the landslide susceptibility data derived from the work of Appleby and others (2019). The more conservative "wet" landslide susceptibility scenario was used in this analysis (Appleby and others, 2019).

The hazard layers were formatted for use in a Python script developed by DOGAMI to apply the Hazus-MH methodology. The earthquake hazard datasets used in the analysis were: ground motion data (PGA, PGV, SA03, and SA10), a landslide susceptibility map, and liquefaction susceptibility map. Permanent ground deformation (PGD) for landslide and liquefaction were both calculated using Hazus-MH methodology for each of the susceptibility maps. In addition to the earthquake data layers, Hazus-MH requires a water table parameter for PGD due to liquefaction. As water table data were unavailable, we set the water table value to a depth of 5 ft (1.5 m).

A deterministic method for a CSZ magnitude 9.0 event was deemed the most likely and impactful earthquake scenario for the study area. Past work has shown that probabilistic models of a 500-year event for this area are roughly the same as the CSZ magnitude 9.0 event.

During the Hazus-MH earthquake analysis, each UDF was analyzed given its site-specific parameters (ground motion and 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 the 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

AOMI	Areas of Mitigation Interest
CCNHMP	Clackamas County Natural Hazard Mitigation Plan
CMZ	channel migration zone
CSZ	Cascadia subduction zone
CWPP	Community Wildfire Protection Plan
DFIRM	Digital Flood Insurance Rate Map
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
FRI	Fire Risk Index
FIS	Flood Insurance Study
FMA	Flood Mitigation Assistance [Grant Program]
GIS	Geographic Information System
HMGP	Hazard Mitigation Grant Program
LAHARZ	[not an acronym] GIS-based menu-driven software for calculating lahar extents
LCS	Lower Columbia–Sandy
MCNHMP	Multnomah County Natural Hazard Mitigation Plan
MHFZ	Mount Hood Fault Zone
NFIP	National Flood Insurance Program
NHMP	natural hazard mitigation plan
NOAA	National Oceanic and Atmospheric Administration
OBDD	Oregon Business Development Department
ODF	Oregon Department of Forestry
OEM	Oregon Emergency Management
OFR	open-file report
OLC	Oregon Lidar Consortium
OPDR	Oregon Partnership for Disaster Resilience
PDM	Pre-Disaster Mitigation [Grant Program]
PGA	peak ground acceleration
PGD	permanent ground deformation
PGV	peak ground velocity
REL	non-profit/religious [building category]
Risk MAP	Risk Mapping, Assessment, and Planning
SA	spectral acceleration
SFHA	Special Flood Hazard Area
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.

Channel Migration – Channel migration is the natural process by which streams move laterally over time. It is typically a gradual phenomenon that works over many years to effect significant migration. In some cases, usually associated with flood events, significant migration can happen rapidly.

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 Special Flood Hazard Areas (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.

Lahar – A flow of material composed of a mixture of hot or cold water, pyroclastic material, and rock fragments flowing down the slopes of a volcano typically within a river valley.

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.

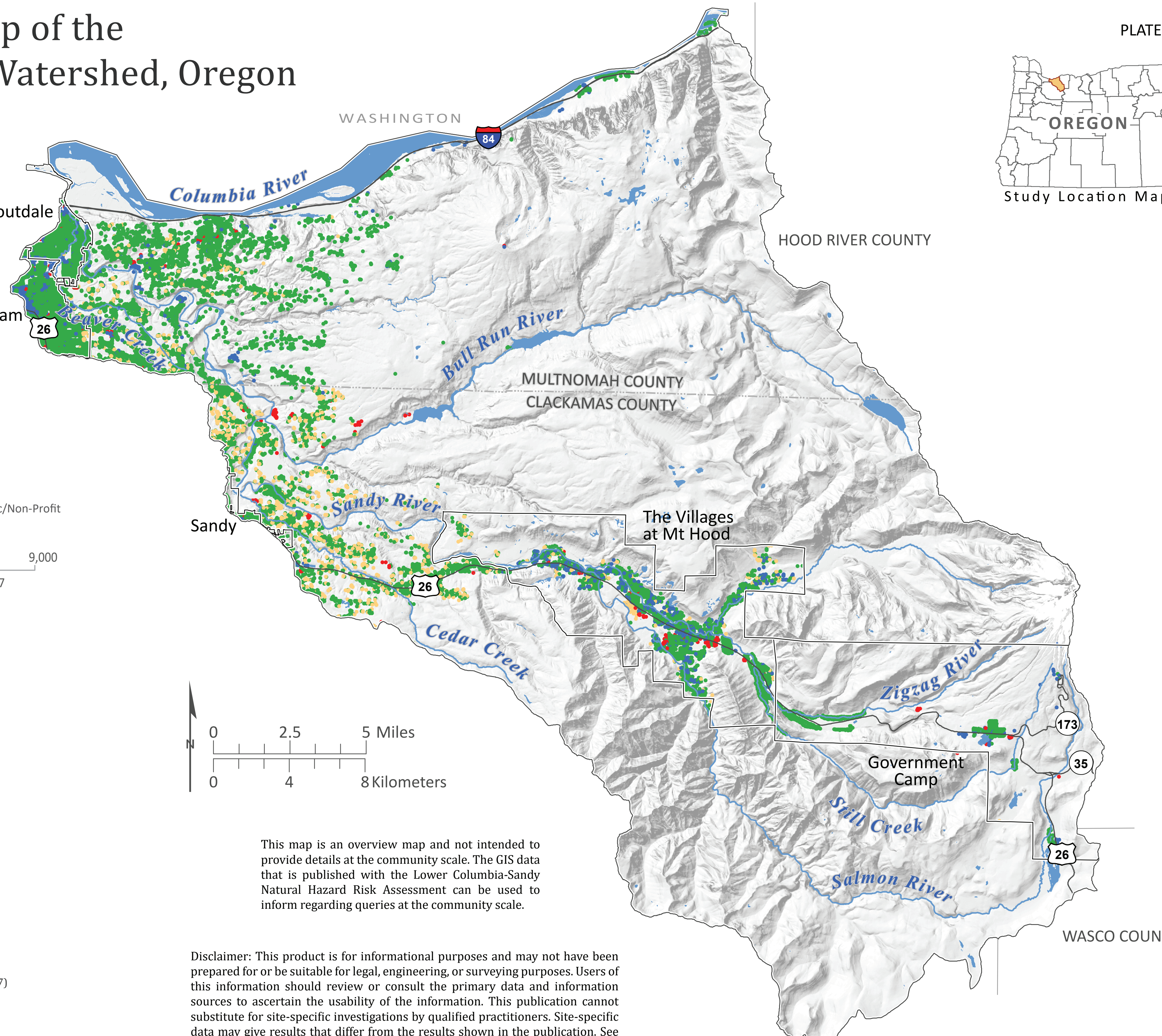
Vulnerability – Characteristics that make people or assets more susceptible to a natural hazard.

APPENDIX E. MAP PLATES

See appendix folder for individual map PDFs.

