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OPEN-FILE REPORT O-25-01

EARTHQUAKE AND TSUNAMI IMPACT ANALYSIS FOR THE OREGON COAST

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2025

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DISCLAIMER

WHAT'S IN THIS REPORT?

The objective of this work is to understand the degree of potential destruction, including building losses, debris generated, fatalities and injuries, and estimated numbers of the displaced populations caused by a full-margin Cascadia Subduction Zone earthquake (M_W 9.0) and accompanying tsunami (M1, L1, and XXL1 scenarios) affecting the Oregon Coast. This revision updates previous work undertaken for the Oregon Coast by including updated USGS earthquake scenarios, improved DOGAMI geology and soil classification classes, and 2020 census data. The goal is to help coastal communities prepare for this inevitable disaster.

Cover, *top left*: Devastation after the 2011 tsunami in Ofunato, Japan. U.S. Navy photo by Mass Communication Specialist 1st Class Matthew M. Bradley: https://www.flickr.com/photos/43397645@N06/5529924184, under license: https://creativecommons.org/licenses/by-nc/2.0/

top right: Photo from Wikimedia commons: https://commons.wikimedia.org/wiki/File:Devastation_after_tsunami_in_Iwaki_2.jpg, Devastation after the 2011 tsunami in Iwaki, Fukushima, Japan. under license: https://creativecommons.org/licenses/by/2.1/jp/deed.en

bottom left: Photo from Wikimedia commons: https://commons.wikimedia.org/wiki/File:US_Navy_050102-N-9593M-040_A_village_near_the_coast_of_Sumatra_lays_in_ruin_after_the_Tsunami_that_struck_South_East_Asia.jpg. U.S. Navy photo by Photographer's Mate 2nd Class Philip A. McDaniel, January 2, 2005

bottom right: Photo from Wikimedia commons: https://commons.wikimedia.org/wiki/File: US Navy 110315-N-5503T-307.jpg. An aerial view of damage to Otsuchi, Japan, after a 9.0 magnitude earthquake and subsequent tsunami devastated the area in northern Japan.
U.S. Navy photo by Mass Communication Specialist 3rd Class Alexander Tidd, March 15, 2011

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXCEL SPREADSHEETS

Microsoft Excel spreadsheets for all seven coastal counties are included in the digital file set of this report. These tables are the basis for this report's figures and hence contain information on the calculated damage and losses, casualties and debris generated data. A summary countywide spreadsheet is also provided.

COMMUNITY PROFILES

Community profiles containing summary information on evacuation walk maps, population demographics, housing characteristics, building inventories, replacement costs, damage losses, debris generated, and casualties are included in the digital file set of this report.

SUPPLEMENTAL FIGURES

Supplemental figures for every community and park that may have visitors residing in them are included in the digital file set of this report. These figures include maps depicting the spatial distribution of resident and visitor populations in the XXL1 tsunami inundation zone, numbers of residents and visitors in every evacuation flow zone for the XXL1 tsunami inundation zone, building occupancy types, combined tsunami and earthquake loss ratios, and debris maps.

UNIT CONVERSION TABLE

Units of Measurements in this Report: The intended audience for this report is local Government and the public. Therefore, we selected English units as the primary units. A conversion table for English to Metric units is included for easier conversion where needed.

	Multiply	By	To obtain
Length:	inch (in)	25.4	millimeter (mm)
	inch (in)	2.54	centimeter (cm)
	foot (ft)	0.305	meter (m)
	yard (yd)	0.914	meter (m)
	mile (mi)	1.609	kilometer (km)
Area:	square foot (ft^2)	0.093	square meter (m^2)
	square mile (mi^2)	2.590	square kilometer (km^2)
	acres	0.405	hectares (ha)
Volume:	cubic ft (ft^3)	0.028	cubic meter (m^3)
	cubic yard (yd^3)	0.765	cubic meter (m^3)
	cubic mile (mi^3)	4.168	cubic kilometer (km^3)
Weight:	ton (US)	0.907	ton (metric)

EXECUTIVE SUMMARY

This report is the final in a series of evaluations of the potential impacts of a Cascadia Subduction Zone (CSZ) earthquake and accompanying tsunami affecting communities and parks along the length of the Oregon Coast. The analyses presented here update previous countywide studies completed by the Oregon Department of Geology and Mineral Industries (DOGAMI) between 2020 and 2023. This important update includes latest U.S. Geological Survey (USGS) megathrust (moment magnitude (M_W) 9.0) earthquake scenarios, improved DOGAMI geology and soil classifications, and the most recent U.S. census data (2020). The information presented in this report provides a comprehensive assessment of the number of people, businesses, and critical facilities located in three CSZ tsunami inundation zones (M1, L1, and XXL1) and the associated damage and impacts from both the earthquake and accompanying tsunami. We used previously developed physical models of a CSZ earthquake and tsunami, evacuation modeling results undertaken by DOGAMI over the past decade, and the Federal Emergency Management Agency (FEMA) Hazus Earthquake and Tsunami models, to produce standardized damage loss estimates for every coastal community (including federal, state, and local parks), debris produced, estimates of injuries, fatalities, and the displaced population. Our population model provides spatially detailed estimates of resident and visitor populations. The tsunami injury and fatality modeling assume a nighttime (2 a.m.) evacuation scenario, such that people are in their homes/hotels/campgrounds at the time of the event. We maximize visitor occupancy in our User Defined Facilities (UDF) by assuming all hotels/second homes/campgrounds are at 100% capacity. Our major findings include the following:

Population Characteristics and Exposure:

- The total resident population on the Oregon Coast within a tsunami inundation zone ranges from 24,351 (M1) to 61,896 (XXL1). We estimate the potential for an additional ~62,760 (M1) to ~118,450 (XXL1) visitors on the Oregon Coast staying in hotel/motels, vacation homes and campgrounds. These data indicate that the visitor population recreating on the Oregon Coast (particularly in summer) may be as much as approximately two to three times greater than the resident population.
- Of the seven coastal counties, Clatsop County has the highest risk due to having the greatest number of residents in a tsunami inundation zone: 12,171 (M1), 16,568 (L1), and 20,930 (XXL1) residents, respectively. In addition, Clatsop County may have as many as ~18,700 (M1) to ~32,000 (XXL1) visitors who overnight in a tsunami inundation zone. Both Tillamook County and Lincoln County are also exposed to considerable human risk with many thousands of residents and visitors potentially located in a tsunami inundation zone.
- Combined, Clatsop, Tillamook, and Lincoln counties account for ~80% (M1) to ~65% (XXL1) of the total coastal resident population located in a tsunami inundation zone. In addition, the three counties are likely to have up to 80% of the total number of visitors to the Oregon Coast in the tsunami inundation zone.

Building Exposure, Damage, and Content Losses:

- We identified ~175,400 buildings along the Oregon Coast. Our Hazus modeling indicated that 92% of these buildings would be damaged following a M_W 9.0 CSZ earthquake. Of these, 24% are estimated to be destroyed, 29% could experience extensive damage, 27% could experience moderate damage, and 19% would be subject to minor damage.
- The number of buildings destroyed by the earthquake was found to be highest in Curry County, due to their close proximity to the subduction zone.

- We estimate 73% (M1) to 87% (XXL1) of buildings in the tsunami inundation zone are likely to be destroyed, initially by the earthquake shaking followed by the large forces associated with the tsunami currents and flow depth.
- Total losses on the Oregon Coast from a M_W 9.0 CSZ earthquake and the three tsunami inundation scenarios was found to range from ~$35.4 billion (M1) to greater than $45 billion (XXL1). These numbers exclude the expected massive economic impact associated with this event, that is likely to produce losses in the hundreds of billions.

Debris Produced:

- We calculate the amount of debris produced by the earthquake and tsunami could range from ~1.6 million (M1) tons to greater than 4.4 million tons on the coast. We note that these numbers are almost certainly at the low end since they exclude damage to roads, ground rip ups, vegetation, and many other potential contributors.

Earthquake Casualties:

- Minor earthquake-related injuries are likely to reach ~6,500 for the Oregon Coast. Of concern are the estimated 1,700 additional people who are likely to experience serious injuries (e.g., fractures, internal organ damage, crush injuries, and burns) that would require immediate hospitalization. Presently, the 11 coastal hospitals have capacity for no more than 480 people (OSSPAC, 2013), such that these facilities would be quickly overwhelmed. Furthermore, earthquake- and tsunami-related damage is likely to affect basic operations (power, water, sanitation) that could compromise the ability of coastal hospitals to respond following the disaster. Fatalities from the earthquake are expected to be low (~240) on the Oregon Coast.

Tsunami Casualties:

- Our Hazus modeling indicates ~740 (M1) to ~1,800 (XXL1) additional injuries to residents due to the tsunami; visitor-related injuries caused by the tsunami could range from ~2,400 (M1) to ~2,800 (XXL1).
- Fatalities caused by the tsunami will be devastating. We estimate ~4,550 (M1) to ~14,000 (XXL1) residents killed, and potentially another ~11,000 (M1) to ~31,700 (XXL1) visitors killed. The latter numbers assume 100% occupancy in hotel/motels, vacation homes, and campgrounds on the Oregon Coast, but ignore the number of day trippers that may be on the coast at the time of the disaster. Reducing the occupancy rates to even 50% indicates the potential for still many thousands of visitors killed. For comparison, the 2011 M_W 9.0 Tohoku Japan tsunami killed ~18,500 people.

Displaced People:

- Following the earthquake and tsunami, local, state, and federal agencies will have to deal with many thousands of displaced residents and visitors who will require immediate short-term shelter and care (days to a few weeks after the disaster).
  - We estimate as many as ~60,300 (M1) to ~80,170 (XXL1) displaced residents. These numbers equate to 27% (M1) to 41% (XXL1) of the total coastal population.
  - Our casualty modeling suggests that coastal communities may have to deal with an additional ~66,400 (M1) to as many as ~96,000 displaced visitors who will require short-term care until they are evacuated from the coast.
- Given the likelihood of significant economic collapse along the coast in the months following the disaster, the coast is likely to be affected by a mass exodus of residents until such time that communities begin the process of rebuilding.

Summary information specific to every coastal community (town or park) and tsunami inundation zone is provided in **Appendix A: Community Profiles**. Although each community has unique circumstances and challenges, our results unequivocally demonstrate that in every community, ***injuries and fatalities from a tsunami can be minimized if people evacuate on foot toward safety as soon as possible and travel as fast as possible.***

1.0 INTRODUCTION

The Oregon Coast is exposed to large megathrust subduction zone earthquakes capable of generating catastrophic tsunamis (Witter and others, 2011). The objective of this report is to examine community exposure to tsunami inundation and earthquake shaking and provide estimates of infrastructure damage and casualties for the Oregon Coast (**Figure 1.1**). This study uses updated CSZ earthquake scenarios developed by Wirth and others (2020), new geologic data summarized in Madin and others (2021), and U.S. 2020 census data and hence provides an important update to previous work undertaken by Allan and others (2020a, b) and Allan and O'Brien (2021, 2022).

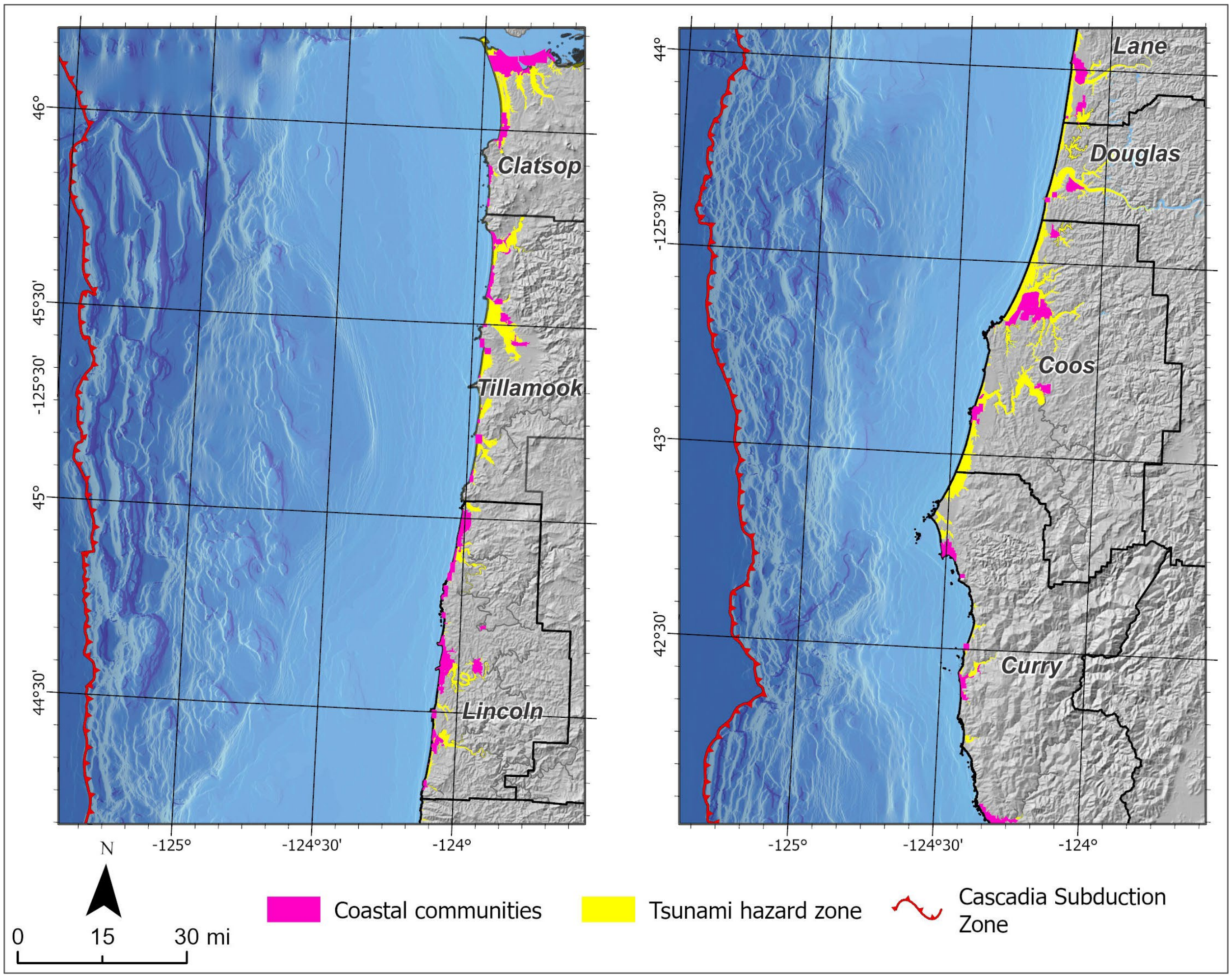
The CSZ geologic record suggests there have been at least 19 megathrust earthquakes greater than M_W 8.5 over the past 10,000 years with an average recurrence of 400 to 500 years (Goldfinger and others, 2012, 2017; Priest and others, 2009; Satake and others, 2003; Walton and others, 2021; Witter and others, 2012). An additional 26 smaller magnitude earthquakes ($>M_W$ 7.4 and $<M_W$ 8.5) are also recorded in various estuaries on the southern Oregon Coast and northern California, suggesting that there are more frequent, and smaller, partial rupture earthquakes and tsunamis (average 220 years) in southern Cascadia. The most recent tsunami generated on the CSZ occurred on January 26, 1700 (Atwater and others, 2005). Goldfinger and others (2017) estimated the conditional probability of an earthquake on the CSZ at 16%–22% in the next 50 years; a partial rupture of the CSZ impacting the southern Oregon Coast has a conditional probability of 37%–43% (Goldfinger and others, 2012). Because many communities on the Oregon Coast have large numbers of people, residences, and businesses located in and adjacent to the tsunami inundation zone, there is a high potential that the next megathrust earthquake and tsunami will result in many fatalities, catastrophic destruction of local infrastructure, and lasting damage to Oregon's economy.

The destructive and life-threatening forces of tsunamis are well known globally, as demonstrated by the 2011 Tōhoku, Japan event that resulted in ~18,500 killed (National Police Agency of Japan, 2020). Most of the deaths in the event were due to drowning (Mori and Takahashi, 2011). The earthquake and tsunami destroyed 121,992 buildings; 282,920 buildings experienced partial collapse and 730,359 buildings were partially damaged. A total of 4,198 roads were damaged, along with 116 bridges (National Police Agency of Japan, 2020).

Following the 2011 Tōhoku, Japan, tsunami, FEMA commissioned a study to standardize quantification of tsunami impacts (FEMA, 2013), which was refined and eventually incorporated into FEMA's Hazus framework (FEMA, 2017). Hazus is a geospatial information system (GIS) software model that produces loss estimates for earthquakes, floods, hurricanes, and tsunamis based on state-of-the-art scientific and engineering risk analyses. Critical inputs needed by Hazus include a wide variety of tsunami modeling, engineering, and societal information, including earthquake ground motion and ground deformation, tsunami inundation, flow velocities and flow depths, building inventories, and population demographics.

Considerable mapping and modeling have been undertaken by DOGAMI to better advise local and state government agencies on the various geologic hazards that could impact the state. For example, DOGAMI and the USGS published ground motion/deformation maps for a M_W 9.0 CSZ earthquake (Madin and Burns, 2013). These data were integral in initial efforts to evaluate impacts from a CSZ event throughout Oregon (OSSPAC, 2013). The work of Madin and Burns (2013) have since been updated by Madin and others (2021) to account for new geological data, including updated soil, liquefaction, and landslide information, as well as recently compiled Cascadia earthquake ensemble modeling undertaken by Wirth and others (2020).

Figure 1.1. Location map showing the seven coastal counties of Oregon, XXL1 tsunami hazard zone (yellow zone) and the community areas (pink) evaluated as part of this M_W 9.0 CSZ earthquake and M1, L1 and XXL1 tsunami inundation scenarios.



Between 2010 and 2013, DOGAMI combined high-resolution terrestrial lidar-derived digital elevation models with detailed bathymetry to model five scenarios for CSZ-generated tsunamis (Priest and others, 2013g; Witter and others, 2011). With the completion of coastwide tsunami inundation mapping (**Figure 1.1**), Priest and others (2015) pioneered new techniques for tsunami evacuation modeling (*Beat the Wave* or BTW) in the cities of Seaside and Gearhart, Clatsop County. These techniques have subsequently been improved upon and evacuation modeling has now been completed for all Oregon Coast communities (Gabel and Allan, 2016; Gabel and Allan, 2017; Gabel and others, 2018a, b; Gabel and others, 2019a, b, c, d; Gabel and others, 2020a, b; Gabel and others, 2021; Gabel and others, 2022a, b; Gabel and others, 2023; Gabel and others, 2024). These studies graphically demonstrate evacuation challenges and mitigation opportunities but do not quantify potential loss of life.

Important for casualty assessments is a spatially explicit population model for the Oregon Coast. Specifically, how many people are in the tsunami inundation zones? What are their demographics? Where are they located in the tsunami zone at the time of the earthquake? Such a model is further complicated because the Oregon Coast experiences large influxes of daytime and overnight visitors throughout the year (Dean Runyan Associates, 2018), but especially in summer months. Many homes and condominium units located in the tsunami inundation zone are second homes or vacation rentals (Raskin and Wang, 2017). Additionally, numerous coastal parks and campgrounds are in the tsunami inundation zone and potentially host many thousands of overnight visitors per day (White, 2018). Each of these considerations must be carefully evaluated and accounted for so that meaningful statistics of both local and visitor populations can be made, which would allow for the documentation of numbers of casualties and displaced people for every community. Finally, *population estimates should assume the highest seasonal occupancy so that design capacities will be based on the maximum potential evacuation need*, while also identifying vulnerable population groups within the tsunami inundation zone that may present special evacuation challenges (DLCD, 2015).

This report provides a coastwide perspective of the potential effect of a CSZ earthquake and accompanying tsunami affecting the Oregon Coast (**Figure 1.1**). The results presented here reflect an important update to previous work undertaken by Allan and others (2020a, b) and Allan and O'Brien (2021, 2022) in order to incorporate new data, including: updated Cascadia earthquake scenarios developed by Wirth and others (2020), new seismic hazard geologic data compiled by Madin and others (2021), and U.S. 2020 census data. Specifically, we evaluate estimates of potential building losses, generated debris, fatalities, and injuries, as well as estimates of the number of displaced people caused by both the earthquake and the accompanying tsunami. The report briefly re-introduces our overall Hazus approach. Results from the coastwide assessment are provided in Section **3.0**, with broad conclusions outlined in Section **4.0** and **5.0**. Summary information specific to each community and tsunami inundation zone is provided in **Appendix A: Community Profiles** and **Appendix B: Supplemental Figures**.

2.0 METHODS

2.1 Overview

Baseline information required by Hazus includes:

1. A physical description of the earthquake and tsunami hazard
2. A comprehensive building database, with each building populated with an occupancy estimate derived from our population model

For the earthquake hazard, we used the median CSZ M_W 9.0 earthquake, which is derived from an ensemble of 30 Cascadia earthquake scenarios (Wirth and others, 2020). For the tsunami hazard, we provide results for three tsunami inundation zones: Medium (M1), Large (L1), and Extra-extra-large (XXL1) (Priest and others, 2013g; Witter and others, 2011). Accordingly, our Hazus model results include earthquake-related damage, debris weight, and casualties simulated for a UDF and then aggregated to a community level, along with similar calculations defined for the three tsunami inundation scenarios. We do not model the earthquake damage and casualties that would occur for those communities located well inland from the coast. **Figure 1.1** identifies those communities (pink shading) evaluated as part of this investigation. **Figure 1.1** includes the XLL1 tsunami inundation zone (yellow shading) for added context.

2.2 Natural Hazard Dataset Development

2.2.1 Earthquake

Wirth and others (2020) produced ground-shaking estimates from 30 M_W 9.0 CSZ earthquake scenarios, determined using a logic-tree approach that varied a suite of earthquake rupture parameters, including the location within the earth where the earthquake rupture starts, down-dip rupture limit, slip distribution, and the location of strong-motion-generating subevents. From these data, they produced an ensemble suite of ShakeMaps[1] based on the median scenario ±1σ[2] and ±2σ which spans the 2nd and 98th percentile ground motions. For the median ensemble ShakeMap, they observed that the Modified Mercalli intensity (MMI), a measure of the ground-shaking intensity, is likely to range from MMI ~8 (severe shaking) along the Oregon Coast to MMI ~7 (very strong shaking) for inland locations such as the Willamette Valley. The southern Oregon Coast could experience MMI 8–9, which equates to violent shaking. According to Wirth and others (2020), the difference between the 2nd and 98th percentile ground motions (i.e., ±2σ around the median) spans 1.5–2.0 MMI units. For the purposes of this risk assessment, we used the bedrock ground motions associated with the median M_W 9.0 CSZ earthquake (Wirth and others, 2020) for use in the FEMA Hazus Advanced Engineering Building Module (AEBM; FEMA, 2010).

Figure 2.1A presents peak ground acceleration (PGA) values compiled from each building location along the Oregon Coast and averaged at the county level, while **Figure 2.1B** presents the spectral acceleration (SA)[3] values for 0.3-second (SA03) and 1.0-second (SA1). These data were originally produced by Wirth and others (2020) and were subsequently compiled by Madin and others (2021, p20) to produce site-amplified probabilistic ground motion maps for Oregon. We include these generalized data to highlight regional variations in earthquake shaking characteristics for the Oregon Coast, since

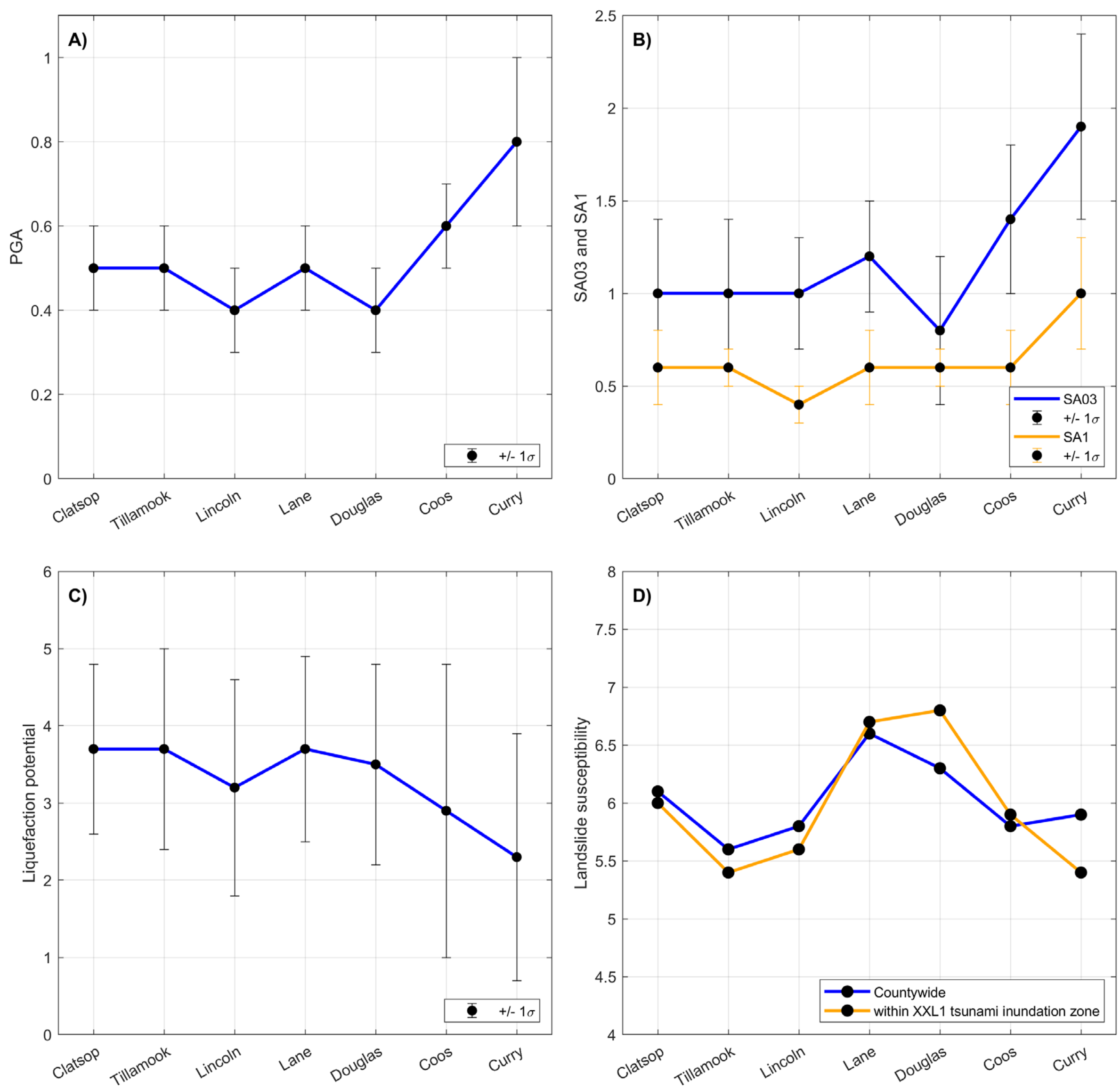
[1] https://earthquake.usgs.gov/data/shakemap/

[2] where σ (sigma) corresponds to the standard deviation of the data, such that ±1σ = ±34.1% either side of the mean, while ±2σ = ±47.7%. Hence, 1σ and 2σ respectively encompass 68.2% and 95.4% of the spread of the data.

[3] SA is a unit that describes the maximum acceleration in an earthquake on an object.

these data are the primary hazard to buildings. In general, both parameters are an approximate measure of building damage potential; PGA is most relevant to short buildings, while SA is important for the relative damage hazard to taller buildings. Note that Hazus uses ground motion values to evaluate building damage potential. Larger values of PGA and SA in southern Oregon (Coos County and Curry County) are due to their close proximity to the CSZ, such that damage potential there is likely to be higher.

