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

OPEN-FILE REPORT O-20-16

NATURAL HAZARD RISK REPORT FOR CLATSOP COUNTY, OREGON

INCLUDING THE CITIES OF ASTORIA, CANNON BEACH, GEARHART, SEASIDE, AND WARRENTON AND THE UNINCORPORATED COMMUNITIES OF ARCH CAPE, SVENSEN-KNAPPA, AND WESTPORT

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2020

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Cover photo: Mouth of the Necanicum River at Seaside, Oregon.
Credit: Oregon ShoreZone, https://www.oregonshorezone.info/images.html,

WHAT'S IN THIS REPORT?

This report describes the methods and results of a natural hazard risk assessment for Clatsop County communities. The risk assessment can help communities better plan for disaster.

Oregon Department of Geology and Mineral Industries Open-File Report O-20-16
Published in conformance with ORS 516.030

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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.

Clatsop_County_Risk_Report_Data.gdb

Feature dataset: Asset_Data

feature classes:

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

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 Clatsop County, Oregon, with funding provided by the Federal Emergency Management Agency (FEMA). It describes the methods and results of the natural hazard risk assessment performed in 2018 by the Oregon Department of Geology and Mineral Industries (DOGAMI) within the study area. The purpose of this project was to provide communities with a detailed understanding of their risk from natural hazards, to give communities the ability to compare their risk across multiple hazards, and to prioritize and take actions that will reduce risk. The results of this study can also inform the natural hazard mitigation planning process.

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

To complete 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. Using this dataset, 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 was the best available at the time the analysis was performed.

In the third task, we performed risk assessments using Esri® ArcGIS Desktop® software. We used 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, tsunami, flood, landslides, coastal erosion, and wildfire hazards.

The findings and conclusions in this report show the potential impacts of hazards in communities within Clatsop County. A Cascadia Subduction Zone (CSZ) event (earthquake and tsunami) will cause extensive damage and losses throughout the county. Our findings indicate that most of the study area's critical facilities are at high risk during a CSZ event. We also found that the two biggest causes of population displacement are a CSZ event (earthquake and tsunami) and landslide hazard. We demonstrate the potential for the reduction in damages and losses from seismic retrofits through building code simulations in the Hazus-MH earthquake model. Flooding is a threat for some communities in the study area, and we quantify the number of elevated structures that are less vulnerable to flood hazard. Our analysis shows that new landslide mapping based on improved methods and lidar information will increase the accuracy of future risk assessments. The risk from coastal erosion is high for most communities along the open coast. During the time of writing, the best available data show that wildfire risk is high in areas along Youngs Bay and the Columbia River. Lastly, we demonstrate that this risk assessment can be a valuable tool for local decision-makers.

Results were broken out for the following geographic areas:

- Unincorporated Clatsop County (rural)
- Community of Svensen-Knappa
- City of Astoria
- City of Gearhart
- City of Warrenton
- Community of Arch Cape
- Community of Westport
- City of Cannon Beach
- City of Seaside

Selected Countywide Results
Total buildings: 25,829
Total estimated building value: $5 billion

Cascadia Subduction Zone Magnitude 9.0 Earthquake[a] Red-tagged buildings[b]: 5,045 Yellow-tagged buildings[c]: 1,314 Loss estimate: $1.2 billion	**Cascadia Subduction Zone Tsunami Inundation** Number of buildings exposed: 8,810 Exposed building value: $1.7 billion
100-year Flood Scenario Number of buildings damaged: 2,529 Loss estimate: $41 million	**Landslide Exposure (High and Very High Susceptibility)** Number of buildings exposed: 7,335 Exposed building value: $1.2 billion
Coastal Erosion Exposure (Moderate Hazard) Number of buildings exposed: 349 Exposed building value: $135 million	**Wildfire Exposure (High Hazard)** Number of buildings exposed: 2,467 Exposed building value: $340 million

[a]Results reflect damages caused by earthquake to buildings outside of the tsunami zone. Earthquake and tsunami results combined estimate the total damages from a CSZ M9.0 event.
[b]Red-tagged buildings are considered to be uninhabitable due to complete damage.
[c]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 informs the decision-making process, so that steps can be taken to prepare for a potential hazard event.

This is the first natural hazard risk assessment analyzing individual buildings and resident population in Clatsop County. It is the most detailed and comprehensive analysis of natural hazard risk to date and provides a new, comparative perspective across hazards. In this report, we describe our assessment results, which quantify the various levels of risk that each hazard presents to Clatsop County communities.

The Oregon coast, Columbia River estuary, and Oregon Coast Range are subject to several significant natural hazards, including riverine and coastal flooding, earthquake, tsunami, landslides, coastal erosion, and wildfire. This region of the state is moderately developed, mostly in cities and unincorporated communities along the Pacific coastline and the Columbia River. Natural hazards that pose a potential threat to development results in risk. The primary goal of the 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 communities. This is accomplished by providing accurate, detailed, and up-to-date 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** provides 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.

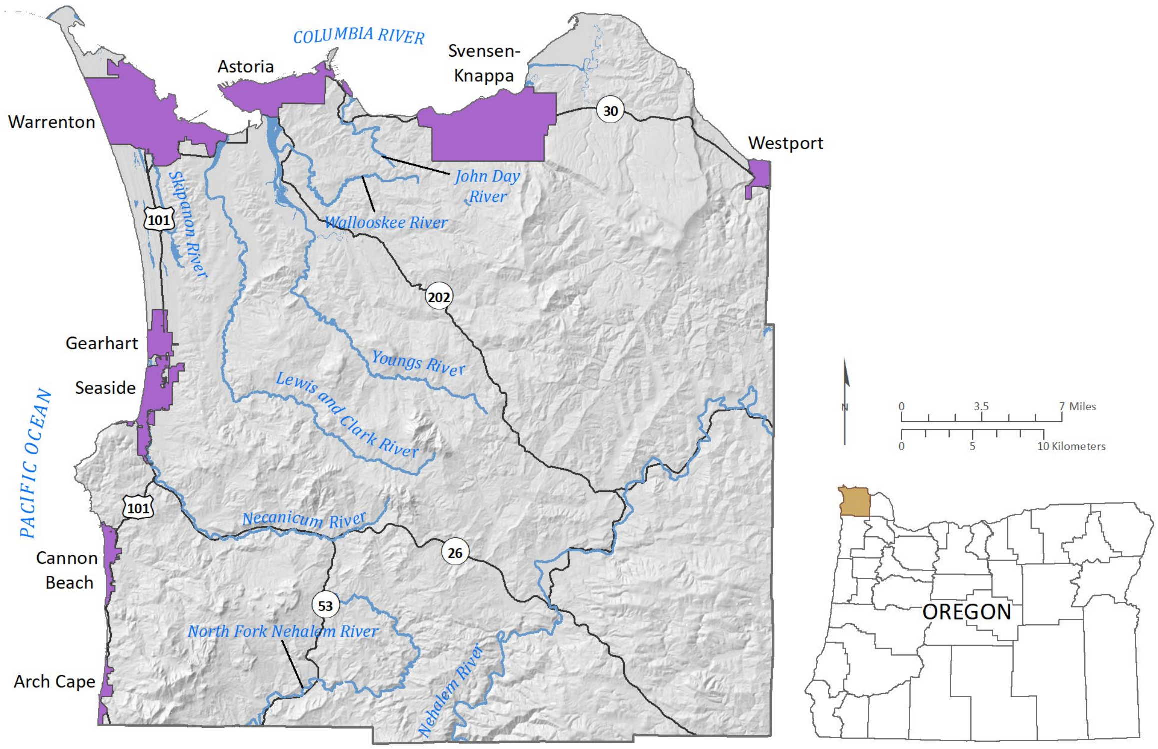
1.2 Study Area

The study area for this project is the entirety of Clatsop County, Oregon. Clatsop County is a coastal county located in the northwestern corner of the state and is bordered by Tillamook County on the south, Columbia County on the east, the Columbia River on the north, and the Pacific Ocean on the west. The total area of Clatsop County is 1,085 square miles (2,810 square kilometers). A significant portion of the county is within state forest land (Clatsop or Tillamook State Forests) or is managed as industrial forest land.

The geography consists of rocky and irregular coastline and dune-backed beaches that form the county's western boundary, estuarine areas (including the Columbia River estuary), stretches of coastal lowlands, and a heavily timbered interior that comprises the main span and several spurs of the Oregon Coast Range.

The population of Clatsop County is 37,039 according to the 2010 U.S. Census Bureau (2010a). The county seat and county's largest community is the City of Astoria. All the communities in the study, incorporated and unincorporated, are close to either the Pacific Ocean or the Columbia River. The incorporated communities are Astoria, Cannon Beach, Gearhart, Seaside, and Warrenton (**Figure 1-1**). The unincorporated communities are Arch Cape, Svensen-Knappa and Westport.

Figure 1-1. Study area: Clatsop County with communities in this study identified.



We selected these unincorporated communities on the basis of population size and density, which make them distinct from the overall unincorporated county jurisdiction. We based the boundaries of these unincorporated communities primarily on the 2010 census block areas.

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 the 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, in which 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 the Clatsop County tax assessor database. 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 natural hazards and the risk assessment methodologies that were applied. See **Table 1-1** for data sources.

Cascadia Subduction Zone (CSZ) Earthquake and Tsunami Risk Assessment

- Hazus-MH loss estimation from a CSZ earthquake magnitude (M) 9.0 event (includes liquefaction and coseismic landslides)
- Exposure to five potential CSZ tsunami scenarios

Flood Risk Assessment

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

Landslide Risk Assessment

- Exposure based on landslide susceptibility (low to very high)

Coastal Erosion Risk Assessment

- Exposure based on coastal erosion zones (none to high)

Wildfire Risk Assessment

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

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

Hazard	Scenario or Classes	Scale/Level of Detail	Data Source
Earthquake (includes liquefaction and coseismic landslides)	CSZ M9.0	Statewide	DOGAMI (Madin and Burns, 2013)
Tsunami	Local Source: Small (300 yr) Medium (425-525 yr) Large (650-800 yr) Extra Large (1,050-1,200 yr) Extra Extra Large (1,200 yr)	Oregon coast	DOGAMI (Priest and others, 2013)
Flood	Depth Grids: 10% (10-yr) 2% (50-yr) 1% (100-yr) 0.2% (500-yr)	Countywide	DOGAMI – derived from FEMA (2018) data
Landslide*	Susceptibility (Low, Moderate, High, Very High)	Statewide	DOGAMI (Burns and others, 2016)
Coastal Erosion	Susceptibility (Not Exposed, Low, Moderate, High)	Portions of the coast within Clatsop County	DOGAMI (Witter and others, 2009; Allan and Priest, 2001)
Wildfire	Risk (Low, Moderate, High)	Regional (Western United States)	ODF (Sanborn Map Company, Inc., 2013)

CSZ M9.0 is Cascadia subduction zone magnitude 9 earthquake.

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

1.4 Previous Studies

One previous risk assessment has been conducted that included Clatsop County by DOGAMI. Wang and Clark (1999: DOGAMI Special Paper 29) ran 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, Clatsop County had a very high loss ratio relative to most counties in the state.

We did not compare the results of this project with the results of the previous study because of limited time and funding and differences in methodologies.

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).

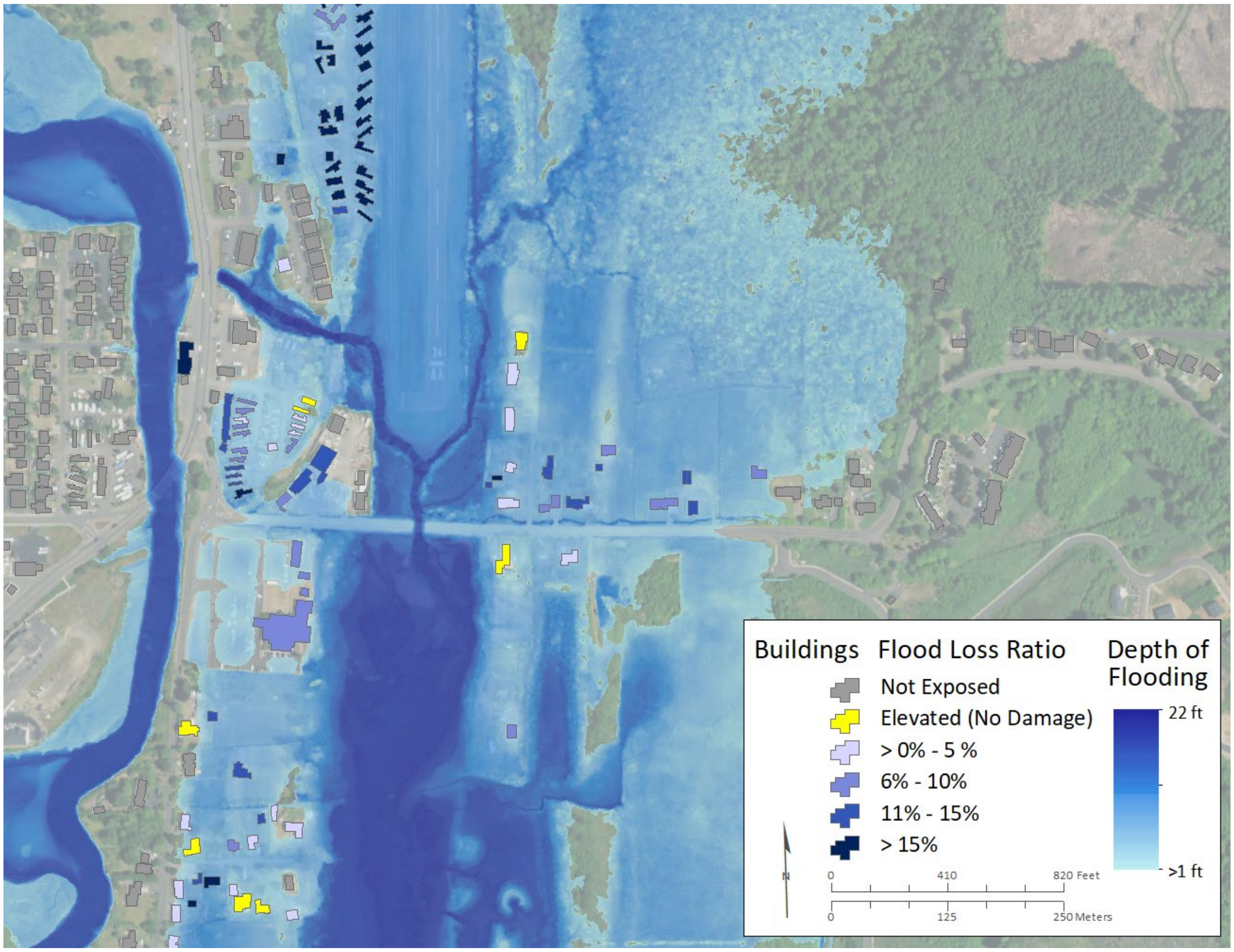
Hazus-MH can be used in different modes depending on the level of detail required. Given the high spatial precision of the building inventory data and quality of the natural hazard data, DOGAMI chose the user-defined facility (UDF) mode. This mode makes loss estimations for individual buildings relative to their "cost," which DOGAMI then aggregates to the community level to report loss ratios. Cost used in general building stock mode is associated with rebuilding using new materials, also known as replacement cost. Within the UDF mode, DOGAMI derived cost from the assessed value rather than replacement cost due to the accessibility and completeness of Clatsop County's assessor data.

The drawback of using the assessed value of a building is that the value of a building fluctuates based on the housing market from year to year, which is a different amount than how much it would cost to rebuild or repair a building. Loss estimations based on replacement cost are closer to the cost of recovery from a flood or earthquake. For Hazus-MH analysis using cost derived from assessed value, the loss estimation provides a better picture on the impact to the county's tax revenue.

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 City of Seaside.



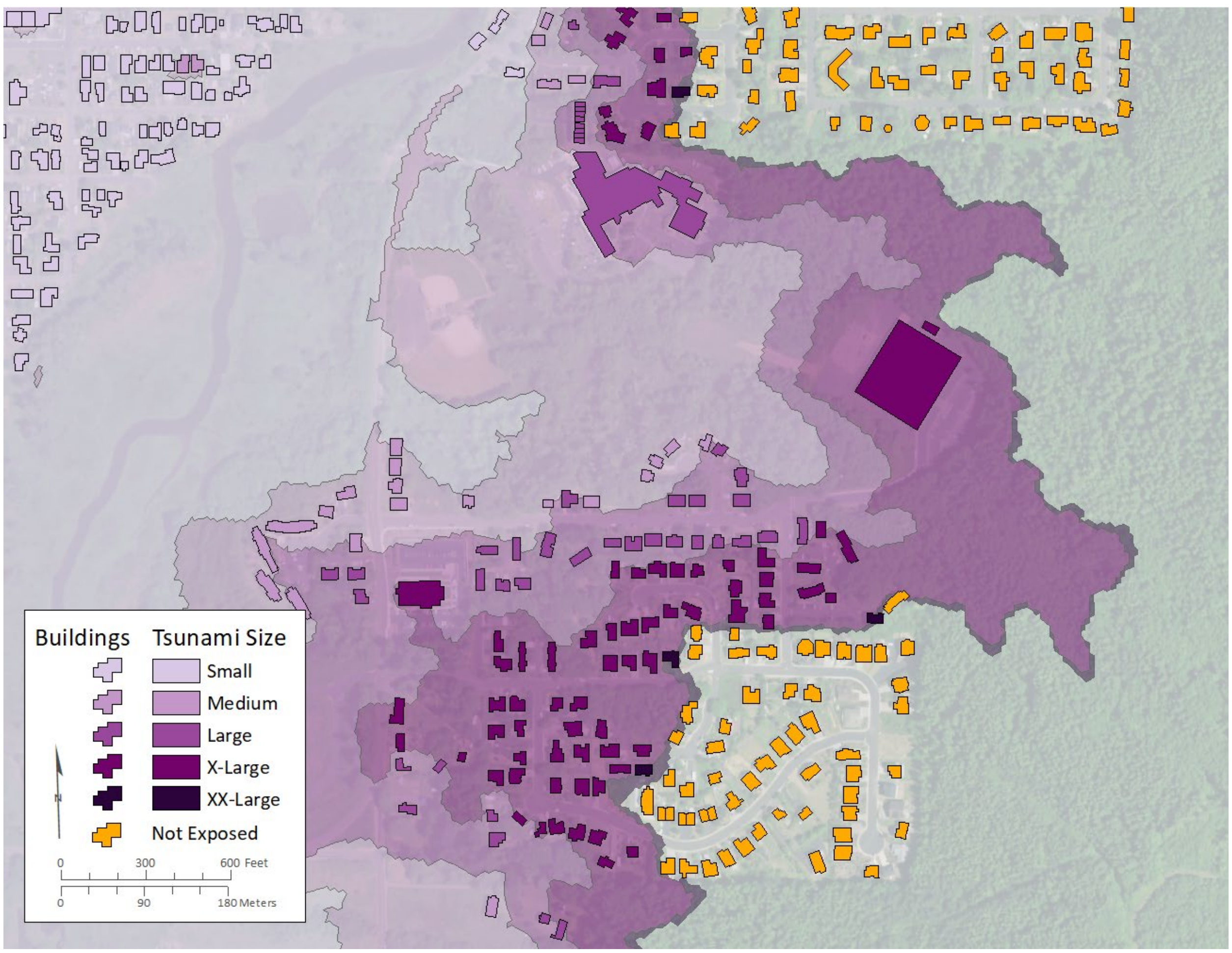
2.2 Exposure

Exposure methodology is calculating the buildings and population that are within a natural hazard zone. This is an alternative 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 what is not threatened. Exposure results are communicated in terms of total building value exposed, rather than loss estimate because the loss ratio is unknown. For example, **Figure 2-2** shows buildings that are exposed to different tsunami scenarios.

> ***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 is used for tsunami, landslide, coastal erosion, and wildfire 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. Tsunami inundation scenarios and building exposure example in the City of Seaside. Note that larger scenarios include the buildings of the smaller scenarios.



2.3 Building Inventory

A key piece of the risk assessment is the countywide building inventory. This inventory consists of all buildings larger than 500 square feet (46.5 square meters), as determined from existing building footprints or tax assessor data. **Figure 2-3** shows an example of building inventory occupancy types used in the Hazus-MH and exposure analyses in Clatsop County. See also Appendix E, **Plate 1** and **Plate 2.**

To use the building inventory within the Hazus-MH methodology, we converted the 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**.

Figure 2-3. Building occupancy types, portion of City of Seaside.

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

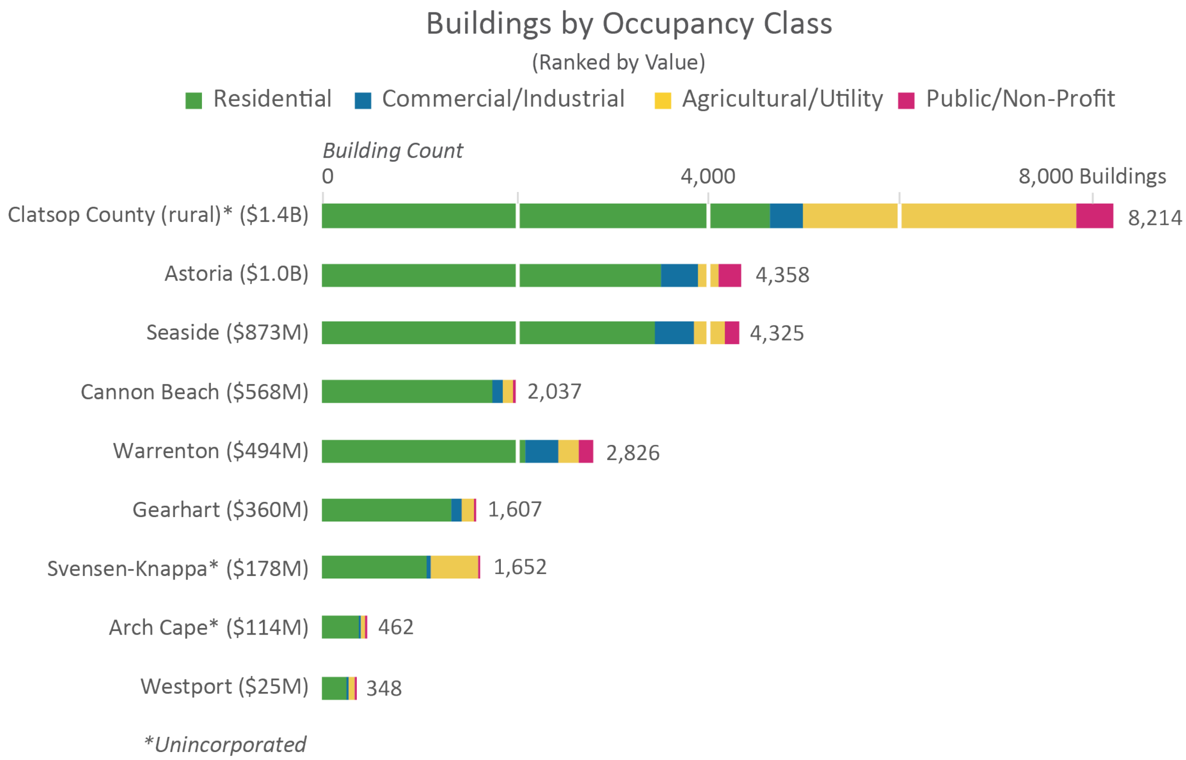
Table 2-1. Clatsop County building inventory.