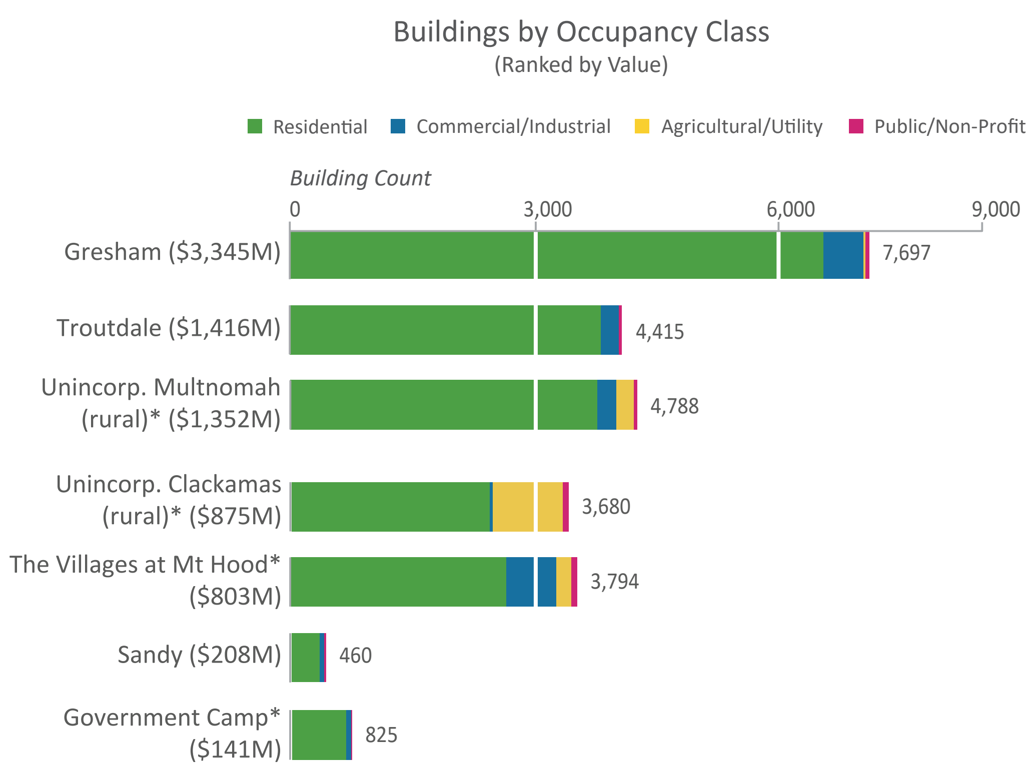
Building Distribution Map of the Lower Columbia-Sandy Watershed, Oregon

PLATE 1



Building Occupancy

- Agricultural / Utility
- Commercial / Industrial
- Public / Non-Profit
- Residential



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

Data Sources:
Building footprints: Oregon Department of Geology and Mineral Industries (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) | Clackamas County Technology Services (2017)
Basemap: U.S. Geological Survey and Oregon Lidar Consortium (2012)
Hydrography: U.S. Geological Survey National Hydrography Dataset (2017)

Projection: NAD 1983 UTM Zone 10N
Software: Esri® ArcMap 10, Adobe® Illustrator CS6

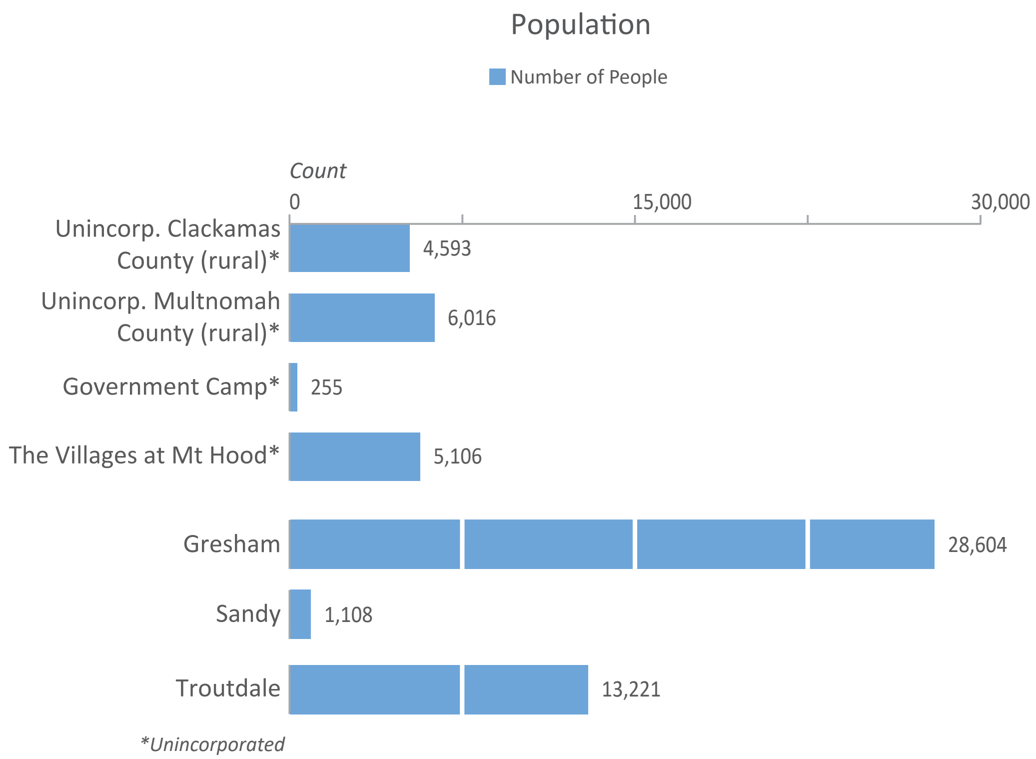
Cartography by: Lowell H. Anthony, 2018

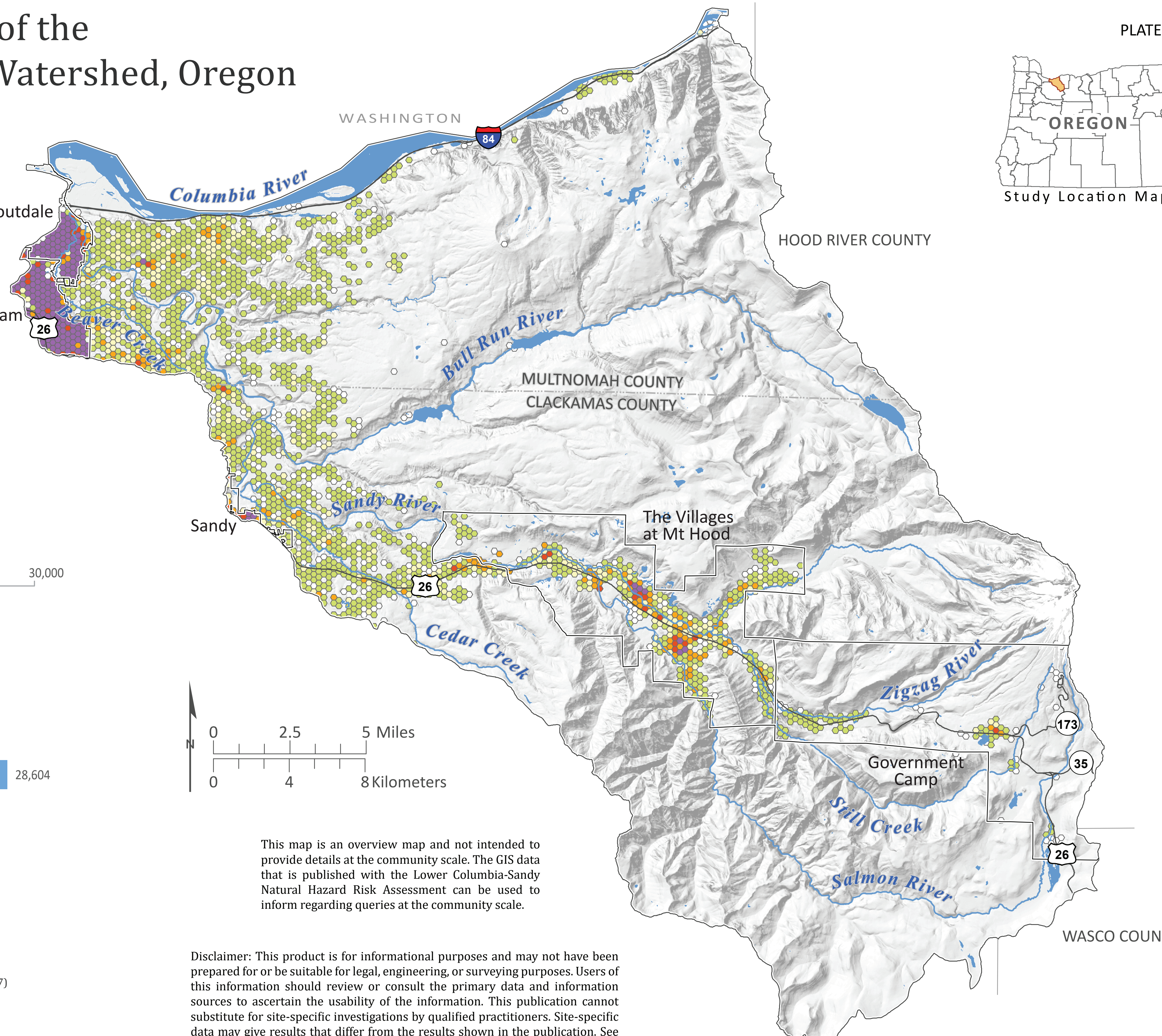
Population Density Map of the Lower Columbia-Sandy Watershed, Oregon