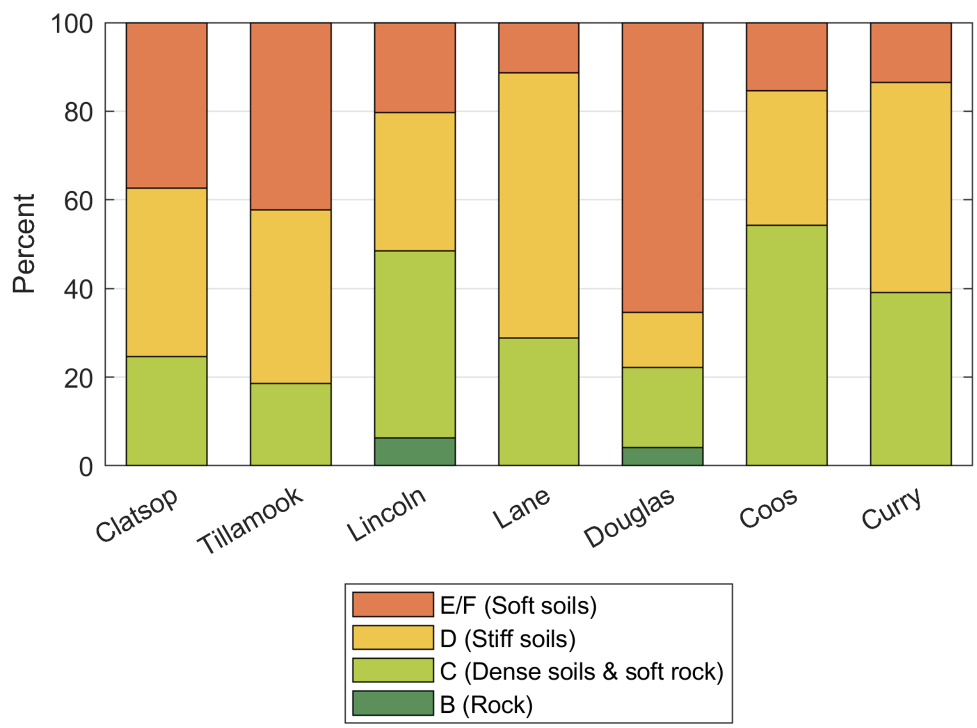
Figure 2.1. Countywide variations in geologic parameters used by Hazus to calculate earthquake damage potential and casualties. A) Peak ground acceleration (PGA), B) spectral acceleration (SA) for 0.3-second and 1.0-second, C) liquefaction susceptibility in the XXL1 tsunami inundation zone, and D) landslide susceptibility in the XXL1 tsunami inundation zone. The range in values (±1σ) for select parameters are characterized by the vertical bars.



The median M_W 9.0 CSZ earthquake data were compiled along with local ground characteristics that influence the amplification of ground shaking, namely liquefaction of soils (**Figure 2.1C**), and earthquake-induced landslides (**Figure 2.1**D) by Madin and others (2021) to produce a new statewide seismic hazard map for Oregon. These latter datasets reflect years of surficial geologic mapping using high-resolution lidar data to produce detailed maps of areas subject to different coseismic geohazard conditions.

The bedrock ground motions were adjusted for discrete areas using the National Earthquake Hazards Reduction Program (NEHRP)-recommended site amplification factors (FEMA, 2015a; implemented as piecewise linear equations by Bauer and others, 2018, Appendix B). Updated NEHRP site classification (Figure 2-4 in Madin and others, 2021) and Hazus-scale liquefaction susceptibility GIS data (Figure 2-5 in Madin and others, 2021) were used in this study. Sites with NEHRP site classification F (meaning a soil that requires site-specific evaluation, as defined by FEMA, 2003, Section 3.5) were reclassified as E (soft soils)—a commonly implemented assumption for loss-estimation purposes (Bauer and others, 2018; Madin and others, 2021). We present a summary of the NEHRP site classification data in **Figure 2.2** for the seven Oregon coastal counties.

Figure 2.2. NEHRP surface materials site classifications for counties on the Oregon Coast.



For liquefaction modeling, we assumed a fully saturated soil. In general, values in the 3 to 5 range (**Figure 2.1C**) indicate Moderate to Very High liquefaction potential. Hazus-scale landslide susceptibility data were obtained by processing landslide susceptibility GIS data compiled by Madin and others (2021). We mapped the 1–4 scale defined by Madin and others (2021) to the FEMA Hazus landslide susceptibility scale of 0–10 as follows: Low corresponds to 1, Moderate corresponds to 4, High corresponds to 7, and Very High corresponds to 10. The mapping corresponds to the WET scenario described by FEMA (2011,

Table 4.15). **Figure 2.1D** presents summary landslide susceptibility data for the Oregon Coast, with values in the 4 to 7 range indicating Moderate to High landslide susceptibility.

2.2.2 Tsunami

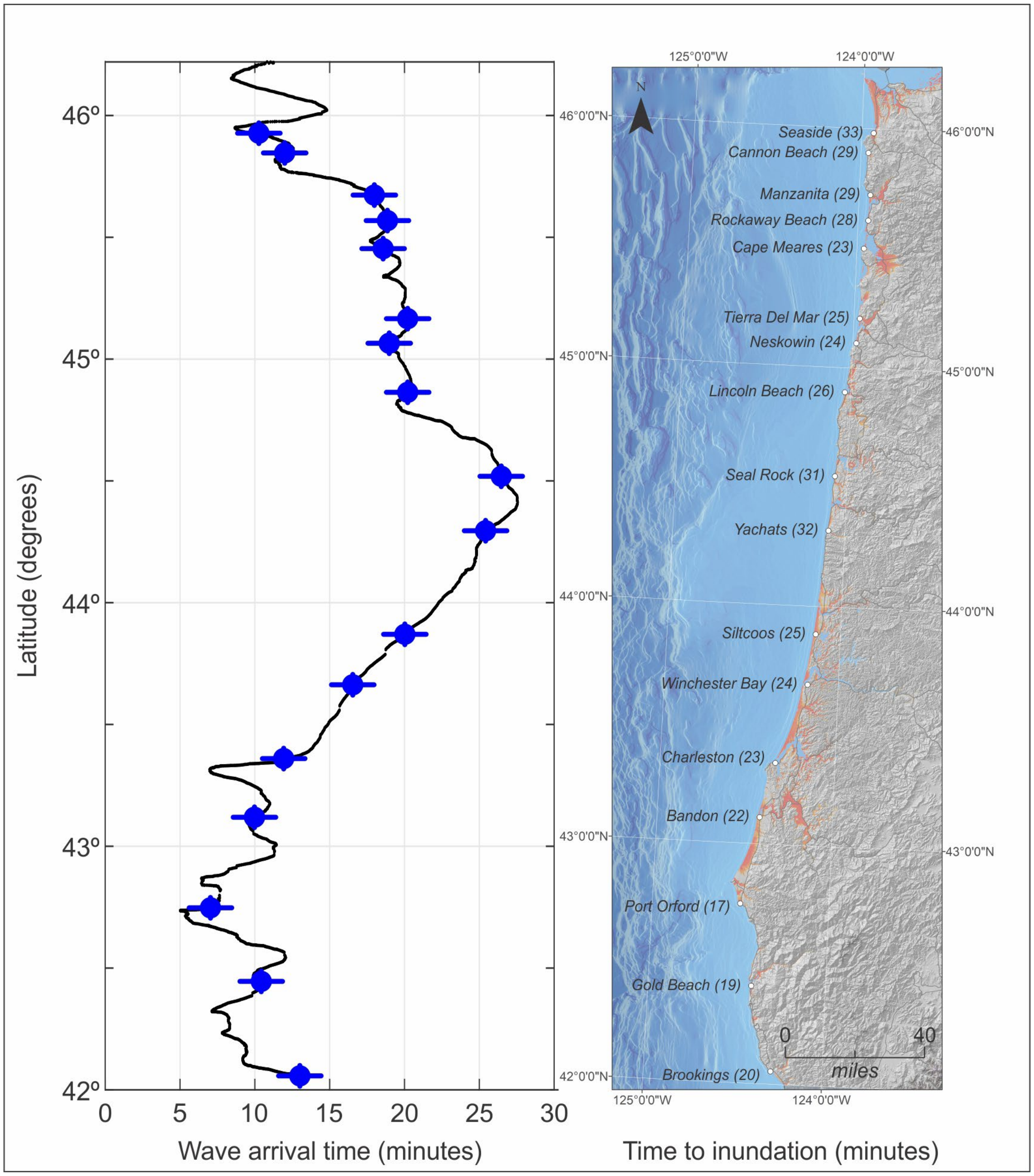
The earthquake scenarios and corresponding surface deformation used to simulate tsunami inundation for the Oregon Coast reflect a full-length rupture of the Cascadia megathrust (Witter and others, 2011, 2013). For the purposes of this study, we calculated damage and casualty statistics for three tsunami inundation scenarios: M1, L1, and XXL1 (Priest and others, 2013g; Witter and others, 2011). Upriver from Astoria in Clatsop County, we used the updated tsunami modeling results (i.e., inundation extents, momentum flux, flow depths, and wave arrival times) for the L1 and XXL1 inundation scenarios from Allan and others (2018) to complete our analyses of Clatsop County; Allan and others did not update the M scenario for the area upriver of Astoria. According to Witter and others (2013), the three tsunami inundation scenarios used here correspond to the following approximate recurrence rates: M1, 1/1,000 years; L1, 1/3,333 years; recurrence for the XXL1 event is not known but is likely ~1/10,000 years.

Maximum flow depths were obtained from Priest and others (2013a, b, c, d, e, f) while the maximum momentum flux was derived from Priest and others (2014a, b, c, d, e, f). The unstructured computational grid model data were converted to raster format for use in Hazus using the Esri® ArcGIS Spatial Analyst Natural Neighbor tool. We specified a 10 ft (3 m) grid resolution, noting that the mean distance between points in the terrestrial regions within the XXL1 tsunami inundation zone was ~16 ft (~5 m). The raster data were then converted to both median depth and median momentum flux using a 0.66 multiplier. The latter is required since the Hazus tsunami building damage and casualty fragility curve parameters are based on median depth and momentum flux values (FEMA, 2017, Section 4.6).

Wave arrival times at the tsunami runup limit were obtained from data originally developed by Priest and others (2013a, b, c, d, e, f). As documented by Bauer and others (2020), an independent spreadsheet that implements the Hazus tsunami casualty model was developed to facilitate analysis and reporting of injuries and fatalities resulting from a tsunami (see Section **2.6**). The original approach relied on a single average wave arrival time per community. For this study, however, we modified the approach to support per-record maximum wave arrival times at the tsunami runup limit (in minutes). This was necessary due to the significant variation in wave arrival times observed along the Oregon Coast and within individual communities. This is particularly important within coastal estuaries and many of the rivers, where wave arrival times can vary by tens of minutes. (**Figure 2.3**). To define the unique wave arrival times, we used the evacuation flow zone[4] polygons defined in our various evacuation modeling studies to associate a group of buildings with a particular tsunami safety destination, also referred to as an exit point. We then determined the maximum wave arrival time at a particular flow zone's exit point and assigned that value (in minutes) to the polygon (e.g., **Figure 2.3** *right*). All buildings within that flow zone were then associated, via a spatial overlay, with that wave arrival time. Wave arrival times for areas located outside our detailed BTW investigations were defined based on average wave arrival times for that section of coast.

[4] Flow zones can be thought of as a watershed, with the exit point representing the head of the watershed.

Figure 2.3. ***left*****) Modeled wave arrival times at the beach.** ***right*****) Average time it takes an XXL1 tsunami to fully inundate various locations on the Oregon Coast. Note: Actual wave arrival and inundation times could vary by several minutes.**



2.3 Building Database Development

A Hazus-compatible building database contains a record for each distinct building. Each record includes essential information for estimating potential damage to the structure and harm to the building's occupants (**Table 2.1**). Information associated with the building record is populated primarily from county assessor records, ancillary datasets, or whenever better data is available (e.g., Lewis, 2007). We followed the methods established by Bauer and others (2018), starting with the building records (e.g., Williams and others, 2021) and modifying or amending records where better information was available.

The UDF datasets developed by DOGAMI attempt to identify all buildings that can be considered a residential facility, including traditional single-family residences, manufactured housing, multifamily residential buildings, condominiums, motels and hotels, dormitories, and assisted living facilities. The datasets contain information on building primary usage (Hazus "occupancy class"), square footage, number of stories, year built, and building type (e.g., wood or steel-frame construction, unreinforced masonry, etc.). Although the UDF dataset was a good starting point, it did not always correctly classify residential structures. Therefore, it required a thorough review, during which many records were manually updated to correct existing attributes.

We improved the UDF dataset as follows. We added a "number-of-units" field, identifying the number of rooms, where available, for motels, multifamily residential, and dormitory building types (Hazus occupancy types "RES4," "RES3," and "RES5," respectively). We further improved the UDF dataset by adding records that capture the locations of individual tent and yurt sites, recreational vehicle spots, and boat slips in marinas that permit overnight docking. Such locations were digitized as points using orthoimagery and other ancillary data sources, such as campground maps. We note that the Hazus earthquake and tsunami building damage model is limited to traditional buildings, and thus, our building loss estimates exclude damage to temporarily occupied structures such as tents, recreational vehicles, and boats.

Table 2.1. Building information required by Hazus earthquake and tsunami model.

Hazus Attribute	Example	Purpose
Location of building	Latitude, Longitude	Ground motion and ground deformation data
Building usage	Single-family Residential; Retail commercial	Repair/replacement cost, number of people per building
Building material	Wood; Steel	Building response to ground motion; debris
Year built	1968	Seismic design level, building response to ground motion
Number of stories	2	Building response to ground motion
Building area	2,250 ft^2 (209 m^2)	Building repair/replacement cost, debris, number of people per building
First floor height	3.0 ft (0.9 m)	Tsunami nonstructural building damage estimate
Daytime occupancy+	2.1 residents	Casualty estimate
Nighttime occupancy+	3.4 residents	Casualty estimate

+*Daytime* and *Nighttime occupancy* are Hazus terminology. For our analysis purposes we populate *Daytime occupancy* with the number of temporary residents in the building at 2 p.m. and *Nighttime occupancy* with the number of permanent residents in the building at 2 a.m. For the purposes of this study, we calculate casualties using the *Nighttime occupancy* only.

We used the RSMeans valuation method for estimating a building's replacement cost (Charest, 2017) where:

$$\text{RSMeans} = \text{building square footage} \times \text{standard cost per square foot} \qquad (1)$$

Per-square-foot replacement costs are derived from the Hazus 6.1 database[5] which incorporated the 2022 RSMeans valuation. Adjustments for inflation or regional variation to the tabular data were not incorporated.

Building replacement cost is not the same as a property's assessed value. For analysis purposes, we assume repair or replacement costs to damaged structures will be charged at standard construction rates, independent of a building's age or the land on which the building is placed. Assessed value includes the land's value, which may fluctuate greatly depending on real estate markets and home improvements. Assessors may also factor in the building's depreciation into the assessed value.

An abnormal shortage of skilled labor or materials can occur following a large-scale disaster. "Demand surge" is a phenomenon resulting in a higher cost to repair buildings after large disasters, compared with the same repair for damage after a small disaster (Olsen and Porter, 2011). Adjusting repair/replacement costs due to a likely demand surge was beyond the scope of this project.

Williams and others (2021) used street-level imagery to determine the building type of all nonsingle-family residential buildings, using the guidance provided by FEMA (2015b); selected records were updated with information from Lewis (2007) and other ancillary data sources. Williams and others (2021) were unable to locate additional building information that might have helped further refine the building-type assignment, or any seismic retrofitting datasets that could be used to update an individual building's seismic design level. Finally, our observations from numerous field visits and analysis of street-level imagery suggested that the statistical distributions for building types identified by FEMA (2011, Tables 3.A1–3.A.10) are not applicable to the Oregon Coast. This is because most commercial and industrial buildings built on the Oregon Coast use wood-frame construction. For single-family residential buildings, our field observations confirmed the FEMA Hazus assumption of 99% wood-frame to 1% other construction (FEMA, 2011, Table 3A.17). For simplicity, we assigned wood frame to all single-family residences except manufactured housing. Wood-frame structures are much less likely to be severely damaged in an earthquake compared to other building types (FEMA, 2011).

2.4 Population Modeling

To estimate injuries and casualties from damaged buildings, the FEMA Hazus earthquake model requires estimates of individual building occupancy (FEMA, 2010). Conversely, people occupying tents, yurts, recreational vehicles, and boats, or who happen to be outside of a building at the time of the earthquake, are assumed to be not injured from the earthquake shaking.

To estimate injuries and fatalities from a tsunami, the modeler must refine the population model to include locations, numbers, population demographics (age), and distance to safety outside the tsunami inundation zone (FEMA, 2017). Typically, people are associated with a building in tsunami modeling, but they can also be placed in temporary lodging, such as in a tent or recreational vehicle, or out on a beach. Given the dynamic human environment, the modeler must therefore make several assumptions about each parameter in order to simulate fatalities and injuries.

[5] FEMA Hazus SQL tables [dbo].[hzRes1ReplCost] for single-family residential; [dbo].[hzReplacementCost] for all other occupancy types.

To minimize the complexity associated with modeling how people will respond in an event, FEMA Hazus documentation recommends modeling be undertaken for two time periods:

- A midweek "2 p.m." scenario in which people are dispersed among work, institutional, and home buildings
- A "2 a.m." scenario, in which most people are in a residential structure (in the Hazus model, hotels/motels are considered residential structures; temporary structures such as a tent or recreational vehicle (RV) were also accounted for in our model).

Such divisions, however, are inadequate to meet the needs of this project, since coastal communities experience considerable temporal (daily, seasonal, and annual) population fluctuations, with large visitor influxes occurring on weekends, especially in the summer. Community planners have previously expressed a strong interest in our modeling accounting for such variations, which could assist with identifying tsunami evacuation challenges and short-term sheltering needs. To better understand these effects, we distinguish two population groups:

- *permanent residents* (coastal residents in the tsunami inundation zone)
- *temporary residents* (visitors in the tsunami inundation zone)

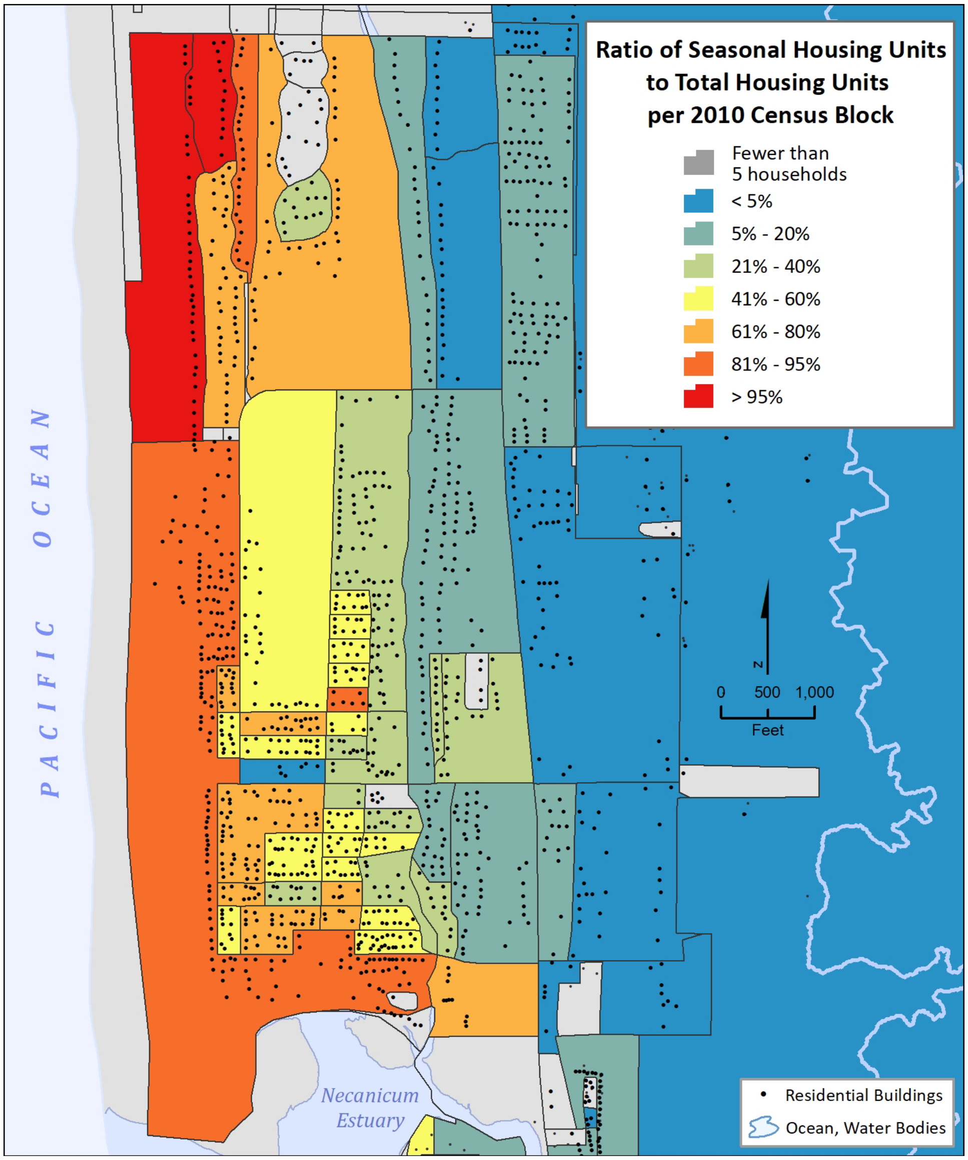
At night, temporary residents occupy residential facilities such as second homes, vacation rentals, condominium units, bed and breakfast facilities, hotels, motels, and campgrounds; permanent residents typically occupy residential structures. During the day, permanent and temporary residents may occupy institutional, educational, commercial, and industrial buildings, along with residential buildings, or may be dispersed throughout the tsunami inundation zone (e.g., at the beach) and thus may not be directly associated with any particular building type.

Development of a detailed temporary population model was therefore motivated by several important factors (Bauer and others, 2020):

1. Computing an overall injury/fatality ratio[6] for the permanent population and assuming that the same ratio could be applied to the temporary population could lead to significantly underestimating the numbers of fatalities and injuries. For example, analysis of U.S. Census data and observation of real estate dynamics on the Oregon Coast indicate a strong spatial correlation between the temporary population's preference to be close to the ocean, and thus farther away from tsunami safety, when compared to the permanent population (Raskin and Wang, 2017; illustrated with 2010 U.S. Census data in **Figure 2.4**).
2. It is reasonable to assume that the temporary population may be less aware of tsunami risk, locations of tsunami safe zones, temporal urgency (e.g., knowing that if you feel strong ground shaking, evacuate immediately), and local evacuation routes compared to permanent residents.
3. Community planners expressed a need for detailed estimates of tsunami injuries and fatalities, as well as estimates of the number of displaced people following a CSZ event. These data are essential for effective mass-care planning. Thus, our modeling of tsunami-caused injuries and fatalities is undertaken assuming maximum occupancy, combining permanent and temporary residents, and distinguishing injuries and fatalities between the respective population groups. In doing so, we provide a range that planners can use to estimate impacts for different occupancy periods throughout the year.

[6] Total number of tsunami injuries and fatalities divided by the total exposed permanent population.

Figure 2.4. Example of "seasonally occupied households" expressed as a percentage ratio of total households per census block in Gearhart, Clatsop County, relative to the distance to the coast. XXL1 tsunami inundation zone shown as a light blue line on the far right. Census blocks with fewer than five households as of 2010 are shown in gray. Residential buildings are shown as dots and include buildings constructed since 2010 that were not captured in the 2010 census. Census block data source: https://www.census.gov/data.html.



Given project scope constraints and discussions with community members, we focused our attention on developing a summer weekend 2 a.m. population model for all communities to maximize estimates of the temporary population overnighting in the tsunami inundation zone, providing a more conservative worst-case tsunami evacuation scenario. Due to the challenge of determining how many day visitors are at the coast on any given day, we are presently not able to include this in our casualty modeling. Nevertheless, since we assume maximum (100%) occupancy in second homes, vacation rentals, condominium units, bed and breakfast facilities, hotels, motels, and campgrounds, our injury, fatality, and displaced population estimates are likely to be still conservative. In contrast to uncertainties in the visitor numbers, planners can view the permanent-resident casualty estimates as a baseline (i.e., lower bound). FEMA guidelines (FEMA, 2012a, p. 3–6) note that full occupancy at the individual building level happens only occasionally and that "point-in-time population models may be used to develop a better understanding of the uncertainty in casualties associated with time, but it is necessary to perform a large number of realizations […] to do this in a meaningful way." Such modeling is beyond the scope of this project. Accordingly, within the baseline (permanent resident population) and upper-bound population that includes temporary visitors, planners can estimate the number of temporary residents present in their communities at other times of year and assume the injury and fatality estimates will scale proportionally. Institutions and businesses, with certain exceptions, are unoccupied under this scenario.

Our permanent resident population occupancy was defined based on locations of residential buildings, numbers of individuals, and age groups using 2020 U.S. Census data. Bauer and others (2020) adopted a more sophisticated approach using geocoded Oregon Department of Motor Vehicle (DMV) driver license registrations. Although more accurate for defining the permanent population, the time required to process DMV records on a coastwide basis was beyond the scope of this investigation. **Section 2.9.4** provides a more in-depth comparison of the two methods.

U.S. Census population data are organized into hierarchical spatial units of varying sizes, the smallest of which is the census block. Census blocks are typically "bounded by visible features such as roads, streams, and railroad tracks, and by nonvisible boundaries such as property lines, city, township, school district, and county limits, and short line-of-sight extensions of roads" (U.S. Census Bureau, n.d.). One level above that is the census block group (CBG), which is how the U.S. population is defined and distributed. **Table 2.2** provides summary statistics for CBG for the seven coastal counties. We include these data simply to provide a measure of the average number of residents per CBG, as well as the range in CBG area for each county.

Table 2.2. Census block group statistics for the Oregon Coast. Note: Number of people reflects the mean number of residents (±1σ) per mean CBG area. Size range provides a measure of the range in CBG area for each county.

		Census Block Group Size	
County	**Number of People**	**Size Range**	**Mean Area**
Clatsop	1,028 people (σ = ±453)	0.1 mi^2 (0.3 km^2) to 300 mi^2 (777 km^2)	24 mi^2 (63 km^2)
Tillamook	923 people (σ = ±373)	0.2 mi^2 (0.4 km^2) to 201 mi^2 (520 km^2)	41 mi^2 (106 km^2)
Lincoln	1,228 people (σ = ±480)	0.1 mi^2 (0.4 km^2) to 246 mi^2 (636 km^2)	25 mi^2 (66 km^2)
Lane	1,158 people (σ = ±393)	0.4 mi^2 (1.1 km^2) to 218 mi^2 (565 km^2)	47 mi^2 (122 km^2)
Douglas	983 people (σ = ±452)	0.2 mi^2 (0.4 km^2) to 322 mi^2 (835 km^2)	91 mi^2 (236 km^2)
Coos	1,011 people (σ = ±426)	0.1 mi^2 (0.3 km^2) to 334 mi^2 (866 km^2)	26 mi^2 (68 km^2)
Curry	1,416 people (σ = ±603)	0.4 mi^2 (1.1 km^2) to 642 mi^2 (1,662 km^2)	107 mi^2 (277 km^2)

In urban areas, census blocks are usually defined at the city-block level, whereas in rural areas, census blocks may cover a few hundred square miles (several hundred square kilometers). Within each CBG, the population may range from negligible to several thousand people. However, unlike DMV records that associate a person with a specific address, CBGs provide a single, aggregated population count. For our purposes, we used updated population statistics obtained from the American Community Survey (ACS; 2018–2022 census data downloaded from the U.S. Census Bureau; https://www.census.gov/programs-surveys/acs; data accessed 2022) at the CBG level. To estimate the size and distribution of the permanent population in our study area, we distributed the population per CBG among the residential buildings and prorated based on square footage. The specific steps associated with this process are summarized in **Table 2.3A** for the permanent population.