Community	Total Number of Buildings	Percentage of Buildings of Clatsop County	Total Estimated Building Value ($)	Percentage of Building Value of Clatsop County
Unincorporated County (rural)	8,214	32%	1,378,964,000	27%
Arch Cape	462	1.8%	113,684,000	2.3%
Svensen-Knappa	1,652	6.4%	178,049,000	3.5%
Westport	348	1.3%	24,928,000	0.5%
Total Unincorporated County	10,676	41%	1,695,624,000	34%
Astoria	4,358	17%	1,037,058,000	21%
Cannon Beach	2,037	7.9%	567,876,000	11%
Gearhart	1,607	6.2%	359,970,000	7.2%
Seaside	4,325	17%	872,504,000	17%
Warrenton	2,826	11%	493,680,000	9.8%
Total Clatsop County	25,829	100%	5,026,712,000	100%

The building inventory was developed from several data sources and was refined for use in loss estimation and exposure analyses. A database of building footprints for a significant portion of Clatsop County was already available from a previous DOGAMI project (Priest and others, 2013). Building footprints in the database were digitized from high-resolution lidar collected in 2009 (North Coast project, Oregon Lidar Consortium; see http://www.oregongeology.org/lidar/collectinglidar.htm). The building footprints provide a spatial location and 2D representation of a structure.

Clatsop County supplied assessor data that we formatted for use in the risk assessment. 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 county assessor and were 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 assessment for both loss estimation and exposure analysis. **Figure 2-4** illustrates the variation of building value and occupancy across the communities of Clatsop County.

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



Note that "Clatsop Co. (rural)" excludes incorporated communities, Arch Cape, Svensen-Knappa, and Westport.

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 (see **Community Risk Profiles**).

Table 2-2. Clatsop County critical facilities inventory.

Community	Hospital & Clinic		School		Police/Fire		Emergency Services		Military		Other*		Total	
	Count	Value ($)	Count	Value ($)	Count	Value ($)	Count	Value ($)	Count	Value ($)	Count	Value ($)	Count	Value ($)
(all dollar amounts in thousands)														
Unincorp. County (rural)	0	0	2	15,839	9	1,253	0	0	2	71,873	7	3,163	20	92,129
Arch Cape	0	0	0	0	2	588	0	0	0	0	2	2,612	4	3,200
Svensen-Knappa	0	0	2	5,279	1	192	1	372	0	0	2	509	6	6,352
Westport	0	0	0	0	1	232	0	0	0	0	2	241	3	473
Total Unincorp. County	0	0	4	21,118	13	2,264	1	372	2	71,873	13	6,526	33	102,154
Astoria	3	39,081	5	101,995	4	6,995	2	17,220	1	22	3	4,005	18	169,318
Cannon Beach	1	9	1	153	2	2,983	0	0	0	0	0	0	4	3,145
Gearhart	1	458	1	5,038	2	836	0	0	0	0	0	0	4	6,332
Seaside	1	16,930	4	31,477	2	2,676	0	0	0	0	2	2,268	9	53,352
Warrenton	2	1,204	3	36,186	2	3,721	0	0	1	4,508	2	4,508	10	50,127
Total Clatsop County	8	57,682	18	195,967	25	19,475	3	17,592	4	76,403	20	17,308	78	384,427

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

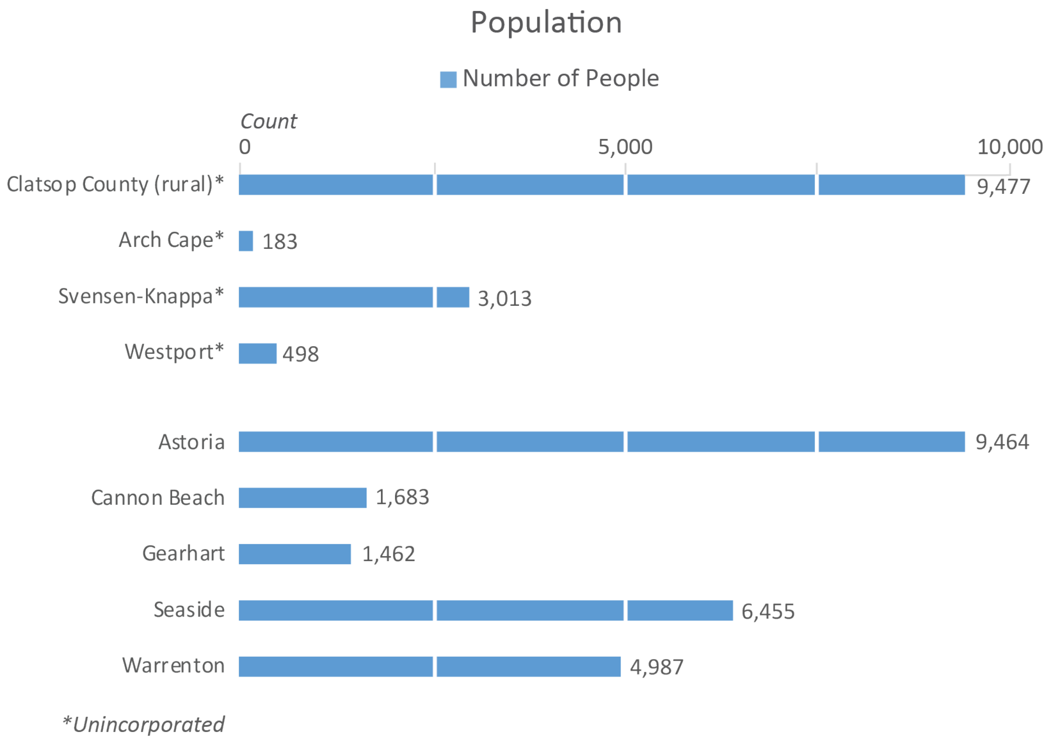
*Category includes buildings that are not traditional (emergency response) critical facilities but are considered critical during an emergency based on input from local stakeholders (e.g., water treatment facilities or airports).

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. Due to lack of information within the assessor and census databases, the distribution includes vacation homes, which in many coastal communities make up some of the total residential building stock. From information reported in the 2010 U.S. Census, American FactFinder regarding vacation rentals within the county and coastal communities, it is estimated that approximately 20% of residential buildings are vacation rentals in Clatsop County (U.S. Census Bureau, 2010b).

From the census data, DOGAMI analyzed the 37,039 residents within the study area who could be affected by a natural hazard scenario. For each natural hazard, with the exception of the CSZ M9.0 earthquake scenario, a simple exposure analysis was used to find the number of potentially displaced residents within a hazard zone. For the CSZ M9.0 earthquake scenario the number of potentially displaced residents was based on a combination of residents exposed to tsunami and those in buildings estimated to be significantly damaged by the earthquake.

Figure 2-5. Total population by Clatsop County community.



3.0 ASSESSMENT OVERVIEW AND RESULTS

This risk assessment considers six natural hazards (earthquake, tsunami, flood, landslide, coastal erosion, and wildfire) that pose a risk to Clatsop County. 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 Countywide Results

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

3.2 Cascadia Subduction Zone Earthquake

> **Understanding the connection between Cascadia subduction zone earthquakes and tsunamis**
>
> During a large CSZ earthquake, the sudden uplift of the North American plate along the CSZ margin is likely to displace enough water to produce a tsunami that will have an impact along the Oregon coast. The proximity of the CSZ to the coastal areas of Oregon make them especially threatened by earthquakes and tsunamis (Madin and Burns, 2013).
>
> Although we discuss CSZ earthquakes and tsunamis as separate hazards in this report, these hazards are closely associated. Their widespread effects and almost simultaneous occurrence present a challenge to planners.

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).

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 build 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 strong (Clague and others, 2000).

Two earthquake-induced hazards are liquefaction and landslides. Liquefaction occurs when saturated soils substantially lose bearing capacity due to ground shaking, causing the soil to behave like a liquid; this action can be a source of tremendous damage. Coseismic landslides are mass movement of rock, debris, or soil induced by ground shaking. All earthquake damages in this report include damages derived from both liquefaction and landslide factors.

Another risk factor associated with the CSZ event is co-seismic subsidence. According to Peterson and others (1997), a CSZ earthquake can result in coastal subsidence of up to 10 feet (3 meters). Low-lying developed areas near beaches and estuaries are most susceptible to this long-term hazard. A significant and permanent lowering of coastal terrain would expose buildings and infrastructure to tidal inundation in low-lying coastal areas that were formerly above high tide (Madin and Burns, 2013). Analysis of this potentially significant hazard is beyond the scope of this project.

3.2.1 Data sources

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 easily the highest seismic risk to this 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.

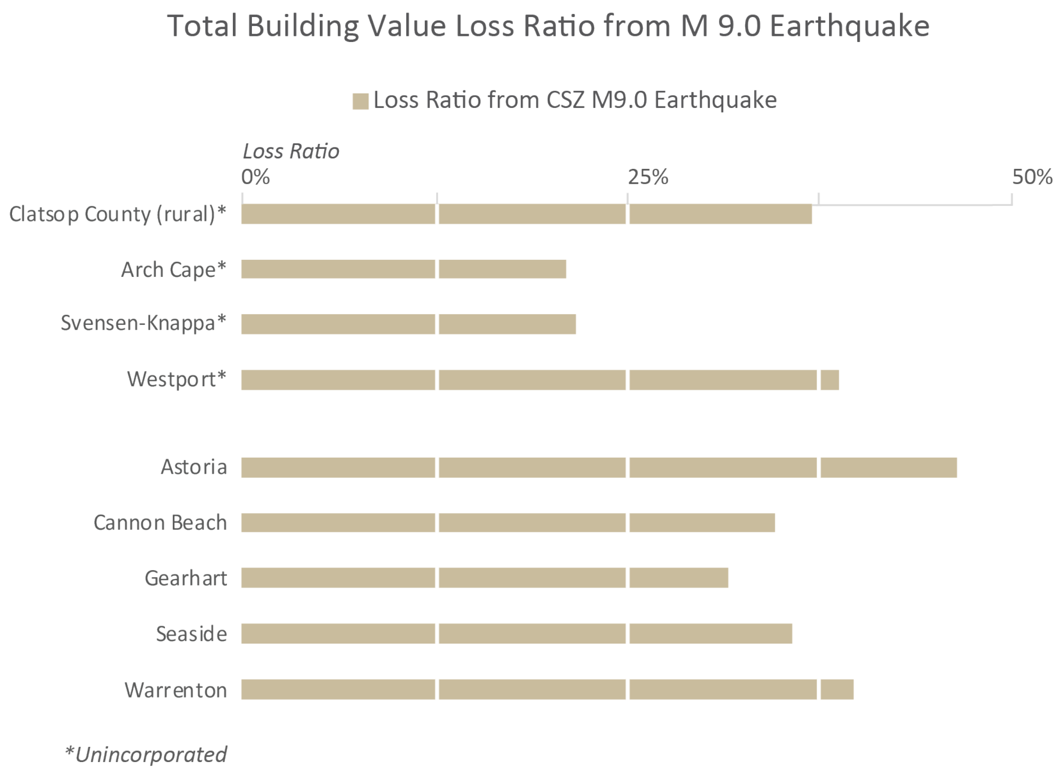
The following hazard layers used for our loss estimation are derived from work conducted by Madin and Burns (2013): National Earthquake Hazard Reduction Program (NEHRP) soil classification, peak ground acceleration (PGA), peak ground velocity (PGV), spectral acceleration at 1.0 second period and 0.3 second period (SA10 and SA03), and liquefaction susceptibility. We also used landslide susceptibility data derived from the work of Burns and others (2016). The liquefaction and landslide susceptibility layers together with PGA were used by the Hazus-MH tool to calculate permanent ground deformation and associated probability.

While the loss estimates and exposure results of the earthquake and tsunami presented in this report describe a singular CSZ scenario, the hazard data used in these analyses are the product of different sources that equate to a slightly different event magnitude. The Medium-sized tsunami scenario was modeled with a CSZ M8.9 earthquake (Priest and others, 2013). The earthquake bedrock ground motions from a M9.0 CSZ earthquake were produced by Arthur Frankel of the USGS (written communication, 2012) and then modified to include site class soil factors (Madin and Burns, 2013). While the tsunami scenario is associated with a specific amount of slip needed to generate a tsunami, the earthquake model is independent of slip with the earthquake energy distributed over the rupture zone. Irrespective of these differences, the two scenarios are comparable and are used in this report.

3.2.2 Countywide results

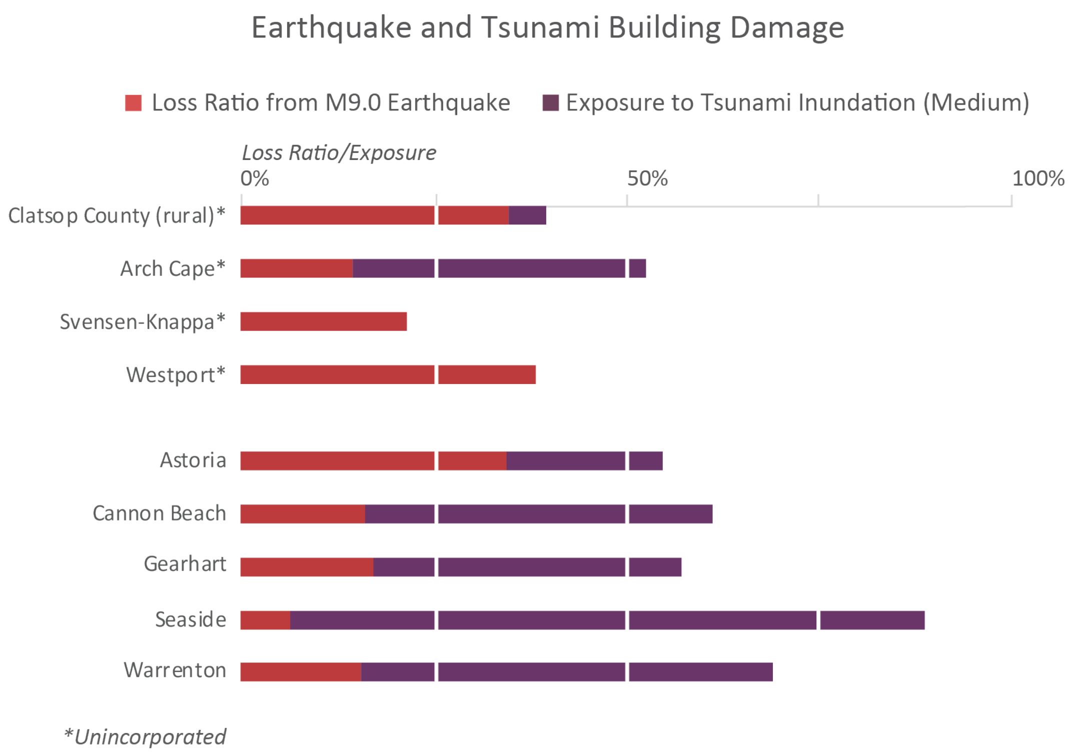
The CSZ event will produce severe ground shaking and ground failure, as well as a large and swiftly moving tsunami (Madin and Burns, 2013). Due to the nearly simultaneous timing of these two natural hazards, we have parsed loss estimate results to avoid double counting. That is, buildings within the (Medium-sized) tsunami zone are reported on the basis of exposure only, while buildings outside the tsunami zone are reported on the basis of Hazus-MH earthquake loss estimates. We assumed that tsunami losses to buildings are complete within the inundation area. Tsunami results are provided in the subsequent tsunami section. **Figure 3-1** shows the loss estimates by community for Clatsop County from a CSZ M9.0 event without the effects from tsunami.

Figure 3-1. Earthquake loss ratio by Clatsop County community.



Because an earthquake can affect a wide area, it is unlike other hazards in this report—every building in Clatsop County, to some degree, will be affected by a CSZ M9.0 earthquake (see Appendix E, **Plate 3**). Hazus-MH loss estimates (see **Table B-2**) for each building are based on a formula in which 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). Loss estimates reported for earthquake are for buildings *outside* the (Medium-sized) tsunami inundation zone. **Figure 3-2** shows loss ratios from the CSZ event (both tsunami and earthquake) for the communities of Clatsop County.

Figure 3-2. Loss ratio in Clatsop County, for both CSZ M9.0 earthquake and tsunami inundation.



Note: Due to the nearly simultaneous timing of a Cascadia subduction zone earthquake and tsunami, loss estimate results have been parsed to avoid double counting. That is, buildings within the (Medium-sized) tsunami zone are reported on the basis of exposure only, while buildings outside the tsunami zone are reported on the basis of Hazus-MH earthquake loss estimates. Tsunami losses to buildings are assumed to be complete within the inundation area.

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, 2015). Red-tagged buildings correspond to a Hazus-MH damage state of “complete,” which means the building is uninhabitable. Yellow-tagged buildings are in the “extensive” damage state, indicating limited habitability. The number of 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 reported for non-functioning critical facilities is only for buildings outside the (Medium-sized) tsunami inundation zone.

The number of potentially displaced residents from the CSZ M9.0 earthquake is based on the number of red-tagged and a percentage of yellow-tagged residences that were determined in the Hazus-MH earthquake analysis results. The number reported for potentially displaced residents is only for residences outside the (Medium-sized) tsunami inundation zone.

Clatsop countywide CSZ M9.0 earthquake results (not including buildings or population within the Medium-sized tsunami zone):

- Number of red-tagged buildings: 5,045
- Number of yellow-tagged buildings: 1,314
- Loss estimate: $1,190,540,000
- Loss ratio: 24%
- Non-functioning critical facilities: 36
- Potentially displaced population: 7,029

The results indicate that the study area would incur significant losses (24%) due to a CSZ M9.0 earthquake. These results are strongly influenced by the overall average age of the building stock. This shows us that the age of the building stock is one metric of earthquake vulnerability for a community. Seismic building codes were implemented in Oregon in the 1970s (Judson, 2012); nearly 75% of buildings in Clatsop County were built before modern seismic building code enforcement (**Table C-2**). Communities within Clatsop County that are composed of older building stock are expected to experience more damage from earthquake than are communities with newer buildings.

Moderate to high liquefaction zones exist throughout the county and in the densest populated areas, which increases the risk from earthquake. Liquefaction could also present difficulties for evacuation from the subsequent tsunami, because liquefaction areas correspond closely with the most likely tsunami inundation zone (Priest and others, 2013). This factor, along with overall age of the building stock and the proximity of Clatsop County to the Cascadia subduction zone, results in high levels of damage.

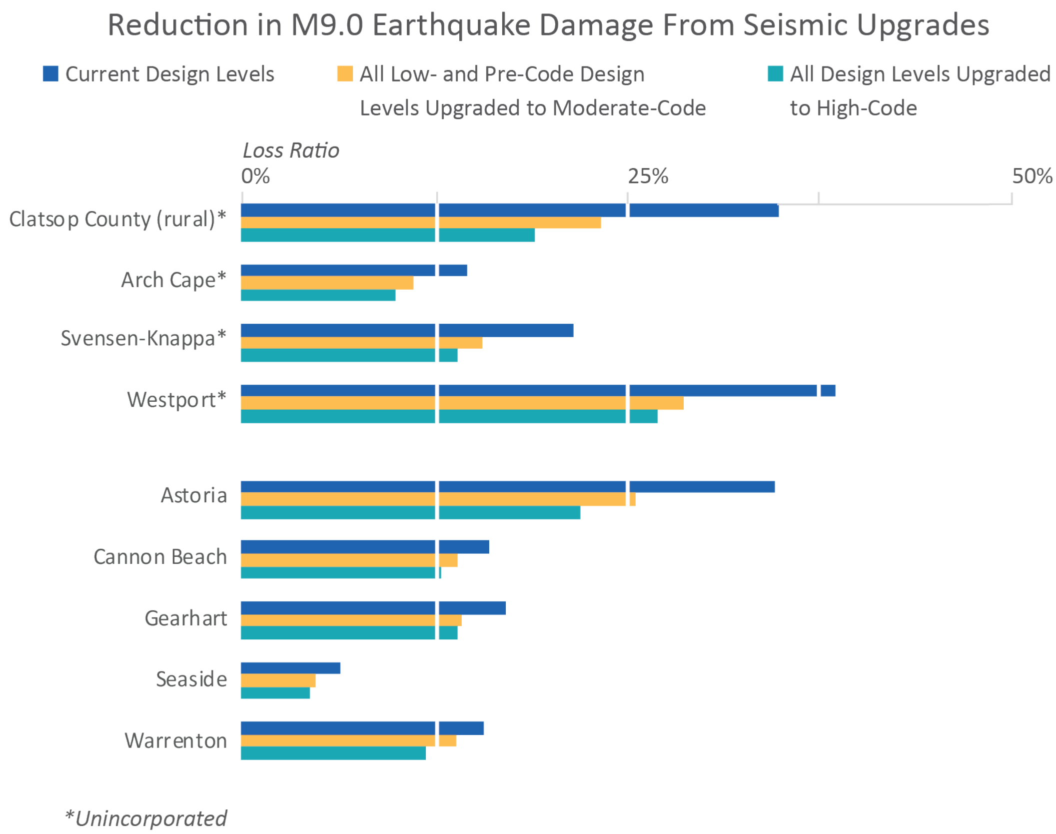
Although damage caused by coseismic landslides was not specifically looked at in this report, it likely contributes a significant amount of the estimated damage from the earthquake hazard in Clatsop County. Landslide exposure results show that 24% of buildings in Clatsop County are within a very high or high susceptibility zone. This indicates that a similar percentage of buildings would be damaged primarily from coseismic landslide rather than from earthquake shaking alone.

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 24% to 17%, when all buildings are upgraded to at least moderate code level (**Table B-2**). While retrofits can decrease earthquake vulnerability, for areas of high landslide or liquefaction, additional geotechnical mitigation may be necessary to have an effect on losses. **Figure 3-3** illustrates the reduction in loss estimates from a CSZ M9.0 earthquake through two simulations in which all buildings are upgraded to moderate code standards or to high code standards. Communities that are mostly within the tsunami hazard zone may need additional tsunami mitigation to reduce vulnerability.

Key Terms:

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

Figure 3-3. CSZ M9.0 earthquake loss ratio in Clatsop County, with simulated seismic building code upgrades.



Note: Loss estimates shown are for buildings outside the tsunami zone only and are reported on the basis of Hazus-MH earthquake loss estimates. Tsunami losses to buildings are assumed to be complete within the inundation area.

3.2.3 Areas of vulnerability or risk

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

- Very high liquefaction soils are found throughout most of the populated coastal portions of Clatsop County, which include the communities of Cannon Beach, Gearhart, Seaside, and within the low-lying areas around the City of Warrenton.
- Building inventory for the City of Astoria is relatively older than other communities in Clatsop County, which implies lower seismic building design codes and thus more vulnerable to earthquake damage. When tsunami damages are disregarded, Astoria's estimated loss ratio from a CSZ earthquake alone is 46% compared to 20%–39% for the other communities in the county.
- 12 (36 when including areas of tsunami inundation) of the 45 critical facilities in the incorporated communities of Clatsop County could be non-functioning due to a CSZ earthquake.
- Because of the liquefaction and landslides, these communities could become disconnected from other communities by severed transportation routes.

> ***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.

