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EARTHQUAKE AND TSUNAMI IMPACT ANALYSIS FOR COASTAL LANE, DOUGLAS, AND COOS COUNTIES, OREGON

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DISCLAIMER

WHAT'S IN THIS REPORT?

This report evaluates a Cascadia Subduction Zone earthquake (M_W 9.0) and tsunami (M1, L1, and XXL1 scenarios) affecting coastal Lane, Douglas, and Coos counties, Oregon, to understand the degree of potential destruction, including building losses, debris generated, fatalities and injuries, and estimated numbers of the displaced populations. The goal is to help coastal communities prepare for this inevitable disaster.

Cover: Photo from Wikimedia commons: https://commons.wikimedia.org/wiki/File: US Navy 110315-N-5503T-307 An aerial view of damage to Otsuchi, Japan, after a 9.0 magnitude earthquake and subsequent tsunami devastated the area in northern Japan.jpg.

U.S. Navy photo by Mass Communication Specialist 3rd Class Alexander Tidd, March 15, 2011

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EXECUTIVE SUMMARY

This report provides an evaluation of the potential impacts of a Cascadia earthquake and accompanying tsunami in coastal Lane, Douglas, and Coos counties. The analyses presented here include an assessment of the number of people, businesses, and critical facilities located in three Cascadia tsunami inundation zones (M1, L1, and XXL1). XXL1 represents the maximum-considered inundation scenario given our knowledge of the Cascadia Subduction Zone (CSZ). Large (L1) and Medium (M1) tsunami zones reflect smaller earthquake and tsunami scenarios that are more likely to occur than XXL1. L1 captures 95% of the uncertainty in tsunami modeling (there is a ~5% chance that the tsunami could exceed the L1 tsunami zone), whereas the M1 scenario captures 78% of the uncertainty (there is a ~22% chance that the tsunami could exceed the M1 tsunami zone).

A major focus of this study is to provide improved estimates of local population demographics in each community to better understand evacuation challenges that could affect different population groups, as well as socioeconomic impacts associated with a CSZ earthquake and tsunami. The results and analyses presented here reflect a comprehensive effort to document the likely effects the next great earthquake and tsunami will have on all three counties.

We used previously developed physical models of a CSZ earthquake and tsunami, "Beat the Wave" tsunami evacuation modeling, and the recently published Federal Emergency Management Agency (FEMA) Hazus Tsunami Model to develop standardized damage loss estimates for each community, as well as estimates of injuries, fatalities, and displaced population. From the building damage losses, we estimated the amount of debris generated. Our population model improves upon previous studies by providing spatially detailed estimates of permanent and temporary populations — the latter quantifying numbers of visitors, which vary widely throughout the calendar year. The tsunami injury and fatality modeling evaluates a nighttime (2 AM) evacuation scenario, which assumes people are in their homes/hotels/campgrounds at the time of the event (as opposed to on the beach or walking around town). We also maximize visitor occupancy by assuming all hotels/second homes/campgrounds are at capacity, to fully quantify potential impacts to permanent and temporary residents. Our major findings include the following:

- Total populations in coastal Lane, Douglas, and Coos counties that are within a tsunami zone are summarized below:

	Permanent population (M1 – XXL1)	Permanent + temporary population (M1 – XXL1)
Lane	550 – 1,870	2,600 – 6,040
Douglas	1,050 – 1,970	3,360 – 5,430
Coos	1,330 – 10,340	4,970 – 20,850

- The fraction of permanent residents within the three tsunami zones varies considerably between communities. These variations reflect contrasting patterns in the general shape and elevation of the county coastlines, whether it is open coast versus up an estuary; inundation extents; and the distribution of permanent residents within the communities. Notable observations:
  - **Siltcoos**, **Sunset Bay**, and **Bullards Beach** campgrounds are 100% inundated in all three scenarios.
  - For the M1 scenario, communities with the largest number of people in the tsunami zone include **Charleston** (32%), **Winchester Bay** (54%), and **Umpqua South Jetty** (49%).
  - **Winchester Bay** is mostly located in the M1 tsunami zone and is 100% within the L1 and XXL1 tsunami zones.

  - **Barview**, **Charleston**, and **Bandon** each have relatively large numbers of people located in the XXL1 tsunami zone — 73%, 52%, and 68% respectively.
  - **Florence**, **Dunes City**, **Lakeside**, **North Bend** and **Coos Bay** have relatively few people in the various tsunami zones.
- All 17 communities and parks distributed along the Lane, Douglas and Coos coastlines can experience significant influxes of visitors, well exceeding their local resident populations. Of note, the population of **Florence** can swell by ~420% to 300% (M1 to XXL1), **Winchester Bay** by ~1,360% to 950%, and **Bandon** by ~210% to 225%. The popularity of these communities as centers of tourism present challenges associated with preparing such a large transient population for a CSZ earthquake and tsunami.
- An understanding of how population demographics are geographically distributed within each tsunami zone can provide an insight into those communities that may experience evacuation challenges. We use people over 65 years of age as a proxy for those who may experience increased evacuation difficulty (reduced evacuation travel speeds). Numbers of people over 65 years of age within a particular tsunami zone is summarized below:

	% of population ≥65 years	Number of ≥65 within M1	Number of ≥65 within L1	Number of ≥65 within XXL1
Lane	35% (M1 & L1), 34% (XXL1)	189	324	715
Douglas	34% (M1 to XXL1)	325	526	617
Coos	33% (M1), 31% (L1), 28% (XXL1)	436	914	2,749

  - At the community level, **Florence**, **Winchester Bay,** and **Bandon** each have a large proportion (41%) of their resident population ≥65 in the XXL1 tsunami zone.
- The number of buildings located in a tsunami zone is a useful metric for determining exposure to the tsunami hazard. Building counts in the tsunami zones are particularly large in **Barview**, **Bandon**, **Coos Bay**, and to a lesser degree **Florence**. Interestingly, the largest single number of buildings fall within the "other" category (~2,102) in unincorporated Coos County, reflecting residential buildings established along the open coast outside of community boundaries, as well as along the shores of the Coos and Coquille estuaries. Communities with particularly high exposure to the tsunami hazard include:

	% buildings inside the tsunami zone		
	M1	**L1**	**XXL1**
Winchester Bay	56%	98%	98%
Charleston	58%	59%	70%
Barview	6%	17%	76%

- Building damage caused by earthquake shaking in the three coastal counties is estimated to be:
  - Lane County: $1.23 billion
  - Douglas County: $420 million
  - Coos County: $4.42 billion

  The large loss estimates for Coos County can be attributed to the effects of liquefaction (and lateral spreading) that are particularly damaging to bayfront infrastructure. Earthquake damage losses in the communities of **Coos Bay** and **North Bend** are substantial and are estimated to reach ~$1.8 billion. Nevertheless, the largest earthquake losses fall within the "other" category (~$1.9 billion) in Coos County, which reflect those buildings located throughout unincorporated Coos County.

- An M1 event could yield damage levels that range from ~10% at **Dunes City** to ~90% at **Bandon** and **Charleston**. Damage caused by the XXL1 tsunami reveals destruction levels of >70% in most coastal communities, including **Florence**, **Reedsport**, **Winchester Bay**, **Coos Bay**, **North Bend**, **Barview**, **Charleston**, and **Bandon**; complete destruction occurs at the Siltcoos, Bullards Beach and Sunset Bay campgrounds. These findings can be attributed to the powerful hydraulic forces associated with the tsunami, and the prevalence of light-frame construction material (i.e., wood frame) on the Oregon Coast.
- Combined earthquake and tsunami damage losses for each tsunami zone and scenario are estimated to be significant:

	M1	**L1**	**XXL1**
Lane	$1.25 billion	$1.27 billion	$1.36 billion
Douglas	$440 million	$464 million	$530 million
Coos	$4.52 billion	$4.62 billion	$5.14 billion

  These estimates reflect community-wide losses associated with the earthquake, combined with destruction caused by the tsunami. Note that these estimates exclude building content losses, such that the numbers may be viewed as minimum estimates.
- The destruction of buildings in coastal Lane, Douglas, and Coos counties is expected to generate substantial debris:

	M1	**L1**	**XXL1**
Lane	40,000 tons	50,500 tons	108,000 tons
Douglas	71,200 tons	106,000 tons	149,000 tons
Coos	191,300 tons	358,000 tons	785,000 tons

  This equates to ~4,000 dump trucks for M1 in Lane County to as much as 78,500 dump trucks for an XXL1 event in Coos County (assuming dump truck capacity of ~10 yd^3). These estimates are almost certainly on the low end, as they do not include debris associated with content from buildings (personal items, business equipment, furniture etc.), road rip-ups, vehicles, and vegetation.
- Modeled tsunami casualties (injuries and fatalities) vary widely between communities. This is due to many factors, but the most important is the relative distance to high ground. We estimate that, combined, countywide fatalities from the tsunami could reflect the following:

	M1	**L1**	**XXL1**
Lane	20	50	200
Douglas	610	1,180	1,380
Coos	440	1,070	5,290

  - Low casualties associated with the M1 scenario in Lane County is indicative of the fact that high ground is located close to the population centers, allowing for quick access to high ground, or the tsunami simply was not large enough to reach them.
  - For the XXL1 tsunami scenario — the largest-considered — the potential for significant fatalities is apparent for **Bandon** (~1,900), the "other" category in Coos County (~1,400), **Winchester Bay (**~1,200), and **Barview (**~980). Overall, the bulk of the fatalities (>61%) are likely to be from the temporary visitor population.

  - High casualties associated with the temporary visitor population is predicated on the assumption that these facilities are at 100% occupancy.
  - Several additional sites with the potential for large visitor fatalities include **Siltcoos River** Campground, **Umpqua South Jetty**, **Sunset Bay** campground and **Bullards Beach** campground. Fatalities in these areas are due to a combination of early wave arrivals and long travel distances required to reach high ground.
  - These results demonstrate a need to evaluate alternative forms of high ground (e.g., vertical evacuation structures) and/or evaluate retrofitting bridges (e.g., Winchester Bay) to withstand the earthquake shaking, thereby allowing for faster evacuation.
- Following the earthquake and accompanying tsunami, communities will have to deal with many hundreds to potentially thousands of displaced people requiring immediate short-term shelter and care (for days to a few weeks), after which many people are likely to be evacuated from the coast. Hazus modeling indicates that the number of displaced people is significantly higher in the XXL1 scenario (~25,400) compared to the M1 scenario (~9,800). We expect large numbers of displaced people to severely challenge the following communities: **Florence**, **Reedsport**, **Coos Bay**, **North Bend**, **Barview** and **Bandon**. Furthermore, an estimated 4,800 people outside of community urban growth boundaries (UGB) and unincorporated boundaries will require shelter and care.
- Compared to fatalities, injuries from the earthquake were found to be moderately low. Overall, the number of critically injured (requiring hospitalization) as a result of the earthquake is on the order of:
  - Lane County: 150
  - Douglas County: 30
  - Coos County: 380
- Injuries caused by the tsunami are expected to be on the order of:

	M1	L1	XXL1
Lane	~20	5	90
Douglas	~590	40	80
Coos	~180	350	1,700

Although each community in coastal Lane, Douglas, and Coos counties 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 destructive and life-threatening forces of tsunamis are well known globally, as demonstrated by the 2011 Tōhoku, Japan event that resulted in 15,899 killed and another 2,529 missing (as of September 10, 2020; National Police Agency of Japan, 2020). Most of the deaths in the event were due to drowning (Mori and Takahashi, 2012). The earthquake and tsunami destroyed 121,992 buildings. A total of 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).

The Oregon Coast is similarly exposed to large megathrust subduction zone earthquakes, capable of generating catastrophic tsunamis (Witter and others, 2011). The Cascadia Subduction Zone (CSZ) geologic record contains evidence of at least 19 earthquakes >8.5 M_W over the past 10,000 years (Goldfinger and others, 2012, 2017; Priest and others, 2009; Satake and others, 2003; Walton and others, 2021; Witter and others, 2012). 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 the tsunami zone, there is a high potential that the next great earthquake and tsunami will result in many fatalities, catastrophic destruction of local infrastructure, and lasting damage to Oregon's economy. 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 Coos, Lane and Douglas County on the southcentral Oregon Coast. In providing such information, we address a specific need expressed in the 2013 Oregon Resilience Plan — to document the "who," "what," and "where" in terms of population exposure, building damage, and socioeconomic impacts (OSSPAC, 2013). The overall approach presented here follows comparable efforts undertaken for Clatsop, Tillamook, and Lincoln counties (Allan and others, 2020a,b; Allan and O'Brien, 2021). The difference here is that we use an updated Cascadia earthquake scenario developed by Wirth and others (2020) and new geologic data summarized in Madin and others (2021).

Following the 2011 Tōhoku, Japan, tsunami, Federal Emergency Management Agency (FEMA) commissioned an effort 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.

In Oregon, considerable mapping and modeling has been undertaken by the Oregon Department of Geology and Mineral Industries (DOGAMI) to better advise local and state government agencies on the various geologic hazards that could impact the state. For example, DOGAMI and the U.S. Geological Survey (USGS) published ground motion/deformation maps for a magnitude (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).

Between 2010 and 2013, DOGAMI combined high-resolution terrestrial lidar-derived digital elevation models (DEMs) with detailed bathymetry to model five scenarios for CSZ generated tsunamis (Priest and others, 2013g; Witter and others, 2011). More recently, DOGAMI pioneered techniques for tsunami evacuation modeling ("Beat the Wave," BTW) at Seaside and Gearhart (Priest and others, 2015), Warrenton/Hammond (Gabel and Allan, 2016), Rockaway Beach, (Gabel and Allan, 2017), Pacific City (Gabel and others, 2018a), Reedsport and Florence (Gabel and others, 2018b), Newport (Gabel and others, 2019a), Lincoln City/unincorporated Lincoln County (Gabel and others, 2019c), the Coos estuary (Gabel and others, 2019b), unincorporated Lincoln County (Gabel and others, 2019d), Port Orford (Gabel and others, 2020a), Nehalem Bay (Gabel and others, 2020b), and Gold Beach (Gabel and others, 2021). These BTW studies graphically demonstrate evacuation challenges and mitigation opportunities but do not quantify potential loss of life. Since 2015, Williams and others (e.g., Williams and others, 2021) developed a Hazus-compatible building inventory for all seven Oregon coastal counties, identifying the location, size, and primary usage (e.g., residential, commercial) of buildings, information fundamental to addressing fatalities and building damage potential.

Although most data needed by Hazus to model the effects of earthquake and tsunami impacts are in place, one key missing element is a spatially explicit population model for the Oregon Coast. Specifically, how many people are located in the tsunami zone, their demographics, and where they are located relative to safety from the tsunami at the time of the earthquake. Such a model is complicated because many Oregon coastal communities experience large influxes of daytime and overnight visitors throughout the year (Dean Runyan Associates, 2018). Many homes and condominium units located in the tsunami zone are second homes or vacation rentals (Raskin and Wang, 2017). Additionally, numerous coastal parks and campgrounds are located in the tsunami zone and potentially host many thousands of overnight visitors per day (White, 2018). Each of these considerations must be carefully evaluated and accounted for in order to generate meaningful statistics of both local and visitor populations and, ultimately, potential casualties and displaced populations associated with a CSZ earthquake and tsunami. Furthermore, *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 zone that may present special evacuation challenges (DLCD, 2015).

The purpose of this report is to evaluate the potential effect of a CSZ earthquake and accompanying tsunami in coastal Coos, Douglas, and Lane counties (**Figure 1-1**). Specifically, we evaluate estimates of potential building losses, generated debris, fatalities, and injuries, as well as estimates of the number of displaced people. The study also provides an assessment of vulnerable populations, essential facilities, and critical infrastructure, which is important to response and recovery. This study integrates previous tsunami modeling with a new Cascadia earthquake model and new population model (comprising permanent and temporary people) for the purpose of:

1. evaluating tsunami evacuation challenges and opportunities on the coast.
2. completing a detailed socioeconomic analysis using several data sources to identify vulnerable communities in the tsunami zone.

This report initially describes and documents our overall Hazus approach. Results from the countywide assessments are provided in Section 3, with broad conclusions outlined in Section 4. Summary information specific to each community and tsunami inundation zone is provided in Appendix A.

Figure 1-1. Location map showing coastal Lane, Douglas, and Coos county communities. Yellow zone depicts the XXL1 tsunami zone.

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 earthquakes (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). Thus, Hazus model results presented here reflect earthquake-related damage, debris weight, and casualties simulated for the entire community and for each of 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 (e.g., Eugene) that are part of a particular county. For injury and fatality estimation we analyzed a "2 AM" scenario, in which an earthquake strikes during the summer (when the number of visitors is the highest) at 2 a.m. (when most people are asleep). The modeling distinguishes the number of casualties experienced by both permanent residents as well as the temporary visitor population. We did not evaluate a 2 PM scenario because the 2 AM scenario defined for summer occupancy conditions assumes maximum occupancy and we believe it is sufficiently conservative to account for uncertainty associated with the movement patterns of day trippers.

2.2 Natural Hazard Dataset Development

2.2.1 Earthquake

Wirth and others (2020) recently developed ground-shaking estimates from 30 M_W 9.0 CSZ earthquakes, determined using a logic-tree approach that varied the location within the earth where the earthquake rupture starts, down-dip rupture limit, slip distribution, and location of strong-motion-generating sub-events. From these data, they produced an ensemble suite of ShakeMaps[1] based on the median scenario $\pm 1\sigma$ and $\pm 2\sigma$, which spans the 2^{nd} and 98^{th} 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) within 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 2^{nd} and 98^{th} percentile ground motions (i.e., $\pm 2\sigma$ around the medium) spans ~1.5-2 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). 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, and earthquake-induced landslides by Madin and others (2021) to produce a

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

new statewide seismic hazard map for Oregon. These latter datasets reflect years of surficial geologic mapping using high-resolution lidar data to produce accurate maps of areas subject to different coseismic geohazard conditions.

The bedrock ground motions were adjusted for discrete areas using 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 soil requires site-specific evaluations, 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). For liquefaction modeling, we assumed a water table level of zero feet (i.e., fully saturated soil). 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).

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). Four representative earthquake slip models were defined and tested, including slip partitioned to a hypothetical splay fault in the accretionary wedge and models that varied the updip limit of slip on the megathrust. Recurrence information was defined from a suite of scientific studies, including work undertaken in coastal estuaries (Nelson and others, 1996, 2006; Peterson and others, 1995; Witter and others, 2003) and on the continental shelf (Goldfinger and others, 2012). Inter-event time intervals that separate the 19 full-margin earthquakes and tsunamis range from as little as 110 to ~1,150 years (Witter and others, 2011, Table 1). Each tsunami scenario was then weighted using a logic tree, to account for the different models, convergence rates, and recurrence. From these data, four time intervals (mean values rounded to the nearest quarter century) were defined as representative of four general earthquake size classes:

- Small (SM) – Five events, mean inter-event time of 300 years (range=~110 to 480 years).
- Medium (M) – 10 events, mean inter-event time of 525 years (range=~310 to 660 years).
- Large (L) – Three events, mean inter-event time of 800 years (range=~680 to 1,000 years).
- Extra Large (XL) – One event, mean inter-event time of 1,150 years, rounded to 1,200 years.