PLATE 2

People per 20 acres

- Building(s) present no permanent residents
- 0 - 10
- 11 - 20
- 21 - 40
- 41 - 80
- 81 +





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

Data Sources:
Population data: U.S. Census (2010)
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) | Clackamas County Technology Services (2017)
Basemap: U.S. Geological Survey and Oregon Lidar Consortium (2012
Hydrography: U.S. Geological Survey National Hydrography Dataset (2017)

Projection: NAD 1983 UTM Zone 10N
Software: Esri® ArcMap 10, Adobe® Illustrator CS6

Cartography by: Lowell H. Anthony, 2018

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M9.0 CSZ Earthquake Shaking Map of the Lower Columbia-Sandy Watershed, Oregon

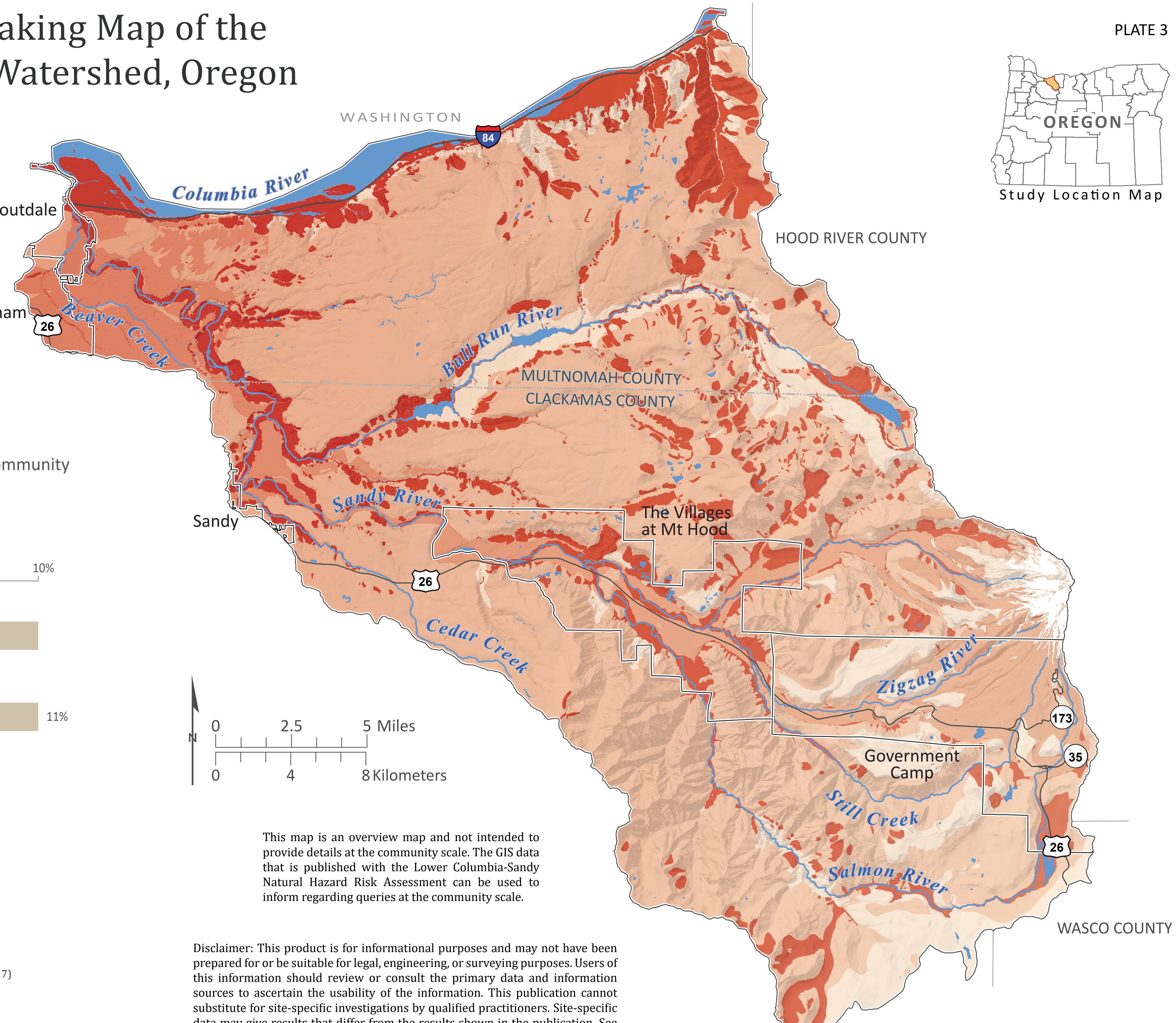
PLATE 3

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.

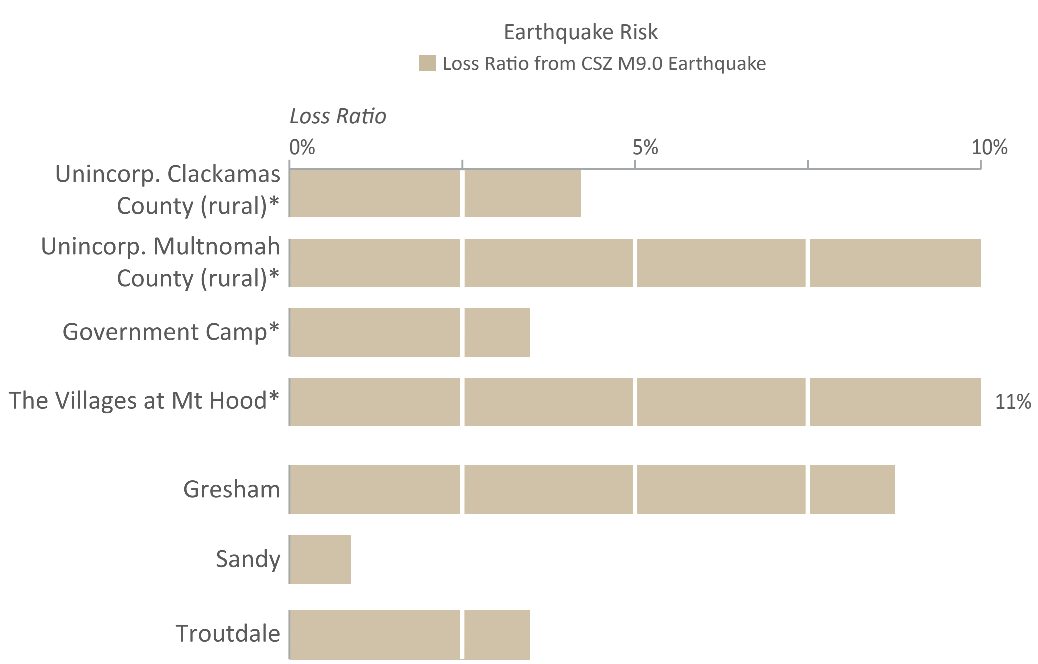
Earthquake Peak Ground Acceleration

(Modified Mercalli Intensity Scale)

