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

INTERPRETIVE MAP 58

NATURAL HAZARD RISK REPORT FOR TILLAMOOK COUNTY, OREGON

INCLUDING THE CITIES OF BAY CITY, GARIBALDI, MANZANITA, NEHALEM, ROCKAWAY BEACH, TILLAMOOK, AND WHEELER AND THE UNINCORPORATED COMMUNITIES OF NESKOWIN, OCEANSIDE, NETARTS, AND PACIFIC CITY

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Cover photo: Tillamook River, Tillamook River Road, December 22, 2014, following a 2-year flood event. Credit: Outlier Solutions, Inc. and LightHawk.

WHAT'S IN THIS REPORT?

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

Oregon Department of Geology and Mineral Industries Interpretive Map 58
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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.

Tillamook_County_Risk_Report_Data.gdb

Feature dataset: Asset_Data

- feature classes:
  - Building_footprints (polygons)
  - UDF_points (points)
  - Communities (polygons)

Raster data: Hazard_Data

- FL_Depth_10.tif
- FL_Depth_50.tif
- FL_Depth_100.tif
- FL_Depth_500.tif

Metadata in .xml file format:

- Building_footprints.xml
- UDF_points.xml
- Communities.xml
- FL_Depth_10.xml
- FL_Depth_50.xml
- FL_Depth_100.xml
- FL_Depth_500.xml

EXECUTIVE SUMMARY

This report was prepared for the communities of Tillamook County, Oregon, with funding provided by the Federal Emergency Management Agency (FEMA). It describes the methods and results of the natural hazard risk assessments performed in 2016 by the Oregon Department of Geology and Mineral Industries (DOGAMI) within the study area. The purpose of this project is to provide communities within the study area a detailed risk assessment of the natural hazards that affect them to enable them to compare hazards and act to reduce their risk. The risk assessments contained in this project quantify the impacts of natural hazards to these communities and enhances the decision-making process in planning for disaster.

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

In the first task, we created a comprehensive asset database for the entire study area by synthesizing assessor data, U.S. Census information, Hazus-MH general building stock information, and building footprint data. This work resulted in a single dataset of building points and their associated building characteristics. With these data we were able to represent accurate spatial location and vulnerability on a building-by-building basis.

The second task was to identify and use the most current and appropriate hazard datasets for the study area. Most of the hazard datasets used in this report were created by DOGAMI and some were produced using high-resolution lidar topographic data. While not all the data sources used in the report are countywide, each hazard dataset were the best available at the time of writing.

In the third task, we performed risk assessments using Esri® ArcGIS Desktop® software. We performed 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, flood, and tsunami inundation scenarios, or susceptible to varying levels of hazard from landslides, coastal erosion, and wildfire.

The findings and conclusions of this report show the potential impacts of hazards in communities within Tillamook County. A Cascadia Subduction Zone (CSZ) event (earthquake and tsunami) will cause extensive damage and losses throughout the county. We ran Hazus-MH earthquake simulations to illustrate the potential reduction in earthquake damage through seismic retrofits. Flooding can be a recurrent problem for many communities in the study area and we quantify the number of elevated structures that are less vulnerable to flood hazard. Our analysis show 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 higher for the communities of Neskowin and Rockaway Beach than others part of Tillamook County. During the time of writing, the best available data show that wildfire risk is moderate for the overall study area. Our findings also indicate that most of the study area's critical facilities are at high risk to a CSZ event (earthquake and tsunami). We also found that the two biggest causes of population displacement are a CSZ event (earthquake and tsunami) and landslide hazard. Lastly, we demonstrate that this risk assessment can be a valuable tool to local decision-makers.

Results were broken out for the following geographic areas:

- Unincorporated Tillamook County (rural)
- Communities of Oceanside and Netarts
- City of Bay City
- City of Manzanita
- City of Rockaway Beach
- City of Wheeler
- Community of Neskowin
- Community of Pacific City
- City of Garibaldi
- City of Nehalem
- City of Tillamook

Selected Countywide Results
Total buildings: 27,371
Total estimated building value: $2.8 billion

Cascadia Subduction Zone Magnitude 9.0 Earthquake[a]
Red-tagged buildings[b]: 7,812
Yellow-tagged buildings[c]: 1,856
Loss estimate: $821 million

Cascadia Subduction Zone Tsunami Inundation
Number of buildings exposed: 5,167
Exposed building value: $561 million

100-year Flood Scenario
Number of buildings damaged: 1,999
Loss estimate: $26 million

Landslide Exposure (High and Very High Susceptibility)
Number of buildings exposed: 7,906
Exposed building value: $779 million

Coastal Erosion Exposure (Moderate Hazard)
Number of buildings exposed: 609
Exposed building value: $117 million

Wildfire Exposure (High Risk)
Number of buildings exposed: 565
Exposed building value: $48 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 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 enhances 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 Tillamook County. It is therefore the most detailed and comprehensive analysis to date of natural hazard risk and provides a comparative perspective never before available. In this report, we describe our assessment results, which quantify the various levels of risk that each hazard presents to Tillamook County communities.

The Oregon coast and Oregon Coast Range mountains 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 the cities and unincorporated communities. 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 community. 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** is a more detailed explanation of the Hazus-MH methodology. **Appendix D** lists acronyms and definitions of terms used in this report. **Appendix E** contains tabloid-size maps showing county-wide hazard maps.

1.2 Study Area

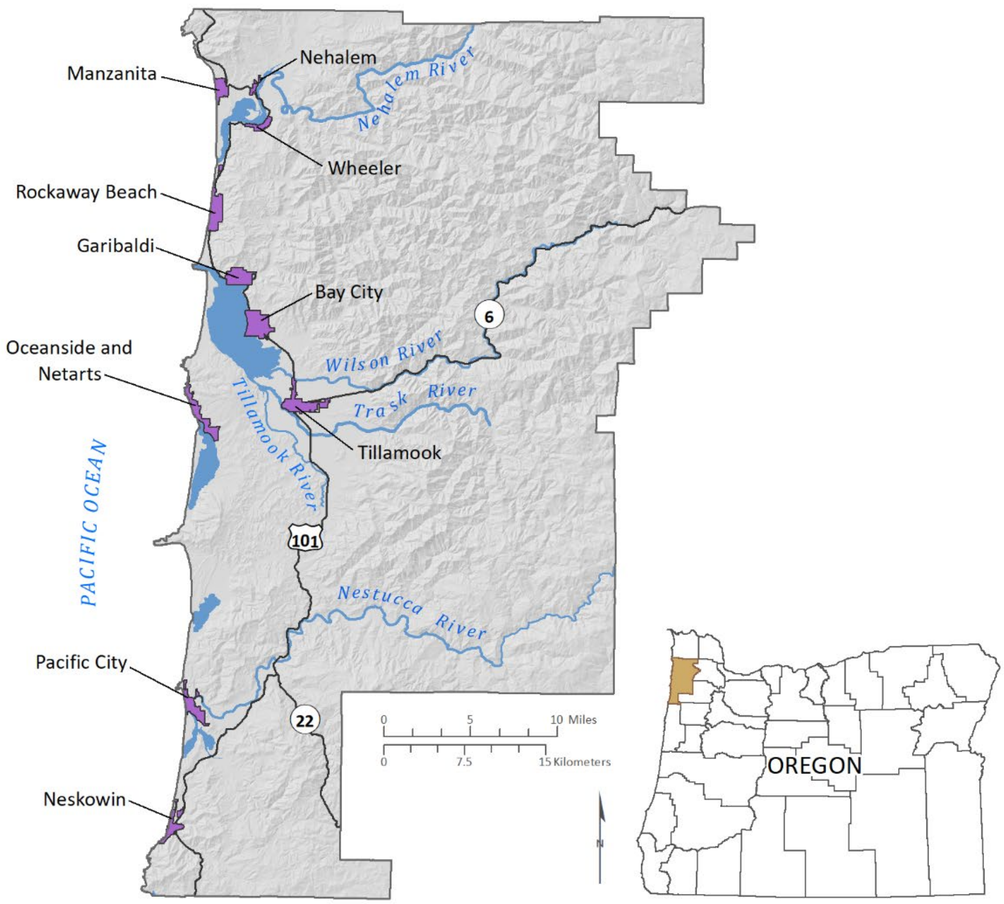
The study area for this project is the entirety of Tillamook County, Oregon. Tillamook County is a coastal county located in the northwestern portion of the state and is bordered by Clatsop County on the north, Washington and Yamhill Counties on the east, Polk and Lincoln Counties on the south, and the Pacific Ocean on the west. The total area of Tillamook County is approximately 1,125 square miles (2,914 square kilometers). A significant portion of the county is within the Tillamook State Forest 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, 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 Tillamook County is 25,250 according to the 2010 U.S. Census Bureau (2010). The county seat and county's largest community is the City of Tillamook. All the communities in the study, incorporated and unincorporated, are in the western portion of the county within a few miles of the Pacific Ocean. The incorporated communities are Bay City, Garibaldi, Manzanita, Nehalem, Wheeler, Rockaway Beach, and Tillamook (**Figure 1-1**). The unincorporated communities are Neskowin, Oceanside and Netarts, and Pacific City.

We selected these unincorporated communities on the basis of population size and density, which makes them distinct from the overall unincorporated county jurisdiction. The boundaries of the unincorporated communities are based on census block areas. We considered using the administrative boundaries defined for Community Planning Advisory Committees (CPACs) as proxies for unincorporated communities but determined that several CPAC areas were too small to produce useful results: building sample sizes would be too small to responsibly characterize losses and exposure relative to other communities. It was also determined that the census block-based areas are very similar to the CPAC boundaries for larger unincorporated communities that were included.

Figure 1-1. Study area: Tillamook County with communities identified.



1.3 Project Scope

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

A critical component of this risk assessment is a countywide building inventory developed from building footprint data and the Tillamook 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 9.0 event
- Exposure to five potential CSZ tsunami scenarios

Flood Risk Assessment

- Hazus-MH loss estimation to four recurrence intervals (10%, 2%, 1%, 0.2% annual chance)
- 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 Tillamook County.

Hazard	Scenario or Classes	Scale/Level of Detail	Data Source
Earthquake	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 (2016) data, included in GIS data for this report
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 Tillamook County	DOGAMI (Stimely and Allan, 2014)
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 where 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

Two previous risk assessments that include Tillamook County have been conducted 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 Tillamook County had a higher loss ratio than most counties in the state.

Wang and others (2001) conducted a Hazus-based earthquake study specifically for Tillamook County. The 2001 study used the same earthquake scenarios as in the Wang and Clark 1999 study. The primary difference was that the 2001 study used an updated version of Hazus-MH, including an updated building inventory and updated seismic hazard maps. The building inventory was further augmented by using a variety of sources (Wang and others, 2001).

We did not compare the results of this project with the results of these previous studies 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).

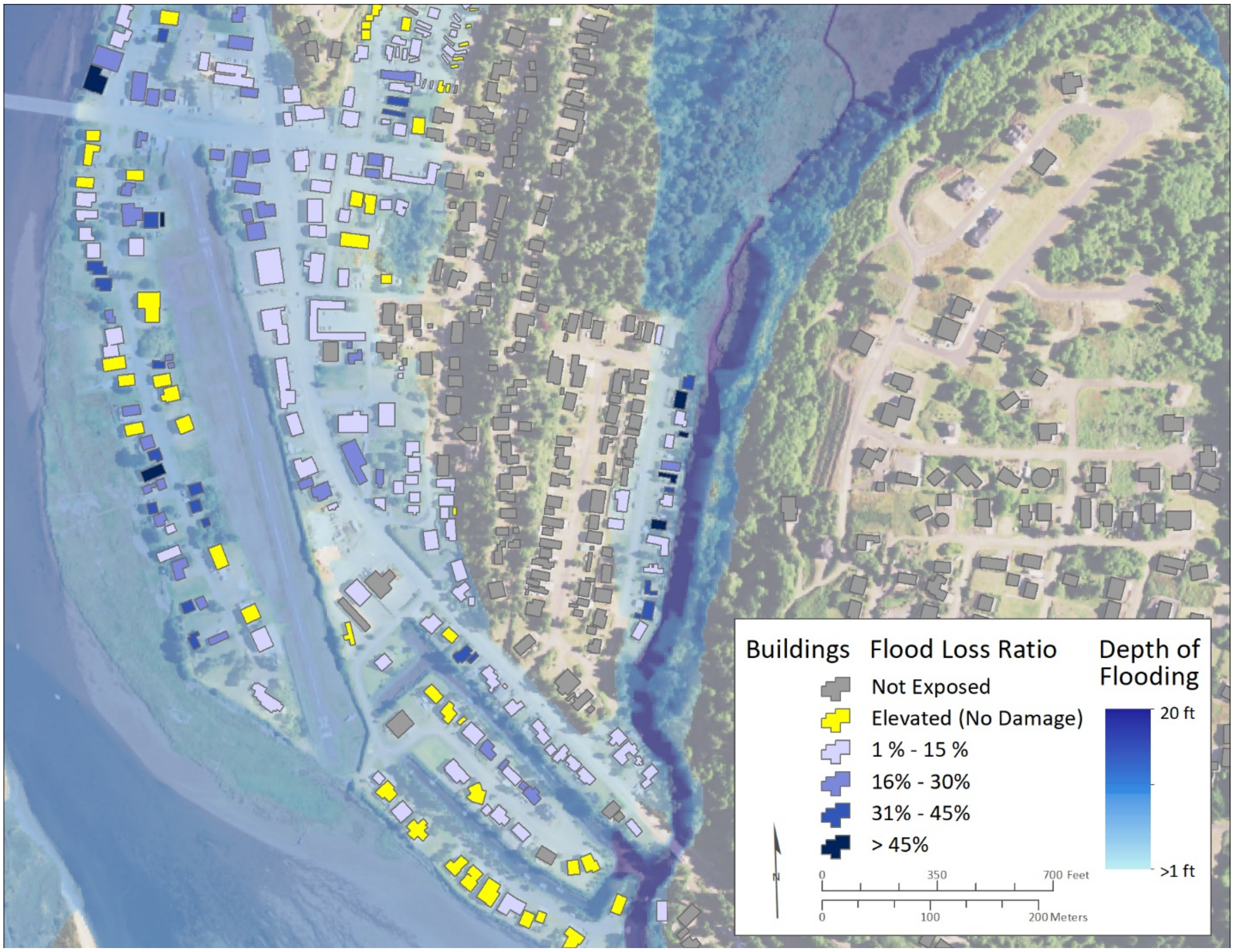
Hazus-MH can be used in different modes depending on the level of detail required. Given the high spatial precision of the building inventory data and quality of the natural hazard data, DOGAMI chose the user-defined facility (UDF) mode. This mode makes loss estimations for individual buildings relative 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 Tillamook 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 community of Pacific City.



2.2 Exposure

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

Exposure methodology 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.

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 Rockaway Beach. 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 (152 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 Tillamook 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 Tillamook.

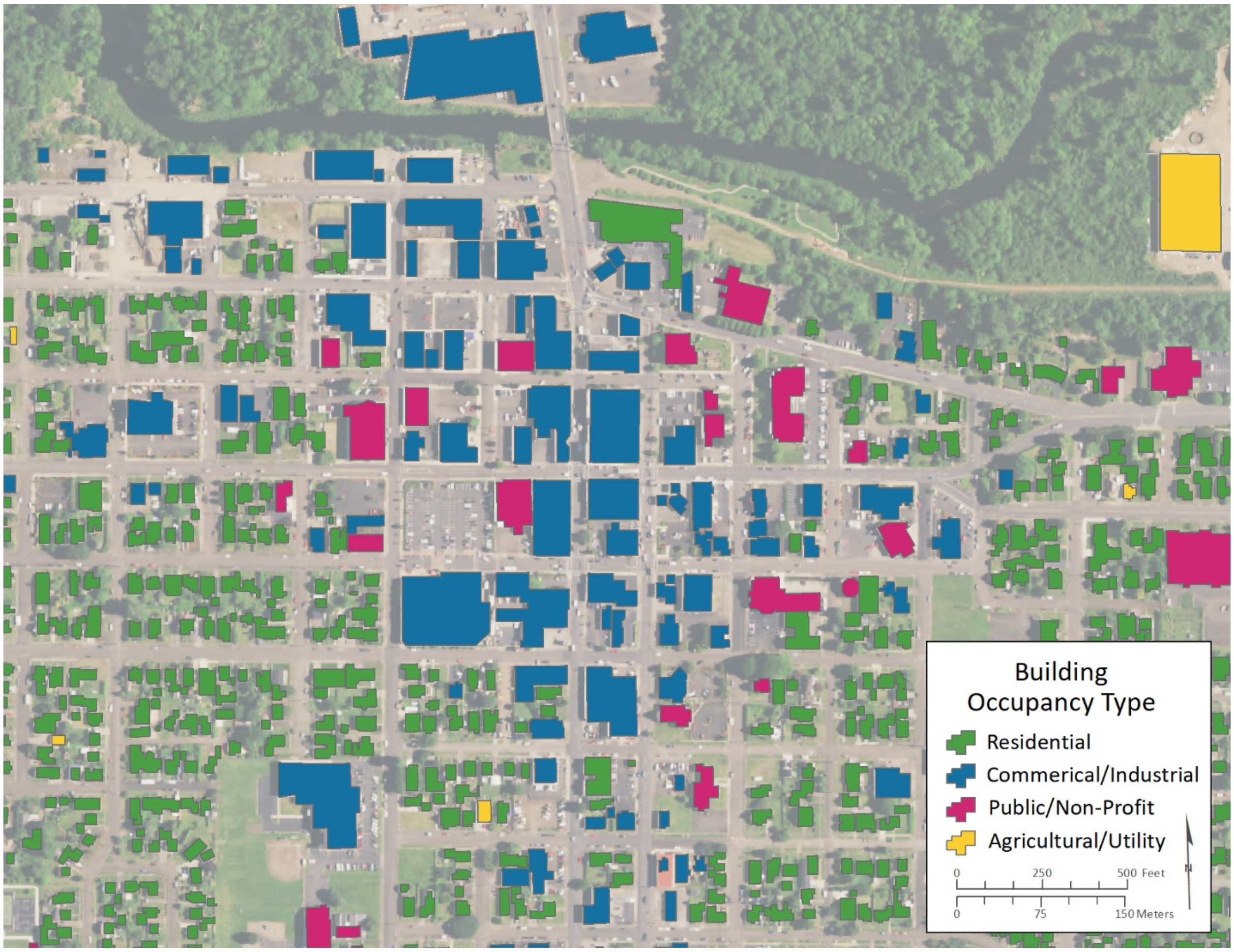


Table 2-1 shows the distribution of building count and value within the UDF database for Tillamook County. A table detailing the occupancy class distribution by community is included in **Appendix B: Detailed Risk Assessment Tables**.

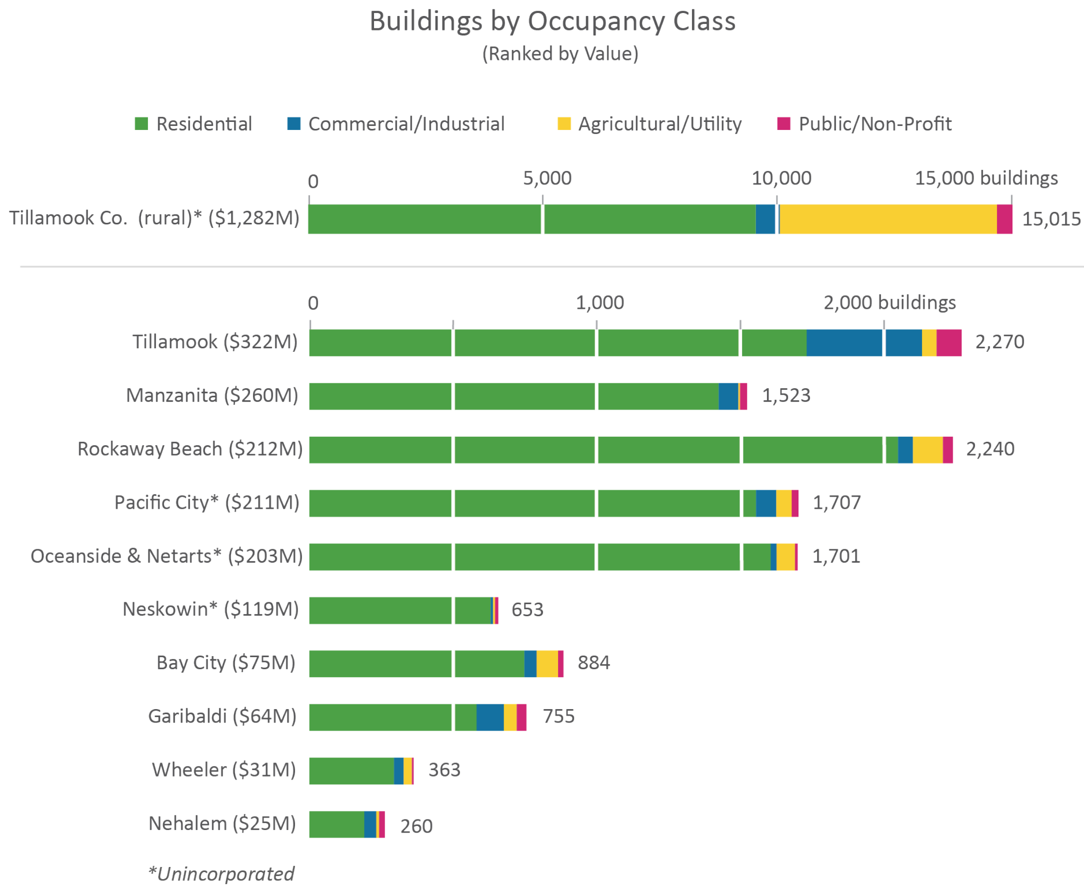
Table 2-1. Tillamook County building inventory.