The mean inter-event time interval multiplied by the CSZ plate convergence rate at each latitude equates to the amount of slip deficit released in each scenario earthquake. Slip was also reduced progressively from north to south on the CSZ to account for evidence in the paleoseismic record of increasing numbers of partial CSZ ruptures from north to south (Goldfinger and others, 2012; Witter and others, 2013). A fifth scenario termed Extra Extra Large (XXL1), which simulated a maximum-considered tsunami not seen in the geologic record, was eventually used to guide evacuation planning (Witter and others, 2011). This last hypothetical scenario assumes 1,200 years of slip deficit release but without any reduction of slip from north to south. According to Witter and others (2013), the defined earthquake size classes correspond to approximate recurrence rates as follows: SM, 1/2,000 years; M, 1/1,000 years; L, 1/3,333 years; and XL, <1/10,000 years. Recurrence for the XXL1 event is not known.

Maximum flow depths were obtained from Priest and others (2013a,b,c,d,e,f), and the maximum momentum flux was derived from Priest and others (2014a,b,c,d,e,f). The unstructured computational grid data were converted to raster format for use in Hazus using the Esri® ArcGIS Spatial Analyst Natural Neighbor tool. We specified a 3-m (~10-ft) grid resolution, noting that the mean distance between points in the terrestrial regions within the XXL1 tsunami zone was ~5 m (~16 ft). The Hazus tsunami building damage and casualty fragility curve parameters (determined by engineers) are based on median depth and momentum flux values, rather than maximum values (FEMA, 2017, section 4.6). To that end, the raster data were subsequently converted to both median depth and median momentum flux using a 0.66 multiplier; the results were also converted to non-SI (English) units for use in Hazus.

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 large variation in maximum wave arrival times observed along the Oregon Coast, especially within the various estuaries. For example, wave arrival times ranges from as little as 12 minutes for a tsunami arriving at the open coast near the mouth of the Coos estuary, compared with 42 minutes for the tsunami to reach downtown Coos Bay. These differences have an enormous bearing on the number of modeled casualties. To resolve this limitation, we used the evacuation flow zone polygons defined in our various "Beat the Wave" studies to associate a group of buildings with a particular tsunami safety destination or exit point. We then determined the maximum wave arrival time at a particular watershed's exit point and assigned that value (in minutes) to the polygon. All buildings within that watershed were then associated, via a spatial overlay, with that wave arrival time. In some open coast communities, such as Bastendorff Beach, the maximum wave arrival time varies only slightly, and a single value was assigned to all buildings. Wave arrival times for areas located outside our detailed "Beat the Wave" investigations were defined based on average wave arrival times for that particular section of coast.

2.3 Building Database Development

A Hazus-compatible building database contains a record for each distinct building. Each record contains 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 or, from ancillary datasets, and when better data is available (e.g., Lewis, 2007). We followed the methods established by Bauer and others (2018), starting with the incorporation of building records previously developed (e.g., Williams and others, 2021) and modifying or amending records where better information was available.

The User-Defined Facilities (UDF) datasets developed by DOGAMI attempts 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 frame, steel frame construction, 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 augmented 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," "RES5," respectively). We further augmented the UDF dataset by adding records to 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 Oregon State Park 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	Extract 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
Square footage	2,250	Building repair/replacement cost; debris; number of people per building
First floor height	3.0	(in feet) Tsunami nonstructural building damage estimate
Daytime occupancy+	2.1	Casualty estimate
Nighttime occupancy+	3.4	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.

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

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

Per-square-foot replacements costs are derived from the Hazus 5.0 database[2], which incorporated the 2014 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

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

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 non–single-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/1% other (FEMA, 2011, Table 3A.17). For simplicity, we assigned wood frame to all single-family residences except manufactured housing.

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). 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 uninjured from the ground motion. To estimate injuries and fatalities from a tsunami, the FEMA Hazus tsunami model requires the user to refine the population model further to include locations, numbers, population demographics (age), and distance to safety outside the tsunami 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.

To minimize the complexity associated with a dynamic human environment, FEMA Hazus documentation recommends modeling be undertaken for two time periods:

- a midweek "2 PM" scenario, in which people are dispersed among work, institutional, and home buildings.
- a "2 AM" 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 RV were also accounted for in our model).

Such divisions, however, are inadequate to meet the needs of this project (Bauer and others, 2020). This is because Oregon coastal communities experience significant temporal (daily, seasonal, and annual) population fluctuations, with large visitor influxes occurring on weekends and in the summer months (Dean Runyan Associates, 2018). Community planners have expressed strong interest that our population model accounts for such variations, which could then be used to assist with identifying tsunami evacuation challenges and short-term sheltering needs. To better understand these effects, we distinguish two broad population groups:

- *permanent residents*, who have established residence within the tsunami zone.
- *temporary residents*, who are visiting the community.

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 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[3] for the permanent population and assuming that the 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 2-1**).
2. It is reasonable to assume that the temporary population may be less aware of tsunami risk, locations of tsunami safe zones, signage, temporal urgency (e.g., 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 Cascadia 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. By doing so, we established a range that planners can use to estimate impacts at non-maximum occupancy periods.

Given project scope constraints and discussions with community members, we focused our attention on developing a summer weekend 2 AM population model for all communities to maximize estimates of the temporary population and thus provide a more realistic worst-case tsunami evacuation scenario for those communities. Although our summer weekend 2 AM population scenario does not account for day trippers to the coast, the injury, fatality, and displaced population estimates derived from this scenario may be considered a conservative estimate (i.e., upper bound), as the population model assumes maximum (100%) occupancy. Conversely, planners can use 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 can 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 extensive modeling for all communities was 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.

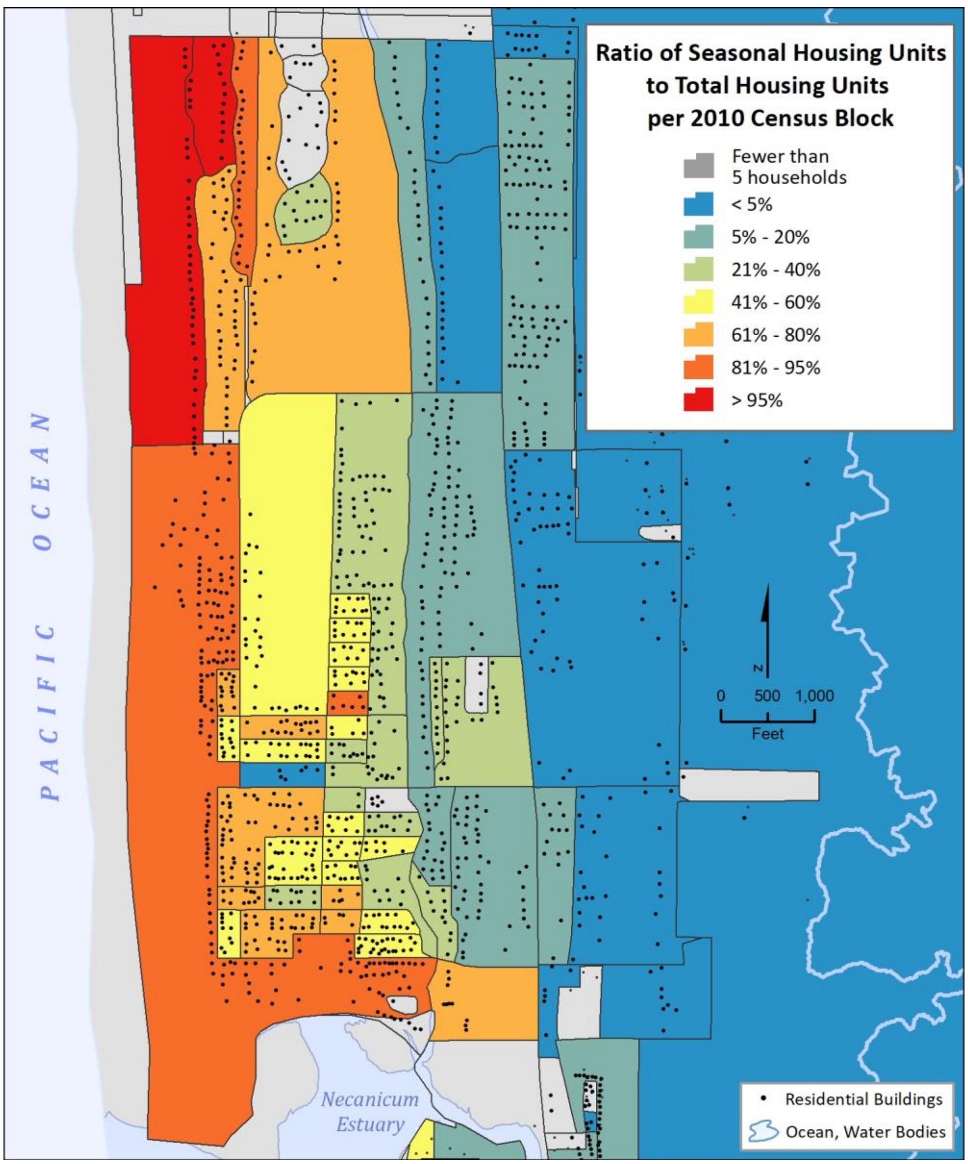
Our summer 2 AM weekend scenario assumes permanent residents are at their homes and that all available designated temporary lodging such as vacation rentals, second homes, vacation condominiums,

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

campsites, marina boat slips, and recreational vehicle spots are fully occupied (i.e., 100% occupancy). Institutions and businesses, with certain exceptions, are considered to be unoccupied.

For permanent resident occupancy, we established locations, numbers of individuals, and age groups using 2010 U.S. Census data. Bauer and others (2020) used geocoded Oregon Department of Motor Vehicle (DMV) driver license registration records as of September 2017 to perform similar analyses for five coastal communities, as DMV records are typically associated with a single-family residential home. Although such an approach is more accurate for defining the permanent population, the time required to process DMV records on a countywide basis was beyond the scope of this investigation.

Figure 2-1. Example of "seasonally occupied households" as a percentage of total households per census block in Gearhart, Oregon, 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 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.



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, which is how the U.S. population is defined and distributed. Error! Reference source not found. provides summary statistics for census block groups in Lane, Douglas, and Coos counties:

Table 2-2. Census block group statistics for Lane, Douglas, and Coos counties.

	Census Block Group Size		
	Number of People	**Size Range**	**Mean Area**
Lane	1,160 people (ρ = ± 390)	110 hectares (270 acres) to 56,525 hectares (139,680 acres)	12,220 hectares (30,200 acres)
Douglas	980 people (ρ = ± 450)	40 hectares (100 acres) to 83,450 hectares (206,220 acres)	23,600 hectares (58,320 acres)
Coos	1,010 people (ρ = ± 430)	28 hectares (70 acres) to 86,635 hectares (214,080 acres)	6,780 hectares (16,750 acres)

In urban areas, census blocks are usually defined at the city block level, whereas in rural areas, census blocks may cover a several hundred square kilometers (few hundred square miles). Within each census block group, the population may range from negligible to several thousand people. However, unlike DMV records that associate a person with a specific address, census block groups provide a single aggregated population count. For our purposes, we used updated population statistics obtained from the American Community Survey (ACS; 2014–2018 census data downloaded from the U.S. Census Bureau; https://www.census.gov/programs-surveys/acs; data accessed 2021) at the census block group level. To estimate the size and distribution of the permanent population in our study area, we distributed the population per census block group among the residential buildings and pro-rated 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 are occupied on a temporary basis by out-of-town visitors. For single-family residential houses, we used the number of bedrooms (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 2010 census data to identify the residential household vacancy rate[4] 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 is 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). This is because specific age groups have been recognized as having different evacuation speeds, which affects their evacuation

[4] H005006, "Total for seasonal, recreational, or occasional use" in the Total Vacancy data per census block, 2010 U.S. Census divided by total number of households in the census block, obtained from Table S1101.

potential. Accordingly, FEMA (2013, 2017) incorporated population demographics into the FEMA Hazus casualty model. This is accomplished by differentiating those people <65 years with those ≥65 years in the Hazus tsunami casualty model (FEMA, 2017), 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). Hence, for our tsunami casualty modeling purposes, an individual is identified as:

1) either permanent or temporary.
2) either < 65 years of age or ≥ 65 years (**Table 2-3**).

Table 2-3. Summary parameters and explanation used to define the process for distributing the permanent resident and visitor populations across U.S. census block groups.

	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				0.7
	Dormitories	1 unit per 400 ft^2				0.9
	Assisted Living	1 unit per 600 ft^2				0.05
B) Temporary Population	Single-family Residential	2 units < 1,500 ft^2 3 units < 2,700 ft^2 4 units < 4,000 ft^2 5 units < 5,500 ft^2 6 units ≥ 5,500 ft^2	2.0	The 2010 census data reports the residential vacancy rate at the census block (CB) 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
	Multifamily Residential	1 unit per 800 ft^2	2.2			0.7
	Hotel/Motel	1 unit per 455 ft^2	1.7			0.7
	Dormitories	1 unit per 400 ft^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 census block group level.

Temporary vacancy rates are taken from 2010 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 and Lincoln County.

2.5 Building Damage and Building Debris Estimation

2.5.1 Earthquake

To calculate combined building losses from an earthquake and tsunami, the Hazus model requires the user to first model earthquake damage using the Hazus User-Defined Facilities (UDF) earthquake model (FEMA, 2011, 2017). In the Hazus earthquake simulation, we used Hazus 5.0 to model a fully saturated soil scenario, with groundwater level at the surface, thereby incorporating the potential impacts of liquefaction. We believe this is a reasonable assumption for low-lying coastal areas.

As noted previously, we model the effects of three discrete tsunami inundation scenarios described by Witter and others (2011) and Priest and others (2013e): M1, L1, and XXL1. These reflect the following CSZ earthquake moment magnitudes (M_W): 8.9 (M1), 9.0 (L1), and 9.1 (XXL1) respectively. Each event is characterized by a unique deformation model to account for the coseismic response. These scenarios contrast with the terrestrial ground motion data from Madin and others (2021), which assume a moment magnitude (M_W) 9.0 CSZ earthquake. For Hazus loss estimation purposes, we determined that the ±0.1 difference in moment magnitude is minor and accounted for by our choice of the “default betas” in the Hazus Advanced Engineering Building Model (probability of damage state; Kircher and others, 2006; Kircher, 2002). 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 event.

Building repair cost estimates were obtained by using the probability of damage state (PDS) values for each building[5]. 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 earthquake-induced ground deformation by community.

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 for the M1, L1, and XXL1 tsunami events by community[6].

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 cost estimates (FEMA, 2017, Section 5.7). We summarized the combined building repair costs for the earthquake and for each of the tsunami inundation scenarios by community[7].

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[5] Hazus SQL table [dbo].[eqUserDefinedFlty].

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

[7] 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 probability of damage state (PDS) data for each building.

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. Thus, 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 5.0 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 post-disaster 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, for each community, we provide estimates of debris generated by the earthquake and the three tsunami scenarios.

Estimates of the amount of debris (expressed as tonnage) generated by the earthquake can be obtained using guidelines provided by FEMA (2010). Our building debris estimates combine guidelines provided by FEMA (2013, Chapter 7, and 2011, Chapter 12). The Hazus tsunami model, when run in conjunction with the Hazus earthquake model, provides the combined probability of damage states 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 probability of damage states estimate for each building (Section **2.5.3**), we estimated the debris tonnage using the FEMA (2011) equation 12-3.

2.6 Injury and Fatality Estimation

We independently evaluated injuries and fatalities resulting from a CSZ earthquake and tsunami, using, the Hazus AEBM model (FEMA, 2010) and the Hazus tsunami model (FEMA, 2017), 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 (FEMA, 2010) to calculate injuries and fatalities, populating the individual buildings with the permanent and temporary population, 2 AM 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). According to FEMA (2011), casualties (both injuries and fatalities) are classified into four levels: minor injuries, injuries requiring hospitalization, life-threatening injuries, and deaths (**Table 2-4**).

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.

Earthquake-induced casualties have been summarized by community, casualty level, and resident status (permanent versus temporary). For comparison with the Hazus tsunami casualty model, we summarized earthquake casualty levels 1 through 3 as “injuries” and casualty level 4 as “fatalities.” We note that in Oregon coastal communities, most residents occupy wood-frame structures at 2 a.m., and such structures are much less likely to be severely damaged in an earthquake compared to other building types (FEMA, 2011).

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 zone have acute awareness of the impending tsunami, that they possess knowledge of or can quickly determine the most optimal route to a tsunami safety area, 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). Although human behavior in an emergency is likely to be highly variable, we believe the results from the Hazus tsunami casualty model provide critically important data for planners to assess the likely impacts of a tsunami and identify areas in their communities where injury and fatality rates will likely be higher, while also providing the ability to quantify the efficacy of proposed 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 standalone 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 needed 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 project requires a model with considerable flexibility for evaluating alternative population and evacuation scenarios (including distinguishing temporary and permanent residents), and, crucially, for testing population assumptions and model parameter settings.
3. 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 objective, which includes a more refined population model disbursed across individual buildings and campgrounds.

More detail on our spreadsheet casualty model is provided by 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. Furthermore, tsunami modeling by Witter and others (2011) indicates that the maximum tsunami runup from a CSZ earthquake is typically associated with the first wave arrival[8].

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 "Beat the Wave" efforts undertaken for multiple coastal communities (Gabel and Allan, 2016, 2017; Gabel and others, 2018a,b, 2019a,b,c,d, 2020a; Priest and others, 2015) 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

[8] 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.

measured on a map. In this report, 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 tsunami 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 further 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 previously for multiple communities including Florence and Reedsport (Gabel and others, 2018b) and the Coos estuary (Gabel and others, 2019b); modeling is currently underway for Bandon. For the purpose of this countywide Hazus assessment, we used the most conservative bridge-out scenario, to account for the likely failure of non-retrofitted bridges. Bridges that have been retrofitted or rebuilt to current engineering standards are designed to withstand the intense ground motion caused by the earthquake.

2.6.2.3 Departure time

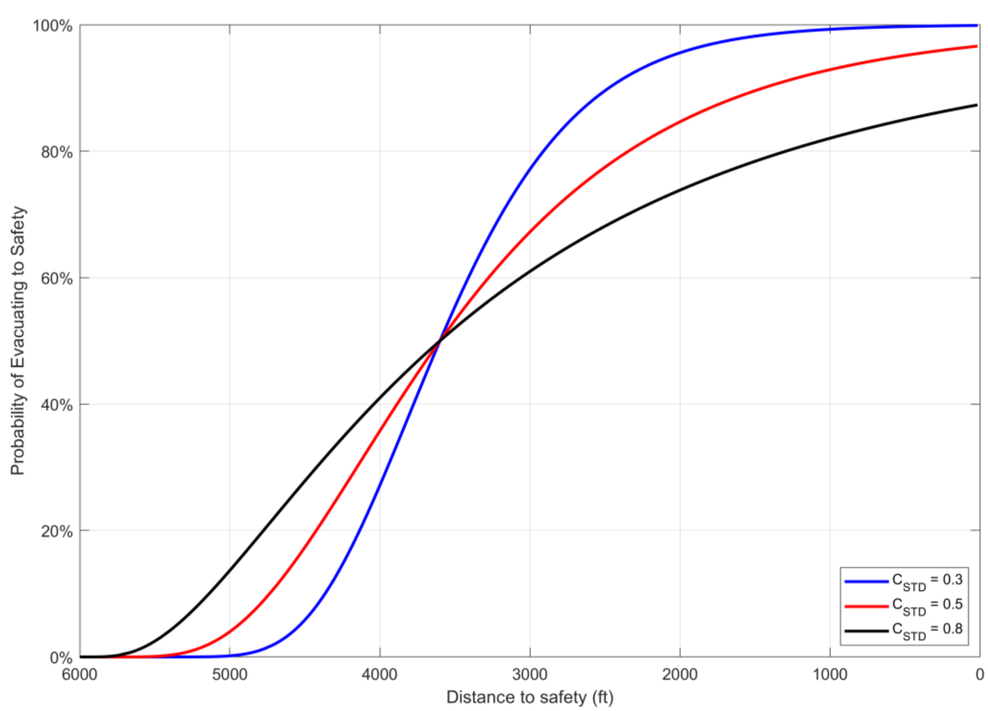
The Hazus tsunami casualty model uses the term "Community Preparedness Level" to reflect the time between the tsunami warning (i.e., earthquake shaking) and actual evacuation of the community (FEMA, 2017). The degree of preparedness is classified according to three categories — good, fair, or poor — 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 such designations do not truly reflect a community's level of preparedness given the large uncertainty in individuals' hazard awareness, their knowledge of evacuation routes, their actual response at the time of the event, and the degree of pre-disaster preparation undertaken by communities to prepare for such an event. Thus, for the purposes of this report we chose not to use the "Community Preparedness" terminology; instead, 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). In this study, we provide injury and fatality estimates assuming 10-minute (good) and 15-minute (fair) group departure (delay) times; we did not model a poor preparedness level, as the casualty numbers associated with this specific category are very large and probably unrealistic.

