Tsunami Vertical Evacuation Structure (VES) Guidance

2026

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Oregon State University's Hatfield Marine Science Center in Newport, OR

Photo Credit: Oregon State University

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Executive Summary

Residents and visitors in Oregon coastal communities will have less than 20 minutes from the time ground shaking **starts** after a Cascadia Subduction Zone (CSZ) earthquake to evacuate from tsunami-hazard zones—often not enough time to reach natural high ground in many areas. For these communities, survival depends not on whether people evacuate, but where evacuation is possible at all.

The CSZ is a 600-mile megathrust fault located 30 to 60 miles offshore the Oregon coast, where the Juan de Fuca plate subducts beneath the North American plate. A CSZ megathrust earthquake is expected to impact the western side of northern California, Oregon, Washington, and British Columbia—home to nearly 24 million people. Following the quake, tsunami waves—ranging in height from several tens of feet to over 100 feet—could reach the coast in as little as 10 to 20 minutes after the shaking **starts**, leaving little time for evacuation.

This report outlines the science, risks, and life-saving countermeasures associated with such an event, with a primary focus on the role of Vertical Evacuation Structures (VES) in tsunami-prone areas of Oregon coastal communities. VES are engineered facilities designed to provide safe refuge above anticipated tsunami inundation levels when natural high ground is too far or inaccessible within the short evacuation window.

Tsunamis are not single waves but arrive as multiple surges, often lasting 10–12 hours, but can last longer. Due to their destructive forces and the mobilized debris, survival rates for individuals caught by the tsunami are typically less than 1%. Timely evacuation is critical. Residents and visitors located within the tsunami inundation zone may not survive if they delay evacuating, are located far from high ground, or experience injuries during the earthquake that prevent timely evacuation.

Evacuation modeling undertaken by the Oregon Department of Geology and Mineral Industries demonstrates that even with no departure delays, the distance that residents and visitors in some coastal communities must travel to reach high ground may be too far to reach before the first tsunami surge arrives. For these communities, high ground must be brought closer to the population centers — a strategy achieved through the implementation of vertical evacuation structures (VES). Furthermore, it is important to recognize that some communities may require multiple VES to effectively serve a community and reduce the potential for large loss of life.

A Roadmap for this Guide

Chapters 1 and 2 provide the essential hazard context that underpins every stage of vertical evacuation structure planning, funding, and community engagement. These chapters consolidate critical information about Cascadia earthquakes, tsunami behavior, expected impacts, evacuation challenges, and Oregon-specific modeling—material that is often scattered across lengthy scientific publications. By presenting this information up front, the guide equips project managers, planners, and local leaders with the foundational knowledge needed to explain why a VES is necessary and what it must be designed to withstand.

This background is also directly useful for developing grant scopes of work, preparing bond measures, and communicating the urgency of the hazard to elected officials and community members. Understanding concepts such as runup elevation, inundation extent, local versus distant tsunami threats, and DOGAMI's Beat the Wave findings helps communities articulate the problem clearly, justify project needs, and demonstrate alignment with state and federal funding priorities.

Readers who are already familiar with Cascadia hazards or who prefer to move directly into VES planning may skip ahead to Chapter 3: Vertical Evacuation Structures. However, for communities preparing proposals, engaging the public, or beginning long-term mitigation planning, the information in Chapters 1 and 2 provides essential context for informed decision-making and effective project development.

Chapter 1: Introduction

Tsunami vertical evacuation structures (VES) are relatively new in the United States, requiring careful planning and regulation, specialized expertise in engineering design including sophisticated site-specific tsunami modeling needed to define flow depths, runup elevations and impact forces, and strong community engagement and collaboration needed to build support and explore funding options.

Recognizing these challenges, the Oregon Department of Emergency Management (OEM) and the Oregon Department of Geology and Mineral Industries (DOGAMI) have created this guide to help Oregon coastal communities plan and implement these life-saving structures.

Currently, three VES have been constructed in the United States (Table 1): two are in Washington state and one in Oregon. Two are new school buildings with a rooftop refuge, while the third is a freestanding tower. Capacity, funding, and other details vary widely between the three VES.

The Washington Military Department (WMD) estimates an additional 58–82 VES are proposed along the outer Washington coast from Ilwaco to Neah Bay (Freitag et al., 2021). To date, no such study has been undertaken for the Oregon Coast. More research is needed to properly evaluate such needs.

Table 1: VES Structures in the United States

Structure Name	Location	Type	Capacity	Year Completed
Ocosta Elementary School Gym	Westport, WA	Elevated Building Roof	~2,000	2016
Gladys Valley Marine Studies Building	Newport, OR	Rooftop Refuge	~900	2019-2020
Shoalwater Bay Tsunami Tower	Tokeland, WA	Freestanding Tower	~400	2022

This document provides guidance for Oregon coastal communities considering the use of VES as a countermeasure to a potentially catastrophic, local-source Cascadia Subduction Zone tsunami. It offers essential information for community planners and regulators involved in zoning, redevelopment, land-use planning, building regulations, and coastal development. In addition, this document may be used to inform local and state elected officials, appointed leaders, and administrative staff.

1.1 Cascadia Subduction Zone Overview

A Tsunami Vertical Evacuation Structure is designed to provide refuge to people from incoming tsunami waves (surges), but it's important to understand that Oregon's greatest tsunami threat begins with a powerful earthquake. These earthquakes are generated by the Cascadia Subduction Zone (CSZ), a 600-mile fault just off our coast. When a major CSZ event occurs, the shaking will be the first sign of danger, and the tsunami that follows may arrive in a matter of tens of minutes after the shaking begins.

Because the earthquake and tsunami are closely linked, this opening section focuses on the earthquake itself, what it is, why it happens, and what it means for coastal communities—before moving on to the tsunami hazards that follow.

The CSZ extends from northern California to roughly the center of Vancouver Island, Canada (Figure 1). It is located approximately 30 to 60 miles west of the Oregon Coast and occurs in a region where the Juan de Fuca (JdF) tectonic plate is diving beneath (subducting) the North American continental plate. Estimates of the rate of convergence is about 1.2 to 1.6 inches per year *(*Gao and others, 2022*).*

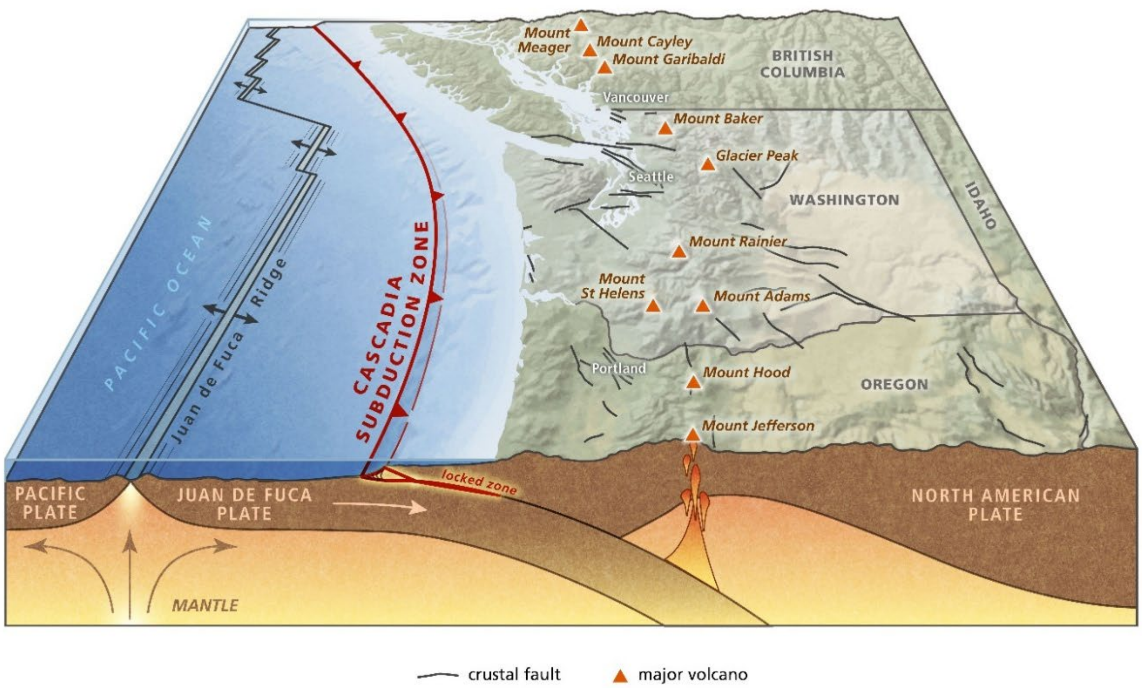

Figure 1: Conceptual map of the CSZ along the Pacific Northwest (PNW) coasts of Oregon and Washington (Image from the Washington Geological Survey (Washington State DNR))

Subduction zones such as the CSZ can produce very large (megathrust) earthquakes (>M_W 8.5) that result in significant uplift of the seafloor (Goda and others, 2024). It is this vertical thrust of the sea floor that produces large tsunamis, capable of inundating low-lying coastal margins and causing catastrophic destruction and large loss of life.

1.1.1 Full Margin Rupture Earthquakes (Magnitude 9.0 Range)

One example of these large subduction zone tsunamis is the March 11, 2011, event that struck the Sendai Plain in northeast Japan. It killed about 18,500 people. Like Japan, the CSZ has an extensive record of past earthquakes and accompanying tsunami. Scientists have documented ~20 full-margin rupture megathrust CSZ earthquakes and accompanying tsunamis over the past 10,000 years (Witter and others, 2011), with the last event (M_W 9.0) having occurred on January 26th, 1700 (Atwater and others, 2004). Based on these data, scientists estimate the average recurrence interval of full ruptures along the CSZ to be approximately 480–505 years (Goldfinger et al., 2016; Nelson et al., 2021).

1.1.2 Partial Rupture CSZ Earthquakes (Magnitude 8.0 Range)

In addition to the ~20 full-margin ruptures, scientists have identified ~23 partial ruptures of the CSZ over the past 10,000 years. Although the recurrence intervals are irregular, they show a long-term trend toward shorter intervals in more recent millennia, with older events spaced farther apart. Full-margin ruptures are frequently followed by “sub-events”—one to six moderate-sized partial ruptures. Most of these partial events occurred along the southern Oregon Coast and into northern California.

Source	Rupture Type	Model	Probability (Next 50 Years)
Goldfinger et al., 2016	Full margin (~M9)	Time-dependent recurrence model	~16–22%
Wirth et al., 2025	Full and partial margin (~M8+)	Time-dependent recurrence model	~30%
Wirth et al., 2025	Full margin (~M9)	Time-independent recurrence model	~10%
Wirth et al., 2025	Full margin (~M9)	Time-dependent Brownian passage-time model	~15%

1.1.3 How often do these events occur?

Data supports the occurrence of at least 42 Cascadia Subduction Zone (CSZ) earthquakes over the past 10,000 years, averaging roughly one event every 238 years. As of January 26, 2026, 326 years have passed since the last major CSZ earthquake, making the current interval historically notable when both full-margin and partial-margin ruptures are considered.

- Over the past 10,200 years, only 9 of 41 known intervals between those 42 events were longer than the current 326-year gap—meaning the southern segment of the fault, impacted most often by these events, has now exceeded 79% of all recurrence intervals.
- Within the last 6,000 years, this 326-year gap is longer than 90 percent of intervals.
- In the most recent 4,000 years, it exceeds 95% of recorded intervals.

- The average recurrence interval for the full 10,000-year record is ~233 years

Projecting forward to 2076 (a 50-year horizon), just 5 of the past 41 intervals exceeded 376 years, and only one of those took place within the last 6,000 years.

Goldfinger et al. (2012) revised their 2012 findings in 2017, reducing some of the average recurrence intervals, particularly for the northern CSZ segments. The most current age estimates are provided in Goldfinger et al. (2025).

1.1.4 Expected Impact Area

Extending from Cape Mendocino, California, to the middle of Vancouver Island, British Columbia, the CSZ is just over 600 miles long at the deformation front which lies roughly 50 miles off the coast, (Pacific Northwest Seismic Network [PNSN], n.d.). More relevant to this publication, however, is the length of the coastline parallel to the fault, which stretches 671 miles. Oregon’s coastline accounts for roughly half that distance. Each coastal community must prepare for a major Cascadia subduction zone earthquake and tsunami.

Although the tsunami will directly impact communities along the coast and up coastal rivers, the earthquake’s shaking will impact communities as far as the Cascade mountain range. In total, over 140,000 square miles of land across Northern California, Oregon, Washington, and British Columbia is expected to be directly impacted by the shaking of the next magnitude 9.0 (M9) earthquake (CEST & IOEM, n.d.) — an area larger than all of Germany, and home to over 23.8 million residents (Esri and others, 2022).

1.2 Tsunamis

A tsunami consists of a series of waves that may affect a coastline for as little as several hours to potentially as long as a few days after its initiation (e.g., Allan and others, 2024). The wave height reflects the height of the tsunami from crest to trough (Figure 2), while the wave amplitude reflects that portion of the wave above the still water level; the still water level simply refers to the level of the ocean surface in the absence of all waves. In deep water (depths greater than several thousand feet), tsunami waves travel at speeds of around 400 to 500 miles per hour (mph), which is comparable to the speed of a large passenger airplane.

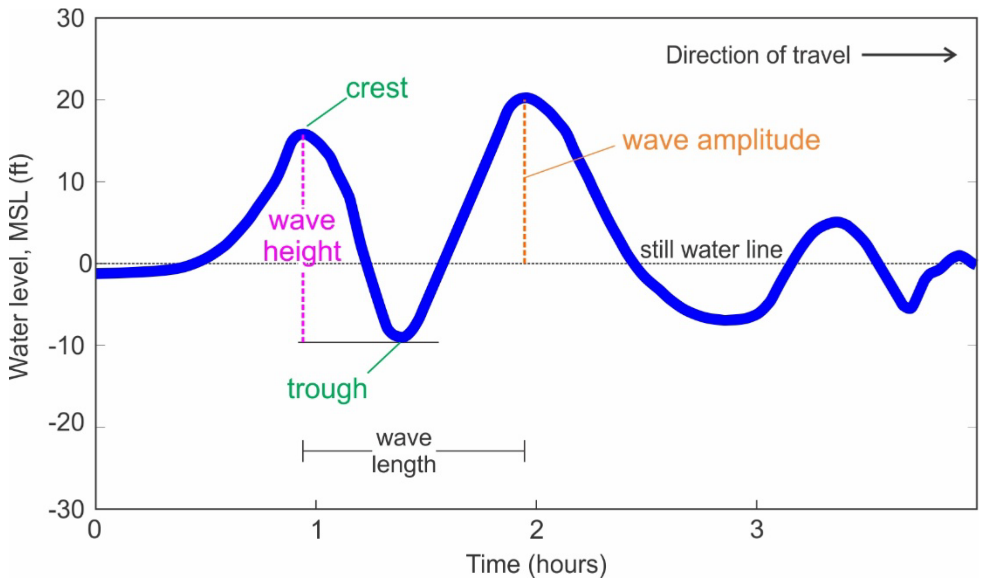

Figure 2: Terms used to describe a tsunami wave form

As the tsunami enters shallow water (water depths of less than a few hundred feet), the tsunami slows down, the length between wave crests becomes shorter, and the height of the tsunami begins to increase significantly. By the time the tsunami has reached the coast, the tsunami is travelling at speeds of about 30 mph.

These changes occur due to complex interactions that take place as the tsunami becomes increasingly affected by the seabed, particularly around offshore submarine banks and canyons. Accordingly, for areas nearer the coast it is important to utilize sophisticated numerical models that account for such complexities to properly simulate the travel and characteristics of tsunamis into shallow water and ultimately on to land.

Figure 3 presents various terms used to describe a tsunami:

- **Runup Elevation**: The runup elevation(s) describes the land elevation point at which the tsunami stops traveling inland.
- **Inundation Extent**: The horizontal inland distance from the shoreline inundated by the tsunami. *Describes how far inland the tsunami travels.*

- **Flow Depth**: The vertical height of the tsunami above the ground elevation for any given location. *Describes how deep the tsunami is for a given location on land.*
- **Maximum Water Level:** The maximum water level height reached by the tsunami relative to a known vertical datum for any given location over the duration of the event. *Simply another measure used to describe how big the tsunami is*.
- **Subsidence:** The sudden vertical lowering of the coast caused by the earthquake.

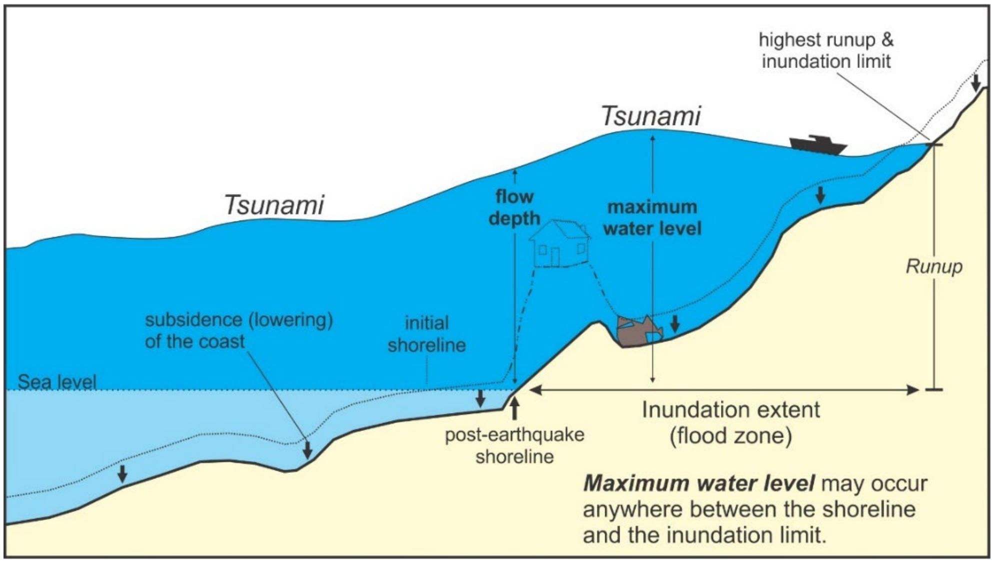

Figure 3: General Tsunami Terms

1.2.1 Distant Tsunami Threats

The Oregon coast is at risk from two potential tsunami sources: *local* and *distant*. Distant-source tsunamis originate from volcanic eruptions; meteotsunamis, which are tsunamis caused by weather disturbances; and subduction zones. Subduction Zones are distributed around the Pacific Basin, including Alaska (Figure 4), Japan, Chile, Tonga, and Southeast Asia.

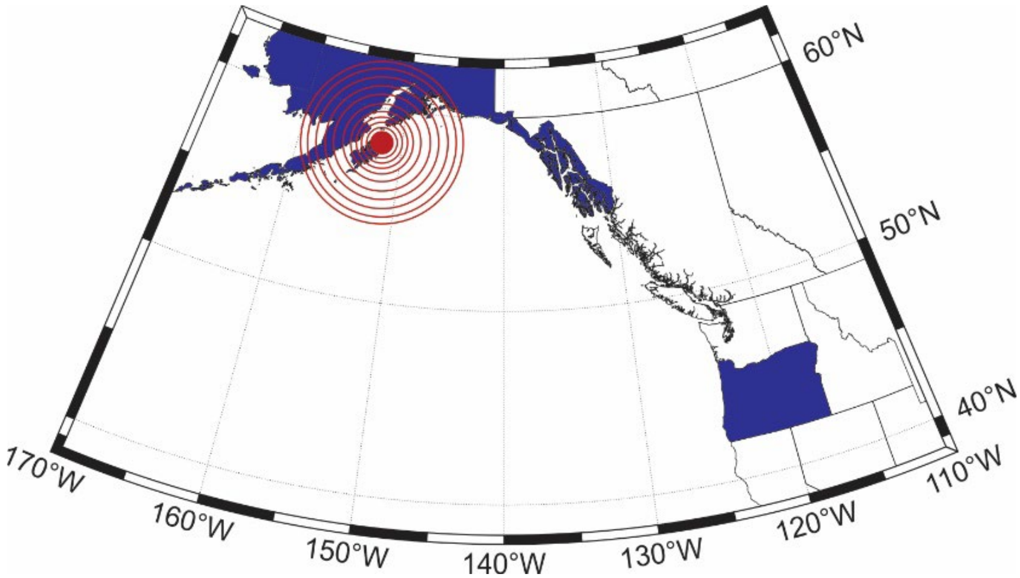

Figure 4: The greatest threat to the Oregon coast from a distant tsunami is an earthquake occurring in the eastern Aleutian Islands, Alaska. Tsunamis originating from this source would strike the coast in approximately 4 hours. Source: DOGAMI

These waves can arrive along Oregon's shores in as little as 4 hours or as long as 15 hours following the earthquake. For example, the great 1964 Alaska tsunami reached the Oregon Coast in about 4 hours (Zhang and others, 2010), while the March 11, 2011, Japan tsunami reached the coast in 9.5 hours (Allan and others, 2012).