3.3 Cascadia Subduction Zone Tsunami

Tsunamis are a natural hazard threat that exists for many of the communities along the Oregon coast. The tsunami addressed in this report is caused by the abrupt change in the seafloor accompanying an earthquake. In a megathrust earthquake, like the CSZ event, the sudden uplift of seafloor is converted into wave energy (Priest and others, 2013). While not included in this report, other important processes that may trigger a tsunami include landslides that start below the water surface and landslides that enter a deep body of water from above the water surface (Witter and others, 2011). Tsunamis can travel thousands of miles across oceans, so that a particular coastal area may be susceptible to two different types of tsunami hazard (Priest and others, 2013):

- Tsunamis caused by distant sources and that travel across the ocean basin, and
- Tsunamis caused by local sources such as the CSZ and that occur immediately adjacent to a coast.

During a CSZ earthquake, the sudden uplift of a portion of the North American plate along the CSZ margin is likely to produce a tsunami that will have an impact along the Oregon coast. This locally generated tsunami poses a significant risk to low-lying coastal and estuarine developed areas in Clatsop County due to the limited warning time of an approaching tsunami. Tsunami inundation zone maps created by DOGAMI can serve as a tool for planning and mitigation efforts. We chose the "Medium" tsunami scenario shown on these maps to report the results of our analysis, because, according to Priest and others (2013), the Medium scenario tsunami is the most likely to occur from a CSZ event.

3.3.1 Data sources

The tsunami hazard data used in this report are from Priest and others (2013). Priest and others modeled areas of expected inundation from five local (CSZ) tsunami scenarios and two distant source scenarios and created a series of inundation maps. The distant source tsunami scenarios were not used in this report. The local tsunami scenarios used in this report for exposure analysis were CSZ "t-shirt" sizes of Small (Sm), Medium (M), Large (L), Extra Large (XL), and Extra Extra Large (XXL).

The slip deficit time intervals for each local source tsunami scenario is as follows (Priest and others, 2013):

- XXL 1,200 years
- XL 1,050–1,200 years
- L 650–800 years
- M 425–525 years
- Sm 300 years

The estimated recurrence rates are from Witter and others (2013) and are:

- XXL = unknown (not seen in 10,000 year record)
- XL = <1/10,000 = <0.01%
- L = 1/3,333 = 0.03%
- M = 1/1,000 = 0.1%
- Sm = 1/2,000 = 0.05%

For this risk assessment, DOGAMI compared the locations of buildings and critical facilities to the geographic extent of the local source tsunami inundation zones to assess the exposure for each community. The exposure results shown below are for the Medium scenario only (see **Table B-3** for all scenarios). 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 at risk to tsunami hazard. See **Appendix B: Detailed Risk Assessment Tables** for cumulative multi-scenario analysis results.

3.3.2 Countywide results

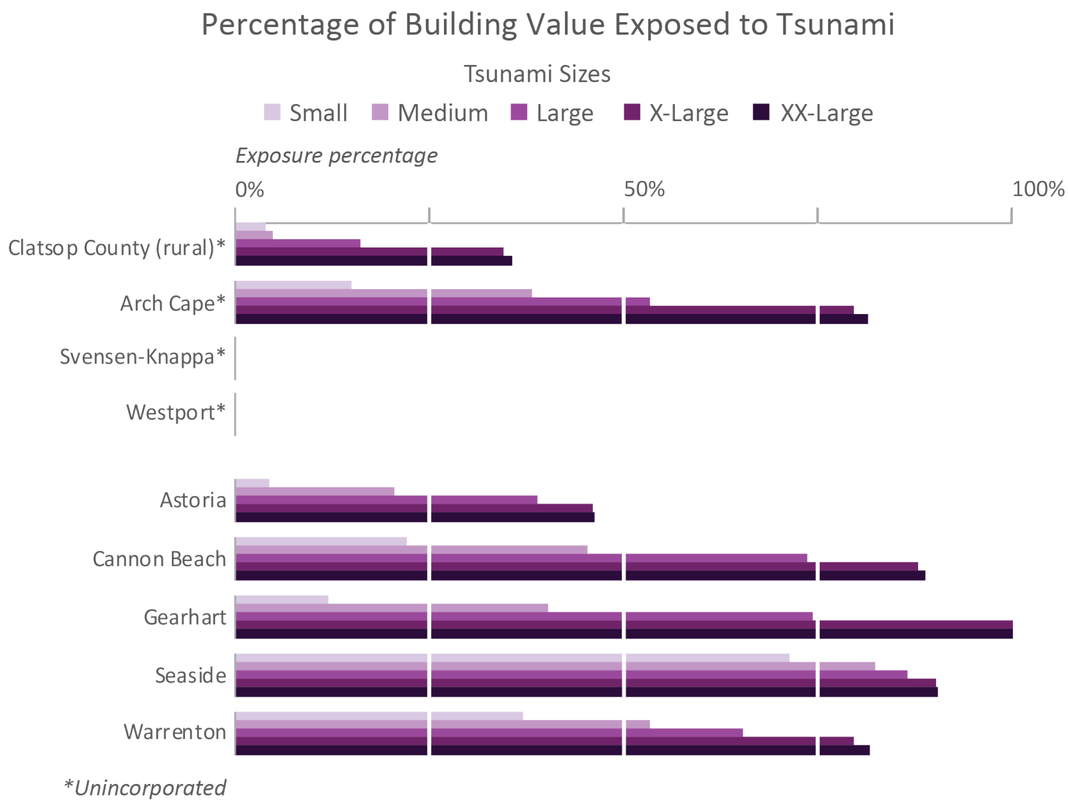
Because every community in this study is relatively near the Pacific Ocean or the Columbia River estuary, nearly all communities would be affected by the largest (XXL) of the DOGAMI calculated tsunami scenarios. However, the Medium-sized tsunami was chosen as the primary scenario for this report because that category represents areas that have the highest potential for losses. All communities built along the open coast, bays, and estuaries will be impacted from a tsunami.

Clatsop countywide CSZ tsunami exposure (Medium-sized tsunami scenario):

- Number of buildings exposed: 8,810
- Exposure value: $1,705,987,000
- Percentage of exposure value: 34%
- Critical facilities exposed: 32
- Potentially displaced population: 11,333

The combination of earthquake and tsunami will have a significant impact to the entire coastal and estuarine portions of rural Clatsop County. Low-lying areas within coastal and estuarine communities are predicted to be inundated by the Medium-sized tsunami scenario. Approximately a third of the county's buildings have exposure to tsunami inundation from the Medium-sized scenario (**Figure 3-4**). In some communities a very high percentage (50% to 80%) of buildings are exposed to tsunami hazard. Over 11,000 permanent residents could be impacted from a CSZ tsunami event and require medical and shelter services. Because there is high risk of tsunami along the entire coast and estuarine areas of Clatsop County, awareness is important for the emergency response immediately after the event and for future planning and mitigation efforts in these areas.

Figure 3-4. Tsunami inundation exposure by Clatsop County community.



3.3.3 Areas of vulnerability or risk

We identified locations within the study area that are comparatively more vulnerable or at greater risk to CSZ generated Medium-sized tsunami hazard:

- A very high percentage (40% to 80%) of developments all along the Pacific coast of Clatsop County is exposed to the Medium-sized scenario tsunami.
- In some of the larger scenarios, 80% to 100% of Arch Cape, Cannon Beach, Gearhart, Seaside, and Warrenton would be inundated by a tsunami.
- Nearly all of the critical facilities in the communities of Cannon Beach, Gearhart, Seaside, and Warrenton could be non-functioning due to a Medium-sized scenario tsunami.

3.4 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 Clatsop County and have the potential to create public health hazards and public safety concerns, close and damage major highways, destroy railways, damage structures, and cause major economic disruption. 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 scenarios, respectively.

Many large rivers in Clatsop County drain into either the Pacific Ocean or the Columbia River, which defines the county's northern boundary. The major rivers within the county are the Lewis and Clark, Necanicum, Nehalem, North Fork Nehalem, Skipanon, John Day, Wallooskee, and Youngs. All the listed rivers are subject to flooding and can cause damage to buildings within the floodplain. Other flooding effects are due to coastal flooding from the Pacific Ocean for low-lying coastal developments and within Clatsop County's estuaries.

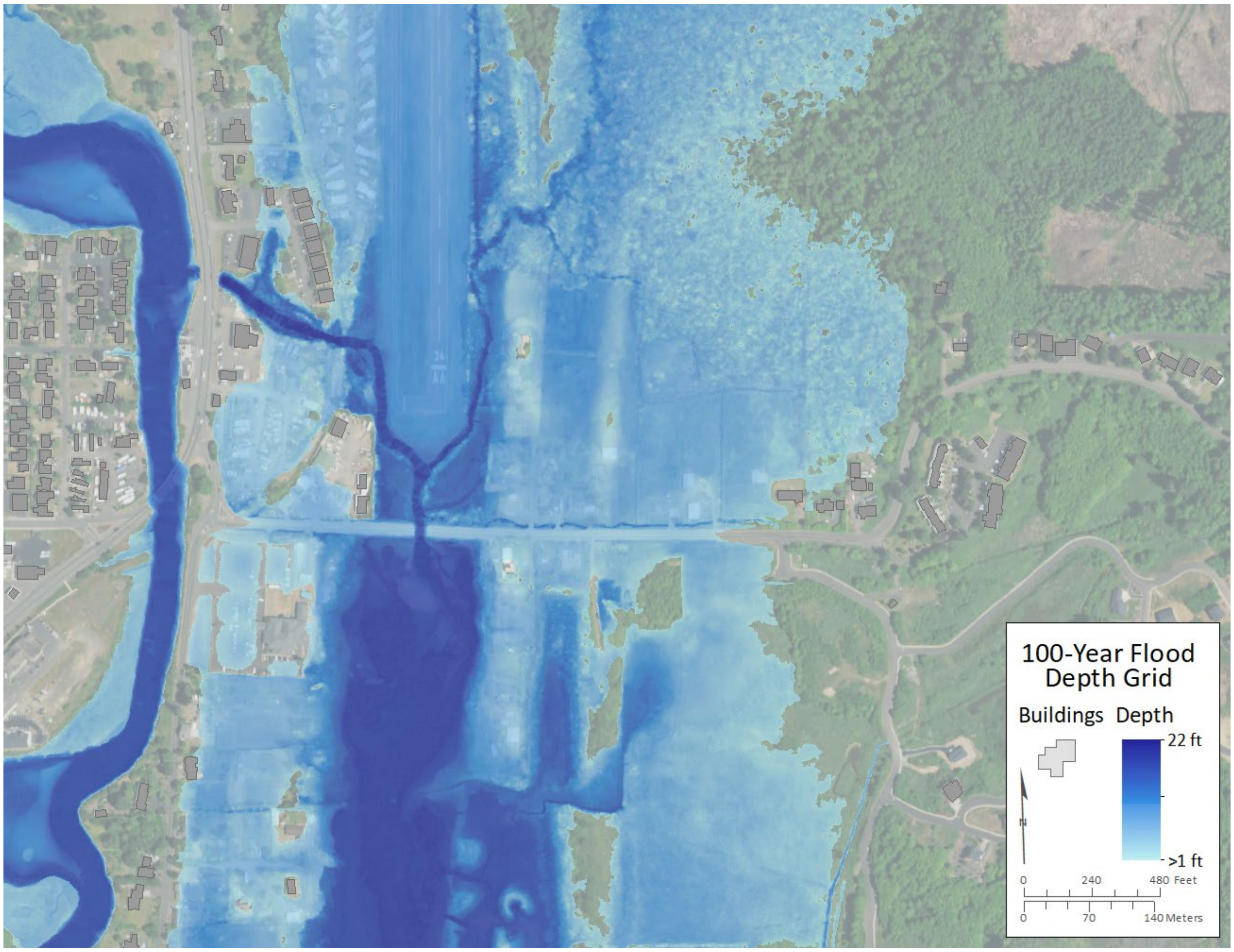
The ability to assess the probability of a flood and the level of accuracy of that assessment are influenced by modeling methodology advancements, better knowledge, and longer periods of record for the stream or water body in question. The impacts of flooding are determined by adverse effects to human 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 looked at in this report.

3.4.1 Data sources

The Flood Insurance Study (FIS) and Flood Insurance Rate Maps (FIRMs) for Clatsop County were updated in 2018 (FEMA, 2018) and included a recently completed study of coastal flooding for the open coast (Allan and others, 2015); these were the primary data sources for the flood risk assessment in this report. At the time of writing coastal flood modeling of the Columbia River for areas in and around the City of Warrenton were not adopted for effective flood maps. Final flood maps for this area are anticipated to be completed by 2020 or 2021. The flood mapping used in the analysis for this report includes the initial (not adopted) mapping and is considered the best available data at the time of writing. The areas in and around the City of Warrenton are subject to change as FEMA continues to evaluate alternatives in coordination with local stakeholders. Further information regarding the National Flood Insurance Program (NFIP) can be found on the FEMA website: https://www.fema.gov/flood-insurance. These were the only flood data sources that DOGAMI used in the analysis, but flooding does occur in areas outside of the mapped areas on the FIRMs.

Depth grids, developed by DOGAMI in 2015 to revise the Clatsop County FIRMs, were used in this risk assessment to determine the level to which buildings are impacted by flooding. Depth grids are raster GIS datasets in which each digital pixel value represents the depth of flooding at that location within the flood zone (**Figure 3-5**). Though considered draft at the time of this analysis, the depth grid data are the best available flood hazard data. Depth grids for four flooding scenarios (10-, 50-, 100-, and 500-year) were used for loss estimations and, for comparative purposes, exposure analysis. The 100-year depth grid included coastal flood modeling that was not available for the other scenarios.

Figure 3-5. Flood depth grid example, portion of the City of Seaside.



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 Clatsop County, occupancy type and basement presence attributes were available from the assessor database for most buildings. Where individual building information was not available from assessor data, we used oblique imagery and street level imagery to estimate these important building attributes. Only buildings in a flood zone or within 500 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 the 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.

3.4.2 Countywide results

For this risk assessment, we imported the countywide UDF data and depth grids into Hazus-MH and ran a flood analysis for each of the four flood scenarios (10-, 50-, 100-, and 500-year). We used the 100-year flood scenario as the primary scenario for reporting flood results (also see Appendix E. **Plate 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.

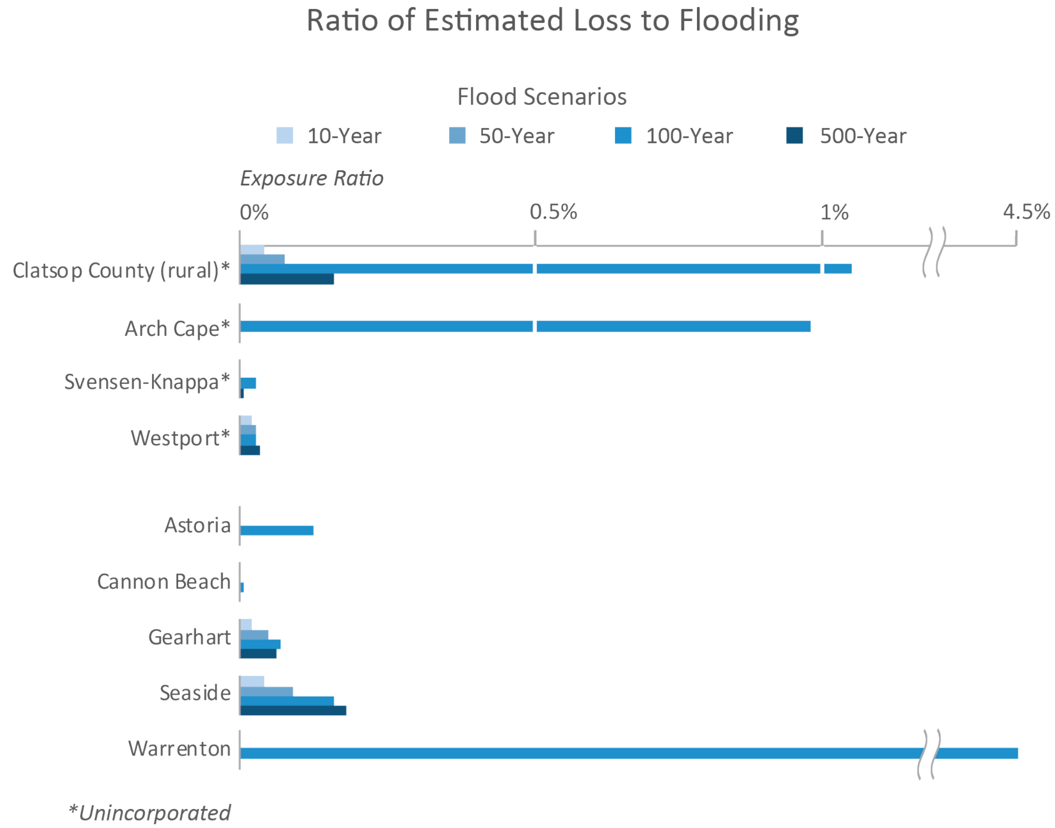
Clatsop countywide 100-year flood loss:

- Number of buildings damaged: 2,529
- Loss estimate: $40,951,000
- Loss ratio: 0.8%
- Damaged critical facilities: 14
- Potentially displaced population: 4,498

3.4.3 Hazus-MH analysis

The Hazus-MH loss estimate for the 100-year flood scenario for the entire county is approximately $41 million. Both riverine and coastal flooding have a significant impact on Clatsop County, especially within the floodplain and in low-lying coastal areas (**Figure 3-6**). In situations with communities where most residents are not within flood designated zones, the loss ratio may not be as helpful as the actual replacement cost and number of residents displaced to assess the level of risk from flooding. The Hazus-MH analysis also provides useful flood data on individual communities so that planners can identify problems and consider which mitigating activities would provide the greatest resilience to flooding.

Figure 3-6. Flood loss estimates by Clatsop County community.



Note: In addition to the four riverine flood scenarios, coastal flooding information is available for the 100-year flood scenario for portions of Clatsop County (rural) and the communities of Arch Cape, Astoria, Cannon Beach, Gearhart, Seaside, and Warrenton.

3.4.4 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 counted 3,011 of Clatsop County's buildings to be within designated flood zones, which was about 12% of the county's buildings. Of these buildings, 482 buildings were elevated above the height of the 100-year flood. This was done by comparing the number of non-damaged buildings from Hazus-MH with the number of exposed buildings in the flood zone. Elevating more of these exposed structures would further reduce the potential damages sustained from flooding. This evaluation also estimates that 4,498 residents might have mobility or access issues due to surrounding water. See appendix **Table B-5** for community-based results of flood exposure.

3.4.5 Areas of vulnerability or risk

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

- Flood exposure to 1,070 buildings and over $20 million in potential losses from a 100-year flood is estimated to be within the leveed areas in Warrenton.

- The developed area between Astoria and Warrenton along Youngs Bay is subject to 100-year flooding. Many buildings in this area are estimated to be damaged from this type of flood.
- From best available data, which is subject to change, the downtown portion of Warrenton is vulnerable to flooding, and only a small percentage of buildings are elevated above the estimated level of flooding.

3.5 Landslide Susceptibility

Landslides are mass movements of rock, debris, or soil most commonly downhill. There are many different types of landslides in Oregon. In Clatsop County, 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, landslides 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).

3.5.1 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 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. Most of the landslide inventory mapping for Clatsop County was done in the early 1970s. Modern methodology and lidar-based elevation data were used to map areas in and around the City of Astoria, as well as the unincorporated community of Westport in the 2012, and mapping near the communities of Cannon Beach and Arch Cape along the coastline was done in 2009.

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.

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. Neither land value losses due to landslides nor potentially hazardous unmapped areas that may pose real risk to communities were examined for this report.

3.5.2 Countywide results

Many Clatsop County 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 Coast Range trends through eastern and central Clatsop County, so much of the area is steep and landslide prone. The combination of rugged terrain, historically active landslides, large amounts of rainfall, and a seismically active region make landslides a serious threat.

We combined high and very high susceptibility zones 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 zones to accurately depict the level of landslide risk to communities. The high and very high susceptibility zones represent areas most prone to landslides and with the highest impact to the community.

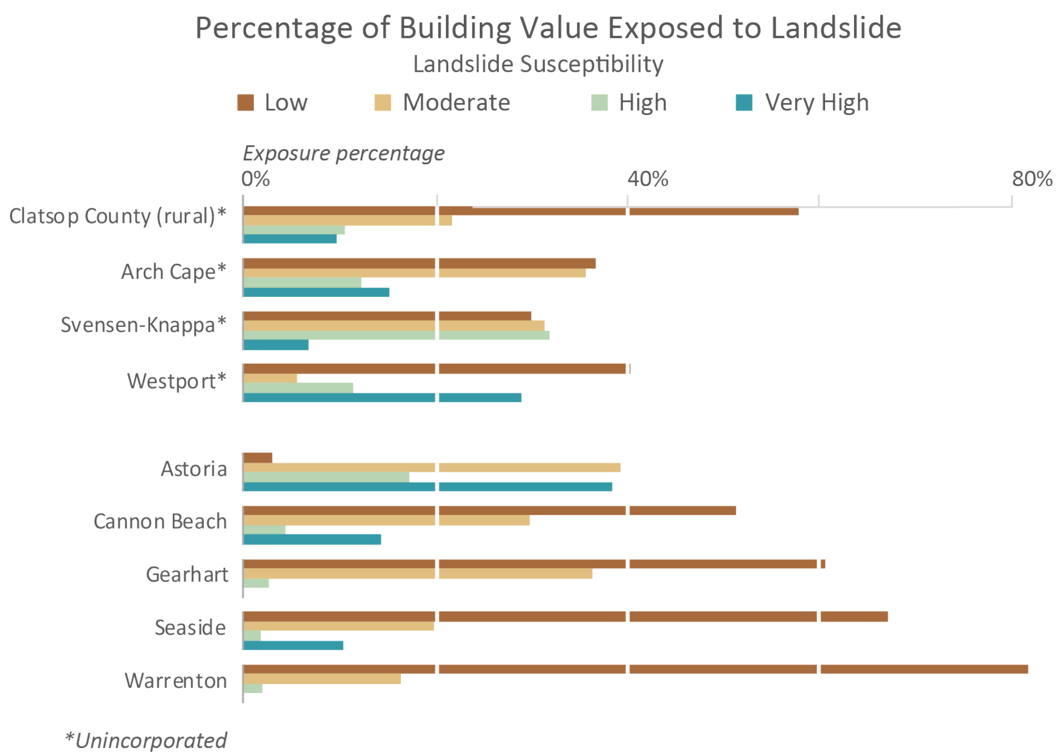
For this risk assessment we compared building locations to geographic extents of landslide susceptibility zones (**Figure 3-7**). Exposure results shown below are for high and very high susceptibility zones. See **Appendix B: Detailed Risk Assessment Tables** for multi-scenario analysis results.

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

- Number of buildings: 7,335
- Exposure value: $1,203,216,000
- Percentage of exposure value: 24%
- Critical facilities exposed: 23
- Potentially displaced population: 12,145

The northern coastal plains and within the wide floodplains of the Columbia River watershed are much less susceptible to landslide hazard than the rest of the county. Approximately a quarter of the county's buildings have exposure to high or very high susceptibility to landslides. Landslide hazard is ubiquitous in a large percentage of undeveloped land and may present challenges for 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 Clatsop County.