After populating the buildings, or in the case of multifamily residential structures, units, with permanent residents, we then assumed the proportion of residential buildings or units that are not occupied by a permanent resident but are occupied on a temporary basis by out-of-town visitors. For single-family residences, we used the number of bedrooms (expressed as units) to determine temporary occupancy (**Table 2.3B**). We populated motels, campgrounds, recreational vehicle parks, and marinas using the number of rooms, tent or RV sites, or boat slips as a baseline, and multiplying by a people-per-unit occupancy assumption (**Table 2.3B**). To accomplish these steps, we used the U.S. 2020 census data to identify the residential household vacancy rate[7] at the census block level. For each UDF, we then multiplied the corresponding vacancy rate by the number of units, establishing the number of units occupied by temporary residents. This value was then multiplied by the people-per-unit value to derive a temporary population per household unit (**Table 2.3B**).

Finally, researchers have recognized that demographic factors can be an important factor in tsunami casualties (summarized by González-Riancho Calzada and others (2015)). Thus, FEMA (2013, 2017) incorporated age into the FEMA Hazus casualty model by differentiating those people <65 years from those ≥65 years, with the latter group assumed to evacuate at slower walking speeds. A 0.8 walking speed reduction factor was used to account for travel speeds used by persons ≥65 (see **Section 2.6.2.4**).

2.5 Building Damage and Building Debris Estimation

2.5.1 Earthquake

To calculate building losses, we first modeled the earthquake damage using the Hazus UDF earthquake model (FEMA, 2011, 2017). In the Hazus earthquake simulation, we used Hazus 6.1 to model a fully saturated soil scenario, with groundwater level at the surface, thereby incorporating the potential impacts of liquefaction. In lieu of site-specific liquefaction data, this is a reasonable assumption for low-lying coastal areas.

As noted previously, we model the damaging effects of three discrete tsunami inundation scenarios, characterized with the following CSZ earthquake moment magnitudes (M_Ws): 8.9 (M1), 9.0 (L1), and 9.1 (XXL1). These scenarios contrast with the terrestrial ground motion data from Wirth and others (2020), which assume a M_W 9.0 earthquake. For Hazus loss estimation purposes, we concluded that the ±0.1 difference in M_W is minor and accounted for by our choice of the "default betas" used when determining the probability of damage state (PDS) in the Hazus Advanced Engineering Building Model (Kircher, 2002; Kircher and others, 2006). The default betas (also referred to as relaxed betas) were crafted by Hazus earthquake model developers to account for greater uncertainties in the ground motion for an earthquake scenario compared to an instrumented earthquake.

Building repair cost[8] estimates were obtained by using the PDS values for each building. The Hazus UDF earthquake model currently overestimates repair costs for UDFs by using overly conservative PDS multipliers for determining a building loss ratio (Bauer, 2016); the building loss ratio reflects the ratio of building damage states relative to the total number of buildings. Using corrected PDS multipliers (described by Bauer, 2016), we calculated per-building repair cost estimates, and then summarized building repair costs due to earthquake ground motion and deformation by community.

[7] H005006, "Total for seasonal, recreational, or occasional use" in the Total Vacancy data per census block, 2020 U.S. Census divided by total number of households in the census block, obtained from Table S1101.
[8] Hazus SQL table [dbo].[eqUserDefinedFlty].

Table 2.3. Summary parameters used to define the process for distributing permanent resident and visitor populations across U.S. CGBs.

	Occupancy Type	Number of Units	People Per Unit	People per UDF: Explanation	People Per UDF: Math	Age <65 Ratio
A) Permanent Population	Single-family Residential	1 unit	The ACS 2014–2018 census data reports the number of permanent residents at the CBG level. For each CBG in the study area, divide the permanent population number by the total number of units within the CBG. This established a people-per-unit value.	The people-per-unit value is then multiplied by the total number of units belonging to each UDF to assign the total number of permanent residents.	[Number of Units] × ([Number of permanent people in CBG] / [number of units in CBG])	0.7
	Multifamily Residential	1 unit per 800 ft^2 (74 m^2)				0.7
	Dormitories	1 unit per 400 ft^2 (37 m^2)				0.9
	Assisted Living	1 unit per 600 ft^2 (56 m^2)				0.05
B) Temporary Population	Single-family Residential	2 units <1,500 ft^2 (139 m^2)	2.0	The 2010 census data reports the residential vacancy rate at the census block level. For each residential UDF, the corresponding vacancy rate was multiplied by the number of units, establishing the number of units occupied by temporary residents. This was then multiplied by the people-per-unit value.	[People Per Unit] × [Number of Units] × [CB Vacancy Rate]	0.7
		3 units <2,700 ft^2 (250 m^2)				
		4 units <4,000 ft^2 (372 m^2)				
		5 units <5,500 ft^2 (511 m^2)				
		6 units ≥5,500 ft^2 (511 m^2)				
	Multifamily Residential	1 unit per 800 ft^2 (74 m^2)	2.2			0.7
	Hotel/Motel	1 unit per 455 ft^2 (42 m^2)	1.7			0.7
	Dormitories	1 unit per 400 ft^2 (37 m^2)	1.0			0.9
	*Recreational Vehicle	1 unit	3.22	For mapping simplicity, some UDF points are assigned multiple units, such as docks in boat marinas.	[Number of Units] × [People Per Unit]	0.3
	*Tent, Yurt	1 unit	3.22			0.9
	**Boat	1 unit	0.1			0.9

Notes:

Permanent population numbers are taken from ACS 2014–2018 census data at the CBG level. Temporary vacancy rates are from U.S. 2020 census data at the census block level.

No permanent residents are assigned to hotel/motel, recreation vehicle, tent, yurt, or boat. No temporary residents are assigned to assisted living.

*Average number of people staying in a recreational vehicle (includes camper trailers), tent, or yurt. Mean value derived from T. Bergerson (Visitor survey of day use and overnight use at Oregon State Park coastal region parks, unpublished Oregon State Parks report, 2012, 151 p.), who evaluated the numbers of recreational visitors camping in coastal state parks.

**Estimates of those residing on a boat were derived from consultation with local ports and marinas in both Clatsop County and Lincoln County.

2.5.2 Tsunami

The M1, L1, and XXL1 median depth and momentum flux grids were input into the Hazus tsunami tool as "Level 3" tsunami data (FEMA, 2017), which reflect advanced-level user-provided tsunami model scenarios. We summarized building repair costs[9] for the M1, L1, and XXL1 tsunami events by community.

2.5.3 Combined earthquake and tsunami

The Hazus tool combines the per-building damage state probabilities from the earthquake and tsunami into an overall damage state probability and then calculates per-building repair[10] cost estimates (FEMA, 2017, Section 5.7), which are subsequently summarized for each community. Building recovery times are provided in the FEMA Hazus methods (FEMA, 2017, Table 7.10), but we chose not to report them, as Bauer and others (2020) argued that the assumptions behind the tabular entries are overly optimistic given the spatial scale of a M_w 9.0 CSZ earthquake and tsunami and the likely catastrophic nature of the event on core infrastructure. Access to labor, material, and investment capital may be constrained for prolonged periods during recovery, in large part due to the anticipated damage to western Oregon's transportation network, infrastructure, and fuel supply (ODOE, 2017; ODOT, 2014; OSSPAC, 2013).

2.5.4 Building debris

The Hazus version 6.1 model (FEMA, 2017, 2018) presently does not provide support for debris estimation from a tsunami event, due in part to the challenges of accounting for debris redistribution from advection, including debris washed out to sea, sediment transport, and uprooted vegetation. While recognizing the complexities associated with estimating debris caused by the earthquake and tsunami, we contend that estimates of debris tonnage derived from damaged buildings are valuable for community planners to better understand the scale of the disaster and, importantly, to develop postdisaster community debris plans. Timely recovery from a major earthquake and tsunami will depend not only on the localized damage in each community, but also on the ability of communities to stage and dispose of earthquake- and tsunami-generated debris. To that end, we include estimates of debris generated.

Estimates of the amount of debris (expressed as US tonnage) generated by the earthquake can be obtained using guidelines provided by FEMA (2010) and FEMA (2013, Chapter 7, and 2011, Chapter 12). The Hazus tsunami model, when run in conjunction with the Hazus earthquake model, provides the combined PDSs for a building's structural and nonstructural components. We first calculated the weight of the building based on the model building type using the values provided by FEMA (2011, Table 12.1). Using the building weight, together with the PDS estimate for each building (Section 2.5.3), we estimated the debris tonnage using the FEMA (2011) equation 12-3. In addition, we also provide gross estimates of damaged building contents using a percentage structure replacement value that is applied to the building class (Table 6-10 in FEMA, 2022).

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[9] Per-building repair cost estimates from the tsunami event by itself were obtained by exporting the Hazus SQL table [dbo].[tsUserDefinedFlty].

[10] Per-building repair costs that combine earthquake and tsunami events were obtained by exporting the Hazus SQL table [dbo].[tsCombUserDefinedFlty]. The table also contains structural and nonstructural PDS data for each building.

2.6 Injury and Fatality Estimation

We independently evaluated injuries and fatalities resulting from a CSZ earthquake and tsunami, with the Hazus AEBM model and the Hazus tsunami model, respectively. Unlike the building damage estimates described previously, the FEMA Hazus methods currently do not provide a method for combining injury and fatality estimates from the two events. The approach we used is described in more detail in the next two sections.

2.6.1 Injuries and fatalities from earthquake

We used the Hazus AEBM model to calculate injuries and fatalities, populating individual buildings with the permanent and temporary population using the 2 a.m. summer weekend occupancy estimates. The *DayOccupants* and *NightOccupants* fields were used as Hazus AEBM inputs for the two population groups. We note that the *DayOccupants* and *NightOccupants* are simply Hazus field names, and their usage does not suggest we modeled a daytime building occupancy.

The Hazus AEBM model first calculates a building's structural and nonstructural PDS from the ground motion and liquefaction/landslide data provided to the model. It then uses the PDS values to calculate injuries and fatalities based on the number of user-specified people occupying the building and the building type. The methodology assumes a strong correlation between building damage and the number and severity (injury level) of casualties (FEMA, 2011), which are classified into four levels: minor injuries, injuries requiring hospitalization, life-threatening injuries, and deaths (**Table 2.4**). Accordingly, we summarized casualty Levels 1 through 3 as injuries and casualty Level 4 as fatalities.

Table 2.4. Hazus earthquake casualty Level descriptions (FEMA, 2011).

Injury Severity Level	Injury Level Description
Level 1: Minor Injuries	Injuries requiring basic medical aid that could be administered by paraprofessionals. These types of injuries would require bandages or observation. Examples: a sprain, a severe cut requiring stitches, a minor burn (first degree or second degree on a small part of the body), or a bump on the head without loss of consciousness. Injuries of lesser severity that could be self-treated are not estimated by Hazus.
Level 2: Injuries Requiring Hospitalization	Injuries requiring a greater degree of medical care and use of medical technology such as X-rays or surgery, but not expected to progress to a life-threatening status. Examples: third-degree burns or second-degree burns over large parts of the body, a bump on the head that causes loss of consciousness, fractured bone, dehydration, or exposure
Level 3: Life-threatening Injuries	Injuries that pose an immediate life-threatening condition if not treated adequately and expeditiously. Examples: uncontrolled bleeding, punctured organ, other internal injuries, spinal column injuries, or crush syndrome
Level 4: Deaths	Instantaneously killed or mortally injured

2.6.2 Injuries and fatalities from tsunami

The Hazus tsunami casualty model estimates are based on a rational-actor pedestrian evacuation model in which all persons in the tsunami inundation zone are aware of the impending tsunami, that they possess knowledge of, or can quickly determine, the most optimal route to high ground, and that all individuals seek safety as pedestrians and not via vehicles. The model assumes a group average (median) departure time and travel (walking) speed and accounts for individual variations from the group average using a lognormal distribution (FEMA, 2017). We recognize that how people will respond in an emergency will vary. Nevertheless, results from the Hazus tsunami casualty model remain useful as they provide planners with vital data to assess the impacts of a tsunami, including identifying areas where injury and fatality rates are likely to be high, capacity of assembly area sites, and for quantifying the efficacy of mitigation solutions such as tsunami vertical evacuation structures. The following sections describe in more detail the overall approach and assumptions used to define injuries and fatalities from a CSZ tsunami.

2.6.2.1 Model implementation

Bauer and others (2020) integrated the Hazus tsunami casualty model into a stand-alone Excel spreadsheet to estimate the likelihood of a casualty for every person, incorporating the individual's distance to the nearest tsunami safety destination, assumptions on group median departure time, and median travel speed. A travel dispersion coefficient (C_{STD}) was also incorporated in the spreadsheet to account for variations (uncertainty) within the group's departure time and evacuation travel speeds. Motivations for developing the spreadsheet versus using the dedicated Hazus tsunami tool are:

1. Our existing tsunami evacuation modeling already provides the required distance to safety data needed by the Hazus tsunami casualty model; the Hazus tsunami casualty model includes the USGS Pedestrian Evacuation Analyst Tool (PEAT; Jones and others, 2014), which performs the same calculations as the DOGAMI approach. Thus, rerunning this capability within Hazus is not warranted.
2. Our Hazus work requires a model with sufficient flexibility for evaluating alternative population and evacuation scenarios.
3. More importantly, the Hazus tsunami model currently estimates casualties at the census block level, not at the building level, and thus uses a worst-case assumption of time-to-safety for all occupants within a particular census block (D. Bausch, written communication, July 2018). The Hazus approach is thus too coarse for our needs, which include a more refined population model disbursed across individual buildings and campgrounds.

More detail on our spreadsheet casualty model is provided in Bauer and others (2020, Appendix C). There, the functional equivalence of the spreadsheet with the FEMA Hazus tsunami Level 2 casualty tool is demonstrated. To minimize confusion, we use the term "Hazus tsunami casualty model" to refer to the FEMA-established methods of estimating injuries and fatalities resulting from a tsunami, and not a specific tool or spreadsheet.

A local-source tsunami provides no warning—the ground shaking itself is the signal to evacuate. Thus, the warning time (T_W) discussed by FEMA (2017) is assumed to be zero for a CSZ tsunami, while the maximum tsunami runup from a CSZ earthquake is typically associated with the first wave arrival (Witter and others, 2011). The Hazus tsunami casualty model is one dimensional and does not incorporate time-sensitive inundation information en route to safety. It simply assumes an evacuee arrived at the maximum tsunami runup (tsunami safety) in time (T_{MAX}). Complex decision points, such as early wave arrivals or bridge failures that are likely to preclude or impact evacuation along certain routes are not evaluated.

2.6.2.2 Distance to safety

The Hazus tsunami casualty model requires the user provide a GIS file that specifies the distance to tsunami safety at all points along the established evacuation routes. Previous BTW efforts undertaken for multiple coastal communities (Gabel and Allan, 2016; Gabel and Allan, 2017; Gabel and others, 2018a, b; Gabel and others, 2019a, b, c, d; Gabel and others, 2020a, b; Gabel and others, 2021; Gabel and others, 2022a, b; Gabel and others, 2023; Gabel and others, 2024) have used the anisotropic least-cost distance approach established by Wood and Schmidtlein (2012) to calculate a distance to safety at all locations along evacuation routes. The distance to safety (referred to as path distance) is adjusted to account for the slope of the ground (steep versus flat) and terrain type (e.g., sand versus pavement) that may slow down a person's ability to evacuate. Given that tsunami evacuation nearly always requires the evacuee to move up in elevation, this adjusted distance to tsunami safety is always greater than the straight-line distance measured on a map. Accordingly, our usage of distance to safety reflects the combined slope and adjusted walking distance.

We associate each building and its occupants with the tsunami evacuation network that specifies the distance to safety by using the Esri ArcGIS Near function. The linear distance from the building footprint's centroid to the evacuation network is added to the distance to safety from the GIS file to derive an overall distance to tsunami safety. We did not implement the method of Wood and others (2016), which has pedestrians evacuating via driveways typically generated on paths perpendicular to the road network. Visual inspection suggested the distance from the building centroid to the evacuation network was minor relative to the overall distance to safety, and such a refinement would only marginally improve the accuracy of the model's results. Moreover, the time to evacuate a building may be accounted for as simply an evacuation delay, which is described below.

A community often has more than one tsunami evacuation scenario defined, which can include the impact of damaged bridges and/or the inclusion of a tsunami vertical evacuation structure. Each scenario has a unique distance to safety GIS dataset, which can be captured separately, when needed. Such scenarios have been evaluated for every Oregon Coast community. For this study, we assume the most conservative "bridges-out" scenario, to account for the likely failure of nonretrofitted bridges. Bridges that have been retrofitted or rebuilt to current engineering standards are designed to withstand the intense ground motion caused by the earthquake and may be available for evacuation by pedestrians after the earthquake.

2.6.2.3 Departure time

The tsunami casualty model uses the term "Community Preparedness Level" to reflect the time between the tsunami warning (i.e., earthquake shaking) and actual evacuation of the community (FEMA, 2017). The degree of preparedness is classified according to three categories—Good, Fair, or Poor—and is dependent on a suite of factors, including tsunami awareness (education/knowledge), preparation of evacuation routes and signage, a community's risk management level, and the presence of emergency loudspeakers and tsunami sirens (FEMA, 2017). According to FEMA, a community with a Good rating could be one that is designated Tsunami Ready by the National Oceanic and Atmospheric Administration (NOAA) National Weather Service. However, we contend that use of such designations does not adequately define a community's preparedness level given the large uncertainty in individuals' hazard awareness, their knowledge of evacuation routes, response at the time of the event, and the degree of pre-disaster preparation undertaken by communities. Accordingly, we focused our efforts on the importance of group departure times.

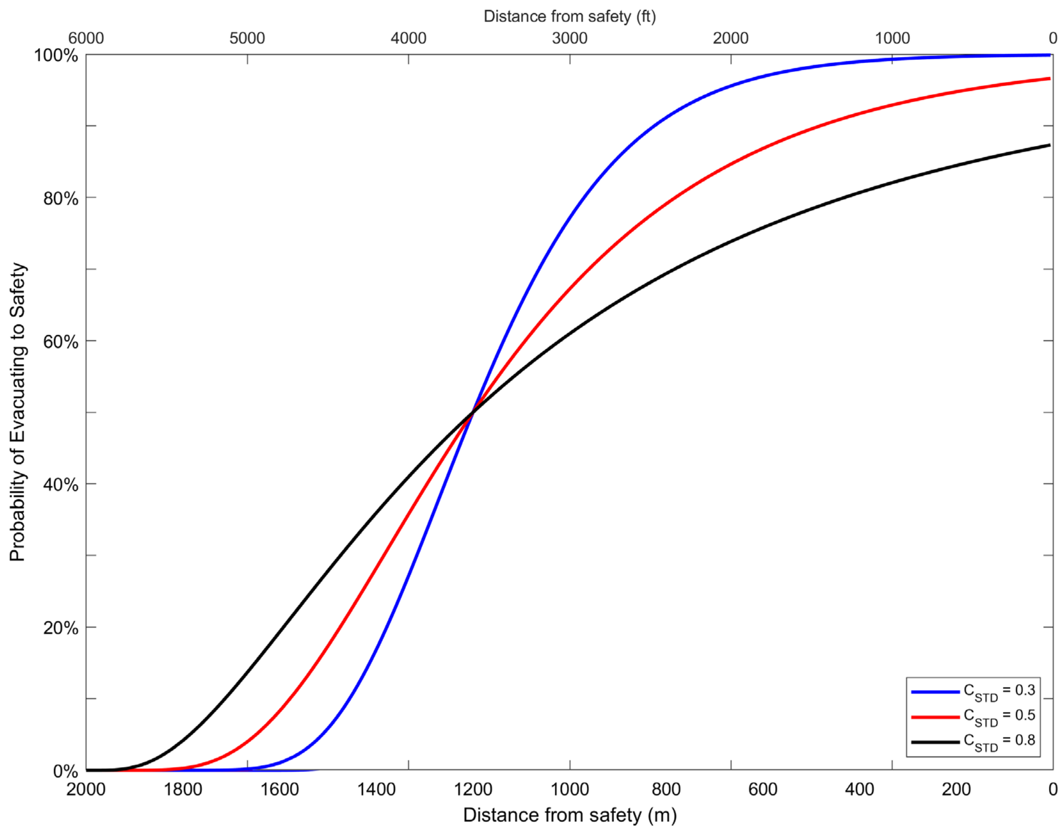
It is essential that our injury and fatality estimates quantify the impact of delays in departure times—often referred to as “milling time” in the literature (Buylova, 2018; Mostafizi and others, 2017; Wood and others, 2016; Wood and Schmidtlein, 2013). Here, we provide casualty estimates assuming 10-minute (Good) and 15-minute (Fair) group departure (delay) times; we did not evaluate a Poor preparedness level, as the casualties associated with this category are enormous and probably unrealistic.

The 10-minute (Good) departure delay is the default value used in our evacuation modeling and refers to the time elapsed since the earthquake started; for campgrounds, we use a 5-minute departure delay since people are egressing from tents or RVs. In both cases, we assume up to 3–5 minutes of earthquake shaking where people drop, cover, and hold on, followed by time for an individual to respond—donning shoes and outdoor clothing, gathering family, or collecting a go-bag—before leaving the building. We also model a 15-minute (Fair) level of preparedness departure time to demonstrate how longer milling causes larger casualties.

The departure time is assumed to be the group median value. However, some individuals may leave earlier and others later (e.g., Makinoshima and others, 2021), while some may walk faster or slower than the group median evacuation speed. The Hazus tsunami casualty model accounts for these variations by adopting a dispersion factor (defined by a lognormal distribution), which can be accounted for by specifying a standard deviation (or *beta*) value (referred to as C_{STD} by FEMA, 2017). For the purposes of our study, we used the Hazus tsunami casualty model defaults of 0.3 and 0.5 for the 10- and 15-minute departure times, respectively, corresponding to the Good/Fair community preparedness levels noted above. **Figure 2.5** illustrates the probabilistic nature of the lognormal distribution model. It assumes a group departure time of 10 minutes, a walking speed of 1.2 miles per second (mps) (4 ft per second (fps)), and a wave arrival time of 25 minutes. An individual departing, given those specifications, can cover 3,600ft (1,097 m). The standard deviation term, C_{STD}, models the dispersion in individual evacuation times and evacuation walking speeds. The model effectively assigns a probability of evacuating to safety that ranges between zero and one. Thus, an individual having traveled 3,600 ft (1,097 m) is not assumed to have safely evacuated but instead is assigned a probability of 0.5 of evacuating safely, accounting for variations in both departure times and travel speeds. Note the asymmetric nature of the lognormal distribution: it implements a conservative assumption regarding a tendency for humans to delay their departure times.

We are unable to quantify how earthquake-induced building damage may inhibit rapid evacuation from a building prior to the arrival of a tsunami. This is clearly of concern in some buildings. For example, older manufactured housing units that may slip off their foundation supports, warping framing and possibly jamming doorframes and windows (EERI, 2014; Maison and Cobeen, 2016; OBCD, 2010; SPA Risk LLC, 2014). Similar situations can also arise due to unsecured nonstructural elements such as large bookcases that are likely to tip over during shaking and could block potential exits. FEMA (2012b, Section D) provides guidelines on minimizing potential constraints to egress, including advice on storing large crowbars and sledgehammers near primary door(s) to facilitate emergency exiting.

Figure 2.5. Hazus tsunami casualty model predictions for a hypothetical wave arrival time of 25 minutes (with no warning time), a group departure time of 10 minutes, an evacuation walking speed of 4 fps (1.2 mps), and variations in the log-normal standard deviation term (C_{STD}).



2.6.2.4 Evacuation speed

We assume a standard 4 fps (1.2 mps) evacuation speed, which equates to 2.7 mph (4.3 kmh) as a baseline for estimating tsunami injuries and casualties; the 4 fps (1.2 mps) travel speed reflects a pace that is used to define crosswalk times. Variations in individuals' walking speeds are incorporated into the C_{STD} standard deviation value discussed previously.

We apply a 0.8 evacuation speed reduction factor for those people aged 65 and over consistent with FEMA (2017), which equates to an evacuation speed of 3.2 fps (2.2 mph, 1.0 mps/3.5 kmh). This reduction is based on analyses of fatalities in recent tsunamis (González-Riancho Calzada and others, 2015; Koyama and others, 2012; Suppasri and others, 2016).

The distance covered by an evacuee can be calculated as follows:

$$\text{Distance Covered} = (T_{ARRIVE} - T_{DEPART}) \times \text{WalkSpeed} \quad (2)$$

where T_{ARRIVE} is the time interval between the earthquake start and the tsunami first wave arrival, T_{DEPART} is the time interval between the earthquake start and when individuals begin evacuating, and WalkSpeed is the specified travel speed. For reference, we calculate the distance an individual could travel prior to a tsunami arriving by using a range of evacuation speeds and wave arrival times (**Table 2.5**).

2.6.2.5 Tsunami injury and fatality estimation

The Hazus tsunami casualty model assumes a 99% likelihood of fatality and 1% likelihood of injury to an individual caught up in a tsunami where the wave depth exceeds 6 ft (1.8 m; FEMA, 2017). Conversely, where the tsunami wave depth is less than 6 ft (1.8 m) the model assumes that 50% are killed and 50% will be injured; this region is referred to as the "partial safety zone." In practice, because the topography of many Oregon coastal communities is relatively steep, the horizontal distance between the 6 ft (1.8 m) and the zero-elevation contours (tsunami safety) is generally small. Bauer and others (2020) indicated that the partial safety zone along the open coast ranges from ~100 to ~300 ft (~30 m to ~90 m) from the tsunami inundation runup limit (**Figure 2.6**). However, more recent evaluations suggest that the partial safety zone can, in fact, be much wider (Allan and O'Brien, 2022), especially in areas subject to broad gentle slopes. **Figure 2.6** demonstrates the variation in width of the partial safety zone in Harbor, Curry County. On the north side of the map the zone is ~50 ft (~15 m) wide; on the south side it is ~400 ft (~122 m) wide.

We defined the partial safety zone by first creating a depth grid in which all areas of the raster <6 ft (1.8 m) was extracted. The extracted partial safety raster was then manually reviewed, and false "islands" or high ground, or spurious data removed. Casualty estimates are reduced to 50% once individuals reach this latter zone. The casualty model provides injury and fatality estimates for each individual, with a likelihood between zero and one. These are in turn summarized to obtain overall injury and fatality estimates at the community level.

2.6.2.6 Sensitivity testing

We varied evacuation speeds (2.0 fps to 10 fps; 0.6 mps to 3.0 mps) in 1.0-fps (0.3-mps) increments and departure times (5 minutes to 20 minutes) in 1-minute increments consistent with Wang and others (2016) and calculated overall injuries and fatalities for each community. Such data can assist in gaining a better understanding of evacuation challenges facing communities and clearly demonstrate the need to evacuate immediately and, importantly, to travel as fast as possible in order to reach high ground. We adjusted the dispersion factor (C_{STD}) as specified in section **2.6.2.3** proportionally for 10-minute and 15-minute departure times.