Community	Total Number of Buildings	Percentage of Buildings of Tillamook County	Total Estimated Building Value ($)	Percentage of Building Value of Tillamook County
Unincorporated County (rural)	15,015	56%	1,282,436,000	46%
Neskowin	653	2%	118,463,000	4%
Oceanside & Netarts	1,701	6%	203,363,000	7%
Pacific City	1,707	6%	212,062,000	8%
Total Unincorporated County	19,076	70%	1,816,324,000	65%
Bay City	884	3%	74,769,000	3%
Garibaldi	755	3%	64,331,000	2%
Manzanita	1,523	6%	259,780,000	9%
Nehalem	260	1%	24,887,000	1%
Rockaway Beach	2,240	8%	211,809,000	8%
Tillamook	2,270	8%	322,398,000	11%
Wheeler	363	1%	30,556,000	1%
Total Tillamook County	27,371	100%	2,804,854,000	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 Tillamook 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.

Tillamook County supplied assessor data that we formatted for use in the risk assessment. The assessor data contains an array of information about each improvement (i.e., building). Taxlot data, which contains property boundaries and other information regarding the property, was obtained from the county assessor and was used to link the buildings with assessor data. The linkage between the two datasets resulted in a database of UDF points that contain attributes for each building. These points are used in the risk assessments for both loss estimation and exposure analysis. **Figure 2-4** illustrates the variation of building value and occupancy across the communities of Tillamook County.

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



Note that "Tillamook Co. (rural)" excludes the incorporated communities, Pacific City, Oceanside/Netarts, and Neskowin.

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. Tillamook County critical facilities inventory.

	Hospital & Clinic		School		Police/Fire		Emergency Services		Military		Other*		Total	
Community	Count	Value ($)	Count	Value ($)	Count	Value ($)	Count	Value ($)	Count	Value ($)	Count	Value ($)	Count	Value ($)
	(all dollar amounts in thousands)													
Unincorp. County (rural)	2	1,780	10	31,489	9	4,426	3	5,353	—	—	1	588	25	43,636
Neskowin	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Oceanside & Netarts	—	—	—	—	2	492	—	—	—	—	—	—	2	492
Pacific City	—	—	—	—	1	227	—	—	—	—	—	—	1	227
Total Unincorp. County	2	1,780	10	31,489	12	5,145	3	5,353	—	—	1	588	28	44,355
Bay City	—	—	—	—	1	231	2	784	—	—	1	2,770	4	3,785
Garibaldi	—	—	1	1,294	1	816	1	414	2	2,849	1	929	6	6,302
Manzanita	—	—	—	—	1	289	1	93	—	—	1	2,069	3	2,451
Nehalem	—	—	1	3,278	1	341	1	141	—	—	—	—	3	3,760
Rockaway Beach	—	—	1	241	2	209	1	1,699	—	—	1	677	5	2,826
Tillamook	2	11,531	7	20,549	2	570	3	1,701	—	—	—	—	14	34,351
Wheeler	1	2,455	—	—	—	—	1	135	—	—	—	—	2	2,590
Total Tillamook County	5	15,766	20	56,851	20	7,601	13	10,320	2	2,849	5	7,033	65	100,420

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

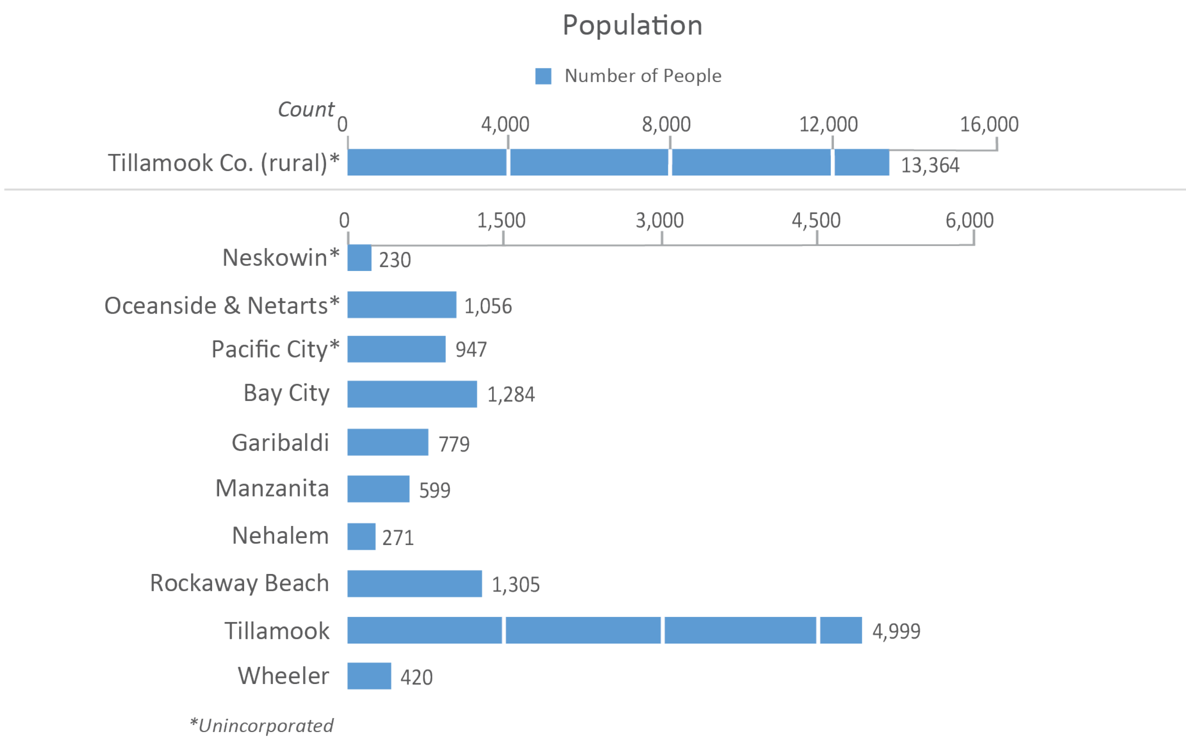
*Category includes buildings that are not traditional (emergency response) critical facilities but considered critical during an emergency based on input from local stakeholders (e.g. water treatment facilities or airports).

2.4 Population

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 a dataset provided by Tillamook County of vacation rentals within the unincorporated county, it is estimated that 7% to 12% of residential buildings in Tillamook County's coastal communities are vacation rentals.

Using this population distribution, DOGAMI estimated the number of permanent residents who could be affected by a natural hazard scenario. For each natural hazard, with the exception of the CSZ magnitude 9.0 earthquake scenario, a simple exposure analysis was used to find the number of potentially displaced residents within a hazard zone. For the CSZ magnitude 9.0 earthquake scenario the potentially displaced residents were 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 Tillamook County community.



Note that change in scale between the unincorporated county and communities.

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 Tillamook 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 entire county. The entire county includes all unincorporated areas, unincorporated communities, and cities within Tillamook County. Individual community results are in **Appendix A: Community Risk Profiles**.

3.2 Cascadia Subduction Zone Earthquake

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

Just off Oregon's coast, the Juan de Fuca tectonic plate slides under the North American plate. This area of interaction between the two plates is known as the Cascadia subduction zone (CSZ). The pressure and friction created by this convergent motion builds potential energy at the plate boundary until the overriding plate suddenly slips, releasing energy that manifests as strong shaking spread over a wide area. Earthquakes along the CSZ occur on average every 500 years and can be extremely large (Madin and Burns, 2013).

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.

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.

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 (1–3 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. We used this method along with the UDF database so that loss estimates could be calculated on a building-by-building basis.

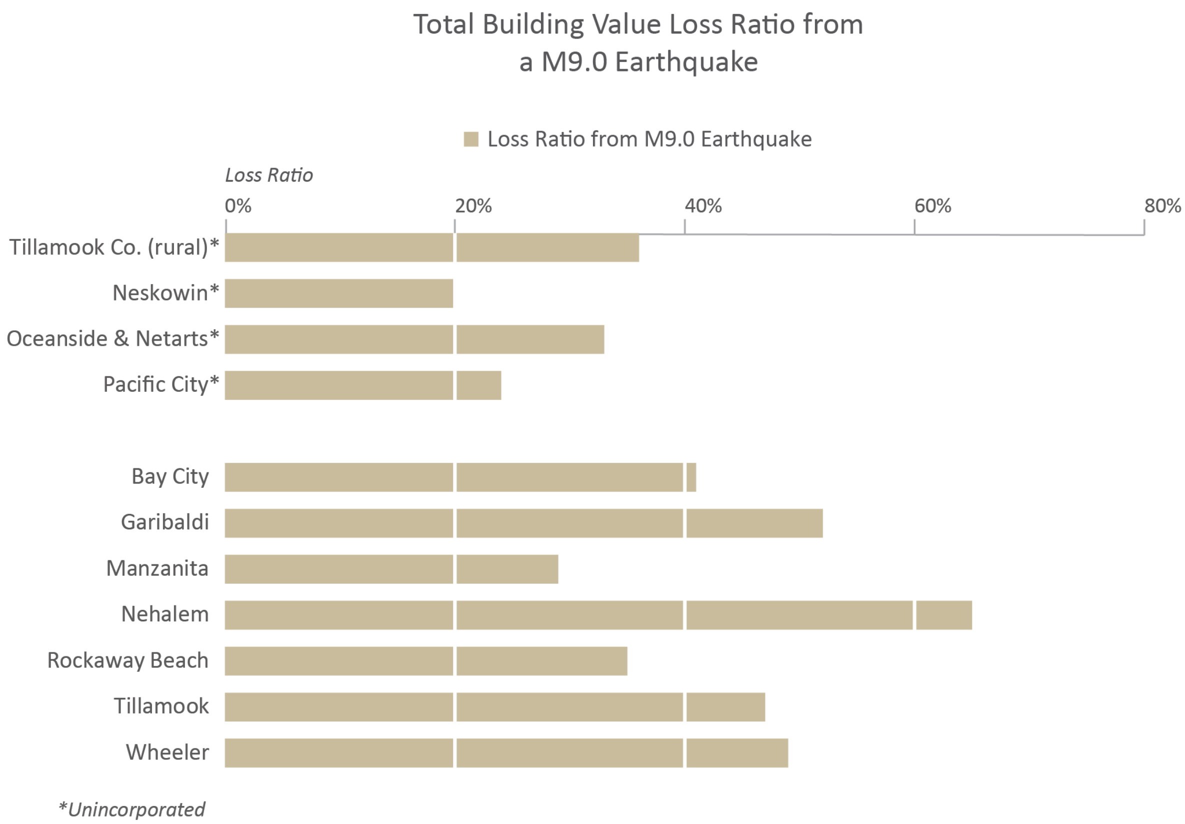
The following hazard layers used for our loss estimation are derived from work conducted by Madin and Burns (2013): National Earthquake Hazard Reduction Program (NEHRP) soil classification, peak ground acceleration (PGA), peak ground velocity (PGV), spectral acceleration at 1.0 second period and 0.3 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 equates 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 (personal 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 was a determining factor for their use in this report.

3.2.2 Countywide results

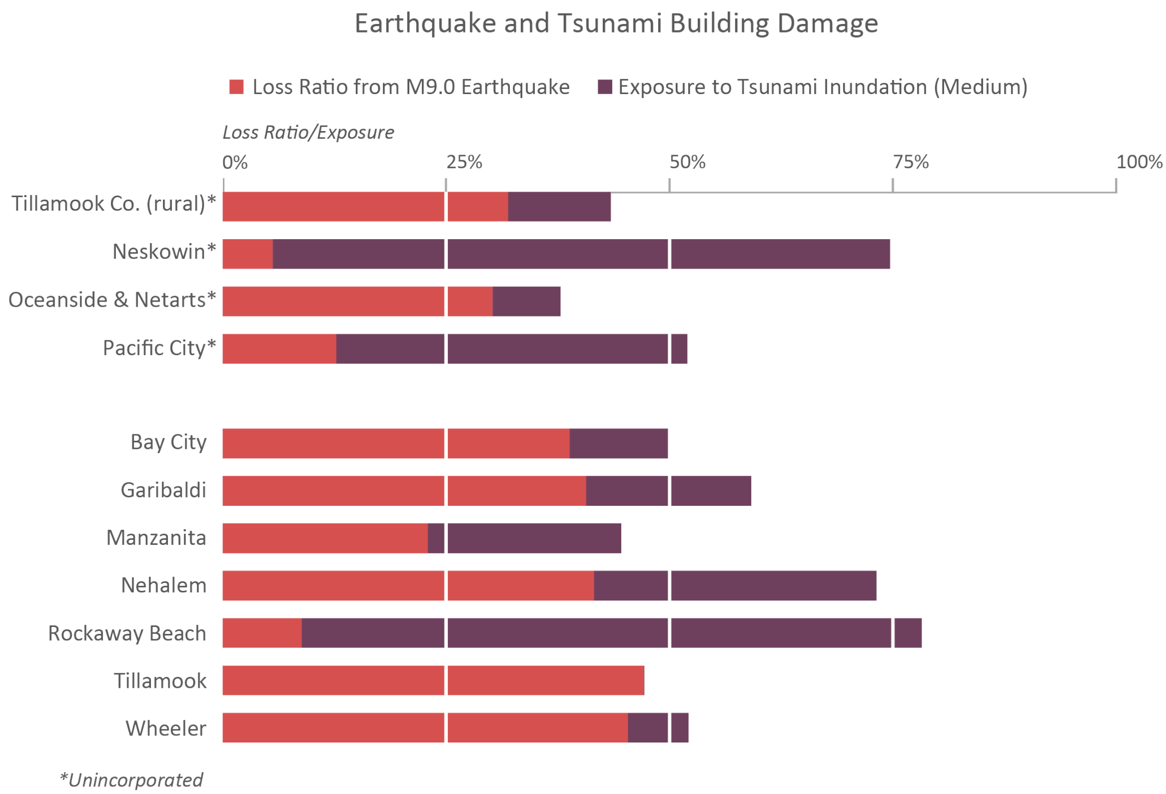
The CSZ event will produce severe ground shaking and ground failure, as well as a large and swift moving tsunami (Madin and Burns, 2013). Due to the nearly simultaneous timing of these two natural hazards, we have parsed loss estimate results to avoid double counting. That is, buildings within the (Medium-sized) 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 Tillamook County from a CSZ M9.0 event without the effects from tsunami.

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



Because an earthquake can affect a wide area, it is unlike other hazards in this report—every building in Tillamook 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 where coefficients are multiplied by each of the five damage state percentages (none, low, moderate, extensive, and complete). These damage states are correlated to loss ratios that are then multiplied by the building dollar value to obtain a loss estimate (FEMA, 2012b). 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 Tillamook County.

Figure 3-2. Loss ratio in Tillamook County, for both CSZ M9.0 earthquake and Medium-sized 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 postearthquake 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.

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

- Number of red-tagged buildings: 7,811
- Number of yellow-tagged buildings: 1,856
- Loss estimate: $820,687,000
- Loss ratio: 29%
- Non-functioning critical facilities: 57
- Potentially displaced population: 7,082

The results indicate that Tillamook County would incur significant losses (29%) 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 Tillamook County were built before modern seismic building code enforcement. Communities within Tillamook County that are composed of an older building stock are expected to experience more damage from earthquake than newer ones.

Moderate to high liquefaction zones exist throughout the county, which increases the risk from earthquake. Another consideration of these areas is that liquefaction could present difficulties for evacuation from the subsequent tsunami, since liquefaction areas correspond closely with the most likely tsunami inundation zone (Priest and others, 2015). This factor, as well as the overall average age of the building stock, along with the proximity of Tillamook County to the Cascadia subduction zone, results in high levels of damage.

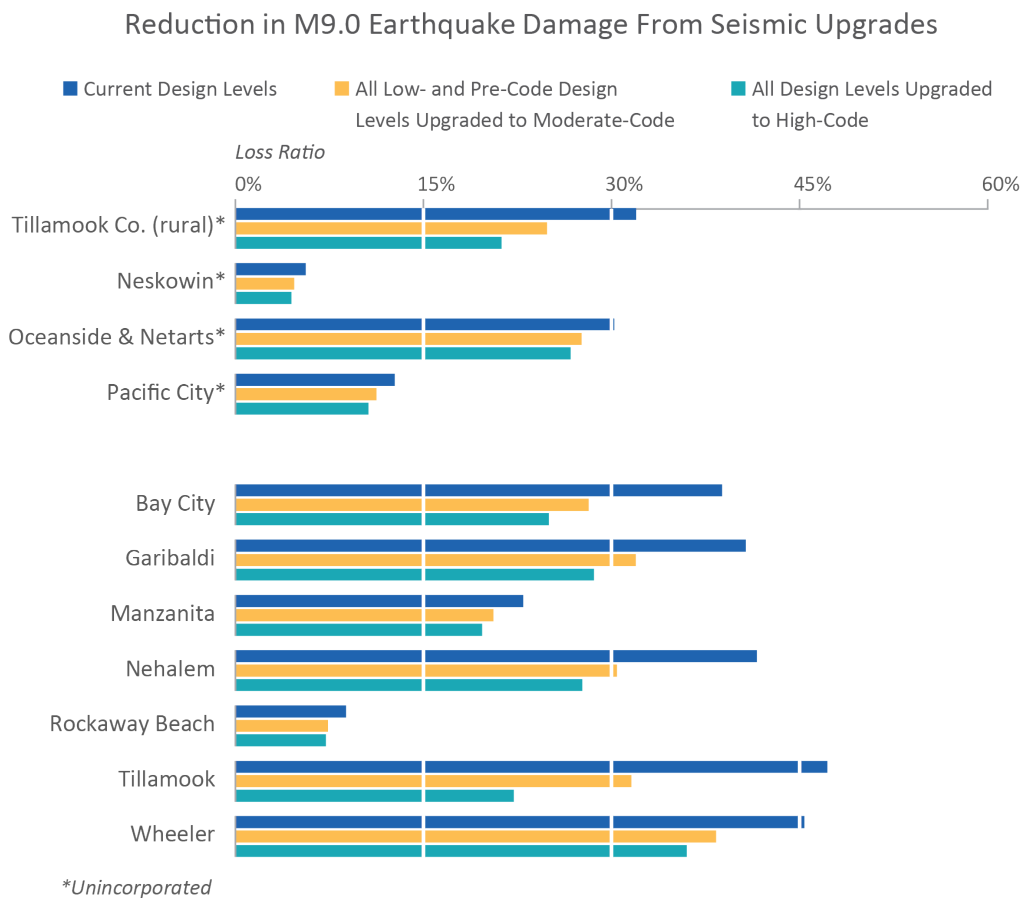
If buildings could be seismically retrofitted to moderate or high code standards, the impact of this event would be greatly reduced. In a simulation by DOGAMI, Hazus-MH earthquake analysis shows that loss estimates drop from 29% to 23%, when all buildings are upgraded to at least moderate code level. While retrofits can decrease earthquake vulnerability, the benefits are minimized in landslide and liquefaction areas, where buildings would

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.

need additional geotechnical mitigation to have an effect on losses. **Figure 3-3** illustrates the reduction in loss estimates from a CSZ M9.0 earthquake through two simulations where all buildings are upgraded to at least moderate code standards and then all buildings to high code standards. Communities that are mostly within the tsunami hazard zone would benefit less from seismic retrofits and would need additional tsunami mitigation to significantly reduce vulnerability.

Figure 3-3. CSZ M9.0 earthquake loss ratio in Tillamook 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:

- High liquefaction soils are found throughout Oceanside and Netarts, except for the northern hilly section of the community.

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.

- Large parts of the communities of Manzanita, Rockaway Beach, and Tillamook are within areas of high liquefaction.
- Building inventories for the communities of Bay City, Garibaldi, Nehalem, Tillamook, and Wheeler are relatively older and may correlate to areas built to lower seismic building codes.

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). 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 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 Tillamook 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 recurrence interval estimated with 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

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 threatened by tsunami hazard. See **Appendix B: Detailed Risk Assessment Tables** for cumulative multi-scenario analysis results.