Figure 3-7. Landslide susceptibility exposure by Clatsop County community.



3.5.3 Areas of vulnerability or risk

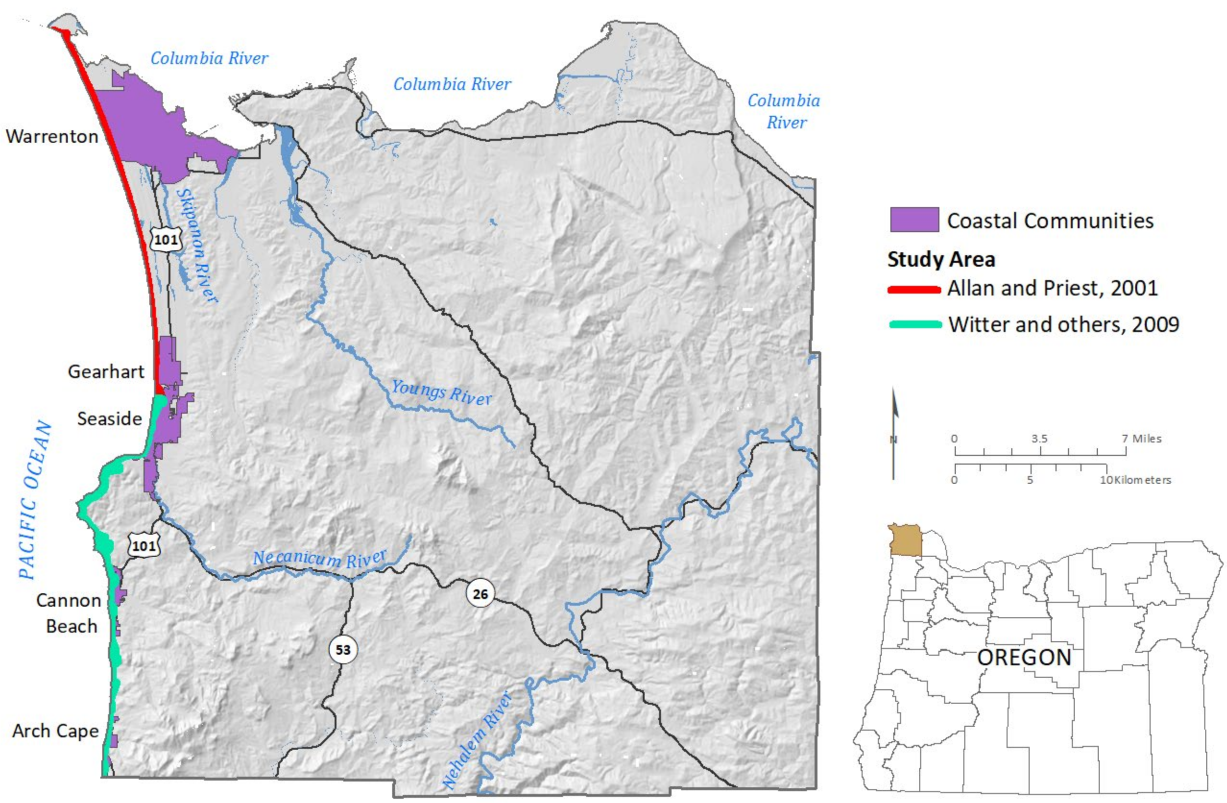
We identified locations within the study area that are comparatively more vulnerable or at greater risk to landslide hazard:

- The landslide hazard for Astoria poses the biggest natural hazard risk to the community. Over half of the community is within areas mapped either very high or high susceptibility to landslide hazard.
- The steep coastal terrain of Cannon Beach and Arch Cape has developed areas considered very high and high susceptibility to landslide hazard.

3.6 Coastal Erosion

Erosion along the coast is a continuous process that occurs through a complex interaction of many geologic, atmospheric, and oceanic factors (including sea level rise). Beaches and dunes are highly susceptible to erosion, especially during large storms coupled with high ocean water levels. Coastal erosion is increasingly affecting people due to development near the beach or coastal bluffs. Typically, shoreline stabilization efforts using riprap are not an effective long-term mitigation (Stimely and Allan, 2014). Whether it is a gradual process or in the form of landslides, coastal erosion can cause loss of property. **Figure 3-8** shows the sections of coastline studied in two reports by Allan and Priest (2001) and by Witter and others (2009) that may be subject to coastal erosion in Clatsop County.

Figure 3-8. Allan and Priest (2001) and Witter and others (2009) coastal erosion study areas extent.



3.6.1 Data sources

Two data sources were used in this report to calculate exposure to coastal erosion. In the southern coastal portion of Clatsop County, the Witter and others (2009) study extends from Seaside in the north to Arch Cape in the south. In the northern coastal portion of Clatsop County, the Allan and Priest (2001) study extends from the mouth of the Columbia River in the north to Gearhart in the south. The hazard zones in the Witter and others (2009) study were combined with the hazard zones from the Allan and Priest (2001) study to comprise the coastal erosion hazard zones for the entire Clatsop County coast.

In the Witter and others (2009) study, the coastal erosion hazard zones were determined using two approaches: measuring the change due to erosional processes on dune-backed beaches and bluff-backed shorelines. The final derived hazard zones reflect the combined effect of both sets of processes. For this study, we based the coastal erosion hazard zones as defined by Witter and others (2009) to indicate levels of probability as high, moderate, and low.

The high hazard zone for dune-backed beaches was based on a large storm wave event coincident with a 3.3 ft (1 m) storm surge. The high hazard zone for bluff-backed shorelines was based on only a relatively low mean rate of gradual erosion. The "active hazard zone" defined within the study was also included into the high hazard zone. The moderate hazard zone for dune-backed beaches was based on an extremely severe storm event coupled with a 5.6 ft (1.7 m) storm surge. The same zone for bluff-backed shorelines was based on an average amount of bluff retreat. The low hazard zone for dune-backed beaches was based on the same scenario as the moderate hazard and also incorporated 6.2 ft (1.9 m) of coastal subsidence from a CSZ event. The low hazard for bluff-backed shorelines was based on a maximum bluff slope failure and gradual bluff retreat for ~100 years (Witter and others, 2009).

In the Allan and Priest (2001) study, the coastal erosion hazard zones were determined for dune-backed beaches. The methods used by Allan and Priest (2001) to define hazard zones for dune-backed beaches were the same used in the Witter and others (2009) study. For this study, we based the coastal erosion hazard zones as defined by Allan and Priest (2001) to indicate levels of probability as high, moderate, and low.

We overlaid buildings and critical facilities on the coastal erosion hazard zones to assess the exposure for each community. The total dollar value of exposed buildings the study area is reported below. We also estimated the number of people threatened by coastal erosion. Land value losses due to coastal erosion were not examined for this project.

3.6.2 Countywide results

Coastal erosion, for obvious reasons, affects only communities and areas along the open coast of Clatsop County. Coastal communities in Clatsop County all have some level of exposure to coastal erosion. The steep nature of the dunes and bluffs adjacent to the ocean offers dramatic scenery but also contributes to coastal erosion hazards.

The moderate hazard category (5.6 ft [1.7 m] storm surge) was chosen as the primary scenario for this report because it fits best for long-term planning purposes: The moderate hazard zone represents an area of a reasonable level of probability with a high level of impact to a community.

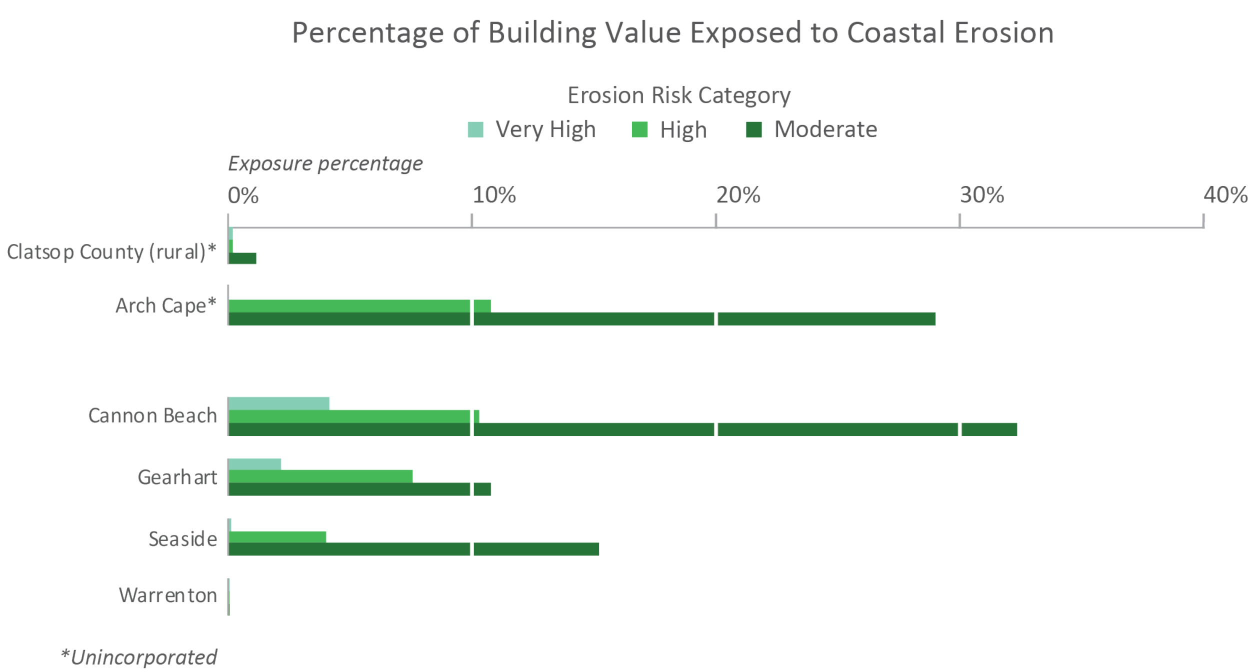
For this risk assessment, we limited the results of the exposure analysis to the communities included in the reports by Witter and others (2009) and Allan and Priest (2001), which are those communities along the Pacific Coast of Clatsop County. The "percentage of exposure value" is the percentage of exposed building value relative to the total building value of the communities within the study areas. We did not include building value from communities outside the study areas in this calculation. See **Appendix B: Detailed Risk Assessment Tables** for multi-scenario analysis results.

Clatsop County coastal communities coastal erosion exposure (Moderate hazard):

- Number of buildings: 349
- Exposure value: $135,900,000
- Percentage of exposure value: 3.6%
- Critical facilities exposed: 0
- Potentially displaced population: 104

The coastal communities of Arch Cape, Cannon Beach, and Gearhart have a moderate level of exposure to coastal erosion hazard. Approximately 10% of the total building value for each of these communities is exposed to moderate coastal erosion hazard. Awareness of this hazard is beneficial for reducing risk for future developments along Clatsop County's coastline. Long-term community plans that make allowance for coastal erosion encourage more resilience within the community. **Figure 3-9** illustrates the distribution of losses due to coastal erosion with the different communities of Clatsop County.

Figure 3-9. Coastal erosion exposure by Clatsop County community.



Note: Beyond the designated communities, in unincorporated Clatsop County, building values total $2.5 million in areas of high coastal erosion hazard, $2.6 million in areas of moderate hazard, and $16 million in areas of low hazard.

3.6.3 Areas of vulnerability or risk

We identified these areas that are estimated to have significant levels of vulnerability or risk to coastal erosion hazard:

- Developed areas in Gearhart, adjacent to Gearhart Ocean State Park, and in Seaside, south of the Necanicum River mouth, are at risk to moderate coastal erosion hazard.
- Large sections of Cannon Beach, south of the Ecola Creek mouth, near Haystack Rock, and residential structures at the very southern end of the city are at risk to high coastal erosion hazard.
- Beachfront residential buildings in Arch Cape are exposed to coastal erosion hazard.

3.7 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 communities often grow in the transition areas between developed areas and undeveloped areas, commonly called 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 commonly include flooding, debris flows, and landslides. Post-wildfire geologic hazards were not evaluated in this project.

As discussed in the 2011 Clatsop County community wildfire protection plan (CCCWPP) there is potential for losses due to WUI fires in Clatsop County. Forests cover approximately 90% of Clatsop County. Forests play an important role in the local economy but also surround homes and businesses (CCCWPP, 2011). In an effort to mitigate wildfire risk, Clatsop County's Comprehensive Plan provides guidance on reducing risk to wildfire. Contact Clatsop County Department of Community Development for specific requirements related to the county's comprehensive plan.

3.7.1 Data sources

The West Wide Wildfire Risk Assessment (WWA; Sanborn Map Company, Inc., 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 Clatsop County.

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 wildfire hazard zones to determine exposure. In certain areas no wildfire data are present; this indicates areas that have minimal risk to wildfire hazard (see **Table B-8**). The total dollar value of exposed buildings the study area is reported below. We also estimated the number of people threatened by wildfire. Land value losses due to wildfire were not examined for this project.

3.7.2 Countywide results

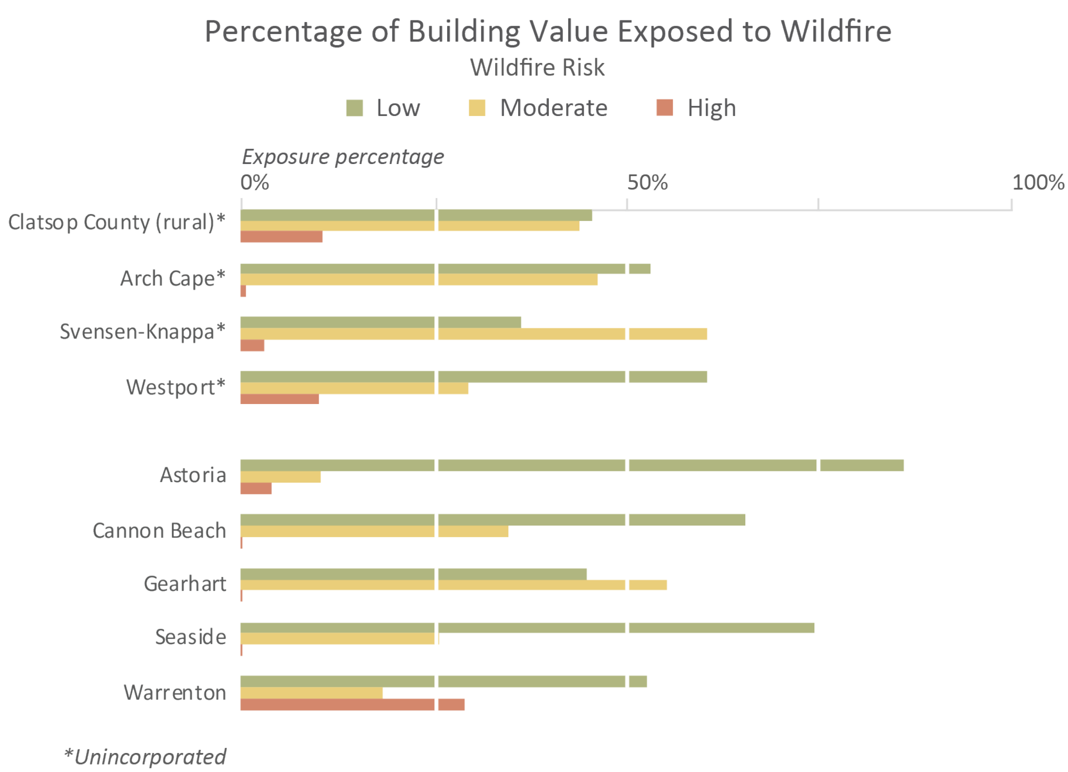
The high hazard category was chosen as the primary scenario for this report because that category represents areas that have the highest potential for losses. However, a large amount of loss would occur if the moderate hazard areas were to burn, as almost every community has ~40% to 60% exposure to moderate wildfire hazard. Still, the focus of this section is on high hazard areas within Clatsop County to emphasize the areas where lives and property are most threatened.

Clatsop countywide wildfire exposure (High hazard):

- Number of buildings: 2,467
- Exposure value: $340,091,000
- Percentage of exposure value: 6.8%
- Critical facilities exposed: 9
- Potentially displaced population: 3,466

For this risk assessment, building locations were compared to the geographic extent of the wildfire risk categories. Some of the communities in Clatsop County are exposed to wildfire hazard. The primary areas of exposure to this hazard are in the forested areas within and around the City of Warrenton, the Youngs Bay estuary area, and the unincorporated county along the Columbia River (see Appendix E, **Plate 7**). The communities of Warrenton, Westport, and to a certain degree Astoria and Svensen-Knappa are at a higher risk to wildfire than other communities in the county. **Figure 3-10** illustrates the distribution of losses due to wildfire with the different communities of Clatsop County. See **Appendix B: Detailed Risk Assessment Tables** for multi-scenario analysis results.

Figure 3-10. Wildfire hazard exposure by Clatsop County community.



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 wildfire hazard:

- Wildfire risk is high for hundreds of homes in the low-lying forested areas in the unincorporated county along the Columbia River. This area also includes the communities of Warrenton, Westport, and to a lesser extent Astoria and Svensen-Knappa.

4.0 CONCLUSIONS

The purpose of this study is to provide a better understanding of potential impacts from multiple natural hazards at the community scale. We accomplished this by using the 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 county's risk reduction efforts. We note several important findings based on the results of this study:

1. **Extensive overall damage and loses are expected from a Cascadia M9.0 earthquake and tsunami –** Due to its proximity to the CSZ, every community in Clatsop County will experience significant impact and disruption from a CSZ M9.0 earthquake event. We limited our analysis to the impacts of an earthquake (including liquefaction and coseismic landslides) and a tsunami. Results show that a CSZ M9.0 event will cause approximately 40% to 70% in building value losses across all communities. Within each community along the Pacific Coast (Arch Cape, Cannon Beach, Gearhart, Seaside, and Warrenton), a very high proportion of these losses would be due to tsunami. Other communities, such as the community of Westport, have little to no tsunami exposure but will have high losses from earthquake alone. The high loss levels estimated in the study area are due to the highly vulnerable building inventory (primarily because of the age of construction), the proximity to the CSZ event, and the amount of development within tsunami zones.
2. **Retrofitting buildings to modern seismic building codes can reduce damages and losses from earthquake –** Seismic building codes have a major influence on earthquake shaking damage estimated by Hazus-MH, a software tool developed by FEMA for calculating loss from natural hazards. We examined potential loss reduction from seismic retrofits (modifications that improve building's seismic resilience) in simulations by using Hazus-MH building code "design level" attributes of pre, low, moderate, and high codes (FEMA, 2012b) in CSZ earthquake scenarios. The simulations were accomplished by upgrading every pre code and low seismic code building to moderate seismic code levels in one scenario, and by 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 earthquake building value loss for the entire study area was reduced from 24% to 17%. We found further reduction to 15% in estimated loss in our simulation only by upgrading all buildings to high code. Some communities would see greater loss reduction than the study area as a whole due to older building stock constructed at pre or low code seismic building code standards. An example is the City of Astoria, which would see a significant reduction in building value loss (from 35% to 26%) by retrofitting all buildings to at least moderate code. This stands in contrast to a community with younger building stock, such as Cannon Beach, which would see a reduction in estimated loss from 16% to 14% of building value. While seismic retrofits are an effective strategy for reducing earthquake shaking damage, it should be noted that earthquake-induced tsunami, landslide, and liquefaction hazards will also be present in some areas, and these hazards require different geotechnical mitigation strategies. Future research focused on tsunami, landslide, and liquefaction hazard specific risk assessments are areas needing a clear understanding of the hazard to inform local decision-makers.
3. **Flooding is a threat for some of the communities in Clatsop County –** Most communities in Clatsop County are estimated to experience less than 1% of total building value loss from the 100-

year flood, the exception is the City of Warrenton with 4.5% of estimated loss. At first glance, Hazus-MH flood loss estimates may give a false impression of risk because they show lower 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. Another consideration is that flood is one of the most frequently occurring natural hazards. Residents and buildings located near the estuaries and coastal margins are at a greater risk from flood than other locations within the study area. The areas that are most vulnerable to flood hazard within the study are residential buildings in Seaside and south of Seaside along the Necanicum River and Neawanna Creek, buildings along Youngs Bay and Youngs River, and large portions of Warrenton (where flood mapping is subject to change).

4. **Elevating structures in the flood zone can reduce vulnerability –** Flood exposure analysis was used in addition to Hazus-MH loss estimation to identify buildings that were not damaged but that were within the area expected to experience a 100-year flood. 482 buildings within flood zones are estimated to be elevated above the level of flooding. By using both Hazus and exposure analysis 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, nearly half of the flood exposed buildings in the City of Seaside are elevated above the estimated level of flooding; more elevated structures can further reduce the estimated damages. The City of Warrenton has a high percentage (93%) of flood exposed buildings that are not elevated above the level of flooding, providing an opportunity to greatly reduce the estimated damages from a 100-year flood event.
5. **New landslide mapping would increase the accuracy of future risk assessments –** Exposure analysis was used to assess the threat from landslide hazard. Landslide is a widespread hazard and is present for some communities within the county. The communities of Arch Cape, Astoria, Cannon Beach, and Westport have very high levels of exposure to landslide hazard. Landslide hazard is a very significant risk for the City of Astoria and poses the greatest natural hazard threat to the community. The landslide hazard data for most of the areas examined in this risk assessment were created before modern mapping technology; future risk assessments using lidar-derived landslide hazard data would provide more accurate results.
6. **Exposure analysis shows that most communities along the open coast are at risk to coastal erosion hazard –** The communities of Cannon Beach and Gearhart, for example, have approximately 10% to 15% of their total building value exposed to high coastal erosion hazard. Many beachfront properties along the Pacific Coast of Clatsop County are exposed to coastal erosion.
7. **Wildfire hazard is high for areas near Warrenton, Youngs Bay, and along the Columbia River –** Exposure analysis shows that buildings in the northern part of the county along the Columbia River are at risk to wildfire hazard, especially around the City of Warrenton and along the Youngs River. However, moderate wildfire hazard is present throughout the county, especially along transportation corridors, and is a potential threat for most communities. We estimate that many communities in Clatsop County have approximately 40% to 60% of exposure to moderate wildfire hazard.
8. **Most of the study area's critical facilities are at high risk to a CSZ earthquake and tsunami –** Critical facilities were identified and were specifically examined in this report. We have estimated that 88% (69) of Clatsop County's 78 critical facilities will be non-functioning after a CSZ event, with 30 of those located within the medium tsunami zone. For comparative purposes, 29% (23)

of critical facilities are at risk to landslide, 18% (14) are exposed to flood hazard, and 11% (9) are exposed to wildfire. There is little to no exposure to critical facilities from coastal erosion.