2.6.3 Combining earthquake and tsunami casualty estimates

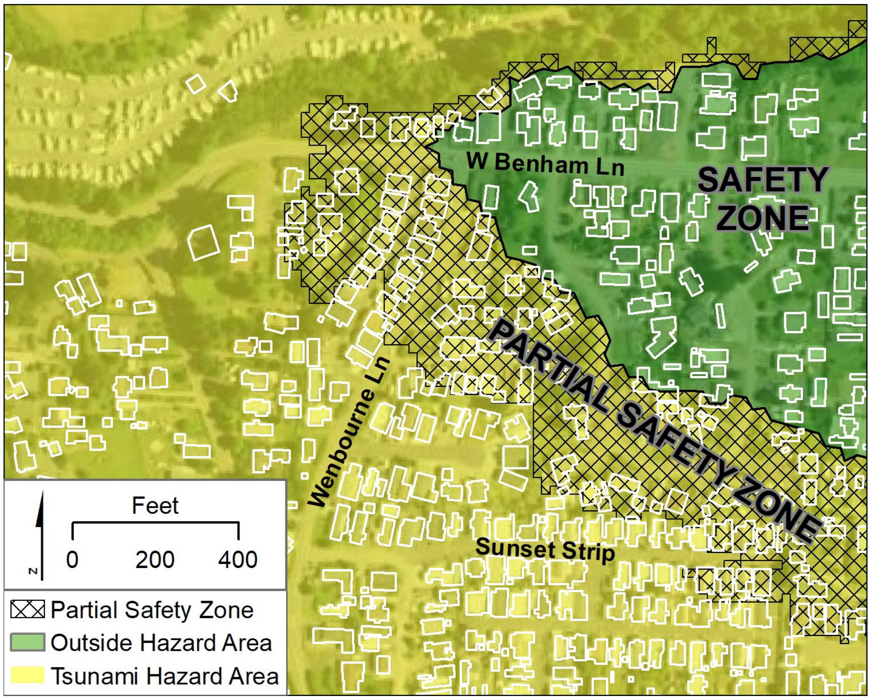
The Hazus approach does not provide a method for combining injury and fatality estimates derived from the earthquake and tsunami modules. Some portion of the people injured during the earthquake may not be able to evacuate in time as they may be disoriented, attend to their injuries or injuries sustained by another household member, or have sustained injuries that prevent or slow their evacuation. We report both sets of casualty numbers (earthquake and tsunami) to provide planners with a more complete accounting of the potential situation. The estimates do not include injuries or fatalities arising from, for example, heart attacks, bridge failures, automobile or maritime accidents, electrocutions from downed power lines, exposure to released hazardous materials, upstream dam failures, ground failures such as earthquake-induced landslides, or fires. Finally, we did not evaluate postdisaster-related casualties due to lack of access to clean water or medicine, interruption of power to life-sustaining medical equipment, exposure due to lack of shelter, disease outbreak, domestic violence, and civil unrest.

Table 2.5. Distance walked for several departure times and tsunami wave arrival times at the tsunami runup limit. We assume warning time is zero. Departure time is the time after earthquake ground motion begins.

Tsunami First Wave Arrival Time (minutes)	Walking Speed Category	Walking Speed fps (mps)	Walking Speed mph (kph)	Distance Walked (in ft) for Various Departure Times (in minutes) 5 min	10 min	15 min	20 min
15	Slow Walk	2 (0.6)	1.4 (2.2)	1,200	600	—	—
	Moderate Walk	4 (1.2)	2.7 (4.4)	2,400	1,200	—	—
	Fast Walk	6 (1.8)	4.1 (6.6)	3,600	1,800	—	—
	Jog	8 (2.4)	5.5 (8.8)	4,800	2,400	—	—
	Run	10 (3.0)	6.8 (11)	6,000	3,000	—	—
20	Slow Walk	2 (0.6)	1.4 (2.2)	1,800	1,200	600	—
	Moderate Walk	4 (1.2)	2.7 (4.4)	3,600	2,400	1,200	—
	Fast Walk	6 (1.8)	4.1 (6.6)	5,400	3,600	1,800	—
	Jog	8 (2.4)	5.5 (8.8)	7,200	4,800	2,400	—
	Run	10 (3.0)	6.8 (11)	9,000	6,000	3,000	—
25	Slow Walk	2 (0.6)	1.4 (2.2)	2,400	1,800	1,200	600
	Moderate Walk	4 (1.2)	2.7 (4.4)	4,800	3,600	2,400	1,200
	Fast Walk	6 (1.8)	4.1 (6.6)	7,200	5,400	3,600	1,800
	Jog	8 (2.4)	5.5 (8.8)	9,600	7,200	4,800	2,400
	Run	10 (3.0)	6.8 (11)	12,000	9,000	6,000	3,000
30	Slow Walk	2 (0.6)	1.4 (2.2)	3,000	2,400	1,800	1,200
	Moderate Walk	4 (1.2)	2.7 (4.4)	6,000	4,800	3,600	2,400
	Fast Walk	6 (1.8)	4.1 (6.6)	9,000	7,200	5,400	3,600
	Jog	8 (2.4)	5.5 (8.8)	12,000	9,600	7,200	4,800
	Run	10 (3.0)	6.8 (11)	15,000	12,000	9,000	6,000

Note: “—" indicates individuals traveling at the designated speed would not reach safety before tsunami arrival.

Figure 2.6. Example of median tsunami depth zone for an XXL1 tsunami at Harbor, Curry County (yellow shading) and partial safety zone (hashed area), where the median water depth falls below 6.6 ft (2.0 m) near the tsunami inundation limit, per Hazus methods (Section 2.6.2.5). The green zone defines the safe area outside of the tsunami inundation zone. Buildings depicted in white.



2.6.4 Displaced population

For mass-care planning purposes, we calculated the number of individuals likely to have safely evacuated from the tsunami inundation zone. Those individuals will need shelter due to the destruction of most buildings by the tsunami. The temporary population that happens to be visiting when the earthquake and tsunami strike will also have shelter needs that may be on the order of days to a few weeks, as arrangements for transportation out of the disaster zone may be delayed.

2.7 Essential Facilities and Key Infrastructure

Previous analyses of essential facilities, special facilities, and key infrastructure located within each city's tsunami inundation zone may be found in Allan and others (2020a, b) and Allan and O'Brien (2021, 2023, 2023). Accordingly, we do not repeat those results here.

2.8 Social Characteristics

Knowledge of the number and distribution of vulnerable population groups within a hazard zone is an important consideration (DLCD, 2015). Our population modeling allowed us to provide demographic information classified into two broad age groups—<65 years of age and ≥65 years—for each tsunami inundation zone. In addition to basic demographic information, we evaluated the ACS data (U.S. Census Bureau, 2022, Table 1.1) in order to extrapolate additional information that may be useful for informing community tsunami education and evacuation planning. These included:

- S0101 Age and Sex
- S1601 Limited English-Speaking Households
- S1810 Disability Characteristics

We obtained the selected ACS tables at the city ("community" in ACS terminology), county, and state level. The 2018–2022 ACS five-year estimates were based on data collected between January 1, 2018, and December 31, 2022. We chose the ACS five-year estimates based on U.S. Census guidance for smaller geographies. We note that the ACS estimates are for the city jurisdiction and not its urban growth boundary (UGB), and that the ACS data are not spatially explicit or at any unit finer than the city. This means that these results may include people that reside outside of a tsunami inundation zone. We include the ACS-provided margin of error (MOE) to emphasize the sampling nature and uncertainty of the survey. The U.S. Census Bureau sets a 90% confidence level, where the estimate and the actual population value will differ by no more than the value of the MOE.

Previous analyses of limited English-speaking households and those households with disabilities located within each city's tsunami inundation zone may be found in Allan and others (2020a, b) and Allan and O'Brien (2021, 2023, 2023). Accordingly, we do not repeat those results here.

2.9 Model and Data Limitations

2.9.1 Earthquake

Our earthquake ground motion and deformation model is based on various assumptions about the Cascadia rupture zone (Madin and others, 2021). Soil amplification, liquefaction susceptibility, and landslide susceptibility values were assigned based on the best-available local geologic data, mapped using high-resolution lidar. Nevertheless, soils, liquefaction, and landslide information compiled by Madin and others (2021) may include generalizations about local conditions that could be better refined in the future, with more detailed community or site-specific mapping efforts.

2.9.2 Debris

Estimates of the weight of debris generated by a CSZ earthquake and tsunami remain imprecise. As noted previously, building contents are calculated using percentage structure replacement values (Table 6-10 in FEMA, 2022) that is a function of the building type. However, these estimates remain approximate. We do not quantify the amount of buoyant debris from damaged buildings that may be washed out to sea, nor do we estimate the weight of concrete and asphalt that would be produced from damaged roads and bridges.

Debris from vehicles was calculated using building occupancy type and county-level vehicle registration data. The registration data provided the count of each type of vehicle for each county. These numbers were then distributed among the buildings based on either the square footage of the building or the number of people occupying the building. Passenger vehicles, campers, and travel trailers were distributed among residential buildings based on population. Vehicle types distributed based on building square footage included: buses to educational buildings, semitrucks to industrial buildings, government vehicles to government buildings, and light and heavy trailers to industrial and residential buildings. RVs and boats are included in the building inventory and no distribution method was required. After all vehicle types were distributed, the approximate weight of each vehicle type was used to calculate the total debris weight from vehicles for each building, RV, and boat. Finally, debris associated with shipping containers, boats, and logs in staging areas are not included. Estimates of the weight of sediment redistributed across the landscape or vegetation removed and transported by the tsunami were also excluded from our analyses.

2.9.3 Economic losses

Our economic loss estimates are limited to the direct cost of repairing a damaged building or replacing a severely damaged building with an equivalent structure. Our model assumes standard labor and material costs and availability of capital and credit. It does not factor in demand surge, which occurs following large disasters and results in higher costs to repair building damage relative to comparable damage observed in smaller disasters (described previously in section **2.3**). Olsen and Porter (2011) reported demand surges ranging from 10% to 40% following several large-scale disasters. Adjusting repair/replacement costs due to a likely demand surge was beyond the scope of this project. Further, we do not quantify permanent loss of use, and thus value, of the land due to ground failure, the presence of spilled hazardous materials, loss of buildable land due to scour and erosion from the tsunami, or loss of use from tidal flooding due to coseismic subsidence.

2.9.4 Population models

Estimates of the permanent population in the tsunami inundation zone are derived from U.S. Census data collected in 2020 and ACS data maintained by the U.S. Census Bureau. This approach differs from Bauer and others (2020), which used Oregon DMV records to identify the number of permanent people in the tsunami inundation zone.

Table 2.6 presents results for four communities where we can compare the approach of Bauer and others (2020) to our latest population modeling. First, both approaches yield comparable resident numbers in Gearhart (Clatsop County) and Rockaway Beach (Tillamook County). This is due entirely to the fact that both communities are completely inundated under the XXL1 scenario, the extent of which is comparable to the boundaries of the CBG. Hence the values reported are similar. In contrast, **Table 2.6** indicates that the CBG results for the permanent population in Lincoln City and Newport (Lincoln County) are considerably higher (~20% to 40%) compared with the DMV approach. There are three possible explanations. First, it may be a function of the latter communities having narrow inundation zones due to having been built on high ground, with large portions of the communities outside of the tsunami inundation zone. Thus, the CBGs in these areas account for people located outside of the tsunami inundation zone. Hence, the process of distributing residents across the UDFs based on those buildings in the tsunami inundation zone may overestimate the number of people living in the tsunami inundation zone. Second, it may be a function of the ACS data having more up-to-date population statistics, though this seems less likely given that DMV records should provide a good representation of numbers of people residing in both communities. Third, Bauer and others (2020) may have undercounted the number of people residing in Lincoln City and Newport.

In contrast, estimates of the temporary population in the four communities (**Table 2.6**) using our latest population model are generally lower, when compared with the Bauer and others (2020) approach. For example, the visitor population in Lincoln City is much lower—a 45% difference. This change is primarily due to the number of people assigned to each room/unit. Bauer and others (2020) used a value of three people per room, the preferred choice by community planners. However, for this study, we chose to use a value of two people per room. Despite the lower numbers of visitors observed in our latest modeling, and given the large uncertainty in numbers of visitors in any given community on any given day, we remain confident in our overall estimates of potential visitor numbers.

Table 2.6. Comparison of the Bauer and others (2020) population model with the approach used in this study.

Community	Bauer and others (2020) (DMV Records)		This Study (CBG Approach)		Population Difference		Building Count		
	Permanent	Temporary[1]	Permanent	Temporary	Permanent	Temporary	XXL1	Entire CBG[2]	Difference[3]
Gearhart	1,495	5,459	1,447	4,532	-3 %	-20 %	1,651	1,961	310
Rockaway Beach	1,440	7,592	1,503	6,642	4 %	-14 %	2,372	4,056	1,684
Lincoln City	2,154	11,844	2,692	8,167	20 %	-45 %	2,523	8,499	5,976
Newport	1,161	7,171	2,002	6,161	42 %	-16 %	1,642	8,394	6,752

Notes:

[1] The temporary population modeling script used by Bauer and others (2020) differed slightly from the present study. In Bauer and others, Lincoln City was assigned three people/bedroom when estimating the temporary population. In the present study we assign two people/bedroom for all communities.

[2] This is the total building count within all CBGs that intersected the community boundary.

[3] Difference in both building counts

The potential for inaccurate population data in a CBG, including undercounting by Bauer and others (2020), is probably the most likely explanation for differences observed in **Table 2.6**. Inaccurate data may be a function of building UDFs not having been fully evaluated for attribute accuracy, leading to over or undercounting of the local population. For this study, great care was taken to evaluate building attributes within the tsunami hazard zone. The specific steps followed are:

1. Is the building a residential occupancy type? If it is, then it contains residents.
2. What type of residential building is it? For example, if it is a multifamily building (e.g., an apartment), it may contain both residents and visitors. Conversely, a hotel only contains visitors.
3. What is the square footage of the building? Depending on the occupancy type, the square footage determines the number of units/rooms, which affects the number of residents living there.

Manually checking the many thousands of buildings outside of the tsunami inundation zone is challenging. An example of how the population statistics may be skewed is described here. Consider an apartment building housing 200 permanent residents is located partly outside of the tsunami inundation zone, but within a CBG. Thus, for the CBG some portion of the apartment are both within and outside the tsunami inundation zone. Because the apartment building is located outside of the tsunami inundation zone, it may have been skipped for further evaluation. However, because the apartment is included in the CBG, those 200 people are inadvertently counted as residing in the tsunami inundation zone. Continuing with this example, let us say that the apartment building was categorized as a hotel and no residents were assigned to it. Now those 200 permanent residents, which are part of the CBG total, are distributed elsewhere in the CBG, skewing the results in other locations.

Other possible ways in which inaccurate population modeling may occur include:

1. A building is not correctly categorized as residential—no residents would be assigned to it.
2. The square footage is incorrect. That means that either more or fewer people will be assigned to the building.

In summary, although great care has been taken to evaluate building UDF attributes, especially those adjacent to the tsunami inundation zone boundary that could potentially skew the population statistics (e.g., multifamily residential), it is possible some of these buildings were misattributed.

Temporary resident estimates and age demographics were based on several key assumptions as described by Bauer and others (2020) and are without doubt the largest challenges when specifying the visitor population on any given day. Finally, our population model does not account for people living in the tsunami inundation zone who are experiencing homelessness. Homeless encampments are likely present within the tsunami inundation zone of many Oregon coastal communities.

2.9.5 Hazus tsunami casualty model

The Hazus evacuation modeling assumes the following responses:

1. Everyone in the tsunami inundation zone will evacuate on foot at some time after the ground stops shaking.
2. Their exit from the building is unimpeded.
3. They take the most optimal route to safety.
4. Their evacuation speed is not limited by congestion from fellow evacuees or the presence of obstacles on roads and trails.

Furthermore, it does not account for certain human behaviors and other factors that could result in higher fatality rates. For example, some portion of the population may be unaware of the impending threat and thus do nothing. Others may be fully aware of the threat but for various reasons, including a fatalistic outlook, choose either not to evacuate or delay their evacuation (Ando and others, 2013; Johnston and others, 2013). Some may tend to a person with disabilities or a person who sustained injuries during the earthquake and thus fail to leave in a timely manner or are greatly limited in their travel speeds. Still others may spend time checking on neighbors. Fatigue may impact a portion of the population over longer travel distances, especially individuals with limited mobility or health-related problems. Delay introduced by descending multiple flights of stairs in multistory structures is also not considered. Finally, our modeling does not consider those people who choose to return to the tsunami hazard zone to locate family members (Makinoshima and others, 2021).

Other nonbehavioral factors that the model does not account for include structural failures in a building leading to jammed doorways and blocked hallways and doorways, which may limit egress. Evacuation on roads and trails is likely to be affected by building debris produced by the ground shaking strewn onto roadways and sidewalks, deformed roads and trails due to lateral spreading resulting from liquefaction, the presence of liquefaction sand boils, and downed power lines. Depending on the number of evacuees, pedestrian and vehicle congestion at chokepoints could also influence travel speeds.

Occupants of boats docked in marinas are assumed to recognize the signs of a major earthquake and be able to safely leave their vessels and exit to high ground via intact docks and dock ramps. Neither seiching within enclosed marinas nor potential damage to the dock or its walkway to dry land is modeled.

Although the Hazus earthquake model estimates earthquake-induced building damage, the Hazus tsunami casualty model does not factor in how damage to a building from the earthquake itself may restrict egress and thus possibly impede evacuation of damaged buildings prior the arrival of a tsunami. This issue may be especially important in older manufactured homes that may slip off their foundation supports, warping framing and possibly jamming doorframes and windows.

Although one can identify shortcomings with the FEMA Hazus tsunami modeling, given its assumptions of ideal behavior on the part of evacuees and intact, unimpeded evacuation routes, the injury and casualty results from the model should be perceived “as starting points and not an end point for tsunami risk-reduction discussions” (Wood and Schmidtlein, 2013, p. 1,625).

3.0 RESULTS

This section presents results of the Hazus analysis used to quantify earthquake- and tsunami-related impacts (i.e., building damage and losses, debris, casualties, and number of displaced people) for the Oregon Coast. Variations in the degree of impact within each community and county are indicative of the diverse population demographics, historical and contemporary development patterns, socioeconomic characteristics, tsunami risk, and bathymetric, topographic, and geologic circumstances. These factors, in turn, influence community preparation, response, and, ultimately, recovery following a CSZ earthquake and tsunami. Unlike our previous earthquake and tsunami impact studies, which evaluated the effects of a CSZ earthquake and tsunami for individual communities, this report will focus on Hazus results summarized for each Coastal County (**Figure 1.1**). For community-specific results, the reader is directed to the countywide tables and community profiles accompanying this report. Due to uncertainties in the size of the tsunami, we present summary information for the M1, L1 and XXL1 scenarios. As a reminder, we identify both the permanent (resident) population within each tsunami inundation zone and include an estimate of the temporary (visitor) population that may also be present. The latter assumes a summer 2 a.m. weekend scenario that maximizes visitor occupancy (i.e., assumes 100% occupancy in all hotel/motels, vacation homes, and camping spots).

3.1 Clatsop County

Figure 3.1 presents summary information on population demographics, casualties, and number of displaced people for coastal Clatsop County (**Figure 1.1**) caused by a M_W9 CSZ earthquake and tsunami. Our updated population modeling indicates 40,720 residents live in coastal Clatsop County, representing an increase of 2,699 (6.6%) residents since the 2010 census. Of the total number of residents, ~12,200 live in the M1 tsunami inundation zone and as many as ~20,900 in XXL1 (**Figure 3.1**). Furthermore, of those people living in the XXL1 tsunami inundation zone, 3% are less than five years of age, 68% are between five and 65, and the remaining 29% are >65 years (**Figure 3.1**). This means that 3,295 (M1) to 6,054 (XXL1) people are over 65 and may be presented with greater evacuation challenges when escaping from the tsunami inundation zone compared with those under 65 years of age.

After evaluating the suite of hotel/motels, vacation homes, and camping facilities throughout coastal Clatsop County, we estimate a further ~18,700 (M1) to ~32,100 (XXL1) visitors may potentially overnight in the tsunami inundation zone. Although many sites in Clatsop County are popular with tourists, the bulk of the visitors are more likely to overnight in Seaside (~10,400), Cannon Beach (~7,450), and Gearhart (~5,000) since these are the communities with the largest concentration of hotel/motels and vacation homes in the XXL1 tsunami inundation zone. As described previously in Allan and others (2020a), most of the visitors tend to be concentrated closest to the beach and hence have the farthest to travel to reach high ground. This is best highlighted in Seaside (**Figure 3.2**, middle of figure), where there is a concentration of hotel/motels adjacent to the Seaside promenade and beach.

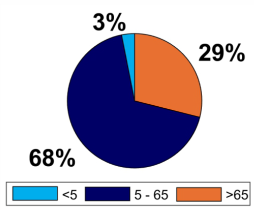
Figure 3.1. Summary population demographics and casualties for coastal Clatsop County. Aside from numbers of residents, all other values have been rounded. Age demographics based on people in the XXL1 tsunami zone.

Clatsop County

Demographics

Resident	40,720
Overnight Visitors (100% Occupancy)	38,600

Age Demographics



Population in Tsunami Zone

	Medium	*Large*	*XX-Large*
Resident	12,171	16,568	20,930
Overnight Visitors (100% Occupancy)	*18,700*	*26,400*	*32,100*

Injuries

Earthquake: 1,330

Injuries in Tsunami Zone

	Medium	Large	XX-Large
Resident	480	530	430
Overnight Visitors (100% Occupancy)	*710*	*670*	*470*

Injuries Requiring Hospitalization ~260

Fatalities

Earthquake: 30

Fatalities in Tsunami Zone

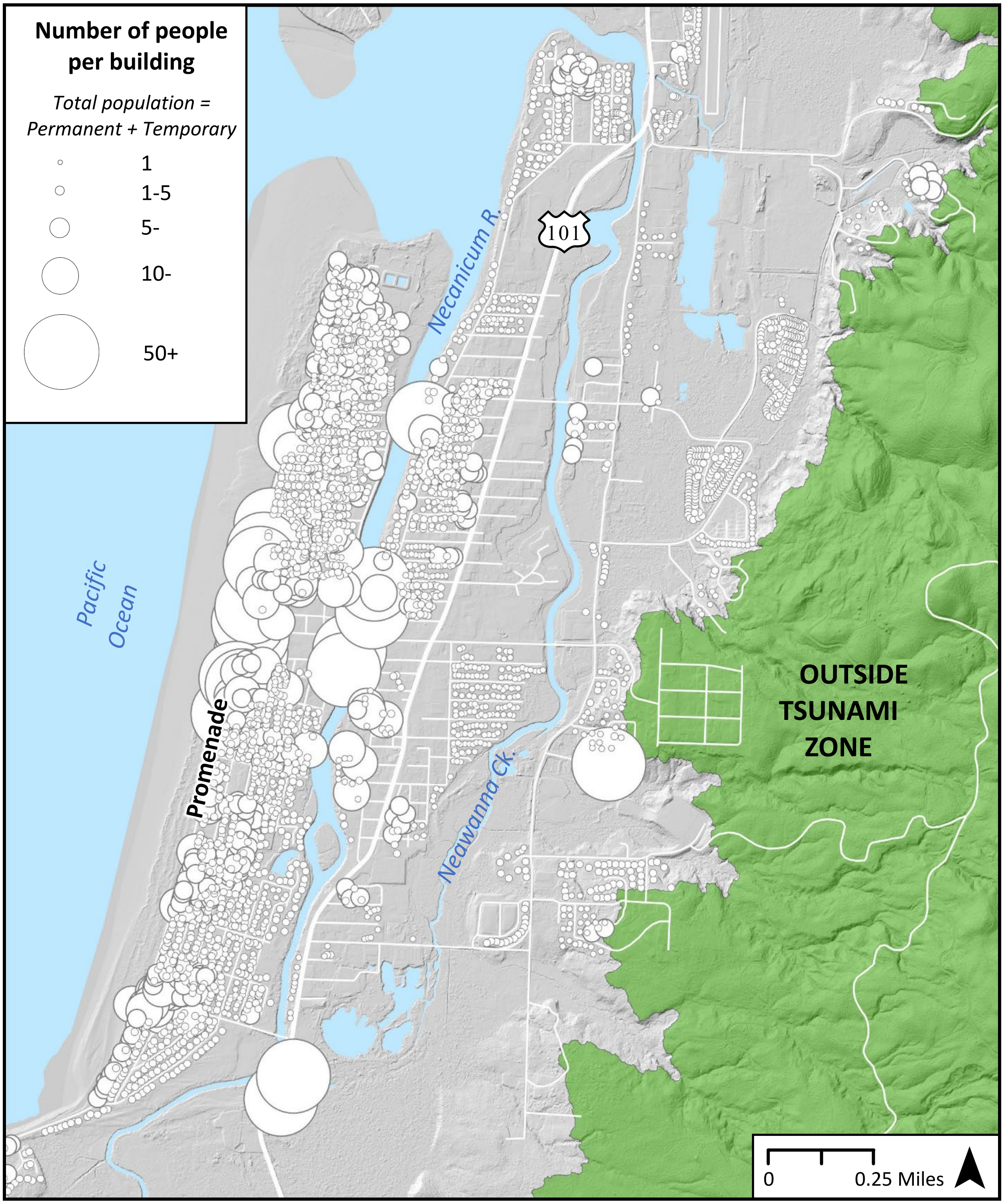
	Medium	Large	XX-Large
Resident	3,740	4,370	7,360
Overnight Visitors (100% Occupancy)	*6,860*	*8,060*	*14,700*

Displaced Population

Earthquake and Tsunami Displaced

	Medium	Large	XX-Large
Resident	10,685	13,940	14,890
Overnight Visitors (100% Occupancy)	*12,930*	*19,150*	*17,590*

Figure 3.2. Map showing the spatial distribution of visitor concentration in the tsunami inundation zone at Seaside, Oregon. Larger circles indicate greater concentrations that tend to be associated with hotel/motels. Gray region defines the tsunami inundation zone, while green is high ground.



Injuries sustained from a CSZ earthquake may be caused by many factors, including falls while evacuating buildings, flying glass, being struck or crushed by falling objects, and/or burns from fires. Injuries may range from mild cuts and bruises to more serious conditions such as fractures, internal organ damage, crush injuries, and burns (Tang and others, 2017). We estimate ~1,320 people injured from the earthquake shaking (**Figure 3.1**). Of these, an estimated 260 people are likely to experience serious injuries requiring immediate hospitalization. An additional ~480 to ~1,190 injuries may be caused by the tsunami (**Figure 3.1**). However, the uncertainty here is large since this depends mostly on how many visitors are recreating on the coast at the time of the disaster. At this time, Hazus does not provide estimates of the degree of injuries caused by the tsunami.

As can be seen in **Figure 3.1**, fatalities caused by a CSZ earthquake are low (30) compared to those killed by the accompanying tsunami. This is indicative of the fact that most buildings constructed on the Oregon Coast tend to be wood-frame structures that ride out the earthquake ground shaking quite well. Large multistory buildings also tend to perform well during earthquakes because they are generally designed to more modern building codes. Most fatalities caused by earthquakes are due to being struck by falling material (Tang and others, 2017) as opposed to building failures. In contrast, fatalities caused by the tsunami are due to drowning. As presented in **Figure 3.1**, the numbers of fatalities caused by the associated tsunami waves are large, ranging from ~3,740 (M1) to ~7,360 (XXL1) residents. Factoring in the visitor population increases the total fatalities to an estimated ~10,600 (M1) to ~22,060 (XXL1) in coastal Clatsop County.

In response to the expected scale of destruction of homes and buildings that will be experienced throughout Clatsop County, we anticipate that this will contribute to significant numbers of displaced residents and visitors. Our estimates presented in **Figure 3.1** are larger than those provided in Allan and others (2020a), since we consider here those people displaced from both the tsunami inundation zone as well as people displaced from their homes outside the tsunami zone as a result of earthquake-related damage. For the latter, we assume a 50% damage exceedance threshold for estimating those displaced from buildings damaged by the earthquake. The destruction caused by the tsunami accounts for 79% (M1) to 91% (XXL1) of the displaced residents in Clatsop County, and 92% (M1) to 99% (XXL1) of the displaced visitors. In total, our modeling indicates that some ~10,700 residents to ~15,000 residents could be displaced by the combined impact of the earthquake and tsunami, along with an additional ~13,000 visitors to ~17,600 visitors. Thus, there are two very significant challenges that face emergency managers at all levels of government: 1) removing the large numbers of visitors from the coast in the days following the earthquake and tsunami, and 2) addressing the longer-term needs (weeks to years) of many residents who will have no homes to return to.

Figure 3.3 presents summary information on building inventory, building damage losses, content losses, and debris generated for coastal Clatsop County. Our modeling indicates that of the 25,242 buildings present, 85% are likely to experience some form of earthquake-related damage. Of these, 12% are projected to be destroyed, 28% would be extensively damaged, and 24% could experience moderate damage (**Figure 3.3**). For coastal Clatsop County, our modeling suggests that 75% (M1) to 91% (XXL1) of buildings in the tsunami inundation zone would probably be destroyed.

Figure 3.3. Summary earthquake and tsunami losses for coastal Clatsop County. Buildings destroyed in the tsunami inundation zone assumes >50% damage. Losses and debris weights have been rounded.