The 10-minute (*good*) departure delay is the default value used in all our BTW tsunami evacuation modeling and refers to the time elapsed since the start of the earthquake. It accounts for up to five minutes of earthquake shaking during which people drop, cover, and hold on, followed by an additional five minutes of individual preparation — donning shoes and outdoor clothing, gathering immediate 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 additional delay time causes community fatalities to increase significantly.

The departure time is assumed to be the group median value. In reality, some individuals may leave earlier and others later. 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-minute and 15-minute departure times, respectively, corresponding to the good/fair community preparedness levels noted above; theses values are the default standard deviation (C_{STD}) recommendations provided by FEMA (2017, Table 6.3). **Figure 2-2** illustrates the probabilistic nature of the lognormal distribution model. It assumes a group departure time of 10 minutes, a walking speed of 1.2 m per second (mps) (4 fps), and a wave arrival time of 25 minutes. An individual departing given those specifications can cover 1,097 m (3,600 feet). 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 0 and 1. As a result, an individual having traveled 1,097 m (3,600 feet) is not assumed to have safely evacuated but instead is assigned a probability of 0.5 of evacuating safely. As previously discussed, this value accounts for dispersion in departure times and walking speeds. Note the asymmetric nature of the lognormal distribution: it implements a conservative assumption regarding a tendency for humans to delay their departure times.

Figure 2-2. 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 1.2 m per second (4 fps), and variations in the lognormal standard deviation term (C_{STD}).



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 understudied concern may be important in 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). The situation can also arise due to unsecured nonstructural elements such as large bookcases that are likely to tip over during shaking and 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.

2.6.2.4 Evacuation speed

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

The Hazus tsunami casualty model incorporates a travel (walking) speed reduction factor for persons aged 65 and over (FEMA, 2017). This assumption is based on analyses of fatalities in recent tsunamis (González-Riancho Calzada and others, 2015; Koyama and others, 2012; Suppasri and others, 2016). Accordingly, we used a 0.8 walking speed reduction factor to account for travel speeds used by persons ≥65, which equates to an evacuation speed of 1 mps (3.2 fps, or 2.2 mph). It is important to emphasize that travel speed is modeled for the group average (median) and is applicable for the entire evacuation route.

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

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

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 start of the earthquake and when the population begins evacuating, and WalkSpeed is the specified travel (walking) 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**). As noted previously (Section **2.6.2.3**), although the group average (median) departure time may be 10 minutes, the Hazus tsunami casualty model accounts for individual variations from the group average by using the cumulative lognormal distribution and dispersion factor.

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 1.8 m (6 feet; FEMA, 2017). Conversely, where the tsunami wave depth is less than 1.8 m (6 ft) the model assumes a likelihood of 50% fatality and 50% injury for individuals caught by the tsunami; 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 1.8 m (6 ft) and the 0-elevation contour (tsunami safety) is generally small compared to the typical distance to safety an individual must travel. Analyses by Bauer and others (2020) indicated that these partial safety distances along the open coast range from ~30 to 90 m (100 to 300 feet, **Figure 2-3**) from the tsunami inundation runup limit. However, more recent evaluations suggest that the partial safety zone can in fact vary substantially, especially in areas subject to broad gentle slopes (**Figure 2-3**). To address this issue, we defined a partial safety zone by creating a depth grid in which all areas of the raster <1.8 m (6 ft) were extracted. The extracted partial safety raster was then manually reviewed, and any false islands or spurious data were removed. Accordingly, the casualty estimates are reduced to 50% once individuals reach this latter zone. The Hazus tsunami casualty model provides injury and fatality estimates for each individual, with a likelihood between 0 and 1. We summarize the individual injury and fatality likelihoods to obtain overall injury and fatality estimates at the community level.

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		Distance Walked (in feet) for Various Departure Times (in minutes)			
		fps	mph	5 min	10 min	15 min	20 min
15	Slow Walk	2	1.4	1,200	600	—	—
	Moderate Walk	4	2.7	2,400	1,200	—	—
	Fast Walk	6	4.1	3,600	1,800	—	—
	Jog	8	5.5	4,800	2,400	—	—
	Run	10	6.8	6,000	3,000	—	—
20	Slow Walk	2	1.4	1,800	1,200	600	—
	Moderate Walk	4	2.7	3,600	2,400	1,200	—
	Fast Walk	6	4.1	5,400	3,600	1,800	—
	Jog	8	5.5	7,200	4,800	2,400	—
	Run	10	6.8	9,000	6,000	3,000	—
25	Slow Walk	2	1.4	2,400	1,800	1,200	600
	Moderate Walk	4	2.7	4,800	3,600	2,400	1,200
	Fast Walk	6	4.1	7,200	5,400	3,600	1,800
	Jog	8	5.5	9,600	7,200	4,800	2,400
	Run	10	6.8	12,000	9,000	6,000	3,000
30	Slow Walk	2	1.4	3,000	2,400	1,800	1,200
	Moderate Walk	4	2.7	6,000	4,800	3,600	2,400
	Fast Walk	6	4.1	9,000	7,200	5,400	3,600
	Jog	8	5.5	12,000	9,600	7,200	4,800
	Run	10	6.8	15,000	12,000	9,000	6,000

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

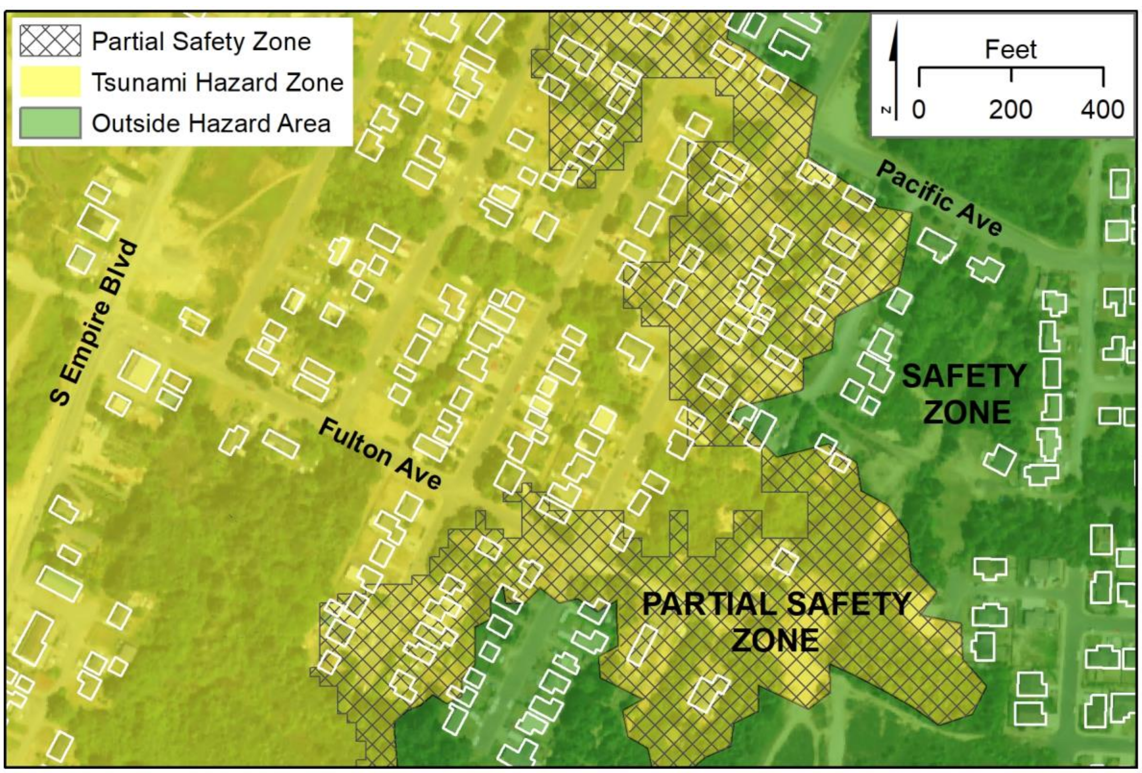
2.6.2.6 Sensitivity testing

We varied evacuation speeds (2 to 10 fps in 1-fps 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. Furthermore, when presented in graphical form, these data can be used in education and outreach materials to reinforce existing tsunami evacuation messaging, stressing key points such as the need to evacuate immediately and, importantly, to travel as fast as possible in order to reach safety in time. 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 a timely manner as they may be disoriented, need to tend to their own injuries or injuries sustained by another household member, or have sustained injuries that prevent or slow an on-foot 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. Furthermore, large-scale natural disasters are known to contribute to illness, injury, or death from other factors such as 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. Quantifying these latter causes of injury or death were beyond the scope of the present investigation.

Figure 2-3. Example of median tsunami depth zone for an XXL1 tsunami at Empire, Coos County (yellow shading) and partial safety zone (hashed area), where the median water depth falls below 2 m (6 ft) near the tsunami inundation limit, per Hazus methods (Section 2.6.2.5). The green zone defines the safe area outside of the tsunami zone. Buildings depicted in white.



2.6.4 Displaced population

For mass care planning purposes, we calculated the number of uninjured individuals likely to have safely evacuated from the tsunami zone. Those individuals will need shelter, as their homes, motels, recreational vehicles, boats, and tents are assumed to be destroyed 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

We provide the names of essential facilities, special facilities, and key infrastructure located within each city's tsunami zone. For this report we use the "essential facility" definition provided in Oregon Revised Statute 455.447, "Regulation of certain structures vulnerable to earthquakes and tsunamis; rules" (2017[9]):

"Essential facility" means:

(A) Hospitals and other medical facilities having surgery and emergency treatment areas.
(B) Fire and police stations.
(C) Tanks or other structures containing, housing or supporting water or fire-suppression materials or equipment required for the protection of essential or hazardous facilities or special occupancy structures.
(D) Emergency vehicle shelters and garages.
(E) Structures and equipment in emergency-preparedness centers.
(F) Standby power generating equipment for essential facilities.
(G) Structures and equipment in government communication centers and other facilities required for emergency response.

We define a "special facility" as one that is likely to contain population segments that may present additional tsunami evacuation challenges. This builds on, but is not limited to, the "special occupancy structure" definition provided in Oregon Revised Statute 455.447. Examples include assisted living facilities, detention facilities, facilities where groups of children are placed in the care of non–family-member adults, and facilities with particular focus on persons with a disability. Facilities with incidental usage by persons with disabilities are not included. Geocoded Quarterly Census of Employment and Wages (QCEW) data obtained from the Oregon Employment Division in September 2018 was another dataset used to evaluate other potential facilities. We created a lookup table wherein we identified a subset of employer types based on their six-digit North American Industrial Classification System code (OMB, 2017) that may host a population that may face additional tsunami evacuation challenges. The table was joined to the QCEW data, which identified specific businesses that could be considered a special facility.

Although great care was taken to develop as complete a list of special facilities in the tsunami zone as feasible, it is acknowledged that not all businesses may have been included. This is mainly because of the provisional nature of the QCEW data, such that some business locations may not have been captured in our overlay analysis. Furthermore, it is important to note that the designation of a building as a "special

[9] https://www.oregonlegislature.gov/bills_laws/ors/ors455.html

facility" should not be interpreted as any statement on the building owner or operator's level of tsunami preparedness. The analysis simply identifies those businesses located in the tsunami zone.

The "key infrastructure" list includes facilities necessary for community recovery but not covered in the essential facilities list and includes such facilities as water treatment plants and electrical substations. We constructed this list from visual inspections of orthoimagery and other ancillary geospatial data sources such as Homeland Infrastructure Foundation-Level Data (https://gii.dhs.gov/hifld/). As with the essential facilities and special facilities list, every effort was taken to develop as complete a list as possible.

2.8 Social Characteristics

The Department of Land Conservation and Development (DLCD; 2015) recommended that a tsunami risk and vulnerability assessment include analyses of the characteristics and locations of populations that may have additional needs or requirements for evacuation. Our modeling allowed us to provide demographic information classified into two broad age groups — <65 years of age and ≥65 years — for each tsunami zone. In addition to basic demographic information, we further queried the ACS data (U.S. Census Bureau, 2018, 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 2014–2018 ACS five-year estimates were based on data collected between January 1, 2014, and December 31, 2018. We chose the ACS five-year estimates based on U.S. Census guidance for smaller geographies (U.S. Census Bureau, 2018, Table 3.1). We note that the ACS estimates are for the city jurisdiction and not its UGB, and that the ACS data are not available by tsunami zone or at any unit finer than the city. 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.

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 imagery. 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

The weight of damaged building contents such as refrigerators and furniture and, where applicable, business inventory such as groceries were not included in our estimates of debris. Furthermore, 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 damaged automobiles, trucks, recreational vehicles, shipping containers, boats, and logs in staging areas are not included, but an estimate can be obtained by using the weights provided by FEMA (2013, Table 7.6). Estimates of the weight of sediment redistributed across the landscape or vegetation removed and transported by the tsunami were also excluded from our analyses.

Commercial movers provide guidelines for estimating the weight of typical household content (e.g., https://www.isapa.org/estimate-weight-household-goods-moving/). The contents of a three-bedroom house is generally estimated to weigh around five tons. Although we do not report on content damage in this study, a reasonable assumption is that nearly all the content of a house in the tsunami zone will be destroyed and will be added to the total debris. The building database developed for this study could be used to calculate the added weight of debris associated with household content.

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, 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 zone are derived from U.S. Census data collected in 2010 and ACS data maintained by the U.S. Census Bureau. This approach differs from the approach of Bauer and others (2020), which used Oregon Department of Motor Vehicle records to identify the number of permanent people in the tsunami zone.

Table 2-6 presents results for four communities where we can compare the approach of Bauer and others (2020) to the approach developed here. With respect to defining the population, **Table 2-6** highlights two differences. First, both approaches yield comparable permanent population numbers in the communities of Gearhart and Rockaway Beach. This is due entirely to the fact that both these communities are virtually 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 are significantly (~20% to 40%) higher when compared with the DMV approach. There are three possible explanations. First, it may be a function of both communities having narrow inundation zones (having been built on high ground), with large portions of the communities outside of the tsunami zone. Thus, the CBGs in these areas account for people located outside of the tsunami zone. Hence, the process of distributing the permanent population across the UDFs based on those buildings in the tsunami zone may be overestimating the number of people actually residing in the tsunami 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, it is possible that Bauer and other (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 the population model approach developed in these countywide assessments are generally lower, when compared with the Bauer and others (2020) approach. For example, the visitor population in Lincoln City is substantially 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 for Lincoln City; this was the preferred choice by community planners. However, for the purposes of this study, we chose to use a standard value of two people per room. Despite the lower numbers of temporary visitors observed in our latest population modeling and given the large uncertainty in the numbers of visitors in any given community on any given day, we remain confident in our overall estimates of potential visitor numbers in coastal Lincoln County.

Table 2-6. Comparison of the Bauer and others (2020) population model approach 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	XXL	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 census block group, 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. In the approach developed here, great care was taken to evaluate building attributes within the XXL inundation 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 such as an apartment, it likely contains both permanent and temporary residents, but if it is a hotel then it only contains temporary residents.
3. What is the square footage of the building? Depending on the occupancy type, the square footage determines the number of units/rooms, which influences the number of residents estimated to live there.

Manually checking the many thousands of buildings outside of the tsunami zone is challenging. An example of how the population statistics may be skewed is described here. Consider an apartment building housing 200 permanent residents that is located partly outside the tsunami zone, but within a CBG; the latter includes an area both within and outside the tsunami zone. Because the apartment building is located outside of the tsunami zone, it may have been skipped for further evaluation. However, because the apartment is included in the census block group, those 200 people are inadvertently counted as residing in the tsunami zone.

Continuing with this example, let us say that the apartment building was categorized as a hotel and no permanent 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 categorized as a residential building – that means no residents are assigned to it.
2. The square footage is incorrect. That means that either more people or fewer people will be assigned to the building than is realistic.

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

Our assignment of 0.318 children for every adult between 18 and 64 years of age (described by Bauer and others, 2020, Appendix B) may either overestimate or underestimate actual numbers. 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 zone who are experiencing homelessness. Homeless encampments are likely present within the tsunami 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 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 vehicles 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 (Johnston and others, 2013), choose not to evacuate. 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.

Other non-behavior factors that the model does not account for include structural failures in a building leading to jammed doorways and blocked hallways and doorways, all of 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 evacuation 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 understudied concern may be especially pronounced in older manufactured housing units 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, debris, injuries, fatalities, etc.) for communities along the Coos, Douglas, and Lane County coastline. Each community is characterized by diverse population demographics, historical and contemporary development patterns, socioeconomic characteristics, tsunami risk, and bathymetric, topographic, and geologic circumstances that influence evacuation potential and building damage. These factors in turn influence community preparation, response, and, ultimately, recovery following a CSZ earthquake and tsunami.

3.1 Population Demographics

Summary population and demographic information for coastal Coos, Douglas, and Lane counties is presented in **Table 3-1** and **Figure 3-1**. Both identify the permanent population within each community's tsunami zone and include a conservative estimate of the temporary population that may also be present. As a reminder, the temporary population is determined from a summer 2 AM weekend scenario that maximizes visitor occupancy (i.e., assumes 100% occupancy in all hotel/motels, vacation homes and camping spots). Examination of **Table 3-1** indicates the following results:

1. The total population present on the Lane, Douglas, and Coos county coastline within a tsunami zone reflect the following:
    a. *Lane County*: ranges from ~550 (M1) to ~1,870 (XXL1) permanent residents (**Table 3-1**), increasing to ~2,600 (M1) to ~6,040 (XXL1) people when accounting for the temporary visitor population.
    b. *Douglas County*: ranges from ~1,050 (M1) to ~1,970 (XXL1) permanent residents (**Table 3-1**), increasing to ~3,360 (M1) to ~5,430 (XXL1) people when accounting for the temporary visitor population.
    c. *Coos County*: ranges from ~1,330 (M1) to ~10,340 (XXL1) permanent residents (**Table 3-1**), increasing to ~4,970 (M1) to ~20,850 (XXL1) people when accounting for the temporary visitor population.