9. **The two biggest causes of displacement to population are a CSZ event (earthquake and tsunami) and landslide –** Displacement of permanent residents from natural hazards was quantified within this report. We estimated that 49% of the population in the county would be displaced due to the combination of earthquake and tsunami. Landslide hazard is a potential threat to 33% of permanent residents, flood hazard puts 12% at risk to displacement, and 9% are exposed to wildfire hazard. A small percentage of residents are at risk to displacement due to coastal erosion.
10. **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 between risks within communities and impacts from each natural hazard. In using Hazus-MH and exposure analysis, these results can assist in developing plans that address the concerns of 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, coastal erosion, and wildfire are extremely unlikely to occur across the fully mapped extent of the hazard zones. For example, areas mapped in the 1% annual chance flood zone will be prone to flooding on occasion in certain watersheds during specific events, but not all at once throughout the entire county or even 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, which is expected to impact the entire study area, and loss estimates for this hazard 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 because it reduces the impact of data outliers.
- **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. We note the tsunami hazard as a possible exception, given the extreme and widespread damage to buildings in recent events in Japan and Sumatra.
- **Population variability** – Many coastal communities in Clatsop County are popular vacation destinations, particularly during the summer. Our estimates of potentially displaced people rely on permanent populations published in the 2010 U.S. Census (U.S. Census Bureau, 2010b). 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 assessment 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. We made certain assumptions regarding data layers to fill in data gaps for 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 require additional research.

6.0 RECOMMENDATIONS

The following areas of research are needed to better understand hazards and to reduce community risk to natural hazards 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 that 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 time for a community to recover from a disaster—this ability is commonly referred to as "resilience."

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

Messaging can be tailored to stakeholder groups. For example, outreach to homeowners could focus on actions they can take to reduce risk to their property. The DOGAMI Homeowners Guide to Landslides (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 are available for local decision-makers in developing their local plans and help identify geohazards and associated risks to the community. The primary framework for accomplishing this is through the comprehensive planning process. The comprehensive plan sets the long-term trajectory of capital improvements, zoning, and urban growth boundary expansion, all of which are planning tools that can be used to reduce natural hazard risk.

Another framework is the 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 the mitigation actions and inform the vulnerability assessment section of the NHMP plan.

While there are many similarities between this report and an NHMP, the 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 to different considerations about emergency response during and after a disaster.

6.3 Emergency Response

Critical facilities will play a major role during and immediately after a natural disaster. This study can help emergency managers identify vulnerable critical facilities and develop contingencies in their 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. At the time of writing, DOGAMI is producing a series of tsunami evacuation maps for recommended pedestrian travel speeds to reach tsunami evacuation zones. The product is called "Beat the Wave" and is available at https://www.oregongeology.org/tsuclearinghouse/beatthewave.htm.

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 structural improvements, such as connecting a building frame to its foundation. Emergency response entities can benefit from the use of the building dataset through identification of potential hazards and populated buildings before and during a disaster. Both reduction of the magnitude of the disaster and increase in the response time contribute to a community's overall resilience.

6.4 Mitigation Funding Opportunities

Several funding options are available to communities that are susceptible to natural hazards and have specific mitigation projects they wish to accomplish. State and federal funds are available for 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 writing this report, FEMA's Hazard Mitigation Assistant Grants include many programs that assist with mitigation funding for natural hazards such as the Hazard Mitigation Grant Program (HMGP), Pre-Disaster Mitigation (PDM) grant program, Building Resilient Infrastructure and Communities (BRIC) program, and the Flood Mitigation Assistance (FMA) program (https://www.fema.gov/grants/mitigation). The SHMO can help with finding further opportunities for earthquake and tsunami assistance and funding.

6.5 Hazard-Specific Risk Reduction Actions

6.5.1 CSZ M9.0 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 88% of critical facilities (**Appendix A: Community Risk Profiles**) will be damaged by the CSZ event, which will have many direct and indirect negative effects on first-response and recovery efforts.
- Identify communities and buildings that would benefit from seismic upgrades.
- Improve the mapping of liquefaction and NEHRP datasets within the county.

6.5.2 Tsunami

- Use approved guides on preparing for tsunamis (e.g., DLCD guide on preparing for the CSZ tsunami: https://www.oregon.gov/lcd/Publications/TsunamiLandUseGuide_2015.pdf).
- Evaluate the community evacuation plan, including consideration for viable vertical evacuation options.

6.5.3 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.
- Map channel migration zones along rivers identified as having moderate or high susceptibility to channel migration (Roberts and Anthony, 2017).

6.5.4 Landslide

- Create modern landslide inventory and susceptibility maps based on lidar-derived topographic data.
- Monitor ground movement in high susceptibility areas.
- Consider land value losses due to landslide in future risk assessments.

6.5.5 Coastal erosion

- Monitor ground movement in high susceptible areas, especially during or after large storms.
- Monitor erosion control structures that are already in place.
- Identify critical facilities and infrastructure near high coastal erosion areas.
- Consider land value losses due to coastal erosion in future risk assessments.

6.5.6 Wildfire related to geologic hazards

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

7.0 ACKNOWLEDGMENTS

This natural hazard risk assessment was conducted by the Oregon Department of Geology and Mineral Industries (DOGAMI) in 2018. It was funded by FEMA Region 10 through its Risk Mapping, Assessment, and Planning (Risk MAP) program (Cooperative Agreement EMW-2014-CA-00288 and EMS-2019-CA-00021). In addition to FEMA, DOGAMI worked closely with the DLCD to complete the risk assessment and produce this report. All communities in the study area participated in the 2015 Clatsop County Natural Hazards Mitigation Plan (https://www.co.clatsop.or.us/sites/default/files/fileattachments/emergency_management/page/512/clatsop_nhmp_2015.pdf). DLCD have begun coordinating with communities on the next NHMP update, which will incorporate the findings from this risk assessment.

We are grateful to many DOGAMI staff who contributed at various levels to this report during the analysis and writing phases, especially Jed Roberts, Bill Burns, John Bauer, and Deb Schueller.

Additionally, we thank people from other agencies and entities who also assisted on this project—from FEMA, Cynthia McCoy, Rynn Lamb, and David Ratte; and from DLCD, Marian Lahav, Pam Reber, and David Lentzner.

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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 their risk. This appendix contains community specific data to provide an overview of the community and the level of risk from each natural hazard analyzed. In addition, for each community a list of critical facilities and assumed impact from individual hazards is provided.

A.1 Unincorporated Clatsop County (Rural)

Table A-1. Unincorporated Clatsop County hazard profile.

Community Overview

Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)
Unincorporated Clatsop County	9,477	8,214	20	1,378,964,000

Hazus-MH Analysis Summary

Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Damaged Buildings	Damaged Critical Facilities	Loss Estimate ($)	Loss Ratio
Flood[2]	1% Annual Chance	1,175	12%	1,044	4	14,547,000	1.1%
*Earthquake**	*CSZ M9.0 Deterministic*	2,275	24%	2,870	14	480,396,000	35%
Earthquake (within Tsunami Zone)		235	2.5%	480	2	24,573,000	1.8%

Exposure Analysis Summary

Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Percent of Exposure
Tsunami	*CSZ – Medium*	1,042	11%	1,040	3	67,075,000	4.9%
Tsunami	Senate Bill 379 Regulatory Line	1,064	11%	1,086	4	135,415,000	9.8%
Landslide	High and Very High Susceptibility	2,836	30%	2,513	11	280,773,000	20%
Coastal Erosion	Moderate Hazard	4	0.0%	20	0	2,595,000	0.2%
Wildfire	High Hazard	1,618	17%	1,324	6	145,792,000	11%

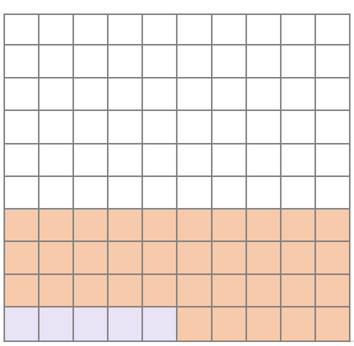
*Earthquake losses were calculated for buildings outside of Medium tsunami zone.

Rows with italicized text and shaded background indicate results should be considered in tandem as they are expected to occur within minutes of one another. Colors correspond to colors in Figure A-1.

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

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

Figure A-1. Unincorporated Clatsop County loss ratio from Cascadia subduction zone event.



Each cell represents 1% of building value, so the grid represents 100% of total building value. The magnitude 9.0 CSZ event is predicted to simultaneously produce a damaging earthquake and tsunami. Hazus-MH modeling for loss ratio is available only for earthquake. Buildings with exposure to the tsunami inundation zone are assumed to be completely damaged, which would be 100% loss ratio. To avoid double counting of buildings, the earthquake loss ratio was calculated only for buildings outside of the tsunami zone.

†Each cell represents 1% of building value

= Estimated losses due to tsunami.

= Estimated losses due to earthquake (outside of tsunami zone).

Table A-2. Unincorporated Clatsop County critical facilities.

	Flood 1% Annual Chance	Earthquake Moderate to Complete Damage	Tsunami CSZ – Medium	Landslide High and Very High Susceptibility	Wildfire High Hazard	Coastal Erosion Moderate Hazard
Critical Facilities by Community	**Exposed**	**>50% Prob.**	**Exposed**	**Exposed**	**Exposed**	**Exposed**
Brownsmead RFPD	X	X	—	—	—	—
Camp Rilea - National Guard Training Center	—	X	—	X	—	—
Elsie/Vinemaple RFPD	—	X	—	X	—	—
Gearhart Rural Fire District	—	—	—	—	—	—
Hamlet Rural Fire District	—	X	—	—	—	—
Jewell School	—	X	—	X	—	—
John Day—Fern Hill Fire Station	—	X	—	X	—	—
Lewis & Clark Elementary	—	X	—	X	X	—
Lewis & Clark RFPD	X	X	X	—	X	—
Miles Crossing Sanitary Sewer District	X	—	X	—	X	—
Mist-Birkenfeld RFPD	—	—	—	—	—	—
Mist-Birkenfeld RFPD - Fishhawk Lake	—	X	—	X	—	—
Olney-Walluski Volunteer Fire & Rescue	—	—	—	X	—	—
Olney-Walluski Water Association	—	X	—	X	—	—
Oregon Military Department	—	X	—	—	X	—
Shoreline Sanitary District	—	X	—	—	—	—
Sundown Sanitation District	—	X	—	—	X	—
Wauna Water District	—	X	—	X	—	—
Wickiup Water District	—	X	—	X	X	—
Youngs River-Lewis & Clark Water	X	X	X	X	—	—

A.2 Unincorporated Community of Arch Cape

Table A-3. Unincorporated community of Arch Cape hazard profile.

Community Overview

Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)
Arch Cape	183	462	4	113,684,000

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	9	5.1%	15	0	1,113,000	1.0%
*Earthquake**	*CSZ M9.0 Deterministic*	20	11%	76	2	16,694,000	15%
Earthquake (within Tsunami Zone)		6	3.5%	32	1	7,126,000	6.3%

Exposure Analysis Summary

Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Percent of Exposure
Tsunami	*CSZ – Medium*	59	32%	162	1	43,350,000	38%
Tsunami	Senate Bill 379 Regulatory Line	88	48%	253	1	63,972,000	56%
Landslide	High and Very High Susceptibility	57	31%	135	1	31,372,000	28%
Coastal Erosion	Moderate Hazard	16	8.9%	50	0	12,270,000	11%
Wildfire	High Hazard	1	0.7%	3	0	838,000	0.7%

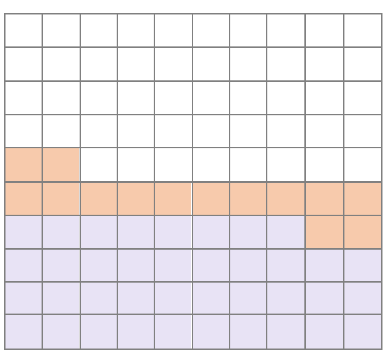
*Earthquake losses were calculated for buildings outside of Medium tsunami zone.

Rows with italicized text and shaded background indicate results should be considered in tandem as they are expected to occur within minutes of one another. Colors correspond to colors in Figure A-2.

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

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

Figure A-2. Unincorporated community of Arch Cape loss ratio from Cascadia subduction zone event.



Each cell represents 1% of building value, so the grid represents 100% of total building value. The magnitude 9.0 CSZ event is predicted to simultaneously produce a damaging earthquake and tsunami. Hazus-MH modeling for loss ratio is available only for earthquake. Buildings with exposure to the tsunami inundation zone are assumed to be completely damaged, which would be 100% loss ratio. To avoid double counting of buildings, the earthquake loss ratio was calculated only for buildings outside of the tsunami zone.

†Each cell represents 1% of building value.

= Estimated losses due to tsunami.

= Estimated losses due to earthquake (outside of tsunami zone).

Table A-4. Unincorporated community of Arch Cape critical facilities.

	Flood 1% Annual Chance	Earthquake Moderate to Complete Damage	Tsunami CSZ – Medium	Landslide High and Very High Susceptibility	Wildfire High Hazard	Coastal Erosion Moderate Hazard
Critical Facilities by Community	**Exposed**	**>50% Prob.**	**Exposed**	**Exposed**	**Exposed**	**Exposed**
Arch Cape Domestic Water Supply	—	X	—	X	—	—
Arch Cape Fire Station	—	—	—	—	—	—
Arch Cape Sanitary District	—	X	—	—	—	—
Cannon Beach Fire and Rescue Arch Cape	—	X	X	—	—	—

A.3 Unincorporated Community of Svensen-Knappa

Table A-5. Unincorporated community of Svensen-Knappa hazard profile.

Community Overview

Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)
Svensen-Knappa	3,013	1,652	6	178,049,000

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	17	0.6%	6	0	44,000	0.0%
*Earthquake**	*CSZ M9.0 Deterministic*	782	26%	523	6	37,280,000	21%
Earthquake (within Tsunami Zone)		0	0.0%	0	0	0	0.0%

Exposure Analysis Summary

Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Percent of Exposure
Tsunami	*CSZ – Medium*	0	0.0%	0	0	0	0.0%
Tsunami	Senate Bill 379 Regulatory Line	10	0.3%	8	0	660,000	0.4%
Landslide	High and Very High Susceptibility	1,129	38%	719	1	68,858,000	39%
Wildfire	High Hazard	112	3.7%	58	0	5,607,000	3.1%

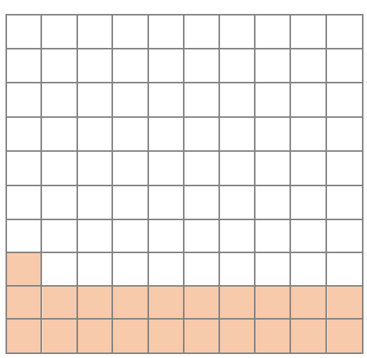
*Earthquake losses were calculated for buildings outside of Medium tsunami zone.

Rows with italicized text and shaded background indicate results should be considered in tandem as they are expected to occur within minutes of one another. Colors correspond to colors in Figure A-3.

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

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

Figure A-3. Unincorporated community of Svensen-Knappa loss ratio from Cascadia subduction zone event.



Each cell represents 1% of building value, so the grid represents 100% of total building value. The magnitude 9.0 CSZ event is predicted to simultaneously produce a damaging earthquake and tsunami. Hazus-MH modeling for loss ratio is available only for earthquake. Buildings with exposure to the tsunami inundation zone are assumed to be completely damaged, which would be 100% loss ratio. To avoid double counting of buildings, the earthquake loss ratio was calculated only for buildings outside of the tsunami zone.

†Each cell represents 1% of building value.

= Estimated losses due to tsunami.

= Estimated losses due to earthquake (outside of tsunami zone).

Table A-6. Unincorporated community of Svensen-Knappa critical facilities.

	Flood 1% Annual Chance	Earthquake Moderate to Complete Damage	Tsunami CSZ – Medium	Landslide High and Very High Susceptibility	Wildfire High Hazard	Coastal Erosion Moderate Hazard
Critical Facilities by Community	**Exposed**	**>50% Prob.**	**Exposed**	**Exposed**	**Exposed**	**Exposed**
Clatsop County Public Works	—	X	—	—	—	—
Clatsop County Sheriff	—	X	—	—	—	—
Hilda Lahti Elementary School	—	X	—	—	—	—
Knappa High School	—	X	—	—	—	—
Knappa Svensen RFPD	—	X	—	—	—	—
Knappa Water Association	—	X	—	X	—	—

A.4 Unincorporated Community of Westport

Table A-7. Unincorporated community of Westport hazard profile.

Community Overview

Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)
Westport	498	348	3	24,928,000

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%	2	0	7,000	0.0%
*Earthquake**	*CSZ M9.0 Deterministic*	220	44%	191	2	9,592,000	38%
Earthquake (within Tsunami Zone)		0	0.0%	0	0	0	0.0%

Exposure Analysis Summary

Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Percent of Exposure
Tsunami	*CSZ – Medium*	0	0.0%	0	0	0	0.0%
Tsunami	Senate Bill 379 Regulatory Line	0	0.0%	0	0	0	0.0%
Landslide	High and Very High Susceptibility	215	43%	135	2	10,066,000	40%
Wildfire	High Hazard	60	12%	63	0	2,524,000	10%

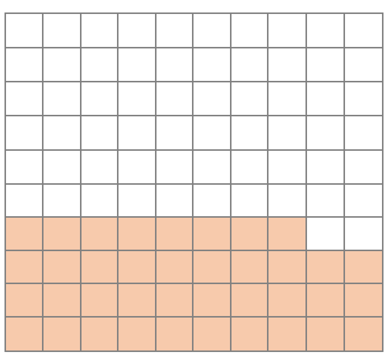
*Earthquake losses were calculated for buildings outside of Medium tsunami zone.

Rows with italicized text and shaded background indicate results should be considered in tandem as they are expected to occur within minutes of one another. Colors correspond to colors in Figure A-4.

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

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

Figure A-4. Unincorporated community of Westport loss ratio from Cascadia subduction zone event.



Each cell represents 1% of building value, so the grid represents 100% of total building value. The magnitude 9.0 CSZ event is predicted to simultaneously produce a damaging earthquake and tsunami. Hazus-MH modeling for loss ratio is available only for earthquake. Buildings with exposure to the tsunami inundation zone are assumed to be completely damaged, which would be 100% loss ratio. To avoid double counting of buildings, the earthquake loss ratio was calculated only for buildings outside of the tsunami zone.

†Each cell represents 1% of building value.

= Estimated losses due to tsunami.

= Estimated losses due to earthquake (outside of tsunami zone).

Table A-8. Unincorporated community of Westport critical facilities.

	Flood 1% Annual Chance	Earthquake Moderate to Complete Damage	Tsunami CSZ – Medium	Landslide High and Very High Susceptibility	Wildfire High Hazard	Coastal Erosion Moderate Hazard
Critical Facilities by Community	**Exposed**	**>50% Prob.**	**Exposed**	**Exposed**	**Exposed**	**Exposed**
Westport Heights Water System	—	X	—	X	—	—
Westport Water Association	—	X	—	X	—	—
Westport Wauna RFPD	—	—	—	—	—	—

A.5 City of Astoria

Table A-9. City of Astoria hazard profile.

Community Overview

Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)
Astoria	9,464	4,358	18	1,037,058,000

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	151	1.6%	71	1	1,302,000	0.1%
*Earthquake**	*CSZ M9.0 Deterministic*	2,501	26%	1,537	10	358,585,000	35%
Earthquake (within Tsunami Zone)		89	0.9%	242	5	118,506,000	11%

Exposure Analysis Summary

Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Percent of Exposure
Tsunami	*CSZ – Medium*	400	4.2%	422	6	211,577,000	20%
Tsunami	Senate Bill 379 Regulatory Line	149	1.6%	183	4	121,798,000	12%
Landslide	High and Very High Susceptibility	6,356	67%	2,890	7	578,107,000	56%
Coastal Erosion	Moderate Hazard	0	0.0%	0	0	0	0.0%
Wildfire	High Hazard	261	2.8%	151	0	41,326,000	4.0%

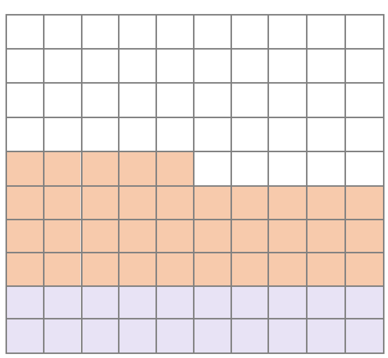
*Earthquake losses were calculated for buildings outside of Medium tsunami zone.

Rows with italicized text and shaded background indicate results should be considered in tandem as they are expected to occur within minutes of one another. Colors correspond to colors in Figure A-5.

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

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

Figure A-5. City of Astoria loss ratio from Cascadia subduction zone event.



Each cell represents 1% of building value, so the grid represents 100% of total building value. The magnitude 9.0 CSZ event is predicted to simultaneously produce a damaging earthquake and tsunami. Hazus-MH modeling for loss ratio is available only for earthquake. Buildings with exposure to the tsunami inundation zone are assumed to be completely damaged, which would be 100% loss ratio. To avoid double counting of buildings, the earthquake loss ratio was calculated only for buildings outside of the tsunami zone.

†Each cell represents 1% of building value.

= Estimated losses due to tsunami.

= Estimated losses due to earthquake (outside of tsunami zone).

Table A-10. City of Astoria critical facilities.

Critical Facilities by Community	Flood 1% Annual Chance Exposed	Earthquake Moderate to Complete Damage >50% Prob.	Tsunami CSZ – Medium Exposed	Landslide High and Very High Susceptibility Exposed	Wildfire High Hazard Exposed	Coastal Erosion Moderate Hazard Exposed
Astoria City Hall	—	X	—	—	—	—
Astoria Fire Department	—	X	X	—	—	—
Astoria Fire Station #2	—	X	—	—	—	—
Astoria Head Start	—	X	—	X	—	—
Astoria Middle School	—	X	—	—	—	—
Astoria Police Department	—	—	X	—	—	—
Astoria Public Works	—	X	X	—	—	—
Astoria Senior High School	—	X	—	X	—	—
Astoria Wastewater Treatment	—	X	—	—	—	—
City of Astoria Reservoir #2	—	—	—	—	—	—
Clatsop Community College	—	X	X	X	—	—
Clatsop County Sheriff Department	—	—	—	—	—	—
Columbia Memorial Hospital	—	X	—	—	—	—
John Jacob Astor Elementary	—	X	—	X	—	—
Oregon State Police	—	X	X	—	—	—
Parks Medical Limited LLC	—	X	—	X	—	—
Providence Heart Clinic North Coast - Astoria	—	X	—	X	—	—
Tongue Point Naval Air Station	X	X	X	X	—	—

A.6 City of Cannon Beach

Table A-11. City of Cannon Beach hazard profile.

Community Overview

Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)
Cannon Beach	1,683	2,037	4	567,876,000

Hazus-MH Analysis Summary

Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Damaged Buildings	Damaged Critical Facilities	Loss Estimate ($)	Loss Ratio
Flood[2]	1% Annual Chance	1	0.0%	3	0	38,000	0.0%
*Earthquake**	*CSZ M9.0 Deterministic*	280	17%	373	0	91,424,000	16%
Earthquake (within Tsunami Zone)		121	7.2%	287	3	103,320,000	18%

Exposure Analysis Summary

Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Percent of Exposure
Tsunami	*CSZ – Medium*	600	36%	799	3	256,840,000	45%
Tsunami	Senate Bill 379 Regulatory Line	692	41%	1,035	3	332,690,000	59%
Landslide	High and Very High Susceptibility	496	30%	417	0	106,908,000	19%
Coastal Erosion	Moderate Hazard	56	3.3%	141	0	58,705,000	10%
Wildfire	High Hazard	3	0.2%	4	0	565,000	0.1%

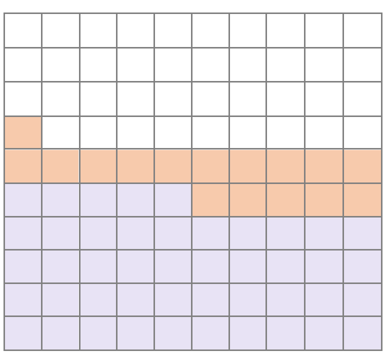
*Earthquake losses were calculated for buildings outside of Medium tsunami zone.