Clatsop County

Building Inventory

Residential	Commercial	Indus/Ag	Government	Education	Religion
18,482	1,242	4,664	597	73	195

Damaged Buildings

Earthquake damage:

Total = 85%

None	Minor	Moderate	Extensive	Complete
15%	22%	24%	28%	12%

	Tsunami Zone		
	Medium	*Large*	*XX-Large*
Buildings destroyed in tsunami zone	75%	84%	91%

Building Losses ($Billion)

Earthquake		*Medium*	*Large*	*XX-Large*
$2.43	+	$1.19	$2.01	$3.13

Content Losses ($Billion)

Earthquake		*Medium*	*Large*	*XX-Large*
$1.82	+	$0.82	$1.40	$2.24

Debris Generated (Earthquake & Tsunami)

Medium	575,900 tons (57,590 truck loads)
Large	852,500 tons (85,250 truck loads)
XX-Large	1,223,100 tons (122,310 truck loads)

Assumes truck capacity of 10 yd^3

Critical Facilities

	fire	enforcement	school	hospital	city hall	public works	sewer	ports & USCG
Medium	6	6	2		1	3	1	7
Large	9	6	4	1	1	3	2	7
XX-Large	12	6	5	2	1	3	2	7

Based on estimates of the damage potential, our Hazus modeling suggests that the earthquake alone could cause ~$2.43 billion in damage in coastal Clatsop County, while the tsunami-related damage is likely to range from ~$1.19 billion to ~$3.13 billion. Accordingly, the combined earthquake and tsunami building damage losses are likely to range from ~$3.62 billion (M1) to ~$5.56 billion (XXL1), depending on the magnitude of the tsunami. Estimates of content losses are also included in **Figure 3.3** and are a percentage of the value of the value of each building (e.g., Table 6-10 in FEMA, 2024). Thus, content losses reflect an additional ~$2.64 billion to ~$4.06 billion for Clatsop County. Combined, we estimate that the total losses in coastal Clatsop County are likely to range from ~$6.26 billion to more than ~$9.62 billion.

The earthquake and tsunami will generate considerable debris throughout the county that will need to be managed. **Figure 3.3** provides estimates of the weight of debris (expressed as tonnage), which varies depending on which tsunami inundation zone is used. Our estimates indicate ~575,900 tons (M1) to ~1,223,100 tons (XX1L) of debris are likely to be generated across the county. However, these estimates are almost certainly on the low end, since they do not consider the added weight associated with household or business contents, rip ups of roads, building foundations, and vegetation. We estimate an additional ~49,000 tons could be associated with household contents alone but are unable to estimate debris weights associated with other building types. Finally, **Figure 3.3** identifies various critical facilities located within each of the three tsunami inundation zones. Of note, we identify many important facilities in all three tsunami hazard zones, including multiple fire stations, law enforcement, schools, public works, and sewer treatment plants. Furthermore, Clatsop County also includes the Port of Astoria, as well as several smaller ports and marinas located in the tsunami inundation zone. All of these are expected to sustain considerable damage.

3.2 Tillamook County

Figure 3.4 presents summary information on population demographics, casualties, and number of displaced people for coastal Tillamook County (**Figure 1.1**). Our updated population modeling using U.S. 2020 census data indicates 27,129 residents live in coastal Tillamook County, which reflects an increase in the local population by ~1,290 (~4.8%). Of those residents living in the tsunami inundation zone, 3,497 are in M1, 5,115 in L1, and 7,545 in XXL1 (**Figure 3.4**). In terms of the demographics of people in the XXL1 tsunami inundation zone, 3% were found to be less than five years of age, 68% are between five and 65, and the remaining 29% are >65 years. This means that 1,125 people to 2,248 people are over the age of 65 and may be presented with greater evacuation challenges when escaping from the tsunami inundation zone compared with those under 65 years of age. We estimate a further ~19,330 (M1) to ~30,250 (XXL1) potential visitors who may overnight in coastal Tillamook County (**Figure 3.4**) staying in hotel/motels, vacation homes, or campgrounds located in the tsunami inundation zone. The bulk of the visitors are likely to overnight in Rockaway Beach (~7,190), Pacific City (~4,710), and Manzanita (~4,070) since these are the communities with the largest concentration of visitor beds in the XXL1 tsunami inundation zone. As noted previously for Seaside, Clatsop County (**Figure 3.2**), most of the visitors tend to be concentrated closest to the beach (e.g., Rockaway Beach, Tillamook County) and hence have the farthest to travel to reach high ground.

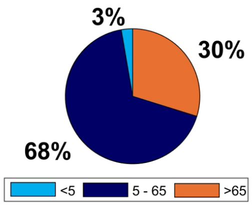
Figure 3.4. Summary population demographics and casualties for coastal Tillamook County. Aside from numbers of residents, all other values have been rounded. Age demographics based on people in the XXL1 tsunami zone.

Tillamook County

Demographics

Resident	27,129
Overnight Visitors (100% Occupancy)	46,600

Age Demographics



Population in Tsunami Zone

	Medium	*Large*	*XX-Large*
Resident	3,497	5,115	7,545
Overnight Visitors	*19,330*	*26,110*	*30,250*

Injuries

Earthquake: 1,250

Injuries in Tsunami Zone

	Medium	Large	XX-Large
Resident	90	100	195
Overnight Visitors (100% Occupancy)	*560*	*520*	*700*

Injuries Requiring Hospitalization ~240

Fatalities

Earthquake: 20

Fatalities in Tsunami Zone

	Medium	Large	XX-Large
Resident	460	750	1,160
Overnight Visitors (100% Occupancy)	*2,370*	*4,200*	*6,590*

Displaced Population

Earthquake and Tsunami Displaced

	Medium	Large	XX-Large
Resident	7,130	8,180	9,770
Overnight Visitors (100% Occupancy)	*18,280*	*23,000*	*24,470*

We estimate ~1,250 people injured from an M_W 9.0 earthquake, of which an estimated 240 people are likely to experience serious injuries requiring immediate hospitalization (**Figure 3.4**). An additional ~90 injuries to ~900 injuries may be caused by the tsunami. At this time, Hazus does not provide estimates of the degree of injuries caused by the tsunami. Similar to Clatsop County, fatalities caused by the earthquake are found to be low (20) compared to those caused by the tsunami, which could range from ~460 (M1) to ~1,160 (XXL1) residents. Factoring in the visitor population increases the total number of fatalities to an estimated ~2,830 (M1) to ~7,750 (XXL1) in coastal Tillamook County (**Figure 3.4**).

Given the degree of likely damage to homes and buildings throughout Tillamook County (described further below), the county can expect to experience many thousands of displaced residents and visitors (**Figure 3.4**). Our estimates presented in **Figure 3.4** are considerably larger than those provided in Allan and others (2020b), since we consider here both those people displaced from the tsunami inundation zone, as well as those people outside of the tsunami zone whose homes are destroyed by the earthquake shaking. As with Clatsop County, we assume a 50% damage exceedance threshold for estimating those displaced from buildings damaged by the earthquake. Our Hazus modeling indicates that the destruction caused by the tsunami accounts for some 43% (M1) to 65% (XXL1) of the displaced residents in Tillamook County and 93% (M1) to 97% (XXL1) of the displaced visitors. The latter again demonstrates that when visitors stay overnight on the coast, the bulk of them are sleeping in the tsunami hazard zone. Accordingly, the county will need to address approximately 7,130 (M1) to ~9,770 (XXL1) displaced residents, and ~18,000 to ~24,000 displaced visitors (**Figure 3.4**). For the M1 tsunami scenario, we find slightly more people are displaced by the earthquake-related building damage, compared with building damage caused by the tsunami. This is likely due to a combination of factors, including the smaller tsunami inundation zone and age of the buildings. For example, most buildings constructed in Tillamook County were built in the 1960s and 1970s, prior to the introduction of earthquake-related building codes.

Figure 3.5 presents information on the number of buildings damaged, losses, and debris generated for Tillamook County. Our Hazus modeling indicates some 85% of the building infrastructure is expected to be damaged by the earthquake. Of these, we estimate 16% of buildings will be completely destroyed, 27% could experience extensive damage, and 22% may be moderately damaged; 15% of the buildings are likely not to experience any significant damage (**Figure 3.5**). For coastal Tillamook County, our Hazus modeling suggests that 74% (M1) to 88% (XXL1) of buildings in the tsunami inundation zone would likely be destroyed. For the latter, we assume that all buildings that sustain >50% damage are probably destroyed, requiring a complete rebuild.

Damage estimates for coastal Tillamook County suggest that earthquake-related building losses are likely to exceed ~$2.41 billion. An additional ~$0.47 billion (M1) to ~$1.45 billion (XXL1) in building losses are expected to occur from the tsunami. Total building losses are therefore likely to range from ~$2.88 billion to ~$3.86 billion (**Figure 3.5**). Including estimates of the content losses raises the total potential losses to ~$5.08 billion to ~$6.76 billion.

Finally, we estimate some ~239,500 tons to ~643,900 tons of debris is likely to be generated by the earthquake and tsunami (**Figure 3.5**). However, these estimates are almost certainly on the low end, since they do not consider the added weight associated with household or business contents, or damage to roads, building foundations, and vegetation. We estimate an additional ~35,800 tons could be associated with household contents alone but are unable to estimate debris weights associated with other building types. Lastly, **Figure 3.5** identifies various critical facilities located within each of the three tsunami inundation zones. Of note, we identify many important facilities in both the L1 and XXL1 tsunami inundation zones, including multiple fire stations, law enforcement, schools, public works, and sewer treatment plants. In addition, we identify two ports that are likely to be destroyed.

Figure 3.5. Summary earthquake and tsunami losses for coastal Tillamook County. Buildings destroyed in the tsunami inundation zone assumes >50% damage. Losses and debris weights have been rounded.

Tillamook County

Building Inventory

Residential	Commercial	Indus/Ag	Government	Education	Religion
19,537	793	6,282	353	58	113

Damaged Buildings

Earthquake damage:

Total = 85%

None	Minor	Moderate	Extensive	Complete
15%	20%	22%	27%	16%

Tsunami Zone

	Medium	*Large*	*XX-Large*
Buildings destroyed in tsunami zone	74%	85%	88%

Building Losses ($Billion)

Earthquake		*Medium*	*Large*	*XX-Large*
$2.41	+	$0.47	$0.89	$1.45

Content Losses ($Billion)

Earthquake		*Medium*	*Large*	*XX-Large*
$1.92	+	$0.28	$0.56	$0.98

Debris Generated (Earthquake & Tsunami)

Medium	239,500 tons (23,950 truck loads)
Large	430,500 tons (43,050 truck loads)
XX-Large	643,900 tons (64,390 truck loads)

Assumes truck capacity of 10 yd^3

Critical Facilities

	fire	enforcement	school	hospital	city hall	public works	sewer	ports & USCG
Medium	3	1	1		1	2	2	2
Large	7	1	2		1	4	4	2
XX-Large	9	3	2	1	3	4	5	2

3.3 Lincoln County

Our population modeling indicates a total of 48,879 residents live in coastal Lincoln County (**Figure 1.1**), with another ~55,300 potential visitors (**Figure 3.6**). These results indicate that Lincoln County gained an additional 998 (2%) residents since the 2010 census was undertaken. Of those residents located in the tsunami inundation zone, 3,874 are in M1, 6,007 in L1 and more than 12,000 in XXL1. Our population modeling suggests another ~11,880 visitors in the M1 tsunami inundation zone, ~18,170 in L1 and ~29,140 in XXL1 (**Figure 3.6**). This assumes 100% occupancy in hotel/motels, vacation homes, and campgrounds. By far the largest concentration of visitors (based on the availability of beds) occurs in the communities of Lincoln City (~7,870), Newport (~4,180), and Gleneden Beach (~3,060). We also observe a very large, disbursed visitor concentration in the “other” category, which suggests many visitors are staying in vacation homes outside the 11 communities that make up coastal Lincoln County. In terms of population demographics in the XXL1 tsunami inundation zone, fewer than 3% were found to be less than five years of age, 62% are between five and 65, and the remaining ~35% are >65 years (**Figure 3.6**). The latter suggests that as many as 1,460 (M1) to 4,185 (XXL1) residents over 65 years of age are in the tsunami inundation zone, which has a bearing on their ability to escape from the tsunami inundation zone.

Earthquake-related casualties are presented in **Figure 3.6**. For Lincon County, an estimated 1,430 injuries are likely to occur because of the earthquake shaking, of which ~290 are expected to require hospitalization. Tsunami-related injuries are low relative to earthquake-related injuries. Furthermore, unlike Clatsop and Tillamook counties, casualty modeling for Lincoln County indicates that they have one of the lowest fatality rates on the Oregon Coast. As can be seen in **Figure 3.6**, fatalities (resident and visitor combined) are estimated to range from ~360 (M1) to ~2,470 (XXL1). As discussed in Allan and others (2021), the main reason for the lower tsunami-related fatalities in Lincoln County is due to the coastal geomorphology, such that the bulk of the population is located on marine terraces that are mostly outside of the tsunami hazard zone. This contrasts with Clatsop and Tillamook counties where the bulk of the population (resident and visitor) are located on low-lying coastal barrier spits and plains within the tsunami inundation zone. Hence, the tsunami risk is significantly higher in Clatsop and Tillamook County compared with the rest of the Oregon Coast. Furthermore, because much of the terrain in Lincoln County is elevated, this tends to produce narrower tsunami hazard zones, with high ground and safety close by. As a result, except for places like Siletz Spit and Alsea Spit, high ground may be reached relatively quickly.

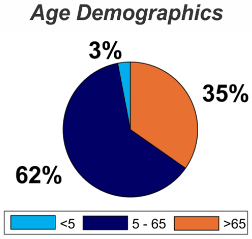
Figure 3.6 indicates the potential for very large numbers of displaced residents and visitors in Lincoln County, second only to Clatsop County. Our population modeling suggests ~9,060 (M1) to ~15,960 (XXL1) displaced residents and an additional ~14,780 to ~29,400 displaced visitors. These estimates are significantly larger than those provided in Allan and others (2021), since we consider here both those people displaced from buildings within the tsunami inundation zone and those displaced from damaged buildings outside the tsunami zone as a result of the strong earthquake shaking. Of the residents that are displaced, we determined that 42% (M1) to 72% (XX1) of them are from within the tsunami inundation zone. In the case of the M1 tsunami inundation scenario, most (58%) of the displaced residents are from outside the tsunami inundation zone, the product of building losses (destruction) due to the earthquake shaking. Conversely, we find that an estimated 79% (M1) to 92% (XXL1) of the displaced visitors are from within the tsunami inundation zone since this is where the bulk of the hotel/motels are located. As noted previously for Clatsop County, these results present two significant challenges for emergency managers: 1) removing the very large numbers of visitors from the coast in the days following the earthquake and tsunami, and 2) addressing the longer-term needs (weeks to years) of many residents who will be displaced.

Figure 3.6. Summary population demographics and casualties for coastal Lincoln County. Aside from numbers of residents, all other values have been rounded. Age demographics are based on people in the XXL1 tsunami zone.

Lincoln County

Demographics

Resident	48,879
Overnight Visitors (100% Occupancy)	55,300



Population in Tsunami Zone

	Medium	*Large*	*XX-Large*
Resident	3,874	6,007	12,059
Overnight Visitors	*11,880*	*18,170*	*29,140*

Injuries

Earthquake

1,440

Injuries in Tsunami Zone

	Medium	Large	XX-Large
Resident	80	55	115
Overnight Visitors (100% Occupancy)	*245*	*150*	*320*

Injuries Requiring Hospitalization ~290

Fatalities

Earthquake

40

Fatalities in Tsunami Zone

	Medium	Large	XX-Large
Resident	90	240	490
Overnight Visitors (100% Occupancy)	*270*	*700*	*1,980*

Displaced Population

Earthquake and Tsunami Displaced

	Medium	Large	XX-Large
Resident	9,060	10,770	15,960
Overnight Visitors (100% Occupancy)	*14,780*	*20,200*	*29,440*

Information on building inventories, damage characteristics, losses, and debris produced by the earthquake and tsunami for coastal Lincoln County are presented in **Figure 3.7**. Modeling using Hazus suggests that the total number of buildings damaged by a M_W 9.0 CSZ earthquake is likely to impact ~91% of the buildings. Of these, we estimate that 15% of the buildings are likely to be destroyed, 25% could experience extensive damage, and another 26% could be moderately damaged. Buildings classified as experiencing slight damage are likely to make up ~24% of the building stock, while an estimated 9% of the buildings are projected to experience no damage. Our Hazus modeling suggests that ~67% (M1) to 85% (XXL1) of buildings in the tsunami inundation zone in coastal Lincoln County would likely be destroyed. Recall, a building is classified as destroyed here if it is modeled to sustain >50% damage.

Based on the above damage levels, our Hazus modeling suggests that a M_W 9.0 CSZ earthquake could cause ~$2.38 billion in damage losses in coastal Lincoln County, while the tsunami-related losses could range from ~$0.41 billion (M1) to ~$1.65 billion (XXL1, **Figure 3.7**). The combined earthquake and tsunami building damage losses are likely to range from ~$2.79 billion to ~$4.03 billion in coastal Lincoln County, depending on the extent of the destruction caused by the tsunami. Estimates of content losses are also included in **Figure 3.7** and, as noted previously, are a percentage of the structures value (e.g., Table 6-10 in FEMA, 2024). Content losses reflect an additional ~$2.08 billion (M1) to ~$2.88 billion (XXL1) for Lincoln County. Thus, total losses in coastal Lincoln County are estimated to range from ~$4.87 billion to ~$6.91 billion (**Figure 3.7**), of which the bulk of the losses will be the product of the earthquake damage.

We estimate ~253,800 tons of earthquake and tsunami (M1) related damage in coastal Lincoln County, increasing to ~754,300 tons if the tsunami reaches an XXL1 size. We estimate an additional ~41,200 tons of residential content losses. Finally, critical facilities in each of the inundation zones are presented in **Figure 3.7**. Lincoln County contains several important ports and marinas in the tsunami inundation zone, along with other key facilities such as sewer treatment plants and fire stations.

Figure 3.7. Summary earthquake and tsunami losses for coastal Lincoln County. Buildings destroyed in the tsunami inundation zone assume >50% damage. Losses and debris weights have been rounded.

Lincoln County

Building Inventory

Residential	Commercial	Indus/Ag	Government	Education	Religion
30,640	2,106	8,284	261	117	158

Damaged Buildings

Earthquake damage:

Total = 91%

None	Minor	Moderate	Extensive	Complete
9%	24%	26%	25%	15%

Tsunami Zone

	Medium	*Large*	*XX-Large*
Buildings destroyed in tsunami zone	67%	76%	85%

Building Losses ($Billion)

Earthquake		Tsunami Zone *Medium*	*Large*	*XX-Large*
$2.38	+	$0.41	$0.85	$1.65

Content Losses ($Billion)

Earthquake		Tsunami Zone *Medium*	*Large*	*XX-Large*
$1.80	+	$0.28	$0.58	$1.08

Debris Generated (Earthquake & Tsunami)

Medium	253,800 tons (25,380 truck loads)
Large	427,600 tons (42,760 truck loads)
XX-Large	754,300 tons (75,430 truck loads)

Assumes truck capacity of 10 yd^3

Critical Facilities

	fire	enforcement	school	hospital	city hall	public works	sewer	ports & USCG
Medium	1	1	1				1	5
Large	2	2	1			1	2	5
XX-Large	7	2	1			1	4	5

3.4 Lane County

Our updated population modeling indicates a total of 18,257 permanent residents in coastal Lane County (**Figure 3.8**). These numbers represent an increase of 885 (4.8%) residents relative to the U.S. 2010 census data. We estimate an additional ~10,300 potential visitors who could overnight in coastal Lane County, of which the largest concentration of visitor beds is in Florence.

Our evaluation of residents in the tsunami hazard zones indicate 569 residents in M1, 962 in L1, and 2,028 in XXL1 (**Figure 3.8**). Numbers of visitors staying in the tsunami inundation zone in coastal Lane County ranges from ~1,980 (M1) to ~3,800 (XXL1). Population demographics within the tsunami inundation zone indicate a slightly larger group of those aged 65 and older in Lane County (39%) compared with the northern coastal counties (**Figure 3.8**). Although those aged 65 and older are less likely to be able to travel quickly on foot, because much of Florence is located on a raised terrace such that the tsunami inundation zone is narrow, most residents and visitors should easily be able to reach nearby high ground quickly due to their short evacuation distances.

Injuries caused by a M_W 9.0 CSZ earthquake are estimated to be ~720 in Lane County (**Figure 3.8**); tsunami-related injuries for residents are very low. Again, these differences are almost entirely due to better access to high ground in coastal Lane County.

When compared with other coastal counties, modeling of earthquake and tsunami-related fatalities for coastal Lane County indicate that the numbers are likely to be low (<100, **Figure 3.8**). However, local, state, and federal emergency responders are likely to have to address large numbers of displaced residents, ranging from ~5,200 (M1) to ~6,350 (XXL1). Displaced visitors requiring short-term care in coastal Lane County are also expected to be very large, with estimates ranging from ~3,080 (M1) to ~4,700 (XXL1) people (**Figure 3.8**). The bulk of the displaced residents are from outside the tsunami inundation zone and reflect displacement from those buildings compromised by the strong earthquake shaking.

Statistics on building inventories, damage characteristics, losses, and debris produced by the earthquake and tsunami are provided for Lane County in **Figure 3.9**. Our Hazus modeling indicates that 95% of the building inventory in Lane County is expected to be damaged because of the M_W 9.0 CSZ earthquake. Overall, we find that 30% of the buildings are likely to be destroyed, 27% could experience extensive damage, 22% could experience moderate damage, and 16% may experience slight damage in Lane County (**Figure 3.9**). Buildings experiencing no damage in Lane County account for 5% of the total inventory, while the percentage of buildings destroyed by the tsunami could range from 58% (M1) to 82% (XXL1). As a result of the damage, building losses from the earthquake shaking in Lane County are estimated to reach ~$1.5 billion (**Figure 3.9**), with another ~$0.02 billion (M1) to ~$0.15 billion (XXL1) in tsunami-related damage. Factoring in content losses could increase total losses in coastal Lane County to ~$2.68 billion to ~$2.88 billion (**Figure 3.9**).

Estimates of the weight of debris produced from both the earthquake and tsunami-related damage are generally low, compared with the other counties. For coastal Lane County, we estimated ~35,800 tons to ~115,100 tons of debris (**Figure 3.9**). Finally, our analyses of critical facilities located in the tsunami inundation zones indicate generally few such facilities in Lane County. Nevertheless, we expect considerable damage to the Port of Siuslaw in Florence in response to even an M1 CSZ tsunami event.

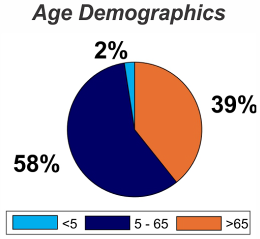
Figure 3.8. Summary population demographics and casualties for coastal Lane County. Aside from numbers of residents, all other values have been rounded. Age demographics are based on people in the XXL1 tsunami zone.

Lane County

Demographics

Resident	18,257
Overnight Visitors (100% Occupancy)	10,300

Age Demographics



Population in Tsunami Zone

	Medium	Large	XX-Large
Resident	569	962	2,028
Overnight Visitors	*1,980*	*2,470*	*3,800*

Injuries

Earthquake: 720

Injuries in Tsunami Zone

	Medium	Large	XX-Large
Resident			20
Overnight Visitors (100% Occupancy)	*2*	*2*	*50*

Injuries Requiring Hospitalization ~150

Fatalities

Earthquake: 20

Fatalities in Tsunami Zone

	Medium	Large	XX-Large
Resident			40
Overnight Visitors (100% Occupancy)	*2*	*2*	*80*

Displaced Population

Earthquake and Tsunami Displaced

	Medium	Large	XX-Large
Resident	5,210	5,560	6,350
Overnight Visitors (100% Occupancy)	*3,080*	*3,540*	*4,700*

Figure 3.9. Summary earthquake and tsunami losses for coastal Lane County. Buildings destroyed in the tsunami inundation zone assume >50% damage. Losses and debris weights have been rounded .

Lane County

Building Inventory

Residential	Commercial	Indus/Ag	Government	Education	Religion
9,431	448	3,847	77	29	35

Damaged Buildings

Earthquake damage:

	None	Minor	Moderate	Extensive	Complete
Total = 95%	5%	16%	22%	27%	30%

	Tsunami Zone		
	Medium	*Large*	*XX-Large*
Buildings destroyed in tsunami zone	58%	63%	82%

Building Losses ($Billion)

Earthquake		*Medium*	*Large*	*XX-Large*
$1.50	+	$0.02	$0.05	$0.15

Content Losses ($Billion)

Earthquake		*Medium*	*Large*	*XX-Large*
$1.13	+	$0.02	$0.03	$0.09

Debris Generated (Earthquake & Tsunami)

Medium	35,800 tons (3,580 truck loads)
Large	54,700 tons (5,470 truck loads)
XX-Large	115,100 tons (11,510 truck loads)

Assumes truck capacity of 10 yd^3

Critical Facilities

	fire	enforcement	school	hospital	city hall	public works	sewer	ports & USCG
Medium						1		1
Large						1		1
XX-Large	1				1	1		1

3.5 Douglas County

Our updated population modeling indicates a total of 6,274 residents in coastal Douglas County (**Figure 3.10**). These numbers represent an increase of 378 (6%) residents relative to the U.S. 2010 census data. Within coastal Douglas County (**Figure 1.1**), we determined 1,141 residents in M1, 1,824 in L1 and 2,220 in XXL1 (**Figure 3.10**); within the tsunami inundation zone, 6% of the local population are less than five years of age, 63% are between five and 65, and 31% are >65 years. We estimate an additional ~4,800 potential visitors who may overnight in coastal Douglas County. Numbers of visitors staying in the tsunami inundation zone ranges from ~2,410 (M1) to ~3,560 (XXL1).

Injuries caused by a CSZ earthquake are estimated to be ~200 in Douglas County (**Figure 3.10**); tsunami-related injuries for residents are very low. Most of the visitor-related casualties in coastal Douglas County are due to visitors staying in campgrounds at Winchester Bay and by the Umpqua River south jetty. Both areas are in the tsunami inundation zone and have relatively long evacuation distances to high ground, which is likely to be challenging for most people. Because of these evacuation distances, coastal Douglas County could experience ~570 (M1) to ~1,180 (XXL1) visitor fatalities (**Figure 3.10**).

Displaced residents in Douglas County are estimated to range from ~2,100 (M1) to ~2,800 people (XXL1, **Figure 3.10**), while the number of displaced visitors could range from ~2,040 (M1) to ~2,500 (XXL1) people.

Statistics on building inventories, damage characteristics, losses, and debris produced by the earthquake and tsunami are provided for Douglas County in **Figure 3.11**. Our Hazus modeling indicates that 85% of the building inventory in Douglas County is expected to be damaged because of the M_W 9.0 CSZ earthquake. Overall, we find that 28% of the buildings are likely to be destroyed, 21% could experience extensive damage, 17% could experience moderate damage, and 20% may experience slight damage (**Figure 3.11**). Buildings experiencing no damage in Douglas County account for 15% of the inventory. Buildings destroyed by the tsunami could range from 54% (M1) to 84% (XXL1) in Douglas County.

As a result of the damage statistics, building losses from the earthquake shaking in Douglas County are estimated to reach ~$0.51 billion, with another ~$0.02 billion (M1) to ~$0.13 billion (XXL1) in tsunami-related damage (**Figure 3.11**); content losses from the earthquake are estimated to reach ~$0.49 billion. As a result, combined earthquake and tsunami losses in coastal Douglas County could range from ~$1.04 billion to ~$1.23 billion.

Estimates of the weight of debris produced from both the earthquake and tsunami-related damage are generally low, compared with the other counties. For coastal Douglas County, we estimated ~76,700 (M1) to ~158,500 tons (XXL1) of debris (**Figure 3.11**).

Finally, our analyses of critical facilities located in the tsunami inundation zones, indicate several facilities that could be impacted in Douglas County. For example, we identified two public works and two wastewater facilities in the tsunami inundation zone, along with several fire stations. In addition, the Port of Winchester Bay and Reedsport are likely to experience considerable damage because of the earthquake and tsunami. The loss of any of these facilities would severely compromise recovery of coastal Douglas County communities.