3.3.2 Countywide results

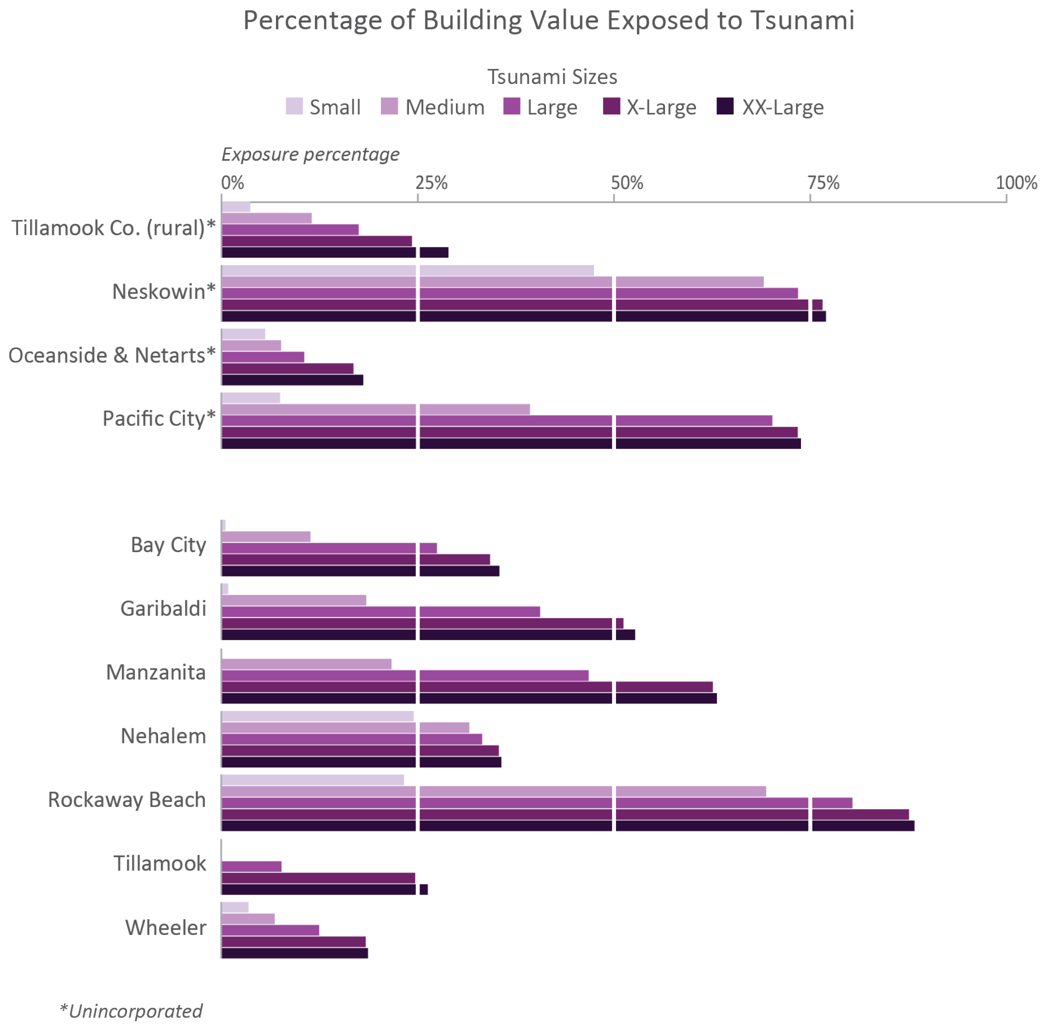
Because every community in this study is relatively near the Pacific Ocean, all communities would be affected by the largest (XXL) of the DOGAMI calculated tsunami scenarios. However, the Medium-sized tsunami was chosen as the primary scenario for this report because that category represents areas that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

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

- Number of buildings exposed: 5,167
- Exposure value: $561,327,000
- Percentage of exposure value: 20%
- Critical facilities exposed: 22
- Potentially displaced population: 2,310

The combination of earthquake and tsunami will have a significant impact to the entire coastal and estuarine portions of rural Tillamook County. Low-lying areas within coastal communities are predicted to be inundated by the Medium-sized tsunami scenario. Approximately a fifth of the county's buildings have exposure to tsunami inundation from the Medium-sized scenario. In some communities a high percentage of development is exposed to tsunami hazard. Two to three thousand 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 Tillamook County, awareness is important for future planning and mitigation efforts in these areas (**Figure 3-4**).

Figure 3-4. Tsunami inundation exposure by Tillamook 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 a CSZ generated Medium-sized tsunami hazard:

- Buildings along the Nestucca River in Pacific City are exposed to tsunami hazard, as portions of the city are within the Medium-sized tsunami zone.
- Buildings along Tillamook Bay in Bay City and Garibaldi are exposed to tsunami hazard.
- Buildings in Neskowin and Manzanita along the coast are exposed to tsunami hazard.
- Coastal and low-lying areas of Rockaway Beach are predicted to be inundated by the Medium-sized tsunami scenario. A significant portion of the community is exposed to this tsunami zone.
- Buildings in Wheeler and Nehalem along the Nehalem River are exposed to tsunami hazard.

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 the most common natural hazard in Tillamook County. Flooding has the potential to create public health hazards, public safety concerns, close and damage major highways, destroy railways, damage structures, and cause major economic disruption. A typical method for determining flood risk is to identify the probability of flooding and the impacts of flooding. The probabilities calculated for flood hazard used in this report are 10%, 2%, 1%, and 0.2%, henceforth referred to as 10-year, 50-year, 100-year, and 500-year scenarios, respectively.

All the rivers in the county drain westward and, eventually, into the Pacific Ocean. The major rivers within the county are the Nehalem, Miami, Wilson, Trask, Tillamook, and Nestucca. 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 Tillamook County's five estuaries.

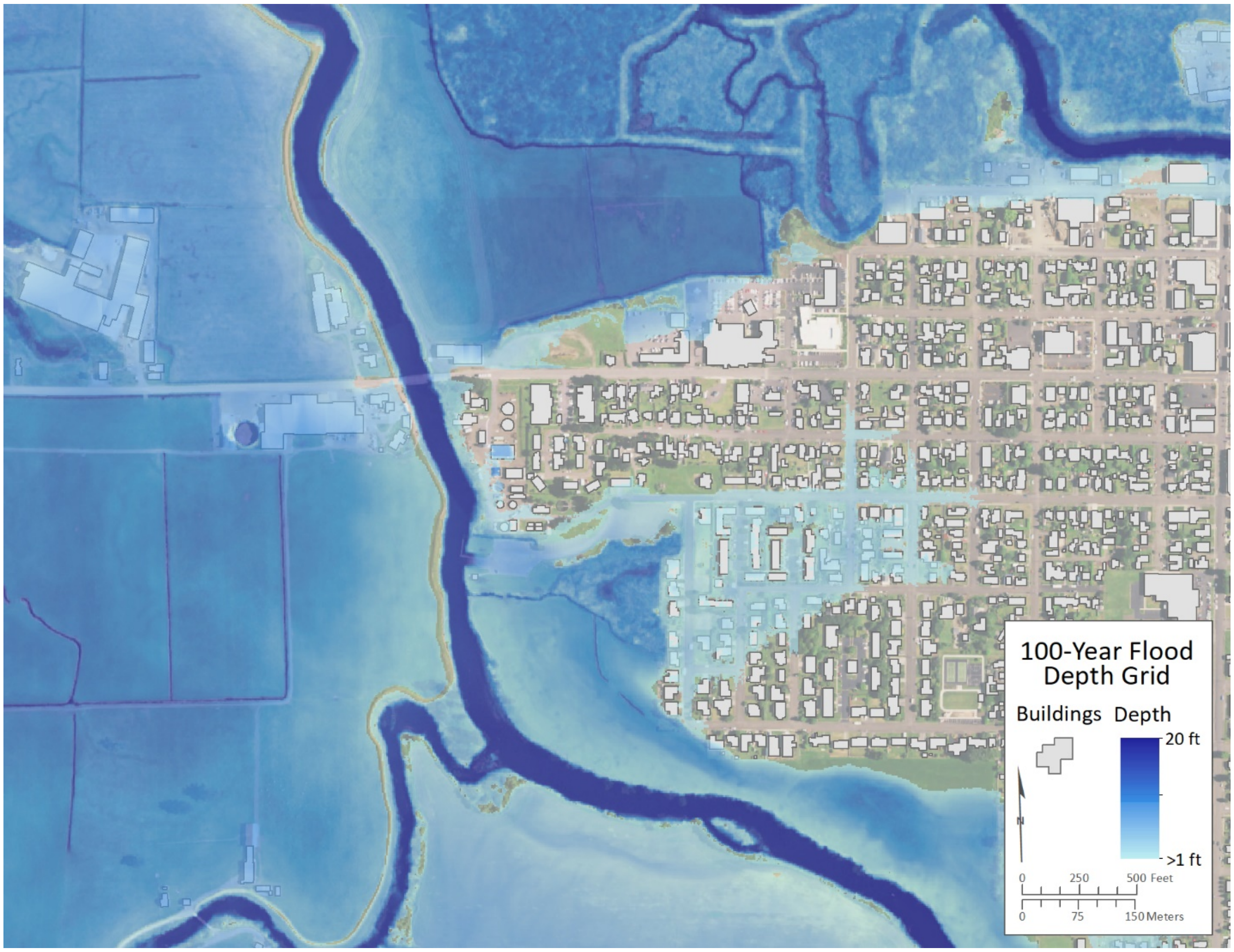
The ability to assess the probability of a flood, and the level of accuracy of that assessment is influenced by modeling methodology advancements, better knowledge, and longer periods of record for the stream or water body in question. The impacts of flooding are determined by adverse effects to human activities within the area and the natural and built environment. Examples of common mitigating activities are to elevate structures above the expected level of flooding or by removing the structure through FEMA's property acquisition ("buyout") program.

3.4.1 Data sources

The Flood Insurance Study (FIS) and Flood Insurance Rate Maps (FIRMs) for Tillamook County were updated in 2016 (FEMA, 2016) and included a recently completed study of coastal flooding (Allan and others, 2015); these were the primary data sources for the flood risk assessment in this report. As of the completion of this report in 2017, the FIS and FIRMs were released as preliminary products. The currently effective FIS and FIRMs were adopted in 1978. Further information regarding the National Flood Insurance Program (NFIP) related statistics can be found on the FEMA website: https://www.fema.gov/policy-claim-statistics-flood-insurance. These were the only flood data sources that DOGAMI used in the analysis, but flooding does occur in areas outside of the detail mapped areas. Flood issues like flash flooding, ice jams, post-wildfire floods, and dam safety were not looked at in this report.

Depth grids, developed by DOGAMI in 2015 to revise the Tillamook 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 where each digital pixel value represents the depth of flooding at that location within the flood zone **(Figure 3-5)**. Though considered draft at the time of this analysis, the depth grid data are the best available flood hazard data. Depth grids for four 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 Tillamook.



Building loss estimates are determined in Hazus-MH by overlaying building data over 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 Tillamook 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 properly elevated above the flood level were not given a loss estimate—but we counted 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.

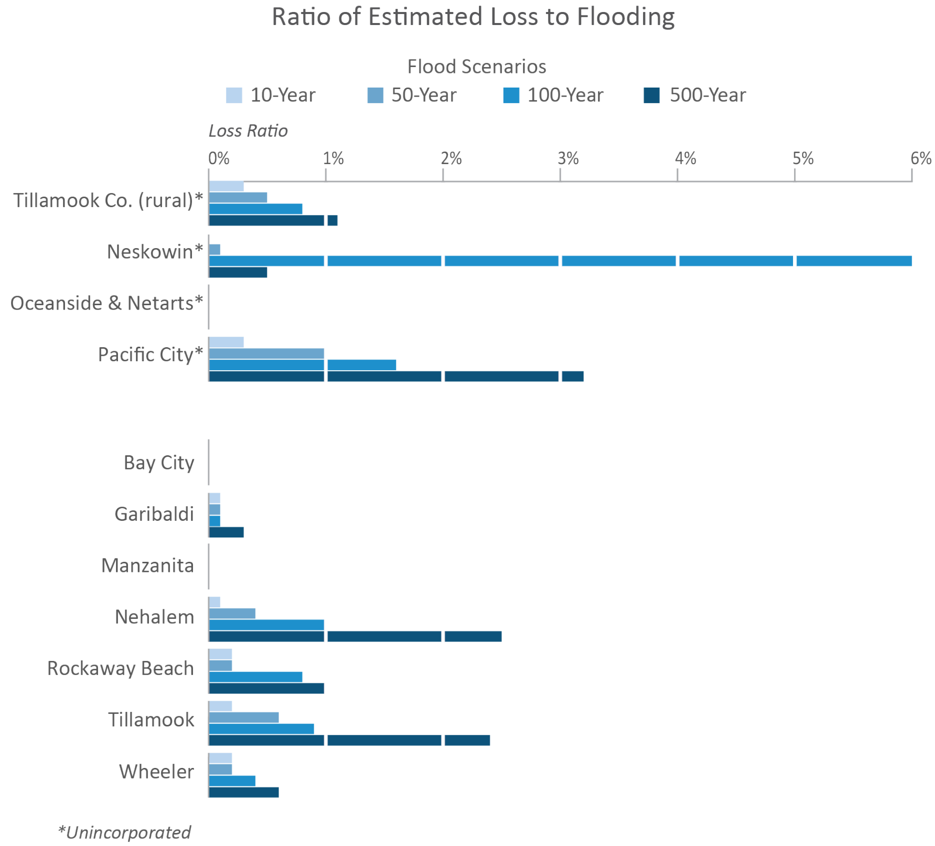
Tillamook countywide 100-year flood loss:

- Number of buildings damaged: 1,999
- Loss estimate: $25,831,000
- Loss ratio: 0.9%
- Damaged critical facilities: 5
- Potentially displaced population: 2,115

3.4.3 Hazus-MH analysis

The Hazus-MH loss estimate for the 100-year flood scenario for the entire county is over $25 million. Both riverine and coastal flooding have a significant impact on Tillamook 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 will provide the greatest resilience to flooding.

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



Note: In addition to the four riverine flood scenarios, coastal flooding information is only available for the 100-year flood scenario for portions of Tillamook County (rural) and the communities of Bay City, Garibaldi, Manzanita, Neskowin, Oceanside and Netarts, and Rockaway Beach.

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. A significant number (10%) of Tillamook County's buildings were found to be within designated flood zones. By comparing the number of non-damaged buildings from Hazus-MH with exposed buildings in the flood zone, we can estimate the number of buildings that could be elevated above the level of flooding. Of the 2,736 buildings that are exposed to flooding, we estimate that 27% or 737 buildings are above the height of the 100-year flood. This evaluation may identify the potential number of residents that 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:

- Developed areas within Neskowin along Neskowin Creek, Kiwanda Creek, and the Pacific Ocean are exposed to the 100-year flood.
- Flood hazard in Pacific City is present along the Nestucca River floodplain.

- Many buildings in the low-lying business area of Nehalem are particularly vulnerable to flooding. This area, along the riverbank, is subject to the 100-year flood due to the close proximity of the Nehalem River. Mitigation actions, such as elevating buildings, may have reduced their vulnerability to flood hazard in this area.
- Many buildings in the low-lying areas of Rockaway Beach along the Pacific Ocean, Rock Creek, and other minor creeks are exposed to the 100-year flood.
- The City of Tillamook lies between two major floodplains created by the Trask, Wilson, and Tillamook Rivers, and their many adjoining tributaries. Many buildings in the low-lying areas of the city are exposed to the 100-year flood.

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 Tillamook 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, they are large, deep, and slow moving or small, shallow, and rapid. Some factors that influence landslide type are hillside slope, water content, and geology. Many triggers can cause a landslide: intense rainfall, earthquakes, or human-induced factors like excavation along a landslide toe or loading at the top. Landslides can cause severe damage to buildings and infrastructure. Fast-moving landslides may pose life safety risks and can occur throughout Oregon (Burns and others, 2016).

3.5.1 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 very recently using new technologies, like lidar-derived topography, and some studies were performed more than 50 years ago. Consequently, SLIDO data vary greatly in scale, scope, and focus and thus in accuracy and resolution across the state. Most of the landslide inventory mapping for Tillamook County was done in the early 1970s. DOGAMI remapped landslide inventory and susceptibility using modern methods for the inhabited portions of Tillamook County in 2019. The landslide risk assessment presented in this report was conducted prior to this 2019 study.

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. Land value losses due to landslides were not examined for this report, in addition to potentially hazardous unmapped areas that may pose real risk to communities.

3.5.2 Countywide results

Many Tillamook 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 runs through eastern Tillamook County, so much of the area is steep and landslide prone. The combination of rugged terrain, historically active landslides, large amounts of rainfall, and frequent large earthquakes make landslide hazard 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. These susceptibility zones represent areas most prone to landslides with the highest impact to the community.

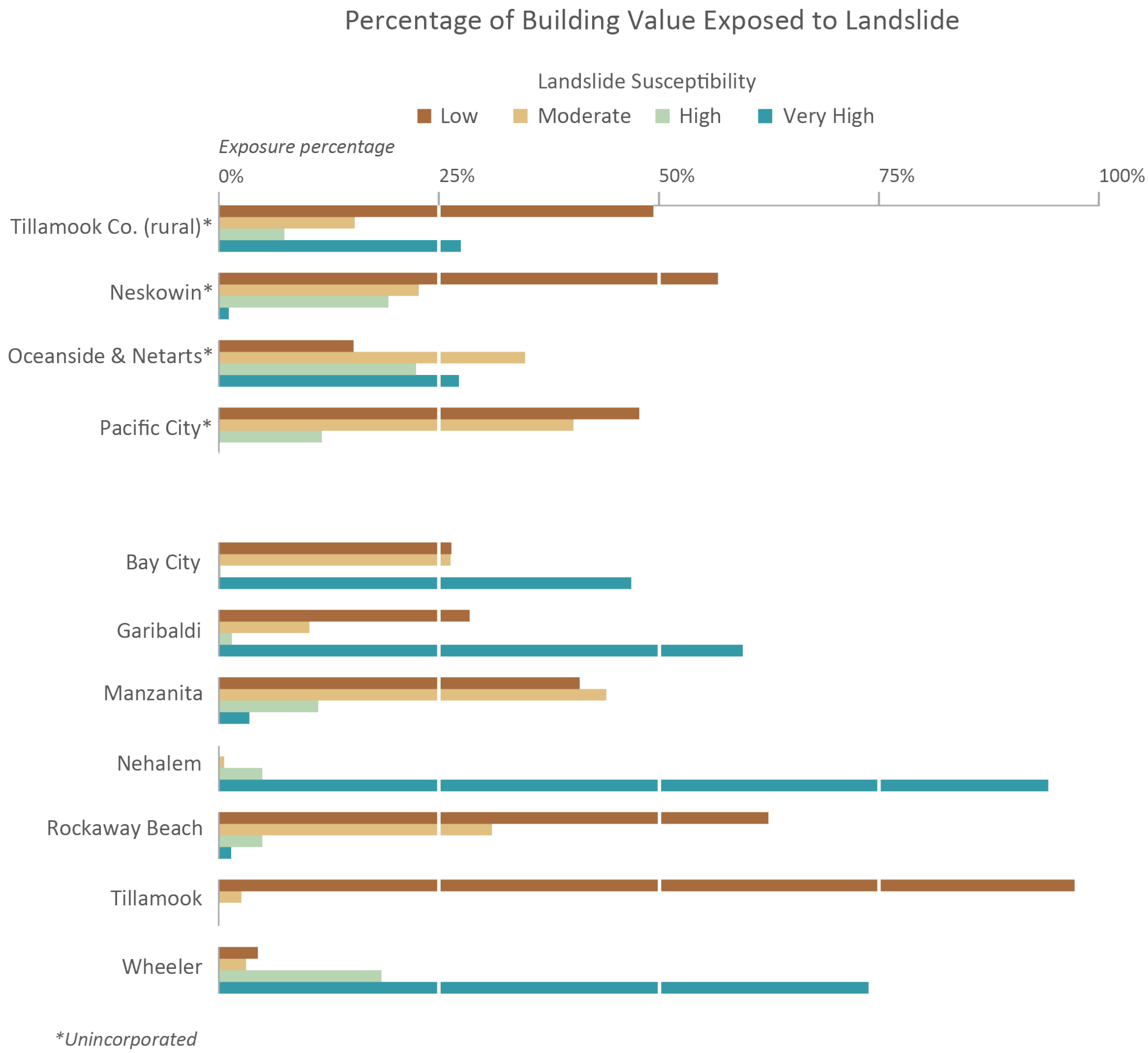
For this risk assessment we compared building locations to geographic extents of the landslide susceptibility zones (**Figure 3-7**). The exposure results shown below are for the high and very high susceptibility zones. See **Appendix B: Detailed Risk Assessment Tables** for multi-scenario analysis results.