Moderate — Severe



Total Building Value Loss Ratio from M9.0 Earthquake per Community



*Unincorporated

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

Data Sources:
Earthquake peak ground acceleration: Madin and Burns (2013)
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) | Clackamas County Technology Services (2017)
Basemap: U.S. Geological Survey and Oregon Lidar Consortium (2012)
Hydrography: U.S. Geological Survey National Hydrography Dataset (2017)

Projection: NAD 1983 UTM Zone 10N
Software: Esri® ArcMap 10, Adobe® Illustrator CS6

Cartography by: Lowell H. Anthony, 2018

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M6.9 MHFZ Earthquake Shaking Map of the Lower Columbia-Sandy Watershed, Oregon

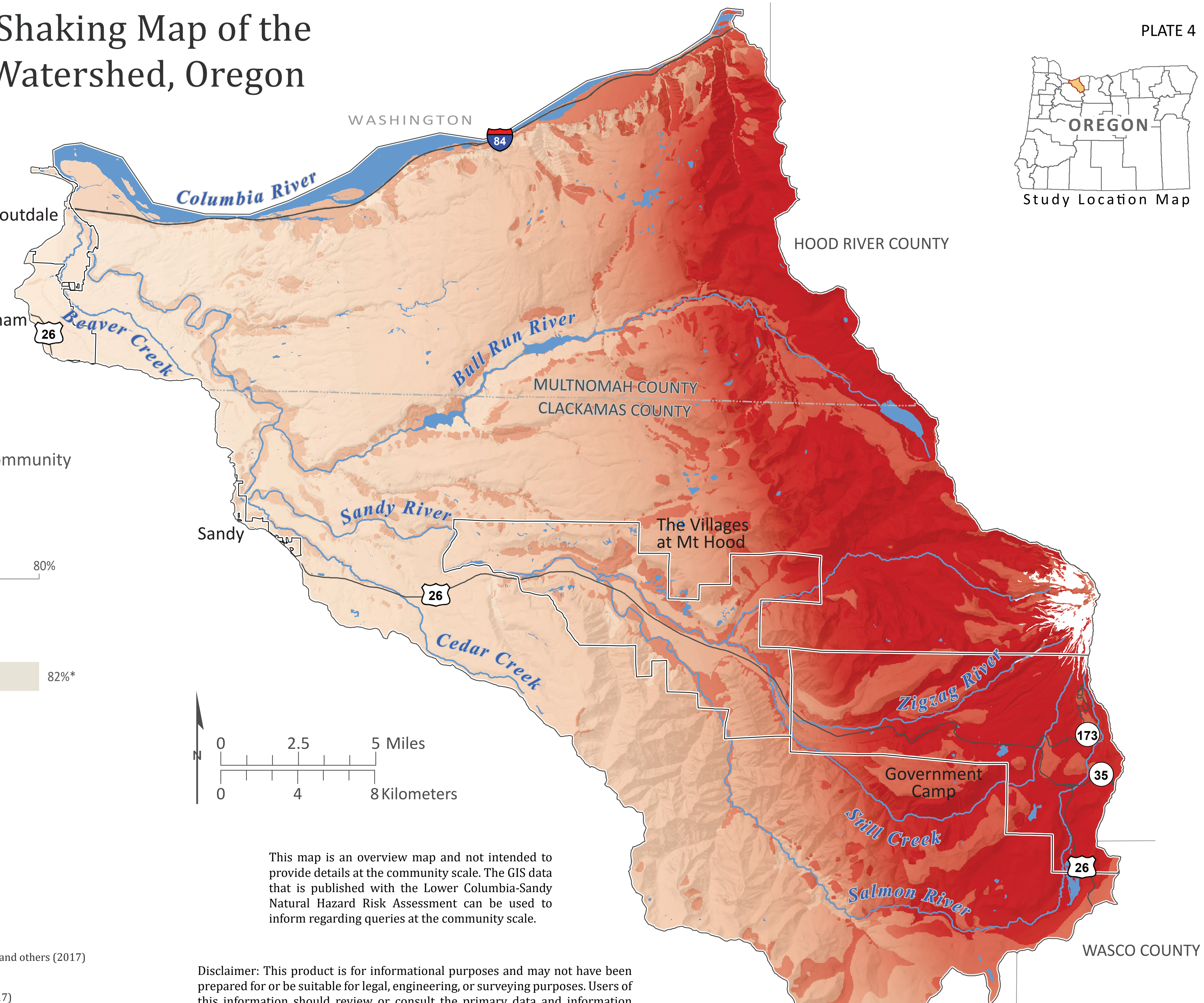
PLATE 4

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.

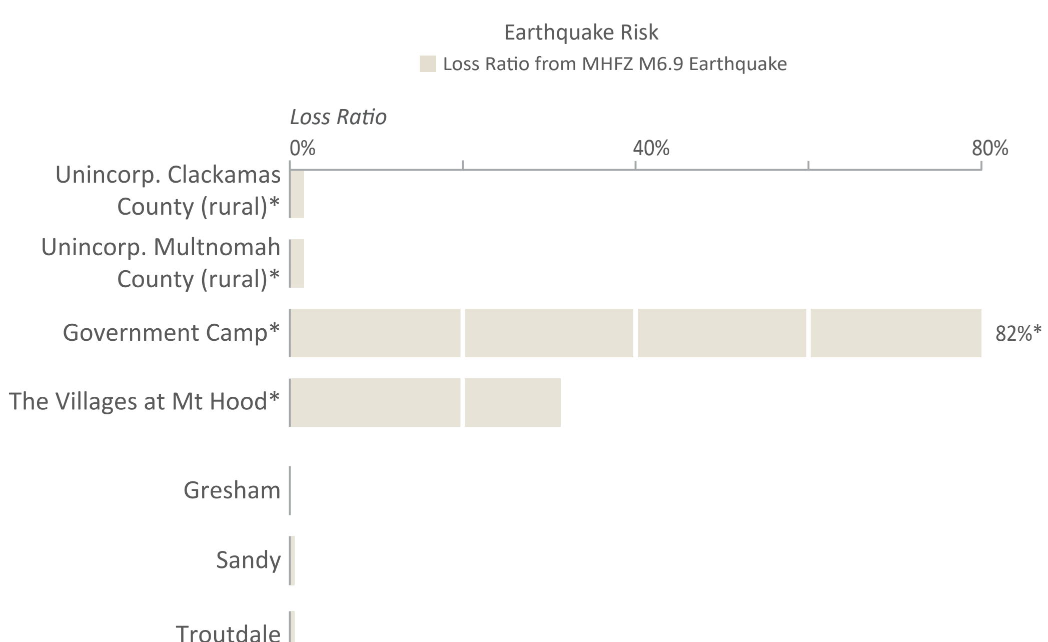
Earthquake Peak Ground Acceleration

(Modified Mercalli Intensity Scale)

Moderate — Severe



Total Building Value Loss Ratio from M9.0 Earthquake per Community



*Unincorporated

*Most of this damage is incurred from the community's most expensive buildings (e.g. Timberline Lodge) in this scenario. The percentage of red and yellow tagged buildings for Government Camp is near 40%.