Such dramatic increases in the local coastal population are indicative of the large number of vacation homes, hotels/motels, and campgrounds distributed throughout the three coastal counties.

2. As expected, the number of permanent and temporary residents within each tsunami zone increase as the tsunami inundation zone increases (i.e., from M1 to XXL1, **Figure 3-1**). By far the largest change occur between the L1 and XXL1 tsunami scenarios, especially in Barview, Charleston, and Bandon.
3. The fraction of the total permanent resident population residing within the three tsunami zones varies widely among communities and parks (**Figure 3-1**). For example, Winchester Bay is mostly located in the M1 tsunami zone and is 100% within the L1 and XXL1 tsunami zones (**Table 3-1**). Siltcoos, Sunset Bay, and the Bullards Beach campground are 100% inundated in all three scenarios. Barview, Charleston, and Bandon each have relatively large numbers of people located in the XXL1 tsunami zone (73%, 52%, and 68% respectively). Within the L1 zone, Charleston, Umpqua South Jetty, and Reedsport have 33%, 49%, and 24% of their populations in the tsunami zone, respectively. For the M1 scenario, communities with the largest number of people in the tsunami zone include Charleston (32%), Winchester Bay (54%), and Umpqua South Jetty (49%). Thus, Winchester Bay, Charleston and the Umpqua South Jetty are especially vulnerable since they have a relatively large proportion of their permanent (and visitor) populations in all three tsunami zones.
4. Florence, Dunes City, Lakeside, North Bend and Coos Bay have relatively few people in the various tsunami zones (**Figure 3-1**, center plot). Florence and North Bend are largely perched on marine terraces and therefore are mostly elevated out of the tsunami inundation zone. Similarly, Dunes City and Lakeside have few people in the tsunami zones, due to these communities being located at the distal end of the tsunami zone such that the tsunami has lost much of its energy as it travels up the Siltcoos River and Tenmile Creek.
5. All 17 communities and parks can experience relatively large influxes of visitors, with totals far exceeding their local resident populations (**Table 3-1** and **Figure 3-1**, right plot). Of note, Florence can swell by ~420% to 300% (M1 to XXL1), Winchester Bay can increase by ~1,360% to 950% (M1 to XXL1), and Bandon can increase by ~210% to 225% (M1 to XXL1). Accordingly, **Figure 3-1** demonstrates the importance of each of these communities as major tourist destinations with potentially large numbers of visitors located in the tsunami zones. Accompanying their popularity as centers of tourism, are challenges associated with preparing such a large transient population for a CSZ earthquake and tsunami.

Table 3-1. The number of residents in the tsunami-hazard zone for coastal communities in Coos, Douglas, and Lane counties, Oregon, based on census block and tsunami-hazard data.

Community	Total Permanent Resident Population	Combined Population (Permanent + Temporary[1])	Number of Permanent Residents			Permanent Residents (%)[2]			Number of Temporary Residents[1]			Permanent + Temporary Percent (%) Increase		
			Medium	Large	XX-Large	Medium	Large	XX-Large	Medium	Large	XX-Large	Medium	Large	XX-Large
Florence	10,291	16,669	404	612	1,326	4	6	13	1,289	1,622	2,709	10	13	24
Dunes City	1,208	2,555	3	6	43	0	0	4	6	11	109	0	1	6
Siltcoos	2	518	2	2	2	—	—	—	516	516	516	100	100	100
Other	5,871	9,796	141	286	495	2	5	8	232	454	841	4	8	14
Lane County Total	17,372	29,538	550	906	1,866	2	4	8	2,043	2,604	4,175	29	30	36
Reedsport	3,932	5,241	553	954	1,115	14	24	28	384	497	635	18	28	33
Winchester Bay	227	2,107	121	222	222	54	98	98	1,527	1,873	1,873	78	99	99
Umpqua South	83	389	41	41	43	49	49	52	301	301	301	88	88	88
Other	1,654	2,612	339	409	594	20	25	36	90	560	644	16	37	47
Douglas County Total	5,896	10,350	1,054	1,626	1,974	34	49	53	2,303	3,231	3,454	50	63	67
Lakeside	1,709	2,386	0	4	108	0	0	6	0	4	68	0	0	7
Coos Bay	15,652	19,483	448	1,022	2,517	3	7	16	545	1,054	1,630	5	11	21
North Bend	9,592	12,123	58	469	1,255	1	5	13	169	209	1,000	2	6	19
Barview	3,122	5,022	147	464	2,286	5	15	73	779	965	1,690	18	28	79
Charleston	190	724	61	62	98	32	33	52	475	476	487	74	74	81
Sunset Bay Park	0	425	—	—	—	—	—	—	425	425	425	100	100	100
Bullards Beach	5	669	5	5	5	100	100	100	284	664	664	43	100	100
Bandon	3,227	6,748	310	465	2,182	10	14	68	338	766	2,706	10	18	72
Other[3]	26,327	36,291	300	838	1,892	1	3	7	626	994	1,833	3	5	10
Coos County Total	59,824	83,872	1,328	3,329	10,343	7	11	34	3,642	5,557	10,503	28	38	54

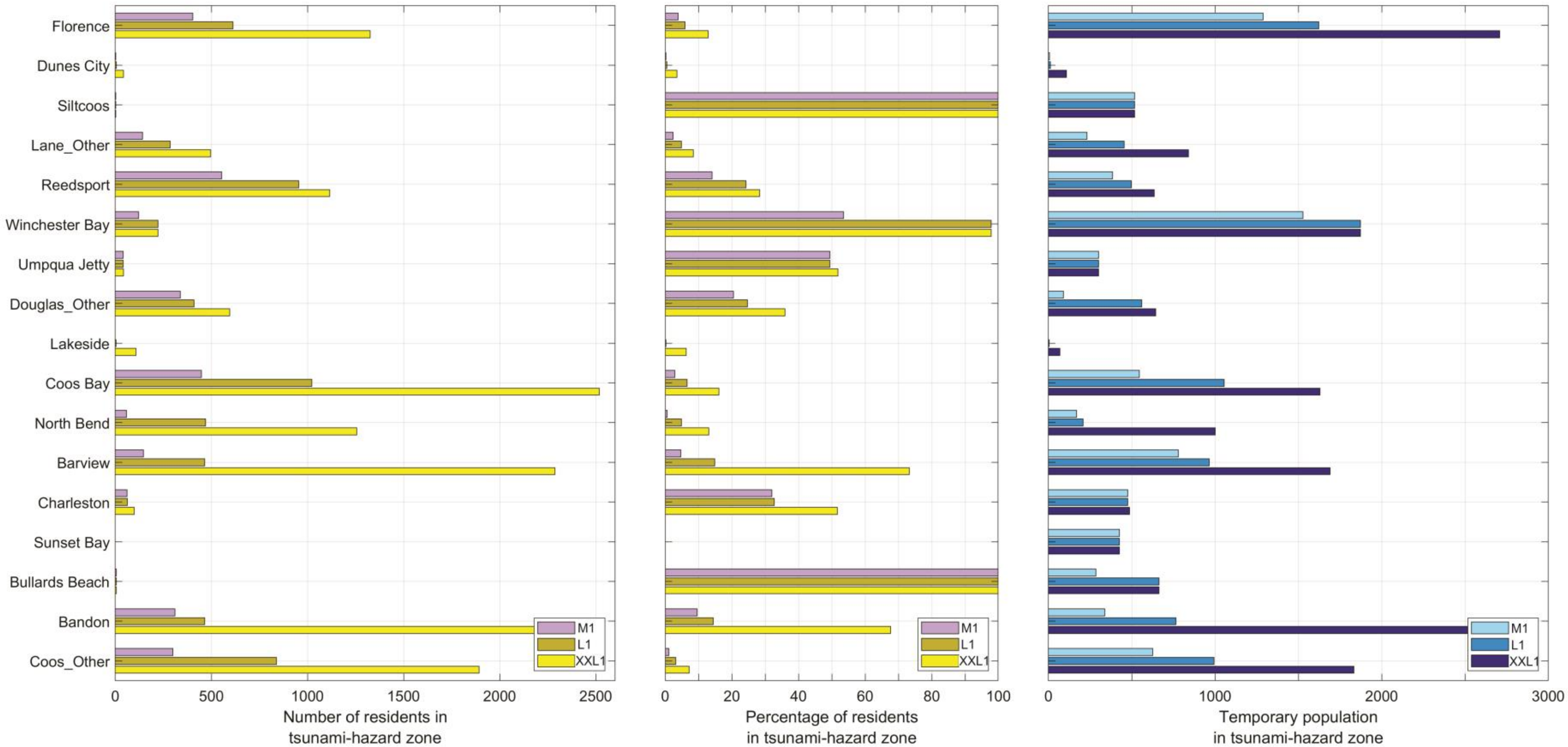
Notes:

[1] Assumes 100% occupancy of second homes, vacation rentals, condominium units, bed and breakfast facilities, hotels, motels, and campgrounds.

[2] Expressed as a proportion of the total resident population.

[3] Denotes all other areas impacted by a Cascadia earthquake and tsunami.

Figure 3-1. A breakdown of permanent and temporary populations inside the tsunami zone, by community. Left and center show the number and ratio, respectively, of permanent residents. Right shows the number of temporary (visitor) population. Note the larger x-axis, highlighting the significant influx of visitors to many of these communities.



Notes:

Percentage of residents expressed as a proportion of the total resident population.

Temporary population estimate assumes 100% occupancy of second homes, vacation rentals, condominium units, bed and breakfast facilities, hotels, motels, and campgrounds.

Figure 3-2 and **Table 3-2** differentiate the local resident population by age group (<65 and ≥65 years of age). Resident age has an important bearing on the ability of people to evacuate quickly, as it directly relates to the speed at which people may be able to travel by foot; recall that the evacuation speed for those ≥65 is reduced by 20% (a 0.8 walking speed reduction factor, see section 2.6.2.4). Thus, communities with larger numbers of people ≥65 years of age may want to consider evaluating where these people are situated, with a focus toward developing community evacuation response plans specific to their needs (e.g., prioritizing mitigation efforts such as constructing a vertical evacuation structure in one part of town over another because more older adults live in that area). As can be seen from **Table 3-2**, the countywide resident population ≥65 for Lane, Douglas, and Coos counties are:

1. *Lane County*: ~35% of the total population in the M1 and L1 tsunami zones, increasing slightly to 36% for XXL1; this equates to ~189, 324, and 715 Lane County residents ≥65 years of age in the M1, L1, and XXL1 zones, respectively.
2. *Douglas County*: ~34% of the total population in all three tsunami zones; this equates to ~325, 526, and 617 Douglas County residents in the M1, L1, and XXL1 zones, respectively, who are ≥65 years of age.
3. *Coos County*: ~33% of the total population in the M1 tsunami zone, decreasing to 31% in the L1 and 28% in the XXL1 tsunami zones; this equates to ~436, 914, and 2,749 Coos County residents in the M1, L1, and XXL1 zones, respectively, who are ≥65 years of age.

The actual number of people age ≥65 and older varies from one community to another, with Florence, Winchester Bay, and Bandon each having a much larger proportion (41%) of people ≥65 in the XXL1 tsunami inundation zones then other communities (**Table 3-2**).

Figure 3-2. Local resident population demographics. Example provided is for the XXL1 tsunami zone. Community profiles in Appendix A provide similar statistics for the M1 and L1 tsunami zones.

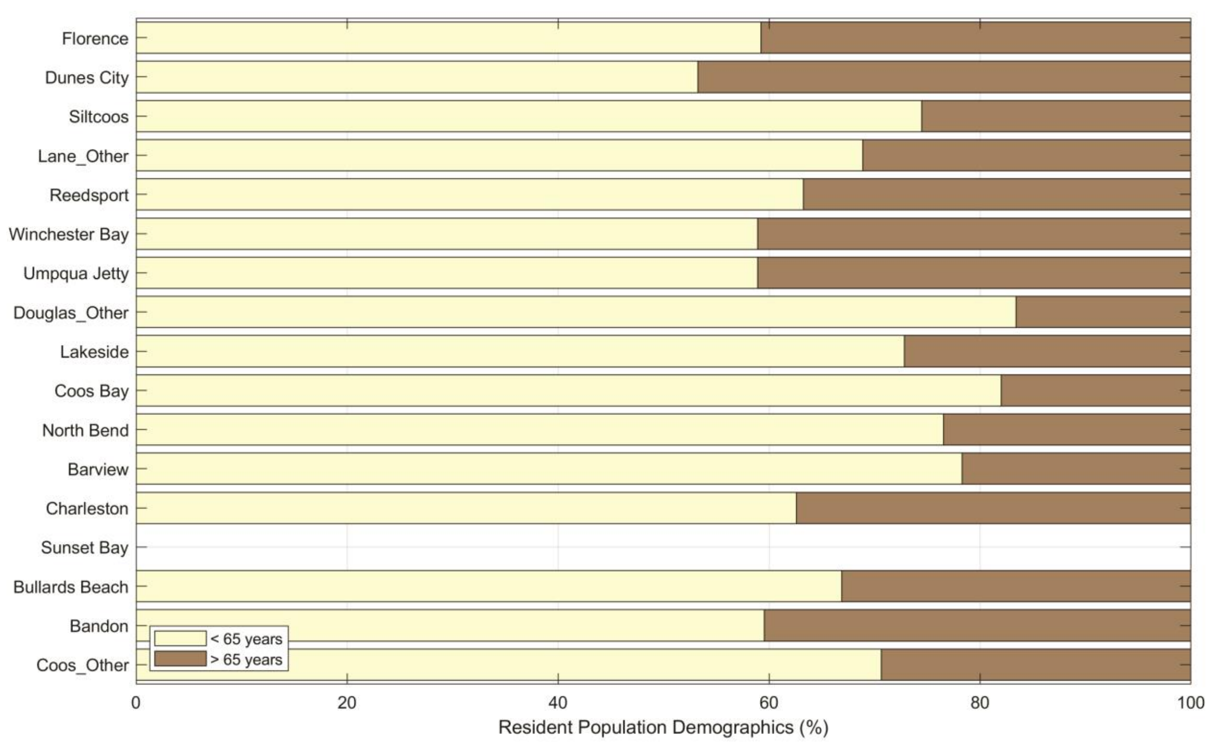


Table 3-2. Permanent resident age demographics per tsunami zone.

	M1			L1			XXL1		
Community	**<65**	**≥65**	**Older Age Ratio[1]**	**<65**	**≥65**	**Older Age Ratio[1]**	**<65**	**≥65**	**Older Age Ratio[1]**
Florence	259	144	36	379	233	38	785	541	41
Dunes City	2	1	47	3	3	47	23	20	47
Siltcoos	2	1	26	2	1	26	2	1	26
Other[2]	98	43	30	198	88	31	341	154	31
Lane County Total	361	189	35	582	324	35	1,151	715	36
Reedsport	349	204	37	603	352	37	705	409	37
Winchester Bay	71	50	41	131	91	41	131	91	41
Umpqua South	24	17	41	24	17	41	25	18	41
Other[2]	284	55	16	343	66	16	496	99	17
Douglas County Total	729	325	34	1,100	526	34	1,357	617	34
Lakeside	0	0		3	1	25	79	29	27
Coos Bay	385	63	14	858	163	16	2,065	453	18
North Bend	43	15	26	351	118	25	961	295	23
Barview	119	28	19	355	110	24	1,790	496	22
Charleston	38	23	37	39	23	37	61	37	37
Sunset Bay Park	NA	NA	NA	NA	NA	NA	NA	NA	NA
Bullards Beach	4	2	33	4	2	33	4	2	33
Bandon	107	203	65	182	283	61	1,299	883	40
Other[2]	197	103	34	624	214	26	1,336	556	29
Coos County Total	892	436	33	2,415	914	31	7,594	2,749	29

Notes:

[1] Ratio of ≥65 relative to total resident population.

[2] Denotes all other areas impacted by a Cascadia earthquake and tsunami.

3.2 Building Damage and Debris

The number of residents (permanent and temporary) per building occupancy type and within the XXL1 tsunami zone is provided for each community in **Table 3-3** and summarized graphically in **Figure 3-3**. Apparent from both the table and figure are notable differences in where people live or visit among the communities. Permanent residents overwhelmingly reside in single-family dwellings, especially in Bandon (70%), Barview (69%), and Dunes City (69%). Multifamily residential buildings in the XXL tsunami zone are more common in North Bend (60%), Coos Bay (46%), Charleston (39%), Florence (37%), and Reedsport (31%). The Umpqua Jetty area (60%) reflects a small sub-section of the Winchester Bay community that contains few buildings as it is mostly dedicated to camping. Countywide averages for permanent residents reflect the following:

1. *Lane County*: single-family residential (74%), manufactured housing (13%), and multifamily residential (13%).
2. *Douglas County*: single-family residential (34%), manufactured housing (29%), and multifamily residential (37%).
3. *Coos County*: single-family residential (60%), manufactured housing (14%), and multifamily residential (25%).

There are notable differences in the predominant building occupancy type among the communities with respect to temporary residents. For example, hotel/motel availability is highest in Coos Bay (52%), followed by North Bend (50%), Florence (27%), Reedsport (26%), and Bandon (23%, **Table 3-3**; **Figure 3-3**). Apparent also from **Figure 3-3** are the large number of single-family residential rental units or vacation homes (e.g., VRBO or Airbnb) available throughout the three coastal counties. For example, Bandon is characterized with a large number (63%) of second homes that are used by temporary visitors, while 37% of homes in Florence are listed as second homes and may be used for vacation purposes. Similarly, Lakeside (84%), Barview (34%), and Reedsport (23%) also have notable numbers of vacation homes. RV and tent sites are particularly abundant in Winchester Bay (82%), Umpqua Jetty (95%), Charleston (82%), Barview (61%), and North Bend (32%); RV and tent camping comprise 100% the occupancy at Siltcoos, Bullards Beach and the Sunset Bay campgrounds. These latter results are especially important as they identify those locations where there are likely to be high visitor concentrations in the tsunami zone. Visitors may have little knowledge of the earthquake and tsunami risk and are less likely to know what to do following a major earthquake or how to locate the nearest area of high ground.

The number of permanent and temporary residents residing in single-family residential buildings in coastal Lane, Douglas, and Coos counties is further evaluated in the final two columns of **Table 3-3**. We focus on single-family residential buildings because they are the dominant housing type on the Oregon Coast and account for a potentially large group of vacationers that may not be directly exposed to tsunami awareness material or evacuation guidance that is occasionally found in hotels, motels, and campgrounds (Bauer and others, 2020). As can be seen in **Table 3-3**, the countywide ratio of permanent residents to single-family homes averages ~1.7, 1.5, and 1.84 in Lane, Douglas, and Coos respectively. Unlike Lincoln, Tillamook, and Clatsop counties, where we identified a surplus of single-family residential homes relative to the actual permanent population in those communities, no such surplus is apparent for Lane, Douglas, and Coos counties.

Table 3-3. Number of residents (permanent and temporary) per building occupancy type in the XXL1 tsunami zone in each community.