Rows with italicized text and shaded background indicate results should be considered in tandem as they are expected to occur within minutes of one another. Colors correspond to colors in Figure A-6.

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

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

Figure A-6. City of Cannon Beach loss ratio from Cascadia subduction zone event.



Each cell represents 1% of building value, so the grid represents 100% of total building value. The magnitude 9.0 CSZ event is predicted to simultaneously produce a damaging earthquake and tsunami. Hazus-MH modeling for loss ratio is available only for earthquake. Buildings with exposure to the tsunami inundation zone are assumed to be completely damaged, which would be 100% loss ratio. To avoid double counting of buildings, the earthquake loss ratio was calculated only for buildings outside of the tsunami zone.

†Each cell represents 1% of building value.

= Estimated losses due to tsunami.

= Estimated losses due to earthquake (outside of tsunami zone).

Table A-12. City of Cannon Beach critical facilities.

	Flood 1% Annual Chance	Earthquake Moderate to Complete Damage	Tsunami CSZ – Medium	Landslide High and Very High Susceptibility	Wildfire High Hazard	Coastal Erosion Moderate Hazard
Critical Facilities by Community	**Exposed**	**>50% Prob.**	**Exposed**	**Exposed**	**Exposed**	**Exposed**
Cannon Beach Elementary	—	X	X	—	—	—
Cannon Beach Fire and Rescue	—	—	—	—	—	—
Cannon Beach Police Department	—	X	X	—	—	—
Providence Health System - Oregon	—	X	X	—	—	—

A.7 City of Gearhart

Table A-13. City of Gearhart hazard profile.

Community Overview

Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)
Gearhart	1,462	1,607	4	359,970,000

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	50	3.4%	34	0	245,000	0.1%
*Earthquake**	*CSZ M9.0 Deterministic*	156	11%	219	0	61,778,000	17%
Earthquake (within Tsunami Zone)		160	11%	278	3	50,774,000	14%

Exposure Analysis Summary

Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Percent of Exposure
Tsunami	*CSZ – Medium*	775	53%	808	3	144,823,000	40%
Tsunami	Senate Bill 379 Regulatory Line	1,103	76%	1,275	3	252,553,000	70%
Landslide	High and Very High Susceptibility	75	5.2%	55	0	9,783,000	2.7%
Coastal Erosion	Moderate Hazard	7	0.5%	81	0	27,241,000	7.6%
Wildfire	High Hazard	1	0.1%	2	0	148,000	0.0%

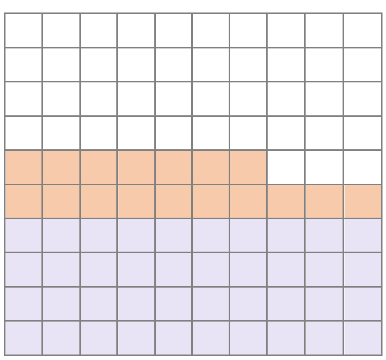
*Earthquake losses were calculated for buildings outside of Medium tsunami zone.

Rows with italicized text and shaded background indicate results should be considered in tandem as they are expected to occur within minutes of one another. Colors correspond to colors in Figure A-7.

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

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

Figure A-7. City of Gearhart loss ratio from Cascadia subduction zone event.



Each cell represents 1% of building value, so the grid represents 100% of total building value. The magnitude 9.0 CSZ event is predicted to simultaneously produce a damaging earthquake and tsunami. Hazus-MH modeling for loss ratio is available only for earthquake. Buildings with exposure to the tsunami inundation zone are assumed to be completely damaged, which would be 100% loss ratio. To avoid double counting of buildings, the earthquake loss ratio was calculated only for buildings outside of the tsunami zone.

†Each cell represents 1% of building value.

= Estimated losses due to tsunami.

= Estimated losses due to earthquake (outside of tsunami zone).

Table A-14. City of Gearhart critical facilities.

	Flood 1% Annual Chance	Earthquake Moderate to Complete Damage	Tsunami CSZ – Medium	Landslide High and Very High Susceptibility	Wildfire High Hazard	Coastal Erosion Moderate Hazard
Critical Facilities by Community	**Exposed**	**>50% Prob.**	**Exposed**	**Exposed**	**Exposed**	**Exposed**
Gearhart Elementary School	—	X	X	—	—	—
Gearhart Police Department	—	X	X	—	—	—
Gearhart Volunteer Fire	—	X	X	—	—	—
Pacific Medical and Surgical Group	—	—	—	—	—	—

A.8 City of Seaside

Table A-15. City of Seaside hazard profile.

Community Overview

Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)
Seaside	6,455	4,325	9	872,504,000

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	760	12%	186	1	1,416,000	0.2%
*Earthquake**	*CSZ M9.0 Deterministic*	343	5.3%	172	1	56,116,000	6.4%
Earthquake (within Tsunami Zone)		1,380	21%	1,402	7	252,513,000	29%

Exposure Analysis Summary

Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Percent of Exposure
Tsunami	*CSZ – Medium*	5,226	81%	3,776	8	718,702,000	82%
Tsunami	Senate Bill 379 Regulatory Line	4,937	77%	3,657	8	703,833,000	81%
Landslide	High and Very High Susceptibility	881	14%	410	1	107,393,000	12%
Coastal Erosion	Moderate Hazard	21	0.3%	56	0	35,067,000	4.0%
Wildfire	High Hazard	0	0.0%	2	0	347,000	0.0%

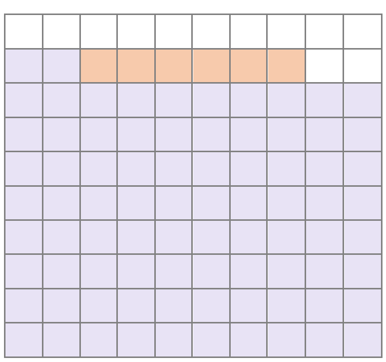
*Earthquake losses were calculated for buildings outside of Medium tsunami zone.

Rows with italicized text and shaded background indicate results should be considered in tandem as they are expected to occur within minutes of one another. Colors correspond to colors in Figure A-8.

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

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

Figure A-8. City of Seaside loss ratio from Cascadia subduction zone event.



Each cell represents 1% of building value, so the grid represents 100% of total building value. The magnitude 9.0 CSZ event is predicted to simultaneously produce a damaging earthquake and tsunami. Hazus-MH modeling for loss ratio is available only for earthquake. Buildings with exposure to the tsunami inundation zone are assumed to be completely damaged, which would be 100% loss ratio. To avoid double counting of buildings, the earthquake loss ratio was calculated only for buildings outside of the tsunami zone.

†Each cell represents 1% of building value.

= Estimated losses due to tsunami.

= Estimated losses due to earthquake (outside of tsunami zone).

Table A-16. City of Seaside critical facilities.

	Flood 1% Annual Chance	Earthquake Moderate to Complete Damage	Tsunami CSZ – Medium	Landslide High and Very High Susceptibility	Wildfire High Hazard	Coastal Erosion Moderate Hazard
Critical Facilities by Community	**Exposed**	**>50% Prob.**	**Exposed**	**Exposed**	**Exposed**	**Exposed**
Broadway Middle School	X	X	X	—	—	—
Seaside Fire and Rescue	—	X	X	—	—	—
Seaside Head Start	—	—	X	—	—	—
Seaside Heights Elementary School	—	X	X	X	—	—
Seaside High School	—	X	X	—	—	—
Seaside Police Department	—	X	X	—	—	—
Seaside Providence Hospital	—	X	—	—	—	—
Seaside Public Works	—	X	X	—	—	—
Seaside Water Treatment	—	X	X	—	—	—

A.9 City of Warrenton

Table A-17. City of Warrenton hazard profile.

Community Overview

Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)
Warrenton	4,987	2,826	10	493,680,000

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	2,335	47%	1,168	8	22,240,000	4.5%
*Earthquake**	CSZ M9.0 Deterministic	452	9.1%	397	1	77,676,000	16%
Earthquake *(within Tsunami Zone)*		1,137	23%	857	6	116,662,000	24%

Exposure Analysis Summary

Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Percent of Exposure
Tsunami	*CSZ – Medium*	3,231	65%	1,803	8	263,619,000	53%
Tsunami	Senate Bill 379 Regulatory Line	2,718	55%	1,544	7	236,453,000	48%
Landslide	High and Very High Susceptibility	100	2.0%	61	0	9,955,000	2.0%
Coastal Erosion	Moderate Hazard	0	0.0%	1	0	23,000	0.0%
Wildfire	High Hazard	1,410	28%	860	3	142,943,000	29%

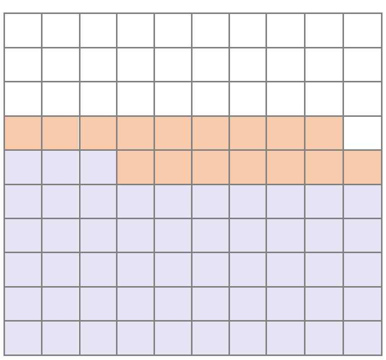
*Earthquake losses were calculated for buildings outside of Medium tsunami zone.

Rows with italicized text and shaded background indicate results should be considered in tandem as they are expected to occur within minutes of one another. Colors correspond to colors in Figure A-9.

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

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

Figure A-9. City of Warrenton loss ratio from Cascadia subduction zone event.



Each cell represents 1% of building value, so the grid represents 100% of total building value. The magnitude 9.0 CSZ event is predicted to simultaneously produce a damaging earthquake and tsunami. Hazus-MH modeling for loss ratio is available only for earthquake. Buildings with exposure to the tsunami inundation zone are assumed to be completely damaged, which would be 100% loss ratio. To avoid double counting of buildings, the earthquake loss ratio was calculated only for buildings outside of the tsunami zone.

†Each cell represents 1% of building value.

= Estimated losses due to tsunami.

= Estimated losses due to earthquake (outside of tsunami zone).

Table A-18. City of Warrenton critical facilities.

	Flood 1% Annual Chance	Earthquake Moderate to Complete Damage	Tsunami CSZ – Medium	Landslide High and Very High Susceptibility	Wildfire High Hazard	Coastal Erosion Moderate Hazard
Critical Facilities by Community	**Exposed**	**>50% Prob.**	**Exposed**	**Exposed**	**Exposed**	**Exposed**
CMH Medical Group Urgent Care	—	—	—	—	—	—
Port of Astoria	X	X	X	—	—	—
Providence Medical Clinic - Warrenton	X	—	X	—	X	—
South Jetty High School	—	X	—	—	—	—
U.S. Coast Guard - Air Station Astoria	X	X	X	—	—	—
Warrenton Fire Department	X	—	X	—	—	—
Warrenton Grade School	X	X	—	—	X	—
Warrenton High School	X	X	X	—	X	—
Warrenton Police Department	X	X	X	—	—	—
Warrenton Public Works	X	X	X	—	—	—

APPENDIX B. DETAILED RISK ASSESSMENT TABLES

Table B-1. Clatsop County building inventory.

(all dollar amounts in thousands)

	Residential			Commercial and Industrial			Agricultural			Public and Non-Profit			All Buildings			
Community	**Number of Buildings**	**Building Value ($)**	**Building Value per Community Total**	**Number of Buildings**	**Building Value ($)**	**Building Value per Community Total**	**Number of Buildings**	**Building Value ($)**	**Building Value per Community Total**	**Number of Buildings**	**Building Value ($)**	**Building Value per Community Total**	**Number of Buildings**	**Number of Buildings per County Total**	**Building Value ($)**	**Building Value per County Total**
Unincorp. County (rural)	4,657	646,370	47%	348	439,782	31.9%	2,820	139,226	10%	389	153,585	11.1%	8,214	32%	1,378,964	27%
Arch Cape	399	103,630	91%	3	1,343	1.2%	48	4,424	4%	12	4,287	3.8%	462	1.8%	113,684	2.3%
Svensen-Knappa	1,103	140,552	79%	30	5,813	3.3%	491	23,228	13%	28	8,456	4.7%	1,652	6.4%	178,049	3.5%
Westport	262	17,450	70%	12	1,997	8.0%	63	2,602	10%	11	2,879	11.5%	348	1.3%	24,928	0.5%
Total Unincorp. County	6,421	908,003	54%	393	448,934	26%	3,422	169,480	10.0%	440	169,207	10.0%	10,676	41.3%	1,695,624	33.7%
Astoria	3,524	539,468	52%	394	200,656	19.3%	214	8,422	1%	226	288,513	27.8%	4,358	17%	1,037,058	21%
Cannon Beach	1,765	485,477	85%	110	50,941	9.0%	116	8,560	2%	46	22,897	4%	2,037	7.9%	567,876	11.3%
Gearhart	1,349	312,942	87%	111	31,379	9%	130	7,470	2%	17	8,180	2%	1,607	6.2%	359,970	7.2%
Seaside	3,467	659,457	76%	394	111,039	13%	327	24,375	2.8%	137	77,633	9%	4,325	16.7%	872,504	17.4%
Warrenton	2,124	273,264	55%	333	133,509	27%	215	12,361	3%	154	74,546	15%	2,826	10.9%	493,680	9.8%
Total Clatsop County	18,650	3,178,611	63%	1,735	976,458	19%	4,424	230,667	5%	1,020	640,975	12.8%	25,829	100.0%	5,026,711	100.0%

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

(all dollar amounts in thousands)

			Total Earthquake Damage*		Earthquake Damage outside of Medium Tsunami Zone							
			Buildings Damaged		Buildings Damaged				Building Design Level Upgraded to at Least Moderate Code			
Community	Total Number of Buildings	Total Estimated Building Value ($)	Sum of Economic Loss	Loss Ratio	Yellow-Tagged Buildings	Red-Tagged Buildings	Sum of Economic Loss	Loss Ratio	Yellow-Tagged Buildings	Red-Tagged Buildings	Sum of Economic Loss	Loss Ratio
Unincorp. County (rural)	8,214	1,378,964	504,969	37%	619	2,251	480,396	34.8%	648	1,404	321,707	23.3%
Arch Cape	462	113,684	23,820	21%	18	59	16,694	14.7%	9	45	12,676	11.2%
Svensen-Knappa	1,652	178,049	38,280	22%	146	377	38,280	21%	118	236	27,790	16%
Westport	348	24,928	9,592	39%	37	154	9,592	38.5%	59	84	7,157	28.7%
Total Unincorp. County	10,676	1,695,624	576,661	34%	820	2,840	544,962	32%	833	1,769	369,331	22%
Astoria	4,358	1,037,058	477,091	46%	345	1,193	358,585	34.6%	112	1,032	264,785	25.5%
Cannon Beach	2,037	567,876	194,744	34%	55	318	91,424	16.1%	27	287	79,933	14.1%
Gearhart	1,607	359,970	112,552	31%	35	184	61,778	17.2%	12	173	51,618	14.3%
Seaside	4,325	872,504	308,629	35%	16	156	56,116	6.4%	13	140	42,047	4.8%
Warrenton	2,826	493,680	194,338	39%	43	354	77,676	16%	49	296	68,779	14%
Total Clatsop County	25,829	5,026,711	1,864,014	37%	1,314	5,045	1,190,540	23.7%	1,046	3,696	876,491	17.4%

*All losses calculated from earthquake inside or outside of Medium tsunami zone.

Table B-3. Tsunami exposure.

(all dollar amounts in thousands)

			Small (Low Severity)			Medium (Moderate Severity)			Large (High Severity)			X Large (Very High Severity)			XX Large (Extreme Severity)		
Community	**Total Number of Buildings**	**Total Estimated Building Value ($)**	**Number of Buildings**	**Building Value ($)**	**Percent of Building Value Exposed**	**Number of Buildings**	**Building Value ($)**	**Percent of Building Value Exposed**	**Number of Buildings**	**Building Value ($)**	**Percent of Building Value Exposed**	**Number of Buildings**	**Building Value ($)**	**Percent of Building Value Exposed**	**Number of Buildings**	**Building Value ($)**	**Percent of Building Value Exposed**
Unincorp. County (rural)	8,214	1,378,964	879	52,749	3.8%	1,040	67,075	4.9%	1,801	221,393	16%	3,145	475,022	34%	3,222	490,567	36%
Arch Cape	462	113,684	69	16,910	15%	162	43,350	38%	233	60,639	53%	360	90,490	80%	372	92,486	81%
Svensen-Knappa	1,652	178,049	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%
Westport	348	24,928	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%
Total Unincorp. County	10,676	1,695,624	948	69,659	4.1%	1,202	110,425	6.5%	2,034	282,032	17%	3,505	565,512	33%	3,594	583,053	34%
Astoria	4,358	1,037,058	151	45,225	4.4%	422	211,577	20%	746	402,271	39%	936	475,812	46%	950	480,166	46%
Cannon Beach	2,037	567,876	357	124,607	22%	799	256,840	45%	1,523	417,186	74%	1,768	498,404	88%	1,792	503,608	89%
Gearhart	1,607	359,970	259	42,678	12%	808	144,823	40%	1,318	267,235	74%	1,607	359,970	100%	1,607	359,970	100%
Seaside	4,325	872,504	3,301	621,310	71%	3,776	718,702	82%	3,904	753,787	86%	4,028	786,052	90%	4,035	787,368	90%
Warrenton	2,826	493,680	1,346	182,788	37%	1,803	263,619	53%	2,101	321,770	65%	2,419	392,963	80%	2,482	402,572	82%
Total Clatsop County	25,829	5,026,711	6,362	1,086,267	22%	8,810	1,705,987	34%	11,626	2,444,281	49%	14,263	3,078,712	61%	14,460	3,116,737	62%

Table B-4. Flood loss estimates.

			(all dollar amounts in thousands)											
			10% (10-yr)			**2% (50-yr)**			**1% (100-yr)***			**0.2% (500-yr)**		
Community	**Total Number of Buildings**	**Total Estimated Building Value ($)**	**Number of Buildings**	**Loss Estimate**	**Loss Ratio**	**Number of Buildings**	**Loss Estimate**	**Loss Ratio**	**Number of Buildings**	**Loss Estimate**	**Loss Ratio**	**Number of Buildings**	**Loss Estimate**	**Loss Ratio**
Unincorp. County (rural)	8,214	1,378,964	110	555	0.0%	199	1,039	0.1%	1,044	14,547	1.1%	346	2,236	0.2%
Arch Cape	462	113,684	0	0	0.0%	0	0	0.0%	15	1,113	1.0%	0	0	0.0%
Svensen-Knappa	1,652	178,049	0	0	0.0%	0	0	0.0%	6	44	0.0%	1	5	0.0%
Westport	348	24,928	2	5	0.0%	2	7	0.0%	2	7	0.0%	2	9	0.0%
Total Unincorp. County	10,676	1,695,624	112	560	0.0%	201	1,046	0.1%	1,067	15,711	0.9%	349	2,249	0.1%
Astoria	4,358	1,037,058	0	0	0.0%	0	0	0.0%	71	1,302	0.1%	0	0	0.0%
Cannon Beach	2,037	567,876	0	0	0.0%	0	0	0.0%	3	38	0.0%	0	0	0.0%
Gearhart	1,607	359,970	12	81	0.0%	26	173	0.0%	34	245	0.1%	33	238	0.1%
Seaside	4,325	872,504	21	346	0.0%	81	765	0.1%	186	1,416	0.2%	234	1,619	0.2%
Warrenton	2,826	493,680	0	0	0.0%	0	0	0.0%	1,168	22,240	4.5%	0	0	0.0%
Total Clatsop County	25,829	5,026,711	145	987	0.0%	308	1,985	0.0%	2,529	40,951	0.8%	616	4,107	0.1%

*1% results include coastal flooding source.

Table B-5. Flood exposure.

			1% (100-yr)*				
Community	**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. County (rural)	8,214	9,477	1,175	12.4%	1,175	14.3%	131
Arch Cape	462	183	9	5.1%	22	4.8%	7
Svensen-Knappa	1,652	3,013	17	0.6%	7	0.4%	1
Westport	348	498	0	0.0%	3	0.9%	1
Total Unincorp. County	10,676	13,171	1,201	9.1%	1,207	11.3%	140
Astoria	4,358	9,464	151	1.6%	146	3.4%	75
Cannon Beach	2,037	1,683	1	0.0%	5	0.2%	2
Gearhart	1,607	1,462	50	3.4%	48	3.0%	14
Seaside	4,325	6,455	760	12%	352	8%	166
Warrenton	2,826	4,987	2,335	47%	1,253	44%	85
Total Clatsop County	25,829	37,223	4,498	12%	3,011	12%	482

*1% results include coastal flooding source.

** Building first-floor height is above flood elevation.

Table B-6. Landslide exposure.

(all dollar amounts in thousands)

			Very High Susceptibility			High Susceptibility			Moderate Susceptibility		
Community	Total Number of Buildings	Total Estimated Building Value ($)	Number of Buildings	Building Value ($)	Percent of Building Value Exposed	Number of Buildings	Building Value ($)	Percent of Building Value Exposed	Number of Buildings	Building Value ($)	Percent of Building Value Exposed
Unincorp. County (rural)	8,214	1,378,964	952	133,908	9.7%	1,561	146,865	11%	2,284	300,221	22%
Arch Cape	462	113,684	69	17,412	15%	66	13,960	12%	167	40,595	36%
Svensen-Knappa	1,652	178,049	119	12,201	7%	600	56,657	32%	441	55,810	31%
Westport	348	24,928	116	7,207	29%	19	2,859	12%	17	1,402	6%
Total Unincorp. County	10,676	1,695,624	1,256	170,728	10%	2,246	220,342	13%	2,909	398,028	23%
Astoria	4,358	1,037,058	2,343	398,233	38%	547	179,873	17%	1,356	407,853	39%
Cannon Beach	2,037	567,876	365	81,833	14%	52	25,075	4.4%	606	169,724	30%
Gearhart	1,607	359,970	0	0	0.0%	55	9,783	2.7%	558	130,786	36%
Seaside	4,325	872,504	364	91,486	11%	46	15,908	1.8%	638	173,610	20%
Warrenton	2,826	493,680	0	0	0%	61	9,955	2.0%	484	81,122	16%
Total Clatsop County	25,829	5,026,711	4,328	742,280	15%	3,007	460,936	9.2%	6,551	1,361,123	27%

Table B-7. Coastal erosion exposure.

			(all dollar amounts in thousands)								
			High Hazard			**Moderate Hazard**			**Low Hazard**		
Community*	**Total Number of Buildings**	**Total Estimated Building Value ($)**	**Number of Buildings**	**Building Value ($)**	**Percent of Building Value Exposed**	**Number of Buildings**	**Building Value ($)**	**Percent of Building Value Exposed**	**Number of Buildings**	**Building Value ($)**	**Percent of Building Value Exposed**
Unincorp. County (rural)	8,214	1,378,964	17	2,505	0.2%	20	2,595	0.2%	54	15,544	1.1%
Arch Cape	462	113,684	0	0	0%	50	12,270	11%	121	33,051	29%
Total Unincorp. County	8,676	1,492,648	17	2,505	0.2%	70	14,865	1%	175	48,595	3.3%
Cannon Beach	2,037	567,876	82	23,499	4.1%	141	58,705	10%	412	183,977	32%
Gearhart	1,607	359,970	28	7,738	2.2%	81	27,241	7.6%	108	38,843	11%
Seaside	4,325	872,504	2	1,260	0.1%	56	35,067	4%	258	132,890	15%
Warrenton	2,826	493,680	1	23	0%	1	23	0%	1	23	0%
Total Clatsop County*	19,471	3,786,677	130	35,024	0.9%	349	135,900	3.6%	954	404,327	11%

*Does not include non-coastal communities (these communities do not factor into total amounts and percentages).