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

Data Sources:
Earthquake peak ground acceleration: Oregon Department of Geology, HAZUS Interpretation of Madin and others (2017)
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) | Clackamas County Technology Services (2017)
Basemap: U.S. Geological Survey and Oregon Lidar Consortium (2012)
Hydrography: U.S. Geological Survey National Hydrography Dataset (2017)

Projection: NAD 1983 UTM Zone 10N
Software: Esri® ArcMap 10, Adobe® Illustrator CS6

Cartography by: Lowell H. Anthony, 2018

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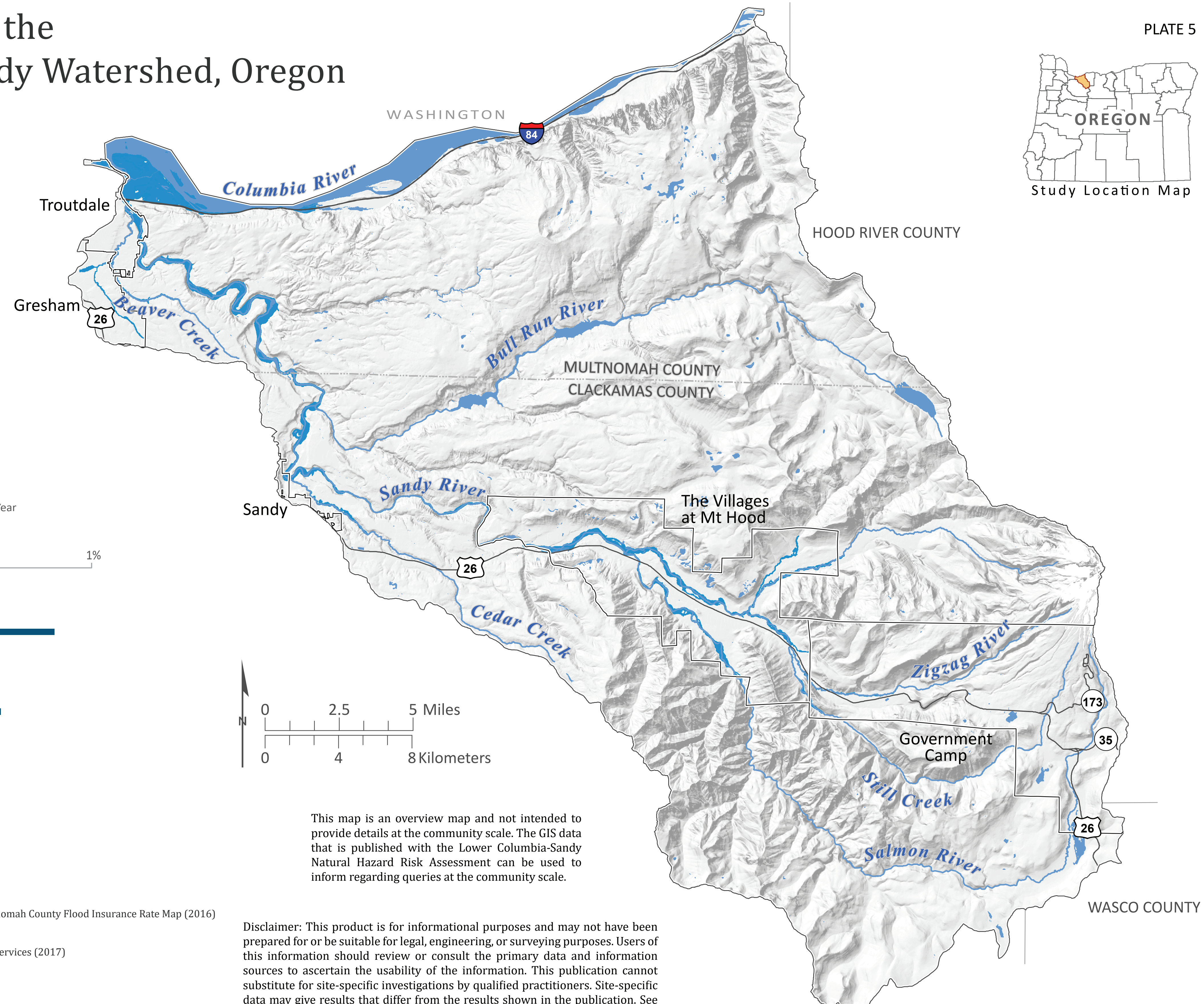
PLATE 5

Flood Hazard Map of the Lower Columbia-Sandy Watershed, Oregon

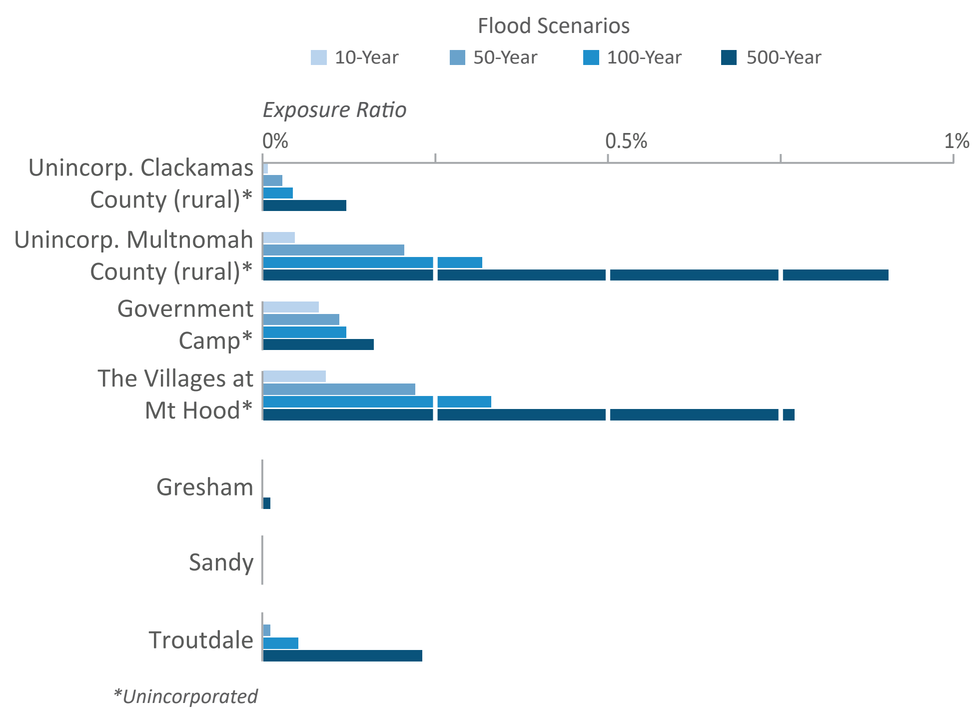
The flood hazard data show areas expected to be inundated during a 100-year flood event. Flooding sources include riverine. Areas are consistent with the regulatory flood zones depicted in Lower Columbia-Sandy Watershed's Digital Flood Insurance Rate Maps.