Areas of the Oregon Coast most susceptible to impacts from distant tsunami threats include open coast beaches; low lying communities near the ocean (e.g., Seaside and Cannon Beach in Clatsop County), and all marine areas, especially those marine areas where water flows become constricted, such as the mouths of estuaries and harbors. Historical evidence suggests that damage from distant tsunami sources is generally very low, since much of the tsunami energy is reduced after traveling across the vastness of the Pacific Ocean (Allan and others, 2012).

When compared to a locally generated tsunami, that reduced energy also results in decreased tsunami flow depths, currents, inundation extents, and tsunami runup. Distant tsunamis are still dangerous. Fatalities, while far lower than a local tsunami event, still occur; however, as described above, warning times for a distant tsunami are measured in hours rather than tens of minutes. That extra time increases the likelihood of a successful evacuation — even from the most hazardous areas — in a timely manner.

1.2.2 Local Tsunami Threats

A locally generated CSZ earthquake (Figure 5) will result in tsunami waves reaching the beach in as little as 10 minutes after the shaking begins in southern Oregon, and about 20 minutes (after the start of the shaking) on the central to northern Oregon Coast, with most coastal communities inundated in about 30 to 35 minutes (Figure 6). As with a distant tsunami threat, a local CSZ tsunami would affect the entire Oregon Coast and can destroy ports and harbors.

However, inundation is greater in a local tsunami event and can destroy low-lying communities, potentially leading to thousands of fatalities. Estimates by Allan and O'Brien (2025) indicate that about 4,500 to 14,000 resident fatalities are possible, increasing to 11,000 to about 31,700 fatalities when including visitors to the coast.

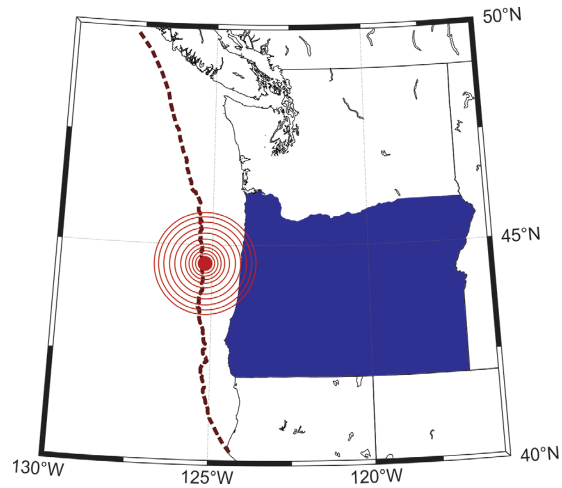

Figure 1. A local CSZ earthquake poses the greatest risk to the Oregon coast. Image provided by DOGAMI.

The challenge for residents and coastal visitors is to recognize the signs that a local tsunami is on its way and will probably arrive within minutes. Important signs that a CSZ tsunami has been generated and is on its way include:

1. **An earthquake that lasts a long time** – The longer the shaking the more likely a tsunami has been generated and is on its way. The duration of ground shaking for a CSZ earthquake is likely to last 3 to 5 minutes.
2. **A sudden change in the character of the ocean** – A quiet sea that has suddenly become rough is a sign to move away from the beach.
3. **The ocean receding unusually far** – This is a sign that water will rush back in much faster and higher than you expect. Head inland or to higher ground as soon as you notice.
4. **A loud noise or roar from the ocean** – This is an indication that the waves are building in size and tsunami waves could arrive within minutes.

To reduce the potential for fatalities from a local CSZ tsunami, several simple steps can be implemented:

1. Ensure people know to evacuate to high ground immediately following the earthquake shaking.
2. Evacuation routes are clearly signposted along the length of the route.
3. Residents and visitors know and practice their evacuation routes.
4. People do not return to the inundation zone until the all-clear is given.

While these steps are critical for many individuals along the coast, there are several areas along the Oregon Coast where high ground is located too far from high ground to reach before the first tsunami surge reaches the shoreline, making timely evacuation challenging, and in some cases impossible. In these locations, constructing Vertical Evacuation Structures (VES) in strategically defined areas could save thousands of lives.

In Japan, some VES were built below actual tsunami heights causing them to be overtopped during the 2011 Tohoku tsunami, causing fatalities among evacuees. However, other VES in Japan were built high enough that they were not overtopped, demonstrates their life-saving potential. In total, 5,428 people successfully evacuated to vertical evacuation sites and designated multi-story buildings (Fraser et al., 2012). Together, these outcomes underscore the need for conservative design heights, clear public guidance, and robust engineering standards to ensure VES provide reliable protection.

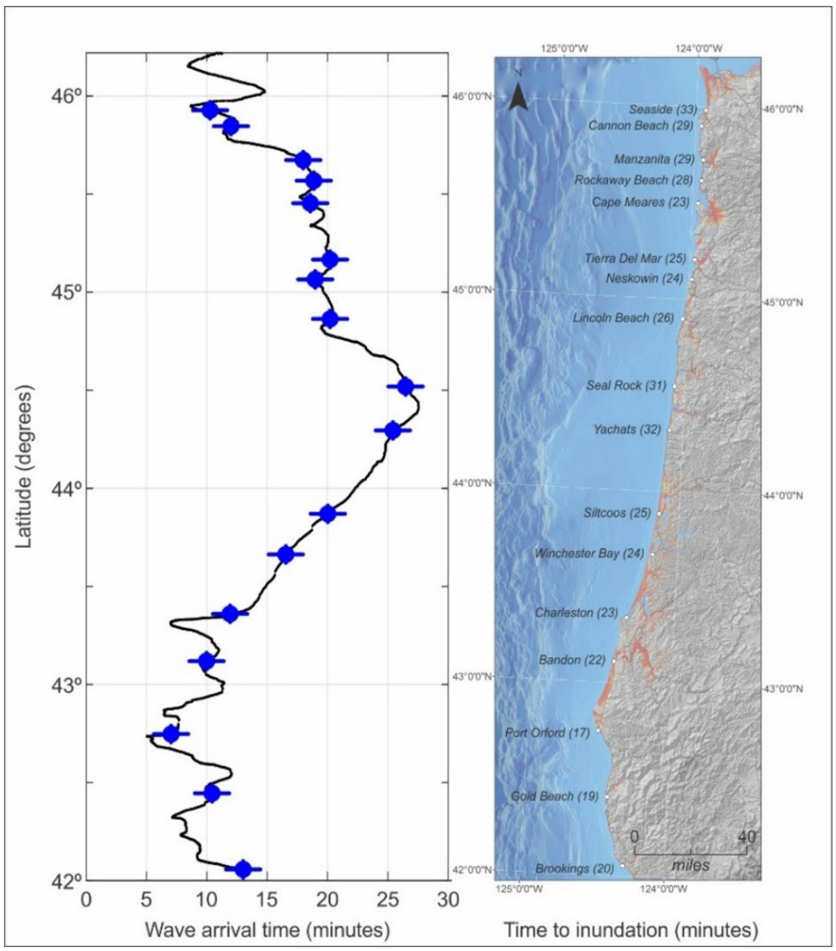

Figure 6: Calculated tsunami wave arrival times for a CSZ tsunami striking the Oregon Coast (Allan and O'Brien, 2025). Left are wave arrival times at the beach; right is time to inundation.

1.2.3 Oregon Coast Tsunami Modeling and Mapping Products

The Oregon Department of Geology and Mineral Industries (DOGAMI) is responsible for producing technical maps and products that address tsunami hazards in the State of Oregon. Tsunami inundation modeling along the Oregon Coast began in the early 1990s following recognition that the Cascadia Subduction Zone (CSZ) can generate large earthquakes and associated tsunamis that could result in catastrophic coastal impacts, including loss of life.

To support hazard assessment and evacuation planning, DOGAMI developed a suite of tsunami inundation scenarios for Cascadia Subduction Zone earthquakes. These scenarios are commonly referred to as "T-shirt size" scenarios, representing a range of earthquake magnitudes and resulting tsunami impacts. The scenarios include Small (S), Medium (M), Large (L), Extra Large (XL), and Extra-Extra Large (XXL) events (Figure 7).

Tsunami Size	Abbreviation	Earthquake Magnitude	Percentage of Inundation Zone Impacted	Return Periods (years)
Small	S	~8.7	26%	2,000
Medium	M	~8.9	79%	1,000
Large	L	~9.0	95%	3,333
Extra-Large	XL	~9.1	98%	5,000
Extra-Extra-Large	XXL	~9.1	100%	10,000

Figure 7: DOGAMI "T-shirt" size CSZ tsunami inundation scenarios modeled for the Oregon Coast. Of note, Washington uses a Mw 9.0 scenario with a 2,500-year return period, comparable to Oregon's "L" scenario. California's 2,475-year product also matches Oregon's "L" scenario, while its 975-year product corresponds to Oregon's "M" scenario.

These scenarios are used to evaluate tsunami inundation and evacuation needs for communities along the Oregon Coast. The XXL scenario represents the maximum considered local tsunami and is widely used for life-safety planning and evacuation mapping.

Beginning in 2009, DOGAMI developed a new generation of tsunami inundation and evacuation maps using updated earthquake source models and tsunami simulations. Modeling conducted between 2010 and 2013 resulted in the production of:

- Coastwide tsunami inundation maps
- Tsunami evacuation maps for 46 coastal communities

Having completed tsunami inundation modeling for the Oregon Coast, the DOGAMI tsunami program has largely focused on three core areas:

- Completing tsunami evacuation modeling for every coastal community to determine how long and over what distances people need to travel to reach high ground.
- Maritime tsunami modeling for major ports and harbors; and,

- Completing detailed Hazus-based risk assessments for every coastal community to document the likely impacts of a CSZ earthquake and tsunami in terms of building damage, losses and casualties.

1.2.4 Tsunami Runup

Tsunami modeling by DOGAMI have indicated that a CSZ tsunami is expected to produce significant runup of the Oregon Coast. Figure 8 presents calculated runup elevations determined for discrete points approximately 300 ft apart along the length of the Oregon Coast for three earthquake rupture scenarios (M, L and XXL). Based on these data, we can see that the *average* runup elevation for the coast is likely to range from 40 ft (M) to 80 ft (XXL) elevation depending on the earthquake rupture scenario (Figure 8). Furthermore, modeling by DOGAMI indicates that tsunami runup is expected to exceed 100 ft in elevation in some locations, particularly for communities such as Gold Beach on the southern Oregon Coast due to their closer proximity to the CSZ.

Ninety percent of the modeled runup is likely to be < 65 ft in an M earthquake, < 82 ft in an L earthquake, and < 120 ft in a maximum considered XXL scenario. The reader should be aware that lower runup elevations shown in Figure 8 include some areas up coastal estuaries, rivers and creeks. Hence, when considering tsunami runup at the coast, one should evaluate the actual runup at the locations of interest (see the ASCE Tsunami Hazard Tool in Appendix C to view runup mapping). Fatalities caused by the tsunami are virtually 100% for any person who is unable to reach high ground in sufficient time and is ultimately caught by the tsunami. Nevertheless, for every step toward high ground, the chance of surviving a tsunami improves.

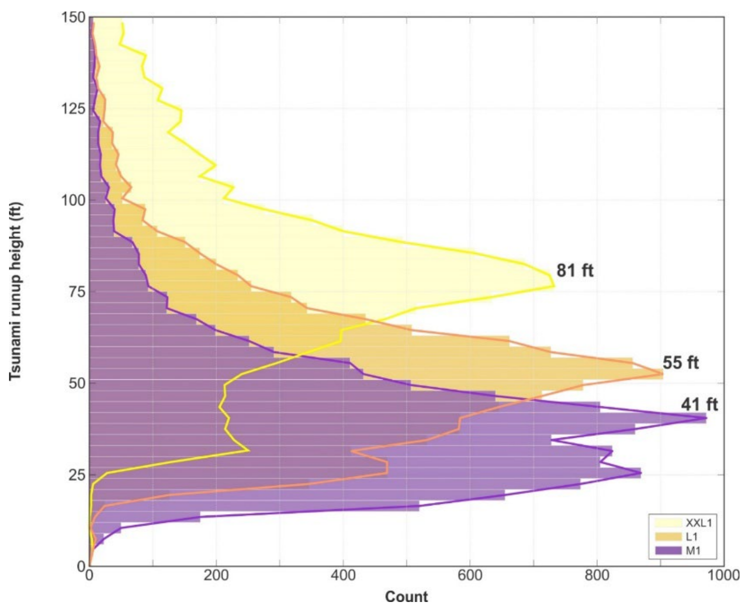

Figure 8: A histogram plot showing the proportion of simulated runup elevations for the M, L and XXL earthquake rupture scenarios determined for open coast areas only. Image provided by DOGAMI.

Chapter 2: A Race to Safety

FEMA defines debris as, "Scattered items and materials either broken, destroyed or misplaced by a disaster."

As the first tsunami wave reaches the Oregon Coast and inundates coastal communities, the forces of the tsunami wave will destroy virtually everything in its path.

Estimates by DOGAMI indicate that a CSZ tsunami is likely to destroy about 70% to 90% of buildings in the tsunami inundation zone and will produce about 4.4 million tons of debris (Allan and O'Brien, 2025). See the Oregon Department of Emergency Management's *Understanding Tsunami Debris and Sediment Planning and Mitigation Guide* (OEM, 2024) for more information.

The debris is then incorporated into the tsunami surges, creating additional dangers to human life, demonstrated by Figure 9.

Figure 9: Impaled Tire, Whittier, Alaska. Photo by OEM, 2025. The tire was impaled by the piece of 2X12 lumber during the March 1964, M9.2 subduction zone earthquake.

Because tsunamis carry immense force and debris, survival once you are in the water is extremely unlikely—typically less than 1%. Research shared in a Cascadia CoPes Hub webinar shows that anyone caught in tsunami flow depths of about 2 meters has only a 1% chance of survival, and even at lower depths the odds are roughly 50/50, with a high likelihood of serious injury. These realities make immediate evacuation to natural high ground or a designated safe location essential for survival (Zuzak, Wood, & Rabinowitz, 2024).

To avoid being swept up in a tsunami, residents and visitors must be able to reach high ground before the first tsunami wave arrives. The total time it takes to reach safety is dependent on the following:

- The time spent taking protective actions (Drop, Cover, Hold On!) during the earthquake shaking.
- Milling time—the delay before people choose to act—cannot be predicted after a CSZ earthquake. There is potential for significant delay, and the associated risk cannot be overstated.
- Time to evacuate buildings and reach the nearest road at the start of the evacuation route.
- The time spent travelling along the evacuation route towards high ground.

There is no way to know how long Oregon residents and visitors will wait before starting their evacuation. The reality is that some will evacuate promptly, while others will not. Delay in evacuation may be influenced by various factors, including the time spent determining what happened prior to leaving (actively seeking out more information); time trying to either seek out or gather people, pets and belongings; a lack of awareness of the hazard; difficulty evacuating a building due to injury or blocked exits; and the shock and paralysis that comes from having experienced such a large earthquake.

Nevertheless, recent earthquake events can tell us something about the behavior of people milling. For example, Mas and others (2013) determined a mean of 7 minutes in 2010 and 2011 surveys at La Punta, Peru, which has experienced several local earthquakes and tsunamis over the last ~400 years, the last being in 1974. More recently, Makinoshima and Imamura (2024) evaluated evacuation response times following the 2011 Japan tsunami for some 49 cities. In general, those closest to the coast experienced the least amount of ‘milling’ behavior, while those further inland (e.g., upriver or up estuary) tended to delay their evacuation (longer milling).

For the open coast sites (nearest to the ocean), people took about 10 minutes prior to evacuating, which included approximately 4 minutes of earthquake shaking that was experienced. Milling times were found to range from as little as 4 minutes to as much as 20 minutes. Makinoshima and Imamura (2024) further noted that people were essentially unable to evacuate during the first 4 minutes of the earthquake, due to the strong ground motions experienced.

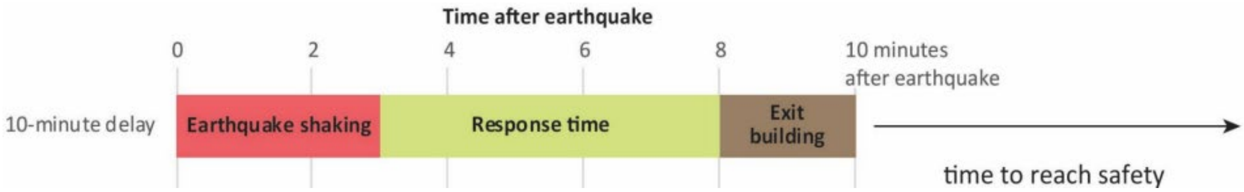

Figure 10: Departure Times and Delays

Over the past decade, DOGAMI have completed pedestrian-evacuation modeling for every coastal community on the Oregon Coast. An important component of their modeling was the incorporation of milling behavior to define more credible pedestrian evacuation travel speeds. After consideration of the length of potential earthquake shaking and milling behavior observed by Mas and others (2013), DOGAMI adopted a 10-minute delay in their “Beat the Wave” analyses (e.g., Gabel and others, 2024).

This departure time included approximately 3 minutes of earthquake shaking (Figure 10), 5 minutes to collect people and belongings, and 2 minutes to exit the building and reach the nearest road. For campgrounds and other locations where significant numbers of people may find themselves outside during the earthquake, DOGAMI used a 5-minute milling scenario. Bauer and others (2020) evaluated several other delayed departure times (10, 15, and 20-minute, Figure 11) to demonstrate the dramatic increase in the potential for fatalities when evacuation is delayed due to increased milling behavior.

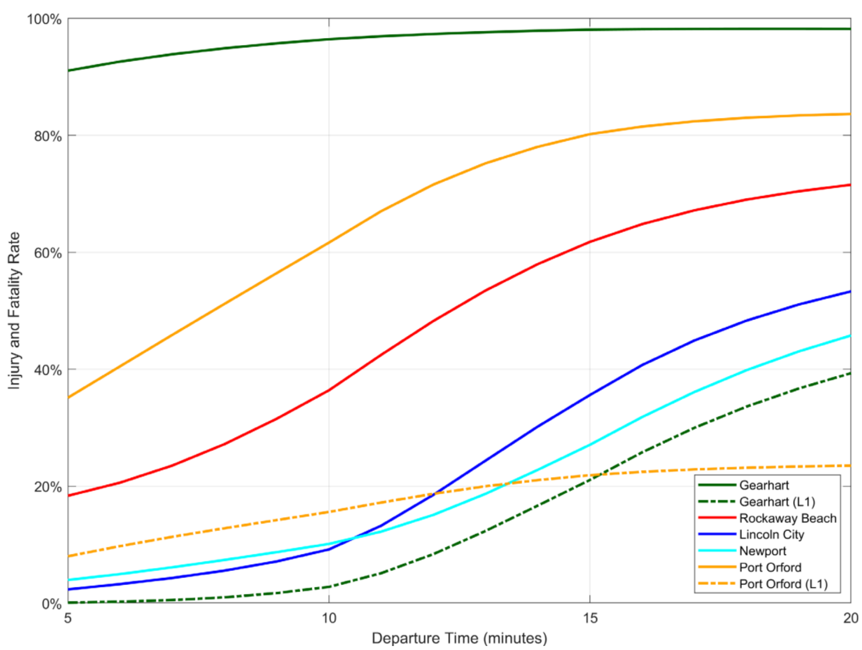

Figure 11: Estimated tsunami injuries and fatalities for each community are shown based on group departure time and a walking speed of 4 fps during a summer weekend at 2 AM, assuming an XXL1 tsunami. Results of an L1 tsunami affecting Gearhart and Port Orford are also included, shown with green and orange dashed lines, respectively.

2.1 Impacts of Departure Delays

With waves arriving so quickly, rapid departure time is critical to surviving a tsunami, and success. According to Wood and others (2025), survivability can be modeled by varying departure delays, as follows.

No departure delay	Individuals begin to evacuate immediately after an earthquake begins
5-min delay	Individuals begin to evacuate once shaking has stopped
10-min delay	Individuals begin to evacuate a few minutes after shaking stops

The research highlights how even small delays in evacuation can drastically increase fatalities during an XXL tsunami scenario.

Figure 12 uses four colored bars to show different evacuation delay scenarios. Each color represents a different delay interval, helping visualize how fatalities rise as delays increase. The red bars specifically indicate people who cannot reach safety even if they start evacuating immediately—because they are too from high ground or in areas with limited escape routes. This underscores that some communities are inherently at high risk, regardless of individual response times.

While the figure includes data from multiple coastal areas, the intent is not to compare regions but to show that this challenge is widespread along the Cascadia coastline. Oregon is the focus here, but similar constraints exist in Washington and California, reinforcing the need for regional solutions.