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

- Number of buildings: 7,906
- Exposure value: $779,159,000
- Percentage of exposure value: 28%
- Critical facilities exposed: 18
- Potentially displaced population: 7,121

The majority of buildings in Tillamook County corresponds to low and moderate susceptibility landslide zones. Still, approximately one third 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 is beneficial to reducing risk for every community and rural area of the county.

Figure 3-7. Landslide susceptibility exposure by Tillamook 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:

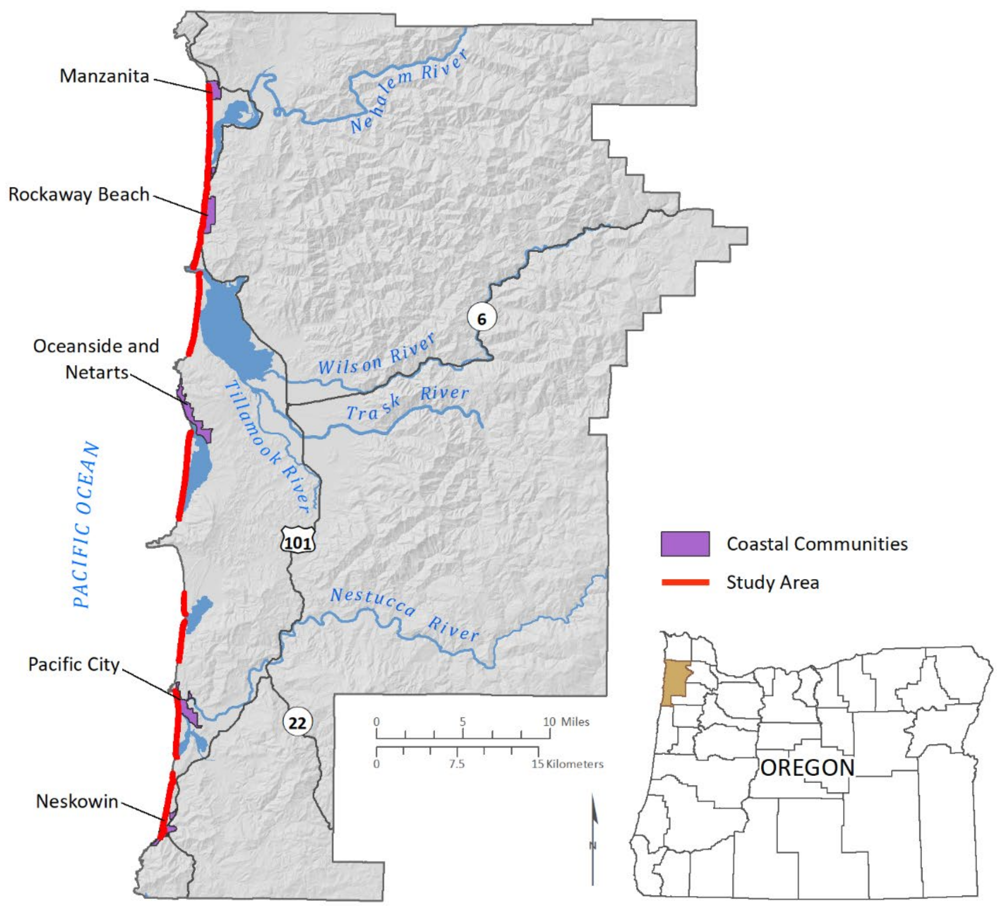
- The landslide hazard for Oceanside and Netarts poses the biggest natural hazard risk to the community. An area deemed very high susceptibility to landslides makes up a large portion of Oceanside.
- An area deemed very high susceptibility to landslides makes up approximately half of the entirety of Bay City. The hilly residential area in the northwest part of Bay City is within a very high landslide susceptibility zone.
- An area deemed very high susceptibility to landslides makes up the majority of Garibaldi and Wheeler.

- A preexisting landslide zone, which is considered very high susceptibility to landslides, has been designated for much of the Nehalem River and surrounding hills. An area deemed very high susceptibility to landslides makes up the majority of the community of Nehalem.

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 subject to coastal erosion studied by Stimely and Allan (2014) in Tillamook County.

Figure 3-8. Stimely and Allan (2014) coastal erosion study area extent.



3.6.1 Data sources

Stimely and Allan (2014) determined coastal erosion hazard zones for dune-backed beaches in Tillamook County by using two methods: storm-induced erosion and erosion due to sea level rise. The final derived hazard zones reflect the combined effect of both sets of processes. We categorized the coastal erosion hazard zones defined by Stimely and Allan (2014) to indicate levels of probability as high, moderate, and low. We based the high hazard zone on a mid-range estimate of 2030 sea level rise (SLR) along with 2%

annual chance (50-year) storm total water level scenario. We based the moderate hazard zone on mid-range 2050 SLR along with the 2% annual chance storm total water level, and the low hazard zone on mid-range 2100 SLR along with the 1% annual chance (100-year) storm total water level.

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 Tillamook County. Coastal communities in Tillamook 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 exposure results for the different coastal erosion hazard zones are cumulative, meaning that buildings within the high hazard zone are also within the moderate hazard zone and buildings within high or moderate hazard zones are also within the low hazard zone. The moderate hazard category (mid-range 2050 SLR) 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. The low hazard does not represent no risk, but rather is a zone of lower probability of occurrence than the high or moderate zones.

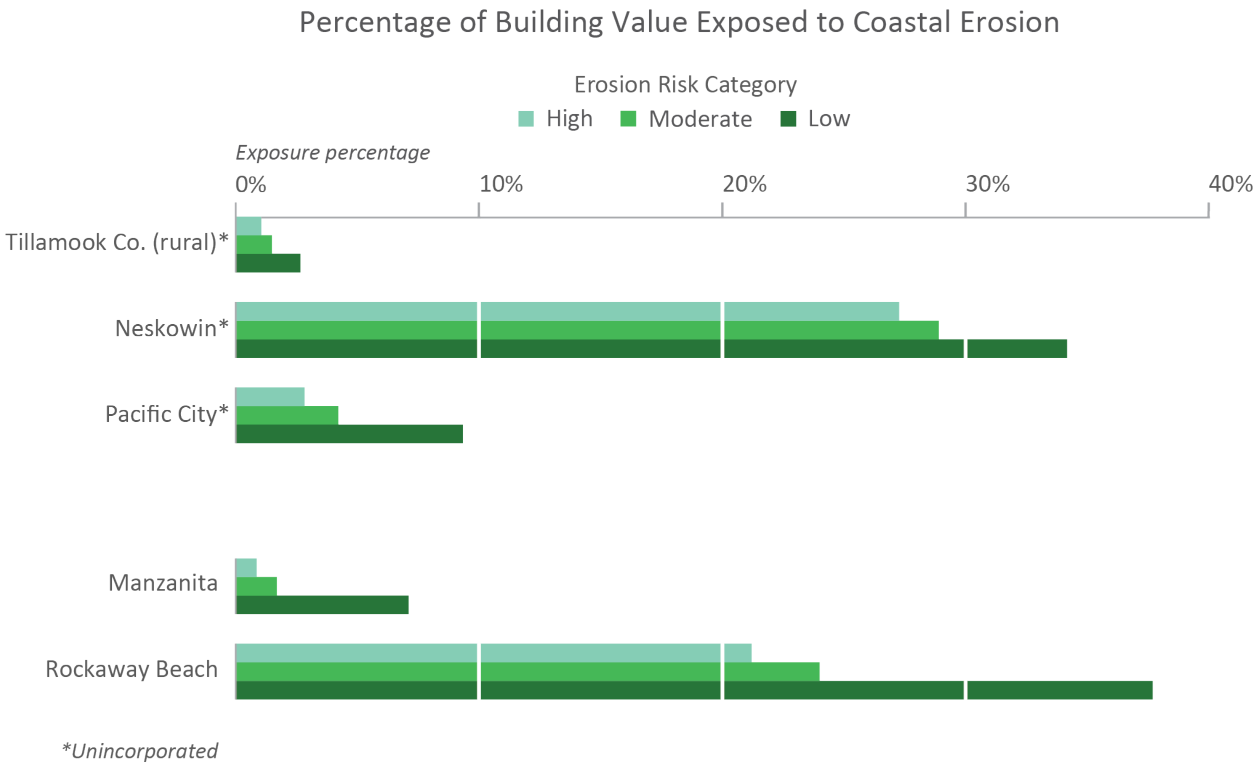
For this risk assessment, we limited the results of the exposure analysis to the communities included in the report by Stimely and Allan (2014), which are those communities along the coast with dune-backed beaches. The "Percentage of exposure value" below does not factor in the noncoastal incorporated communities of Tillamook County. See **Appendix B: Detailed Risk Assessment Tables** for multi-scenario analysis results.

Tillamook countywide coastal erosion exposure (Moderate hazard):

- Number of buildings: 609
- Exposure value: $117,050,000
- Percentage of exposure value: 5.6%
- Critical facilities exposed: 0
- Potentially displaced population: 156

Most coastal communities and unincorporated areas of Tillamook County have a marginal level of exposure to coastal erosion; the exceptions are Neskowin and Rockaway Beach. These two communities have approximately one quarter of their overall building value exposed to moderate coastal erosion hazard. Awareness of this hazard is beneficial to reducing risk for future developments along Tillamook 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 Tillamook County.

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



Note: Beyond the designated communities, in unincorporated Tillamook County, building values total $13.4 million in areas of high coastal erosion hazard, $18.9 million in areas of moderate hazard, and $33.9 million in areas of low hazard.

3.6.3 Areas of vulnerability or risk

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

- The residential area in Neskowin along the coast and north of the Neskowin Creek mouth is likely to experience coastal erosion.
- Coastal erosion risk exists in Pacific City for several homes along the beach just north of the Pacific Avenue Bridge.
- The entire mostly residential area along the coast in Rockaway Beach is likely to experience coastal erosion. During times of high tide occurring along with powerful storms, the rate of erosion can greatly increase.

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 often development occurs in the wildland-urban interface (WUI) (Sanborn Map Company, Inc., 2013). The most common wildfire conditions include hot, dry, and windy weather; the inability of fire protection forces to contain or suppress the fire; the occurrence of multiple fires that overwhelm committed resources; and a large fuel load (dense vegetation). Once a fire has started, its behavior is influenced by numerous conditions, including fuel, topography, weather, drought, and development (Sanborn Map Company, Inc., 2013). Post-wildfire geologic hazards can also present risk. These usually include flooding, debris flows, and landslides. Post-wildfire geologic hazards were not evaluated in this project.

There is potential for losses due to WUI fires in Tillamook County. Forests cover approximately 90% of Tillamook County. Forests play an important role in the local economy but also surround homes and businesses (VLG Consulting and Pearson, 2011). In an effort to limit exposure to wildfire, Tillamook County's Comprehensive Plan (Tillamook County Planning Commission, 1982) provides guidance on reducing risk to wildfire. Contact Tillamook 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, 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 Tillamook County.

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

We overlaid the buildings layer and critical facilities on each of the fire risk zones to determine exposure. In certain areas no wildfire data is present which 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

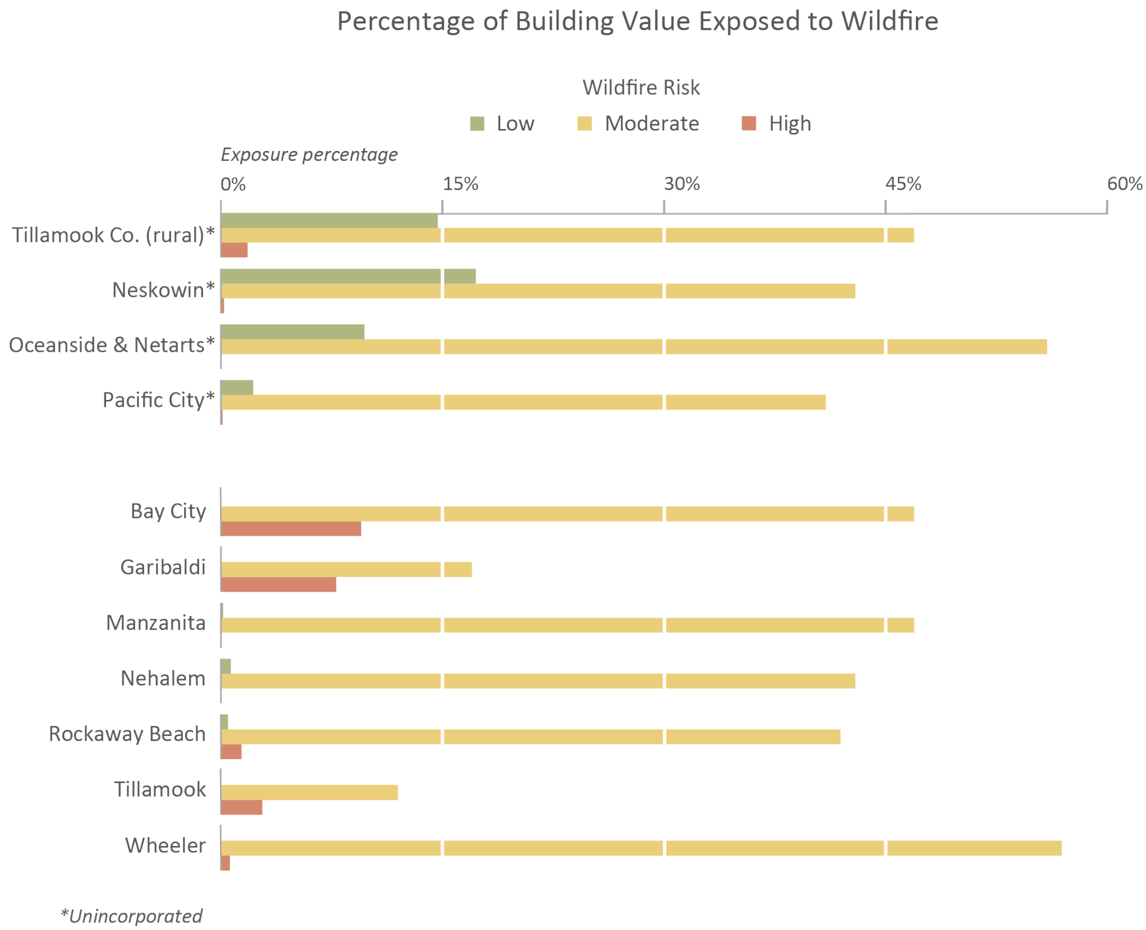
The high-risk category was chosen as the primary scenario for this report because that category represents areas that have the highest potential for losses. However, a large amount of loss would occur if the moderate risk areas were to burn, as almost every community has ~40–50% of exposure to moderate wildfire risk. Still, the focus of this section is on high risk areas within Tillamook County to emphasize the areas where lives and property are most threatened.

Tillamook countywide wildfire exposure (High risk):

- Number of buildings: 565
- Exposure value: $47,527,000
- Percentage of exposure value: 1.7%
- Critical facilities exposed: 4
- Potentially displaced population: 590

For this risk assessment, building locations were compared to the geographic extent of the wildfire risk categories. We found that most communities in Tillamook County do not have high risk exposure to wildfire with 1.7% of countywide building value exposed. The primary areas of exposure to this hazard are in the forested unincorporated areas of the county (see Appendix E, **Plate 7**). The communities of Bay City, Garibaldi, and to a certain extent Tillamook 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 Tillamook County. See **Appendix B: Detailed Risk Assessment Tables** for multi-scenario analysis results.

Figure 3-10. Wildfire risk exposure by Tillamook 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 forested areas in the eastern portion of unincorporated Tillamook County (rural).

4.0 CONCLUSIONS

The purpose of this study is to provide a better understanding of potential impacts from multiple natural hazards at the community scale. We accomplish this by using the latest natural hazard mapping and loss estimation tools to quantify expected damage to buildings and potential displacement of permanent residents. The comprehensive and fine-grained approach to the analysis provides new context for the county's risk reduction efforts. We note several important findings based on the results of this study:

- **Extensive overall damage and loses are expected from a Cascadia M9 earthquake and tsunami -** Due to its proximity to the Cascadia subduction zone (CSZ), every community in Tillamook County will experience significant impact and disruption from a CSZ magnitude 9.0 (M9.0) earthquake event. Event impacts that were examined are limited to earthquake (including ground deformation) and tsunami. Results show that a CSZ M9.0 event will cause building losses of 40% to 60% across all communities. Some communities like Rockaway Beach and Neskowin can expect a very high percentage of losses due to tsunami. Other communities like the City of Tillamook have little to no tsunami exposure but will have high losses from earthquake alone. The high vulnerability of the building inventory (primarily because of the age of construction), the proximity to the CSZ event, and the amount of development within tsunami zones all contribute to the estimated levels of losses expected in the study area.
- **Retrofitting buildings to modern seismic building codes can reduce damages and loses from earthquake shaking -** Seismic building codes have a major influence on earthquake shaking damage estimated by Hazus-MH, a software tool developed by the Federal Emergency Management Agency (FEMA) for calculating loss from natural hazards. We examined potential loss reduction from seismic retrofits (modifications that improve 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 (non-existent) and low seismic code building to moderate seismic code levels in one scenario, and then further 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 loss for the entire study area was reduced from 29% to 23%. We found further reduction in estimated loss in our simulation to 20% 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 Tillamook, where a significant loss reduction (from 47% to 32%) could occur by retrofitting all buildings to at least moderate code. This stands in contrast to a community with younger building stock, such as Manzanita, which would see loss reduction go from 23% to 21%. 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.
- **Flooding can be a recurrent problem for many communities in Tillamook County -** Many buildings within the floodplain are vulnerable to significant damage from flooding. At first glance, Hazus-MH flood loss estimates may give a false impression of risk because they show fairly low

damages for a community relative to other hazards we examined. This is possibly due to the inappropriate comparison between risk-based loss estimation and exposure results, as well as the limited area impacted from flooding. An average of 9% loss was calculated for buildings within the 100-year flood zone. Residents and buildings located near the estuaries and coastal margins are at a greater risk from flood than they are at other locations within the study area because these areas are more highly developed than other areas in the county and are susceptible to flooding. During a 100-year flood event, most of the communities in the study area are expected to sustain losses close to 1% of total building value. While some communities—Manzanita, Oceanside, and Netarts—have little to no flood risk, other communities like Neskowin, Pacific City, and Tillamook have significant estimated losses from flooding.

- **Elevating structures in the flood zone reduces 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. By using both analyses in this way, the number of elevated structures within the flood zone could be quantified. This showed possible mitigation needs in flood loss prevention and the effectiveness of past activities. For example, the community of Nehalem, through a partnership with local and state government, received federal assistance to elevate structures above the estimated flood height. Several business buildings in Nehalem were elevated to two feet above the 100-year base flood elevation, indicating successful flood mitigation actions.
- **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 Nehalem, Wheeler, and Garibaldi all have very high levels of exposure to landslide hazard. The landslide hazard data used in this risk assessment were created before modern mapping technology; future risk assessments using lidar-derived landslide hazard data would provide more accurate results.
- **Areas in Neskowin and Rockaway Beach are at risk to coastal erosion hazard** - Exposure analysis shows that some communities are vulnerable to coastal erosion hazard. The communities of Neskowin and Rockaway Beach, for example, have approximately a quarter of their total building value exposed to moderate coastal erosion hazard.
- **Wildfire risk is moderate for the overall study area -** Exposure analysis shows that buildings in the eastern part of the county are vulnerable to wildfire hazard. High wildfire hazard is primarily limited to a few heavily forested rural areas. However, moderate wildfire hazard is present throughout the county and so is a potential threat for communities.
- **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 within this report. We have estimated that 89% of Tillamook County's 65 critical facilities will be non-functioning after a CSZ event. In comparison, 8% (5) of critical facilities are vulnerable to 100-year flooding.
- **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 37% of the population in the county would be displaced due to the combination of earthquake and tsunami. Landslide hazard is a potential threat to 28% of permanent residents, and 5% of permanent residents are vulnerable to displacement from flood hazard. A small percentage of residents are at risk to displacement from wildfire and coastal erosion.

- **The results allow communities the ability to compare across hazards and prioritize their needs -** Each community within the study area was assessed for natural hazard exposure and loss. This allowed for comparison of risk between communities and impacts from each natural hazard. In using Hazus-MH and exposure analysis, these results can assist in developing plans that address the concerns for those individual communities.