Community	Total Number of Single-Family Residential Homes	Number of Residents														Ratio of Permanent Residents to Number of Single-Family Residential Homes	Ratio of Permanent and Temporary Residents to Number of Single-Family Residential Homes, Summer Weekend
		Single-Family Residential		Manufactured Housing		Multifamily Residential		Hotel/ Motel		Mobile[1]		Other[2]		Total[3]			
		Perm	Temp	Perm	Temp	Perm	Temp	Perm	Temp	Perm	Temp	Perm	Temp	Perm	Temp		
Florence	639	586	1,003	248	114	492	345	0	722	0	524	0	0	1,326	2,709	1.30	3.05
Dunes City	26	29	48	9	6	4	1	0	22	0	32	0	0	43	109	1.47	3.52
Siltcoos	1	2	1	0	0	0	0	0	0	0	515	0	0	2	516	2.19	3.15
Other	251	408	436	67	20	21	10	0	49	0	325	0	0	495	841	1.89	3.71
Lane County Total	917	1,025	1,488	324	140	517	356	0	794	0	1,397	0	0	1,866	4,175	1.72	3.36
Reedsport	527	394	144	378	78	343	80	0	167	0	167	0	0	1,115	635	1.46	1.89
Winchester Bay	186	80	127	106	49	35	40	0	114	0	1,543	0	0	222	1,873	1.00	1.95
Umpqua South Jetty	13	3	2	10	3	30	10	0	0	0	287	0	0	43	301	1.00	1.35
Other	162	351	161	58	4	186	25	0	0	0	454	0	0	594	644	2.52	3.54
Douglas County Total	888	827	433	552	134	594	154	0	280	0	2,451	0	0	1,974	3,454	1.5	2.18
Lakeside	49	70	58	31	9	6	2	0	0	0	0	0	0	108	68	2.07	3.43
Coos Bay	609	1,152	276	210	9	1,156	111	0	852	0	382	0	0	2,517	1,630	2.24	2.70
North Bend	268	473	108	25	2	757	65	0	503	0	322	0	0	1,255	1,000	1.86	2.27
Barview	968	1,587	570	571	52	128	19	0	15	0	1,034	0	0	2,286	1,690	2.23	2.87
Charleston	48	53	26	6	1	38	9	0	51	0	400	0	0	98	487	1.24	1.79
Sunset Bay Park	0	0	0	0	0	0	0	0	0	0	425	0	0	0	425	NA	NA
Bullards Beach	3	5	4	0	0	0	0	0	0	0	660	0	0	5	664	NA	NA
Bandon	988	1,395	1,693	227	37	364	210	0	624	0	143	0	0	1,986	2,706	1.64	3.39
Other[4]	1,140	1,478	793	338	32	37	5	0	5	0	938	0	59	1,852	1,833	1.59	2.32
Coos County Total	4,073	6,214	3,527	1,408	142	2,485	420	0	2,050	0	4,304	0	59	10,108	10,503	1.84	2.68

Notes:

[1] Mobile includes tents, boats, and recreational vehicles.

[2] Other includes dormitories, retirement villages and private camps.

[3] Aggregate of all permanent and temporary building occupancy types.

[4] Denotes all other areas impacted by a Cascadia earthquake and tsunami.

"Perm" is permanent and "Temp" is temporary population.

Figure 3-3. Building occupancy type for permanent (left) and temporary (right) residents in the XXL1 tsunami zone, by community. ***(continued on next page)***

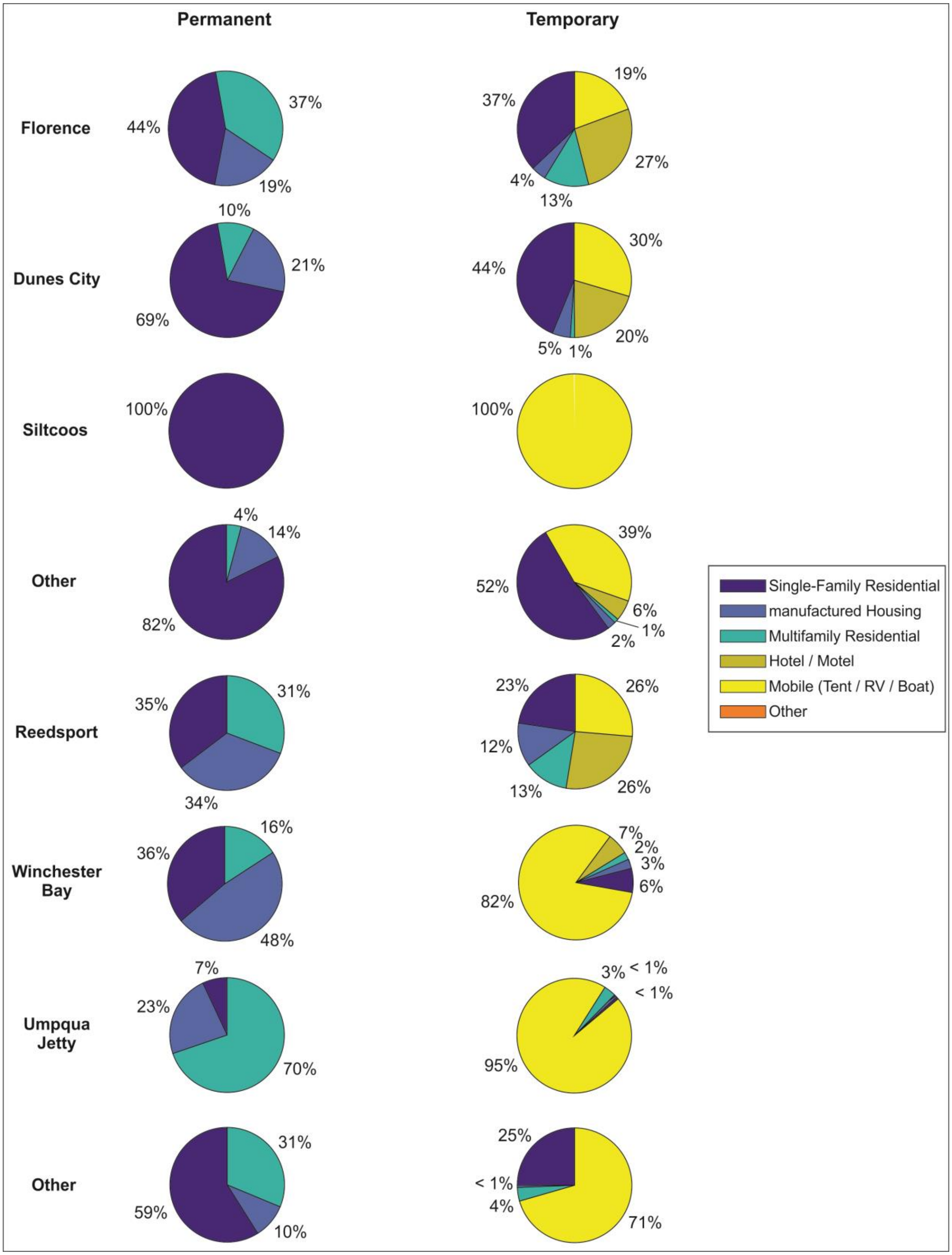
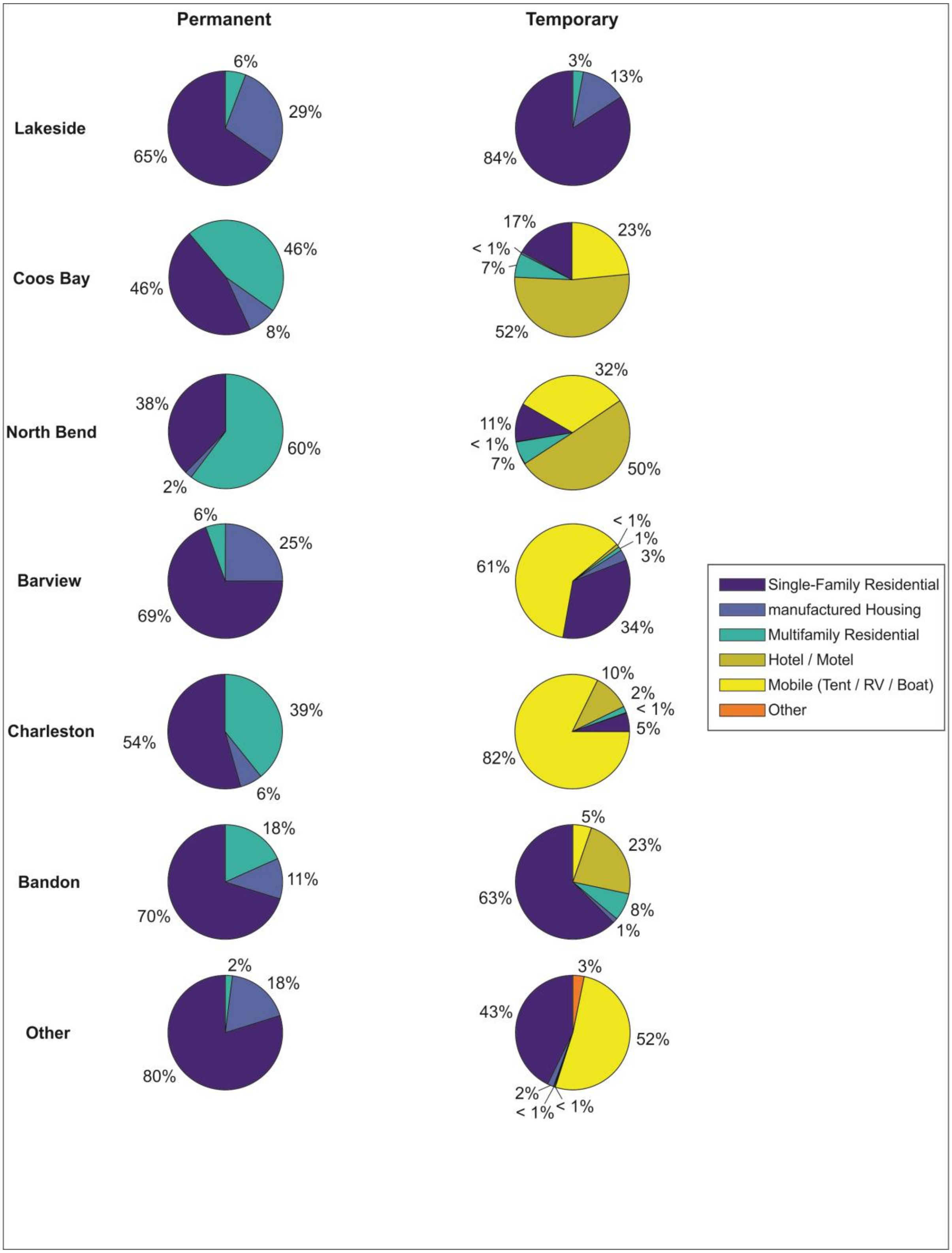


Figure 3-3. ***(continued)*** **Building occupancy type for permanent (left) and temporary (right) residents in the XXL1 tsunami zone, by community.**



An evaluation of the ratio of permanent and temporary visitors is provided in the final column of **Table 3-3**. It indicates the degree to which the local population may grow as visitors (predominantly vacationers) stay in those destinations. Larger ratios imply the availability of more beds, thereby highlighting those communities that are more likely to be major recreation destinations. In addition, the results may further help to highlight the importance of vacation homes, especially during a summer weekend when visits to the coast tend to be maximized compared with the baseline that considers just the permanent residents; compare the last two columns of **Table 3-3**. Bandon (3.4) and Florence (3.05) have the highest permanent and temporary populations relative to the number of single-family residential homes. Large ratios are also observed in the Lane and Douglas County "other" category (3.71% and 3.5%, respectively), which is likely capturing second homes located in the Heceta Beach and Gardiner areas. Hence, the local community in these areas may at times have an unusually large visitor population that may not be aware of the Cascadia tsunami hazard, let alone be prepared to deal with such an event.

Integral to pre- and post-disaster planning is knowledge of what will happen to buildings in the various communities because of earthquake ground motion and subsequent tsunami forces. These data are presented in **Table 3-4**. Note **Table 3-4** also includes estimates of the broader community-wide earthquake-related damage expected to occur both inside and outside of the tsunami zone. **Figure 3-4** graphically summarizes the results of **Table 3-4**.

The number of buildings located in each of the three tsunami zones is provided in the second through fourth columns of **Table 3-4** and plotted as bar graphs in **Figure 3-4** *(*upper left). Not surprisingly, Florence, Reedsport, Coos Bay, Barview, and Bandon have large numbers of buildings located in a tsunami zone. Nevertheless, in total the largest number of buildings occurs outside of the Coos County community boundaries and reflects those buildings summarized in the "other" category (~2,100). The bulk of these are residential buildings, established mainly along the shores of the Coos and Coquille estuaries, outside the city boundaries. For Charleston and to a lesser extent Umpqua River jetty, the relatively small change between M1 and XXL1 is indicative of the fact that these areas are inundated by tsunamis in all three scenarios, such that the exposure risk at these sites is especially high.

Building replacement costs (assuming complete destruction) are shown in **Figure 3-4** (upper right) for each of the tsunami zones. Coos Bay ($711 million), Bandon ($540 million), North Bend ($402 million), and Coos County "other" ($599 million) are likely to see significant building losses in the XXL1 tsunami zone. Countywide building replacement costs for each tsunami zone reflect the following:

1. Lane County: total $152 million (M1), $223 million (L1), and $385 million (XXL1).
2. Douglas County: total $204 million (M1), $306 million (L1), and $372 million (XXL1).
3. Coos County: total $675 million (M1), $1.25 billion (L1), and $2.63 billion (XXL1).

Damage caused by earthquake shaking is presented in **Figure 3-4C** for each tsunami zone, along with the community-wide earthquake-related damage estimate (cyan bars). These latter data reflect earthquake damage across the entire community urban growth boundary along the Oregon Coast. Since Lane and Douglas counties extend well into the Willamette Valley, we exclude those areas from the analyses and results presented here. As can be seen in **Table 3-4**, the costs associated with earthquake damage across the three tsunami zones are estimated to be:

1. Lane County: $84 million (M1), $114 million (L1), and $187 million (XXL1).
2. Douglas County: total $125 million (M1), $178 million (L1), and $209 million (XXL1).
3. Coos County: total $399 million (M1), $700 million (L1), and $1.3 billion (XXL1).

Table 3-4 and **Figure 3-4** show discrete community earthquake damage losses, which range from $400 million in Coos Bay to ~$2 million at the Umpqua South Jetty site. The state parks and recreation areas show damage levels in the tens of thousands. Earthquake damage losses in areas beyond the specified communities ("other" category) are estimated to reach $273 million in Coos County.

The countywide earthquake damage losses outside the tsunami zones are the difference between losses inside a tsunami zone and the countywide totals (determined from **Table 3-4**); this equates to ~$5.47 billion (M1), $5.09 billion (L1), and $4.35 billion (XXL1) in losses outside of the tsunami zones. These data become important when considering the total damage losses caused by the combined tsunami and earthquake. The decrease in damage losses outside the tsunami zones is indicative of the increasing inundation (and tsunami-caused damage) as one moves from M1 to XXL1.

Combined earthquake and tsunami damage for each tsunami zone is included in **Table 3-4** and **Figure 3-4D**. These results indicate losses that range from ~$733 million (M1) to ~$2.7 billion (XXL1) across the three counties. Factoring in the additional earthquake losses outside the tsunami zones, our analyses indicate total losses on the order of:

1. Lane County: ~$1.25 billion (M1), ~$1.27 billion (L1), and ~$1.36 billion (XXL1).
2. Douglas County: total ~$440 million (M1), ~$464 million (L1), and ~$530 million (XXL1).
3. Coos County: total ~$4.52 billion (M1), ~$4.62 billion (L1), and ~$5.14 billion (XXL1).

Note that these estimates exclude building content losses and damage to roads, so these totals may be viewed as minimum estimates. At the community level, Coos Bay experiences the largest combined losses (i.e., inside and outside the tsunami zone), which reaches ~$1.2 billion, followed by damage losses in areas beyond the specified communities ("other" category) at ~$2.1 billion.

As can be seen from the earthquake building loss ratio (**Table 3-4E**), earthquake damage accounts for the bulk of the total building damage in Lane County. Significant building damage due to earthquake shaking is observed in Florence, Reedsport, Coos Bay, Charleston and Bandon. This is probably due to a combination of factors, including ground failure through liquefaction and lateral spreading, and the presence of older buildings.

Incorporating damage caused by the tsunami results in destruction levels for an M1 event that range from ~10% (Dunes City) to 90% (Charleston and Bandon; **Figure 3-4E)**. Destruction levels for an M1 event are especially high in Barview (79%), Coos Bay (72%), North Bend (70%), and Reedsport (70%). For an XXL1 size event, **Table 3-4** indicates >84% destruction in multiple communities, including Florence, Reedsport, Winchester Bay, Barview, Charleston and Bandon. The lowest destruction levels are generally observed in the more distal tsunami zone, such as Dunes City (~56% destruction) and Lakeside (52% destruction). Significant destruction at Winchester Bay, Barview, Charleston, and Bandon is indicative of the large number of buildings in the tsunami zone, large hydraulic forces associated with the tsunami and the prevalence of light-frame construction material (i.e., wood frame) on the Oregon Coast. Combined earthquake and tsunami damage estimates (**Table 3-4**) are:

1. Lane County: ~67% destroyed in the M1 event, 69% in the L1 event, and 81% in the XXL1 event.
2. Douglas County: ~69% destroyed in the M1 event, 71% in the L1 event, and 85% in the XXL1 event.
3. Coos County: ~73% destroyed in the M1 event, 72% in the L1 event, and 78% in the XXL1 event.

Although not included in **Table 3-4**, our Hazus analyses indicate that of the total number of buildings assessed, damage potential is estimated to be on the order of:

1. Lane County: 30% are expected to be destroyed, 27% are expected to experience extensive damage, and 22% of the buildings are expected to suffer moderate damage. 16% of the remaining buildings are expected to experience slight damage, and ~5% are expected to experience no damage.
2. Douglas County: 28% are expected to be destroyed, 21% are expected to experience extensive damage, and 17% of the buildings are expected to suffer moderate damage. 19% of the remaining buildings are expected to experience slight damage, and ~15% are expected to experience no damage.
3. Coos County: 23% are expected to be destroyed, 28% are expected to experience extensive damage, and 31% of the buildings are expected to suffer moderate damage. 14% of the remaining buildings are expected to experience slight damage, and ~3% are expected to experience no damage.

Finally, **Table 3-4** and **Figure 3-4F** indicate that the weight of debris generated countywide could range from ~33,000 tons (M1) in Lane County to ~785,000 tons (XXL1) in Coos Cunty. This equates to ~3,300 dump trucks for M1 and as many as 78,500 dump trucks for an XXL1 event. These estimates are almost certainly on the low end, as they do not include debris associated with content from buildings (personal items, business equipment, etc.), road rip-ups, vehicles, and vegetation. If we assume an additional five tons of personal items as debris per residential building (typical for most residential buildings), this adds ~4% additional weight to the building debris estimates provided in **Table 3-4**.

Table 3-4. Earthquake- and tsunami-induced building damage and debris estimates by community.