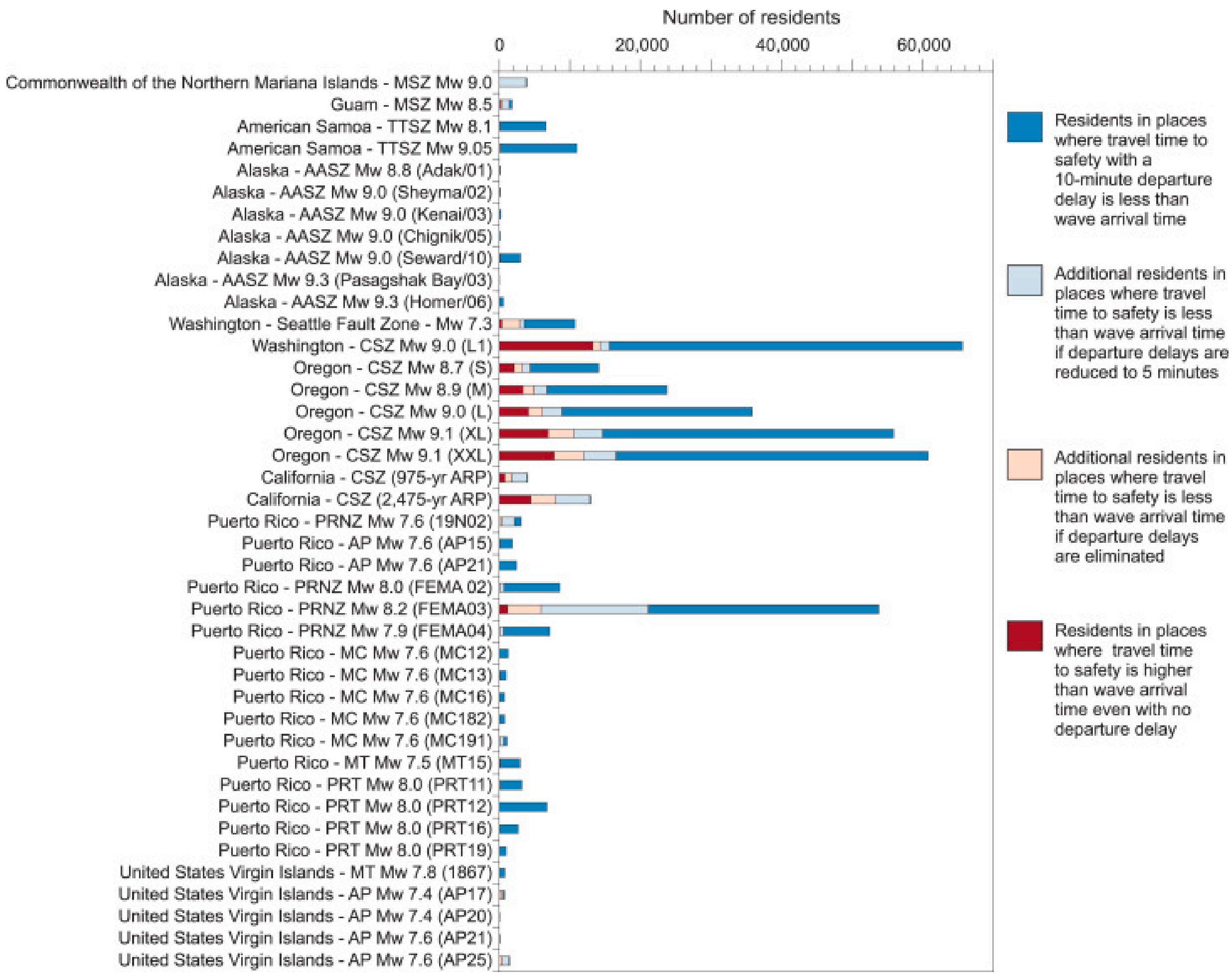

Figure 12: Residents Unable to Evacuate (Wood, N. and others, 2025)

Dr. Diego Melgar is an Associate Professor at the University of Oregon's Department of Earth Sciences. He also serves as the Director for the Cascadia Region Earthquake Science Center (CRESCENT). In an interview with PBS, Dr. Melgar discusses the realities faced by those in places like Seaside, Oregon; Long Beach, Washington; or Crescent City, California. He states that for some locations within those cities, "You'd have to run at [Jamaican sprinter and eight-time Olympic gold medalist] Usain Bolt speeds *for forty minutes sustained*, to be able to get out of the way [of an incoming Cascadia tsunami]. That's just not going to happen." (Public Broadcasting Service [PBS Terra], 2024)

For reference, Usain Bolt's top recorded speed is 27.8 miles per hour (mph). As shown in Figure 13, pedestrian sprinting evacuation speeds are much lower and even those sprinting speeds are generally not intended to be sustained for 40-minute durations.

Table 3-1. Pedestrian evacuation speed categories and their conversions.

Description	Feet per Second (fps)	Miles per Hour (mph)	Minutes per Mile
Slow walk	>0–2	>0–1.4	>44
Walk	2–4	1.4–2.7	44–22
Fast walk	4–6	2.7–4.1	22–14.7
Jog	6–8	4.1–5.5	14.7–11
Run	8–10	5.5–6.8	11–8.8
Sprint	10–14.7	6.8–10	8.8–6.0
Unlikely to survive	>14.7	>10	<6.0

Note: walking at speeds of 2–4 fps is considered a reasonable measure for the elderly and for adults who may be mobility impaired (see Figure 6 of Fraser and others, 2014).

Figure 13: Pedestrian Evacuation Speeds (DOGAMI O-19-08)

2.2 DOGAMI "Beat the Wave" Maps

DOGAMI has modeled tsunami pedestrian evacuations for every Oregon coastal community in the tsunami zone in a series called "Beat the Wave," based on modeling techniques first developed by the U.S. Geological Survey (Wood and Schmidtlein 2012). Technical papers accompany maps like the ones shown in Figure 14, and detail how fast an individual would need to move from any location within the zone all the way to safety (high ground).

Figure 14 shows the tsunami evacuation "landscape" for North Neskowin, Tillamook County (Gabel and others, 2019). The nearest high ground for people in the vicinity of Kinnikinnick Dr is a high promontory to the east (e.g., Hillcrest Dr) and the only way to get there is by crossing a marsh using the "tsunami trail" (dashed line at bottom of left panel). Even with this trail, people will only reach safety in time if they sustain a run (5.5-6.8 mph). The central panel demonstrates increases to travel speeds, should that trail be unavailable due to flooding or landslides. In this scenario, DOGAMI models show that evacuation speeds will need to maintain a sprint (6.8-10 mph) to survive.

Vertical evacuation structures shorten the distance residents and visitors need to travel to reach safety, improving the likelihood of survival, as shown in the bottom right image of Figure 14. In this scenario, travel speeds are dramatically reduced with the presence of a hypothetical VES on Bear Mountain (a nearby isolated basaltic hill), dropping necessary evacuation speeds to a slow walk (<1.4 mph).

Examples of VES impacts on other Oregon communities can be found in DOGAMI's "Beat the Wave" maps. Links are provided in *Appendix A.*

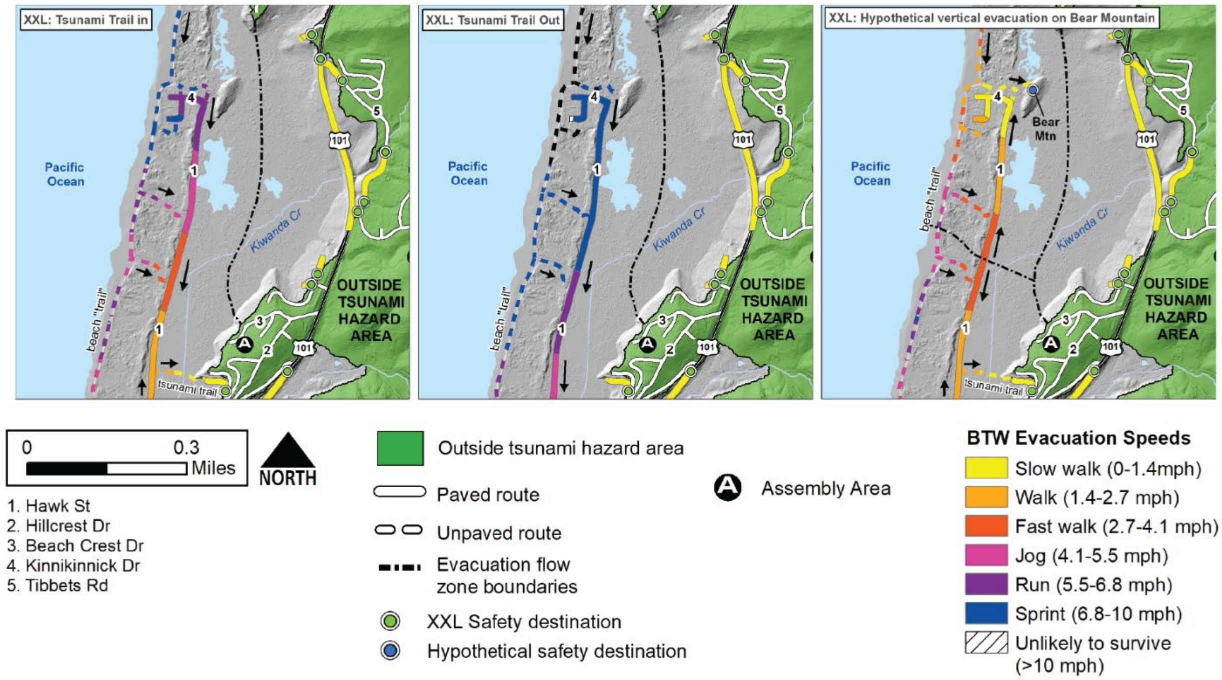

Figure 14: Neskowin, Oregon Evacuation Times (Gabel, L., and others, 2019).

Sleeter and others, (2017) found that, "approximately 23% of residents and 15% of employees in tsunami-hazard zones are in areas where modeled pedestrian-evacuation times are greater than wave-arrival times, suggesting the need for vertical-evacuation refuges or other long-term mitigation strategies to save lives."

Ultimately, DOGAMI scientists estimate ~4,550 to 14,000 Oregon residents could be killed in medium-sized (M) and extra extra-large (XXL) tsunami scenarios, respectively, with the potential for another 11,000 (M) to 31,000 (XXL) visitor fatalities (Allan and others, *2025*).

2.3 Seaside and Cannon Beach

DOGAMI conducted tsunami evacuation modeling in Seaside and Cannon Beach to help communities evaluate how quickly people can evacuate following the CSZ earthquake. The study focused on pedestrian evacuation routes and survivability under present-day conditions and hypothetical mitigation scenarios, including VES and seismic bridge retrofits.

Using the "Beat the Wave" model, DOGAMI calculated the minimum walking speeds needed to escape the tsunami, accounting for terrain, wave arrival times, and a 10-minute delay after earthquake shaking. Survivability was assessed using a realistic walking speed of 4 feet per second (2.7 mph), suitable for mixed populations.

Key findings include:

- In **Seaside**, only 25% of residents are expected to survive under current conditions. A single VES could increase survival to 50%, and adding more VES structures could raise it to 85%.
- In **Cannon Beach**, 90% of residents are expected to survive due to nearby high ground. However, the downtown area is isolated by Ecola Creek. Retrofitting the Fir Street Bridge could increase downtown survivability from 2% to 77%, and strategically placed VES structures could save up to 100% of residents in some locations.

The modeling supports emergency planning, public awareness, and funding justification for life-saving infrastructure like VES and bridge retrofits. Below, Figure 15 and Figure 16 show how many lives could be saved by building tsunami VES in certain locations within Seaside and Cannon Beach, respectively.

	Survivors				Non-Survivors
Scenario	Permanent residents	Temporary residents*	Total population**	Improvement from Current-conditions (Total pop)	Total population**
Current-conditions	2,400	1,800	4,200	-	12,700
All bridges in	2,500	2,000	4,500	300	12,400
VES: Convention Center	3,500	5,000	8,500	4,300	8,400
VES: Outlet Mall	4,200	3,800	8,000	3,800	8,900
VES: Goodman Park	4,100	4,300	8,400	4,200	8,500
VES: Former high school	3,000	2,400	5,400	1,200	11,500
VES: Cartwright Park	3,000	3,600	6,600	2,400	10,300
2 VES: Convention Center & Outlet Mall	4,700	6,500	11,200	7,000	5,700
3 VES: Convention Center, Outlet Mall & Cartwright Park	5,000	7,500	12,500	8,300	4,400
4 VES: Convention Center, Outlet Mall, Cartwright Park & Goodman Park	5,600	8,700	14,300	10,100	2,600

* Results do not account for day visitors, which can increase the number of visitors in Seaside by ~9,000 people–16,000 people.

** Total population = permanent residents + temporary residents

Figure 15: Number of Survivors in North Seaside for all VES scenarios with "current conditions" scenario for comparison.

Scenario	Survivors: Permanent residents	Survivors: Temporary residents*	Survivors: Total population	Survivors: Improvement from Current-conditions (Total pop)	Non-Survivors: Total population
Current-conditions	800	3,900	4,700		800
VES: 2nd & Spruce	900	4,600	5,500	800	0
VES: Larch & 1st	900	4,400	5,300	600	200
VES: Adams & Spruce	900	4,600	5,500	800	0
VES: City Hall	800	3,900	4,700	0	800

* Results do not account for day visitors, which can increase the number of visitors in Cannon Beach by ~6,000 people.

** Total population = permanent residents + temporary residents

Figure 16: Number of survivors in north Cannon Beach for all VES scenarios with "current conditions" scenario for comparison.

Chapter 3: Vertical Evacuation Structures

Many communities can successfully evacuate to natural high ground by improving education, signage, drills, and route accessibility. These preparedness activities—such as maintaining evacuation paths, installing clear signage, conducting community drills, and strengthening key routes—are effective when high ground can be reached in time.

However, this paper focuses on situations where natural high ground is too far to reach before tsunami arrival. In these locations, the primary life-saving strategy is to shorten the distance to safety with vertical evacuation structures (VES).

VES provide elevated refuge within the inundation zone when natural high ground is not accessible. They have proven effective in past tsunamis, including the 2011 Great East Japan Earthquake, where many VES enabled people to survive when inland evacuation was impossible.

There are generally three types of VES: buildings, towers, and berms. The final design for a community depends on factors such as the number of people who will need to use the VES, local land use policies, community input, potential additional uses for the structure, and available funding. In some cases, a single VES may not be sufficient, and communities may require multiple structures to adequately serve their population. The type of VES selected ultimately depends on the site's physical characteristics, such as local geology, tsunami hydrodynamics and flow depths, and available space, and the community's needs.

When evaluating buildings as potential vertical evacuation sites, planners should consider how many people can realistically reach the structure and how easily they can do so. This includes occupants already inside, and those within a walkable distance who may rely on the building for refuge. Accessibility is critical: evacuation routes should be clear, direct, and usable by people of all ages and abilities, with minimal physical barriers that cannot be modified.

Demographics play a key role in design. Facilities near schools should accommodate children and staff, providing safe, direct routes and sufficient capacity for large groups. Structures serving retirement communities or populations with limited mobility should prioritize ramps, minimal stairs, and other accessibility features. In areas with high tourist activity, VES should account for visitors unfamiliar with local routes, offering clear signage and ample space to safely shelter temporary populations. Considering these demographic factors ensures VES are effective and appropriate for the communities they serve.

For VES towers, planners should evaluate the population within a practical evacuation radius and assess whether the structure can support additional community functions—such as recreational space or tourism amenities—when not in use for emergency refuge.

It is also important to recognize that these towers will typically require a waiver or variance if they exceed local building height restrictions. Because zoning regulations vary by jurisdiction, planners must carefully navigate differing requirements and approval processes.

In addition, planners need to evaluate how the tower will interact with its surroundings, including potential effects on nearby buildings, infrastructure, and the natural environment. Thoughtful citing and design are essential to ensure the structure improves overall safety without introducing new risks or land-use conflicts. Together, these factors help determine whether a VES tower is both practical and advantageous for the community it is designed to serve.

3.1 Buildings

When planning for tsunami vertical evacuation, buildings play a critical role in providing accessible, elevated refuge. Whether purpose-built or adapted from existing structures, the goal is to identify safe spaces that can withstand tsunami forces and be reached quickly by those at risk.

This section explores a range of building types—from parking garages and schools to commercial centers and community facilities—that offer potential for vertical evacuation. Each option presents unique advantages and challenges, but all must be evaluated for structural integrity, accessibility, and their ability to serve the community both during emergencies and in everyday life.

All VES options will benefit from considering the following:

- **Shelter and Supplies:** Plan for additional structures on top of the VES (e.g., supply caches, shelters) to protect evacuees from wind, rain, and cold. Without shelter, hypothermia risk is high during prolonged exposure.
- **Duration of Isolation:** Tsunami surges may persist for up to 24 hours; provisions for water, food, sanitation, and light medical care are also essential.

3.1.1 Multi-Story Parking Garages

Parking garages are strong candidates for vertical evacuation due to their open design, which allows water to pass through with minimal resistance. They offer 24/7 pedestrian access and include interior ramps that enable easy movement to higher levels. The rooftop can serve additional community functions, such as parks, observation areas, or sports facilities. In tourist areas, these structures also generate revenue through parking fees (FEMA, 2019).

3.1.2 Community Facilities

Vertical evacuation spaces can be integrated into community facilities such as recreation centers, libraries, museums, sports complexes, and emergency services buildings. When not used for evacuation, these spaces can support a range of public functions that benefit the community. However, dual-use facilities must be carefully planned to avoid interfering with their emergency role. Potential issues include clutter that could block access, or limited availability outside normal building opening hours. Ideal secondary uses should support high occupancy and allow 24/7 access (FEMA, 2019).

Haiqal et al. (2019) found that tsunami evacuation buildings should not remain idle until disaster strikes—they need to be part of everyday community life. When people regularly use these buildings, they become familiar with their location, entrances, and overall safety, eliminating hesitation during an emergency when every second counts. One practical recommendation is to repurpose lower floors as public facilities, such as libraries or community spaces, to attract daily visitors, especially families and children. This approach builds trust in the building's strength and creates a sense of comfort and accessibility. Well-maintained structures that look solid inspire confidence, while poor upkeep undermines trust—even if the building is structurally sound. Ultimately, design, accessibility, maintenance, and public trust remain critical factors. The goal is simple: when the ground shakes, people should move immediately, without debating where to go.

3.1.3 Commercial and Residential Facilities

Vertical evacuation spaces can be incorporated into commercial buildings such as multi-story hotels, restaurants, and retail centers. In these settings, upper-level areas like meeting rooms or ballrooms—if located above the tsunami inundation level—can serve as refuge zones. For example, during the 2011 Tohoku tsunami, an apartment building functioned as a vertical evacuation site, with exterior stairs providing 24/7 access to designated upper floors (FEMA, 2019).

3.1.4 School Facilities

Like other community facilities, public and private schools offer essential services and can also serve as vertical evacuation sites. New school construction presents opportunities—and potential funding sources—for integrating tsunami refuge areas, as seen with Ocosta Elementary School (see case study below, Chapter 5.1). These projects often gain added public support due to their role in protecting children. To be effective, school buildings must be either tall enough or located on elevated ground to serve as safe refuge during a tsunami (FEMA, 2019).

3.1.5 Existing Buildings

Some existing buildings could potentially serve as vertical evacuation structures, though they typically need to be constructed with reinforced concrete and steel to withstand tsunami forces. These structures must undergo engineering evaluations to ensure they meet seismic and tsunami safety standards, including elevation requirements based on local modeling. While many small coastal towns lack buildings with ideal construction, historical evidence shows that even some non-specialized buildings have withstood tsunami events. With proper assessment and possible retrofitting, certain existing buildings may be viable for vertical evacuation. Evaluating both structural integrity and functional suitability is essential (FEMA, 2019).

One final consideration from Fraser, S. A. et al. (2012):

> *"Fire was a significant issue during and immediately after [the 2011 Japan] tsunami; many buildings burned, and some evacuation centres narrowly avoided catching fire while occupied by evacuees. In Kesennuma, over 50,000 litres of oil spilled from ruptured oil tanks and engulfed several areas around [tsunami vertical evacuation buildings] TVEB… In Ishinomaki, fire spread within one hour of the earthquake to the Kadonowaki school building where people had taken refuge, but evacuees were fortunately able to relocate to high ground nearby before fire spread to the school.*
>
> *"Observations from Tohoku support the need for solutions to minimize the spread of fire and to prevent fire damage to TVEB, such as fire-retardant cladding and shutters. The potential for fire damage also led to one interviewee citing the need for emergency communication links in TVEB in case of urgent need of rescue."*

3.2 Towers

Towers are typically independent structures featuring an elevated platform where individuals can gather during emergencies. While some are built solely for evacuation purposes, others may serve additional functions, such as observation decks or bird-watching sites. Compared to other evacuation solutions, towers usually require less space.

One example is the Shoalwater Bay Tribe Tsunami Tower in Tokeland, Washington, which opened in March of 2022. The freestanding steel tower structure has an estimated capacity to support 400 people. It stands 50 feet high and is designed to withstand a CSZ earthquake, liquefaction and L1 tsunami conditions. Notably, it is the first standalone tsunami VES in North America. Similar tsunami evacuation towers have also been constructed in Japan (Washington EMD & UW IHMPR, 2018). See the case studies for more information.