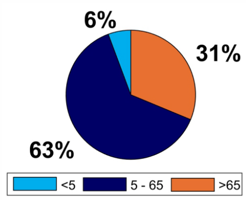
Figure 3.10. Summary population demographics and casualties for coastal Douglas County. Aside from numbers of residents, all other values have been rounded. Age demographics are based on people in the XXL1 tsunami zone.

Douglas County

Demographics

Resident	6,274
Overnight Visitors (100% Occupancy)	4,800

Age Demographics



Population in Tsunami Zone

	Medium	*Large*	*XX-Large*
Resident	1,141	1,824	2,220
Overnight Visitors	*2,410*	*3,350*	*3,560*

Injuries

Earthquake: 200

Injuries in Tsunami Zone

	Medium	Large	XX-Large
Resident		5	10
Overnight Visitors (100% Occupancy)	*570*	*130*	*40*

Injuries Requiring Hospitalization ~40

Fatalities

Earthquake: 10

Fatalities in Tsunami Zone

	Medium	Large	XX-Large
Resident	1	10	20
Overnight Visitors (100% Occupancy)	*570*	*1,020*	*1,180*

Displaced Population

Earthquake and Tsunami Displaced

	Medium	Large	XX-Large
Resident	2,140	2,580	2,790
Overnight Visitors (100% Occupancy)	*2,040*	*2,470*	*2,500*

Figure 3.11. Summary earthquake and tsunami losses for coastal Douglas County. Buildings destroyed in the tsunami inundation zone assume >50% damage. Losses and debris weights have been rounded.

Douglas County

Building Inventory

Residential	Commercial	Indus/Ag	Government	Education	Religion
2,786	213	1,138	76	19	39

Damaged Buildings

Earthquake damage:

Total = 85%

None	Minor	Moderate	Extensive	Complete
15%	20%	17%	21%	28%

Tsunami Zone

	Medium	*Large*	*XX-Large*
Buildings destroyed in tsunami zone	54%	61%	84%

Building Losses ($Billion)

Earthquake		Tsunami *Medium*	Tsunami *Large*	Tsunami *XX-Large*
$0.51	+	$0.02	$0.05	$0.13

Content Losses ($Billion)

Earthquake		Tsunami *Medium*	Tsunami *Large*	Tsunami *XX-Large*
$0.49	+	$0.02	$0.04	$0.10

Debris Generated (Earthquake & Tsunami)

Medium	76,700 tons (7,670 truck loads)
Large	114,400 tons (11,440 truck loads)
XX-Large	158,500 tons (15,850 truck loads)

Assumes truck capacity of 10 yd^3

Critical Facilities

	fire	enforcement	school	hospital	city hall	public works	sewer	ports & USCG
Medium	3	1					1	3
Large	3	2				2	1	3
XX-Large	3	2				2	2	3

3.6 Coos County

Using 2020 census data, we estimate 60,846 residents in coastal Coos County (**Figure 1.1**), of which 1,270 are in M1, 3,363 are in L1, and 10,366 are in XXL1 (**Figure 3.12**). Overall, the county experienced a decrease in the local population by 1,022 (1.7%) since the 2010 census. After evaluating the suite of hotel/motels, vacation homes, and camping facilities throughout coastal Coos County, we estimate a further ~25,100 potential visitors. Of these, approximately ~3,500 are found in the M1 tsunami inundation zone, ~5,400 are in L1, and ~10,400 are in XXL1. Although many sites in Coos County are popular with tourists, the largest concentration of visitor beds are found in Coos Bay (~1,600), Barview (~1,755), and Bandon (~2,600); these numbers reflect visitors in the XXL1 tsunami inundation zone. Of those residents living in the XXL1 tsunami inundation zone, 5% were found to be less than five years of age, 68% are between five and 65, and the remaining 27% are >65 years. This suggests that ~440 (M1) to ~2,780 (XXL1) people are over 65 and may experience greater evacuation challenges compared with those under 65.

Our Hazus modeling for a M_W 9.0 CSZ earthquake indicates an estimated 1,880 potential injuries, of which ~390 people are likely to experience serious injuries requiring immediate hospitalization. The latter would almost certainly cripple the ability of medical facilities in the county to provide appropriate care. Resident and visitor injuries caused by the tsunami range from ~90 in the M1 tsunami inundation zone, increasing to as high as ~1,560 in XXL1. Earthquake-related fatalities are estimated to reach ~60, while the number of fatalities resulting from the tsunami could range from ~80 (M1) to ~1,770 (XXL1). Factoring in the visitor population increases the number of tsunami-related fatalities to ~250 (M1) to more than ~4,100 (XXL1).

Figure 3.12 includes estimates of the number of people who are likely to be displaced following the M_W 9.0 CSZ earthquake and accompanying tsunami. These estimates are larger than those provided in Allan and others (2022), since we consider both those people displaced from the tsunami inundation zone and those displaced from homes outside the tsunami inundation zone that are damaged by the earthquake shaking. As can be seen in **Figure 3.12**, the number of residents displaced by the earthquake and tsunami could range from ~11,690 (M1) to ~16,630 (XXL1). This represents 19% (M1) to 27% (XXL1) of the total number of residents in coastal Coos County that are likely to require long-term assistance. In the case of the combined earthquake and M1 and L1 tsunami inundation scenarios, we find that the bulk of the residents that are displaced by a CSZ disaster (90% (M1), and 77% (L1)) are those who are residing outside of the tsunami inundation zone. In other words, the damage caused by the earthquake ground shaking displaces more people when compared with tsunami-related damage. In contrast, with the combined earthquake and XXL1 tsunami inundation scenario, we observe approximately equal numbers of people being displaced from within and outside the tsunami inundation zone. These findings are not surprising since most Coos County residents have homes that are located at higher elevations, outside of the tsunami inundation zone.

The increase in damage potential in coastal Coos County is indicative of the shift to much stronger PGA associated with the earthquake shaking (**Figure 2.1**), since all the communities are located closer to the subduction zone. We estimate ~6,500 to ~9,600 visitors will also be displaced following the disaster, requiring short-term assistance (**Figure 3.12**). As with the other counties, the bulk of the displaced visitor population are from the tsunami inundation zone. These numbers are substantial and will burden the county and state in the days to weeks after the disaster.

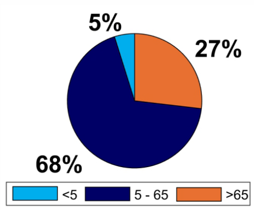
Figure 3.12. Summary population demographics and casualties for coastal Coos County. Aside from numbers of residents, all other values have been rounded. Age demographics are based on people in the XXL1 tsunami zone.

Coos County

Demographics

Resident	60,846
Overnight Visitors (100% Occupancy)	25,100

Age Demographics



Population in Tsunami Zone

	Medium	*Large*	*XX-Large*
Resident	1,272	3,363	10,366
Overnight Visitors	*3,500*	*5,430*	*10,430*

Injuries

Earthquake: 1880

Injuries in Tsunami Zone

	Medium	Large	XX-Large
Resident	25	100	710
Overnight Visitors (100% Occupancy)	*70*	*200*	*850*

Injuries Requiring Hospitalization ~390

Fatalities

Earthquake: 60

Fatalities in Tsunami Zone

	Medium	Large	XX-Large
Resident	80	310	1,770
Overnight Visitors (100% Occupancy)	*170*	*500*	*2,400*

Displaced Population

Earthquake and Tsunami Displaced

	Medium	Large	XX-Large
Resident	11,690	13,030	16,630
Overnight Visitors (100% Occupancy)	*6,520*	*7,820*	*9,570*

Coastal Coos County has 42,882 buildings. Our Hazus modeling suggest that 97% of the buildings could experience some form of structural damage because of the M_W 9.0 CSZ earthquake shaking. Of these, we estimate that 23% of the buildings are likely to be destroyed, 28% could experience extensive damage, 32% are likely to experience moderate damage, and 14% could experience no damage (**Figure 3.13**). In addition, we determined that within the tsunami inundation zone, the number of destroyed buildings could range from 64% (M1) to 78% (XXL1) of the inventory.

As a result of the earthquake and tsunami related building damage, building losses from the earthquake alone could exceed ~$5.11 billion, with another ~$0.11 billion (M1) to ~$0.88 billion (XXL1) caused by the tsunami. Accompanying the building losses due to the earthquake shaking, we estimate another ~$4.2 billion in content losses (**Figure 3.13**); additional content losses in the tsunami inundation zone were determined to range from ~$0.09 billion (M1) to ~$0.61 billion (XXL1). Total losses associated with the combined earthquake and tsunami damage are expected to range from ~$9.5 billion to ~$10.6 billion, most of which will be the product of the earthquake shaking.

Coastal Coos County is likely to experience ~198,900 (M1) to more than ~835,000 (XXL1) tons of earthquake and tsunami related debris generated by the earthquake and tsunami. We estimate an additional ~21,000 tons of residential content losses but are unable to estimate debris generated from other infrastructure categories. Finally, critical facilities in each of the inundation zones are presented in **Figure 3.13**. Coos County has several important ports (Ports of Coos Bay and Port of Bandon) and marinas in the tsunami inundation zone, along with other key facilities such as public works, fire stations and schools.

Figure 3.13. Summary earthquake and tsunami losses for coastal Coos County. Buildings destroyed in the tsunami inundation zone assume >50% damage. Losses and debris weights have been rounded.

Coos County

Building Inventory

Residential	Commercial	Indus/Ag	Government	Education	Religion
29,145	1,826	11,418	232	136	125

Damaged Buildings

Earthquake damage:

Total = 97%

None	Minor	Moderate	Extensive	Complete
3%	14%	32%	28%	23%

Tsunami Zone

	Medium	*Large*	*XX-Large*
Buildings destroyed in tsunami zone	64%	62%	78%

Building Losses ($Billion)

Earthquake		*Medium*	*Large*	*XX-Large*
$5.11	+	$0.11	$0.23	$0.88

Content Losses ($Billion)

Earthquake		*Medium*	*Large*	*XX-Large*
$4.22	+	$0.09	$0.19	$0.61

Debris Generated (Earthquake & Tsunami)

Medium	198,900 tons (19,890 truck loads)
Large	375,000 tons (37,500 truck loads)
XX-Large	837,800 tons (83,780 truck loads)

Assumes truck capacity of 10 yd^3

Critical Facilities

	fire	enforcement	school	hospital	city hall	public works	sewer	ports & USCG
Medium	1	1	1			1	1	5
Large	2	1	1		1	2	1	5
XX-Large	4	3	2		1	3	1	5

3.7 Curry County

Figure 3.14 presents summary information on population demographics, casualties, and number of displaced people for coastal Curry County (**Figure 1.1**). According to the U.S. 2020 census data, we identify 23,234 permenent residents in coastal Curry County, of which 1,826 live in the M1 tsunami inundation zone, 3,277 in L1, and 6,749 in XXL1. We estimate capacity for another ~16,600 temporary visitors (~4,940 in M1, ~6,220 in L1 and ~9,200 in XXL1). Consistent with the other counties, these results demonstrate that the visitor population may be on the order of 1.4 to three times the resident population. Within the resident population, 2% were found to be less than five years of age, 56% are between five and 65, and 41% are >65 years. Based on these data, ~2,800 people over the age of 65 in the tsunami inundation zone may experience greater evacuation challenges when evacuating from the tsunami inundation zone compared with those under 65 years of age.

Our Hazus modeling suggests ~1,410 people in coastal Curry County could be injured by the earthquake (**Figure 3.14**), with another ~60 (M1) to ~290 (XXL1) residents injured by the tsunami. An additional ~250 to ~400 visitors could also be injured because of the tsunami. We estimate ~300 people are likely to experience serious injuries due to the earthquake and would require hospitalization. In addition to those injured, our Hazus modeling estimates ~60 people killed by the earthquake, while ~180 (M1) to ~3,230 (XXL1) residents are likely to be killed by tsunami (**Figure 3.14**). Including visitors raises the total number of fatalities to ~1,010 (M1) to ~7,970 (XXL1). **Figure 3.14** includes estimates of the number of residents and visitors that may be displaced by a M_W9.0 CSZ earthquake and tsunami. We estimate ~14,460 (M1) to ~13,780 (XXL1) displaced residents will require significant short- to long-term assistance after the event. Most of the residents displaced by a CSZ event in Curry County are located outside of the tsunami inundation zone. We estimate an additional ~8,760 (M1) to ~7,700 (XXL1) visitors who will require short-term food and shelter prior to evacuation from the disaster zone.

Figure 3.15 presents information on the expected building damage, losses, and amount of debris that could be produced by a M_W 9.0 CSZ earthquake and accompanying tsunami. We identify 20,454 buildings distributed throughout coastal Curry County (**Figure 3.15**, top line). Of these, our Hazus modeling indicates that 99% of the buildings are likely to experience some degree of structural damage in response to the earthquake shaking: 51% of the building inventory is likely to be destroyed, 25% could sustain extensive damage, 17% could experience moderate damage, and 5% is likely to experience minor damage (**Figure 3.15**). Buildings experiencing no damage make up 1% of the total building inventory. For coastal Curry County, our modeling suggests that 89% (M1) to 95% (XXL1) of buildings in the tsunami inundation zone would likely be destroyed.

Our Hazus modeling indicates that building losses caused by the earthquake alone are estimated to be ~$3.17 billion, with an additional ~$0.16 billion (M1) to ~$0.67 billion (XXL1) in tsunami-related losses. Content losses from the earthquake reflect an additional ~$2.47 billion, and another ~$0.10 billion (M1) to ~$0.45 billion (XXL1) in losses from the tsunami inundation zone (**Figure 3.15**). In total, we estimate that a M_W9.0 CSZ earthquake and accompanying tsunami could result in damage related losses ranging from ~$5.9 billion (M1) to ~$6.76 billion (XXL1). Because of the considerable damage to infrastructure, we estimate that the amount of debris that would be generated could range from ~183,600 tons (M1) to greater than ~614,200 tons (XXL1) (**Figure 3.15**). We estimate an additional ~18,600 tons of residential content losses but are unable to estimate debris generated from other infrastructure categories. Finally, critical facilities in each of the inundation zones are presented in **Figure 3.15**. Curry County contains several important ports and marinas in the tsunami inundation zone, along with other key facilities such as fire stations, law enforcement, schools, and hospitals.

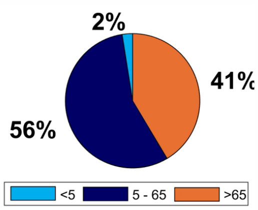
Figure 3.14. Summary population demographics and casualties for coastal Curry County. Aside from numbers of residents, all other values have been rounded. Age demographics are based on people in the XXL1 tsunami zone.

Curry County

Demographics

Resident	23,234
Overnight Visitors (100% Occupancy)	16,600

Age Demographics



Population in Tsunami Zone

	Medium	*Large*	*XX-Large*
Resident	1,826	3,277	6,749
Overnight Visitors	*4,940*	*6,220*	*9,200*

Injuries

Earthquake

1420

Injuries in Tsunami Zone

	Medium	Large	XX-Large
Resident	60	250	290
Overnight Visitors (100% Occupancy)	*250*	*505*	*400*

Injuries Requiring Hospitalization ~300

Fatalities

Earthquake

60

Fatalities in Tsunami Zone

	Medium	Large	XX-Large
Resident	180	790	3,230
Overnight Visitors (100% Occupancy)	*830*	*1650*	*4,740*

Displaced Population

Earthquake and Tsunami Displaced

	Medium	Large	XX-Large
Resident	14,460	14,645	13,780
Overnight Visitors (100% Occupancy)	*8,760*	*8,790*	*7,710*

Figure 3.15. Summary earthquake and tsunami losses for coastal Curry County. Buildings destroyed in the tsunami inundation zone assume >50% damage. Losses and debris weights have been rounded.

Curry County

Building Inventory

Residential	Commercial	Indus/Ag	Government	Education	Religion
13,337	961	5,889	175	65	27

Damaged Buildings

Earthquake damage:

	None	Minor	Moderate	Extensive	Complete
Total = 99%	1%	5%	17%	25%	51%

	Tsunami Zone		
	Medium	*Large*	*XX-Large*
Buildings destroyed in tsunami zone	89%	91%	95%

Building Losses ($Billion)

Earthquake		*Medium*	*Large*	*XX-Large*
$3.17	+	$0.16	$0.30	$0.67

Content Losses ($Billion)

Earthquake		*Medium*	*Large*	*XX-Large*
$2.47	+	$0.10	$0.20	$0.45

Debris Generated (Earthquake & Tsunami)

Medium	183,600 tons (18,360 truck loads)
Large	313,600 tons (31,360 truck loads)
XX-Large	614,200 tons (61,420 truck loads)

Assumes truck capacity of 10 yd^3

Critical Facilities

	fire	enforcement	school	hospital	city hall	public works	sewer	ports & USCG
Medium	2	1	1		1	1	1	4
Large	2	3	1	2	1	1	1	4
XX-Large	4	4	2	2	2	2	1	4

3.8 Regional Comparisons

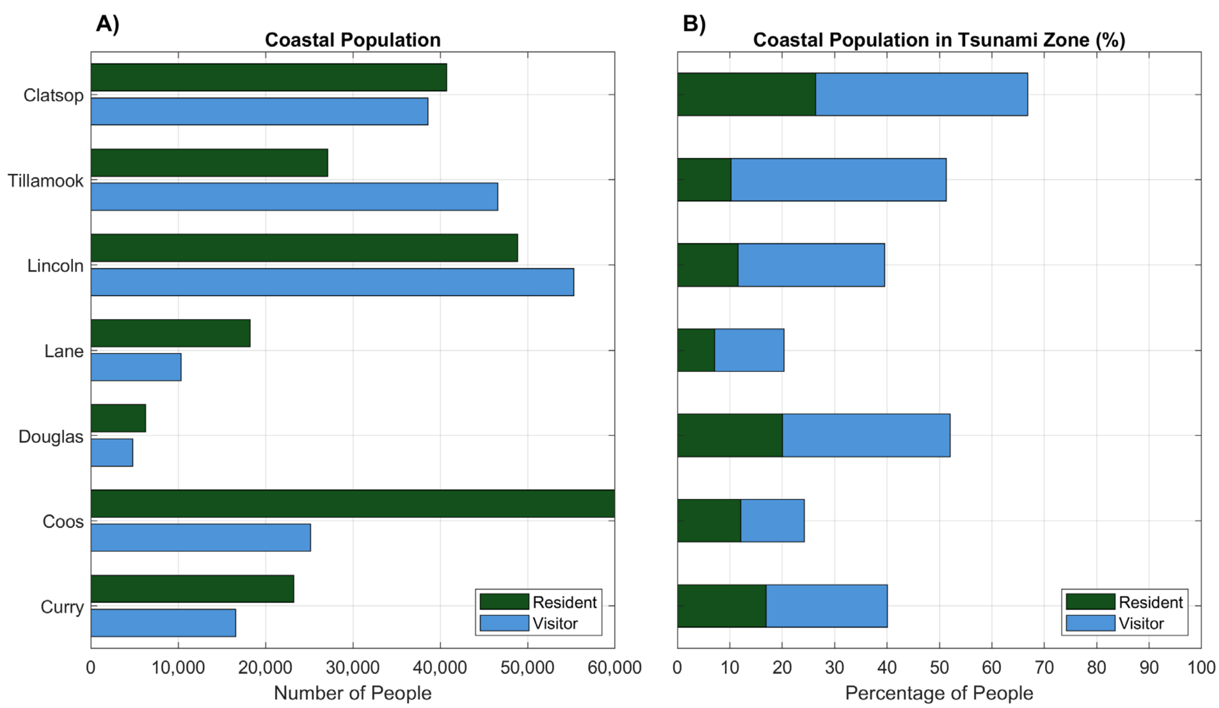
This section evaluates regional patterns between the seven coastal counties (**Figure 1.1**). The sections discussed include:

- general population demographics, including numbers of residents and visitors in the M1, L1 and XXL1 tsunami zones
- estimates of earthquake and tsunami related building damage and losses
- debris estimates
- casualties, including injuries and fatalities for both the M_W 9.0 CSZ earthquake and accompanying M1, L1 or XXL1 tsunami inundation scenarios
- total number of displaced people in response to the earthquake and tsunami inundation scenarios.

3.8.1 Coastal population

Figure 3.16 presents summary information about the resident and visitor population on the Oregon Coast, while **Figure 3.17** delves deeper by distinguishing the population numbers by tsunami zone.

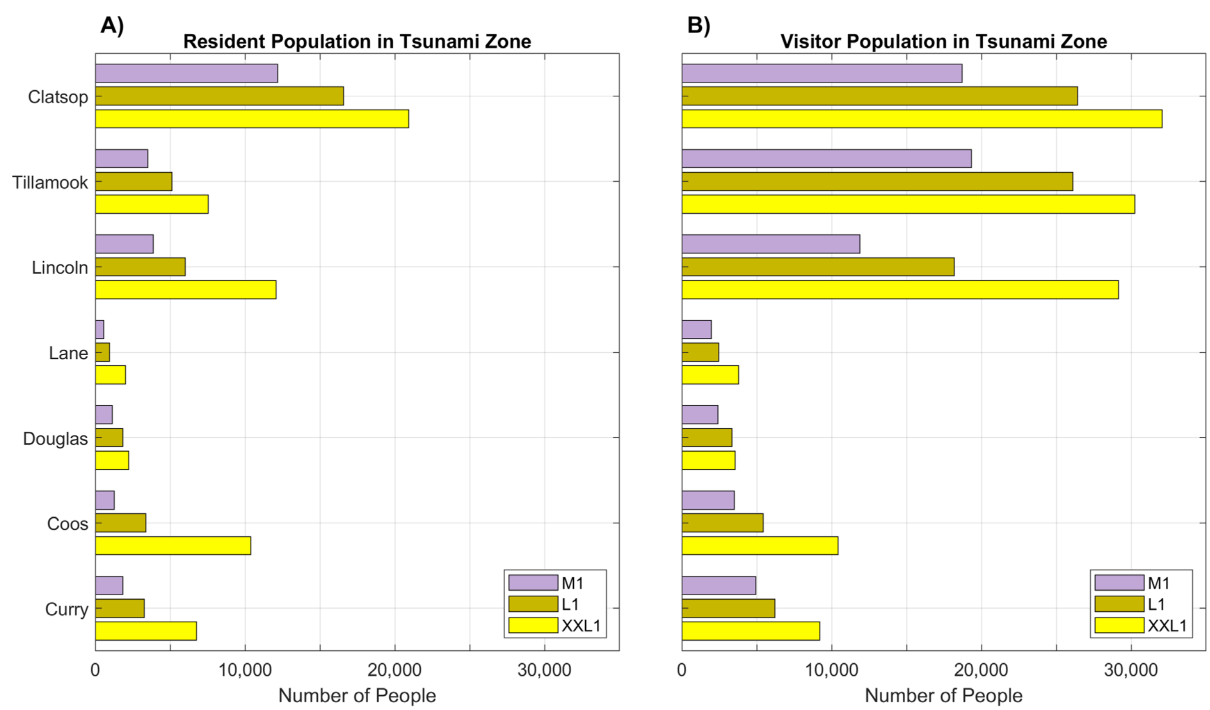
Figure 3.16. Summary population characteristics for Oregon Coast counties. A) Number of residents and estimated visitors that could overnight in the respective counties, assuming 100% occupancy. B) Number of residents and visitors in the XXL1 tsunami inundation zone, expressed as a percentage of the total population.



As can be seen in **Figure 3.16A**, the largest resident coastal population is found in Coos County (~60,846 people), followed by Lincoln (48,879) and Clatsop (40,720) counties. Conversely, the largest potential concentration of overnight visitors is found on the central Oregon Coast in Lincoln County (~55,300), and in Tillamook (~46,600) and Clatsop (~38,600) counties on the northern Oregon Coast. The visitor numbers are indicative of all three counties having the largest concentration of hotel/motels, vacation homes, and camping facilities on the Oregon Coast. Lane and Douglas counties have the smallest potential number of visitors. However, when we visualize the proportion of residents and visitors in the tsunami hazard zone (**Figure 3.16B**), the pattern is different. Overall, **Figure 3.16B** shows that Clatsop County has the highest combined exposure of residents and visitors, with 67% of residents and visitors located in the XXL1 tsunami inundation zone, followed by Douglas County (52%) and Tillamook County (51%); Lane (20%) and Coos (24%) counties have the smallest population exposure to tsunami hazards. In the case of Douglas County, the larger exposure depicted in **Figure 3.16B** stems from having most of its residents and visitors near Winchester Bay, in the tsunami inundation zone.

Figure 3.17A and **B** highlight areas of exposure and risk associated with each of our tsunami inundation scenarios. As can be seen in both Figures, there are significantly greater numbers of residents in the tsunami inundation zone in Clatsop and Lincoln counties (**Figure 3.17A**). Conversely, **Figure 3.17B** confirms that the greatest tsunami exposure and risk to visitors occur in both Clatsop and Tillamook counties, followed by Lincoln County.

Figure 3.17. Summary population numbers for permanent residents and visitors for Oregon Coast counties.



3.8.2 Building damage and losses

Figure 3.18 presents summary building damage states in response to a M_W 9.0 CSZ earthquake and accompanying M1, L1 or XXL1 tsunami inundation scenario. Modeled Hazus damage states caused by the earthquake are provided in the top plot (**Figure 3.18A**), while damage caused by the combined earthquake and tsunami are included in the bottom plot (**Figure 3.18B**). Variations in the results depicted in the top plot reflect differences in the type and age of building construction, the presence of manufactured homes, the number of buildings established in terrain that may be subject to landslides or liquefaction, and various other factors.

Figure 3.18. Coastwide estimates of a M_W 9.0 CSZ earthquake and tsunami building damage states. A) Earthquake building damage states expressed as a percentage of the 2024 building inventory. B) Combined earthquake and tsunami building destruction within the respective tsunami inundation zone; damage estimates in B) assume >50% damage state.