	Number of Buildings by Tsunami Zone			Building Replacement Cost by Tsunami Zone[1] ($ Million)			Earthquake Building Loss by Tsunami Zone[2] ($ Million)			Earthquake Building Loss by Community[3]		Combined Earthquake and Tsunami Building Loss by Tsunami Zone ($ Million)			Combined Earthquake and Tsunami Building Loss by Tsunami Zone (%)			Combined Earthquake and Tsunami Building Debris by Tsunami Zone (Tons)		
Community	**Medium**	**Large**	**XX-Large**	**Medium**	**Large**	**XX-Large**	**Medium**	**Large**	**XX-Large**	**($ Million)**	**Building Loss Ratio**	**Medium**	**Large**	**XX-Large**	**Medium**	**Large**	**XX-Large**	**Medium**	**Large**	**XX-Large**
Florence	153	310	909	117	163	279	69	92	150	832	299%	81	120	241	70%	73%	86%	23,555	36,004	79,809
Dunes City	4	6	41	1	1	6	0	0	3	62	992%	0	0	4	10%	19%	56%	9	12	1,288
Siltcoos	1	1	1	0	0	0	0	0	0	0	53%	0	0	0	100%	100%	100%	71	71	71
Other[4]	153	290	477	34	59	100	15	22	34	336	337%	19	34	68	57%	57%	69%	9,299	14,383	26,766
Lane County Total	311	607	1,428	152	223	385	84	114	187	1,230	420%	101	154	313	59%	62%	78%	32,934	50,469	107,934
Reedsport	472	762	897	122	183	212	78	108	122	284	134%	86	123	177	70%	67%	84%	44,888	62,441	84,911
Winchester Bay	168	292	292	29	46	46	15	24	24	24	52%	18	38	45	60%	84%	98%	8,491	16,954	20,330
Umpqua South Jetty	26	27	31	6	6	7	2	2	2	5	75%	3	6	6	46%	94%	96%	972	1,695	2,053
Other[4]	134	210	349	46	71	107	30	45	61	111	104%	33	50	86	72%	71%	80%	16,845	24,789	41,491
Douglas County Total	800	1,291	1,569	204	306	372	125	178	209	424	91%	140	217	315	62%	79%	89%	71,196	105,878	148,784
Lakeside	0	6	75	0	4	17	0	2	7	100	608%	0	2	9		62%	52%	0	184	2,991
Coos Bay	312	619	1,233	298	511	711	186	308	400	1,061	149%	214	356	501	72%	70%	71%	88,628	150,401	203,529
North Bend	75	265	613	85	204	402	52	113	208	690	172%	60	137	288	70%	67%	72%	18,207	47,576	102,404
Barview	123	330	1,492	32	75	289	17	39	156	195	68%	25	61	271	79%	81%	94%	9,557	20,913	106,748
Charleston	186	189	223	64	64	71	41	42	44	51	72%	58	63	69	90%	97%	97%	25,394	28,068	30,806
Sunset Bay Park	3	3	3	0	0	0	0	0	0	0	81%	0	0	0	100%	100%	100%	187	188	188
Bullards Beach	13	13	14	2	2	2	1	1	1	1	47%	1	2	2	56%	95%	100%	471	749	919
Bandon	182	290	1,447	89	139	540	57	80	241	412	76%	80	117	480	90%	84%	89%	31,249	45,586	168,123
Other[4]	373	918	2,088	105	247	597	44	115	272	1,912	320%	54	158	422	52%	64%	71%	16,574	64,052	168,929
Coos County Total	1,267	2,633	7,188	675	1,246	2,630	399	700	1,329	4,424	177%	492	896	2,043	73%	72%	78%	190,266	357,717	784,638

Notes:

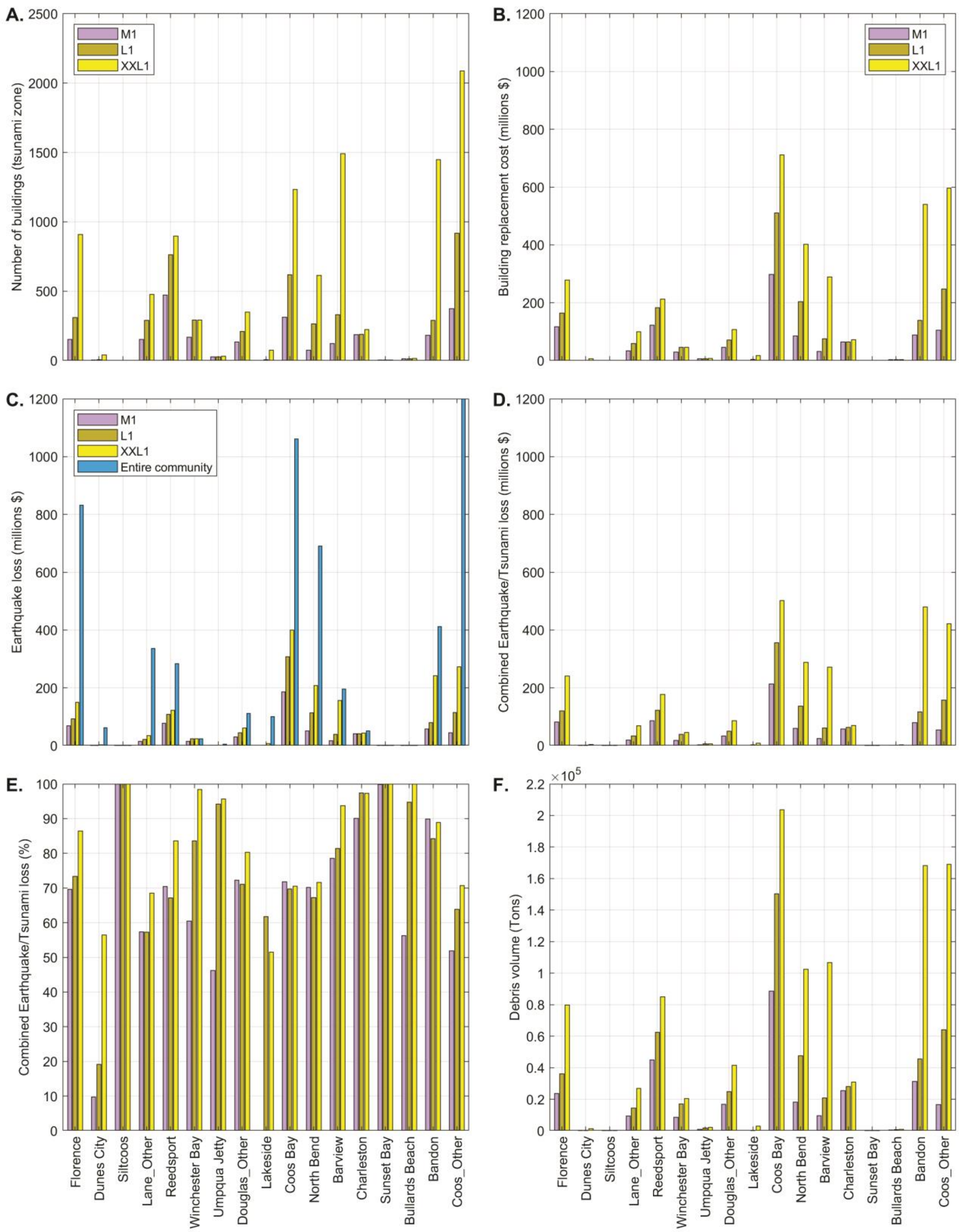
[1] Total cost to replace buildings in each tsunami zone

[2] Earthquake building losses defined for each tsunami zone

[3] Earthquake building losses defined for the entire community (inside and outside the tsunami zone)

[4] Denotes all other areas impacted by a Cascadia earthquake and tsunami.

Figure 3-4. Community overview showing (A) number of buildings per tsunami zone, (B) total replacement costs (millions of $), (C) earthquake losses (millions of $), (D) combined tsunami and earthquake losses (millions of $), also expressed as a (E) ratio, and (F) debris generated (weight).



3.3 Earthquake-Caused Injuries and Fatalities

Our Hazus analyses indicate that injuries from a CSZ earthquake greatly outnumber fatalities (**Table 3-5**). Modeled injuries experienced by residents and visitors are expected to be highest in Florence, Coos Bay and North Bend, followed by the "other" category. The latter numbers are of concern as these will be spread out over a very broad area. This will make it extremely challenging and time consuming to medivac the injured to appropriate field hospitals.

Table 3-5. Earthquake-induced injuries and fatalities determined for each community, expressed as a total for the county.

		Permanent Residents				Temporary Residents			
Community Zone	**Total Population[2]**	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 1**	**Level 2**	**Level 3**	**Level 4**
Florence	16,669	291	72	5	9	116	28	2	4
Dunes City	2,555	12	3	0	0	19	5	0	1
Siltcoos	518	0	0	0	0	0	0	0	0
Other[1]	9,796	98	23	1	2	42	10	1	2
Lane County Total	29,538	401	97	7	11	177	42	4	6
Reedsport	5,241	56	14	1	2	13	3	0	1
Winchester Bay	2,107	8	2	0	0	9	3	0	1
Umpqua South Jetty	389	2	0	0	0	0	0	0	0
Other[1]	2,612	31	7	1	1	6	1	0	0
Douglas County Total	10,350	96	24	2	4	28	7	1	2
Lakeside	2,386	47	12	1	2	13	3	0	1
Coos Bay	19,483	289	71	6	11	58	16	2	4
North Bend	12,123	157	39	4	7	51	15	2	4
Barview	5,022	86	21	2	3	16	4	0	0
Charleston	724	5	1	0	0	5	2	0	1
Sunset Bay State Park	425	0	0	0	0	0	0	0	0
Bullards Beach	669	0	0	0	0	0	0	0	0
Bandon	6,748	79	20	2	3	88	25	3	6
Other[1]	36,291	424	97	7	11	102	24	2	4
Coos County Total	83,872	1,088	261	21	37	333	87	10	19

Notes:

See **Table 2-4** for a more complete description of Hazus-defined injury levels. Level 1 denotes minor injuries, level 2 denotes injuries requiring hospitalization, level 3 denotes life-threatening injuries, level 4 denotes fatalities.

[1] Denotes all other areas impacted by a Cascadia earthquake and tsunami.

[2] Assumes 100% occupancy of second homes, vacation rentals, condominium units, bed and breakfast facilities, hotels, motels, and campgrounds.

Of the total number of injuries identified across all three counties (~2,000), Hazus estimates ~560 people are likely to require hospitalization (i.e. level 2 and level 3 injuries). The low fatality (~50) and injury estimates relative to the total population in these communities and caused by earthquake are likely due to the prevalence of wood-frame construction. However, we note that even if injuries are minor, impacted persons may delay evacuation from a tsunami zone while they tend to injuries.

3.4 Tsunami-Caused Injuries and Fatalities

Casualty numbers (injuries plus fatalities) attributed to a Cascadia tsunami are presented in **Table 3-6** and graphically in **Figure 3-5**. Overall, our Hazus modeling indicates that tsunami related casualties will greatly exceed earthquake-related casualties, especially when accounting for the combined resident and visitor populations. Notably, injuries caused by the tsunami average about 29% (±16%) of the total number of casualties, indicating that tsunami related deaths account for a larger proportion of the casualties (**Table 3-7**). This is because the Hazus tsunami casualty model estimates that people who do not escape from the tsunami zone are much more likely to die than to be injured and survive. Those who are injured are largely confined to a small narrow band where the tsunami flow depth falls below 1.8 m (~6 feet; see Section 2.6.2.5).

As can be seen in **Table 3-6** and **Figure 3-5**, modeled tsunami casualties vary widely between the communities. This is due to many factors, but most important is the relative distance to high ground. For the M1 scenario, estimated casualties are confined mainly to three areas: Winchester Bay (~6 residents/1,140 visitors), Charleston (~6 resident/195 visitor), and Sunset Bay State Park (~0 residents/145 visitors). Casualties in these three communities are overwhelmingly related to the campgrounds. Hence, for the M1 tsunami scenario, our Hazus modeling suggests either few or no casualties in the remaining three counties; note that these latter estimates fall within the margin of error in the Hazus modeling. Aside from the previously mentioned communities located at the open coast, low casualty numbers determined for the M1 scenario are indicative of the fact that most of the communities are:

1) built on high ground (e.g., marine terraces at Florence),
2) high ground is located close to the population centers allowing for quick access out of the inundation zone, or
3) are located well away from the coast (e.g., Dunes City and Lakeside) such that the M1 event does not reach them.

The number of casualties associated with the XXL1 tsunami scenario increase dramatically from the M1 scenario, ranging from no expected casualties (e.g., Dunes City, Reedsport, Lakeside, and North Bend) to as many as ~1,900 at Bandon, ~1,400 in the Coos County "other" category, ~1,200 in Winchester Bay, and ~980 in Barview (**Table 3-6**). In each of these areas, most of those expected to lose their lives (>69% in Lane and Douglas County and ~61% in Coos County) are likely to be visitors. Overall, we find the average number of fatalities observed in the permanent population across all three counties is low, averaging ~1.5% for the M1 scenario, increasing to 7.4% for the XXL scenario. For some communities such as Bandon and Barview, the percentage of resident fatalities are 38% and 21%, respectively, for the XXL1 scenario. Several additional sites characterized by the potential for large visitor fatalities include the Siltcoos River Campground, Umpqua South Jetty, Sunset Bay campground, and Bullards Beach campground. The large number of potential fatalities at each of the campgrounds can be attributed to a combination of early tsunami wave arrivals and the significant travel distances required to reach high ground. High casualty numbers in Bandon and Winchester Bay are also due to early wave arrivals and potentially large numbers of people in the tsunami zone. Evacuation modeling of Winchester Bay (Gabel and others, 2018b) and Barview (Gabel and others, 2019b) identified a few key mitigation options that could be implemented to reduce fatalities, including retrofitting the Salmon Harbor Bridge in downtown Winchester Bay and improving signage in places like Barview. Use of a vertical evacuation structure in Barview was discounted largely because such structures would not effectively serve the community since no single road emerges as a primary evacuation route, with evacuation routes being broadly dispersed among several roads in the area.

We estimate that, combined, countywide fatalities from the tsunami could reflect the following:

1. Lane County: ~20 killed in an M1 event, ~50 in an L1 event, and ~200 in an XXL1 event.
2. Douglas County: ~610 killed in an M1 event, ~1,180 in an L1 event, and ~1,380 in an XXL1 event.
3. Coos County: ~440 killed in an M1 event, ~1,070 in an L1 event, and ~5,290 in an XXL1 event.

As noted above, most of the potential fatalities are likely to come from the temporary visitor population. Given that these casualty estimates are only for 11 communities and three major state parks, total deaths caused by even an M1 CSZ tsunami, when accounting for all 38 communities (and numerous state parks) on the Oregon Coast, will likely exceed Oregon Seismic Safety Policy Advisory Commission's original estimate of ~5,000 people killed (OSSPAC, 2013). For context, tsunami casualties provided by OSSPAC (2013) are based on an M1 tsunami earthquake scenario, which covers ~79% of the DOGAMI tsunami inundation scenarios and did not consider the temporary visitor population. Using the same event scenario, our combined assessment for Clatsop (Allan and others, 2020a), Tillamook (Allan and others, 2020b), Lincoln (Allan and others, 2021) and those reported here indicate ~4,100 fatalities within the resident population for the M1 scenario, along with an additional ~10,600 fatalities within the visitor population. These results indicate that estimates by OSSPAC (2013) are low for a major Cascadia event.

Figure 3-5 presents a graphical summary of the estimated fatalities and displaced population for all three tsunami scenarios. Casualties are presented on the left of **Figure 3-5**, and estimates of the displaced population are on the right. The permanent resident population reflects the following color scheme: purple (M1), gold (L1), and yellow (XXL1). We provide contrasting cool colors to characterize different visitor occupancy levels (we assume 10%, 50%, and 100% occupancy level scenarios).

Since the permanent resident population is easiest to define in our population model, we argue that this likely reflects a low-end estimate of casualty numbers associated with each of the three tsunami events. This is shown in **Figure 3-5** by the left edge of the dark blue bars. Conversely, the resident plus visitor population (assuming 100% occupancy), is characterized by the length of the entire bar (right edge of the pale blue shaded region). Accordingly, the area in between reflects the uncertainty associated with the visitor population that could be present in the tsunami zone within each of the communities. One could speculate on visitor occupancy as we have done here by developing scenarios that vary from 10% (e.g., winter occupancy conditions, dark blue shading) or 50% (an average visitor occupancy, cyan shading) to define the potential number of casualties and displaced people. Refining such estimates, guided by local input, would help clarify a range of possible scenarios leading to more informed evaluations. As noted previously, the large number of casualties estimated for Winchester Bay in Douglas County in each of the three Cascadia scenarios (**Figure 3-5**, left) demonstrates the importance of a single pedestrian bridge in that community for effective evacuation to high ground and hence safety from the tsunami. Discussions with county personnel suggest that this key bridge is expected to fail, which forces people to take a much longer evacuation route westward toward the Umpqua lighthouse, in the direction of the oncoming tsunami. Large casualty numbers may also occur at Barview and Bandon during an XXL1-size tsunami due to the potentially large numbers of people and businesses in the tsunami zone. Conversely, low casualty numbers in most of the other communities are due entirely to the fact that high ground is close by (or the communities are at the distal ends of the tsunami zone), enabling more people to reach safety in time. Regardless of differences in local geography, it is evident from **Figure 3-5** that the number of casualties associated with even an M1 size event (especially when factoring in the temporary visitor population) has the potential to be large when scaled up to the rest of the Oregon Coast.

For the displaced population (**Figure 3-5**, *right* and **Table 3-8**), we can make similar assumptions about the local population groups. Apparent from the figure is the extremely large number of displaced visitors that each community could potentially have to deal with. This is most apparent for Florence, Coos Bay, North Bend, Barview, and Reedsport, each of which might potentially have to deal with several thousand people, many of whom would be nonresidents. The extremely large number of displaced people in the Coos 'Other' category after an XXL1 event will be especially challenging post disaster as many of these people will be disbursed widely across the county, making evacuation extremely difficult. Identifying these groups early on and providing or encouraging pre-disaster preparation (e.g., being two-week ready) will be key to their survival.

Although the number of displaced people increases significantly from M1 (~9,800) to XXL1 (~25,400) (**Table 3-8**), our Hazus results demonstrate that even a medium (M1) event would result in the displacement of many thousands of people. These numbers are indicative of the fact that many of these coastal communities are major tourist destinations with large numbers of vacation homes, camping spots, and to a lesser extent hotel/motels located in the tsunami zone. The low number of displaced people in places such as Sunset Beach State Park and Umpqua South Jetty under the XXL1 scenario (**Figure 3-5**, right) suggests that most people would be killed, because high ground under this scenario is not easily reached in time. In this case, evacuees traveling at a walking pace would not survive. In these areas, required evacuation speeds needed to survive the XXL1 event are faster than a walk (e.g., fast walk to jog).

Finally, the assumptions and observations described previously about tsunami casualties are predicated on the fact that people will evacuate from the tsunami zone within 10 minutes from the start of earthquake shaking. If people respond slowly and take an additional five-minute delay (i.e., a 15-minute departure time), the casualty numbers will increase significantly (**Table 3-7**). As can be seen from the table, a five-minute difference in the departure delay could cause the number of casualties to increase by 4,400 people. Thus, efforts directed at reducing human response times are critical for reducing overall casualties.

Table 3-6. Estimated injuries and fatalities associated with three CSZ tsunami scenarios by community, based on a 2 AM summer weekend scenario . Tsunami injury and fatality estimates assume a departure time of 10 minutes after the start of earthquake shaking.