Flood Hazard Zone

100-Year Flood (1% annual chance)



Ratio of Estimated Loss to Flooding



*Unincorporated

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

Data Sources:
Flood hazard zone (100-year): Clackamas County Flood Insurance Rate Map (2016) | Multnomah County Flood Insurance Rate Map (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) | Clackamas County Technology Services (2017)
Basemap: U.S. Geological Survey and Oregon Lidar Consortium (2012
Hydrography: U.S. Geological Survey National Hydrography Dataset (2017)

Projection: NAD 1983 UTM Zone 10N
Software: Esri® ArcMap 10, Adobe® Illustrator CS6

Cartography by: Lowell H. Anthony, 2018

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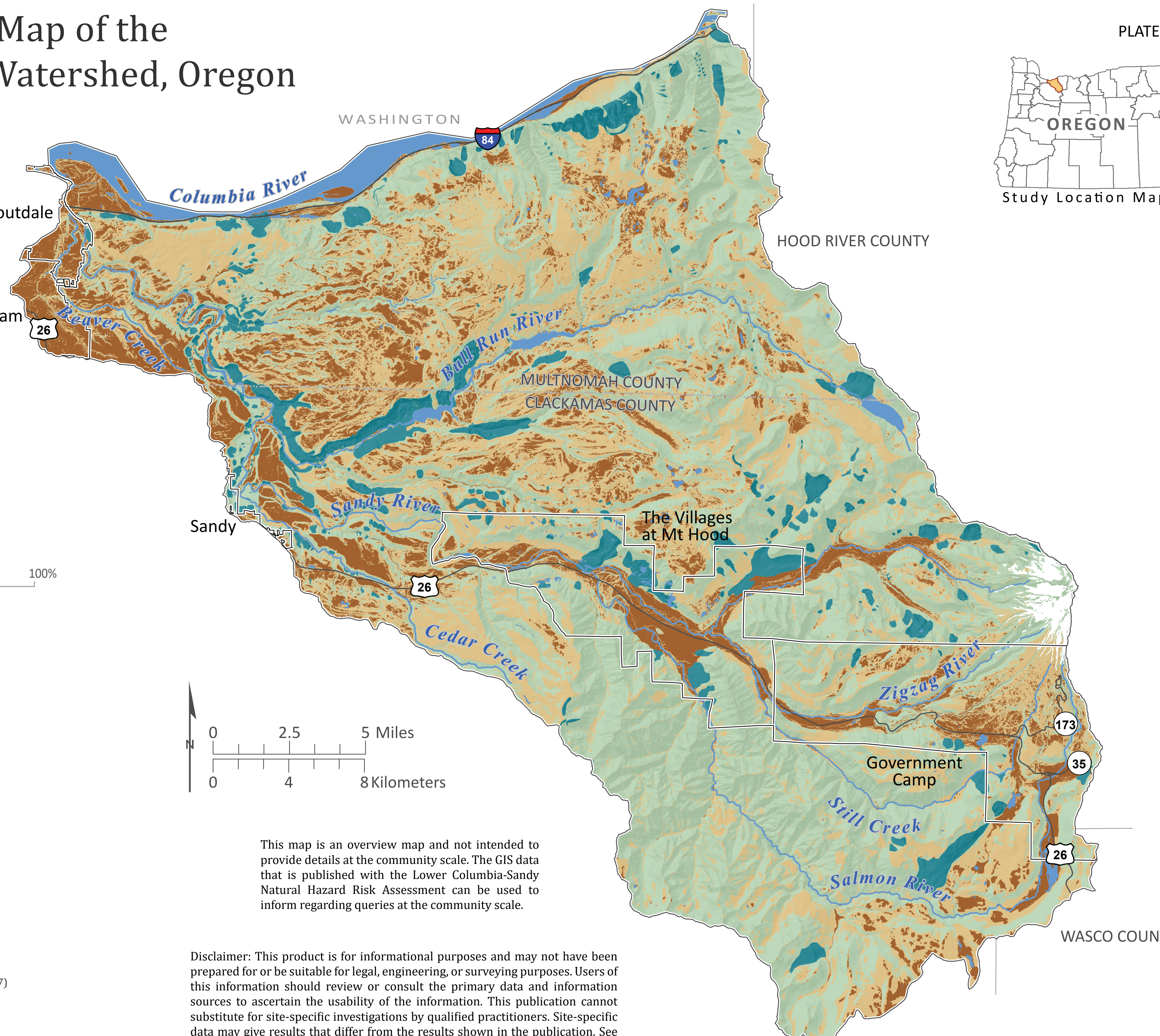
Landslide Susceptibility Map of the Lower Columbia-Sandy Watershed, Oregon

PLATE 6

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.

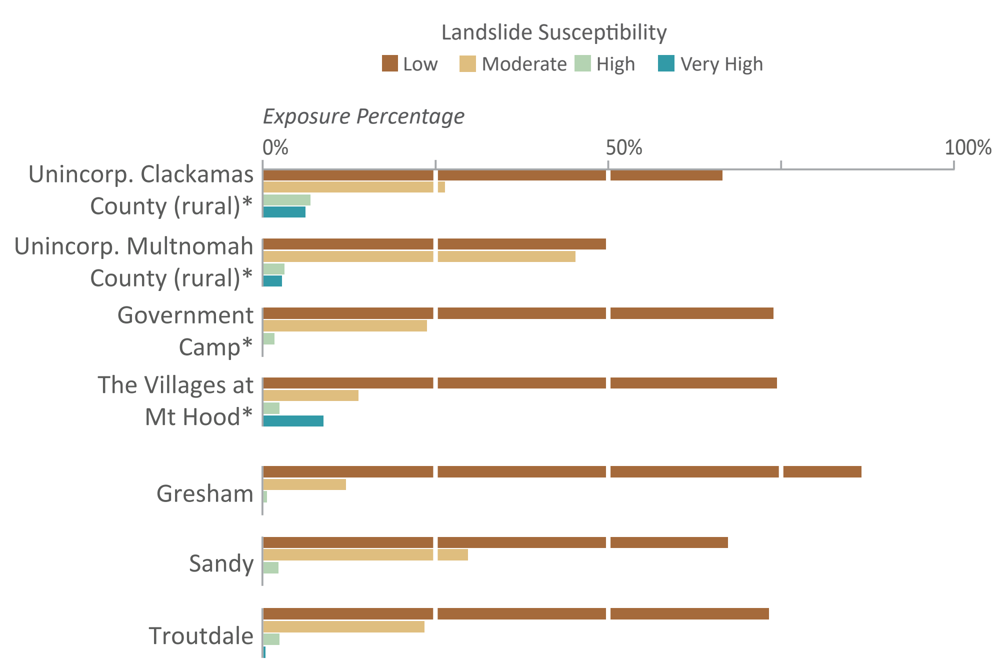
Landslide Susceptibility

- Low
- Moderate
- High
- Very High



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

Percentage of Building Value Exposed to Landslide



*Unincorporated

Data Sources:
Landslide susceptibility: Oregon Department of Geology, 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) | Clackamas County Technology Services (2017)
Basemap: U.S. Geological Survey and Oregon Lidar Consortium (2012)
Hydrography: U.S. Geological Survey National Hydrography Dataset (2017)

Projection: NAD 1983 UTM Zone 10N
Software: Esri® ArcMap 10, Adobe® Illustrator CS6

Cartography by: Lowell H. Anthony, 2018

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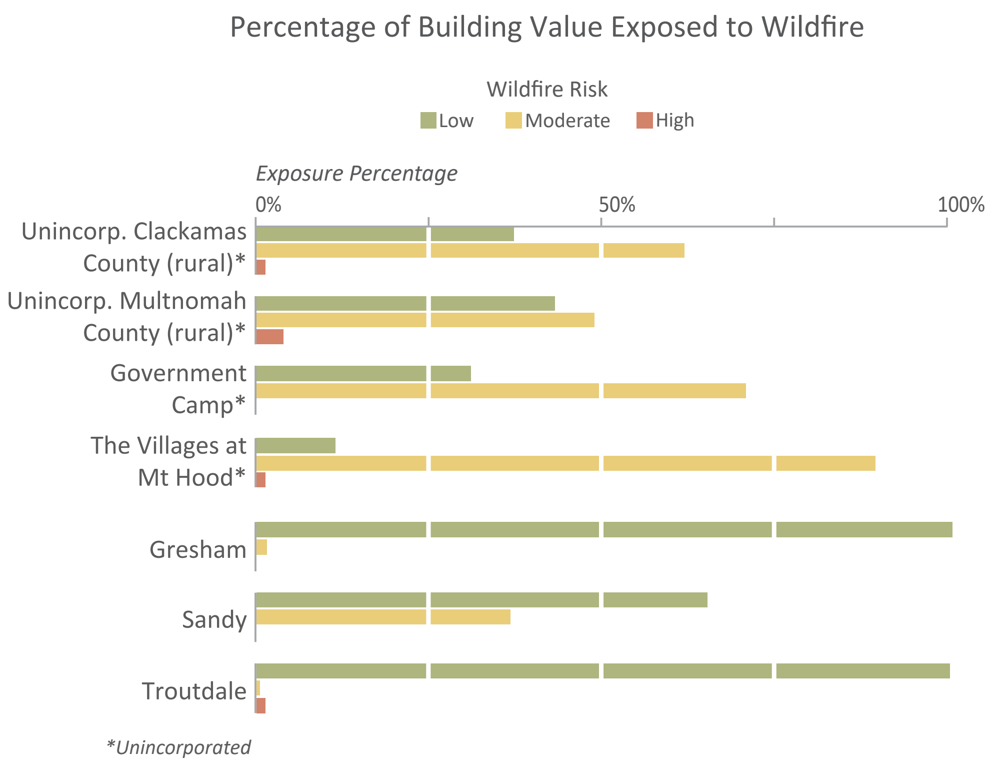
Wildfire Risk Map of the Lower Columbia-Sandy Watershed, Oregon