5.0 LIMITATIONS

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

- **Spatial and temporal variability of natural hazard occurrence** – 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 un-reinforced 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 Tillamook 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, 2010). As a result, we are underestimating the number of people that may be at risk to hazards, especially during periods of high temporary population. Although Tillamook County provided DOGAMI with vacation rental data for the unincorporated portions of the study area, the data gaps for the incorporated communities prevented us from using this data source.
- **Data accuracy and completeness** – Some datasets in our risk assessments had incomplete coverage or no high resolution data within the study area. We used lower resolution data to fill gaps where there was incomplete coverage or where high resolution was not available. Assumptions to amend areas of incomplete data coverage were made based on reasonable methods described within this report. However, we are aware that some uncertainty has been

introduced from these data amendments at an individual building scale. At community-wide scales the effects of the uncertainties are slight. Data layers in which assumptions were made to fill gaps are: building footprints, population, some attributes derived from the assessor database, and landslide susceptibility. Many of the datasets included known or suspected artifacts, omissions and errors, identifying or repairing these problems was beyond the scope of the project and are areas needing additional research.

6.0 RECOMMENDATIONS

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

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

Messaging can be tailored to stakeholder groups. For example, outreach to homeowners could focus on actions they can take to reduce risk to their property. The DOGAMI Homeowners Guide to Landslides (http://www.oregongeology.org/sub/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 will be available soon for communities in Tillamook County.

The building database that accompanies this report presents many opportunities for future pre-disaster mitigation, emergency response, and community resilience improvements. Vulnerable areas can be identified and targeted for awareness campaigns. These campaigns can be aimed at pre-disaster mitigation through, for example, improvements of the structural connection of the frame to the 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 has two programs that assist with mitigation funding for natural hazards: Hazard Mitigation Grant Program (HMGP) and Pre-Disaster Mitigation (PDM) Grant Program. FEMA also has a grant program specifically for flooding called Flood Mitigation Assistance (FMA). The SHMO can help 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 89% 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.

6.5.2 Tsunami

- Use approved guides on preparing for tsunamis (e.g., DLCD guide on preparing for the CSZ tsunami) http://www.oregon.gov/LCD/OCMP/docs/Publications/TsunamiGuide20170130.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.

6.5.4 Landslide

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

6.5.5 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

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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 Tillamook County (Rural)

Table A-1. Unincorporated Tillamook County hazard profile.

Community Overview

Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)
Unincorporated Tillamook County	13,364	15,015	25	1,282,436,000

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	1,078	8.1%	1,106	1	10,178,000	0.8%
*Earthquake**	*CSZ M9.0 Deterministic*	*4,129*	*31%*	*6,098*	*19*	*412,821,000*	*32%*
Earthquake (within Tsunami Zone)		202	1.5%	647	2	48,911,000	3.8%

Exposure Analysis Summary

Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Percent of Exposure
Tsunami	*CSZ M9.0 – Medium*	*753*	*5.6%*	*1,692*	*2*	*147,262,000*	*11%*
Tsunami	Senate Bill 379 Regulatory Line	1,071	8.0%	2,213	3	236,786,000	18.5%
Landslide	High and Very High Susceptibility	4,428	33%	4,933	9	449,331,000	35%
Coastal Erosion	Moderate Hazard	59	0.4%	161	0	18,928,000	1.5%
Wildfire	High Risk	408	3.1%	383	1	22,892,000	1.8%

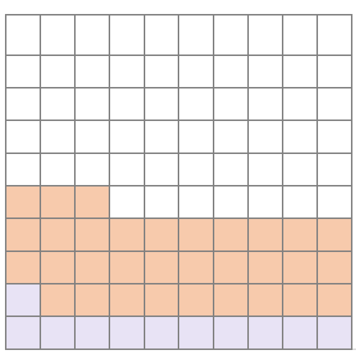
*Earthquake losses were calculated for buildings outside of Medium tsunami zone.

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 Tillamook 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 Tillamook County critical facilities.

Critical Facilities by Community	Flood 1% Annual Chance Exposed	Earthquake Moderate to Complete Damage >50% Prob.	Tsunami CSZ M9.0 – Medium Exposed	Landslide High and Very High Susceptibility Exposed	Wildfire High Risk Exposed	Coastal Erosion Moderate Hazard Exposed
Adventist Clinic North		X		X		
Adventist Clinic South		X		X		
Cape Meares Fire Station #73						
Fire Mountain School		X		X		
Neah-Kah-Nie Jr./Sr. High School		X	X			
Nehalem Bay Fire and Rescue #11		X				
Nehalem Bay Fire and Rescue #13		X				
Neskowin Valley School		X		X		
Nestucca Fire and Rescue Station #87 (Hebo)	X			X		
Nestucca High School		X		X		
Nestucca RFPD Beaver #83		X				
Nestucca RFPD Blaine #86		X				
Nestucca RFPD Neskowin #84		X	X	X		
Nestucca RFPD Sand Lake #85					X	
Nestucca Valley Elementary		X		X		
Nestucca Valley Middle School		X				
South Fork Prison Camp		X				
South Prairie Elementary School		X				
Tillamook Adventist School						
Tillamook Co. Public Works - South		X		X		
Tillamook County Sheriff's Office and Oregon State Police		X				
Tillamook Fire Station South Prairie Station #72		X				
Tillamook Co. Public Works		X				
Tillamook Youth Correctional Facility		X				
Trask River High School		X				

A.2 Unincorporated Community of Neskowin

Table A-3. Unincorporated community of Neskowin hazard profile.

Community Overview

Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)
Neskowin	230	653	0	118,463,000

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	38	17%	82	0	7,132,000	6%
*Earthquake**	*CSZ M9.0 Deterministic*	*10*	*4.5%*	*32*	*0*	*6,719,000*	*5.7%*
Earthquake (within Tsunami Zone)		22	9.6%	95	0	17,550,000	15%

Exposure Analysis Summary

Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Percent of Exposure
Tsunami	*CSZ M9.0 – Medium*	*133*	*58%*	*461*	*0*	*81,824,000*	*69%*
Tsunami	Senate Bill 379 Regulatory Line	149	65%	516	0	94,368,000	80%
Landslide	High and Very High Susceptibility	63	27%	132	0	24,187,000	20%
Coastal Erosion	Moderate Hazard	36	16%	110	0	34,149,000	29%
Wildfire	High Risk	0	0%	2	0	288,000	0.2%

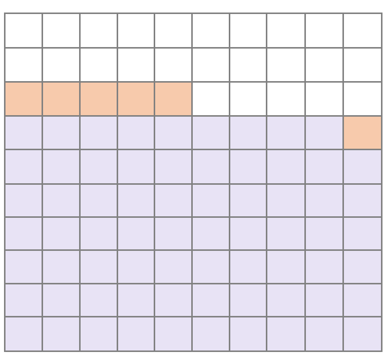
*Earthquake losses were calculated for buildings outside of Medium tsunami zone.

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 Neskowin 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).

Note: the unincorporated community of Neskowin has no identified critical facilities.

A.3 Unincorporated Communities of Oceanside and Netarts

Table A-4. Unincorporated communities of Oceanside and Netarts hazard profile.

Community Overview

Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)
Oceanside & Netarts	1,056	1,701	2	203,363,000

Hazus-MH Analysis Summary

Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Damaged Buildings	Damaged Critical Facilities	Loss Estimate ($)	Loss Ratio
Flood[2]	1% Annual Chance	4	0.4%	4	0	4,000	0%
*Earthquake**	*CSZ M9.0 Deterministic*	*363*	*34%*	*626*	*1*	*61,694,000*	*30%*
Earthquake (within Tsunami Zone)		5	0.5%	32	0	5,243,000	2.6%

Exposure Analysis Summary

Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Percent of Exposure
Tsunami	*CSZ M9.0 – Medium*	*16*	*1.5%*	*88*	*0*	*15,432,000*	*7.6%*
Tsunami	Senate Bill 379 Regulatory Line	178	17%	448	1	55,891,000	28%
Landslide	High and Very High Susceptibility	406	38%	738	1	101,235,000	50%
Wildfire	High Risk	0	0%	0	0	0	0%

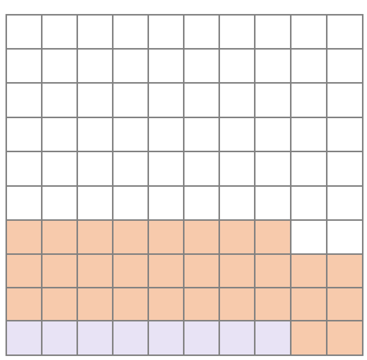
*Earthquake losses were calculated for buildings outside of Medium tsunami zone.

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-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 communities of Oceanside and Netarts 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-5. Unincorporated communities of Oceanside and Netarts critical facilities.

	Flood 1% Annual Chance	Earthquake Moderate to Complete Damage	Tsunami CSZ M9.0 – Medium	Landslide High and Very High Susceptibility	Wildfire High Risk	Coastal Erosion Moderate Hazard
Critical Facilities by Community	**Exposed**	**>50% Prob.**	**Exposed**	**Exposed**	**Exposed**	**Exposed**
Netarts Oceanside RFPD Station #61		X				
Netarts Oceanside RFPD Station #62				X		

A.4 Unincorporated Community of Pacific City

Table A-6. Unincorporated community of Pacific City hazard profile.

Community Overview

Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)
Pacific City	947	1,707	1	212,062,000

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	270	29%	361	1	3,301,000	1.6%
*Earthquake**	*CSZ M9.0 Deterministic*	*100*	*11%*	*238*	*0*	*27,117,000*	*13%*
Earthquake (within Tsunami Zone)		112	12%	280	1	23,727,000	11%

Exposure Analysis Summary

Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Percent of Exposure
Tsunami	*CSZ M9.0 – Medium*	*386*	*41%*	*806*	*1*	*83,301,000*	*39%*
Tsunami	Senate Bill 379 Regulatory Line	638	67%	1,280	1	160,370,000	76%
Landslide	High and Very High Susceptibility	125	13%	183	0	24,930,000	12%
Coastal Erosion	Moderate Hazard	4	0.4%	25	0	8,909,000	4.2%
Wildfire	High Risk	1	0%	3	0	226,000	0.1%

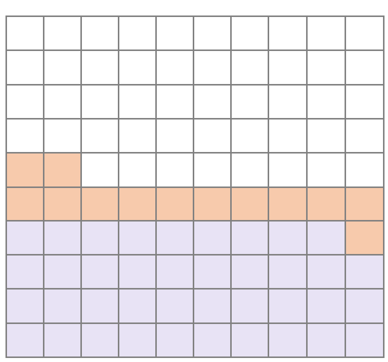
*Earthquake losses were calculated for buildings outside of Medium tsunami zone.

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-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 Pacific City 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-7. Unincorporated community of Pacific City critical facilities.

	Flood 1% Annual Chance	Earthquake Moderate to Complete Damage	Tsunami CSZ M9.0 – Medium	Landslide High and Very High Susceptibility	Wildfire High Risk	Coastal Erosion Moderate Hazard
Critical Facilities by Community	**Exposed**	**>50% Prob.**	**Exposed**	**Exposed**	**Exposed**	**Exposed**
Nestucca RFPD Pacific City Station #82	X	X	X			

A.5 City of Bay City

Table A-8. City of Bay City hazard profile.

Community Overview				
Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)
Bay City	1,284	884	4	74,769,000

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	5	0.4%	0	0	0	0%
*Earthquake**	*CSZ M9.0 Deterministic*	*454*	*35%*	*404*	*2*	*29,283,000*	*39%*
Earthquake (within Tsunami Zone)		16	1.2%	18	2	1,873,000	2.5%

Exposure Analysis Summary							
Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Percent of Exposure
Tsunami	*CSZ M9.0 – Medium*	*77*	*6%*	*62*	*2*	*8,455,000*	*11%*
Tsunami	Senate Bill 379 Regulatory Line	83	6.5%	64	2	8,657,000	12%
Landslide	High and Very High Susceptibility	690	54%	480	0	35,262,000	47%
Wildfire	High Risk	94	7.3%	58	2	7,089,000	9.5%

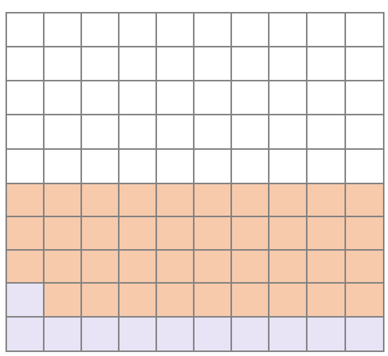
*Earthquake losses were calculated for buildings outside of Medium tsunami zone.

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 Bay City 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-9. City of Bay City critical facilities.

	Flood 1% Annual Chance	Earthquake Moderate to Complete Damage	Tsunami CSZ M9.0 – Medium	Landslide High and Very High Susceptibility	Wildfire High Risk	Coastal Erosion Moderate Hazard
Critical Facilities by Community	**Exposed**	**>50% Prob.**	**Exposed**	**Exposed**	**Exposed**	**Exposed**
Bay City City Hall		X				
Bay City Fire Department		X				
Bay City Public Works		X	X		X	
Bay City Water Treatment		X	X		X	

A.6 City of Garibaldi

Table A-10. City of Garibaldi hazard profile.

Community Overview

Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)
Garibaldi	779	755	6	64,331,000

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	13	1.7%	21	0	79,000	0.1%
*Earthquake**	*CSZ M9.0 Deterministic*	*304*	*39%*	*346*	*4*	*26,266,000*	*41%*
Earthquake (within Tsunami Zone)		16	2.1%	61	1	7,490,268	12%

Exposure Analysis Summary

Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Percent of Exposure
Tsunami	*CSZ M9.0 – Medium*	*56*	*7.2%*	*91*	*1*	*11,870,000*	*18%*
Tsunami	Senate Bill 379 Regulatory Line	67	8.6%	65	3	13,848,000	22%
Landslide	High and Very High Susceptibility	575	74%	534	3	39,334,000	61%
Wildfire	High Risk	79	10%	83	1	5,014,000	7.8%

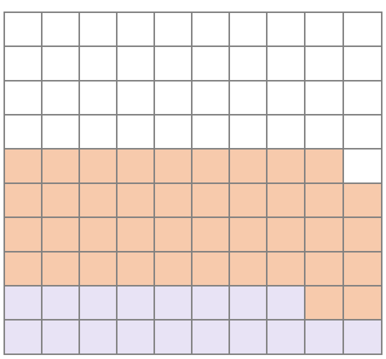
*Earthquake losses were calculated for buildings outside of Medium tsunami zone.

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 Garibaldi 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-11. City of Garibaldi critical facilities.

Critical Facilities by Community	Flood 1% Annual Chance Exposed	Earthquake Moderate to Complete Damage >50% Prob.	Tsunami CSZ M9.0 – Medium Exposed	Landslide High and Very High Susceptibility Exposed	Wildfire High Risk Exposed	Coastal Erosion Moderate Hazard Exposed
City of Garibaldi Fire Department / City Hall / Police				X		
Garibaldi Elementary School		X		X		
Garibaldi Public Works		X				
Garibaldi Wastewater Treatment Plant		X				
United States Coast Guard – Admin.		X		X	X	
Coast Guard Station - Tillamook		X	X			

A.7 City of Manzanita

Table A-12. City of Manzanita hazard profile.

Community Overview

Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)
Manzanita	599	1,523	3	259,780,000

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%	1	0	11,000	0%
*Earthquake**	*CSZ M9.0 Deterministic*	*131*	*22%*	*354*	*3*	*60,520,000*	*23%*
Earthquake (within Tsunami Zone)		24	4%	98	0	16,217,318	6.2%

Exposure Analysis Summary

Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Percent of Exposure
Tsunami	*CSZ M9.0 – Medium*	*94*	*16%*	*354*	*0*	*56,238,000*	*22%*
Tsunami	Senate Bill 379 Regulatory Line	186	31%	688	0	122,616,000	47%
Landslide	High and Very High Susceptibility	97	16%	206	0	38,439,000	15%
Coastal Erosion	Moderate Hazard	6	1.0%	25	0	4,389,000	1.7%
Wildfire	High Risk	0	0%	0	0	0	0%

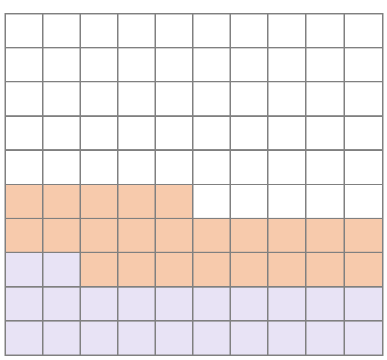
*Earthquake losses were calculated for buildings outside of Medium tsunami zone.

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 Manzanita 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-13. City of Manzanita critical facilities.

	Flood 1% Annual Chance	Earthquake Moderate to Complete Damage	Tsunami CSZ M9.0 – Medium	Landslide High and Very High Susceptibility	Wildfire High Risk	Coastal Erosion Moderate Hazard
Critical Facilities by Community	**Exposed**	**>50% Prob.**	**Exposed**	**Exposed**	**Exposed**	**Exposed**
Manzanita City Hall		X				
Manzanita Department of Public Safety		X				
Manzanita Water Treatment Plant		X				

A.8 City of Nehalem

Table A-14. City of Nehalem hazard profile.

Community Overview

Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)
Nehalem	271	260	3	24,886,000

Hazus-MH Analysis Summary

Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Damaged Buildings	Damaged Critical Facilities	Loss Estimate ($)	Loss Ratio
Flood[2]	1% Annual Chance	41	15%	37	1	281,000	1.1%
*Earthquake**	*CSZ M9.0 Deterministic*	*101*	*38%*	*110*	*2*	*10,361,000*	*42%*
Earthquake (within Tsunami Zone)		19	7.0%	48	1	5,748,000	23%

Exposure Analysis Summary

Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Percent of Exposure
Tsunami	*CSZ M9.0 – Medium*	46	17%	61	1	7,856,000	32%
Tsunami	Senate Bill 379 Regulatory Line	0	0%	0	0	0	0%
Landslide	High and Very High Susceptibility	266	99%	259	3	24,735,000	99%
Wildfire	High Risk	0	0%	0	0	0	0%

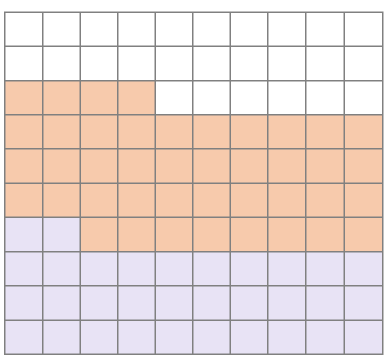
*Earthquake losses were calculated for buildings outside of Medium tsunami zone.

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 Nehalem 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-15. City of Nehalem critical facilities.

Critical Facilities by Community	Flood 1% Annual Chance	Earthquake Moderate to Complete Damage	Tsunami CSZ M9.0 – Medium	Landslide High and Very High Susceptibility	Wildfire High Risk	Coastal Erosion Moderate Hazard
	Exposed	>50% Prob.	Exposed	Exposed	Exposed	Exposed
County Public Works - North		X		X		
Nehalem Elementary School		X		X		
Nehalem Volunteer Fire Department/City Hall	X	X	X	X		

A.9 City of Rockaway Beach

Table A-16. City of Rockaway Beach hazard profile.

Community Overview

Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)
Rockaway Beach	1,305	2,240	5	211,809,000

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	152	12%	170	1	1,671,000	0.8%
*Earthquake**	CSZ M9.0 Deterministic	*238*	*18%*	*326*	*0*	*18,881,000*	*8.9%*
Earthquake *(within Tsunami Zone)*		287	22%	616	5	55,611,000	26%

Exposure Analysis Summary

Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Percent of Exposure
Tsunami	*CSZ M9.0 – Medium*	*722*	*55%*	*1,525*	5	*146,945,000*	*69%*
Tsunami	Senate Bill 379 Regulatory Line	730	56%	1,543	4	149,434,000	71%
Landslide	High and Very High Susceptibility	78	6%	104	0	13,436,000	6.3%
Coastal Erosion	Moderate Hazard	52	4%	288	0	50,675,000	24%
Wildfire	High Risk	6	0.5%	25	0	2,938,000	1.4%

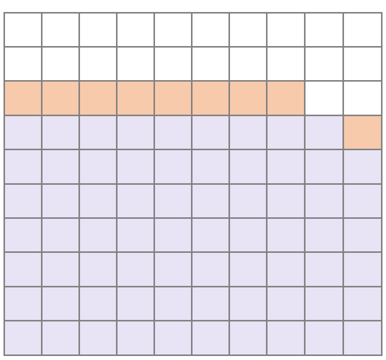
*Earthquake losses were calculated for buildings outside of Medium tsunami zone.

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 Rockaway 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-17. City of Rockaway Beach critical facilities.

	Flood 1% Annual Chance	Earthquake Moderate to Complete Damage	Tsunami CSZ M9.0 – Medium	Landslide High and Very High Susceptibility	Wildfire High Risk	Coastal Erosion Moderate Hazard
Critical Facilities by Community	**Exposed**	**>50% Prob.**	**Exposed**	**Exposed**	**Exposed**	**Exposed**
Neah-Kah-Nie School District		X	X			
Rockaway Beach City Hall and Public Works		X	X			
Rockaway Beach Fire Dept.	X	X	X			
Rockaway Beach Water Treatment Plant		X	X			
Rockaway Beach Police Dept.		X	X			

A.10 City of Tillamook

Table A-18. City of Tillamook hazard profile.