	Number of Permanent Residents by Tsunami Zone			Estimated Number of Temporary Residents by Tsunami Zone[1]			Injuries and Fatalities to Permanent Residents by Tsunami Scenario			Injuries and Fatalities to Temporary Residents by Tsunami Scenario[1]			Injuries and Fatalities to Permanent Residents by Tsunami Scenario, Percent[2]			Injuries and Fatalities to Temporary Residents by Tsunami Scenario, Percent[3]		
Community Zone	**Medium**	**Large**	**XX-Large**	**Medium**	**Large**	**XX-Large**	**Medium**	**Large**	**XX-Large**	**Medium**	**Large**	**XX-Large**	**Medium**	**Large**	**XX-Large**	**Medium**	**Large**	**XX-Large**
Florence	404	612	1,326	1,289	1,622	2,709	0	0	5	0	0	14	0%	0%	0%	0%	0%	1%
Dunes City	3	6	43	6	11	109	0	0	0	0	0	0	0%	0%	0%	0%	0%	0%
Siltcoos	2	2	2	516	516	516	0	0	0	43	47	115	1%	1%	11%	8%	9%	22%
Other[4]	141	286	495	232	454	841	0	1	45	0	1	117	0%	0%	9%	0%	0%	14%
Lane County Total	550	906	1,866	2,043	2,604	4,175	0	1	50	43	49	246	0%	0%	5%	2%	2%	9%
Reedsport	553	954	1,115	384	497	635	0	0	0	0	0	0	0%	0%	0%	0%	0%	0%
Winchester Bay	121	222	222	1,527	1,873	1,873	5	8	19	1,138	1,143	1,244	4%	3%	9%	74%	61%	66%
Umpqua South Jetty	41	41	43	301	301	301	2	2	8	56	57	166	5%	5%	18%	19%	19%	55%
Other[4]	339	409	594	90	560	644	0	3	6	0	0	10	0%	1%	1%	0%	0%	2%
Douglas County Total	1,054	1,626	1,974	2,303	3,231	3,454	7	13	34	1,194	1,200	1,420	2%	2%	7%	23%	20%	31%
Lakeside	0	4	108	0	4	68	0	0	0	0	0	0		0%	0%		0%	0%
Coos Bay	448	1,022	2,517	545	1,054	1,630	0	0	9	0	0	9	0%	0%	0%	0%	0%	1%
North Bend	58	469	1,255	169	209	1,000	0	0	0	0	0	0	0%	0%	0%	0%	0%	0%
Barview	147	464	2,286	779	965	1,690	1	4	669	52	66	604	1%	1%	29%	7%	7%	36%
Charleston	61	62	98	475	476	487	6	10	32	195	261	377	10%	16%	33%	41%	55%	78%
Sunset Bay State Park	0	0	0	425	425	425	0	0	0	144	291	422				34%	68%	99%
Bullards Beach	5	5	5	284	664	664	0	1	5	32	111	324	2%	14%	91%	11%	17%	49%
Bandon	310	465	2,182	338	766	2,706	13	141	1,307	18	59	1,652	4%	30%	60%	5%	8%	61%
Other[4]	300	838	1,892	626	994	1,833	33	111	640	122	366	962	11%	13%	34%	19%	37%	52%
Coos County Total	1,328	3,329	10,343	3,642	5,557	10,503	52	267	2,662	561	1,152	4,350	4%	9%	22%	15%	21%	42%

Notes:

[1] Assumes 100% occupancy of second homes, vacation rentals, condominium units, bed and breakfast facilities, hotels, motels, and campgrounds.

[2] Casualties expressed as percentage of those injured or killed in the tsunami zone relative to the total number of community-wide permanent residents.

[3] Casualties expressed as percentage of those injured or killed in the tsunami zone relative to the total number of community-wide temporary residents, assuming 100% occupancy.

[4] Denotes all other areas impacted by a Cascadia earthquake and tsunami.

Table 3-7. Injury and fatality estimates for an XXL1 tsunami for two median departure times.

Community Zone	Number of Permanent Residents	Total Number of Residents (Permanent + Temporary[1])	10-Minute Departure				15-Minute Departure			
			Injuries	Fatalities	Total	Injuries Ratio[2]	Injuries	Fatalities	Total	Injuries Ratio[2]
Florence	10,291	16,669	1	18	19	7%	41	375	416	10%
Dunes City	1,208	2,555	0	0	0	26%	0	3	3	8%
Siltcoos	2	518	26	89	115	23%	28	290	318	9%
Other[3]	5,871	9,796	58	103	162	36%	70	341	411	17%
Lane County Total	17,372	29,538	86	210	296	23%	139	1,008	1,148	11%
Reedsport	3,932	5,241	0	0	0	49%	24	54	78	31%
Winchester Bay	227	2,107	55	1,208	1,264	4%	62	1,517	1,579	4%
Umpqua South Jetty	83	389	15	159	174	9%	12	242	254	5%
Other[3]	1,654	2,612	7	9	16	46%	30	138	168	18%
Douglas County Total	5,896	10,350	78	1,376	1,454	27%	129	1,950	2,079	15%
Lakeside	1,709	2,386	0	0	0	42%	1	3	4	18%
Coos Bay	15,652	19,483	7	11	18	37%	51	288	339	15%
North Bend	9,592	12,123	0	0	0	40%	12	60	73	17%
Barview	3,122	5,022	297	975	1,273	23%	318	1,999	2,317	14%
Charleston	190	724	55	354	409	14%	32	454	487	7%
Sunset Bay State Park	0	425	30	392	422	7%	17	406	423	4%
Bullards Beach	5	669	57	272	329	17%	38	472	510	7%
Bandon	3,227	6,748	1,047	1,913	2,960	35%	846	2,931	3,777	22%
Other[3]	26,327	36,291	229	1,373	1,602	14%	208	1,725	1,933	11%
Lincoln County Total	59,824	83,872	1,722	5,291	7,012	26%	1,523	8,338	9,861	13%

Notes:

[1] Assumes 100% occupancy of second homes, vacation rentals, condominium units, bed and breakfast facilities, hotels, motels, and campgrounds.

[2] Tsunami Injuries ratio is the number of tsunami injuries divided by total number of tsunami casualties (injuries plus fatalities).

[3] Denotes all other areas impacted by a Cascadia earthquake and tsunami.

Figure 3-5. Left: Estimated casualty numbers by community for M1, L1, and XXL1 tsunami events, assuming various visitor occupancy levels. Right: Estimates of the displaced population in each community, assuming various occupancy levels.

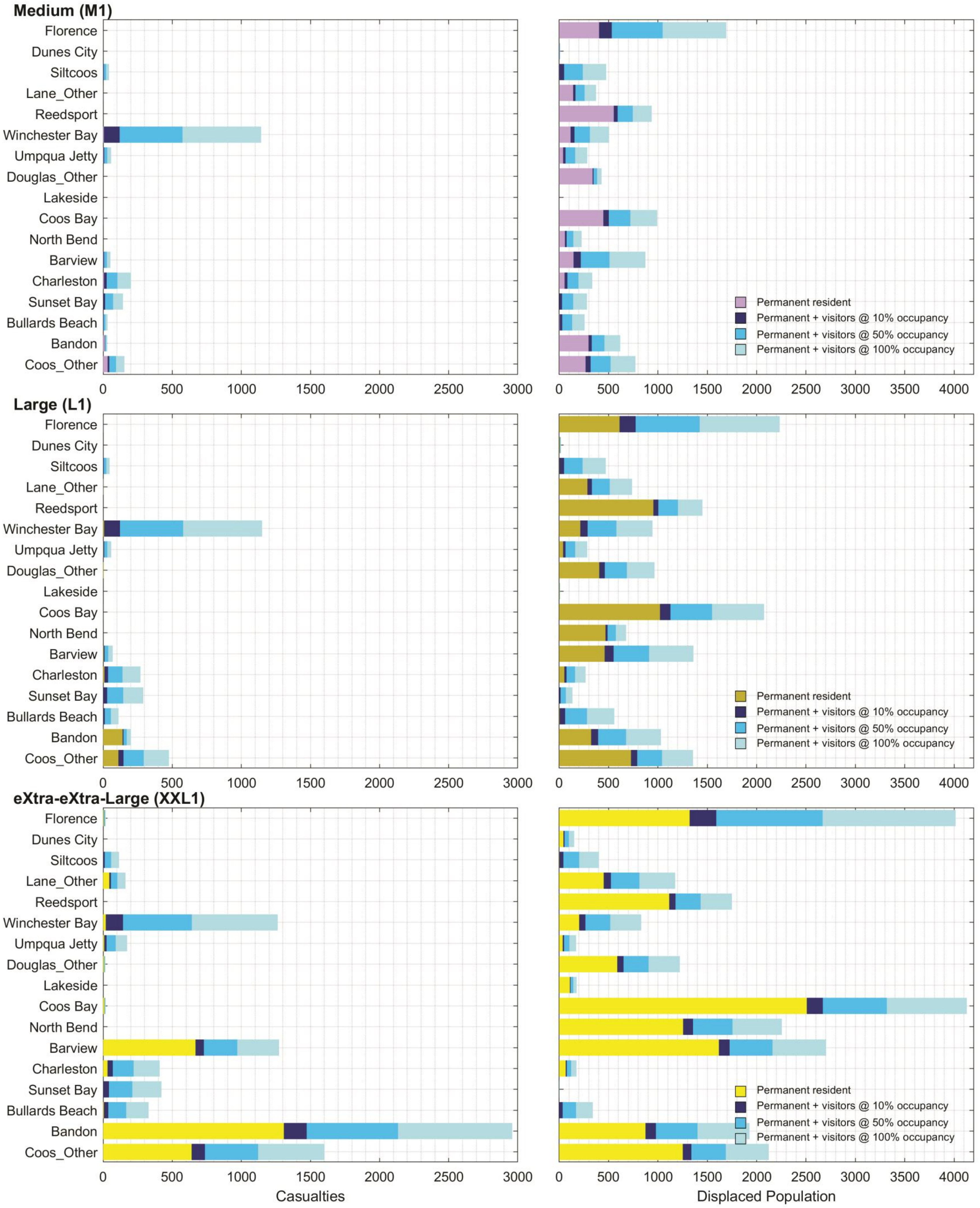


Table 3-8. Displaced population by tsunami zone.

Community Zone	Displaced Population[1] by Tsunami Scenario		
	M1	L1	XXL1
Florence	1,692	2,234	4,017
Dunes City	9	17	152
Siltcoos River Campgrounds	497	475	429
Other[2]	373	739	1,233
Lane County Total	2,571	3,465	5,831
Reedsport	937	1,451	1,750
Winchester Bay	1,074	977	886
Umpqua South Jetty	308	286	186
Other[2]	429	967	1,229
Douglas County Total	2,748	3,681	4,052
Lakeside	0	8	176
Coos Bay	993	2,075	4,136
North Bend	227	678	2,256
Barview	884	1,371	3,001
Charleston	433	307	231
Sunset Bay State Park	292	174	33
Bullards Beach State Park	272	593	397
Bandon	627	1,103	2,975
Other[2]	808	1,506	2,352
Coos County Total	4,535	7,816	15,556

Notes:

[1] Permanent plus temporary population. For the temporary population we assume 100% occupancy of second homes, vacation rentals, condominium units, bed and breakfast facilities, hotels, motels, and campgrounds.

[2] Denotes all other areas impacted by a Cascadia earthquake and tsunami.

3.5 Essential Facilities and Key Infrastructure

Table 3-9 provides a summary list of critical facilities and key infrastructure located in the M1, L1, and XXL1 tsunami hazard zones in Lane, Douglas, and Coos counties.

Table 3-9. Critical facilities and key infrastructure in coastal Lane, Douglas, and Coos county tsunami inundation zones.

				Tsunami Zone		
County	**Community**	**Description**	**Category**	**M1**	**L1**	**XXL1**
Lane	Florence	Water Treatment Plant	water treatment	x	x	x
		Siuslaw Valley F & R - Station 2	fire department	—	—	x
Douglas	Reedsport	Douglas County Sheriff's Office	police department	—	x	x
		Public Works - City Shop	public works	—	—	x
		Reedsport Water Treatment Plant	water treatment	—	—	x
		Reedsport Police Dept	police department	x	x	x
		Reedsport Fire Dept Station 1	fire department	x	x	x
		Reedsport Public Works	public works	—	x	x
Douglas	Winchester Bay	U.S. Coast Guard Umpqua River Station	U.S. Coast Guard Station	x	x	x
		Winchester Bay RFPD	fire department	x	x	x
		Water Treatment Plant	water treatment			
Douglas	Other	Communication Structure	communications	x	x	x
		Gardiner RFPD	fire department	x	x	x
Coos	Lakeside	Water Treatment Plant	water treatment	—	—	x
Coos	Coos Bay	Coos Bay Police Dept	police department	x	x	x
		Coos Bay Water Treatment Plant No. 1	water treatment	—	x	x
		Coos Bay Water Treatment Plant No. 2, Empire	water treatment	x	x	x
		Communication Structure	communications	x	x	x
		South Coast Head Start School	school	x	x	x
		U.S. Coast Guard Cutter Orcas	U.S. Coast Guard Station	x	x	x
Coos	North Bend	Bangor Elementary School	school	—	—	x
		North Bend Water Treatment Plant	water treatment	x	x	x
		North Bend Fire Dept Station 2	fire department	—	x	x
		Southwest Oregon Regional Airport	airport	—	x	x
		U.S. Coast Guard Air Station North Bend	U.S. Coast Guard Station	—	x	x
		Waterfall Medical Clinic	hospital	—	—	x
Coos	Barview	Charleston RFPD Station 1	fire department	—	—	x
Coos	Charleston	Charleston RFPD - Station 3	fire department	x	x	x
		U.S. Coast Guard Navigation Team Coos Bay	U.S. Coast Guard Station	x	x	x
		U.S. Coast Guard Station Coos Bay	U.S. Coast Guard Station	x	x	x

County	Community	Description	Category	Tsunami Zone		
				M1	L1	XXL1
Coos	Bandon	Bandon Police Dept	police department	—	—	x
		Bandon Water Treatment Plant	water treatment	x	x	x
		Bandon Fire Dept	fire department	—	x	x
		North Bend Medical Center	hospital	—	—	x
		Ocean Crest Elementary School	school	—	—	x
		U.S. Coast Guard Station Coquille River	U.S. Coast Guard Station	x	x	x
Coos	other	Communication Structure	communications	x	x	x
		Millington RFPD 5 Station 1	fire department	—	—	x

Notes:
"x" denotes present in the inundation zone.

3.6 Social Characteristics

We used American Community Survey (ACS) social characteristic data to identify some societal characteristics for each community throughout the three counties. Of specific interest are the distribution of Spanish-speaking households and individuals with disabilities. Both datasets are important because they have a direct bearing on tsunami outreach and education (e.g., providing translated informational materials or identifying individuals with disabilities who may need additional assistance with developing evacuation plans or actual evacuation). As noted previously, a limitation of these data is that they span the entire community and are not at a resolution that would allow us to better define these statistics by tsunami zone. Additional information relating to the use of ACS data may be found in Appendix A of Bauer and others (2020).

Table 3-10 identifies the number of Spanish-speaking households (and those speaking other languages) in coastal Lane, Douglas, and Coos counties. Overall, Spanish-speaking households are the most prevalent in the "other" Coos Bay category (~4%), North Bend (~3%), and Reedsport (~3%). Reedsport has the largest group of Spanish-speaking households that speak limited English (~2%).

Table 3-11 presents information on the percentages of people with disabilities throughout the three coastal counties. Overall, these results indicate the proportion of the local population with disabilities ranges from a low of ~19% in North Bend to highs of 32% in Florence and ~25% in Barview. Of particular concern is the relatively large number of individuals with vision, cognitive, or ambulatory disabilities. These include:

- ~12% of people in Barview have indicated vision challenges.
- Individuals with cognitive challenges make up ~22% of residents in Winchester Bay and ~12% of residents in Florence.
- Individuals with ambulatory needs make up sizable portions of Florence (~20%), Barview (~16%), Lakeside (~16%), and Coos Bay (~12%).

These results point to the need to better understand the distribution and needs of those with disabilities in the tsunami zone, as many of these people will almost certainly need help evacuating. Because the ACS data are not sufficiently detailed, not all of these individuals necessarily reside in the tsunami zone. Local emergency managers may wish to assess specific community needs.

Table 3-10. Household spoken language statistics.

Community	Number of Households Speaking Spanish	Percent of Households Speaking Spanish with MoE[1]	Number of Limited English-Speaking, Spanish Households	Percent of Households Speaking Spanish and with Limited English	Number of Limited English-Speaking, Other Language Households
Florence	29	0.7% ± 0.6%	—	—	10
Dunes City	4	0.7% ± 1.0%	—	—	—
Lane County	7,613	5.1% ± 0.3%	1,047	0.7% ± 1.0%	2,147
Reedsport	53	2.9% ± 2.1%	31	1.7% ± 1.6%	31
Winchester Bay	—	—	—	—	—
Douglas County	1,076	2.4% ± 0.4%	194	0.4% ± 0.2%	256
Lakeside	20	2.2% ± 3.5%	—	—	—
Coos Bay	255	3.8% ± 1.5%	41	0.6% ± 0.5%	41
North Bend	122	3.2% ± 1.9%	26	0.7% ± 1.1%	34
Barview	7	0.8% ± 1.4%	—	—	—
Charleston	—	—	—	—	—
Bandon	26	1.7% ± 2.7%	—	—	—
Coos County	838	3.2% ± 0.7%	120	0.5% ± 0.4%	141

Note:

Data taken from American Community Survey 2013–2017 five-year estimates.

[1]MoE denotes margin of error.

Table 3-11. Number of individuals with disabilities (by type) for coastal Lane, Douglas, and Coos counties.

Community	Total Number of Individuals*	Number of Individuals* with a Disability	Percent of Individuals with a Disability	Hearing	Vision	Cognitive	Ambulatory	Self-Care	Independent Living
Florence	8,646	2,798	32.4% ± 3.6%	11.4% ± 2.4%	6.0% ± 1.9%	12.4% ± 2.7%	20.3% ± 3.7%	7.0% ± 1.7%	12.2% ± 2.5%
Dunes City	1,304	252	19.3% ± 3.8%	6.9% ± 2.4%	1.5% ± 1.4%	8.0% ± 3.3%	9.6% ± 3.3%	3.7% ± 2.6%	10.1% ± 3.4%
Lane County	361,882	60,677	16.8% ± 0.5%	5.3% ± 0.3%	2.8% ± 0.2%	7.5% ± 0.4%	8.7% ± 0.3%	3.1% ± 0.2%	7.1% ± 0.3%
Reedsport	4,037	824	20.4% ± 3.4%	7.3% ± 2.4%	5.0% ± 2.0%	6.1% ± 2.4%	11.2% ± 3.2%	4.5% ± 2.0%	7.2% ± 2.7%
Winchester Bay	376	81	21.5% ± 15.0%	0.0% ± 8.3%	0.0% ± 8.3%	21.5% ± 15.0%	6.4% ± 11.4%	6.4% ± 11.4%	7.3% ± 12.5%
Douglas County	106,896	22,467	21.0% ± 0.8%	8.1% ± 0.5%	3.4% ± 0.4%	7.8% ± 0.7%	10.6% ± 0.6%	2.9% ± 0.3%	6.7% ± 0.6%
Lakeside	1,874	452	24.1% ± 6.9%	9.4% ± 3.8%	3.2% ± 2.3%	10.2% ± 4.2%	16.0% ± 5.4%	7.2% ± 3.4%	10.6% ± 4.1%
Coos Bay	15,888	3,518	22.1% ± 2.6%	4.8% ± 1.1%	3.9% ± 1.4%	11.1% ± 2.1%	12.3% ± 1.9%	5.1% ± 2.0%	12.0% ± 2.4%
North Bend	9,468	1,798	19.0% ± 3.1%	6.6% ± 1.6%	4.3% ± 1.7%	8.5% ± 1.9%	10.0% ± 2.5%	3.9% ± 1.4%	9.9% ± 2.4%
Barview	2,021	510	25.2% ± 6.7%	11.9% ± 4.5%	6.7% ± 3.7%	6.7% ± 3.6%	16.3% ± 6.2%	3.4% ± 2.2%	9.7% ± 4.0%
Charleston	—	—	—	—	—	—	—	—	—
Bandon	2,995	575	19.2% ± 5.6%	6.1% ± 3.2%	4.3% ± 3.2%	7.6% ± 3.6%	13.5% ± 4.6%	5.4% ± 2.9%	7.8% ± 3.8%
Coos County	62,058	14,509	23.4% ± 1.5%	7.6% ± 0.7%	4.1% ± 0.7%	9.9% ± 1.1%	13.8% ± 1.1%	5.2% ± 0.8%	10.5% ± 1.0%

Notes:
Data taken from ACS 2013–2017 five-year estimates.
An individual with a disability may have more than one difficulty.
* Permanent residents as defined from ACS.