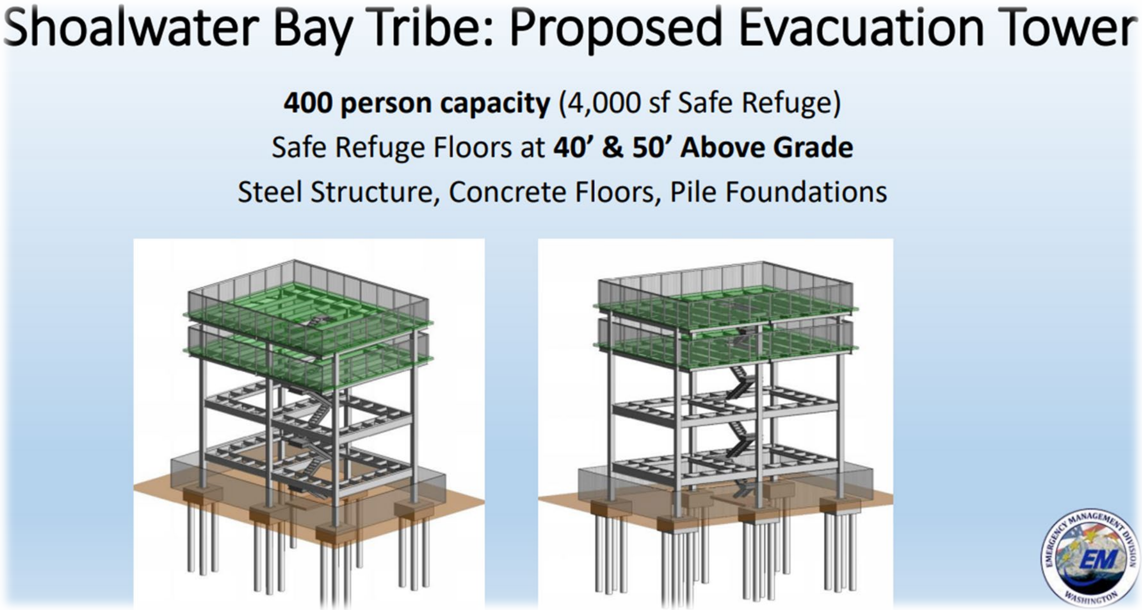

Figure 17: Shoalwater Bay Tribe Evacuation Tower

Figure 18: Shoalwater Bay Tribe Tsunami Tower – Tokeland, Washington. Photo Credit: Washington Military Department.

3.2.1 Potential Benefits

According to FEMA's *Guidelines for Design of Structures for Vertical Evacuation from Tsunamis*, the following are potential benefits for building a tower or single-purpose facility:

- They can be located away from areas prone to debris or other site-related hazards.
- There is no need to incorporate them into existing building designs or compromise them due to conflicting uses.
- Being independent structures, they avoid vulnerabilities linked to adjoining buildings.
- They remain consistently available for occupants and won't be cluttered with furniture or storage from other activities.
- As single-purpose, standalone facilities, they tend to be easier to design, get permits for, and build since they don't have to accommodate everyday use. This allows for simpler structural designs and can reduce initial construction costs.

3.3 Berms as Vertical Evacuation Options

When natural high ground is unavailable, berms—engineered, man-made mounds of earth—can provide elevated areas of safety above anticipated tsunami runup heights. Berms offer a cost-effective alternative to stand-alone vertical evacuation structures (VES), particularly in locations with sufficient open space (Wiser et al., n.d.).

3.3.1 Design and Construction Considerations

- Structure and Materials: Berms typically have a large footprint and are constructed with compacted soil. Cost savings can be achieved by incorporating recycled materials (e.g., concrete, masonry, asphalt) from local demolition projects.
- Slope and Accessibility: Gentle access ramps with a maximum slope of 1:4 ensure accessibility for all evacuees, including those with mobility challenges.
- Protection and Durability: Berm sides must be reinforced to withstand incoming and outgoing tsunami waves. Berms are inherently resistant to large debris impacts (e.g., shipping containers), making them suitable for coastal or port-adjacent sites.
- Structural Enhancements: Taller berms may require concrete elements and foundation work, increasing costs. These factors should be considered during site selection and design.

3.3.2 Design Occupancy and Cost

- Small berm (~1,000 sq ft): ~125 people
- Large berm (~100,000 sq ft): ~12,500 people
- Estimated construction costs: $300,000–$900,000, depending on height, footprint, and materials (Wiser et al., n.d.).

3.3.3 Multi-Use Potential

To enhance community support and justify investment, berms can be integrated into public spaces:

- Seating at sports fields
- Picnic and viewing areas
- Public gathering spaces

3.3.4 Planning Questions

- Is there sufficient open space for a berm with adequate capacity?
- How many people are within walking distance?
- How will the berm affect nearby buildings and landscape?
- Can the berm serve additional community functions?
- Is a vertical evacuation tower a more suitable alternative?

3.3.5 Additional Considerations

- **Space Constraints:** Because berms are accessed via sloped earth rather than stairs or ramps, they typically require a larger physical footprint. This can be challenging in coastal areas where property is highly valued. As a result, communities may be especially reluctant to dedicate land to a berm rather than other developments.
- **Access Advantages:** Berms often provide multiple access points (potentially 360°), allowing more people to ascend simultaneously compared to stairs or elevators.
- **Post-Tsunami Egress:** Despite sediment redistribution, berms’ natural shape likely leaves at least one accessible descent point after surges stop.
- **Purpose Distinction:** Berms designed for erosion control differ significantly from those intended as VES—design standards must reflect life-safety requirements.

Figure 19: Berm, Port of Sendai, Japan

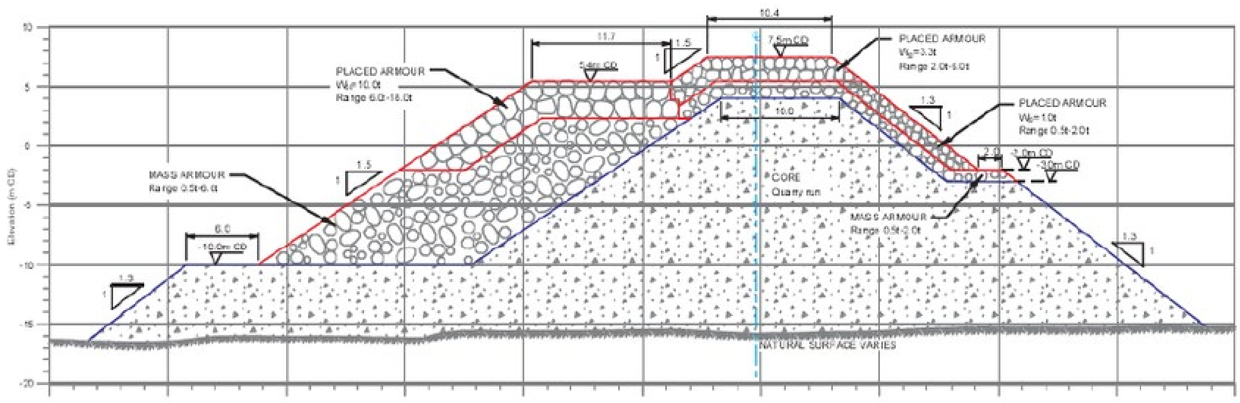

Figure 20: Berm Schematic (Mocke, R. and others, 2009)

3.4 Comparison of Vertical Evacuation Structure (VES) Types

VES Type	Advantages	Limitations / Considerations
Multi-Story Parking Garages	• Open structural design allows tsunami water to pass through, reducing structural resistance. • Interior ramps allow easy movement to higher levels. • Typically accessible 24/7. • Rooftop spaces can support community use (parks, sports courts, observation areas). • Can generate revenue in tourist areas through parking fees.	• Must be specifically engineered or verified to withstand tsunami and seismic forces. • May require structural reinforcement if originally designed only for parking. • Access routes must remain clear during emergencies.
Community Facilities (recreation centers, libraries, museums, sports complexes, emergency service buildings)	• Provides dual use for everyday community functions. • Encourages familiarity with evacuation sites through regular use. • Can support large occupancy during normal operations. • Helps build community trust and awareness.	• Everyday uses may create clutter or barriers that obstruct evacuation access. • Buildings may not be open 24/7 unless specifically designed for emergency access. • Requires careful operational planning to maintain readiness.
Commercial and Residential Buildings (hotels, apartments, retail centers)	• Often located in areas with high population density. • Upper floors may already be above inundation levels. • Exterior stair access can allow 24/7 entry. • Uses existing infrastructure rather than constructing new structures.	• Structural capacity must be verified to withstand tsunami forces. • Access for the public may be restricted or limited. • Building owners must agree to designate refuge areas. • Evacuation capacity may be limited compared to purpose-built structures.
School Facilities	• Often centrally located within communities. • Strong public support due to protection of children. • New construction can integrate vertical evacuation design. • Large structures with significant occupancy capacity.	• Must be tall enough or located on elevated ground to function safely. • Access outside school hours may be limited without planning. • Structural design must meet tsunami and seismic standards.

Existing Buildings (Retrofitted)	• May reduce construction costs compared to building new structures. • Uses existing infrastructure already familiar to residents. • Can provide evacuation options in communities with limited land availability.	• Many coastal buildings are not designed for tsunami loads. • Requires detailed engineering evaluation and possible retrofitting. • Structural limitations may prevent safe use. • Fire hazards and secondary impacts must be considered.
Towers (Standalone Vertical Evacuation Structures)	• Purpose-built for tsunami evacuation. • Can be located strategically away from debris hazards. • Independent structure avoids vulnerabilities of adjacent buildings. • Typically available at all times and free from clutter. • May require less land than berms.	• May have limited capacity depending on platform size. • Requires dedicated construction and funding. • May require zoning waivers for height restrictions. • Stairs may present accessibility challenges for some populations.
Berms (Engineered Earth Mounds)	• Cost-effective compared to many structural solutions. • Resistant to debris impacts. • Gentle slopes can improve accessibility. • Multiple access points allow many people to ascend simultaneously. • Can support recreational uses (seating, parks, gathering areas).	• Requires large land footprint. • May be difficult to site in dense coastal areas with high land value. • Tall berms may require structural reinforcement, increasing costs. • Must be carefully designed to meet life-safety standards.

3.5 Situations Where Different VES Types May Be Most Appropriate

VES Type	Most Suitable Conditions	Key Planning Considerations
Multi-Story Parking Garages	• Dense downtown or tourist areas • Locations with high vehicle demand • Areas where dual-use infrastructure is desired	• Must be designed or retrofitted to meet tsunami and seismic standards. • Ensure pedestrian access during emergencies. • Rooftop refuge areas must meet design elevation requirements.
Community Facilities (recreation centers, libraries,	• Community hubs with frequent public use • Locations where public familiarity with the structure is beneficial	• Must always maintain clear evacuation access. • Operational plans needed to ensure emergency availability outside normal hours.

civic buildings)	• Areas seeking multi-purpose public infrastructure	• Structural design must meet VES standards.
Commercial or Residential Buildings	• Urban or resort areas with multi-story development • Locations where new construction is planned • Areas where existing tall buildings are available	• Public access must be addressed through agreements with owners. • Structural capacity must be verified. • Refuge areas must be clearly marked and accessible during emergencies.
School Facilities	• Communities where schools are located within tsunami hazard zones • Areas where protecting large numbers of children is a priority • Locations planning new school construction	• Structures must meet tsunami design standards. • Refuge areas must be accessible outside school hours if serving the public. • Safe evacuation routes to the building must be identified.
Existing Buildings (Retrofitted)	• Small coastal communities with limited land for new structures • Areas where suitable reinforced buildings already exist • Locations where retrofitting is more cost-effective than new construction	• Detailed engineering assessment required. • May require structural reinforcement. • Access and refuge areas must be clearly defined and maintained.
Standalone Towers	• Areas with limited land availability • Locations where buildings cannot meet design standards • Communities need quick, purpose-built evacuation options	• Capacity may be limited compared to other options. • Accessibility for people with mobility limitations must be considered. • Height restrictions or zoning approvals may be required.
Berms (Earthen Mounds)	• Communities with available open space (parks, athletic fields, undeveloped land) • Locations where large numbers of people must be accommodated • Areas where lower-cost solutions are needed	• Large footprint required. • Must meet design elevation and slope requirements. • May affect surrounding landscape or development patterns.

3.6 Conclusion

VES are a critical component of tsunami preparedness, offering lifesaving refuge when natural high ground is unavailable or inaccessible. Buildings, towers, and berms each present distinct opportunities and challenges, and the most effective solutions depend on a community's geography, population needs, and available resources. Careful evaluation of factors such as accessibility, capacity, secondary uses, and environmental impacts ensures that these structures are not only safe but also practical and beneficial in daily life. Lessons from past tsunami events highlight the importance of resilient design, including fire resistance and clear evacuation routes, to safeguard occupants during complex emergencies. Ultimately, successful VES planning requires balancing engineering standards with community input and long-term usability, ensuring that every structure contributes to both immediate safety and broader resilience.

Chapter 4: VES Case Studies

4.1 Ocosta Elementary School

Ocosta Elementary School, located near Westport, Washington, was the first tsunami vertical evacuation structure built in North America. The project was the result of collaboration between the Ocosta School Board, five communities within the Ocosta School District, and numerous partners, working together to support a successful outcome (Washington EMD, 2018; University of Washington Institute for Hazards Mitigation Planning and Research).

There was early recognition that the community wanted to protect the children from the threat of tsunamis, so when the community needed a new school, the decision was made to incorporate a VES into the school's design to ensure the structure could also help other community members.

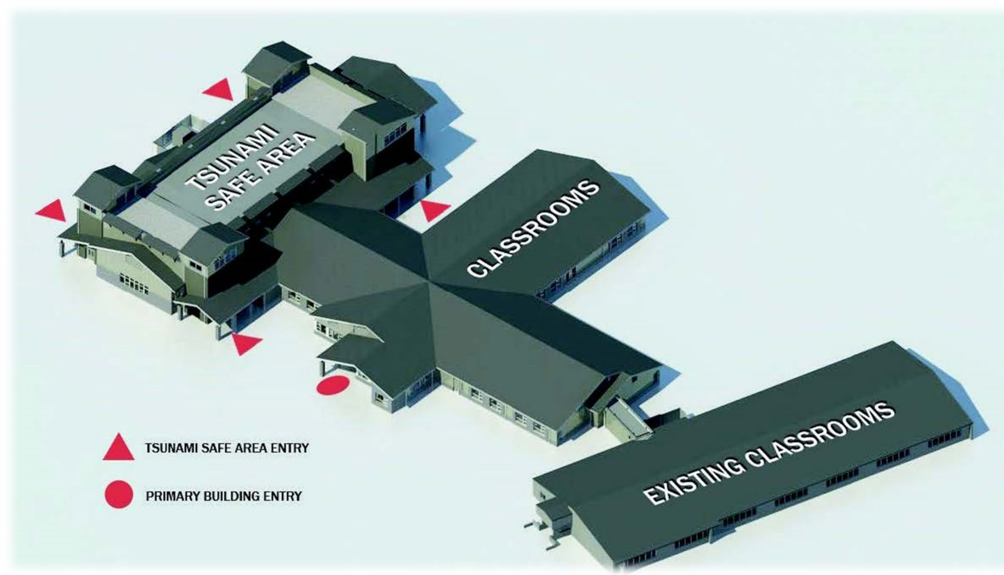

Figure 21: Computer rendering of Ocosta Elementary School – Westport, WA. Image Credit: TCF Architecture

Their Stakeholder Committee, comprised of senior groups, city government officials, Tribes, the Chamber of Commerce, PTA members, community service groups, teachers, and realtors were critical in facilitating the necessary conversations. Prospective firms presented to committee members and invited them to tour their firms before the committee chose which firms to hire. The superintendent served as the community leader and internal project manager.

Support from the Washington State Educational Service District (ESD), which provided bond planning and facility construction services, helped guide project management for the Ocosta Elementary School vertical evacuation structure. Securing funding was a central challenge throughout the project. District leadership and a stakeholder committee initially applied for a hazard mitigation grant from the Federal Emergency Management Agency (FEMA), but also developed contingency plans in case the application was unsuccessful.

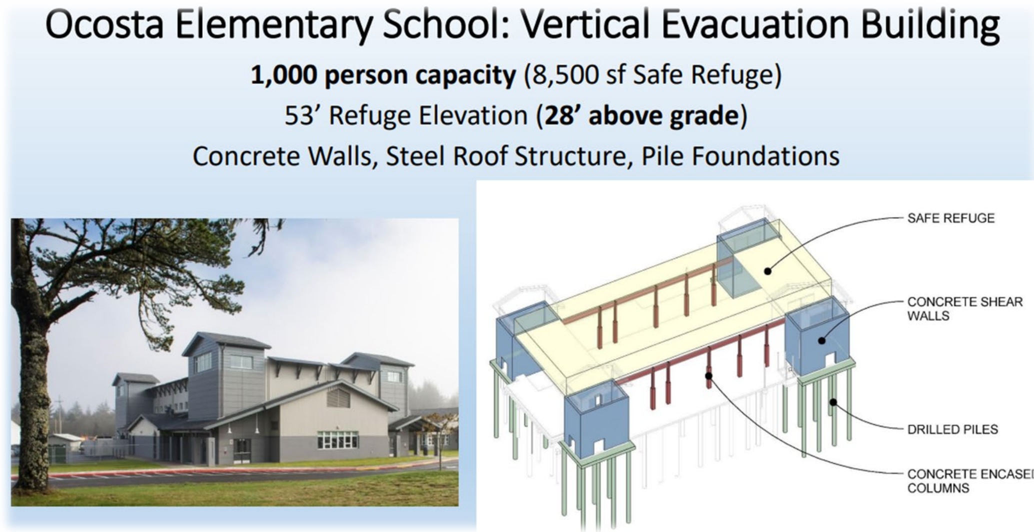

Figure 22: Ocosta Elementary School VES

When FEMA did not award the grant, the community moved forward by funding most of the project through municipal bonds. The limited budget required extensive cost analysis and careful design decisions. For example, the project team ultimately chose not to include an elevator because of its high cost and the likelihood that it would not function after strong earthquake shaking. Instead, architects designed large stair towers to provide access to the roof.

The completed structure required 160 concrete piles that extend 50 feet deep. According to Degenkolb engineer Kale Ash, while the total cost of the building amounted to $16 million, the total cost was only about ten percent more than a non-fortified school (TCF Architecture, 2016). The building can accommodate 1,000 people.

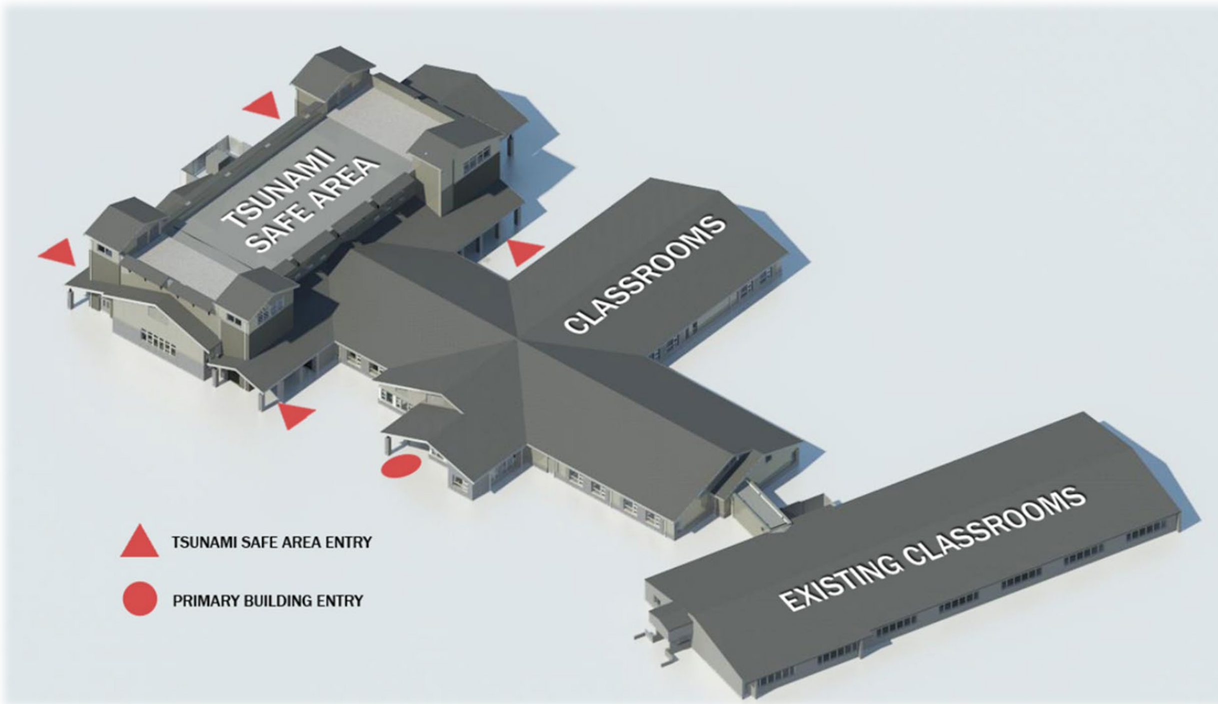

Figure 23: Layout of Tsunami Safe Area at Ocosta Elementary School. Image by TCF Architecture, https://www.tcfarchitecture.com/project/ocosta-elementary-school/

While a vertical evacuation structure is designed to serve as a life-safety refuge, it cannot ensure that every community member and non-resident will be able to reach it in time. Visitors may not be made aware of the resource either during a rapidly evolving tsunami event. As a result, there is a real possibility that repeated tsunami surges will carry substantial debris, including structural materials, household contents, and, tragically, individuals who were unable to evacuate. This design reality informed Ocosta's decision to use solid, ~six-foot-tall walls around the rooftop evacuation area. Limiting visibility to debris-laden and potentially traumatic surge conditions was considered essential for reducing psychological distress among evacuees, particularly children, while also providing a robust physical barrier against wind- and water-driven hazards. For these reasons, solid perimeter walls may be an important design consideration for other communities planning tsunami vertical evacuation structures.