Table B-8. Wildfire exposure.

(all dollar amounts in thousands)

			High Hazard			Moderate Hazard		
Community	**Total Number of Buildings**	**Total Estimated Building Value ($)**	**Number of Buildings**	**Building Value ($)**	**Percent of Building Value Exposed**	**Number of Buildings**	**Building Value ($)**	**Percent of Building Value Exposed**
Unincorp. County (rural)	8,214	1,378,964	1,324	145,792	11%	4,083	605,685	44%
Arch Cape	462	113,684	3	838	1%	227	52,459	46.1%
Svensen-Knappa	1,652	178,049	58	5,607	3%	993	107,642	60%
Westport	348	24,928	63	2,524	10%	82	7,334	29%
Total Unincorp. County	10,676	1,695,624	1,448	154,762	9.1%	5,385	773,120	46%
Astoria	4,358	1,037,058	151	41,326	4%	681	106,239	10%
Cannon Beach	2,037	567,876	4	565	0.1%	877	196,905	35%
Gearhart	1,607	359,970	2	148	0.0%	929	198,891	55%
Seaside	4,325	872,504	2	347	0%	915	223,486	25.6%
Warrenton	2,826	493,680	860	142,943	29%	645	90,771	18%
Total Clatsop County	25,829	5,026,711	2,467	340,091	6.8%	9,432	1,589,414	32%

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 compiled a UDF database for all buildings in Clatsop County for use in both flood and earthquake modules of Hazus-MH. We used the Clatsop County assessor database (acquired in 2017) 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 (unpublished) 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 the Clatsop County assessor database wherever possible, but in many cases that database did not provide the necessary information. The following is list of attributes and their sources:

- **Longitude** and **Latitude** – Location information that provides Hazus-MH the x and y positions of the UDF point. This allows for an overlay to occur between the UDF point and the flood or earthquake input data layers. The hazard model uses this spatial overlay to determine the correct hazard risk level that will be applied to the UDF point. The format of the attribute must be in decimal degrees. A simple geometric calculation using GIS software is done on the point to derive this value.
- **Occupancy class** – An alphanumeric attribute that indicates the use of the UDF (e.g., "RES1" is a single family dwelling). The alphanumeric code is composed of seven broad occupancy types (RES = residential, COM = commercial, IND = industrial, AGR = agricultural, GOV = public, REL = non-profit/religious, EDU = education) and various suffixes that indicate more specific types. This code determines the damage function to be used for flood analysis. It is also used to attribute the Building Type field, discussed below, for the earthquake analysis. The code was interpreted from "Stat Class" or "Description" data found in the Clatsop County assessor database. 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. The value was obtained from the Clatsop County assessor database. Where not available, cost was based on the square

footage of the building footprint or from the square footage found in the Clatsop County assessor database. When multiple UDFs occupied a single taxlot, the overall cost of the taxlot was distributed to the UDFs based on square footage.

- **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 Clatsop County assessor database. Where not available the year of "1900" was applied (8% of the UDFs).
- **Square feet** – The size of the UDF is used to pro-rate the total improvement value for taxlots with multiple UDFs. The value distribution method will ensure that UDFs with the highest square footage will be the most expensive on a given taxlot. This value is also used to pro-rate the **Number of people** field for Residential UDFs within a census block. The value was obtained from DOGAMI's building footprints; where (RES) footprints were not available, we used the Clatsop County assessor database.
- **Number of stories** – The number of stories for an individual UDF, along with **Occupancy class**, determines the applied damage function for flood analysis. The value was obtained from the Clatsop County assessor database 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 **First floor height** values 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 have one. The value was obtained from the Clatsop County assessor database where available. For UDFs without assessor information for basements that are within the flood zone, closer inspection using Google Street View™ mapping service or available oblique imagery was used to ascertain basement presence.
- **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 (Clatsop County assessor data) or observation via oblique imagery or the Google Street View™ mapping service.
- **Building type** – This attribute determines the construction material and structural integrity of an individual UDF. It is used by Hazus-MH to estimate earthquake losses by determining which damage function will be applied. This information was not in the Clatsop 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 more informatio*n*). This information is derived from the **Year built** attribute (Clatsop Assessor) and state 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 number of people affected by a given hazard. This attribute is derived from the 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 area boundaries; unincorporated community areas were based on building density.

C.2.3 Seismic building codes

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

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

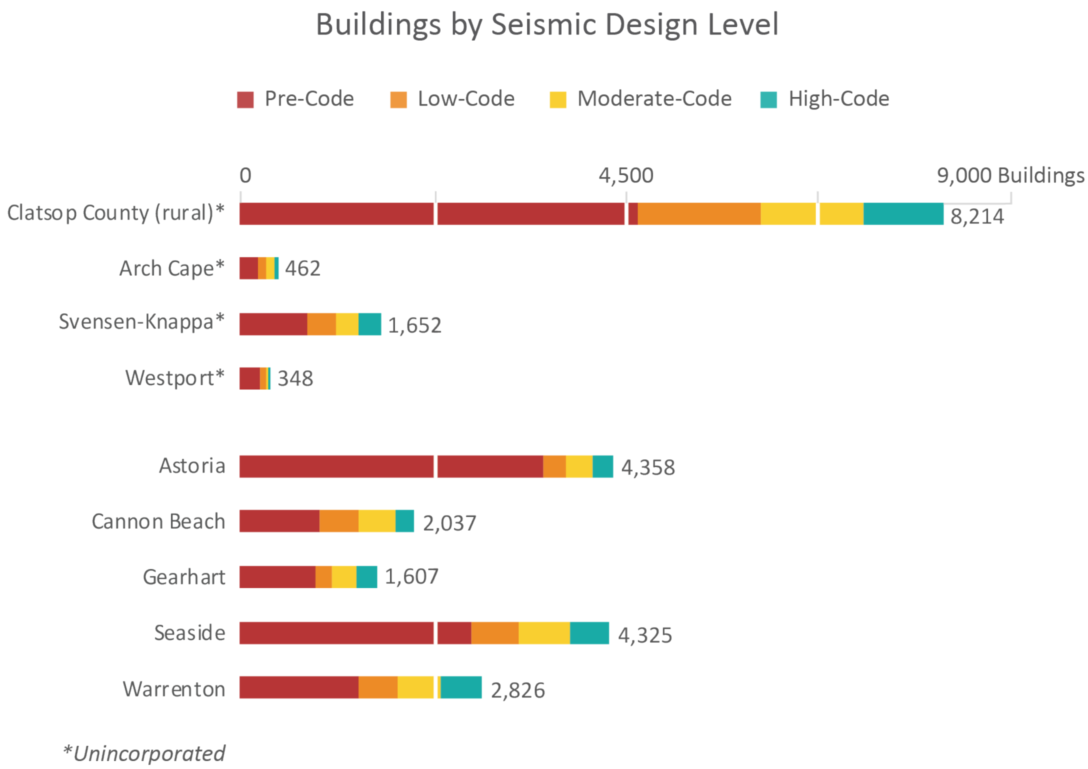
Building Type	Year Built	Design Level	Basis
Single Family Dwelling (includes Duplexes)	prior to 1976	Pre-Code	Interpretation of Judson (2012)
	1976–1991	Low-Code	
	1992–2003	Moderate-Code	
	2004–2016	High-Code	
Manufactured Housing	prior to 2003	Pre-Code	Interpretation of OR BCD 2002 Manufactured Dwelling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

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

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

Community	Total Number of Buildings	Pre Code Number of Buildings	Pre Code Percentage of Buildings	Low Code Number of Buildings	Low Code Percentage of Buildings	Moderate Code Number of Buildings	Moderate Code Percentage of Buildings	High Code Number of Buildings	High Code Percentage of Buildings
Unincorp. County (rural)	8,214	4,651	57%	1,428	17%	1,198	15%	937	11.4%
Arch Cape	462	223	48%	91	19.7%	87	18.8%	61	13.2%
Svensen-Knappa	1,652	799	48%	323	20%	277	17%	253	15.3%
Westport	348	255	73%	59	17%	21	6%	13	3.7%
Total Unincorp. County	10,676	5,928	56%	1,901	17.8%	1,583	14.8%	1,264	11.8%
Astoria	4,358	3,558	82%	257	6%	315	7%	228	5.2%
Cannon Beach	2,037	931	46%	462	22.7%	442	21.7%	202	9.9%
Gearhart	1,607	883	55%	200	12%	277	17%	247	15.4%
Seaside	4,325	2,715	63%	556	13%	586	14%	468	10.8%
Warrenton	2,826	1,391	49%	457	16.2%	503	18%	475	17%
Total Clatsop County	25,829	15,406	60%	3,833	14.8%	3,706	14.3%	2,884	11.2%

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



C.3 Flood Hazard Data

DOGAMI developed flood hazard data in 2015 for a revision of the Clatsop County FEMA Flood Insurance Study (FEMA, 2016). The hazard data were based on a combination of previous flood studies and new riverine and coastal hydrologic and hydraulic analyses. For riverine areas, 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." For coastal zones and other stillwater flood areas, a 100-year stillwater elevation was used to create the depth grid.

A countywide, 2-meter (~6.5 foot), 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): Site Ground Motion and Ground Deformation Map Development. The landslide susceptibility data from ORP were replaced with newer and more accurate data (Burns and others, 2016).

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 feet (1.5 meters).

A deterministic method for a CSZ magnitude 9.0 event was deemed the most likely and impactful earthquake scenario for Clatsop County. 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 the influence these errors have on the final outcome. Before applying the Hazus-MH methodology, closely examining the top 10 largest area UDFs and the top 10 most expensive UDFs is advisable. Special consideration can also be given to critical facilities due to their importance to communities.

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

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

APPENDIX D. ACRONYMS AND DEFINITIONS

D.1 Acronyms

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

D.2 Definitions

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

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

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

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

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

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

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

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

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

Liquefaction – Describes a phenomenon in which 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

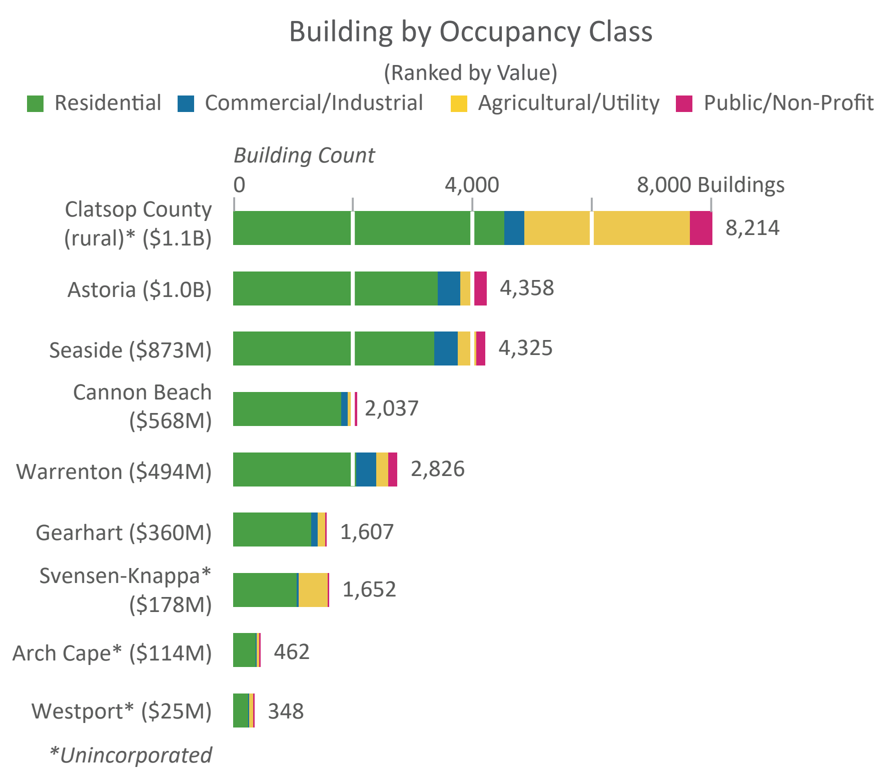
See appendix folder for individual map PDFs.

Building Distribution Map of Clatsop County, Oregon

PLATE 1

Building Occupancy

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



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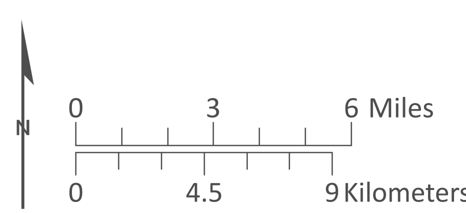
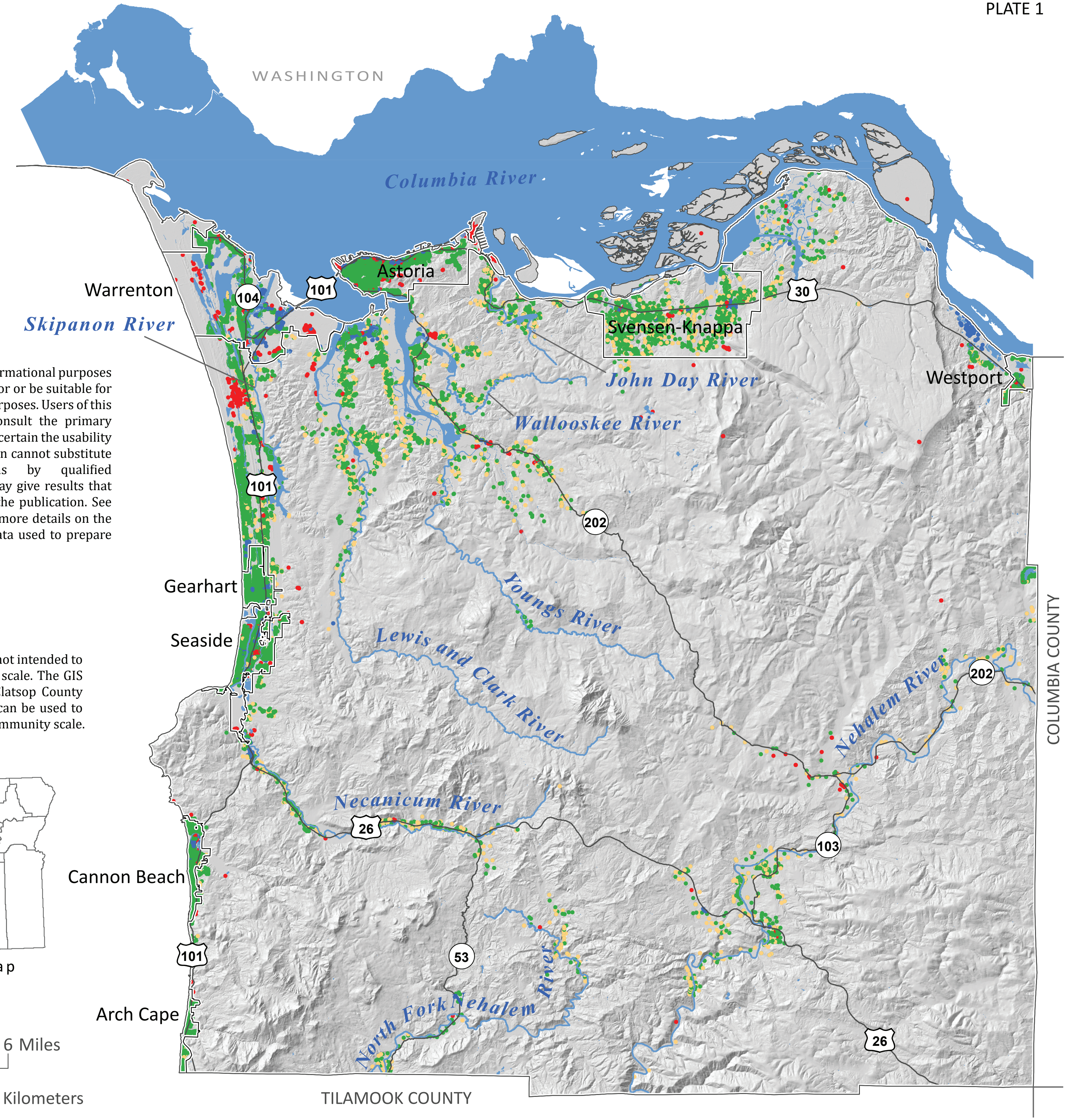
This map is an overview map and not intended to provide details at the community scale. The GIS data that is published with the Clatsop County Natural Hazard Risk Assessment can be used to inform regarding queries at the community scale.

Study Location Map





Data Sources:
Building footprints: Oregon Department of Geology and Mineral Industries (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)
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

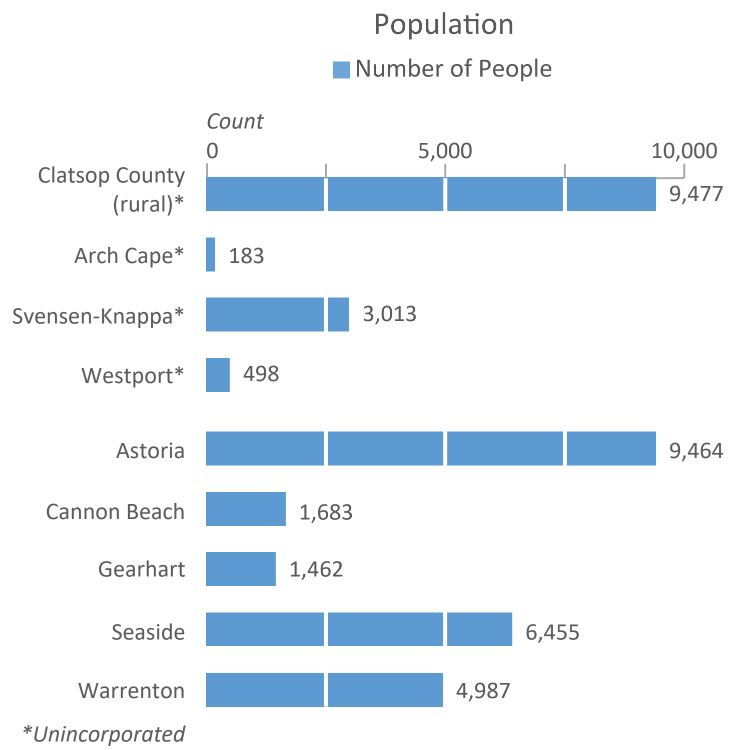
Cartography by: Lowell H. Anthony, 2018

Population Density Map of Clatsop County, Oregon

PLATE 2

People per 20 acres

- Building(s) present no permanent residents
- 1 - 5
- 6 - 15
- 16 - 30
- 31 - 60
- 61+



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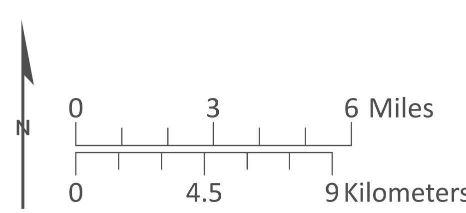
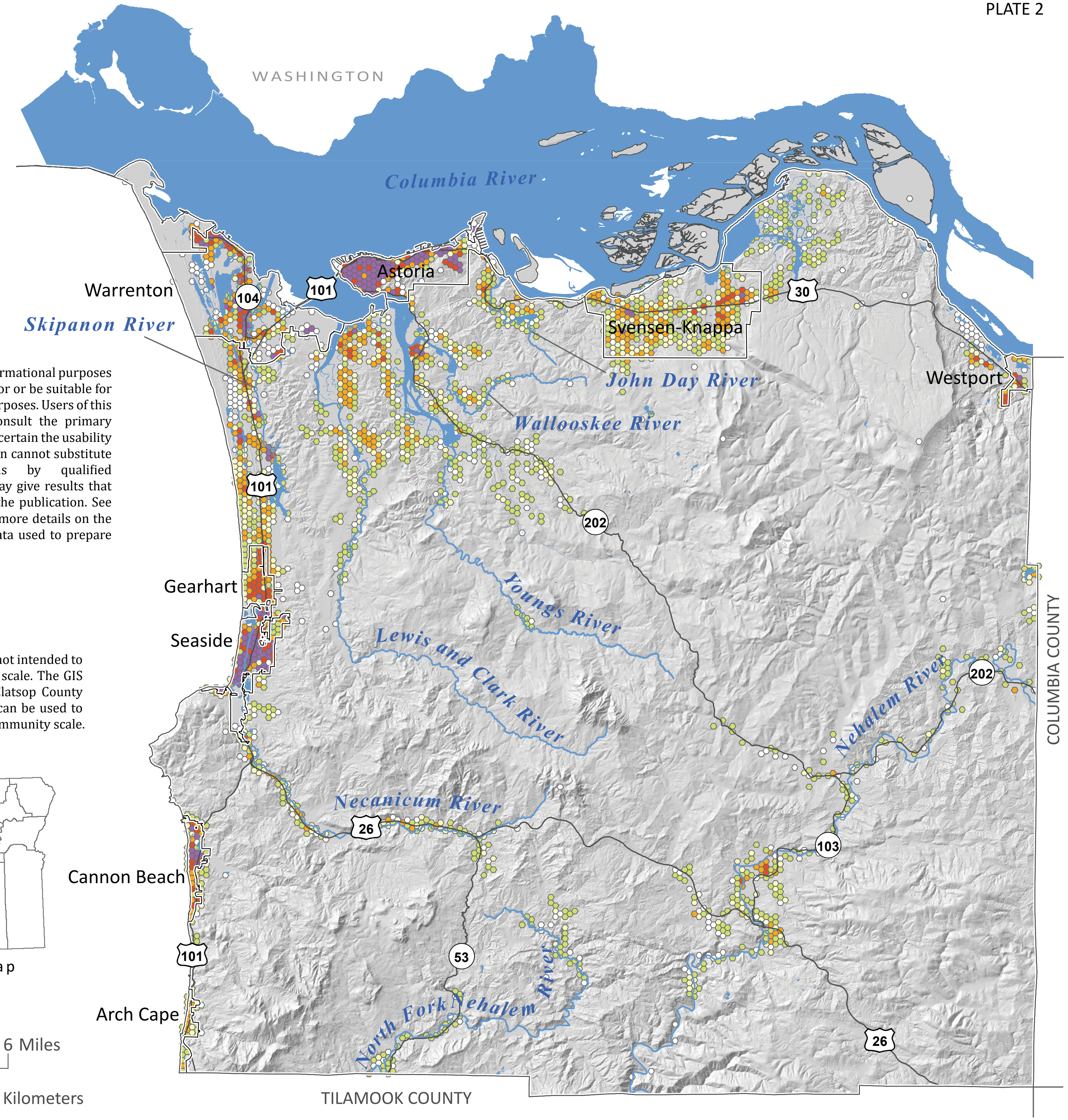
Study Location Map





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)
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