4.0 DISCUSSION

This study extends the original work undertaken by Bauer and others (2020) and Allan and others (2020a,b, 2021) by implementing the 2017 FEMA Hazus methods on a countywide basis in order to estimate building damage, losses, and casualties from a CSZ earthquake and tsunami. The approach adopted here has been guided by the best available information on a CSZ earthquake (Mw 9.0; Madin and others, 2021; Wirth and others, 2020) and M1, L1 and XXL1 tsunami inundation scenarios (Priest and others, 2013e), together with a detailed building database and a population model that accounts for both permanent and temporary residents (2 AM occupancy). Although previous studies evaluated statewide casualty estimates for permanent residents (OSSPAC, 2013), our study significantly expands on this initial work by evaluating in greater detail the expected impacts of three different tsunami inundation scenarios that could impact coastal Lane, Douglas, and Coos counties. In particular, the present study extends the population model to include new information that helps us evaluate the temporary visitor population, types of housing that permanent and temporary residents occupy, and their relative distances to high ground and hence safety. Such information is critically important because communities on the Oregon Coast presently do not have adequate information on the likely socioeconomic effects of a CSZ earthquake and accompanying tsunami. Accordingly, we hope that the information presented in this report may be used to assist with community pre- and post-disaster planning, including addressing such needs as the development of tsunami evacuation wayfinding signage plans, mass-care planning, debris removal plans, vertical evacuation structure plans, and individual community tsunami evacuation facilities' improvement plans[10].

Building damage: Our analyses reveal that the earthquake alone accounts for significant community-wide building losses that range from a few tens of thousands of dollars in Dunes City to ~$1.06 billion in Coos Bay (**Table 3-4**). An estimated $832 million in damage is expected for the City of Florence. These variations reflect differences in the type and age of building construction, the size and purpose of the community, the density of buildings (e.g., a state park versus a town), and the number of buildings established in terrain that may be subject to landslides or liquefaction. Countywide losses in coastal Lane, Douglas, and Coos counties caused by a CSZ earthquake are projected to reach ~$6.08 billion, most of which will occur in Coos Bay, Florence, North Bend, and areas outside of the Coos County community boundaries ("other").

Damage to buildings from the tsunami is expected to be catastrophic — the smallest amount of earthquake/tsunami destruction this analysis predicts is ~10% of buildings lost for the M1 scenario at Dunes City campground. The greatest losses (>80%) are in the communities of Florence, Reedsport, Winchester Bay, Barview, Charleston, and Bandon in an XXL1 event. Siltcoos River Campground, Umpqua South Jetty, Sunset Bay State Park, and Bullards Beach State Park are effectively wiped out as well. Much of this destruction can be attributed to the magnitude of the tsunami hydraulic forces and the prevalence of light-frame (mainly wood) construction, which is vulnerable to tsunami damage. In addition, except for a few inland areas such as Lakeside and Dunes City, most of the communities and campgrounds are built on low-lying coastal plains or estuary deposits that are inundated in an XXL1 event.

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

Combined earthquake and tsunami damage indicate the following losses:

	M1	L1	XXL1
Lane	$1.25 billion	$1.27 billion	$1.36 billion
Douglas	$440 million	$464 million	$530 million
Coos	$4.52 billion	$4.62 billion	$5.14 billion

Note that these estimates are approximate and exclude building content losses, such that these are minimum estimates.

Building debris: Debris generated from the destruction of these of buildings will be scattered throughout the tsunami zone. Planners should consider that buoyant debris within the tsunami zone will be redistributed and may accumulate around low points, which often include key transportation routes (Park and Cox, 2019), within ports and harbors, and in navigation channels. Jetties such as those built at the mouth of the Siuslaw, Umpqua, and Coos estuaries are expected to be severely damaged or completely destroyed. Such effects are likely to compromise marine traffic access into the estuaries and thus the ports of Siuslaw, Winchester Bay, and Coos. Our analyses indicate that the approximate weight of debris produced from building damage could reflect the following:

	M1 (tons)	L1 (tons)	XXL1 (tons)
Lane	40,000	50,500	108,000
Douglas	71,200	106,000	149,000
Coos	190,300	358,000	785,000

This equates to ~4,000 dump trucks for M1 event in Lane County and as much as 78,500 dump trucks for an XXL1 event in Coos County. These estimates are almost certainly on the low end, as they do not include debris associated with content from buildings (personal items, business equipment, etc.), road rip-ups, vehicles, and vegetation. Nonetheless, the amount of debris listed here provides a starting point for communities as they begin the process of developing earthquake/tsunami debris plans.

Injuries and fatalities: Our analyses indicate that the permanent resident population present in each of the three counties is:

	M1	L1	XXL1
Lane	550	910	1,870
Douglas	1,050	1,630	1,970
Coos	1,330	3,330	10,340

Including the temporary (visitor) population visiting the coast in the calculation increases the overall coastal population substantially. Our Hazus analyses presented in **Table 3-1** suggest that the temporary visitor population could potentially reflect the following:

	M1	L1	XXL1
Lane	2,040	2,600	4,180
Douglas	2,300	3,230	3,450
Coos	3,640	5,560	10,500

These results highlight the tremendous burden that each community could potentially face following a CSZ earthquake and tsunami. However, it should be recognized that these totals are conservative since they 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 displaced visitors will be on the coast, in addition to the displaced permanent residents, who will need emergency care and support following a Cascadia event. Further refinements to these numbers are therefore critical for communities to develop short-term mass-care plans and for state and federal agencies to develop their long-term plans.

Our Hazus casualty results estimate the number of people killed in the tsunami zones in each county could reflect the following:

	M1	L1	XXL1
Lane	20	50	210
Douglas	610	1,180	1,380
Coos	440	1,070	5,290

Estimates provided in the Oregon Resilience Plan suggest that fatalities could range from ~600 to ~5,000 for the entire coast (OSSPAC, 2013). Of note, the results from OSSPAC were based on an M1 event that accounts for 79% of the expected inundation scenarios. Thus, the M1 results presented here are more consistent with the same size earthquake event used in the OSSPAC assessment. Combining results for the M1 scenario modeled in Lane, Douglas, and Coos counties with those from our Clatsop (Allan and others 2020a), Tillamook (Allan and others 2020b), and Lincoln County studies (Allan and O'Brien, 2021), we estimate ~4,100 permanent resident casualties, increasing to ~14,800 when factoring in the temporary visitor populations (assuming 100% occupancy). Accordingly, it is apparent that coast-wide tsunami fatality estimates for even an M1 tsunami could be substantial for the Oregon Coast, potentially approaching levels observed in the 2011 Tōhoku, Japan, event.

To assist the public, considerable hazard related information has been developed over the past decade to enable coastal communities and visitors to make informed decisions. These include detailed evacuation maps for every coastal community, which are available in print 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 evacuate to and how fast they need to travel to reach safety. These efforts demonstrate the simple fact that for every community:

Casualties attributed to a CSZ tsunami can be substantially reduced if people undertake the following simple steps:

1. ***Practice their evacuation routes.***
2. ***Evacuate as soon as possible after the earthquake.***
3. ***Travel as fast as possible (e.g., a fast walk, jog, or run) 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 curricula on tsunami hazards, improving signage, and implementing frequent evacuation drills reminding people of where they need to go. 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.

We quantified impacts to both temporary and permanent populations in our injury and fatality estimates for two reasons. First, planners can apply their own judgment to their community's population at offpeak times, such as assuming that wintertime temporary population is 10%–50% of peak summertime (e.g., **Figure 3-5**). Second, tsunami preparation and education awareness levels of permanent residents versus temporary populations are likely to differ. For example, temporary populations generally have little to no knowledge of the hazard, evacuation procedures, or optimal routes to safety and are more likely to engage in counterproductive milling (delay) behaviors that will lead to greater risk of death. In contrast, we hypothesize that permanent residents are generally better prepared (are aware of the hazard and their evacuation routes) and are 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.

Depending on the community, the temporary population on average may be 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 closest to the beach. This sets up a problematic situation where a presumed less-informed group is farther away from safety and may take longer to depart, with resultant higher proportion of fatalities compared to the permanent residents. Although some hotel/motels in Lane, Douglas, and Coos counties are similarly located next to the ocean, high ground is generally closer to these facilities when compared with similar establishments in the northern counties. In other locations such as inside the Coos and Umpqua estuaries, although hotel/motels may be close to the water, they are generally located further up the estuary and hence have a little more time to reach 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. The 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). However, about half the population indicated they were unlikely or very unlikely to wait for tsunami confirmation (24.3% and 22.8%, respectively). Many of the respondents (78 out of 207, or 38%) indicated they would attempt to evacuate by driving, which would be problematic given Seaside's constrained road evacuation network. 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 zone; many incorrectly identified their house as being outside the tsunami zone. Only a small portion of the respondents identified themselves as secondary homeowners (5% respondents), 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 local, state, and federal levels.

Displaced population: Given the near-complete destruction of buildings within the tsunami zone (**Table 3-8**), planners should assume that all people who were in the area impacted by the tsunami and who successfully evacuated will need short-term (days to weeks) and perhaps even longer-term shelter (weeks to months for permanent residents who previously resided in the tsunami zone). The large influx of temporary visitors in the summertime will increase demands on mass care facilities, placing even greater strain on local, state, and federal emergency managers. A major concern identified for all three counties is the potentially large number of people outside of community boundaries who will also be impacted by the earthquake and tsunami. Given how spread out many of these people are, a major challenge for emergency managers will be figuring out how to get supplies to people, while also evacuating many of these people to centralized locations where emergency shelters are established. Key to this process is to ensure that these people are well prepared and hence are “two-week” ready to ensure they can survive until help arrives.

5.0 CONCLUSION AND RECOMMENDATIONS

This study has evaluated the degree of impact associated with three CSZ tsunami scenarios in order to document potential building losses, debris weight, fatalities, injuries, and displaced populations throughout coastal Lane, Douglas, and Coos counties. The overarching goal of this work is to assist communities in their overall hazard preparation by identifying some of the expected challenges that will occur when the next great earthquake occurs on the CSZ and a tsunami is triggered. Great care has been taken as part of this study to address the needs of local communities. Discussions with local community planners, undertaken by Bauer and others (2020), helped frame the overall study approach and assumptions applied in our latest countywide Hazus modeling.

Education

Our analyses have improved estimates of fatalities and identified the presence of potentially very large temporary visitor populations, variations in the spatial concentration of both population groups within each community, and potential challenges facing those with physical or mental disabilities. 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, or tents) and where these lodgings are predominantly located provide insights about the potential challenges that may face a community. Such information may help local communities better target their tsunami education/outreach activities and messaging to address the lack of hazard awareness by visitors, while also meeting the unique needs of the residential community. For example, ~82% of people visiting Winchester Bay are likely to stay at the campground near the port dock. Although high ground is close by, the evacuation route is over a bridge that is likely to fail, compromising safe evacuation. The only alternative is evacuation up a steep bluff immediately behind the campground or toward the Umpqua lighthouse, both of which require the evacuees to run toward the incoming tsunami. The data in this report provides local governments with the necessary information needed to evaluate various options, such as the construction of a vertical evacuation structure or hardening a bridge, that may ultimately best serve residents and visitors.

Besides vacation homes, our analyses demonstrate that a number of the coastal communities have significant numbers of hotels/motels located in the tsunami zone (especially XXL1). Those that do include Coos Bay, North Bend, Florence, Reedsport, and Bandon, where hotels and motels account for 52%, 50%, 27%, 26%, and 23% of beds where visitors may stay, respectively. Luckily, high ground is relatively close for each of these communities such that investment in appropriate signage, education of lodging staff, and access to high-resolution “neighborhood” scale evacuation maps in every hotel/motel room may be sufficient. Thus, tsunami education and outreach targeting each of these lodging groups become essential in order to mitigate against the potentially large loss of life likely to occur without such measures.

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

1) The first is the development by Oregon Emergency Management of the "Tsunami Safe" program (*Hospitality Begins With Safety*). This effort focuses on increasing tsunami awareness among hospitality industry employees, including providing key tsunami and safety instructions that may 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 inundation zone. Evacuation guidance assumes that hospitality staff at every establishment 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), developed a "print-your-own-tsunami-brochure" tool that is integrated in the NANOOS Visualization System (NVS) tsunami evacuation portal (http://nvs.nanoos.org/TsunamiEvac). This tool allows individuals or businesses to develop their own custom evacuation brochures for any location on the Oregon Coast. More recently, DOGAMI has initiated the development of higher-resolution tsunami evacuation neighborhood maps[11] that can be printed with conventional printers. It is thus conceivable that hotel/motel rooms could display tsunami evacuation maps in a manner similar to the fire escape exit maps required in every room. Increasing local awareness of these tools should thus 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 could include funds to post and maintain tsunami wayfinding signage of 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, 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.

Mitigation

Tsunami evacuation modeling throughout coastal Lane, Douglas, and Coos counties 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 routes to areas outside the tsunami zone. Such efforts, guided by our evacuation modeling results, are now being implemented in multiple communities on the northern Oregon Coast, including Seaside, Cannon Beach, Manzanita, and Newport. In each of these communities, a "beach to safety" plan has been developed for core evacuation routes, and signage consisting of posted signs as well as thermoplastic signage on roads and paths is being implemented. Signs of this nature need to be spaced sufficiently close together and illuminated at night so that the signage may be easily seen at all times.

Consideration should also be directed at 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 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 actually walking an evacuation route. Although we recognize that such an approach may be disruptive to the local economy and difficult to organize,

[11] https://www.oregongeology.org/tsuclearinghouse/pubs-evacbro_neighborhoods.htm

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 March 11, 2011 (e.g., Nakaya and others, 2018; Sun and Yamori, 2018).

Mitigation options to improve evacuation may also include facility improvements such as seismic retrofits of key bridges or the construction of vertical evacuation structures. Although seismically retrofitting bridges will be critically important for post-disaster recovery (e.g., the Umpqua bridge by Reedsport or the Megler Bridge in Coos Bay), the only community we identified as having a dependency on bridges for evacuation purposes was Winchester Bay. Construction of vertical evacuation towers in a few key locations could potentially save lives. Of the communities examined here, the community of Barview is particularly exposed to the tsunami hazard (Gabel and others 2019b).

In many communities, people reside in older manufactured housing. 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 exiting. Such tools may provide manufactured housing occupants with a low-cost solution for rapidly exiting their structure in the critical time interval between earthquake cessation and tsunami arrival.

Response

Our analyses demonstrate that destruction of buildings in the tsunami 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. The need for shelter is likely to last many weeks until tsunami evacuees can be relocated out of the disaster area. This will be especially challenging for communities with potentially large numbers of temporary residents, 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 here, depending on the time of year, the number of displaced persons could range from a few tens (e.g., Dunes City) to potentially many thousands (e.g., Coos Bay, Florence, North Bend, Barview, and Bandon, in a worst-case summer scenario with every vacancy filled).

Mass casualties will vary significantly from community to community due to exposure and access to high ground. Overall, injuries caused by the tsunami alone were found to be low, averaging about 4% to 15% across the coastal communities, depending on the scenario. This finding is not unexpected because most people who are unable to evacuate in time and are caught by the tsunami are killed. Combined earthquake and tsunami related injuries presented here reflect the following:

	M1	L1	XXL1
Lane	750	730	810
Douglas	750	200	240
Coos	1,980	2,150	3,520

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 Cascadia 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 illness. To that end, further work is required to better refine these casualty numbers.

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 well beyond the scope of this investigation. Nevertheless, we can speculate on several likely scenarios. Overall, building destruction in coastal Lane, Douglas, and Coos counties could yield an estimated ~302,000 tons of debris in the M1 scenario, increasing to ~515,000 tons for L1, and over one 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 throughout the three counties (5,878 buildings), we estimate an additional 29,400 tons (assuming five tons per household) of debris could be generated from personal effects. This equates to ~3% of the total volume of debris reported in Table 3-4. The estimated building replacement cost for coastal Lane, Douglas, and Coos counties is likely to exceed $6.2 billion in an M1 event, $6.4 billion in L1, and $7.0 billion in an XXL1 earthquake and tsunami. These numbers emphasize that regardless of the size and characteristics of the next Cascadia earthquake and tsunami, the impact will be severe for the Oregon Coast.

Wood-frame construction dominates many Oregon coastal communities. The majority of such buildings in the tsunami zone will probably be completely destroyed by the tsunami. This means that for Lane, Douglas and Coos counties, 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, tsunami refugees will likely migrate away from such communities, further decimating the local economy. The housing situation will likely be compounded by the altered coastal landscape due to subsidence effects caused by the earthquake. For example, the earthquake deformation models used to simulate tsunami inundation estimate that the coastline could drop by the following amounts (data derived from Witter and others, 2011):

	M1	L1	XXL1
Lane	0.8 m (2.6 ft)	1.2 m (3.9 ft)	1.8 m (5.9 ft)
Douglas	1.3 m (4.1 ft)	1.8 m (5.9 ft)	2.7 m (8.9 ft)
Coos	2.1 m (6.9 ft)	3.0 m (9.8 ft)	4.7 m (15.4 ft)

Such changes will inevitably lead to accelerated rates of coastal erosion along with 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 change progressively decreasing over time as the coastline re-equilibrates to the new sea level regime.

Finally, our analyses indicate that many buildings in the tsunami 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 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.

Vulnerable Populations

We provided population estimates from American Community Survey (ACS) data for selected population groups that may have special challenges understanding preparedness messages or evacuating (Section 3.6). The ACS estimates are for the entire community, including people outside the tsunami zone, so the total number of individuals identified in this report is likely to be higher than those actually in the tsunami zone. 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[12], which tracks electricity-dependent Medicare populations and the Centers for Disease Control and Prevention's Behavioral Risk Factor Surveillance System (BRFSS)[13], which tracks health-related risk behaviors, chronic health conditions, and use of preventive service 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.

Finally, our model does not account for populations living in the tsunami zone who are currently experiencing homelessness. However, homeless encampments are likely present in the tsunami zones of many Oregon coastal communities, and outreach messaging should include this population.

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[12] https://empowermap.hhs.gov/

[13] https://www.cdc.gov/brfss/index.html

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