4.2 Gladys Valley Marine Studies Building

The Gladys Valley Marine Studies Building (GVMSB) at Oregon State University's Hatfield Marine Science Center in Newport, Oregon, was developed as a multi-use academic facility that incorporated Vertical Evacuation Structure (VES) capacity within a mapped tsunami inundation zone. Located on the South Beach peninsula, the building supports research and teaching functions while also providing a rooftop refuge intended to enhance life safety during a Cascadia Subduction Zone earthquake and tsunami event.

This case study was informed by an interview conducted on April 4, 2025, between OEM Mitigation Special Projects Team Lead Mike Crop and Hatfield representatives Cinamon Moffett and Mark Farley. The discussion provided insight into how the building evolved from a conventional research facility expansion into a facility that integrated vertical evacuation capacity within a regulated coastal hazard environment.

Figure 24: Gladys Valley Marine Studies Building; Image Credit: OEM

The construction of a new building on the Hatfield Campus moved forward within the framework of Oregon Senate Bill 379, which restricted certain types of development in tsunami inundation zones and required demonstration that occupant safety could be ensured. At the time of planning, the Hatfield campus was projected to host peak seasonal populations approaching 900 individuals, not including additional federal agency personnel operating nearby. Horizontal evacuation to Safe Haven Hill would remain part of the campus emergency plan; however, the limited time between earthquake rupture and modeled tsunami arrival prompted evaluation of additional life-safety strategies as part of the new building design.

Hatfield functions as Oregon State University's primary coastal research campus and houses multiple co-located federal and state agency partners. The campus relies on a large-scale seawater laboratory system that delivers between 700,000 and 1,000,000 gallons per day and supports integrated marine science research. When exploring the addition of a new building to campus, alternative sites outside the inundation zone were evaluated, and while upland locations reduced geotechnical exposure, relocating the facility would have separated classrooms from laboratories and research infrastructure central to campus operations. Even if constructed outside the hazard zone, students and researchers would still have required routine access to facilities within the inundation area. As described in the interview, the planning process ultimately shifted toward strengthening life-safety capacity at the existing coastal campus rather than relocating core functions.

The GVMSB was also developed within a community culture that had long emphasized tsunami preparedness. Hatfield conducted annual evacuation drills since 2005 and achieved NOAA Tsunami Ready designation in 2013. As noted in the interview, community discussions following the 2011 Tohoku earthquake and tsunami increased regional awareness of Cascadia risk and supported the inclusion of visible vertical evacuation capacity within the new building.

The resulting building design was engineered to withstand intense ground shaking associated with a major Cascadia earthquake and to resist tsunami forces consistent with DOGAMI-modeled large-scale scenarios. The performance objective was to maintain structural integrity to allow occupants to move to elevated refuge prior to wave arrival.

Independent seismic and tsunami engineering studies informed the final design. Geotechnical investigations confirmed high liquefaction potential due to unconsolidated dredge spoils underlying the peninsula. To address this condition, the project incorporated deep soil mixing to improve soil stability and reduce settlement and lateral spreading during strong ground shaking. The structural system included reinforced concrete shear wall cores and redundant lateral force-resisting elements designed to perform under severe seismic loading. Anchorage and structural detailing addressed hydrodynamic and buoyant forces associated with tsunami inundation, while exterior wall systems incorporated breakaway concepts intended to relieve water pressure without compromising the primary structural frame. Each of these engineering features supports the ingenuity of the rooftop assembly area.

The rooftop was engineered as an emergency assembly area capable of accommodating approximately 920 occupants for up to 48 hours. A disaster cache was incorporated to support short-term survivability and included potable water, food, sanitation supplies, temporary shelter materials, communication equipment, lighting, personal warmth provisions, and trauma first aid supplies (Graves, Susan M., 2021).

Access to the rooftop refuge was provided by a prominent exterior ramp, interior stairwells and elevator service. ADA-informed Accessibility accommodations were incorporated into the design to support evacuation for individuals with mobility limitations. Wayfinding and internal evacuation signage were added to encourage upward movement following significant ground shaking and to reinforce the building's dual role as both academic facility and refuge.

In the end, the Gladys Valley Marine Studies Building demonstrated how an academic facility located within a regulated tsunami inundation zone could integrate geotechnical stabilization, enhanced seismic performance, and rooftop refuge capacity into a single multi-use structure. While no building could eliminate tsunami risk under extreme conditions, the project reflected a deliberate effort to align hazard modeling, statutory requirements, engineering design, and institutional mission to strengthen life-safety capacity at a coastal research campus.

4.3 Tokeland's Tower

The Tokeland Vertical Evacuation Tower is located just outside the Shoalwater Bay Indian Tribe Reservation in Tokeland, Washington. As the first free-standing tsunami vertical evacuation structure in the United States, it represents a major milestone in national tsunami preparedness. The tower was designed to protect both Tribal members and the surrounding

Tokeland community, offering life-saving refuge for more than 400 people—far exceeding the tribe's population—and serving anyone who can reach it within a 15–20-minute walking distance.

Figure 25: The Shoalwater Bay Indian Tribe's tsunami vertical evacuation tower in Tokeland, Washington—the first free-standing structure of its kind in the United States.

The tower stands over 50 feet tall and includes two reinforced refuge decks at 40 and 50 feet above ground. Each deck provides 2,000 square feet of space engineered to support shoulder-to-shoulder occupancy during a tsunami event. Its foundation consists of concrete pilings driven 55 feet into reinforced sandy soils, providing stability against severe earthquake shaking, liquefaction, and tsunami forces. The design was informed by University of Washington research on maximum wave heights and engineered to withstand extreme loads even when fully occupied. The structure includes lighting from the base of the staircase to the top, designed to remain operational after an earthquake, allowing the tower to function as a visible safety beacon during nighttime evacuations.

Because the tower is not classified as a multi-use facility, it was not required to meet ADA standards. Incorporating a compliant ramp would have exceeded available project resources, resulting in a structure that individuals with mobility disabilities, including wheelchair users, may be unable to access independently. This highlights a critical lesson for future projects: vertical evacuation structures are intended to serve entire communities, which is most likely to be accomplished through accessibility planning that is considered early in the design and funding process. Evaluating ADA-aligned options such as compliant ramps, mechanical lifts, or other inclusive approaches during grant applications or bond development can help ensure equitable access.

The project was funded through a combination of $1.2 million from the Shoalwater Bay Indian Tribe and more than $3 million from a FEMA Hazard Mitigation Grant, marking the first successful use of FEMA funding for a vertical evacuation tower. The tower is dedicated to Auntie Lee Shipman, the Tribe's former emergency manager, whose leadership and advocacy were instrumental in securing funding and advancing the project. Her efforts transformed the community's outlook from vulnerability to resilience and demonstrated the importance of strong project champions and long-term commitment, as projects of this scale often take years to materialize.

The tower's first and second floors include wind walls that provide some protection from wind, with the first floor offering additional overhead cover. The second level has no roof and is therefore more exposed to the elements. Even on calm spring days, temperatures can be chilly on both floors, and during wet, windy Pacific Northwest storms, evacuees may need to remain on the tower for up to 24 hours. This creates a risk of hypothermia. To support extended refuge, large bins on the tower hold tarps, emergency blankets, food, water, communications equipment, emergency toilets, sanitation supplies, and basic medical supplies. These totes are low to the ground and can double as makeshift seating on the concrete floors.

Figure 26: Tokeland Tower (Auntie Lee Tower) first floor

The tower includes lighting along the entire staircase and on both refuge levels. This lighting is designed to remain operational after the earthquake and tsunami, which is critical because widespread power outages are likely. If the event occurs at night, the illuminated tower will stand out as a beacon, helping guide people toward safety even if they are unfamiliar with vertical evacuation structures. Signage on both floors helps evacuees understand what to expect upon arrival. To protect the structure, tall gates surround the base, and an “in case of emergency, break glass” key ensures that whoever arrives first can unlock the gate. This forethought supports both safety and vandalism prevention.

Figure 2: Tokeland Tower Storage Bin Sign

Figure 3: Tokeland Tower Tsunami Information Sign.

While the tower itself is engineered to withstand tsunami forces, the stairs are not and may be washed away during the event. This could require alternative means of descending the tower after the tsunami. The lack of ADA-compliant access also limits independent use by individuals with mobility disabilities. Additionally, the second refuge level’s lack of overhead cover increases exposure to wind and rain, which can be significant during prolonged post-event sheltering.

Lessons learned from Tokeland are already shaping future vertical evacuation structures. A new tower planned for Westport, Washington, and scheduled to break ground in 2026, includes a ramp for ascending that is designed to wash away in the tsunami, while the stairs are engineered to survive. This approach reflects evolving best practices and demonstrates how early projects like Tokeland can inform more resilient and inclusive designs. Additional information and images are available through the Washington Military Department’s website. https://mil.wa.gov/news/tsunami-vertical-evacuation-structure-headed-to-westport

4.4 Safe Haven Hill

Safe Haven Hill, a collaborative effort involving the city of Newport, the Federal Emergency Management Agency (FEMA), the Oregon Department of Emergency Management (OEM), and the Oregon Department of Transportation (ODOT), is a designated vertical evacuation site. While not a VES, it is an example of an evacuation improvement. Located on a natural hill just southwest of the Yaquina Bay Bridge on Newport's South Beach peninsula, the hill rises about 85 feet above sea level. It serves as the primary tsunami assembly point for residents, visitors, and employees from locations such as the Hatfield Marine Science Center, Oregon Coast Aquarium, NOAA Marine Operations, and Oregon Coast Community College (Running, D., and others, 2012).

Figure 29: Safe Haven Hill Map (Story Map: NOAA Mitigates the Impact of Killer Waves, 2017).

Geotechnical & Site Planning

- Developed through a collaborative geotechnical investigation (Running, D., and others, 2012), which confirmed the site's suitability despite being composed mainly of sand

- The assessment recommended trail improvements, tree clearing for capacity, restroom/storage facilities, and evacuation route signage to enhance accessibility and safety.

Safety & Community Preparedness

- The hill is integrated into annual community tsunami drills, including the Great Oregon ShakeOut, with agencies walking participants up the hill to evaluate evacuation timing (OSU, 2017).
- Newport emergency maps and smartphone apps highlight Safe Haven Hill as a key south Newport assembly point, alongside Oregon Coast Community College and the Municipal Airport.

Challenges & Improvements

- Access routes were originally steep, overgrown, and inconsistently signed.

Ongoing upgrades, supported by local authorities, include trail stabilization, lighting, pavement markings, and removal of vegetation to improve evacuation efficiency and capacity

Where improvements, such as the Safe Haven Hill project, are not viable, and the distance to safety must be reduced, the goal is possible through the strategic placement of tsunami vertical evacuation structures (VES).

"Tsunami vertical evacuation is an important strategy for enhancing disaster preparedness because it provides the most effective alternative to evacuation inland or to high ground in areas at risk of local tsunami. During and immediately after the Great East Japan tsunami of March 11th, 2011, a large number of tsunami vertical evacuation structures provided safe refuge in the inundation zone."

- (Fraser and others, 2012)

Chapter 5: Preparing for a Vertical Evacuation Structure

Tsunami vertical evacuation structures are unique and complex, because they must perform functions that ordinary buildings were never designed to handle. They must endure both earthquake shaking and tsunami forces, stand high enough to stay above expected flooding, and hold large groups of people who need to reach safety within minutes.

Planning, modeling, designing, and constructing these structures is different from a typical building project. Strong community involvement and leadership are necessary to evaluate the need for a VES, plan for potential locations, secure funding, construct, and conduct maintenance on both the structure and the VES cache. Partnerships with local, state, federal agencies, universities, and technical experts are key to VES project success.

5.1 Planning and Implementing VES in Oregon

5.1.1 Overview

This chapter adapts the framework of FEMA's *Guidelines for Design of Structures for Vertical Evacuation from Tsunamis* to Oregon's context. While the decision-making process outlined here follows FEMA's structure, the content has been tailored to reflect Oregon's coastal hazards, communities, and planning considerations. The original FEMA guidance remains a key reference for technical details.

5.1.2 Initiating the Process

Planning for vertical evacuation structures (VES) in Oregon can originate from multiple sources, including grassroots advocacy, local government initiatives, or formal hazard mitigation planning. Successful projects rely on early and ongoing engagement from a wide range of stakeholders—public agencies, community groups, planners, engineers, businesses, and nonprofits. Inclusive participation improves public awareness, builds community support, and broadens opportunities for funding, helping ensure that VES planning and construction are well-coordinated and supported.

5.1.3 Assess the Hazard

The first step in VES planning is a thorough assessment of the tsunami hazard for the community. This includes understanding the potential severity, frequency, and characteristics of tsunami events, particularly those generated by the Cascadia Subduction Zone (CSZ). Key components of this assessment include:

- **Tsunami Inundation Modeling**: Use high-resolution, site-specific models to estimate wave heights, flow velocities, and inundation extents. This identifies areas at greatest risk and informs potential VES locations.

- **Return Periods and Scenario Planning**: Evaluate the likelihood of varying tsunami sizes, using DOGAMI's "T-shirt sizes" from Small to XXL, to plan for both frequent, smaller events and rare, catastrophic full-margin CSZ events.
- **Co-Seismic Hazards**: Assess additional earthquake-related risks that could affect evacuation and structural integrity, including liquefaction, landslides, and ground shaking intensity.
- **Mapping and Data Integration**: Communities can use Oregon-specific resources such as DOGAMI's Tsunami Inundation Maps and "Beat the Wave" analyses, in combination with the USGS pedestrian evacuation modeling toolkit (https://www.usgs.gov/node/279276), population data and local infrastructure information to create comprehensive maps showing hazard zones, estimated wave arrival times, and barriers to evacuation.
- **Site-Specific Conditions**: Consider local topography, land use, and access to natural high ground. Low-lying areas with limited access may require engineered solutions such as berms, towers, or reinforced buildings.

This assessment forms the foundation for all subsequent planning, ensuring that decisions about VES placement, design, and necessity are grounded in scientific data and tailored to each community's unique risks.

5.1.4 Evaluate Risk

After completing the hazard assessment, communities should evaluate the potential risk to life and infrastructure. This evaluation considers population density and distribution, the vulnerability of residents and visitors—including children, seniors, and people with mobility limitations—and the accessibility of evacuation routes. Critical facilities such as schools, hospitals, and emergency services should be assessed for their ability to withstand earthquake shaking and tsunami forces, and the availability of natural or engineered refuges should be mapped.

DOGAMI's *"Beat the Wave"* modeling provides valuable insights into pedestrian evacuation challenges, highlighting locations where timely evacuation may be difficult. While this tool is not publicly accessible, communities can replicate its methodology using the USGS pedestrian evacuation modeling toolkit (https://www.usgs.gov/node/279276). Evaluating these factors allows communities to estimate potential casualties under different scenarios and determine whether a VES—or complementary mitigation measures, such as improved signage, retrofitted bridges, or land-use changes—is warranted. This step ensures that risk evaluation builds on the hazard assessment and supports informed, data-driven decisions for VES implementation.

To assess anticipated levels of shaking at a VES site, **site-specific modeling is required**. The information below cannot replace such modeling but provides a baseline for understanding the severity of the hazard in a given area.

DOGAMI offers extensive Oregon-specific modeling for earthquake and tsunami impacts along the coast. The *2025 Earthquake and Tsunami Impact Analysis for the Oregon Coast* (https://pubs.oregon.gov/dogami/ofr/O-25-01/O-25-01_EqTsu-Impact_report_02.pdf) provides a detailed overview, including population exposure, building damage, debris, casualties, and displacement for three tsunami inundation zones (M1, L1, XXL1).

Key findings include:

- Population Exposure
  - Resident population in inundation zones: 24,351 (M1) to 61,896 (XXL1)
  - Visitor population: ~62,760 (M1) to ~118,450 (XXL1), potentially 2–3× resident population in summer

- Casualties
  - Earthquake injuries: ~6,500 minor; ~1,700 serious; fatalities ~240
  - Tsunami injuries: 740–1,800 residents; 2,400–2,800 visitors
  - Tsunami fatalities: 4,550–14,000 residents; 11,000–31,700 visitors (assuming full occupancy of overnight facilities)

Models of CSZ earthquake intensity scenarios have produced shaking intensity maps (Figures 27 and 28; Madin et al., 2021; Petersen et al., 2024). The color scheme is based on the **Modified Mercalli Intensity (MMI) Scale** (Figure 29), which relates shaking intensity to observed effects at a given location. Hot colors (yellow to red) indicate strong to extreme shaking (MMI VI–X), while cool colors (green to blue) indicate lower intensities.

In general, a CSZ event is expected to produce:

- Severe (MMI VIII) to violent (MMI IX) shaking across much of southwest Oregon, especially along the coast
- Very strong (MMI VII) to severe (MMI VIII) shaking along the central to northern Oregon Coast
- Moderate to strong shaking (MMI V–VII) inland between the Coast Range and the Cascades
- Lower shaking intensities east of the Cascades (MMI III–V)

This evaluation provides the foundation for determining risk levels, guiding VES placement, and identifying complementary mitigation strategies to protect lives and infrastructure.

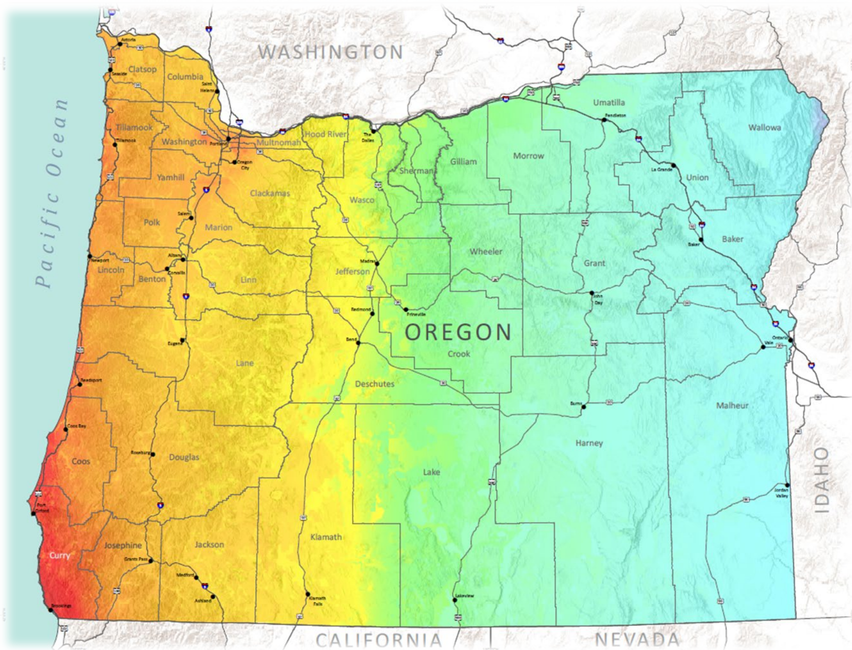

Figure 30: Perceived shaking and damage potential for a CSZ MW 9 earthquake (Madin and others, 2021). Explanation of colors provided in Figure 29.