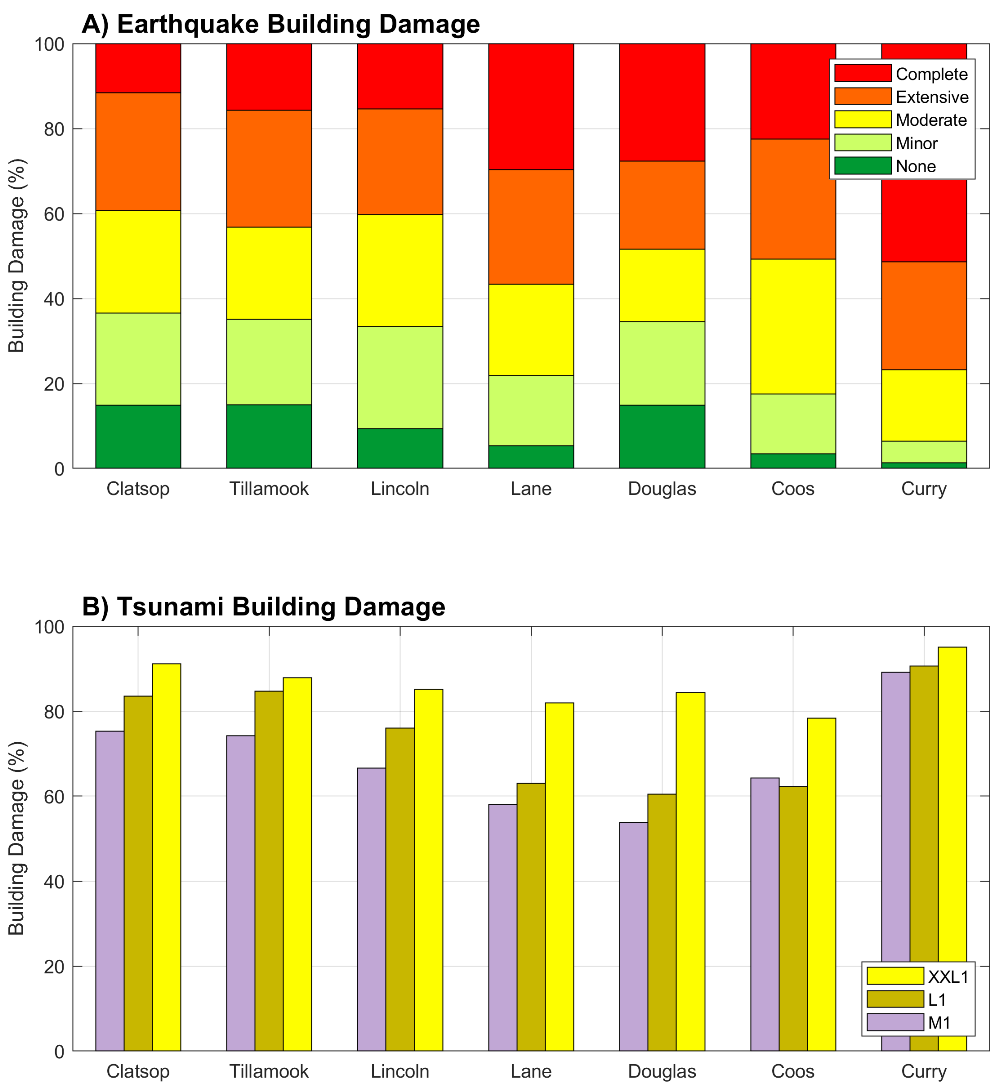
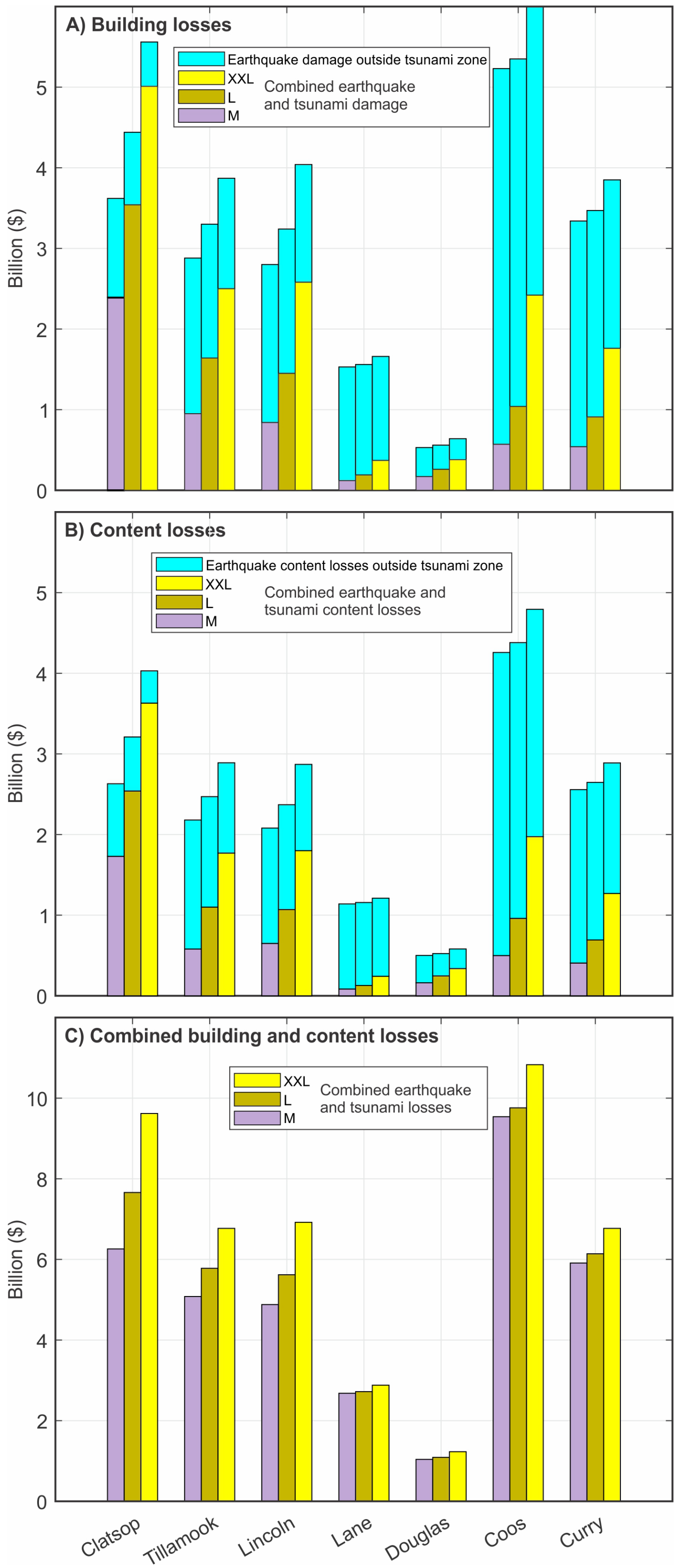


Figure 3.18A indicates that complete destruction of buildings from the earthquake shaking are highest (51%) on the south coast in Curry County. This is probably due to Curry County being located closest to the earthquake rupture zone and is indicative of the shift to much higher PGA values in the County (average PGA = 0.8, **Figure 2.1A** and **Figure 2.1B**). This is also reflected in the Modified Mercalli Intensity (MMI) index for the south coast, where ground shaking is expected to fall within the severe to violent range (MMI 8–9, heavy damage potential, Plate 2 in Madin and others (2021)). Slightly higher complete losses in Lane (30%) and Douglas (28%) counties may be due to the types of buildings in those areas, particularly their age and construction types (e.g., wood frame construction, masonry buildings, mobile homes). As can be seen in **Figure 3.18A**, buildings experiencing slight to no damage tend to be highest in the northern three counties, where average PGA values on the northern Oregon Coast are ~0.5 (**Figure 2.1**). With respect to tsunami-related damage (**Figure 3.18B**), our Hazus modeling indicates generally greater destruction occurs in Clatsop and Tillamook counties, followed by Lincoln County. However, by far the greatest percentage of buildings damaged in the tsunami inundation zones occurs on the southern Oregon Coast in Curry County, where the combination of strong ground motions from the earthquake shaking and extreme runup levels from the tsunami combine to cause catastrophic destruction.

Figure 3.19 presents the estimated building and content losses for the Oregon Coast, expressed as billions of dollars. These data are divided into structural building losses caused by the earthquake and tsunami (**Figure 3.19A**), content loss estimates (**Figure 3.19B**), and the combined building and content losses caused by the M_W 9.0 CSZ earthquake and the three tsunami inundation scenarios (**Figure 3.19C**).

Variations in the dollar totals are indicative of the number of communities present in each county, number of buildings present, their value and the damage statistics. Overall, these results reinforce regional patterns noted previously, with the largest losses from building damage occurring in Clatsop and Coos counties, with comparatively smaller losses in Douglas County. In terms of replacement costs, our Hazus modeling indicates that losses are highest in Clatsop County (**Figure 3.19A**), resulting in some ~$3.6 billion (M1) to ~$5.5 billion (XXL1) in damage related costs. Tsunami-related losses are also generally higher in Tillamook County and Lincoln County when compared with the south coast counties. Conversely, earthquake-related losses are considerably higher in Coos County relative to the rest of the coast (**Figure 3.19A**). There are several potential reasons for this. First, it may be due to Coos County having some of the oldest building stock on the coast (mean age = 1958, compared with the late 1960s on the north coast). Second, besides Lincoln County, Coos County has the second largest number of buildings on the coast. Third, the county is located closer to the CSZ when compared with the northern counties, making them more susceptible to strong earthquake-related (PGA) forces. Although Coos County experiences very large losses as a result of the earthquake, building losses caused by the tsunami make up a considerably smaller portion of the losses (**Figure 3.19A**). This is because many of the buildings in places like Coos Bay and North Bend have been built outside of the tsunami inundation zone. As can be seen in **Figure 3.19A**, building losses in Coos County are likely to range from ~$5.2 billion to >$6 billion. Earthquake-related damage is also high in Curry County, where considerable destruction is expected to occur due to strong PGA forces.

Figure 3.19. Coastwide summary of building and content losses for each county.



Content losses are a percentage of the structures value (e.g., Table 6-10 in FEMA, 2024) and are thus a modest measure of the value of items inside buildings. The results presented in **Figure 3.19B** indicate larger content losses from the tsunami in Clatsop County. Content losses in Lane County and Douglas County are the lowest on the Oregon Coast simply because there are significantly fewer buildings in the tsunami inundation zone. Content losses from just the earthquake-related damage are comparable for Clatsop, Tillamook, and Lincoln counties being about $1.8 billion to ~$1.92 billion. In contrast, content losses from earthquake related damage is highest in Coos County (~$4.22 billion) followed by Curry County (~$2.47 billion).

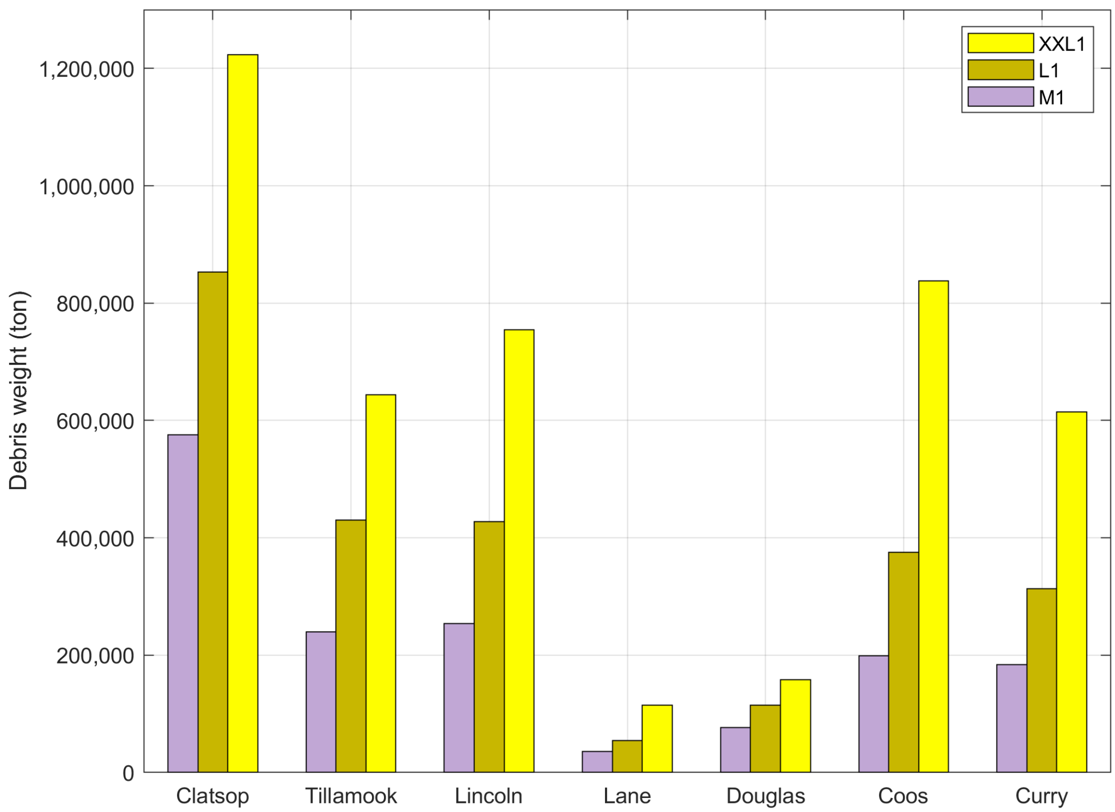
Finally, the combined losses produced by the structural damage to buildings and content losses are presented in **Figure 3.19**C. These results indicate that the largest countywide losses occur in Coos County (~$9.54 billion to ~$10.83 billion) followed by Clatsop County (~$6.26 billion to ~$9.62 billion). In total, we estimate that a M_W 9 CSZ earthquake and accompanying tsunami is likely to cause an estimated $35.4 billion to more than $45 billion in losses. However, in reality the losses can be expected to be considerably larger since these estimates ignore the concomitant economic effects across the coast (e.g., collapse of fishery and tourism related activities and accompanying service industry jobs), and in the Willamette Valley where earthquake related damage can be expected to impact all forms of the economy of Oregon. Accordingly, a M_W 9.0 CSZ earthquake and accompanying tsunami is likely to produce losses on the order of several hundred billion to the state.

3.8.3 Debris

Debris generated from the destruction of buildings by a M_W 9.0 CSZ earthquake and tsunami can be expected to be scattered throughout the tsunami inundation zone. Emergency managers and planners should consider that buoyant debris within the tsunami inundation zone will be redistributed and may accumulate around low points, which often include key transportation routes (Park and Cox, 2019), as well as within ports and harbors, and in navigation channels. Jetties, such as those built at the mouth of the major estuaries (e.g., Columbia River (Clatsop County), Tillamook Bay (Tillamook County), Yaquina Bay (Lincoln County), Siuslaw estuary (Lane County), Umpqua estuary (Douglas County), Coos Bay (Coos County), Rogue and Chetco Rivers (Curry County)), are expected to be severely damaged or destroyed. This will almost certainly compromise marine traffic access into the estuaries and ports until such time as the navigation channels are dredged and port infrastructure is rebuilt.

Figure 3.20 presents summary information on the weight of debris generated by a CSZ earthquake and tsunami. As noted in **Section 2.9.2**, estimates of the weight of debris generated by the earthquake and tsunami are approximate, since we are presently unable to quantify many of the contributors to overall debris, including the amount of buoyant debris from damaged buildings that may be washed out to sea, estimates of the weight of concrete and asphalt that would be produced from damaged roads and bridges, debris associated with shipping containers, boats, and logs in staging areas, and many other types. Hence, the estimates presented in **Figure 3.20** are likely to be low.

Figure 3.20. Coastwide estimated debris weight (tons) produced by a M_W 9.0 CSZ earthquake and M1, L1 or XXL1 tsunami.

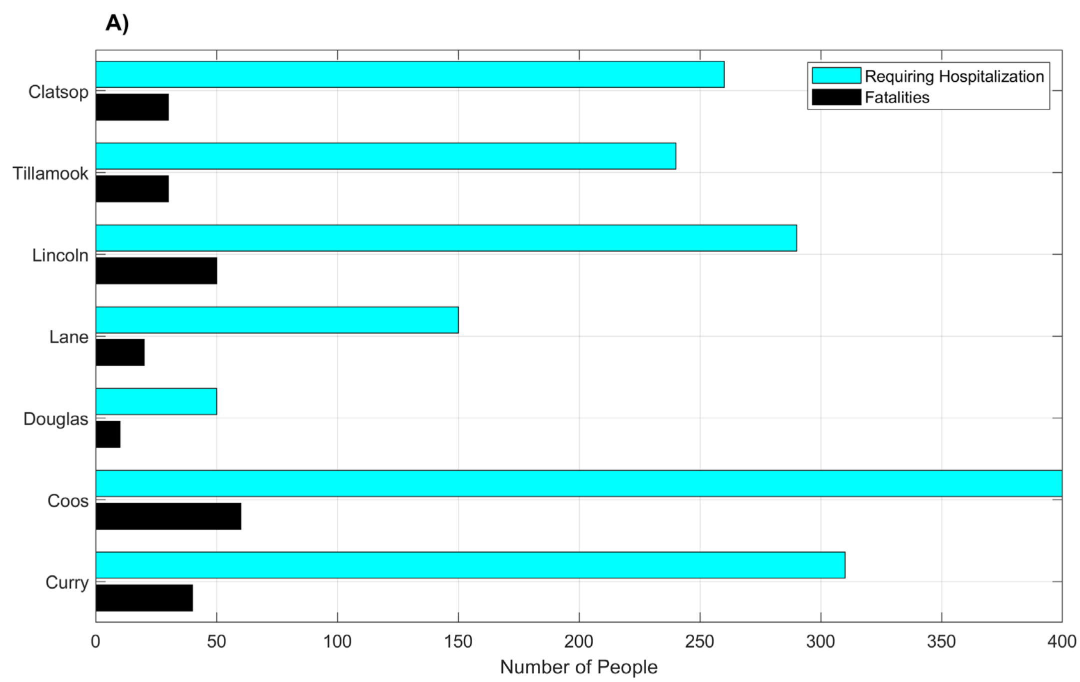


As can be seen in **Figure 3.20**, we estimate ~600,000 tons (M1) to ~1.2 million tons (XXL1) of debris generated in Clatsop County. Debris produced in both Tillamook County and Lincoln County could range from ~200,000 (M1) to ~750,000 tons (XXL1). In Coos County, we estimate ~200,000 (M1) to ~800,000 tons (XXL1) of debris; debris generated in Curry County could range from ~180,000 tons (M1) to 614,000 tons in XXL1 event. In total, we estimate ~ 1.6 to ~4.4 million tons of debris generated by the combined earthquake and tsunami. In comparison, the 2011 Japan tsunami produced ~24 million tons of debris (Bagulayan and others, 2012). Nonetheless, the weight of debris calculated here provides a starting point for communities as they begin the process of developing earthquake/tsunami debris plans.

3.8.4 Earthquake and tsunami casualties (injuries and fatalities)

Our Hazus modeling indicates approximately 6,540 minor injuries from a CSZ earthquake, with slightly higher numbers on the south coast in Coos and Curry counties (average ~1,300 people) compared with the northern coastal counties (average ~1,080 people). Many of these injuries are likely to reflect mild cuts and bruises caused by falls, flying glass, and/or being struck by falling objects (Tang and others, 2017). More serious earthquake-related injuries requiring hospitalization may include fractures, internal organ damage, crush injuries, and burns (Tang and others, 2017). **Figure 3.21** presents county by county summaries of earthquake-related injuries requiring hospitalization and fatalities. Across the entire coast, we estimate ~1,700 serious injuries requiring some form of hospitalization. Given the paucity of available critical care hospital beds on the Oregon Coast, uncertainties in estimates of critical care needs, and potential damaging effects from the earthquake to hospital operations (loss of power, water, etc.), crucial medical care is likely to be extremely challenging in the days following the disaster. As a result, efforts to build resilience in coastal hospitals remain an ongoing effort (e.g., Wang and Nourse, 2019; Wang, 2021). However, such efforts are unable to address the lack of capacity needed to meet post-disaster needs. Hence, county, state, and federal post-disaster plans should evaluate additional options, such as the equivalent of combat support hospitals used by the military. Finally, our modeling indicates ~240 coastwide fatalities due to a CSZ earthquake (**Figure 3.21**).

Figure 3.21. Coastwide casualty estimates associated with a M_W 9.0 CSZ earthquake.

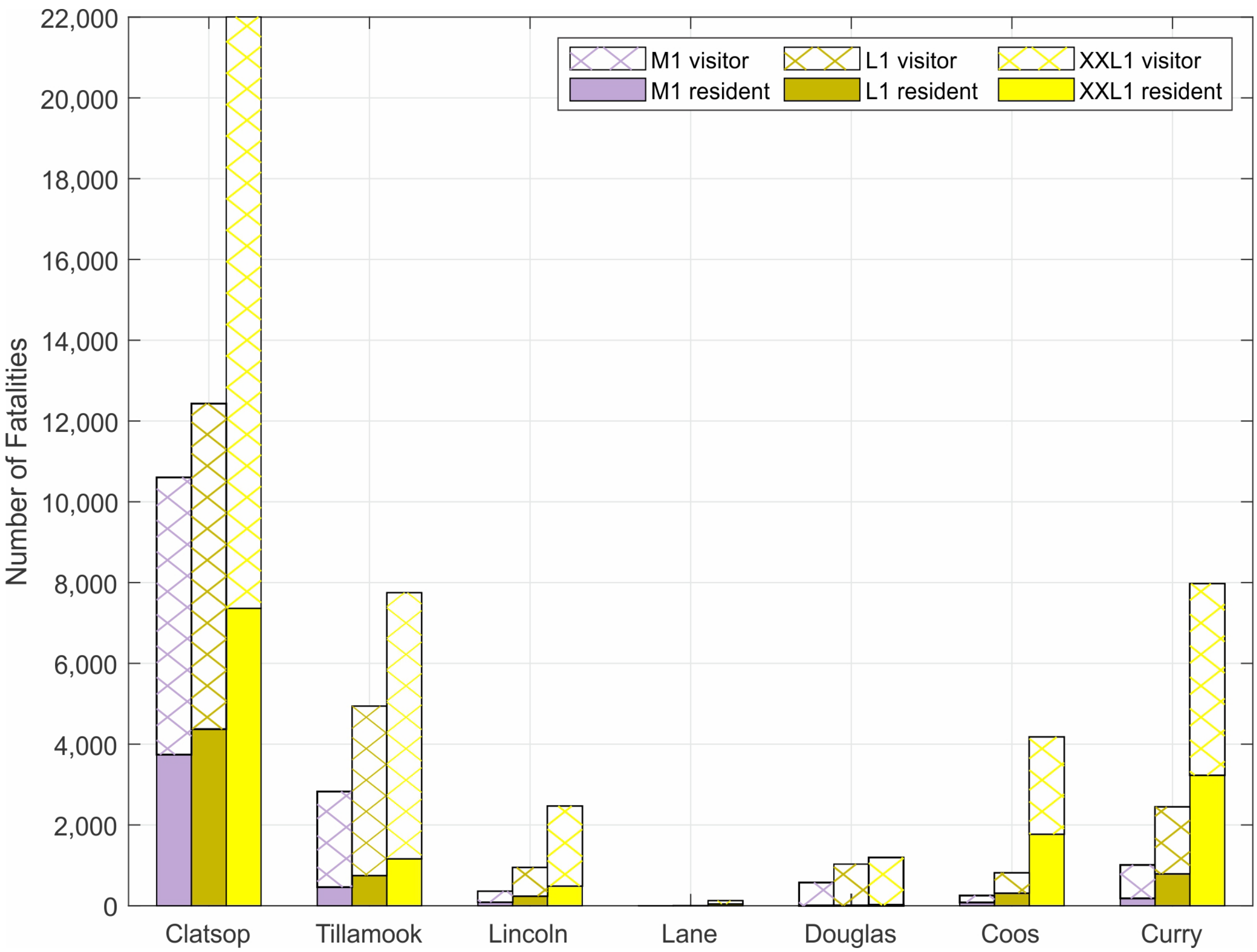


We present tsunami-related fatalities in **Figure 3.22**. Our Hazus casualty modeling indicates an estimated ~4,550 (M1) to ~14,000 (XXL1) residents killed by a CSZ tsunami, along with an additional ~11,070 (M1) to 31,670 (XXL1) visitor fatalities (**Figure 3.22**). Therefore, the total number of fatalities could potentially range from ~15,000 (M1) to more than 45,000 (XXL1), when accounting for both residents and visitors. For context, the 11 March, 2011 Tōhoku, Japan, tsunami killed more than 18,500 people (National Police Agency of Japan, 2020). Although our estimates of visitor fatalities are conservative, since we assume 100% occupancy of every hotel/motel, vacation home and campground on the Oregon Coast, such a scenario may not be implausible and could potentially occur in the height of summer. Furthermore, our population modeling ignores those visitors who may be visiting the coast for day trips, which in some locations (e.g., Seaside and Cannon Beach in Clatsop County) could easily exceed several thousand additional people. Hence, the large fatality estimates provide here are not out of the question.

As can be seen in **Figure 3.22**, the largest potential fatalities are likely to occur in Clatsop County, followed by Curry and Tillamook counties. In contrast, the central to southcentral Oregon Coast (**Figure 1.1**) that includes Lincoln, Lane and Douglas counties is expected to experience significantly fewer fatalities. Again, differences here can be attributed to a variety of factors, including regional coastal geomorphology, extent of tsunami inundation zones, ease of access to high ground, and population characteristics.

Finally, our fatality estimates for the Oregon Coast exceed those provided in the Oregon Resilience Plan (OSSPAC, 2013) due to our more sophisticated casualty modeling of residents and, importantly, the inclusion of visitor casualty estimates. OSSPAC estimated ~600 to ~5,000 total fatalities based on an "average" tsunami event. Our M1 tsunami hazard zone most closely approximates the scenario used by OSSPAC (2013). Using this scenario, we estimate ~4,550 resident fatalities caused by the tsunami, and another 240 fatalities due to the earthquake. However, when factoring in visitors, fatalities exceeding ~15,000 people are probably not unrealistic. Accordingly, even an "average" (M1) tsunami inundation scenario and CSZ earthquake is likely to result in very large numbers of fatalities, approaching levels observed in the 2011 Tōhoku, Japan, event.

Figure 3.22. Coastwide fatality estimates for three CSZ tsunami inundation scenarios.



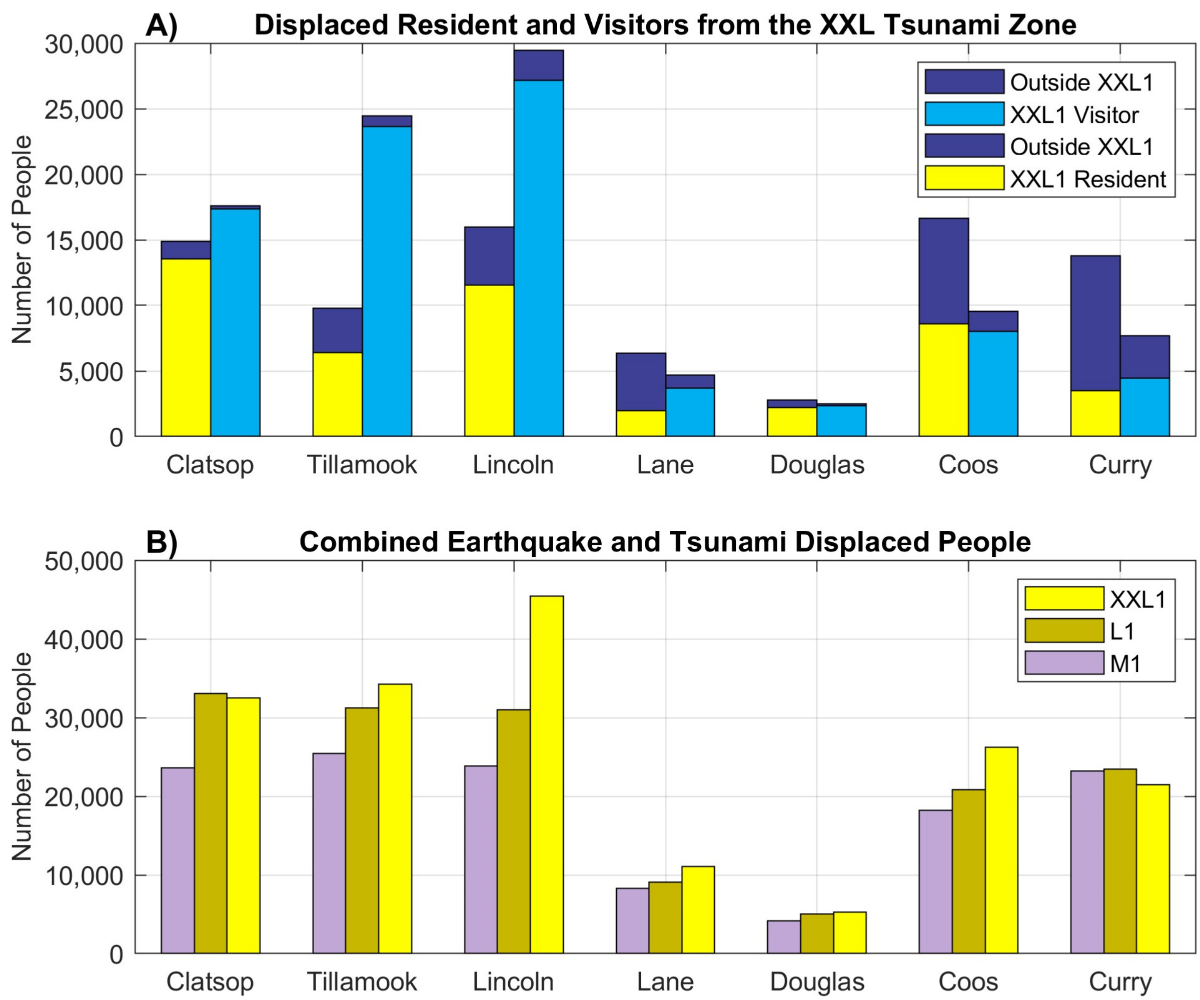
3.8.5 Displaced population

The magnitude of the destruction of infrastructure on the Oregon Coast following a CSZ earthquake and tsunami will result in both short and long-term displacement of people living and visiting the Oregon Coast. As discussed in the county summaries, we evaluated those people displaced from the tsunami inundation zone, as well as the number of people displaced from homes damaged by earthquake shaking outside the respective tsunami inundation zone. For the latter, we assume a 50% damage exceedance threshold for estimating those displaced from buildings damaged by the earthquake.