M9.0 CSZ Earthquake Shaking Map of Clatsop County, Oregon

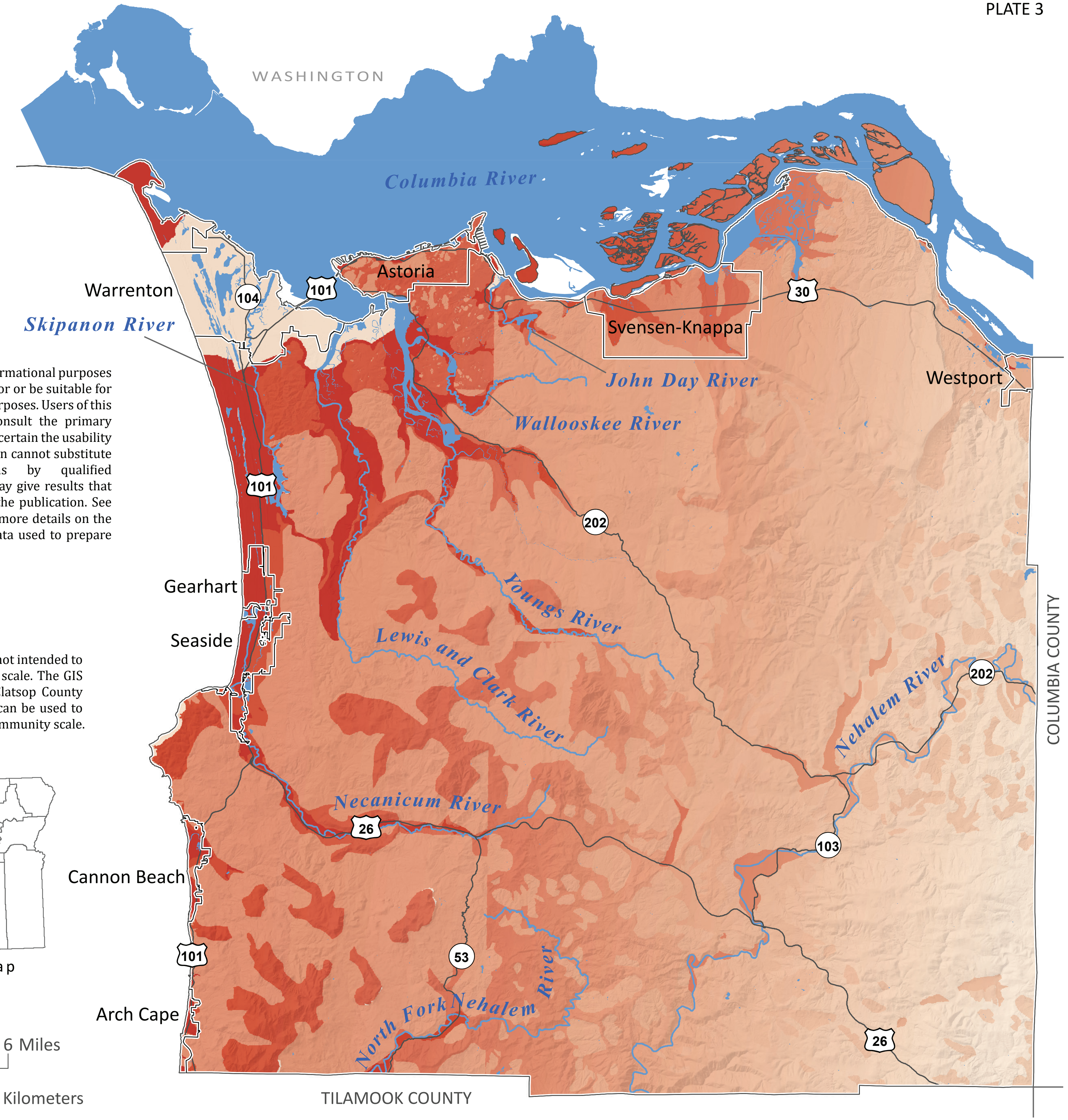
PLATE 3

Earthquake Peak Ground Acceleration

(Modified Mercalli Intensity Scale)

Moderate — Severe

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



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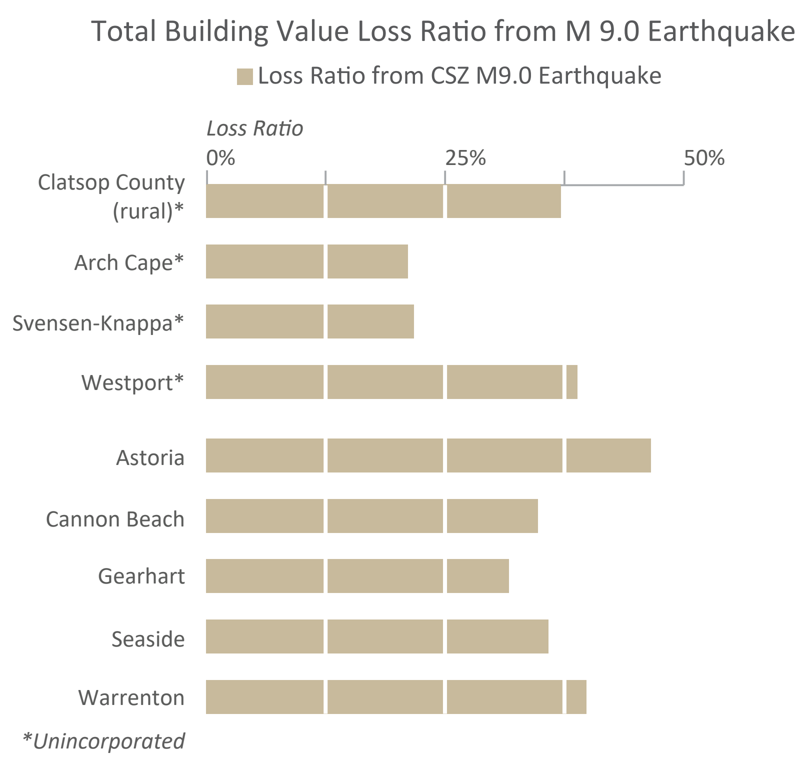


Study Location Map

N

0 3 6 Miles

0 4.5 9 Kilometers

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)
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

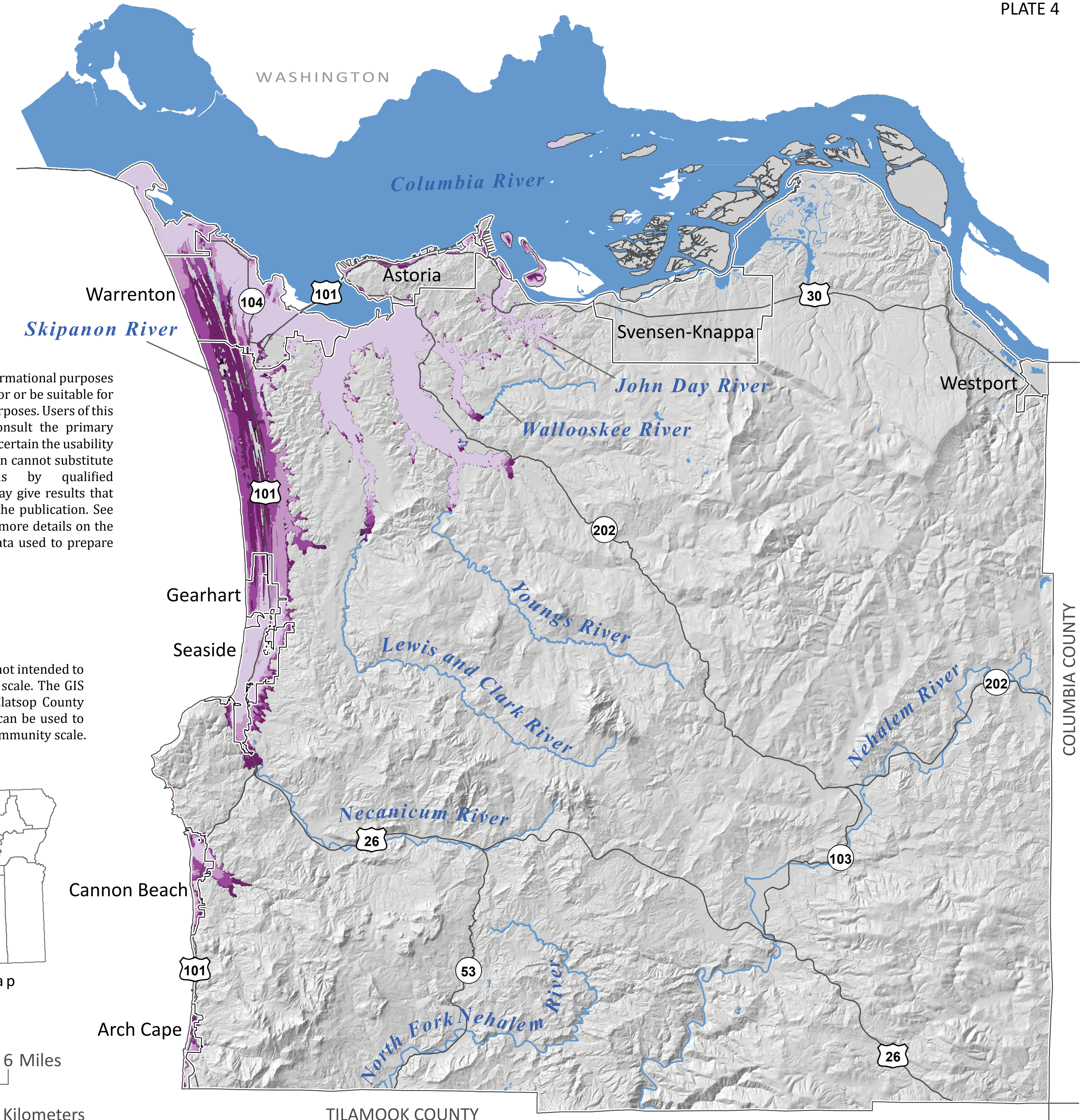
PLATE 4

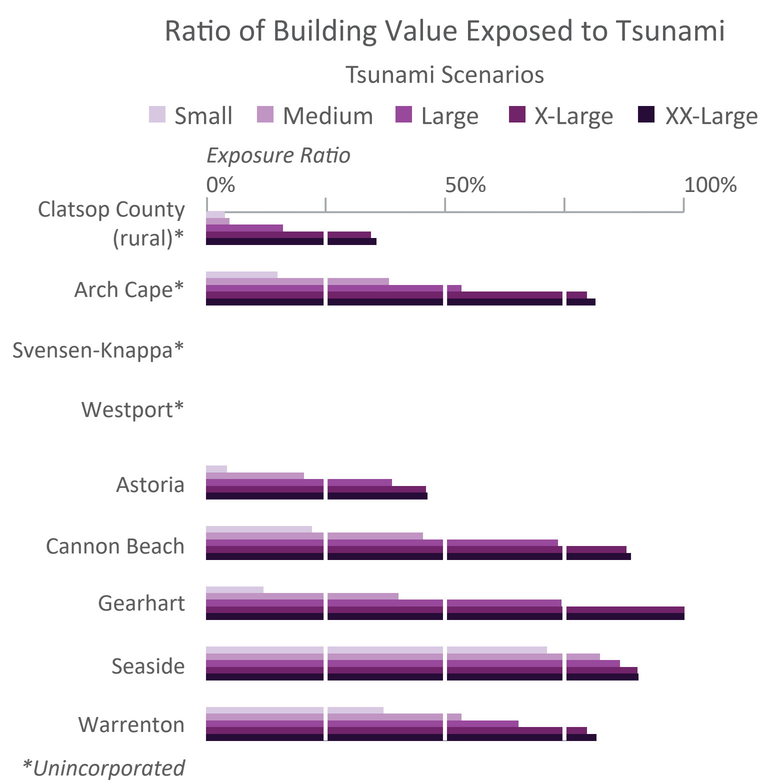
Tsunami Inundation Map of Clatsop County, Oregon

Tsunami Hazard Zone

- Small
- Medium
- Large
- X-Large
- XX-Large

The tsunami hazard data show areas of expected inundation from several local tsunami scenarios produced from a magnitude 9.0 CSZ earthquake. The scenarios were categorized based on "t-shirt" sizes, ranging from Small to XX-Large.





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Study Location Map

N

0 3 6 Miles

0 4.5 9 Kilometers

Data Sources:
Tsunami Hazard Zones: Oregon Department of Geology, Priest and others (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)
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

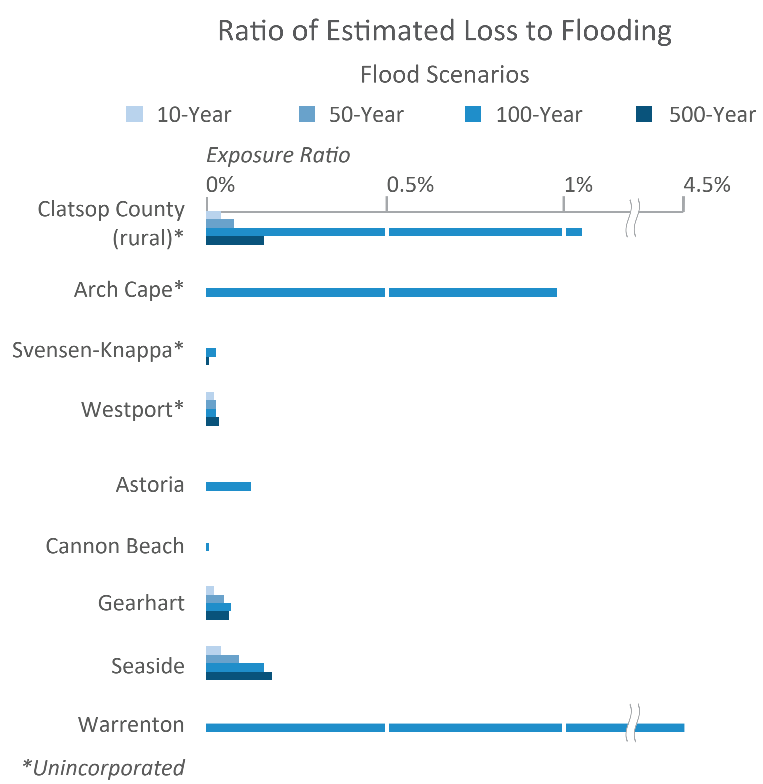
Flood Hazard Map of Clatsop County, Oregon

PLATE 5

Flood Hazard Zone

100-Year Flood (1% annual chance)

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 Clatsop Counties Digital Flood Insurance Rate Maps.



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Study Location Map

Data Sources:
Flood hazard zone (100-year): Clatsop County Flood Insurance Rate Map (2018)
Roads: Oregon Department of Transportation Signed Routes (2013)
Place names: U.S. Geological Survey Geographic Names Information System (2015)
City limits: Oregon Department of Transportation (2014)
Basemap: 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

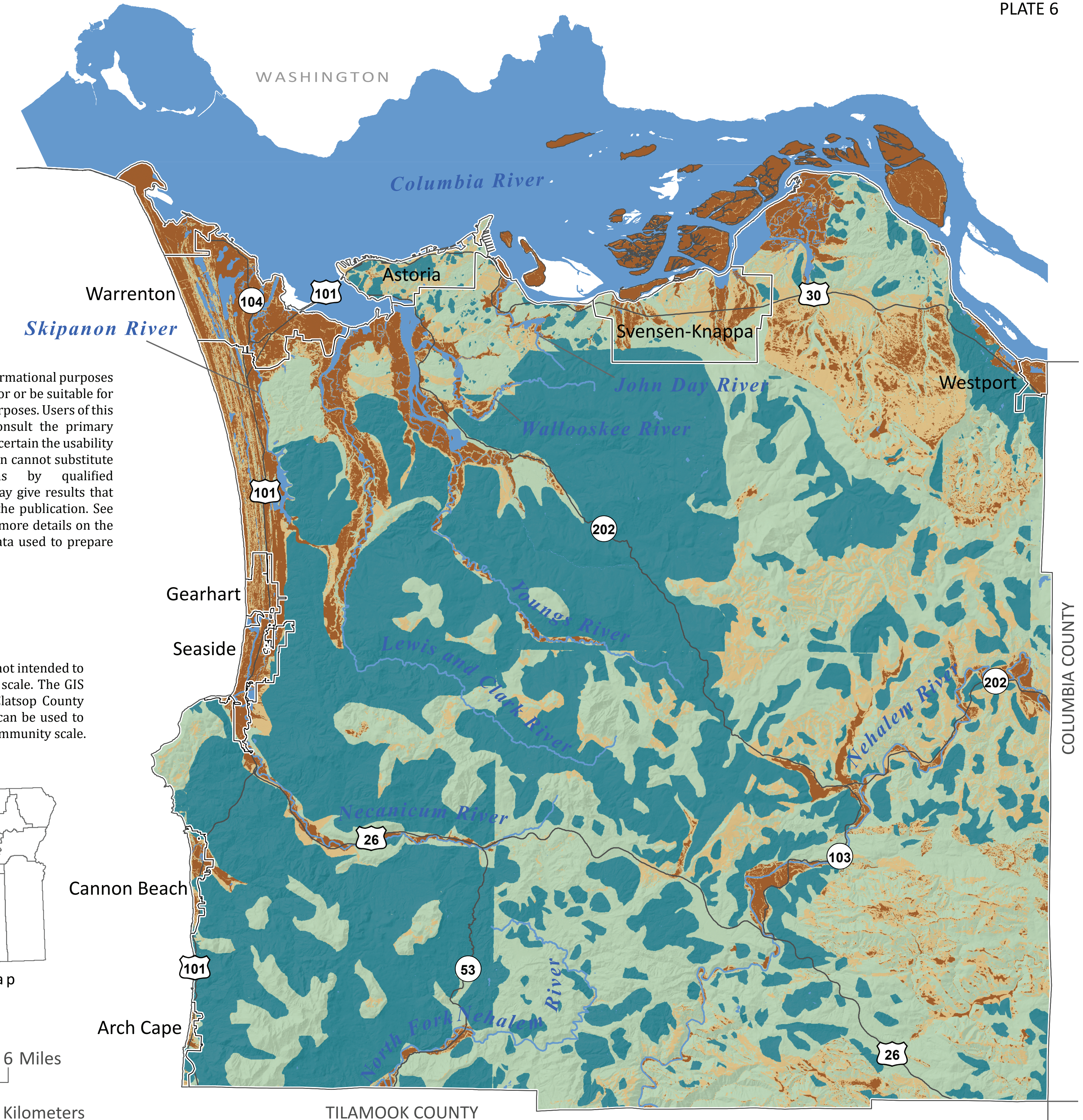
Landslide Susceptibility Map of Clatsop County, Oregon

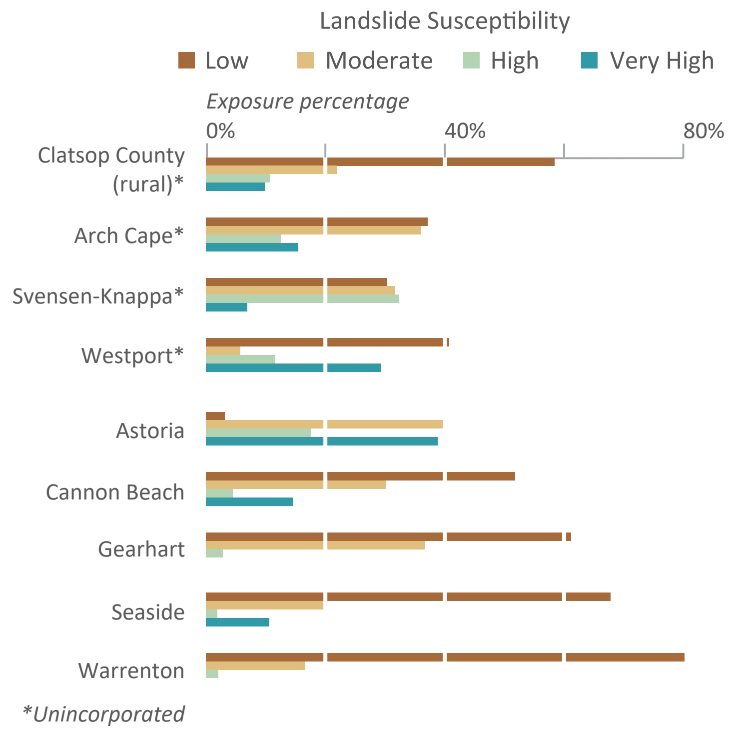
PLATE 6

Landslide Susceptibility

- Low
- Moderate
- High
- Very High

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.





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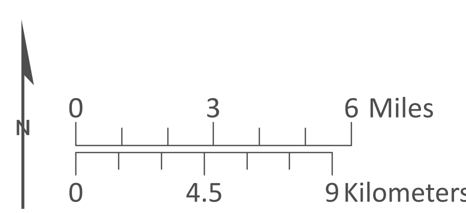
Study Location Map



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)
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

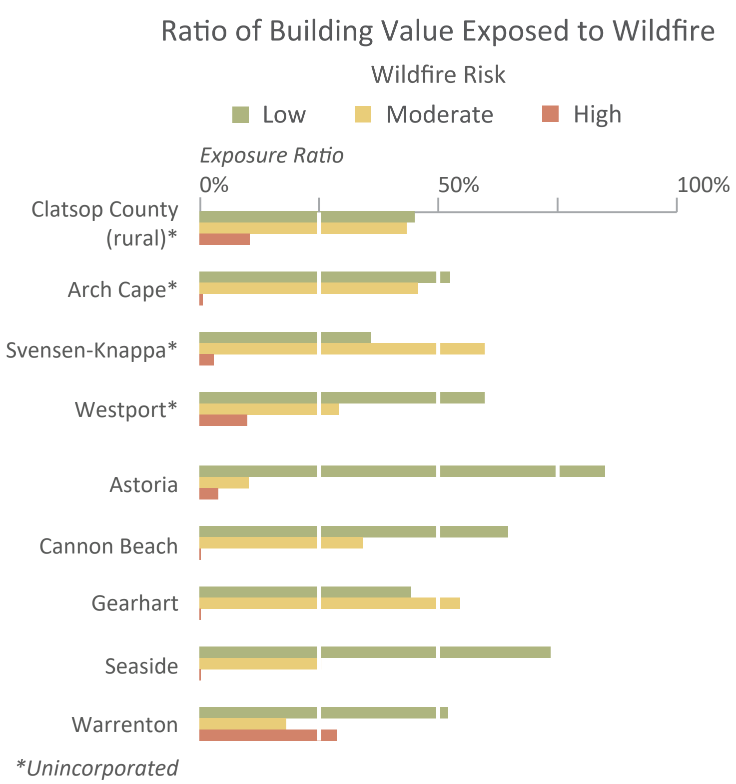
Wildfire Risk Map of Clatsop County, Oregon

PLATE 7

Wildfire Risk

- Low
- Moderate
- High

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).



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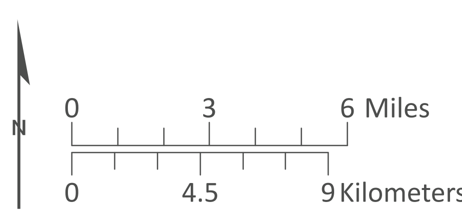
Study Location Map



Data Sources:
Wildfire risk data: Oregon Department of Forestry, Sanborn Map Company, Inc. (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)
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