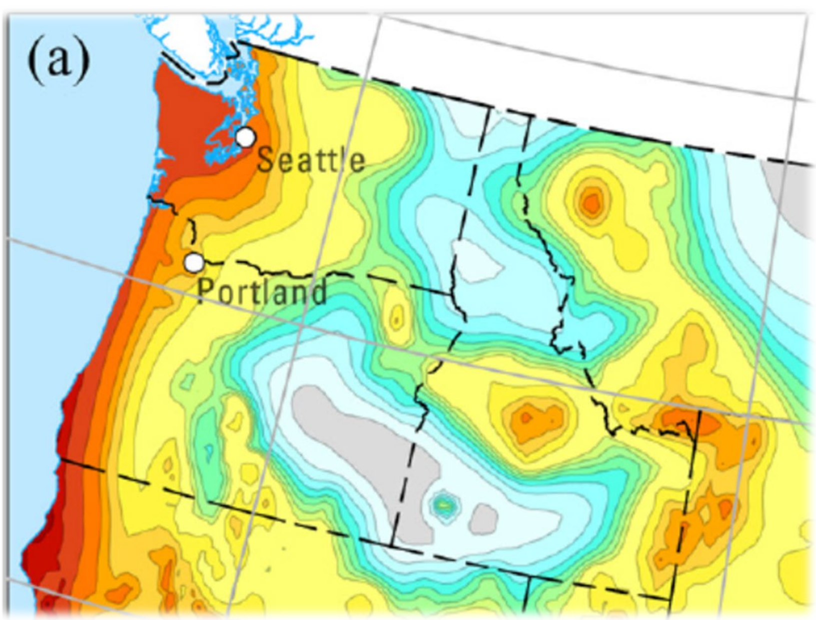

Figure 31: Estimated shaking for a 2% chance of being exceeded in the next 50 years, based on the 2023 national seismic hazard model for average ground conditions (site class B/C). (Petersen et al., 2024)

Intensity	Shaking	Description/Damage
I	Not felt	Not felt except by a very few under especially favorable conditions.
II	Weak	Felt only by a few persons at rest,especially on upper floors of buildings.
III	Weak	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
IV	Light	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	Moderate	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI	Strong	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII	Very strong	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
VIII	Severe	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX	Violent	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X	Extreme	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.

Figure 32: Abbreviated description of the levels of Modified Mercalli Intensity, USGS.

Many factors that go into modeling a given event (Cascadia) and magnitude (i.e., magnitude 9) contribute to the variability for shaking intensity, as described by Wirth and others, 2020 below.

> “Existing Cascadia earthquake scenarios assume that shaking will be identical along the length of the rupture zone for a given site condition and distance from the fault. These scenarios do not accurately capture important effects that impact ground shaking, such as rupture directivity and amplification from deep sedimentary basins. Furthermore, as its name suggests, this ShakeMap represents a single earthquake scenario. However, a range of possible ground motions may be expected depending on the earthquake’s rupture characteristics (e.g., **hypocenter location, down-dip extent, slip distribution**; Wirth, Frankel, et al., 2018).”

Visit Appendix C: Interactive GIS Mapping Resources for more information.

5.1.5 Model of Evacuation Scenarios

Simulation of pedestrian evacuation scenarios helps communities visualize how people might reach safety under different tsunami conditions. Using GIS-based analyses or pedestrian modeling tools, planners can estimate evacuation times, identify potential bottlenecks, and evaluate where VES could most effectively reduce loss of life. These models also support public education and stakeholder engagement, helping residents and officials understand evacuation challenges and priorities.

It is important to distinguish evacuation scenario modeling, which informs planning and outreach, from site-specific hydrodynamic modeling used in structural design. Engineering-level hydrodynamic models simulate wave forces, flow velocities, and inundation depths to ensure that proposed structures can withstand physical tsunami impacts. Both modeling approaches together help in the understanding of community risk and guide practical, resilient VES planning.

5.1.6 Determine Evacuation Needs

Based on hazard assessment, risk evaluation, and evacuation modeling, communities should determine the specific evacuation requirements for each location. This includes identifying whether vertical evacuation is necessary, selecting the appropriate type of structure, estimating capacity, and prioritizing sites where natural high ground is inaccessible within available evacuation time.

Oregon-specific resources, such as DOGAMI's "Beat the Wave" reports (See Appendices) and Earthquake and Tsunami Impact Analyses, can guide these decisions. Planners should consider:

- Seasonal or fluctuating populations, including tourists and temporary visitors
- Proximity to schools, retirement communities, and high-density areas
- Accessibility for populations with mobility limitations
- Land availability and constraints for construction

Integrating these factors ensures that VES placement and design are practical, equitable, and aligned with the needs of Oregon coastal communities.

5.1.7 Identify Sites and Design Heights

Once evacuation needs are determined, potential VES sites should be identified and analyzed using Oregon-specific topographic and hazard data. Steps include:

1. **Identify Locations:** Use DOGAMI's "Beat the Wave" maps and the USGS pedestrian evacuation modeling toolkit (https://www.usgs.gov/node/279276) to locate tsunami-vulnerable areas.
2. **Determine Topography, Elevations, and Flow Depths:** See information on the **ASCE Tsunami Hazard Tool** in Appendix C.
3. **Determine Design Refuge Elevation:** Set the refuge elevation above the design inundation depth using ASCE 7-22 procedures (e.g., 1.3× maximum inundation depth as a planning target) to provide appropriate safety margins.
4. **Visualization and Model Structures:** Develop building information modeling (BIM) representations to aid community review, cost estimation, and design optimization.
5. **Site Integration:** Project models into local GIS or 3D environments to ensure compatibility with existing infrastructure and land use.
6. **Cost Estimation:** Conduct quantity surveys and generate cost estimates based on structure type, design height, and Oregon-specific construction costs.

7. **Prioritize Structures:** Rank sites based on community needs, evacuation capacity, population density, proximity to critical facilities, and land constraints.

This systematic process ensures that each VES is strategically located, sized appropriately, and designed to provide safe refuge for the intended population.

5.1.8 Design, Build, and Operate

Selected VES must meet strict design standards for structural loads, including soil, flood, wind, snow, rain, ice, earthquake, and tsunami. ASCE 7-22, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*, provides engineering guidance incorporated into the 2019 Oregon Structural Specialty Code and the International Building Code.

Coordination among all stakeholders, including engineers, planners, building officials, and the community, is critical. Detailed planning, permitting, and quality assurance are required due to the unique engineering demands. Once constructed, VES must have established protocols for use, maintenance, drills, and public education to always ensure readiness.

5.2 Project Safe Haven (Washington)

In Washington State, early planning for vertical evacuation structures (VES) was supported through a coordinated effort led by state agencies and academic partners to help guide coastal communities and complete some of the foundational analysis needed for VES planning. **Project Safe Haven** (not to be confused with Safe Haven Hill in Newport, Oregon) was led by the Washington Emergency Management Division and the University of Washington, with funding from the National Tsunami Hazard Mitigation Program (University of Washington [UW] et al., 2012). The project was intended to provide technical guidance and preliminary planning information that communities could use when evaluating tsunami mitigation options, while still allowing local jurisdictions to pursue their own site-specific solutions.

The core purpose of Project Safe Haven was to identify where VES should ideally be placed to save the most lives and how many structures would be needed in each community. Using hazard modeling and community input, planners evaluated population distribution, evacuation time constraints, and geographic limitations to develop site-specific recommendations.

The proposed VES designs included stand-alone towers, earthen berms, tower-berm combinations, and reinforced buildings (e.g., fire stations and parking garages) that could serve as safe havens during a tsunami.

For example, in Grays Harbor County, planners determined that 32 vertical evacuation structures would be necessary to protect approximately 18,450 residents living in high-risk zones. These recommendations considered design heights to exceed anticipated wave levels, structural types suited to land constraints, and cost estimates to guide funding priorities and phased construction.

To date, Oregon has not conducted a comparable statewide planning effort, and coastal communities may need to initiate their own evaluations to determine whether VES are appropriate and where they may be needed.

Chapter 6: Involve Local Emergency Partners

As discussed in the chapter above, when it comes to evaluating tsunami mitigation strategies for your community, VES should be considered by seeking answers to the following questions:

- Does your community need vertical evacuation structures?
  - If so, how many VES are needed?
  - Where are they needed?
  - How many people/pets will need to seek refuge on the VES?

To find the answers to these questions, engage with state tsunami experts at the DOGAMI and include local city, county or Tribal emergency managers. The findings should be reported to the city, unincorporated community, or Tribal leaders.

6.1: Creating Opportunities for Community Engagement

Effective community engagement plays a central role in planning and implementing VES projects. These projects require local input to identify appropriate sites, understand evacuation behavior, and build support for long-term use and maintenance. Because tsunami risk varies by location and community context, engagement efforts often include working with local leaders, gathering input from residents, and coordinating with agencies and organizations involved in emergency management and land use planning. In many cases, a designated local lead, such as an emergency manager, Tribal staff member, or community organizer, may help coordinate these efforts and maintain continuity throughout the project.

Engagement activities should be structured to reach a broad cross-section of the community, including groups who may face barriers to participation or evacuation. This can include older adults, people with disabilities, non-English speakers, Tribal nations, low-income households, seasonal workers, and visitors. In practice, this often involves using multiple outreach methods, such as in-person meetings, online tools, workshops, and translated or accessible materials. Tailoring engagement approaches to local cultural and community contexts can help improve participation and ensure that planning reflects a range of needs and experiences.

6.1.1 Community Leaders

- Often serve dual roles (e.g., internal project manager).
- Include emergency managers, Tribal leaders, elected officials, etc.
- Maintain project momentum, transparency, and community trust.
- Collaborate with experts and guide public engagement efforts.

6.1.2 Stakeholder Committee Members

- A diverse group of engaged community members (including CERT leaders, local government staff, etc.).
- Participate in early research, site analysis, funding exploration, and team selection.

- Provide local input, help educate others, and build public support.
- Offer feedback to keep the project on schedule and within budget.

6.1.3 Emergency Managers

- Serve as connectors among local government, agencies, and residents.
- Assist with mitigation planning, risk assessments, and emergency preparedness.
- Help coordinate public education events and expert forums.
- Support grant identification and applications with OEM assistance.
- Work throughout the project to protect life, infrastructure, and resilience.

To help guide the process, a Community Engagement Toolkit is included in Appendix D as an optional resource to support meaningful, community-centered planning. Developed by the U.S. Department of Housing and Urban Development.

6.2 Community Engagement Toolkit

The US Department of Housing and Urban Development provides a *Community Engagement Toolkit: Building Purpose and Participation* as an optional resource. The toolkit provides a structured, people-centered approach to engagement. It outlines how to build a strong foundation by understanding community context and relationships, develop inclusive and accessible engagement strategies, and implement and evaluate those strategies over time. The toolkit emphasizes trust-building, iterative processes, and ensuring that community input meaningfully shapes outcomes *(HUD, 2025)*.

6.2.1 Part One: Creating a Strong Base for Active and Sustained Community Engagement

Understanding Community Context

- Actively learn about the cultural, geographical and historical elements of the community.
- Talk directly with community members in casual settings.
- Walk around the community and observe daily life.

Tap Into Existing Networks

- Research primary community groups, leaders, and spaces.
- Reach out to community stakeholders.
- Facilitate introductory and informational conversations.
- Identify existing physical or digital platforms that could serve as a community hub.
- Build trust.

Create a Community Advisory Team

- Make sure diverse perspectives are included.
- Create meaningful invitations.
- Team build to set the team up for success.

Design for an Iterative Process

- Create a timeline for community review.
- Create a set of shared outcomes and trackable metrics.
- Define a set of approaches to use.
- Empower the community through collecting feedback.

Develop a Timeline

- Compile all necessary activities.
- Determine appropriate process phasing and timeline.
- Outline a budget for community engagement and costs for development activities.
- Make sure to allocate room for iterations and new information that will arise through the engagement process.

Secure Funding

- Identify potential sources of funding.
- Create a budget that centers equity and compensation for the networks and existing community channels that will support engagement.

6.2.2 Part Two: Developing an Engagement Strategy that Empowers Community

Identify Challenges and Opportunities

- Conduct a context-specific situational analysis.
- Assess learnings to provide important insight to the program at hand.

Developing a Shared Vision and Understanding of Community

- Build a foundation of shared values for project development.
- Help build collective ideas for community development.
- Lead community visioning workshops to identify goals and desired outcomes.
- Work to incorporate this vision into the specific development or program at hand.

Developing the Community Engagement Plan

- Work with community organizations.
- Strategize how to reach those who don’t feel welcome, able, or safe to participate.
- Identify the most impactful activities from an accessibility standpoint.

- Create a communications strategy that allows the public to provide input.
- Design and develop engagement materials.
- Create opportunities for feedback.

6.2.3 Part 3: Conducting Engagement and Evaluating Impact

Implement Your Community Engagement Plan

- Plan according to the timeline and budget; adapt as necessary.
- Strategically choose methods of engagement based on demographics.
- Create content that will resonate with the people you hope to reach.
- Work with community organizations to leverage existing trust and communication networks.
- Utilize a community hub for centralized convening (virtual or physical).
- Present the program ideas and design in the context of the community vision to help obtain informed and meaningful feedback.
- Employ virtual platforms to help reach diverse stakeholders.

Continuing to Foster Community Relationships

- Build trust with community members through sustained engagement.
- Host community activities that facilitate interaction.
- Create or utilize existing digital or physical spaces for ongoing communication.

Use An Iterative Approach to Facilitate Ongoing Evaluation

- Create metrics of evaluation.
- Collect data prior to, during, and after activity completion.
- Regularly review feedback and data to assess program effectiveness.
- Identify key opportunities to course correct and pivot if necessary.
- Make data and feedback available to all stakeholders.
- Measure success as the alignment of community vision and real outcomes.

6.3 World Café Method

Meetings should include subject matter experts such as architects, geologists, engineers, tsunami modelers, planners, and emergency managers. Inform the community of the risk while maintaining a sense of hope and opportunity. Make the public meetings engaging with humor, prizes, and food. One successful way to begin the planning phase of such a project is known as the World Café method. It is a powerful way to engage people in meaningful conversations and is particularly useful for large group dialogues (World Cafe Method, 2023).

Here are the key components of a World Café:

- **Setting**: Create a warm and inviting environment, often modeled after a café. Think: small round tables with checkered or white linen tablecloths, colored pens, and flowers.
- **Welcome and Introduction**: Begin with a friendly welcome and introduce participants to the World Café process. Share the Café Etiquette to put everyone at ease.
- **Small-Group Rounds**: Participants engage in several rounds of conversation (usually 20 minutes each) at small tables. After each round, they move to a different table.
- **Questions**: Each round starts with a thoughtfully crafted question related to the event's context and purpose.
- **Harvest**: Individuals share insights and results from their conversations with the larger group.

In addition to facilitating discussion, it is important to clearly explain to participants how their input will be used. Share the next steps in the planning process, including how insights from the World Café will inform decision-making, hazard planning, or community projects. Highlight opportunities for continued engagement, such as follow-up meetings, workshops, or ways to stay involved online. This transparency reinforces trust, encourages ongoing participation, and helps the community feel that their contributions are meaningful and actionable.

Chapter 7: Funding Considerations

Vertical evacuation structures designed to withstand earthquake and tsunami forces require enhanced strength and flexibility compared to typical buildings. This involves incorporating seismic detailing, measures to prevent progressive collapse, specialized breakaway walls, and deeper foundations to improve overall durability. Consequently, construction costs for these structures tend to be higher than standard buildings. While exact cost comparisons are scarce, available studies suggest that structural costs may increase by 10% to 20% due to these added design features (Washington EMD, 2018) & (FEMA, 2019).

7.1 A Business Case for Mitigation

Building a vertical evacuation structure is about saving lives. The structures are needed; however, costs often become a major component of the conversation. For example, when designing a new building, the cost is typically 20% more to incorporate vertical evacuation standards (Washington EMD, 2018). As shown in some of the case studies above, the structures are expensive. To help alleviate hesitancy around the expenditures is a 2019 report by the National Institute of Building Science (NIBS), which quantified the money saved by taking mitigation actions.

The most significant benefit of constructing a VES is the potential to save lives. While the financial cost of these projects can be substantial, the value of human life far outweighs the expense. According to FEMA, the Value of Statistical Life (VSL) is estimated at $12.5 million per person. This figure helps quantify the life-saving potential of mitigation efforts and supports cost-benefit analyses. When lives are at stake, even high-cost projects like VES construction can demonstrate strong economic justification through the lens of avoided fatalities (FEMA, 2024).

Benefit-cost ratios (BCRs) for various mitigation strategies highlight the economic value of investing in disaster resilience. Among the strategies studied, adopting model building codes yields the highest return, saving $11 for every $1 spent, due to their broad impact on reducing future damages. Federal mitigation grants follow, offering a $6 return per dollar, reflecting their effectiveness in funding large-scale, risk-reducing projects. Private-sector building retrofits, exceeding code requirements, and infrastructure mitigation each provide a $4 return per dollar spent, demonstrating that proactive investments—whether by individuals, businesses, or governments—consistently result in significant cost savings and enhanced community resilience. These findings underscore the importance of prioritizing mitigation in planning and policy decisions.

Some of their findings are summarized in Figure 30. For more details, a link to the full report is available in the reference section of this paper.

	Adapt Code	Above Code	Building Retrofit	Lifeline Retrofit	Federal Grants
Overall Benefit-Cost Ratio	11:1	4:1	4:1	4:1	6:1
Cost ($ billion)	$1/year	$4/year	$520	$0.60	$27
Benefit ($ billion)	$13/year	$16/year	$2,200	$2.50	$160

7.2 Funding Sources

Various funding options are available for vertical evacuation projects and are summarized below. They are consolidated from the following three resources: *(Washington EMD, 2018), (FEMA, 2019), & (DLCD, 2015).*

7.2.1 Property Taxes (Ad Valorem Taxes)

- Collected by local governments, ports, and special districts.
- Based on property value, with limits set by Oregon's constitution.
- Funds flow into general revenue for broad government use.
- New districts can form with voter approval.

7.2.2 Utility Service Fees

- Charged by municipalities or districts for utilities like water, sewer, stormwater, parks, and transportation.
- Include operating and capital components.
- Usually managed through enterprise funds.

7.2.3 System Development Charges (SDCs)

- One-time fees on new or certain redevelopment projects.
- Fund capital improvements expanding infrastructure capacity (water, wastewater, drainage, transportation, parks).
- Cannot be used for maintenance or replacement.
- Must be established by ordinance and supported by a Capital Improvement Plan.
- Can be applied to tsunami evacuation infrastructure if linked to transportation or parks improvements.
- Credits may be given if developers fund improvements.

7.2.4 Lodging Tax

- State and local transient lodging taxes (hotel/motel).
- Local additions require most revenue to be spent on tourism-related purposes.
- Local governments enact via ordinance.

7.2.5 Local Excise Taxes

- Taxes on sales like gas, food, beverage, or real estate.
- Subject to voter approval or state law.
- Revenues are often dedicated to specific uses (e.g., streets, parks).

7.2.6 Urban Renewal / Tax Increment Financing (TIF)

- Property tax revenues in a designated district are “frozen.”
- Increments above the base are used for public improvements.
- Useful but sometimes controversial.

7.2.7 Debt Financing (Bonds)

- Local governments borrow by issuing bonds.
- General Obligation (GO) bonds are backed by full taxing power and require voter approval.
- Revenue bonds have less security, often no voter approval is needed.
- Used for large capital projects.

7.2.8 Local Improvement Districts (LIDs) / Special Assessment Districts

- Property owners in a geographic area pay assessments based on benefit received.
- Funds local public improvements, including tsunami evacuation route upgrades.
- Governed by local ordinances and Bancroft Bonding Act.
- Requires professional and legal guidance.

7.2.9 Federal, State, and Local Grants

- Grants from federal/state agencies can fund mitigation projects.
- Contact the Oregon Department of Emergency Management for available programs.
- Tax incentives and zoning concessions can encourage private investment.

7.2.10 Public-Private Partnerships (P3)

- Collaborations with private or Tribal developers to integrate evacuation infrastructure (e.g., in hotels).
- Require clear agreements on access and liability.

7.2.11 Self-Funding Through Co-located Facilities

- Combining evacuation structures with revenue-generating uses like parking garages or schools.
- Revenues help offset construction and maintenance costs.

7.2.12 Development Impact Fees and Developer Exactions

- One-time fees or requirements on new development to offset public infrastructure costs.
- Exactions require a legal nexus between development impact and required contribution.
- Must advance legitimate public purpose, be proportional, and connected to development impact.
- For tsunami mitigation, exactions reduce life safety risk by funding evacuation improvements.
- Supported by legal findings and professional guidance.

7.2.13 Service Areas

- Designated zones taxed at higher rates where services are provided.
- Can be combined with development regulations for equitable cost-sharing.

7.2.14 Land Trusts

- Nonprofits that conserve land by acquisition or conservation easements.
- Used to acquire developable land in high-risk tsunami zones.
- Can establish buffer zones and open spaces for evacuation.

7.2.15 Conservation Easements

- Legal agreements limiting land use to protect conservation or safety values.
- Landowners retain ownership but give up some development rights.
- Permanent and binding on future owners.
- Help reduce tsunami risk by restricting development in vulnerable areas.

7.2.16 Transferable Development Credits (TDC) / Transfer of Development Rights (TDR)

- Allow shifting development rights from high-risk (sending) areas to safer (receiving) areas.
- Oregon currently limits TDR to resource lands with conservation value.
- If resource lands overlap tsunami zones, TDR can discourage development in hazardous areas.
- Acts as an incentive-based land use tool for hazard mitigation.

A notable example of successful funding and implementation is the Ocosta Elementary School in Westport, Washington, which became the site of the first vertical evacuation refuge structure in the United States. The project was made possible through a combination of municipal bonds and community support, resulting in a multi-use facility that serves both educational purposes and as a designated tsunami refuge.