Community Overview

Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)
Tillamook	4,999	2,270	14	322,398,000

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	505	10%	205	1	3,060,000	0.9%
*Earthquake**	*CSZ M9.0 Deterministic*	*1,086*	*22%*	*947*	*13*	*153,126,000*	*47%*
Earthquake (within Tsunami Zone)		0	0%	3	0	58,000	0%

Exposure Analysis Summary

Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Percent of Exposure
Tsunami	*CSZ M9.0 – Medium*	*1*	*0%*	*3*	*0*	*71,000*	*0%*
Tsunami	Senate Bill 379 Regulatory Line	180	3.6%	74	0	9,177,000	2.8%
Landslide	High and Very High Susceptibility	0	0%	1	0	13,000	0%
Wildfire	High Risk	3	0%	8	0	8,892,000	2.8%

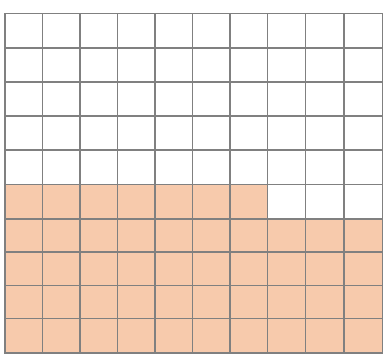
*Earthquake losses were calculated for buildings outside of Medium tsunami zone.

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-10.

[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-10. City of Tillamook 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 (tsunami damage negligible for this community).

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

Table A-19. City of Tillamook critical facilities.

Critical Facilities by Community	Flood 1% Annual Chance	Earthquake Moderate to Complete Damage	Tsunami CSZ M9.0 – Medium	Landslide High and Very High Susceptibility	Wildfire High Risk	Coastal Erosion Moderate Hazard
	Exposed	>50% Prob.	Exposed	Exposed	Exposed	Exposed
County Health Department		X				
East Elementary School		X				
Liberty Elementary School		X				
Pacific Christian School		X				
Sacred Heart Catholic School		X				
Tillamook 911 Center		X				
Tillamook Bay Community College						
Tillamook City Hall		X				
Tillamook City Police Dept.		X				
Tillamook Co. Public Works - Central		X				
Tillamook Fire Dist. Main Station #71		X				
Tillamook High School	X	X				
Tillamook Junior High School		X				
Tillamook Regional Medical Center		X				

A.11 City of Wheeler

Table A-20. City of Wheeler hazard profile.

Community Overview

Community Name	Population	Number of Buildings	Critical Facilities[1]	Total Building Value ($)
Wheeler	420	363	2	30,556,000

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	2.1%	12	0	113,000	0.4%
*Earthquake**	*CSZ M9.0 Deterministic*	*166*	*40%*	*179*	*2*	*13,898,000*	*45%*
Earthquake (within Tsunami Zone)		9	2.1%	14	0	1,100,000	3.6%

Exposure Analysis Summary

Hazard	Scenario	Potentially Displaced Residents	% Potentially Displaced Residents	Exposed Buildings	Exposed Critical Facilities	Building Value ($)	Percent of Exposure
Tsunami	*CSZ M9.0 – Medium*	*25*	*6%*	*24*	*0*	*2,072,000*	*6.8%*
Tsunami	Senate Bill 379 Regulatory Line	61	14.5%	72	1	6,281,000	20.6%
Landslide	High and Very High Susceptibility	391	93%	336	1	28,256,000	92%
Wildfire	High Risk	0	0%	3	0	188,000	0.6%

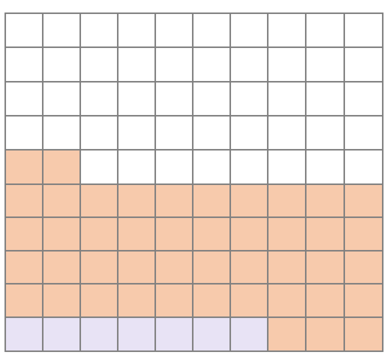
*Earthquake losses were calculated for buildings outside of Medium tsunami zone.

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-11.

[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-11. City of Wheeler 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-21. City of Wheeler critical facilities.

	Flood 1% Annual Chance	Earthquake Moderate to Complete Damage	Tsunami CSZ M9.0 – Medium	Landslide High and Very High Susceptibility	Wildfire High Risk	Coastal Erosion Moderate Hazard
Critical Facilities by Community	**Exposed**	**>50% Prob.**	**Exposed**	**Exposed**	**Exposed**	**Exposed**
Nehalem Valley Care Center		X		X		
Wheeler City Hall and Public Works		X				

APPENDIX B. DETAILED RISK ASSESSMENT TABLES

Table B-1. Tillamook 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)	9,542	835,847	65%	514	153,910	12%	4,630	183,819	14%	329	108,860	8.5%	15,015	55%	1,282,436	46%
Neskowin	631	115,828	98%	8	1,642	1%	7	128	0%	7	865	0.7%	653	2%	118,463	4%
Oceanside & Netarts	1,606	196,094	96%	20	2,091	1%	64	1,259	1%	11	3,919	1.9%	1,701	6%	203,363	7%
Pacific City	1,555	195,882	92%	70	11,216	5%	54	1,408	1%	28	3,556	1.7%	1,707	6%	212,062	8%
Total Unincorp. County	13,334	1,343,651	74%	612	168,858	9.3%	4755	186,615	10%	375	117,200	6.4%	19076	70%	1,816,324	65%
Bay City	748	54,962	74%	43	13,242	18%	75	2,102	3%	18	4,463	6.0%	884	3%	74,769	3%
Garibaldi	582	39,527	61%	95	14,532	23%	45	1,676	3%	33	8,596	13%	755	3%	64,331	2%
Manzanita	1,425	245,415	94%	68	9,743	4%	6	141	0%	24	4,481	1.7%	1,523	6%	259,780	9%
Nehalem	191	13,733	55%	42	4,753	19%	10	292	1%	17	6,109	25%	260	1%	24,886	1%
Rockaway Beach	2,049	196,117	93%	51	6,245	3%	105	1,698	1%	35	7,749	3.7%	2,240	8%	211,809	8%
Tillamook	1,731	139,379	43%	401	119,603	37%	51	3,849	1%	87	59,567	19%	2,270	8%	322,398	11%
Wheeler	295	24,825	81%	33	4,261	14%	29	573	2%	6	897	2.9%	363	1%	30,556	1%
Total Tillamook County	20,355	2,057,610	73%	1,345	341,237	12%	5,076	196,945	7%	595	209,061	7.4%	27,371	100%	2,804,854	100%

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

			(all dollar amounts in thousands)									
			Total Earthquake Damage*		**Earthquake Damage outside of Medium Tsunami Zone**							
	Total Number of Buildings	**Total Estimated Building Value ($)**	**Buildings Damaged**		**Buildings Damaged**				**Building Design Level Upgraded to at Least Moderate Code**			
Community			**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)	15,015	1,282,436	461,731	36%	1,254	4,844	412,821	32%	1,657	3,023	318,719	25%
Neskowin	653	118,463	24,269	20%	6	26	6,719	5.7%	2	23	5,568	4.7%
Oceanside & Netarts	1,701	203,363	66,937	33%	81	545	61,694	30%	97	447	56,135	28%
Pacific City	1,707	212,062	50,844	24%	45	192	27,117	13%	42	147	23,839	11%
Total Unincorp. County	19,076	1,816,324	603,781	33%	1,387	5,608	508,350	28%	1,798	3,640	404,261	22%
Bay City	884	74,770	31,161	41%	79	325	29,283	39%	84	229	21,059	28%
Garibaldi	755	64,331	33,756	52%	53	293	26,266	42%	43	244	20,531	32%
Manzanita	1,523	259,780	76,738	29%	52	306	60,520	23%	28	270	53,424	21%
Nehalem	260	24,886	16,109	65%	11	99	10,361	42%	11	85	7,572	30%
Rockaway Beach	2,240	211,809	74,492	35%	45	281	18,881	8.9%	110	171	15,650	7.4%
Tillamook	2,270	322,398	153,185	47%	198	749	153,126	47%	167	499	101,753	32%
Wheeler	363	30,556	14,998	49%	29	150	13,898	45%	22	127	11,708	38%
Total Tillamook County	27,371	2,804,854	1,004,221	36%	1,856	7,812	820,687	29%	2,263	5,265	635,958	23%

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

Table B-3. Tsunami exposure.

(all dollar amounts in thousands)

Community	Total Number of Buildings	Total Estimated Building Value ($)	Small (Low Severity)			Medium (Moderate Severity)			Large (High Severity)			X Large (Very High Severity)			XX Large (Extreme Severity)		
			Number of Buildings	Building Value ($)	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)	15,015	1,282,436	520	46,924	3.7%	1,692	147,262	11%	2,548	223,814	18%	3,585	311,080	24%	3,706	370,556	29%
Neskowin	653	118,463	268	56,198	47%	461	81,824	69%	485	86,960	73%	505	90,680	77%	508	91,182	77%
Oceanside & Netarts	1,701	203,363	62	11,292	5.6%	88	15,432	7.6%	141	21,433	11%	289	34,177	17%	326	36,738	18%
Pacific City	1,707	212,062	175	15,825	7.5%	806	83,301	39%	1,252	148,741	70%	1,349	155,610	73%	1,355	156,498	74%
Total Unincorp. County	19,076	1,816,324	1,025	130,239	7.2%	3,047	327,819	18%	4,426	480,948	26%	5,728	591,548	33%	5,895	654,974	36%
Bay City	884	74,770	4	370	0.5%	62	8,455	11%	136	20,515	27%	220	25,581	34%	234	26,459	35%
Garibaldi	755	64,331	9	549	0.9%	91	11,870	18%	197	26,106	41%	320	32,923	51%	336	33,894	53%
Manzanita	1,523	259,780	0	0	0.0%	354	56,238	22%	703	121,483	47%	950	162,519	63%	966	163,906	63%
Nehalem	260	24,886	45	6,091	25%	61	7,856	32%	67	8,261	33%	76	8,790	35%	77	8,872	36%
Rockaway Beach	2,240	211,809	591	49,215	23%	1,525	146,945	69%	1,888	170,195	80%	2,077	185,405	88%	2,095	186,898	88%
Tillamook	2,270	322,398	0	0	0.0%	3	71	0.2%	84	24,651	7.6%	403	79,471	25%	482	84,661	26%
Wheeler	363	30,556	14	1,047	3.4%	24	2,072	6.8%	33	3,798	12%	53	5,608	18%	56	5,703	19%
Total Tillamook County	27,371	2,804,854	1,688	187,511	6.7%	5,167	561,327	20%	7,534	855,957	31%	9,827	1,091,845	39%	10,141	1,165,367	42%

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)	15,015	1,282,436	553	3,277	0.3%	923	6,930	0.5%	1,106	10,178	0.8%	1,369	13,888	1.1%
Neskowin	653	118,463	3	12	0.0%	22	93	0.1%	82	7,132	6.0%	61	609	0.5%
Oceanside & Netarts	1,701	203,363	0	0	0.0%	1	1	0.0%	4	4	0.0%	6	83	0.0%
Pacific City	1,707	212,062	90	543	0.3%	268	2,167	1.0%	361	3,301	1.6%	492	6,711	3.2%
Total Unincorp. County	19,076	1,816,324	646	3,832	0.2%	1,214	9,191	0.5%	1,553	20,615	1.1%	1,928	21,291	1.2%
Bay City	884	74,770	0	0	0.0%	0	0	0.0%	0	0	0.0%	3	11	0.0%
Garibaldi	755	64,331	7	47	0.1%	14	71	0.1%	21	79	0.1%	39	189	0.3%
Manzanita	1,523	259,780	0	0	0.0%	0	0	0.0%	1	11	0.0%	0	0	0.0%
Nehalem	260	24,886	6	31	0.1%	15	98	0.4%	37	281	1.1%	53	627	2.5%
Rockaway Beach	2,240	211,809	70	370	0.2%	122	522	0.2%	170	1,671	0.8%	293	2,140	1%
Tillamook	2,270	322,398	52	600	0.2%	136	1,880	0.6%	205	3,060	0.9%	307	7,840	2.4%
Wheeler	363	30,556	5	49	0.2%	5	71	0.2%	12	113	0.4%	14	187	0.6%
Total Tillamook County	27,371	2,804,854	786	4,929	0.2%	1,506	11,833	0.4%	1,999	25,831	0.9%	2,637	32,285	1.2%

*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)	15,015	13,364	1,078	8.1%	1,360	9.1%	254
Neskowin	653	230	38	17%	135	21%	53
Oceanside & Netarts	1,701	1,056	4	0.4%	49	2.9%	45
Pacific City	1,707	947	270	29%	475	28%	114
Total Unincorp. County	19,076	15,593	1,390	8.9%	2,019	11%	466
Bay City	884	1,284	5	0.4%	7	0.8%	7
Garibaldi	755	779	13	1.7%	31	4.1%	10
Manzanita	1,523	599	0	0	4	0.3%	3
Nehalem	260	271	41	15%	49	19%	12
Rockaway Beach	2,240	1,305	152	12%	345	15%	175
Tillamook	2,270	4,999	505	10%	269	12%	64
Wheeler	363	420	9	2.1%	12	3.3%	0
Total Tillamook County	27,371	25,250	2,115	8.4%	2,736	10%	737

*1% results include coastal flooding source.

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)	15,015	1,282,436	3,680	353,459	28%	1,253	95,872	7.5%	2,531	198,311	15%
Neskowin	653	118,463	8	1,353	1.1%	124	22,834	19%	195	26,971	23%
Oceanside & Netarts	1,701	203,363	446	55,589	27%	292	45,647	22%	652	70,937	35%
Pacific City	1,707	212,062	2	42	0.0%	181	24,888	12%	597	85,603	40%
Total Unincorp. County	19,076	1,816,324	4,136	410,443	23%	1,850	189,240	10%	3,975	381,820	21%
Bay City	884	74,770	476	35,108	47%	4	154	0.2%	261	19,717	26%
Garibaldi	755	64,331	516	38,377	60%	18	956	1.5%	84	6,627	10%
Manzanita	1,523	259,780	44	9,050	3.5%	162	29,389	11%	651	114,586	44%
Nehalem	260	24,886	250	23,502	94%	9	1,233	5.0%	1	151	0.6%
Rockaway Beach	2,240	211,809	19	2,932	1.4%	85	10,504	5.0%	661	65,832	31%
Tillamook	2,270	322,398	0	0	0.0%	1	13	0.0%	54	8,273	2.6%
Wheeler	363	30,556	263	22,601	74%	73	5,655	19%	10	947	3.1%
Total Tillamook County	27,371	2,804 ,854	5,704	542,013	19.3%	2,202	237,145	8.5%	5,697	597,954	21%

Table B-7. Coastal erosion exposure.

(all dollar amounts in thousands)

Community*	Total Number of Buildings	Total Estimated Building Value ($)	High Hazard			Moderate Hazard			Low Hazard		
			Number of Buildings	Building Value ($)	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)	15,015	1,282,436	109	13,418	1.0%	161	18,928	1.5%	309	33,885	2.6%
Neskowin	653	118,463	95	32,205	27.2%	110	34,149	28.8%	156	40,374	34.1%
Pacific City	1,707	212,062	3	5,991	2.8%	25	8,909	4.2%	88	19,740	9.3%
Total Unincorp. County	17,375	1,612,961	207	51,614	3.2%	296	61,986	3.8%	553	93,999	5.8%
Manzanita	1,523	259,780	10	2,225	0.9%	25	4,389	1.7%	103	18,410	7.1%
Rockaway Beach	2,240	211,809	241	44,795	21.1%	288	50,675	23.9%	534	79,618	37.6%
Total Tillamook County*	21,138	2,084,550	458	98,634	4.7%	609	117,050	5.6%	1,190	192,027	9.2%

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

[1]The coastal erosion zone of Low 1 determined by Stimely and Allan (2014) corresponds to Low.

Table B-8. Wildfire exposure.

			(all dollar amounts in thousands)					
			High Risk			**Moderate Risk**		
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)	15,015	1,282,436	383	22,892	1.8%	8,130	607,204	47%
Neskowin	653	118,463	2	288	0.2%	319	50,895	43%
Oceanside & Netarts	1,701	203,363	0	0	0%	866	113,942	56%
Pacific City	1,707	212,062	3	226	0.1%	656	86,116	41%
Total Unincorp. County	19,076	1,816,324	388	23,406	1.3%	9,971	858,157	47%
Bay City	884	74,770	58	7,089	9.5%	456	34,921	47%
Garibaldi	755	64,331	83	5,014	7.8%	93	11,144	17%
Manzanita	1,523	259,780	0	0	0%	681	121,658	47%
Nehalem	260	24,886	0	0	0%	105	10,822	43%
Rockaway Beach	2,240	211,809	25	2,938	1.4%	782	89,488	42%
Tillamook	2,270	322,398	8	8,892	2.8%	218	37,552	12%
Wheeler	363	30,556	3	188	0.6%	180	17,373	57%
Total Tillamook County	27,371	2,804,854	565	47,527	1.7%	12,486	1,181,115	42%

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 Tillamook County for use in both flood and earthquake modules of Hazus-MH. We used the Tillamook County assessor database (acquired in 2015) 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 Tillamook 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 Tillamook 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 Tillamook 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 Tillamook 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 Tillamook County assessor database. Where not available the year of "1900" was applied (7.8% 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 Tillamook 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 Tillamook 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 Tillamook 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 (Tillamook 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 Tillamook 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 (Tillamook 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 (United

States Census Bureau, 2010) 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 Tillamook County. **Table C-1** outlines the benchmark years that apply to buildings within Tillamook County.

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

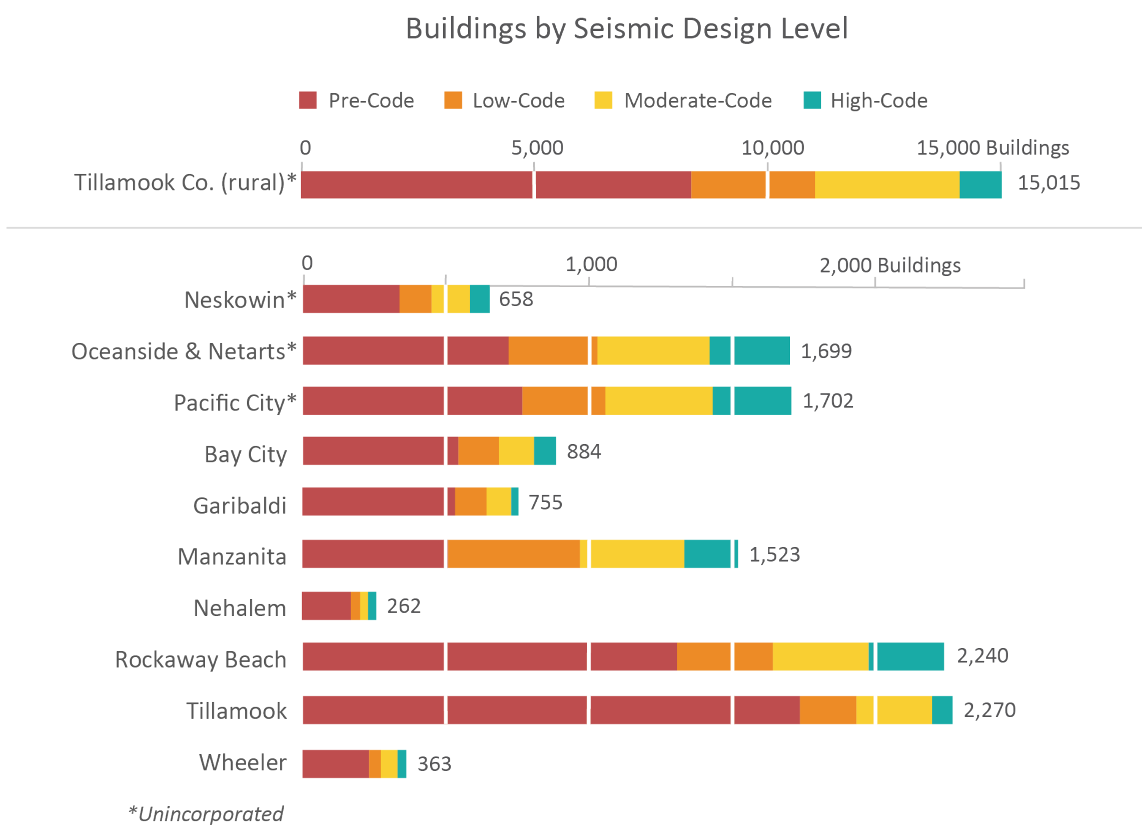
Building Type	Year Built	Design Level	Basis
Single Family Dwelling (includes Duplexes)	prior to 1976	Pre Code	Interpretation of Judson (Judson, 2012)
	1976–1991	Low Code	
	1992–2003	Moderate Code	
	2004–2016	High Code	
Manufactured Housing	prior to 2003	Pre Code	Interpretation of OR BCD 2002 Manufactured Dwelling Special Codes (Oregon Building Codes Division, 2002)
	2003–2010	Low Code	
	2011–2016	Moderate Code	Interpretation of OR BCD 2010 Manufactured Dwelling Special Codes Update (Oregon Building Codes Division, 2010)
All other buildings	prior to 1976	Pre Code	Business Oregon 2014-0311 Oregon Benefit-Cost Analysis Tool, p. 24 (Business Oregon, 2015)
	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 Tillamook County.