PLATE 7

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 (Fire Risk Index) is derived from a combination of the Fire Threat Index (fire history and behavior) and the Fire Effects Index (infrastructure and assets).

Wildfire Risk

- Low
- Moderate
- High



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

Data Sources:
Wildfire risk data: Oregon Department of Forestry (2013)
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) | Clackamas County Technology Services (2017)
Basemap: U.S. Geological Survey and Oregon Lidar Consortium (2012)
Hydrography: U.S. Geological Survey National Hydrography Dataset (2017)

Projection: NAD 1983 UTM Zone 10N
Software: Esri® ArcMap 10, Adobe® Illustrator CS6

Cartography by: Lowell H. Anthony, 2018

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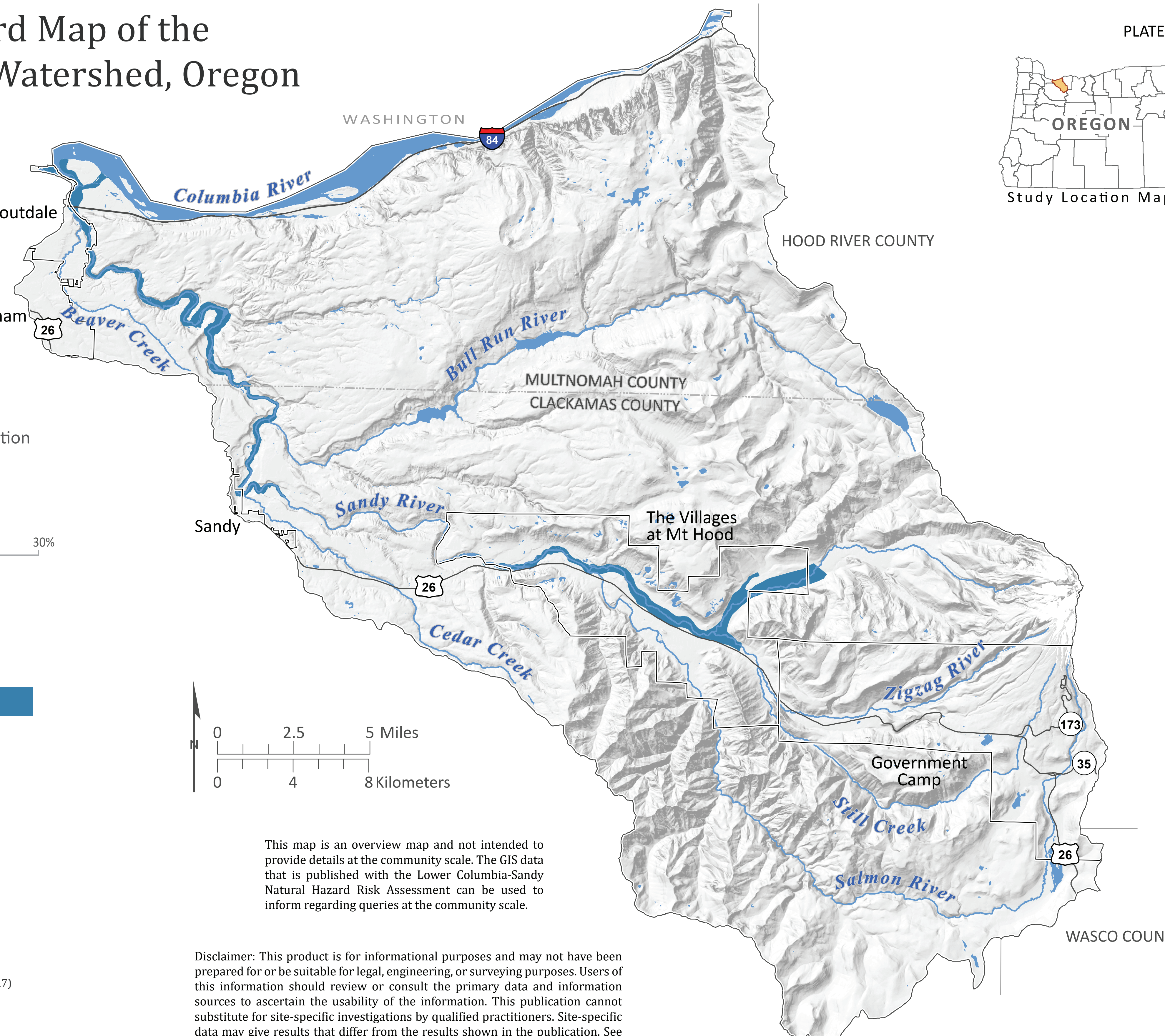
Channel Migration Hazard Map of the Lower Columbia-Sandy Watershed, Oregon

PLATE 8

The channel migration hazard data show areas expected to be exposed in a 100-year period. In the upper portions of drainages in the study area (just below Mount Hood), channel migration hazards are severe.

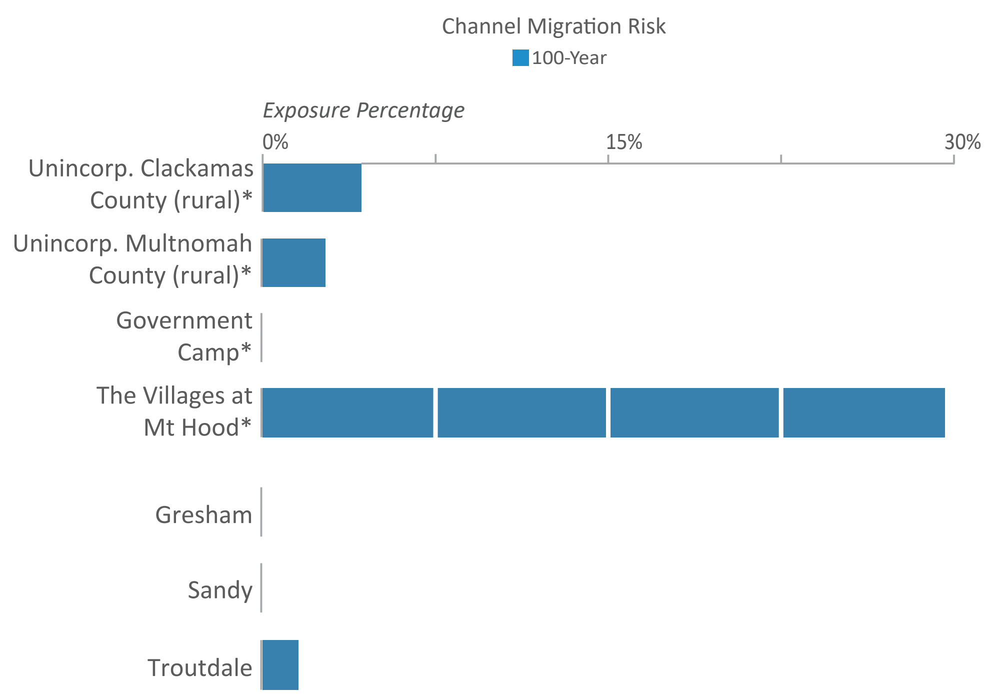
Channel Migration Exposure

Channel Migration Zone



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

Percentage of Building Value Exposed to Channel Migration



*Unincorporated

Data Sources:
Channel Migration hazard zone (100-year): Oregon Department of Geology, English and others (2013) | Natural Systems Design, 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) | Clackamas County Technology Services (2017)
Basemap: U.S. Geological Survey and Oregon Lidar Consortium (2012
Hydrography: U.S. Geological Survey National Hydrography Dataset (2017)