Coastwide summary results are presented in **Figure 3.23**. Overall, we find that more people (residents and visitors) are displaced by the tsunami on the northern Oregon Coast, particularly in Clatsop and Lincoln counties (yellow bars in **Figure 3.23**), while a greater number of people on the south coast in Coos County and Curry County are displaced by the earthquake. Conversely, visitors displaced from the tsunami inundation zone are overwhelmingly from Lincoln, Tillamook, and Clatsop counties (light blue bars in **Figure 3.23**). In total, our results indicate ~60,000 (M1) to ~80,000 (XXL1) displaced residents, who will require short to long-term housing. We estimate another ~66,000 (M1) to ~96,000 (XXL1) potential visitors who will need to be returned to their home communities elsewhere in the state/country in the days to weeks following the disaster.

These results serve to highlight the importance of the Oregon Coast as a recreational destination, as well as the tremendous burden that coastal communities could potentially face following a CSZ earthquake and tsunami. However, it should be recognized that our results are based on a conservative visitor population model since we assume every lodging facility is fully booked and in use at the time of the event. Although 100% occupancy is an unlikely scenario, the point remains that there is a high probability that significant number of visitors will be displaced on the coast in addition to the displaced permanent residents who will need emergency care following a Cascadia event. This is certainly true when considering the number of potential day visitors to the Oregon Coast, who are not presently accounted for in our casualty modeling. Further refinements to these numbers are therefore critical for communities to develop effective short-term plans (e.g., pre- and post-disaster plans that address food and shelter needs, as well as those killed or injured) and long-term plans that address the future recovery of coastal communities.

Figure 3.23. Coastwide estimates of displaced residents and visitors from a CSZ earthquake and tsunami. A) evaluates residents and visitors displaced from within and outside of the XXL1 tsunami inundation zone, and B) Numbers of displaced people based on the combined impact of a M_W 9.0 CSZ earthquake and three tsunami inundation scenarios.



4.0 DISCUSSION

This study updates previous work undertaken by Allan and others (2020a,b, 2021, 2022 and 2023) by implementing updated FEMA Hazus modeling for the entire Oregon Coast in order to estimate building damage, losses, and casualties from a CSZ earthquake and accompanying tsunami. The approach adopted here has been guided by the best-available information on a CSZ earthquake (M_W 9.0; Madin and others, 2021; Wirth and others, 2020) and three tsunami inundation scenarios (M1, L1, and XXL1; Priest and others, 2013e), together with a detailed building database and population model that accounts for both permanent and temporary residents (2 a.m. occupancy). The results presented here also use the latest (2020) census information.

Our study significantly improves on OSSPAC's 2013 statewide casualty estimates by extending the population modeling to include temporary visitors, using the most current census and building inventory data, evaluating the expected impacts of three different tsunami inundation scenarios, and incorporating evacuation modeling (relative distances to high ground). This study also examined the expected destruction and damage caused by the earthquake using the latest geohazard information. Because of the ongoing expansion of coastal communities, changes in demographics, concentration of hotels and motels near the beach within the tsunami inundation zone, up-to-date casualty, building, and content losses are critically important to local, state, and federal emergency responders. We anticipate that the information presented in this report may be used to assist with pre-disaster and post-disaster planning, including addressing such needs as the development of tsunami evacuation wayfinding signage, mass care plans, debris removal, vertical evacuation structures, and individual community tsunami evacuation facilities improvement plans.[11]

Considerable hazard related information has been developed over the past decade by DOGAMI and Oregon Emergency Management (OEM) to enable coastal communities and visitors to make informed decisions. These include detailed evacuation maps for every coastal community, which are available in print (e.g., www.oregontsunami.org) and online (e.g., http://nvs.nanoos.org/TsunamiEvac). In addition, recent tsunami evacuation modeling undertaken by DOGAMI has helped clarify where people need to go and how fast they need to travel to reach safety in time. Through these efforts we demonstrate that ***the number of casualties caused by a CSZ tsunami may be substantially reduced if people know and practice their evacuation routes, evacuate as soon as possible, and travel as fast as possible to safety.***

Building a culture of tsunami awareness on the Oregon Coast that reduces the potential injury and fatality rate can be accomplished through concerted education/outreach campaigns, developing school curriculums on tsunami hazards, improving signage, and implementing, at minimum, annual tsunami evacuation drills. Oregon Emergency Management has developed a guidance document for how to organize and hold a tsunami evacuation drill (OEM, 2017), providing a valuable starting point for coastal communities intending to pursue this option.

In this report, we quantified impacts to both temporary and permanent populations in our casualty estimates for two reasons. First, planners can apply their own judgment to their community's population at off-peak time, for example, assuming a winter temporary population that is 10%–50% of peak summertime temporary population. Second, tsunami preparation and education awareness levels of permanent residents versus temporary populations will differ. For example, temporary populations generally have little to no knowledge of the tsunami hazard, evacuation procedures, or optimal routes to safety. They are also much more likely to engage in counterproductive milling (delay) behaviors that will

[11] https://www.oregon.gov/LCD/Publications/TsunamiLandUseGuide_2015.pdf

lead to greater risk of death. In contrast, permanent residents are generally slightly better prepared (aware of the hazard) and maybe less likely to delay their departure following an earthquake. Again, planners can apply their own judgment on the level of preparedness, including departure times and evacuation speeds, between the groups, to better refine the estimates of injuries and fatalities that may occur in their community.

In general, the temporary population, on average, tend to be located closer to the ocean—thus farther away from safety—compared with the permanent resident population. Market forces often drive such housing arrangements (Raskin and Wang, 2017). This is certainly the case for several Oregon coastal communities, including Seaside and Cannon Beach in Clatsop County, and Rockaway Beach in Tillamook County, where hotels, motels, and rental homes are located immediately adjacent to the beach. This sets up a problematic situation where a presumably less-informed group is farther away from safety and may take longer to depart, with the consequence of a higher proportion of fatalities. Although many hotel/motels are similarly located close to the ocean in other counties (e.g., Lincoln City and Newport in Lincoln County, and Gold Beach in Curry County), high ground is generally closer to these facilities when compared with similar establishments in the northern counties. There are also notable differences in wave arrival times that strongly affect the casualty modeling (**Figure 2.3**). For example, because coastal Curry County is located close to the subduction zone and hence the tsunami source, the tsunami reaches the shoreline much faster (~8–10 minutes) when compared to the central and northern Oregon Coast (~15 to 20 minutes), allowing very little time to evacuate from buildings and travel toward high ground.

However, even with permanent residents, our assumptions of individuals' preparation and awareness may not match actual preparedness. For example, we assume a 10-minute departure time after the earthquake begins. Grumbly and others (2019) noted that permanent residents in a Washington coastal town underestimated the distance to tsunami safety and were often not aware of the optimal route to safety at different locations in their community. City of Seaside survey data gathered by Buylova (2018) pointed to a pressing need for continued education on the tsunami threat. That study targeted primary and secondary homeowners but did not sample vacationers. Regarding the initiation of evacuation, 29.6% of survey respondents indicated that they would likely wait for confirmation of a tsunami prior to evacuation (i.e., phone notification or hearing a siren). About half the resident population indicated they were unlikely (24.3%) or very unlikely (22.8%) to wait for tsunami confirmation. Many of the respondents (38%) indicated they would attempt to evacuate by driving, which would be problematic given the constrained coastal road networks that are expected to be significantly disrupted by the earthquake. Oregon state and county emergency management officials strongly discourage vehicular travel following an earthquake and instead emphasize travel on foot. The top three behaviors respondents said they would very likely carry out after a major earthquake are evacuating to higher ground immediately following the earthquake (51%), contacting loved ones (49.5%), and checking social media and television (40.3%).

The underlying field survey data used in Buylova (2018) provided further insights into education challenges. Among the 209 respondents, 17% did not correctly identify their home as being in or out of the tsunami inundation zone; many incorrectly identified their house as being outside the tsunami inundation zone. Only a small portion of the respondents identified themselves as secondary homeowners (5%), and no significant difference was observed in perceptions or in plans between primary and secondary homeowner groups. Continued tsunami education and outreach are critically important for local residents as well as visitors in order to build the necessary culture of awareness needed to survive such a disaster. Education and outreach can be achieved through awareness programs at all levels of government as well as volunteer avenues such as community emergency response teams.

5.0 CONCLUSION AND RECOMMENDATIONS

This study presents a comprehensive analysis of the destructive effects of a M_W 9.0 CSZ earthquake and three tsunami inundation scenarios developed for the Oregon Coast. The goal of this work is to estimate potential building and content losses, debris weight, casualties (injuries and fatalities), and numbers of displaced people for the entire coast. The overarching objective is to assist communities in their hazard preparation. Great care has been taken as part of this study to address the needs of local communities. Discussions with community planners undertaken by Bauer and others (2020) and the authors over the past several years helped frame the overall study approach and assumptions applied in our Hazus modeling. The work undertaken on the Oregon Coast to assess tsunami risk in coastal communities and from previous tsunami disasters such as the 2011 Tōhoku tsunami demonstrates that casualties may be reduced by performing the following simple steps:

1. ***Practice evacuation routes.***
2. ***Evacuate as soon as possible after the earthquake.***
3. ***Travel as fast as possible on foot (e.g., a fast walk, jog, or run) to safety.***

5.1 Education

Our analyses have improved estimates of fatalities and identified the presence of potentially very large temporary visitor populations as well as variations in the spatial concentration of both population groups within each community. Addressing these factors will be an important part of education and outreach at both the local and state level.

Our community-based information on the types of lodging visitors may occupy (e.g., motels, vacation rentals, second homes, RVs, and/or tents in campgrounds) and where these lodgings are predominantly located, provide improved insights about the potential challenges that may face a community. Such information may help local communities better target their tsunami education and outreach activities and messaging to address the lack of hazard awareness by visitors, while also meeting the unique needs of communities. The data in this report provide local governments with the necessary information needed to begin to evaluate various mitigation options, such as the construction of a vertical evacuation structure or hardening of a bridge, that may ultimately best serve residents and visitors.

Besides vacation homes, our analyses indicate that several coastal communities have large numbers of hotels/motels and recreational camping/RV sites located in the tsunami inundation zone (especially XXL1). For example, the communities of Seaside and Cannon Beach (Clatsop County), Rockaway Beach (Tillamook County), and Gold Beach (Curry County) have numerous hotels and motels adjacent to the beach in locations where evacuation distances to high ground are relatively long, or the tsunami arrives quickly. For these communities, significant evacuation challenges exist such that the potential for large loss of life is high. For these places, investment in appropriate signage, education of lodging staff, and access to high-resolution evacuation maps in every hotel/motel room may help educate and prepare visitors. However, in a few cases, the combination of early tsunami wave arrivals and/or long evacuation routes suggest that those communities consider implementing other options such as vertical evacuation structures. Thus, tsunami education and outreach targeting each of these lodging groups is essential to mitigating the potentially large loss of life.

Two key approaches are in place to begin addressing such needs:

1) The first is the development by Oregon Emergency Management of the "Tsunami Safe[12], Hospitality Begins With Safety" program. This program focuses on increasing tsunami awareness among hospitality industry employees so that such information may then be disseminated to hotel/motel guests. Trained hospitality staff can provide accurate messaging to the public before and during an event and, importantly, are able to help guide people out of the tsunami inundation zone. Evacuation guidance provided by hospitality staff assumes that staff at every establishment are familiar with evacuation protocols and know exactly where their nearest point of high ground is located.
2) To address evacuation information needs, DOGAMI staff, in partnership with the Northwest Association of Networked Ocean Observing Systems (NANOOS), have enhanced the NANOOS Visualization System tsunami evacuation portal (http://nvs.nanoos.org/TsunamiEvac) to include evacuation routes. This tool allows individuals or businesses to identify an evacuation route for any location in the tsunami inundation zone. DOGAMI also developed high-resolution tsunami evacuation neighborhood[13] and *Beat the Wave*[14] maps that can be printed with conventional printers. Finally, DOGAMI has built the capability to produce custom evacuation maps for any given location on the Oregon Coast on an as-needed basis. Although this is presently only available on a per-request basis, in time, we hope to make such a tool more broadly available. It is thus feasible today, that hotel/motel rooms could display tsunami evacuation maps similar to fire escape exit maps that are required in every room. Increasing local awareness of these tools should be integrated in any future planned outreach activity.

Finally, building a culture of awareness is needed to survive the next CSZ tsunami. Such an effort includes funding to post and maintain tsunami wayfinding signage in sufficient density along core evacuation routes and to establish and support tsunami coordinators in every county. Tsunami coordinators could assist with identifying locations of people with disabilities, those aged 65 and over, work with the local hotel/motel industry to develop appropriate evacuation map products, lead the planning of evacuation drills, and perform needed outreach at the grassroots level.

5.2 Mitigation

Tsunami evacuation modeling undertaken for every Oregon Coast community demonstrates that improving existing evacuation trails for unimpeded passage—along with increased saturation of tsunami wayfinding signage—will help save lives. Of particular importance is having a sufficiently dense network of signs (posted and/or on road/path surfaces) that direct people along core evacuation routes to areas outside the tsunami inundation zone. Such efforts, guided by our evacuation modeling results, are now being implemented in multiple communities on the northern Oregon Coast, including Seaside and Cannon Beach (Clatsop County), Manzanita and Tierra del Mar (Tillamook County), Newport (Lincoln County), and Coos Bay (Coos County). In each of these communities, a "Beach to Safety" plan has been developed for core evacuation routes consisting of posted signs as well as thermoplastic signage placed directly on road surfaces and paths. Signs of this nature need to be spaced sufficiently close together and illuminated at night so that they may be easily seen at all times.

Consideration should be given to barriers that may impede rapid evacuation. For example, downed power lines could pose a significant barrier to safe evacuation if the wires remain live following the

[12] Tsunami Safe : Tsunami Safety - English : English : State of Oregon
[13] https://www.oregongeology.org/tsuclearinghouse/pubs-evacbro_neighborhoods.htm
[14] https://www.oregongeology.org/tsuclearinghouse/pubs-evacbro_BTW.htm

earthquake. Communities could initiate conversations with local utility districts to assess if power can be immediately shut down during a major earthquake or if new power lines could be buried underground and existing ones relocated.

We recommend and encourage local communities to practice periodic tsunami evacuation drills, ideally on at least an annual basis, to instill a culture of tsunami hazard awareness for residents and visitors. Studying an evacuation map is not the same as physically walking an evacuation route. Although we recognize that such an approach may be disruptive to the local economy and difficult to organize, holding periodic drills will save lives. Such a culture is in practice in Japan and likely helped save many thousands of lives during the catastrophic tsunami event on 11 March 2011 (e.g., Nakaya and others, 2018; Sun and Yamori, 2018).

Mitigation options to improve evacuation and reduce loss of life may also include facility improvements such as seismic retrofits of key bridges (e.g., Ecola Creek in Cannon Beach, Clatsop County), new pedestrian bridges in places like Winchester Bay (Douglas County), or the construction of vertical evacuation structures. Although seismically retrofitting bridges will be critically important for post-disaster recovery, our evacuation modeling (e.g., Gabel and others, 2021) and evaluation of vertical evacuation sites (e.g., Gabel and others, 2024) suggest that few communities on the Oregon Coast are truly dependent on bridges for evacuation purposes. The exceptions are downtown Cannon Beach, Clatsop County and Winchester Bay, Douglas County, where new bridges could potentially save hundreds of lives. Likewise, construction of vertical evacuation structures in several key strategic locations (e.g., Seaside and Cannon Beach in Clatsop County, and Gold Beach, Curry County) could potentially save many thousands of lives.

In many communities, people reside in older manufactured housing. This is especially the case in Lincoln and Coos counties. Manufactured homes installed prior to 2003 are susceptible to slipping off their foundations during earthquake shaking (OBCD, 2010; SPA Risk LLC, 2014; Maison and Cobeen, 2016; EERI, 2014), potentially blocking or compromising egress. Even if a manufactured house is relatively close to high ground, compromised egress may hinder timely evacuation. Seismic upgrades of such structures to current building standards may be cost prohibitive. FEMA (2012b, Section D) advises having large crowbars and sledgehammers stored near potentially compromised primary doors to facilitate emergency egress. Such tools may provide manufactured housing occupants with a low-cost solution for rapidly exiting their structures in the critical time interval between earthquake cessation and tsunami arrival.

5.3 Response

This study demonstrates that destruction of buildings in the tsunami inundation zone will be virtually complete, whether the scenario is M1 or XXL1. Accordingly, all Oregon coastal communities will need to be prepared to shelter large numbers of people who escape the tsunami, as well as those who cannot return to homes outside the tsunami inundation zone that have been critically damaged by the earthquake. The need for shelter is likely to last many weeks until those displaced by the earthquake and tsunami can be relocated out of the disaster area. This will be especially challenging for communities with potentially large numbers of visitors, all of whom are unlikely to be able to return to their permanent homes for at least several weeks, given the anticipated disruption to the regional transportation network and fuel supply (ODOT, 2014; ODOE, 2017). As demonstrated throughout this report, depending on the time of year, the number of displaced persons could reach many tens of thousands.

Mass casualties will vary significantly from community to community due to exposure and access to high ground. Overall, injuries caused by the tsunami relative to fatalities are low, averaging about 13% to 16% across the three inundation scenarios for all counties. This result is not unexpected because most people who are unable to evacuate in time and are caught by the tsunami are killed. However, as noted in **Section 3.8.4**, serious earthquake-related injuries requiring hospitalization could reach ~1,700 people, and potentially even higher. Given that there are about 483 licensed beds at the 11 coastal hospitals (OSSPAC, 2013), these facilities can be expected to be quickly overwhelmed. Because of this capacity issue, Wang (2018) examined approaches for coastal hospitals to better prepare for a M_W 9.0 CSZ event, including improving building seismic resiliency, establishing a resilience network where knowledge and training could be shared, and evaluating and planning for fuel and water needs. In addition to these suggestions, mass-care planning is necessary to prepare coastal hospitals for a potential surge in injuries and illnesses. To that end, further work is required to better refine these casualty numbers.

5.4 Recovery

A CSZ earthquake and tsunami will be catastrophic to both the state and local economies. At the local level, these impacts will vary substantially. Quantifying such economic impacts is beyond the scope of this investigation. Nevertheless, we can speculate on several likely scenarios. Overall, building destruction on the coast could yield an estimated ~1.6 million tons of debris in the M1 scenario, increasing to ~2.6 million tons for L1, and ~4.4 million tons in an XXL1 event. These estimates are almost certainly on the low end, as they exclude the content volume within buildings (e.g., personal and business-related items), vehicles, and other forms of debris. Utilizing the number of households on the coast (~34,800 buildings) in the XXL1 tsunami inundation zone, we estimate an additional ~192,000 tons (assumes five tons per household) of debris could be generated from personal effects. This equates to ~4% of the total volume of debris noted above. The estimated building replacement cost for each of the tsunami inundation zones is likely to exceed $7.6 billion in an M1 event, $11.3 billion in L1, and $17.4 billion for the XXL1 tsunami inundation zone; these data exclude the replacement cost for earthquake-damaged buildings. As reported in **Section 3.8.2**, the combined earthquake and tsunami total losses are expected to range from $35.4 billion (M1) to more than $45 billion (XXL1). These numbers demonstrate that, regardless of the size and characteristics of the next CSZ earthquake and tsunami, the impact will be catastrophic for the coast and state of Oregon.

Wood-frame construction dominates many Oregon coastal communities. Most of these buildings located in a tsunami inundation zone will probably be destroyed by the tsunami. This means that there is likely to be a significant shortage of suitable housing in the months and perhaps years following the disaster. In the absence of housing, displaced residents will likely migrate away from such communities, further impacting a community's local economy. The lack of housing will likely be compounded by the altered coastal landscape due to subsidence effects caused by the earthquake. For example, an M1 CSZ earthquake and tsunami could result in ~2.5 ft (~0.76 m) of subsidence (data derived from Witter and others, 2011), increasing to ~5.8 ft (~1.8 m) in an XXL1 event on the central Oregon Coast. Conversely, the same M1 scenario on the southern Oregon Coast is estimated to produce ~7.9 ft (~2.4 m) of subsidence, increasing to ~20 ft (~6 m) in an XXL1 CSZ scenario. Higher rates of subsidence on the southern Oregon Coast, in Curry County, are anticipated due to those communities being located closest to the subduction zone. Furthermore, coastal subsidence will inevitably lead to accelerated rates of coastal erosion that will likely affect all forms of coastal shorelands (beaches, dunes and coastal bluffs), as well as increased incidences of coastal flooding in low-lying areas. These changes can be expected to be significant in the weeks to months following the event, with further erosion progressively decreasing over time as the coastline re-equilibrates to a new sea level regime.

Finally, our analyses indicate that many buildings in the tsunami inundation zone are outside existing coastal or riverine FEMA flood zones. As a result, owners are not required by federally backed mortgage lenders to carry flood insurance. However, flood insurance is available to all building owners in the tsunami inundation zone through the National Flood Insurance Program, which covers building loss due to a tsunami (FEMA, 2018) and can aid in community recovery. More information on the National Flood Insurance Program can be obtained from https://www.fema.gov/flood-insurance.

5.5 Vulnerable Populations

We did not perform an update to our previous estimates (Allan and others, 2020a, 2020b; Allan and O'Brien, 2021, 2022, 2023) of vulnerable populations from ACS data for selected population groups that may have special challenges understanding preparedness messages or evacuating. Planners wanting to further understand the specific locations of vulnerable populations are encouraged to discuss the situation with their local public health preparedness coordinators. Other resources include the emPOWER database,[15] which tracks electricity-dependent Medicare populations and the Centers for Disease Control and Prevention's Behavioral Risk Factor Surveillance System (BRFSS),[16] which tracks health-related risk behaviors, chronic health conditions, and use of preventive services by U.S. residents. Although our focus in this study was on quantifying casualties from a local tsunami, such information on vulnerable populations can also be useful when planning evacuation from distant-source tsunamis.

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[15] https://empowermap.hhs.gov/
[16] https://www.cdc.gov/brfss/index.html

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8.0 APPENDIX A: COMMUNITY PROFILES

Appendix A includes additional summary information specific to each community. These data include the effects of both the earthquake and accompanying tsunami (M1, L1, and XXL1) that can inform preparation, recovery, and mitigation planning.

A) Area analyzed: We summarized data, when possible, within the community's designated UGB. Planners consider the UGB as a more inclusive and useful aggregation unit compared to city limits. However, some data are available only at the city limits level, specifically, the most current population estimates and U.S. Census Bureau American Community Survey (ACS) data. For unincorporated communities, we used a geospatial layer of unincorporated community boundaries compiled by the Department of Land Conservation and Development (DLCD). The summary community profile maps highlight several datasets, including the boundary used for analysis (UGB, city limits, or DLCD outline, depending on data availability), building placements, and tsunami inundation zone. In addition, the maps include the results of the evacuation modeling (path distances) based on a 1.2 mps (4 fps or 2.7 mph; a moderate walk speed) evacuation speed (with 10-minute delay) out of the inundation zone. We distinguish the chance of successful evacuation (green lines) versus increased likelihood of fatality (red lines). In all cases, the likelihood of successful evacuation improves significantly if individuals increase their evacuation speed or leave sooner (reduced milling time).

B) Population demographics: These data reflect the permanent (resident) population within each respective tsunami inundation zone (M1, L1, and XXL1), expressed as absolute numbers and as a percentage of the total community population. A conservative estimate of the number of temporary visitors is also presented, assuming 100% occupancy of vacation homes, hotel/motels, and camping areas. Additional demographic information of the permanent population distinguishes those less than five years of age, five to 65 years, and those over 65 years of age.

C) Distance to safety: Distance to safety plots show the number of permanent and temporary residents as a function of distance to safety. The closer a person is to safety (i.e., right side of the figure), the greater the chance of successful evacuation. The distance to safety figure includes a 1.2 mps (4 fps) threshold line (vertical dash black line). Left of this line, the model assumes people will not be able to evacuate out of the inundation zone in time, while those to the right have a greater chance of surviving. We also include a two-standard deviation gray dash line that highlights uncertainty in the 1.2 mps (4 fps) threshold, which is a function of the wave arrival time and uncertainty in peoples' travel speed. Finally, we include a cumulative percent curve to further define the proportion of people relative to safety in the community.

D) Distance to safety and building type: This figure is similar to C) Distance to Safety, with the exception that it defines the tendency of people (residents and visitors) to be in particular building types. Here we distinguish between the following building types: single-family residential, manufactured housing, multifamily residential, hotel/motel, and mobile (e.g., tent, RV, etc.). These data define where people tend to be predominantly located. For example, many coastal hotel/motels tend to be located close to the ocean and are mostly used by visitors.

E) Building losses: The effects of a M_w 9.0 CSZ earthquake and accompanying tsunami (M1, L1, and XXL1) in terms of economic losses and debris generated are included in this figure. For each tsunami inundation zone, we define the number of buildings in the zone and the building replacement cost. Earthquake losses are defined for the tsunami inundation zone and as a total for the entire community; content losses are also estimated and included separately. These data are then combined with the tsunami losses calculated by Hazus. Finally, the weight of debris generated by the tsunami is presented. As a reminder, these data do not include the weight of content in buildings and therefore reflect a minimum value.

F) **Fatalities and displaced population:** To standardize tsunami injury and fatality estimation across all communities, we assume the entire population, as a group, evacuates at 4 fps (2.7 mph, 1.2 mps), which is regarded as a moderate walk. In all cases, we factor in a 10-minute evacuation delay prior to getting underway that accounts for approximately three minutes of expected earthquake shaking and up to seven minutes for people to organize themselves, leave the building, and begin to evacuate. For each community, we provide graphical representations of the modeled fatalities, for both permanent and temporary residents. For the temporary population we provide 10% and 50% occupancy estimates in addition to the full 100% to represent a scenario where a community's visitor lodging is not at full capacity (e.g., winter, midweek). The displaced population is defined as the difference between the local (permanent) population and the fatalities (for permanent and temporary). We also include numbers of people displaced due to building damage caused by the earthquake shaking outside the tsunami inundation zone for completeness. Planners can apply their own judgment as to the occupancy levels associated with the temporary visitors and adjust downward from the 100% occupancy estimate.

9.0 APPENDIX B: SUPPLEMENTAL FIGURES

Building Loss Ratio

The building loss ratio from damage caused by the earthquake and tsunami relative to the total number of buildings in the community. Results are aggregated and symbolized at the census-block level and are illustrated individually for the M1, L1, and XXL1 tsunami inundation zones. Building loss ratios inside the tsunami inundation zone are based on both earthquake and tsunami damage, while loss ratios outside of the tsunami inundation zone are from earthquake damage only. Results are limited to the community boundary.

Debris

Debris, in tons, generated by the earthquake and XXL1 tsunami. Results are aggregated and symbolized at the census-block level and are limited to the XXL1 tsunami inundation zone.

Evacuation Flow Zones

Tsunami evacuation flow zones are mapped for the XXL1 tsunami inundation zone. Each flow zone defines an area within the inundation zone that shares a single, or geographically similar, safety destination. The total, permanent and temporary population within each flow zone is reported in a table.

Occupancy

Building occupancy type is symbolized at the individual building level for the entire community. In addition to buildings, boats, campsites, and RVs, which are important feature types in this study, are also displayed.

Permanent Residents

The number of permanent residents. Results are aggregated and symbolized at the census-block level and are limited to the XXL1 tsunami inundation zone.

Temporary Residents

The number of temporary residents. Results are aggregated and symbolized at the census-block level and are limited to the XXL1 tsunami inundation zone.