		Pre Code		Low Code		Moderate Code		High Code	
Community	**Total Number of Buildings**	**Number of Buildings**	**Percentage of Buildings**	**Number of Buildings**	**Percentage of Buildings**	**Number of Buildings**	**Percentage of Buildings**	**Number of Buildings**	**Percentage of Buildings**
Unincorp. County (rural)	15,015	8,366	56%	2,607	17%	3,310	22%	732	5%
Neskowin	653	338	52%	107	16%	144	22%	64	10%
Oceanside & Netarts	1,701	719	42%	296	17%	433	25%	253	15%
Pacific City	1,707	767	45%	275	16%	435	25%	230	13%
Total Unincorp. County	19,076	10,190	53%	3,285	17%	4,322	23%	1,279	7%
Bay City	884	543	61%	141	16%	131	15%	69	8%
Garibaldi	755	534	71%	110	15%	86	11%	25	3%
Manzanita	1,523	509	33%	432	28%	431	28%	151	10%
Nehalem	260	172	66%	32	12%	27	10%	29	11%
Rockaway Beach	2,240	1,308	58%	322	14%	388	17%	222	10%
Tillamook	2,270	1,737	77%	193	9%	274	12%	66	3%
Wheeler	363	232	64%	43	12%	62	17%	26	7%
Total Tillamook County	27,371	15,225	56%	4,558	17%	5,721	21%	1,867	7%

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



C.3 Flood Hazard Data

DOGAMI developed flood hazard data in 2015 for a revision of the Tillamook 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 Tillamook 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 and reduce the influence these errors have on the final outcome. Before applying the Hazus-MH methodology, closely examining the top 10 largest area UDFs and the top 10 most expensive UDFs is advisable. Special consideration can also be given to critical facilities due to their importance to communities.

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

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

APPENDIX D. ACRONYMS AND DEFINITIONS

D.1 Acronyms

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

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

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

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

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.

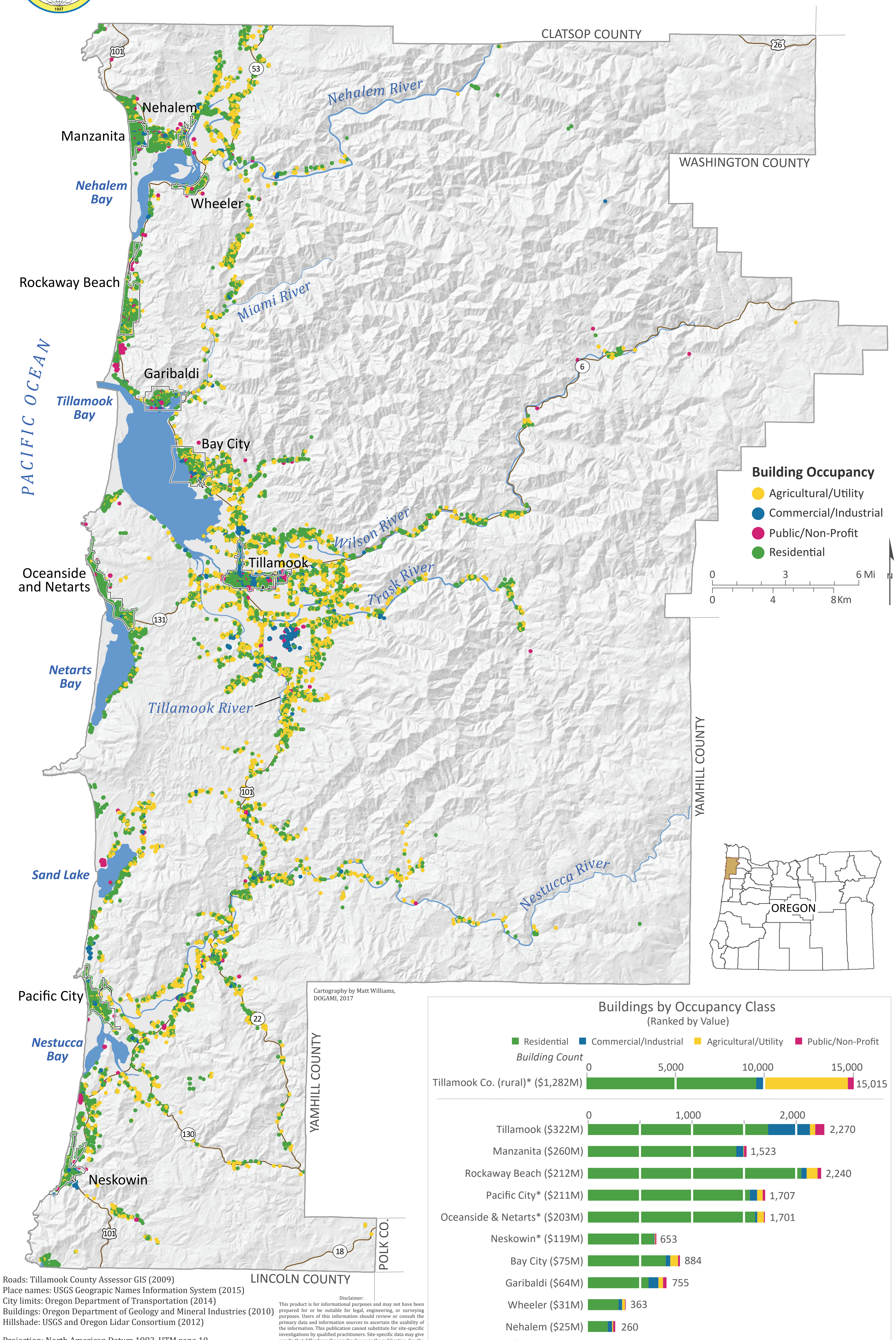
Vulnerability – Characteristics that make people or assets more susceptible to a natural hazard.

APPENDIX E. MAP PLATES

See appendix folder for individual map PDFs.

PLATE 1

Building Distribution Map of Tillamook County, Oregon



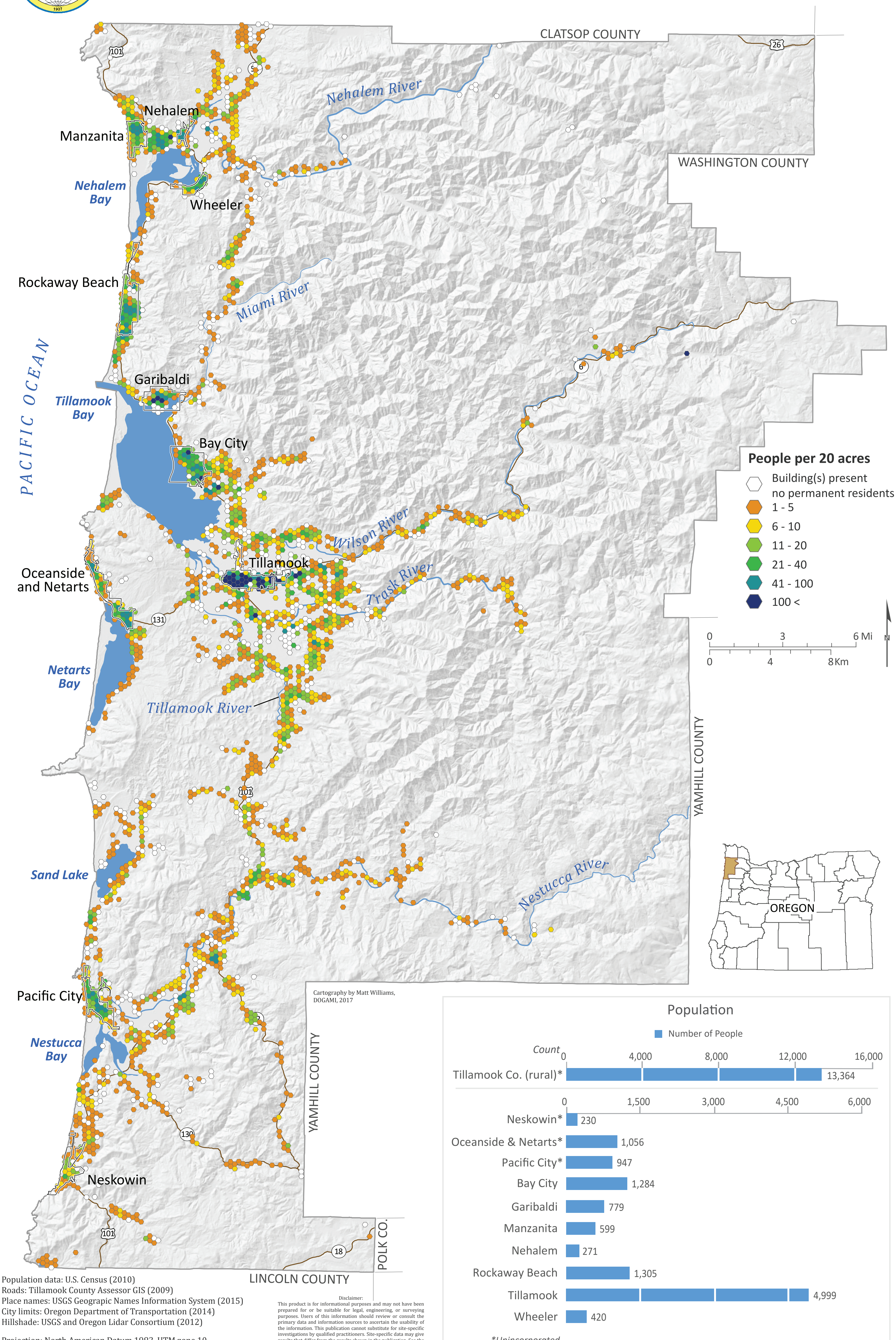
Roads: Tillamook County Assessor GIS (2009)
Place names: USGS Geograpic Names Information System (2015)
City limits: Oregon Department of Transportation (2014)
Buildings: Oregon Department of Geology and Mineral Industries (2010)
Hillshade: USGS and Oregon Lidar Consortium (2012)

Projection: North American Datum 1983, UTM zone 10.
Software: Esri ArcMap 10, Adobe Illustrator CS6.

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

PLATE 2

Population Density Map of Tillamook County, Oregon



Population data: U.S. Census (2010)
Roads: Tillamook County Assessor GIS (2009)
Place names: USGS Geograpic Names Information System (2015)
City limits: Oregon Department of Transportation (2014)
Hillshade: USGS and Oregon Lidar Consortium (2012)

Projection: North American Datum 1983, UTM zone 10.
Software: Esri ArcMap 10, Adobe Illustrator CS5.

Disclaimer:
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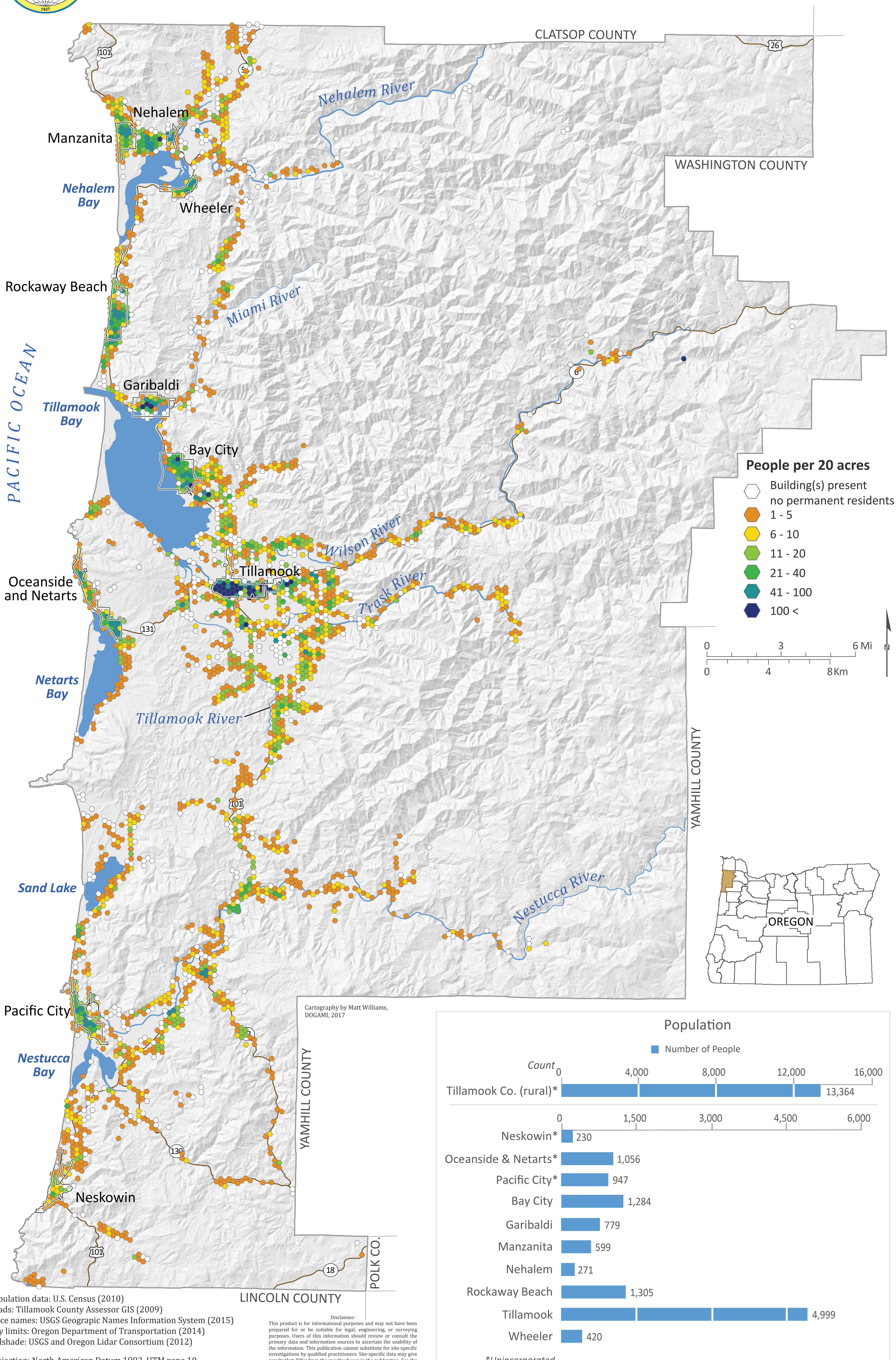


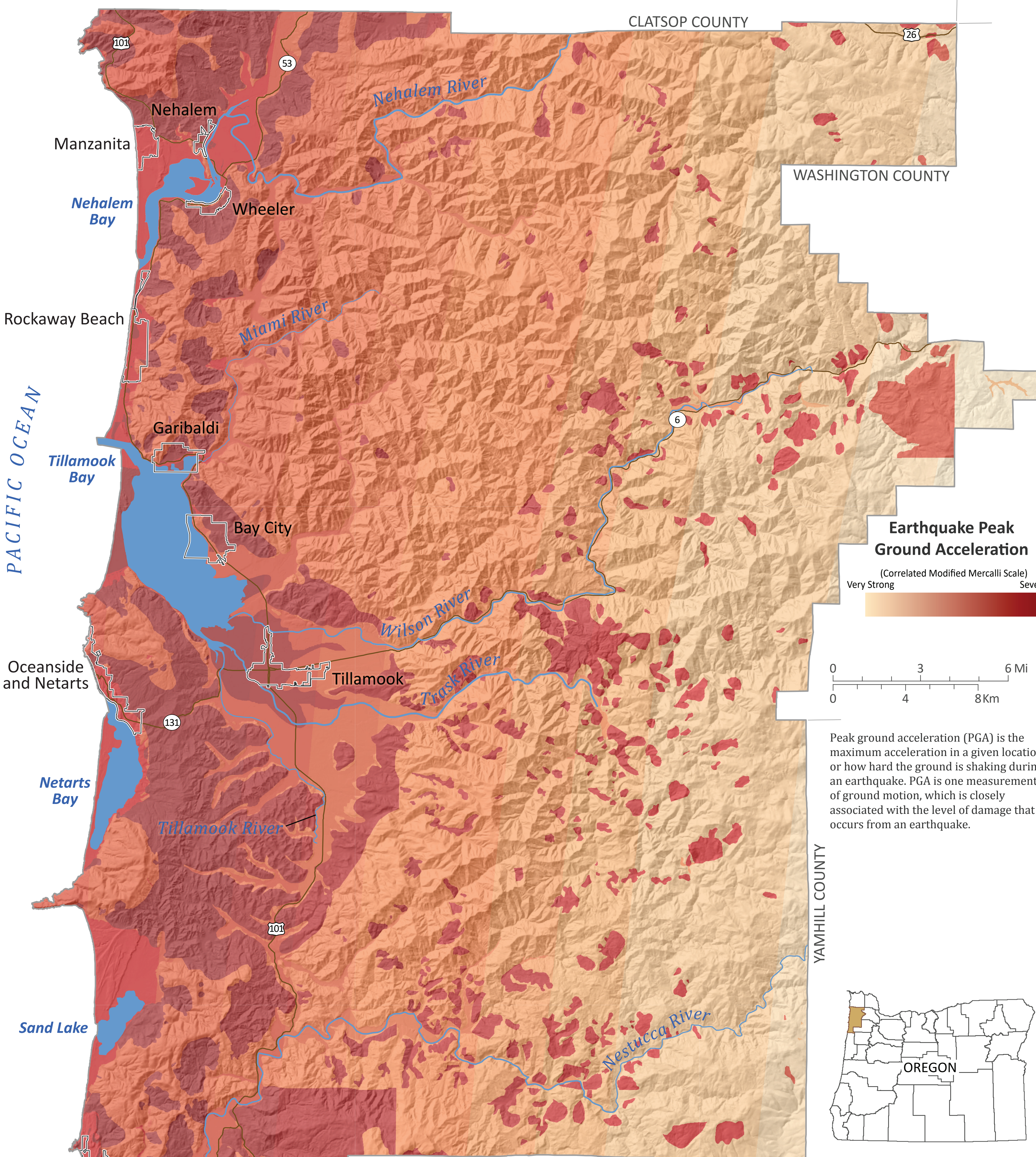
Population data: U.S. Census (2010)
Roads: Tillamook County Assessor GIS (2009)
Place names: USGS Geograpic Names Information System (2015)
City limits: Oregon Department of Transportation (2014)
Hillshade: USGS and Oregon Lidar Consortium (2012)

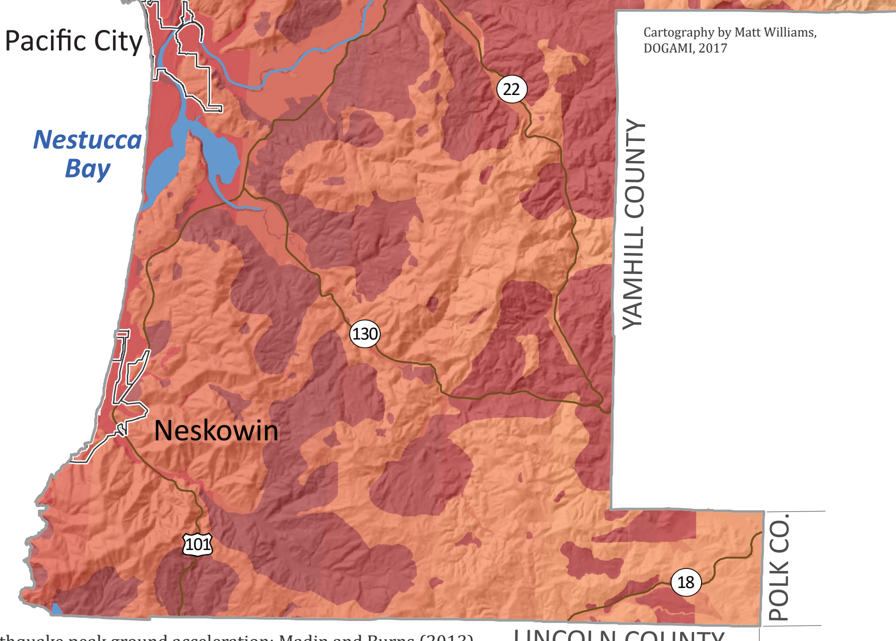
Projection: North American Datum 1983, UTM zone 10.
Software: Esri ArcMap 10, Adobe Illustrator CS5.