Projection: NAD 1983 UTM Zone 10N
Software: Esri® ArcMap 10, Adobe® Illustrator CS6

Cartography by: Lowell H. Anthony, 2018

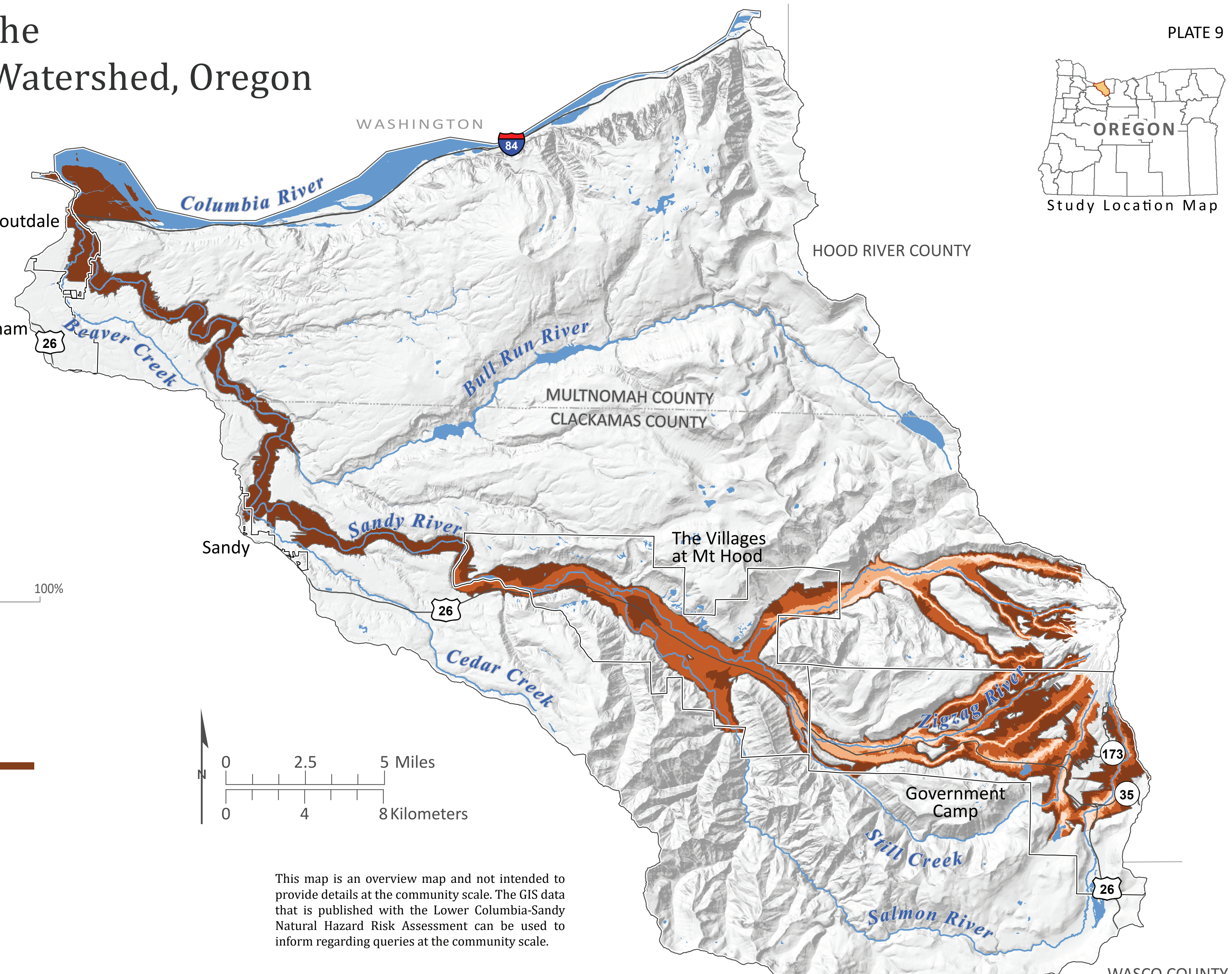
Lahar Exposure Map of the Lower Columbia-Sandy Watershed, Oregon

PLATE 9

The lahar hazard data show areas of expected exposure from several local lahar scenarios produced from a volcanic event on Mt Hood. The scenarios were categorized based on "t-shirt" sizes, ranging from Small to X-Large.

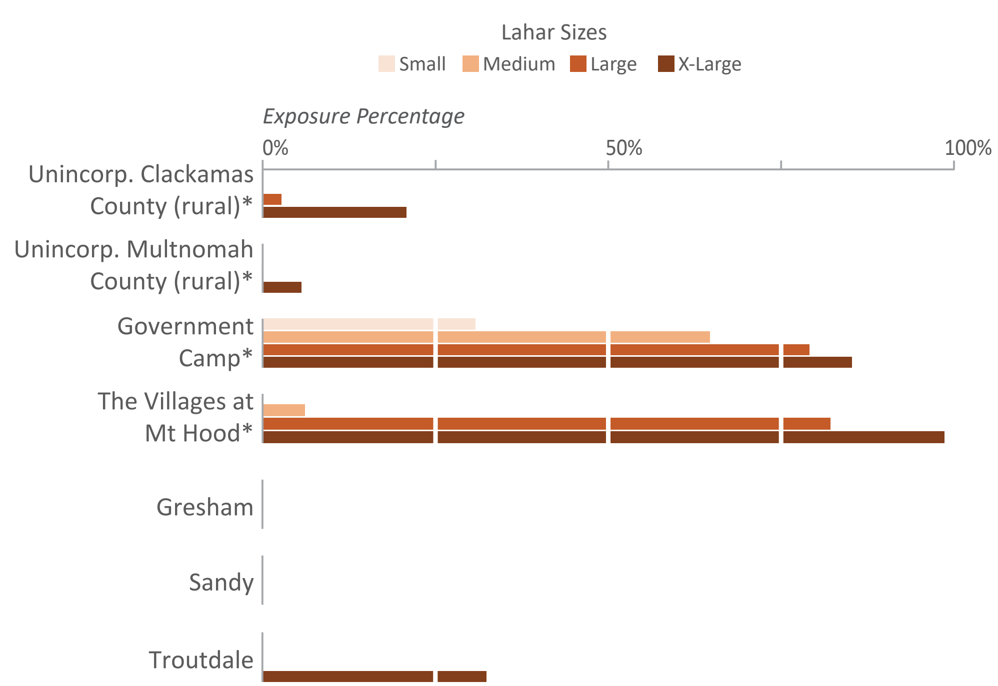
Lahar Hazard Zone

- Small
- Medium
- Large
- X-Large



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

Percentage of Building Value Exposed to Lahar



*Unincorporated

Data Sources:
Lahar Hazard Zones: Oregon Department of Geology, 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) | Clackamas County Technology Services (2017)
Basemap: U.S. Geological Survey and Oregon Lidar Consortium (2012
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Projection: NAD 1983 UTM Zone 10N
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