Chapter 8: Project Team

A tsunami evacuation tower is not just a building; it is a life-saving structure deeply rooted in earth science, engineering, emergency planning, and community engagement. Delivering this kind of specialized, high-impact infrastructure requires a coordinated team of experts. Due to the complexity of VES projects, strong collaboration and clear role definition are essential. A thoughtful selection process should be used to hire qualified professionals, and time must be allocated for ongoing coordination throughout planning and design.

Because vertical evacuation structures are intended to protect entire communities, project teams should also consider perspectives related to accessibility, cultural inclusion, and social vulnerability. Incorporating these perspectives early in planning helps ensure that evacuation infrastructure serves people of all ages, abilities, and backgrounds, including populations who may face additional challenges during disasters.

8.1 Project Manager

This person serves as the primary advocate for the project. Often a respected local official or staff member, the project manager serves as the primary liaison between the project team and the community. They participate in planning, site research, team selection, and funding reviews. During construction, they coordinate logistics and may work alongside a hired construction manager. Their leadership helps maintain momentum and community support throughout the life of the project.

8.2 Geologist

Geologists help communities understand the risks posed by earthquakes and tsunamis. They map tsunami inundation zones and evacuation routes, assist in early-stage site assessments, and develop public education materials. Their expertise is critical in hazard identification and planning, making them valuable partners at every level of the project.

8.3 Tsunami Modeler

Tsunami modelers develop or update inundation models to estimate wave heights, flow dynamics, and structural forces. These models guide the design of evacuation structures, helping determine required height and strength. Modelers collaborate closely with engineers and remain involved throughout the design process, especially when project sites or parameters change.

8.4 Evacuation Modelers

Evacuation modelers analyze how people are likely to move during a tsunami event, using pedestrian-travel modeling tools to estimate travel times, identify barriers, and highlight areas where timely evacuation may not be possible. Their work helps communities understand where vertical evacuation structures may be needed and how many people they must serve.

8.5 Population and Exposure Analysts

Specialists in population data assess who is at risk within the tsunami hazard zone, including residents, workers, visitors, and individuals with mobility limitations. By combining demographic data with evacuation modeling outputs, they identify "hotspots" where large numbers of people are unlikely to reach natural high ground in time. This analysis supports equitable planning and ensures that vertical evacuation structures are sited where they will save the most lives.

8.6 Structural Engineer

The structural engineer designs buildings that can withstand both seismic shaking and tsunami forces. They coordinate with architects, tsunami modelers, and geotechnical engineers to ensure the structure meets life-safety and performance standards. Their work includes evaluating hydrodynamic loads, debris impacts, and seismic resilience.

8.7 Geotechnical Engineer

Geotechnical engineers conduct subsurface investigations, including borings and soil analysis. They assess risks such as liquefaction, scour, and settlement, and recommend foundation systems and ground improvements. These elements are especially important in coastal zones with sandy soils and limited bedrock, and they can significantly influence project costs.

8.8 Architect

The architect leads the design of the evacuation structure, ensuring it is functional, cost-effective, and compliant with applicable codes. They balance aesthetics with community needs and budget constraints, and coordinate with engineers, the internal project manager, and stakeholders. Architects often serve as the project team lead and engage with the public to reflect community values in the design.

8.9 State Hazard Mitigation Officer

State Hazard Mitigation Officers assist communities in identifying and securing federal and state funding, particularly through grant programs. They help with grant applications, administer awarded funds, and support broader disaster resilience goals. Their role is essential in financing VES projects and ensuring compliance with funding requirements.

8.10 Community Leaders

Community leaders, including emergency managers, Tribal leaders, elected officials, and fire chiefs, play a vital role in championing the project. Their leadership ensures transparency, stakeholder engagement, and legislative support. They may also serve as internal project managers or advocates for funding and public outreach.

8.11 Stakeholder Committee Members

A well-rounded stakeholder committee should reflect the diversity of the community, including CERT team members, educators, business owners, and local government staff. Committee members assist with site selection, funding strategies, public engagement, and design decisions. While not formal decision-makers, they build trust and serve as liaisons between the project team and the broader public.

8.12 Emergency Managers

Emergency managers facilitate coordination between the community and government agencies. They support planning, mitigation, and recovery efforts, organize public forums, and assist with grant applications. Their overarching mission is to protect life, property, and infrastructure while fostering community resilience.

8.13 Local Planning Department

The local planning department ensures that a Vertical Evacuation Structure is feasible within the community's land-use and regulatory framework from the outset. Planners review potential sites for zoning compatibility, identify required land-use approvals, and map out the permitting steps needed for the project to move forward. Their early and continuous coordination helps avoid regulatory delays, ensures the structure integrates with surrounding land uses and transportation networks, and keeps the project aligned with local plans and policies.

8.14 Accessibility Specialist

Accessibility specialists ensure that the evacuation structure and associated routes are usable by people of all abilities. They advise the design team on accessible pathways, stair and ramp design, handrails, signage, and other features that support safe evacuation for individuals with mobility, vision, hearing, or cognitive disabilities. Their guidance helps ensure compliance with the Americans with Disabilities Act and promotes inclusive design that allows the widest possible range of community members to reach safety during a tsunami event.

8.15 Public Health and Social Vulnerability Specialists

Public health and social vulnerability specialists help identify populations that may face additional challenges during a tsunami evacuation. Using demographic, health, and social data, they highlight factors such as age, disability, language barriers, and transportation access that may affect evacuation capability. Their analysis supports equitable planning by helping the project team understand which populations may need additional outreach, infrastructure, or evacuation support.

8.16 Tribal Cultural Liaison

Tribal cultural liaisons facilitate coordination and consultation with Tribal governments and communities whose cultural resources, lands, or members may be affected by the project. They provide guidance on culturally significant landscapes, traditional knowledge, and appropriate consultation processes. Their involvement helps ensure that evacuation planning respects Tribal sovereignty and incorporates perspectives that can strengthen community resilience.

8.17 Community Engagement and Equity Outreach Specialists

Community engagement specialists support inclusive outreach and public participation throughout the project. They help design and facilitate meetings, workshops, and communication strategies that reach a broad cross-section of the community, including historically underserved populations. Their work may include coordinating multilingual outreach, improving public meeting accessibility, and ensuring that community feedback is incorporated into project planning and design.

8.18 Education and School Safety Representatives

Education and school safety representatives help ensure that the needs of students, educators, and school facilities are considered in evacuation planning. Schools often house large numbers of children who must evacuate quickly during a tsunami event. These representatives coordinate with the project team to align vertical evacuation planning with school emergency preparedness plans and help ensure that evacuation structures and routes are appropriate for school populations.

8.19 Public Works and Transportation Planners

Public works and transportation planners help integrate the evacuation structure with surrounding infrastructure and transportation networks. They assess sidewalks, road crossings, lighting, drainage, and other elements that influence how people move during an evacuation.

Their involvement helps ensure that evacuation routes are safe, accessible, and maintained over time, and that the project aligns with existing infrastructure plans.

8.20 Risk Communication Specialists

Risk communication specialists help develop clear and effective messaging about tsunami hazards and evacuation procedures. They assist the project team in communicating complex risk information in ways that are understandable and actionable for the public. Their work supports community preparedness by helping residents and visitors understand when and how to evacuate, and by ensuring that warnings and preparedness materials reach diverse audiences.

Chapter 9: Regulatory Requirements for Building VES

Oregon requires local land use planning, statewide planning guidelines (DLCD, 2015). Local plans must align with statewide planning goals. It is always important to research the building codes and zoning regulations that affect a community throughout the planning process to ensure that the project's budget won't be caught short due to a recent code change. Hazard standard used, at the time of this publication:

Earthquake	ASCE 7-16 / 7-22 Seismic Chapters	All buildings, especially Risk Cat. III–IV
Tsunami	ASCE 7-16 / 7-22 Chapter 6; FEMA P-646	Coastal Risk Cat. III–IV buildings
Code Basis	2022 OSSC (based on 2021 IBC)	Updated to reflect national standards

9.1 Overview of ASCE 7-22 Tsunami Provisions

The 2022 edition of the ASCE/SEI 7 Standard, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*, includes Chapter 6: Tsunami Loads and Effects, which provides comprehensive guidance for designing structures to resist tsunami forces. These provisions are intended to establish minimum structural requirements for buildings located in tsunami-prone areas.

Key points for application in Oregon:

- Mandatory for Risk Category III and IV buildings within tsunami-prone zones, including the Oregon Coast.
- Guidance covers:
  - Tsunami design zones
  - Hydrodynamic and debris impact loads
  - Buoyancy and scouring effects
  - Structural elevation and redundancy

9.1.1 Vertical Evacuation Structures (VES)

Tsunami-resilient structures, such as vertical evacuation towers and safe schools, must be designed to meet ASCE 7 tsunami provisions and FEMA P-646: *Guidelines for Design of Structures for Vertical Evacuation from Tsunamis*.

Design considerations include:

- Site-specific tsunami modeling coordinated with DOGAMI and licensed structural engineers.
- Capability to resist combined seismic and tsunami loads, including water impact, debris impact, scour, and uplift.

9.1.2 Development of Tsunami Design Zones (TDZ)

The ASCE established the Tsunami Loads and Effects Subcommittee in 2011 to develop Chapter 6 in the ASCE 7-16 Standard. This included creation of probabilistic Tsunami Design Zone (TDZ) maps based on a 2,475-year tsunami scenario (2% probability in 50 years).

Key points:

- Maps cover the U.S. West Coast, Alaska, and Hawaii.
- Intended to guide the design of Risk Category III and IV buildings, including schools, hospitals, emergency operations centers, and vertical evacuation structures.
- ASCE TDZ maps are probabilistic, considering multiple earthquake and tsunami scenarios, whereas DOGAMI maps are deterministic, based on defined worst-case scenarios.

Limitations identified in early ASCE 7-16 maps include:

- Coarse 60-meter grid resolution.
- Limited Cascadia Subduction Zone earthquake source models.

9.1.3 Oregon Regulatory Adoption

Key legislative and code milestones:

- SB 379 (2020): Repealed tsunami regulatory line.
- HB 2605 (2021): Adopted ASCE 7-16 guidance for Risk Category III and IV buildings.
- Oregon Building Codes Division (2022): Interim adoption of ASCE 7 Chapter 6 provisions into the 2019 Oregon Structural Specialty Code (OSSC).

Requirements:

- Buildings in TDZs must be designed to resist tsunami loads based on the Maximum Considered Tsunami (MCT).
- MCT corresponds to a 2,475-year mean recurrence interval (2% probability of exceedance in 50 years).
- Reference OSSC Section 1615 and ASCE 7 Chapter 6 for design criteria.

9.1.4 Ongoing and Future Work

DOGAMI is collaborating with the ASCE Tsunami Loads and Effects Committee to:

- Update probabilistic TDZ maps for Oregon using higher-resolution grids.
- Incorporate improved understanding of the Cascadia Subduction Zone.
- Replace original ASCE 7-16 TDZ maps for eventual adoption in 2028.

Current studies focus on Lincoln, Tillamook, and Clatsop Counties.

9.2 Oregon Tsunami Hazard Overlay Zone

The Oregon Department of Land Conservation and Development (DLCD) oversees statewide land use planning and provides guidance for managing tsunami risk through the *Tsunami Land Use Guide* (2015). The guide describes the development and implementation of a Tsunami Hazard Overlay Zone, a land-use planning tool applied alongside existing zoning regulations to help coastal communities reduce tsunami risk and improve long-term resilience, particularly from local-source events such as those generated by the Cascadia Subduction Zone.

The concept of regulating development in tsunami hazard areas in Oregon originated in the early 1990s as tsunami modeling first began along the Oregon Coast. In 1995, the State adopted the SB379 tsunami regulatory line (Priest, 1995), the first official tsunami regulatory line developed in the United States. Based on early tsunami inundation modeling conducted by the Oregon Department of Geology and Mineral Industries (DOGAMI), the regulatory line was intended to limit the placement of certain high-risk or critical facilities within areas subject to tsunami inundation.

Under SB379, specifically ORS 455.446 and ORS 455.467, construction of certain new essential facilities and special occupancy structures was restricted within the tsunami inundation zone. These included schools, hospitals, police and fire departments, emergency operations centers, and buildings for colleges or adult education schools with a design occupancy greater than 500 persons. Other proposed developments within the tsunami hazard zone required consultation with DOGAMI scientists.

Following development of the SB379 regulatory line, DOGAMI began producing first-generation tsunami evacuation maps for Oregon coastal communities. Between 1997 and 2007, tsunami modeling and evacuation mapping were completed for 12 coastal communities with support from the National Tsunami Hazard Mitigation Program (NTHMP).

Today, tsunami land-use planning in Oregon builds on this earlier work using Tsunami Hazard Overlay Zones based on updated tsunami hazard mapping. The boundaries of the overlay zones correspond to areas identified as inundated on DOGAMI Tsunami Inundation Maps (TIMs), which provide the technical basis for identifying tsunami hazard areas and applying land-use regulations intended to reduce community vulnerability.

9.2.1 Key Definitions

Essential Facilities: Critical response infrastructure such as hospitals, fire stations, emergency shelters, and emergency operations centers.

Hazardous Facilities: Buildings or facilities containing dangerous materials that could pose a risk to public safety if damaged during a tsunami.

Special Occupancy Structures: High-occupancy buildings such as large schools, detention centers, or major public assembly venues.

Substantial Improvement: Any building repair, reconstruction, or improvement exceeding 50 percent of the structure's market value.

Tsunami Vertical Evacuation Structure: An engineered structure designed to safely shelter evacuees above projected tsunami inundation levels.

Tsunami Inundation Maps (TIMs): Maps produced by DOGAMI identifying areas likely to be inundated during tsunami events. These maps are used to determine where tsunami hazard overlay zone regulations apply.

9.2.2 Purpose

The purpose of the Tsunami Hazard Overlay Zone is to reduce community risk from Cascadia Subduction Zone tsunamis by:

- Minimizing loss of life and property damage
- Reducing social and economic disruption
- Supporting community recovery and long-term resilience

These regulations generally apply to new development and redevelopment, rather than existing structures.

9.2.3 Core Approaches of the Overlay Zone

Restricting High-Risk Uses: The overlay zone restricts or prohibits development of certain high-risk uses within tsunami hazard areas, including essential facilities, hazardous facilities, and special occupancy structures as defined under ORS 455.

Examples include:

- Hospitals
- Fire and police stations
- Emergency operations centers
- Large schools
- Jails and detention centers
- Public assembly buildings

Local jurisdictions may adopt stricter restrictions if desired.

Requiring Evacuation Infrastructure: New development must provide or support evacuation infrastructure consistent with a Tsunami Evacuation Facilities Improvement Plan (TEFIP).

TEFIPs identify evacuation routes, infrastructure improvements, and planning priorities necessary to ensure that residents and visitors can reach safety in a tsunami event.

Development requirements may include:

- Providing on-site and off-site evacuation access
- Installing evacuation signage
- Improving evacuation routes
- Constructing vertical evacuation structures when needed
- Paying fees in lieu of improvements where direct upgrades are not feasible

Single-family homes on existing lots are typically exempt from these requirements.

Flexible Development Option: The overlay zone may provide a Flexible Development Option, similar to a Planned Unit Development (PUD), allowing adjustments to zoning standards such as setbacks or lot sizes in exchange for enhanced tsunami risk reduction measures.

These measures may include:

- Development clustering in lower-risk areas
- Construction of vertical evacuation structures
- Integration of evacuation infrastructure into site design
- Mixed-use development patterns that support safer land use

Projects utilizing the flexible development option must demonstrate mitigation measures that exceed minimum code requirements.

9.2.4 Applicability

The Tsunami Hazard Overlay Zone applies to all land located within the XXL tsunami inundation zone as mapped on DOGAMI Tsunami Inundation Maps. Regulatory requirements may vary depending on the tsunami scenario affecting a given area (for example, L, M, or XXL scenarios).

All uses permitted under the base zoning district remain allowed unless specifically restricted or prohibited by the overlay zone provisions.

9.2.5 Allowed and Prohibited Uses

All uses permitted under the underlying base zoning district are allowed unless specifically restricted by the tsunami hazard overlay zone.
Certain high-risk or essential facilities may be prohibited within tsunami hazard zones unless exemptions are granted.

These may include:

- Hospitals
- Fire and police stations

- Emergency response facilities
- Large schools and detention centers
- Major public assembly buildings

Certain critical infrastructure or high-density developments may also be restricted depending on mapped tsunami hazard severity.

9.2.6 Evacuation Route Improvements

New development (except single-family homes on existing lots) must provide safe and accessible evacuation routes consistent with the applicable Tsunami Evacuation Facilities Improvement Plan.

Requirements may include:

- Providing on-site and off-site evacuation access
- Installing evacuation signage
- Upgrading evacuation routes
- Constructing vertical evacuation structures where needed
- Paying fees in lieu of improvements when on-site improvements are not feasible

9.2.7 Tsunami Vertical Evacuation Structures

Tsunami Vertical Evacuation Structures are engineered structures designed to provide refuge above projected tsunami inundation levels where natural high ground is not accessible within the available evacuation time.

Within tsunami hazard overlay zones:

- Vertical evacuation structures should be designed to provide refuge above the **XXL tsunami inundation level**.
- These structures may be **exempt from typical zoning height limitations**.
- Case-by-case exceptions may be considered by local jurisdictions, although refuge elevations should not fall below the **L scenario inundation level**.

Vertical evacuation structures play a critical role in providing life-safety protection in coastal communities where evacuation to natural high ground is not feasible within available warning times.

Summary

No single document can present all the issues and hurdles of planning for tsunami mitigation. This report addresses the catastrophic risk posed by a future magnitude 9.0 (M9) earthquake and subsequent tsunami generated by the Cascadia Subduction Zone, a 600-mile-long megathrust fault off the Pacific Northwest coast. Ground shaking followed by quick tsunami wave arrival times—potentially within 10 minutes from the start of the shaking—threatens tens of thousands of lives along Oregon's coastline.

Through analysis of tsunami behavior, evacuation timelines, and regional hazard modeling, the study identifies two major vulnerable populations: those who delay evacuation and those physically unable to reach high ground in time. Inundation models suggest thousands of fatalities could occur, even under optimal evacuation conditions, given the current availability and condition of regional infrastructure.

The report highlights the critical role that Vertical Evacuation Structures (VES)—including towers, berms, and specially engineered buildings—can play in reducing life-safety risk for communities located within tsunami hazard zones. Drawing from real-world examples in Oregon and Washington, it outlines best practices for site selection, public engagement, funding and regulatory frameworks including ASCE 7-22 tsunami design standards.

The report identifies DOGAMI's Beat-the-Wave evacuation modeling as an important analytical approach for understanding where timely pedestrian evacuation may be challenging. While the Beat-the-Wave tool itself is not publicly accessible, communities can apply the same underlying methodology using the publicly available USGS *Pedestrian Evacuation Analyst* toolkit.

Together with a community-centered planning process and coordination across local, Tribal, state, and federal funding partners, these resources support informed decision-making about where vertical evacuation structures may be appropriate. The publication concludes that vertical evacuation can be a highly effective strategy for reducing tsunami-related fatalities in the most vulnerable coastal areas.

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Appendix A: DOGAMI “Beat the Wave” Products and Coastal Analyses

“**Beat the Wave” Technical Reports & Maps** (main page)
These documents evaluate how people could evacuate on foot during a worst-case XXL tsunami generated by a magnitude 9.1 CSZ earthquake. The documents model tsunami arrival times, identify realistic evacuation routes, and calculate the minimum walking speeds needed to reach safety—assuming delays after shaking, limited travel paths, and potential bridge failures. The documents also outline mitigation options—such as new routes, strengthened infrastructure, and improved signage—to help communities reduce evacuation time and increase survivability.

“Beat the Wave” Tsunami Evacuation Route Maps (main page)
According to DOGAMI, the maps provide broad guidance on evacuation routes and show the walking speeds needed to outrun a worst-case local CSZ tsunami. If your location falls outside the mapped area, you can use the NANOOS evacuation zone web viewer to look up an address or view additional regions and then create a personalized evacuation map for your community.
Use the NANOOS evacuation zone web map viewer

“**Beat the Wave” Story Map: Local and Distant Tsunami Evacuation Zones**
Tsunami evacuation maps help people understand whether they are in a distant-tsunami zone, a local CSZ tsunami zone, or a safe zone—and that knowledge directly shapes how they should respond during an emergency. The maps show how far each type of tsunami could reach, highlight areas that would flood only in a local event, and reveal where both threats overlap. By comparing these zones, residents and visitors can determine how far they need to travel to reach safety, whether their location is at risk from different tsunami sources, and what level of preparedness is necessary. Using this resource gives people a clearer picture of their true exposure and helps them make informed decisions that improve their chances of surviving a tsunami.

Large-Extent Tsunami Evacuation Maps (main page)
Per DOGAMI, “The tsunami inundation limits shown on maps listed below represent *the worst-case scenarios* for tsunamis generated from local (CSZ) and distant earthquakes.”

Detailed, Neighborhood-Specific Tsunami Evacuation Maps (main page)
Per DOGAMI, “You can print these page-size (8.5 x 11 inch) neighborhood-specific maps on your printer at a readable scale. Take time to practice your tsunami evacuation plan and route.