PLATE 3

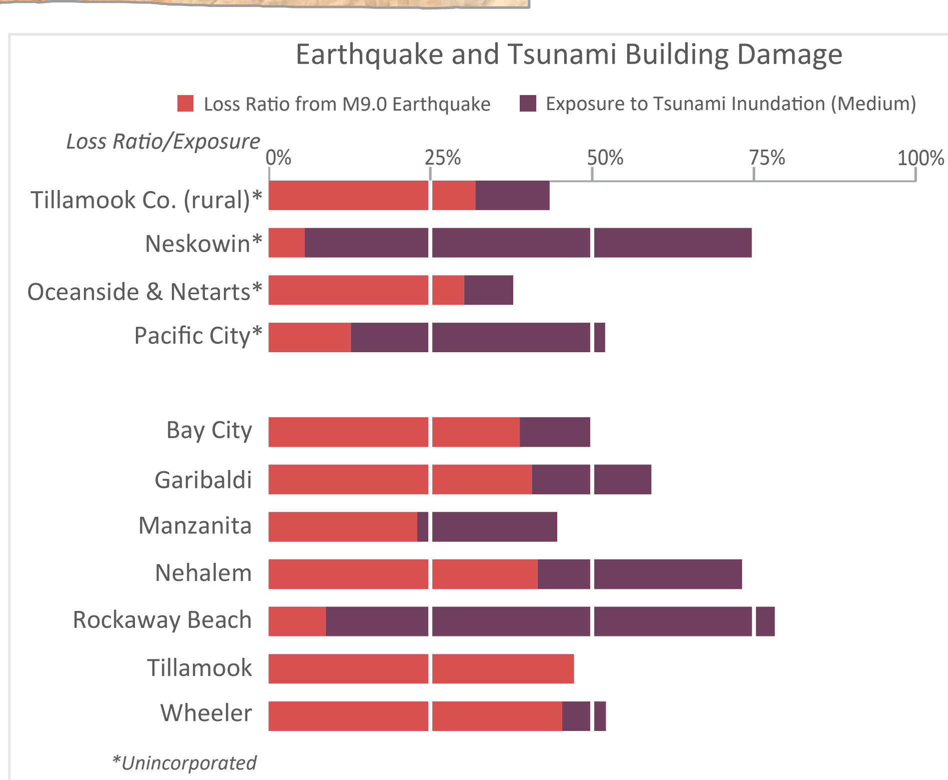
M9.0 CSZ Earthquake Shaking Map of Tillamook County, Oregon

The area where the Juan de Fuca tectonic plate slides under the North American plate is known as the Cascadia subduction zone (CSZ). Earthquakes along the CSZ occur on average every 500 years and can be extremely large. Data shown here are for a magnitude 9.0 event.





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



Earthquake peak ground acceleration: Madin and Burns (2013)
Roads: Tillamook County Assessor GIS (2009)
Place names: USGS Geograpic Names Information System (2015)
City limits: Oregon Department of Transportation (2014)
Hillshade: USGS and Oregon Lidar Consortium (2012)

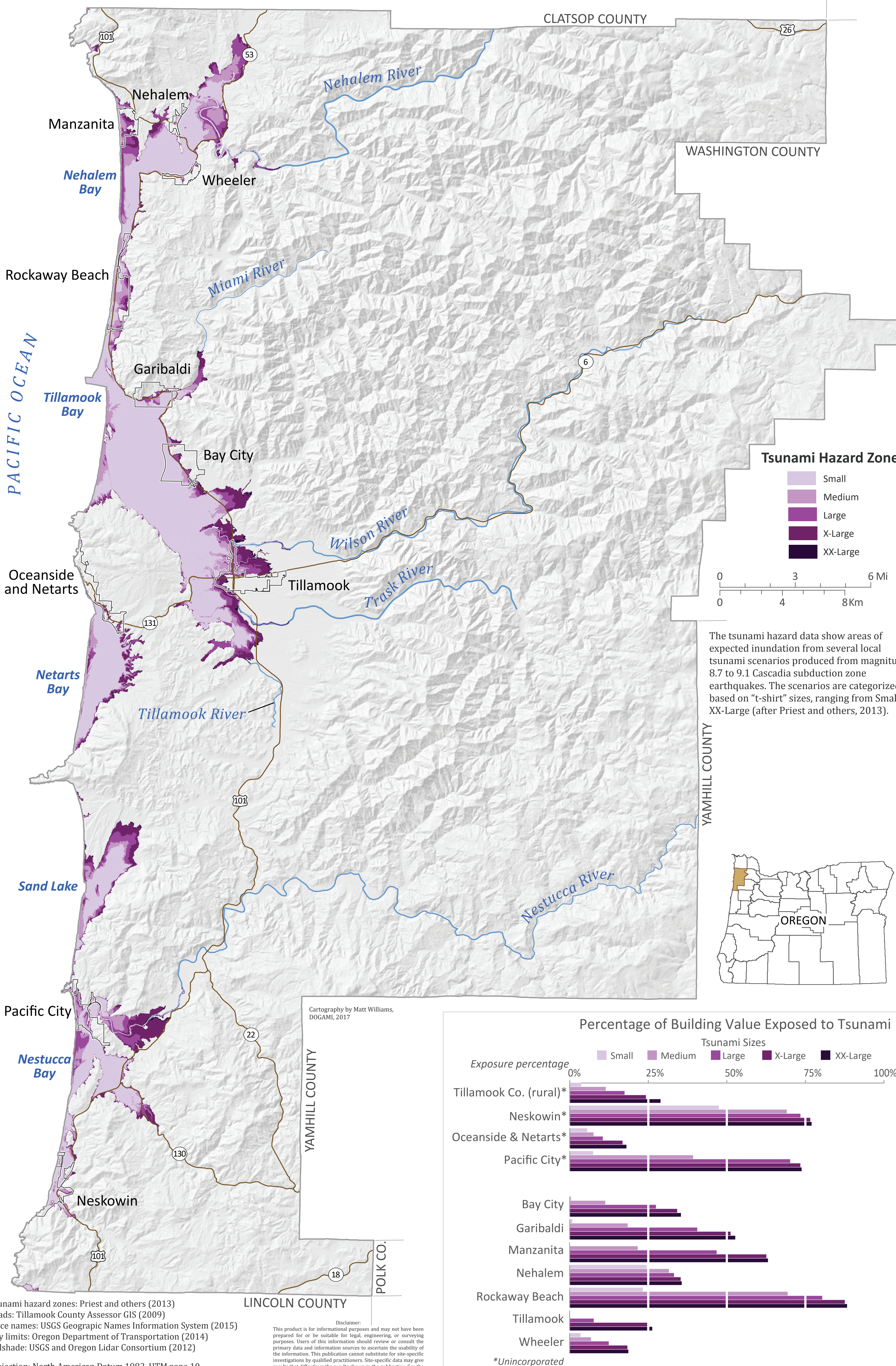
Projection: North American Datum 1983, UTM zone 10.
Software: Esri ArcMap 10, Adobe Illustrator CS5.

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

PLATE 4

Tsunami Inundation Map of Tillamook County, Oregon

The area where the Juan de Fuca tectonic plate slides under the North American plate is known as the Cascadia subduction zone (CSZ). Earthquakes along the CSZ occur on average every 500 years and can be extremely large.



The tsunami hazard data show areas of expected inundation from several local tsunami scenarios produced from magnitude 8.7 to 9.1 Cascadia subduction zone earthquakes. The scenarios are categorized based on "t-shirt" sizes, ranging from Small to XX-Large (after Priest and others, 2013).

Tsunami hazard zones: Priest and others (2013)
Roads: Tillamook County Assessor GIS (2009)
Place names: USGS Geograpic Names Information System (2015)
City limits: Oregon Department of Transportation (2014)
Hillshade: USGS and Oregon Lidar Consortium (2012)

Projection: North American Datum 1983, UTM zone 10.
Software: Esri ArcMap 10, Adobe Illustrator CS5.

Disclaimer:
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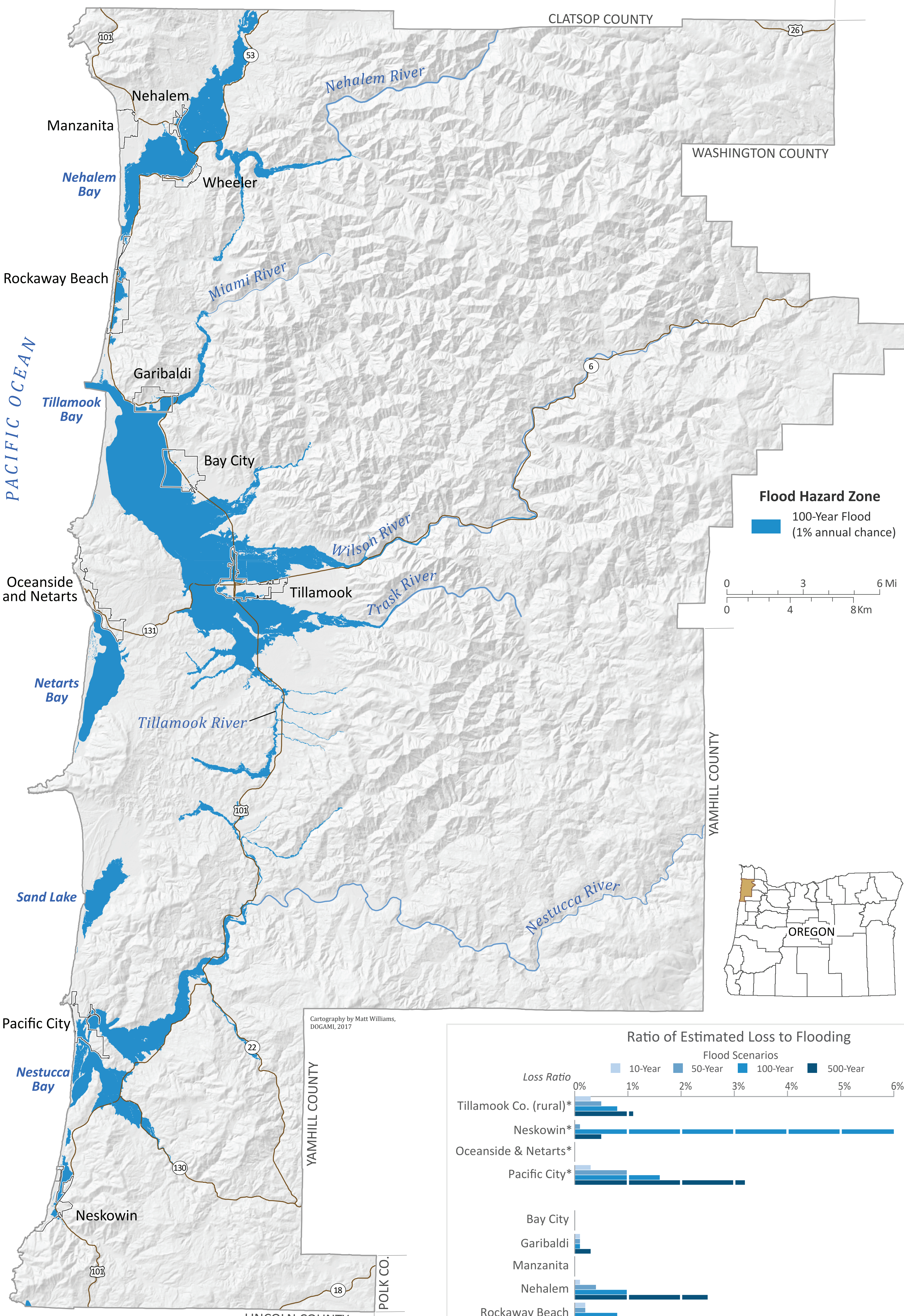
PLATE 5

Flood Hazard Map of Tillamook County, Oregon

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



Flood hazard zone (100-year): DOGAMI (2015)
Roads: Tillamook County Assessor GIS (2009)
Place names: USGS Geographic Names Information System (2015)
City limits: Oregon Department of Transportation (2014)
Hillshade: USGS and Oregon Lidar Consortium (2012)

Projection: North American Datum 1983, UTM zone 10.
Software: Esri ArcMap 10, Adobe Illustrator CS5.

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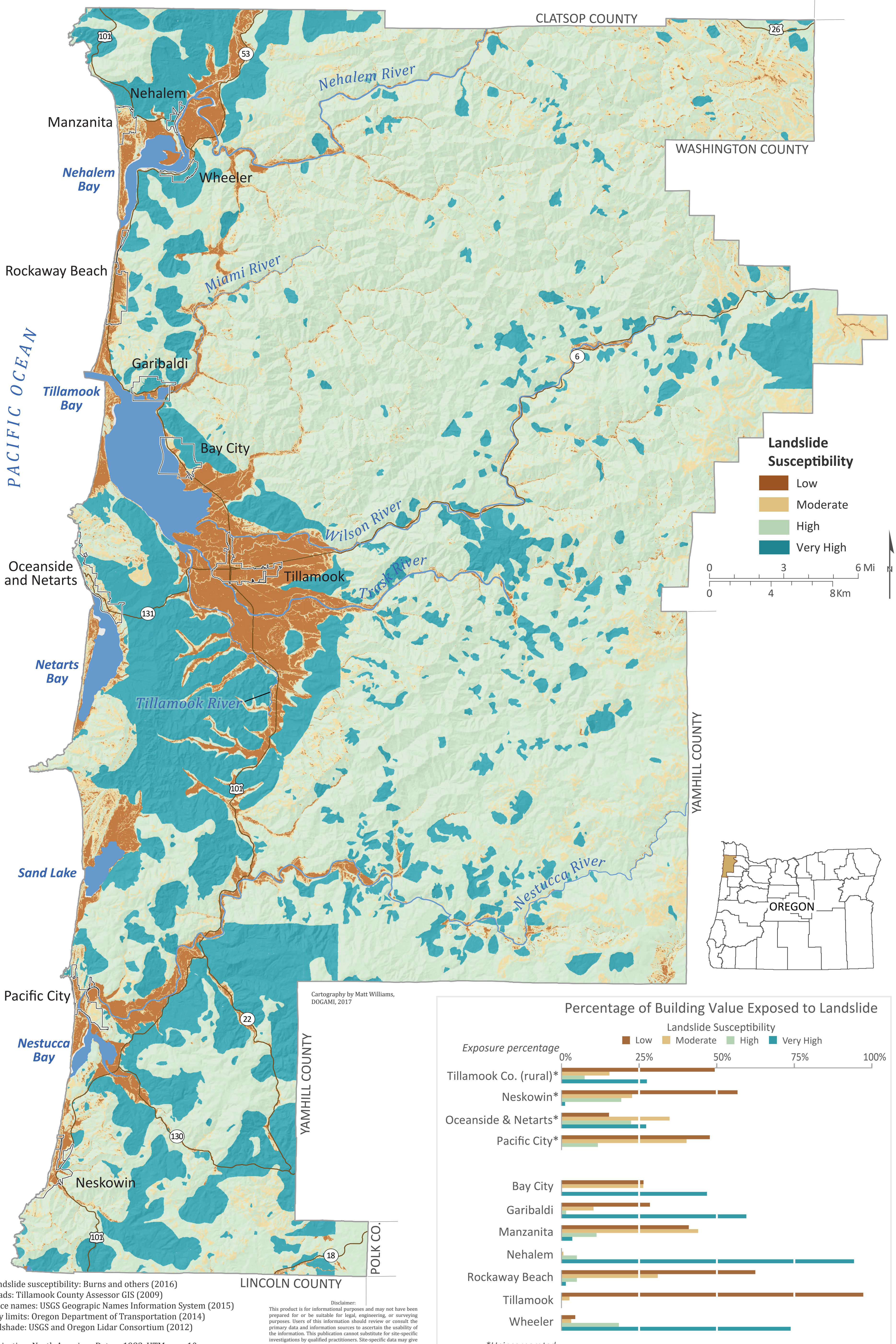
PLATE 6

Landslide Susceptibility Map of Tillamook County, Oregon

Landslide susceptibility is separated into zones that describe the general level of hazard from landslides. The dataset is an aggregation of three primary sources: landslide inventory (SLIDO), generalized geology, and slope.



Cartography by Matt Williams, DOGAMI, 2017

Landslide susceptibility: Burns and others (2016)
Roads: Tillamook County Assessor GIS (2009)
Place names: USGS Geograpic Names Information System (2015)
City limits: Oregon Department of Transportation (2014)
Hillshade: USGS and Oregon Lidar Consortium (2012)

Projection: North American Datum 1983, UTM zone 10.
Software: Esri ArcMap 10, Adobe Illustrator CS5.

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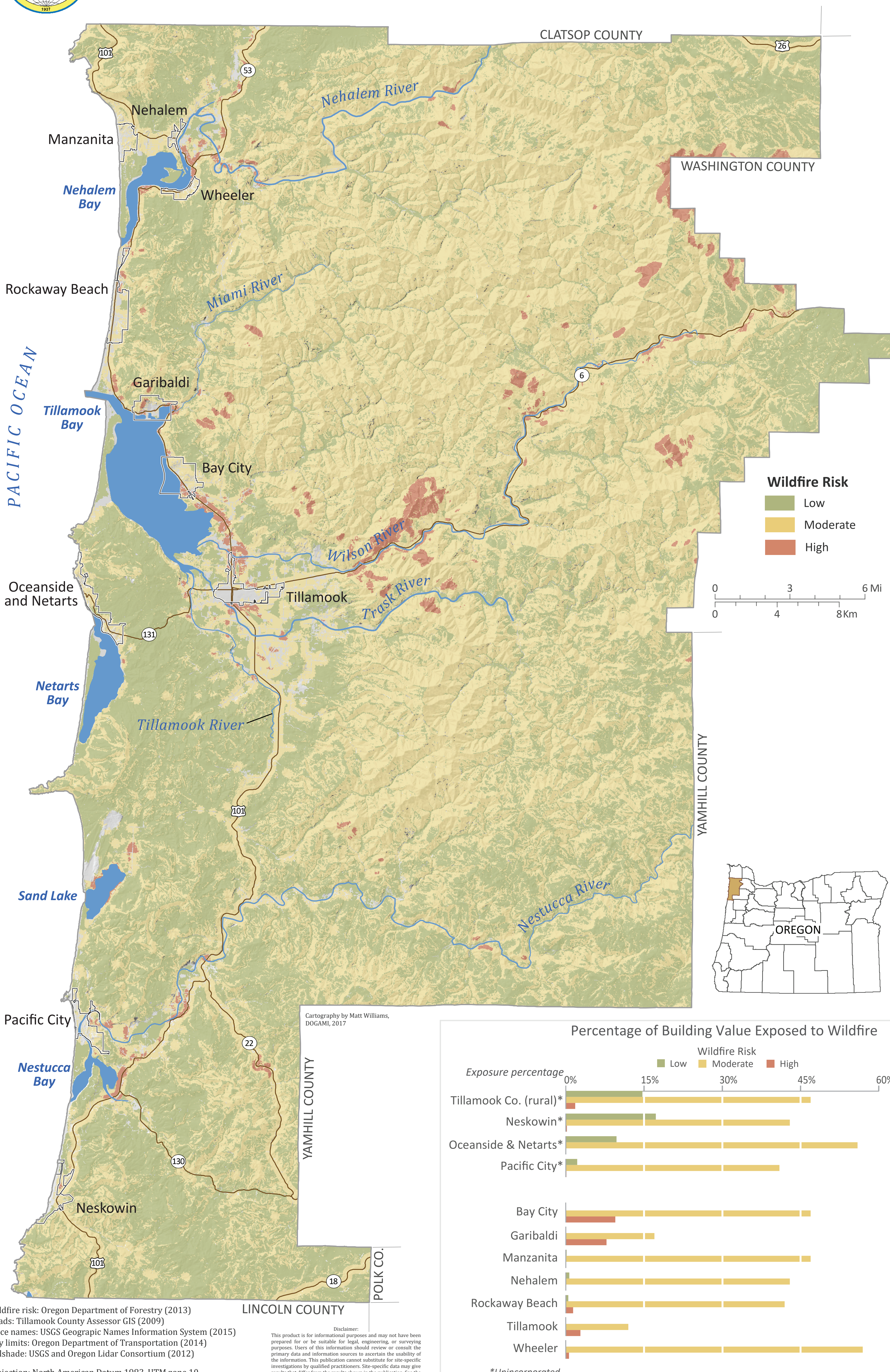
PLATE 7

Wildfire Risk Map of Tillamook County, Oregon

Wildfire risk is categorized as Low, Moderate, or 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).



Cartography by Matt Williams, DOGAMI, 2017

Wildfire risk: Oregon Department of Forestry (2013)
Roads: Tillamook County Assessor GIS (2009)
Place names: USGS Geograpic Names Information System (2015)
City limits: Oregon Department of Transportation (2014)
Hillshade: USGS and Oregon Lidar Consortium (2012)

Projection: North American Datum 1983, UTM zone 10.
Software: Esri ArcMap 10, Adobe Illustrator CS5.

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