DOGAMI Earthquake and Tsunami Impact Analysis for the Oregon Coast

This report provides the most comprehensive and up-to-date analysis of the potential impacts of a CSZ earthquake and tsunami on Oregon’s coastal communities. It updates previous studies with the latest USGS earthquake scenarios, improved geology and soil data, and 2020 census information, making it highly relevant for planning.

Key strengths include:

- **Detailed Exposure Analysis:** Estimates of residents, visitors, businesses, and critical facilities in three tsunami zones (M1, L1, XXL1).
- **Casualty and Displacement Estimates:** Injury and fatality modeling for both earthquake and tsunami impacts, plus displaced population estimates.
- **Community-Level Profiles:** Specific data for every coastal town and park, supporting localized planning.
- **Evacuation Insights:** Reinforces that rapid evacuation on foot is the most effective life-saving measure, highlighting the urgency for vertical evacuation strategies.

This resource is essential for planners because it combines physical hazard modeling, population exposure, and impact estimates into actionable information for risk reduction and resilience planning.

Appendix B: Foundational Resources for VES

Preparing for a Cascadia Subduction Zone Tsunami: A Land Use Guide for Oregon Coastal Communities

This guide serves as an essential resource because it helps Oregon's coastal communities understand and plan for one of their most serious natural hazards—a local CSZ earthquake and tsunami. By outlining land use strategies that reduce exposure, improve evacuation options, and strengthen the built environment, the document gives communities practical tools to increase safety and resilience long before a disaster occurs. It supports informed decision making, aligns with broader hazard mitigation planning, and helps local governments adopt policies that protect lives, reduce damage, and speed recovery. Communities can use this guide to tailor land use approaches to their unique geography, ensuring that preparedness efforts are grounded in science, coordinated across agencies, and effective in reducing long term tsunami risk.

Tsunami Evacuation Drill Guidebook: How to Plan a Community-Wide Tsunami Evacuation Drill

This guide helps coastal communities plan, conduct, and improve tsunami evacuation drills—one of the most effective ways to save lives during a fast arriving CSZ tsunami. It explains why practice matters, showing that communities with regular drills respond faster, evacuate more confidently, and experience far fewer casualties during real events. The document also highlights broader benefits: drills strengthen community preparedness, reveal gaps in emergency plans, support eligibility for hazard mitigation grants, keep volunteers engaged, and build public confidence in their ability to reach safety on foot. By offering practical, experience based guidance, the guidebook equips communities with the knowledge and structure needed to run meaningful evacuation exercises and increase overall resilience.

Tsunami Resilience on the Oregon Coast

This document helps communities, planners, and policy makers understand the implications of Oregon's 2019 decision to lift the long-standing ban on building critical facilities within tsunami inundation zones. It explains the history behind earlier restrictions, reviews the state's ongoing tsunami planning efforts, and examines current codes and standards that affect coastal safety. By drawing on testimony from experts, agencies, and local stakeholders, the report provides a well-informed foundation for future policy decisions and offers guidance on how Oregon can maintain and improve tsunami resilience despite the regulatory change.

Comparison of Oregon Tsunami Hazard Scenarios to a Probabilistic Tsunami Hazard Analysis (PTHA)

This report helps engineers, planners, and emergency management professionals understand how different tsunami -modeling approaches compare when estimating the forces that a CSZ tsunami could impose on coastal infrastructure—especially bridges. By analyzing differences between DOGAMI's deterministic tsunami scenarios and AECOM's probabilistic hazard models, the document highlights where the two methods align, where they diverge, and why those discrepancies matter. It also offers guidance on which tsunami scenarios provide the most conservative basis for designing resilient structures, identifies data and modeling limitations, and recommends improvements for future simulations. As a result, the report supports more informed, science based decisions about infrastructure design standards, hazard mitigation, and long--term coastal resilience.

Resilience of Oregon Coastal Communities in Response to External Stressors

This report is useful because it reveals how Oregon's coastal communities experience stress, adapt to change, and mobilize—or struggle to mobilize—around major challenges. By documenting the real world factors that strengthen or weaken community resilience—such as local capacity, cohesion, leadership, demographic stability, and competing day-to-day pressures—it helps decision makers understand whether a community could plan for, support, and maintain a tsunami vertical evacuation structure. The findings show that long-term resilience projects often compete with more immediate social and economic concerns, meaning some communities may lack the bandwidth to take on a complex, resource intensive safety investment. Using these insights, planners can better judge whether a vertical evacuation structure is feasible, whether the community can sustain it, and what additional support or engagement would be needed to make such a project successful.

Tsunami Hazard Mitigation and Preparedness: A Perspective from State and Territory Tsunami Programs in the High Tsunami Risk Pacific Region

This document explains how the National Tsunami Hazard Mitigation Program (NTHMP) and state tsunami programs work together to build community level readiness for locally generated tsunamis. It highlights the critical role of education, inundation mapping, coordinated planning, and consistent state-to-local collaboration in reducing loss of life. The report also outlines the concrete preparedness gains made through NTHMP funding, including improved evacuation planning, vertical evacuation guidance, better mapping standards, expanded public outreach, and increased numbers of TsunamiReady communities. By identifying what makes community-based tsunami planning effective—and what resources and partnerships are required to sustain it—the document helps decision makers evaluate whether their community has the support, capacity, and long-term framework needed to successfully implement and maintain major mitigation projects such as a tsunami vertical evacuation structure.

Region 10 Cascadia Subduction Zone (CSZ) Earthquake and Tsunami Plan

This federal response plan outlines how all levels of government and the private sector will coordinate during the first, most critical two weeks after a catastrophic CSZ earthquake and tsunami. By describing expected regional impacts, the roles of federal and state partners, and the essential "Community Lifelines" that must be stabilized to save lives, the plan helps local communities understand what external support they can rely on—and where local preparedness gaps will remain. For communities considering a tsunami vertical evacuation structure, this document clarifies the scale of the disaster, the limits of outside assistance, and the importance of having reliable, self-sufficient life safety measures in place before a CSZ event occurs.

Improved Cascadia Earthquake Source Models for Tsunami Hazard Assessments

This report provides the most advanced and scientifically updated understanding of how a CSZ earthquake could rupture and generate a tsunami. By integrating new seismic imaging (CASIE21), geologic records, and expert consensus, it produces thousands of improved source scenarios that will form the basis of the next national probabilistic tsunami hazard assessment. These refined models offer a far more accurate picture of potential tsunami size, force, and variability than earlier scenarios. For communities considering a tsunami vertical evacuation structure, this document is directly relevant: it defines the range of credible worst-case events the structure must withstand, clarifies uncertainties in tsunami behavior, and ensures that local planning is aligned with the best available science.

Variable population exposure and distributed travel speeds in least-cost tsunami evacuation modelling

This study is valuable because it advances tsunami evacuation modelling by accounting for real world variability in how people move, where they are located at different times of day, and how quickly they begin evacuating after an earthquake. Unlike earlier models that assumed fixed travel speeds and immediate departure, this method incorporates changing population exposure, a range of walking speeds, and uncertain departure times—factors that strongly influence whether people can reach safety before a near-field tsunami arrives. By producing more realistic estimates of who can and cannot evacuate in time, the approach helps emergency managers identify high risk areas, refine evacuation routes, plan for refugees, and design more accurate training and casualty estimation scenarios.

2024 Statewide IronOR Exercise Monitoring Portfolio ***& IronOR 24 Exercise***

This 2024 functional exercise demonstrates how local, Tribal, state, federal, private sector, and nongovernmental partners coordinate during days 5–7 after a catastrophic M9.0 CSZ earthquake and tsunami. IronOR 24 tests real operational capabilities—protecting responder health and safety, building a statewide common operating picture, assessing damage in affected communities, supporting underserved populations, identifying resource gaps, and beginning the transition from response to recovery. By showing how agencies share information, validate needs, and provide technical assistance under extreme conditions, the exercise offers communities a realistic picture of what external support will look like and where local preparedness must fill the gap.

Resiliency 2025: Improving Our Readiness for the Cascadia Earthquake and Tsunami

This document is an important resource because it outlines Oregon's statewide strategy for preparing for a catastrophic M9.0 Cascadia earthquake and tsunami—an event expected to cause massive loss of life, long-term infrastructure failure, and severe economic disruption. Building on the 2013 Oregon Resilience Plan, it highlights the urgent gaps in the state's readiness and presents six priority actions to strengthen seismic safety, protect critical energy supplies, expand early warning capabilities, improve household preparedness, bolster local emergency management capacity, and update resilience planning with the latest science. By defining what must be done now to reduce recovery times and prevent long-term population and economic decline, the document provides a roadmap for policymakers, communities, and partners working to safeguard Oregon's future.

NCEI/WDS Global Historical Tsunami Database, 2100 BC to Present
The Global Historical Tsunami Database compiles detailed information on more than 2,400 tsunamis worldwide, spanning over four millennia. It provides two complementary datasets: one documenting tsunami source characteristics—including event location, magnitude, cause, and overall impacts—and another detailing runup observations such as wave heights, inundation distances, arrival times, and site-specific damage. Together with the Natural Hazards Map Viewer, which visualizes tsunami sources, runups, major earthquakes, and volcanic eruptions, the database offers a comprehensive picture of how tsunamis behave and what consequences they produce.

National Disaster Risk Assessment, A Guide for National Practitioners: Sendai Framework for Disaster Risk Reduction 2015-2030.

This document is a useful resource because it provides an updated, flexible framework for conducting national and local disaster risk assessments that align with the Sendai Framework. It emphasizes inclusive governance, evidence-based decision making, and an adaptive, iterative process that countries can tailor to their own contexts.

By incorporating lessons learned since the 2017 edition, the guidelines help governments integrate disaster risk assessment with climate adaptation and sustainable development planning. The addition of practical tools gives policy makers concrete methods for strengthening local capacity, improving data use, and embedding risk assessment into long-term national strategies. Overall, the framework supports more accurate understanding of hazards, vulnerabilities, and capacities—critical foundations for planning effective mitigation measures and building resilient communities.

USGS Variations in community exposure and sensitivity to tsunami hazards in Oregon
This document provides a detailed, data-driven assessment of community exposure and vulnerability to tsunami hazards along the Oregon coast. By quantifying populations, economic assets, critical facilities, and dependent-population centers within tsunami-inundation zones, it highlights the specific areas and communities most at risk, such as Seaside in Clatsop County. The report also identifies variations in sensitivity and exposure among cities, capturing factors like age, housing type, and land use that influence community vulnerability. By integrating these demographic, economic, and geographic insights, the study offers essential guidance for identifying where VES are needed, prioritizing resources, and supporting emergency preparedness, mitigation, and recovery planning. In short, it translates scientific modeling and hazard data into actionable information for local governments, planners, and emergency managers to make informed, life-saving decisions.

USGS Community clusters of tsunami vulnerability in the US Pacific Northwest
This study provides a valuable framework for understanding population vulnerability to tsunamis along the U.S. Pacific Northwest coast, including Oregon. By combining geospatial analysis, evacuation modeling, and community clustering, it identifies who is at risk, how quickly populations could reach safety, and which communities face the greatest evacuation

challenges. The classification of communities into distinct vulnerability groups—ranging from low exposure to high exposure with insufficient evacuation time—offers actionable insights for prioritizing resources and interventions. For Oregon, these findings support targeted preparedness strategies, including public education, evacuation drills, and the strategic placement of vertical evacuation structures (VES), ensuring that mitigation efforts align with the specific demographic and geographic needs of each coastal community.

USGS Pedestrian flow-path modeling to support tsunami evacuation and disaster relief planning in the U.S. Pacific Northwest

This study highlights the critical role of pedestrian evacuation modeling in preparing coastal communities for tsunamis, focusing on how populations move to safety and which areas may face access challenges. Using geospatial, least-cost-distance modeling in Washington communities, the research identifies efficient evacuation pathways, assembly points, and potential obstructions caused by earthquake-induced ground failures. The approach provides insights into the number and characteristics of evacuees, and gaps in accessible refuge locations. For Oregon, these methods underscore the importance of integrating vertical evacuation structures (VES) into evacuation planning, particularly in areas where natural high ground is inaccessible or evacuation routes may be blocked, helping communities optimize site placement, capacity, and outreach strategies to improve overall life-safety outcomes.

USGS Estimated annualized losses from potential building damage and fatalities due to earthquake-generated tsunamis in the United States

This study quantifies the potential life-safety and economic impacts of earthquake-generated tsunamis across the U.S., highlighting high-risk areas including Oregon's coast. By estimating building damage and residential fatalities under multiple hazard scenarios, it underscores the urgent need for proactive mitigation. For Oregon, these findings support the planning and implementation of vertical evacuation structures (VES) to protect residents, visitors, and critical infrastructure from tsunami hazards.

Perceptions of Earthquake and Tsunami Issues in U.S. Pacific Northwest Port and Harbor Communities

While earthquake and tsunami hazards in the U.S. Pacific Northwest are well-studied, societal vulnerability remains less understood. This research surveyed public and private stakeholders in coastal communities to assess perceptions of hazard risks, preparedness, and priorities for future mitigation. Findings show that earthquakes and tsunamis are widely regarded as credible threats, but recovery planning and organizational resilience are underemphasized. Differences in perceptions between Oregon and Washington, and between public and private sectors, highlight the need for targeted outreach, planning, and education to strengthen community readiness and resilience.

Vulnerability of port and harbor communities to earthquake and tsunami hazards: The use of GIS in community hazard planning

Earthquakes and tsunamis pose critical risks to Oregon's coastal port and harbor communities, making targeted mitigation and preparedness essential. Using GIS to integrate hazard, natural, and socioeconomic data enables communities to identify areas of highest vulnerability and concentrations of at-risk populations and critical infrastructure. These insights are particularly important for planning vertical evacuation structures (VES), as they help prioritize locations, assess potential capacity needs, and guide resource allocation to maximize life safety and community resilience during tsunami events.

Vulnerability assessment of a port and harbor community to earthquake and tsunami hazards: Integrating technical expert and stakeholder input

The Pacific Northwest faces the potential for catastrophic earthquakes and tsunamis, putting coastal ports and harbors at risk. A multiagency effort—including Oregon Sea Grant, Washington Sea Grant, NOAA Coastal Services Center, and the USGS Center for Science Policy—is enhancing community resiliency through hazard mitigation and preparedness planning. In the Yaquina River, Oregon, pilot community, vulnerability assessments highlighted populations most at risk and identified critical nonstructural concerns, such as limited hazard awareness, communication gaps, and evacuation logistics. These findings underscore the importance of planning and implementing vertical evacuation structures (VES) and other life-safety measures tailored to local needs.

DOGAMI *Oregon Seismic Hazard Database (OSHD)*

The **Oregon Seismic Hazard Database (OSHD-1.0)** is the first comprehensive collection of seismic hazard data for Oregon, making it an essential tool for planning and risk assessment. It provides:

- **Detailed Hazard Mapping:** Includes ground shaking, liquefaction, and landslide probability maps based on both USGS probabilistic models and an ensemble of 30 CSZ Mw 9.0 earthquake simulations.
- **Updated Geology and Soil Data:** Incorporates high-resolution lidar mapping for improved accuracy in identifying geohazard conditions.
- **Scenario and Probabilistic Data**: Supports both emergency response planning (scenario-based Cascadia events) and engineering/lifeline vulnerability assessments (probabilistic hazard data).
- **User-Friendly Visuals:** Maps showing perceived shaking strength, damage potential, and probability of damaging shaking help non-specialists understand risk.
- **GIS Integration:** Provides geospatial layers for advanced analysis and integration into local planning tools.

This resource is critical because it combines statewide hazard data with local amplification effects, enabling planners to prioritize vertical evacuation structures and other mitigation strategies based on the most accurate seismic risk information available.

Assessing the Vulnerability of the US Pacific Northwest Region to Tsunami Hazards

This research provides a regional assessment of tsunami hazards in the Pacific Northwest, highlighting the urgent need for improved mitigation strategies. Using GIS-based spatial analysis and descriptive statistics, the study evaluates earthquake and tsunami risks, including:

- **High Vulnerability:** Demonstrates widespread exposure to earthquakes and tsunamis, with the Pacific Northwest facing greater risk than most U.S. regions.
- **Potential Impacts:** Estimates catastrophic consequences—fatalities, infrastructure destruction (roads, bridges, dams), and economic losses exceeding $100 billion.
- **Detailed Hazard Insights:** Maps and spatial data reveal concentrations of landslide risk, liquefaction zones, and areas vulnerable to flooding and erosion.
- **Policy and Planning Gaps:** Identifies impediments such as outdated plans, ineffective policies, and rapid population growth that increase vulnerability.
- **Recommendations:** Calls for stronger policies and continued spatial analysis to guide preparedness and resilience efforts.

It combines scientific hazard assessment with socio-economic factors, offering actionable insights for policy development, emergency planning, and prioritizing vertical evacuation strategies.

Cascadia Tsunami Casualty Estimates: Prepared for Healthcare Preparedness Program of the Oregon Health Authority's Health Security, Preparedness and Response.

The Cascadia Tsunami Casualty Estimates Report provides critical data on expected casualties from a magnitude 9 Cascadia earthquake and resulting tsunami along the Oregon coast. Key contributions include:

- **Detailed Casualty Estimates:** Nearly 20,000 expected casualties, primarily fatalities, even under the assumption of optimal foot evacuation. County-level breakdowns identify the highest-risk areas (Clatsop and Tillamook Counties).
- **Health Impact Insights:** Describes direct health effects of tsunamis, including injuries from debris and structural collapse, and conditions like "tsunami lung" caused by near-drowning.
- **Planning Applications:** Designed to support hospital surge planning, emergency response, and resource allocation for coastal healthcare facilities, which will face high patient demand while operating at reduced capacity.
- **Visitor and Resident Risk:** Estimates include both permanent residents and peak visitor populations during summer nights, highlighting the scale of potential disaster.

This resource is essential for medical preparedness and evacuation planning, as it links casualty projections to healthcare system resilience and underscores the urgency of rapid evacuation and vertical evacuation strategies.

United Nations Office for Disaster Risk Reduction [UNDRR] World Tsunami Awareness Day: Fighting inequality for a resilient future

World Tsunami Awareness Day (WTAD), established by the United Nations in 2015 and observed annually on November 5, promotes global awareness about tsunami risk reduction and preparedness. The campaign aligns with the Sendai Framework for Disaster Risk Reduction and emphasizes inclusive, community-based resilience strategies. WTAD highlights how poverty, inequality, and social vulnerabilities increase tsunami risk and how disasters exacerbate these conditions, disproportionately impacting women, children, older adults, and persons with disabilities.

It calls for a whole society approach to disaster risk reduction, ensuring equitable access to early warning systems, preparedness resources, and decision-making processes. By focusing on education, advocacy, and social equity, WTAD provides a global framework for integrating awareness campaigns and inclusive strategies into local tsunami preparedness and vertical evacuation planning.

Washington Department of Natural Resources TsuInfo Alert

TsuInfo Alert is a bi-monthly newsletter that connects scientists, emergency managers, and planners with the latest tsunami research and preparedness updates. Published by the Washington Geological Survey for the National Tsunami Hazard Mitigation Program, it is funded through NOAA's National Weather Service. This resource is a quick way to stay informed on best practices and emerging science for tsunami resilience.

Estimated Average Annualized Tsunami Losses for the United States

The purpose of this document is to provide a comprehensive, science-based assessment of earthquake-generated tsunami risk across U.S. coastal states and territories, including Oregon. Developed through collaboration between FEMA, NOAA, USGS, and state partners, it compiles and analyzes existing tsunami hazard data, return periods, and exposure estimates to establish a national baseline of relative tsunami risk. The document supports informed decision-making for resilience policies, evacuation planning, and mitigation strategies by identifying high-risk areas, estimating potential losses to buildings and populations, and prioritizing investments such as Vertical Evacuation Structures (VES). While focused on earthquake-generated tsunamis, it represents a foundational step toward improving community preparedness and reducing life-safety risks in vulnerable coastal regions.

Tsunami Overview pages

United States Geological Survey [USGS]. (2018). *Tsunamis and tsunami hazards*. https://www.usgs.gov/special-topics/water-science-school/science/tsunamis-and-tsunami-hazards

National Oceanic and Atmospheric Administration [NOAA]. (n.d.). *NOAA tsunami Program*. https://www.tsunami.noaa.gov/

Oregon Department of Emergency Management [OEM]. (n.d.-b). *Tsunami: Hazards and Preparedness*. https://www.oregon.gov/OEM/hazardsprep/Pages/Tsunami.aspx

NOAA's National Weather Service. (n.d.). *Tsunami safety*. https://www.weather.gov/safety/tsunami

Federal Emergency Management Agency [FEMA]. (n.d.). *Earthquakes Dashboard*. https://gis-fema.hub.arcgis.com/pages/earthquakes

Appendix C: Interactive GIS Mapping Resources

NANOOS Tsunami Evacuation Route Viewer

The NANOOS Tsunami Evacuation Portal offers routable road mapping for tsunami evacuations. This enables anyone to generate an evacuation route for various locations on the Oregon coast. Some locations will provide a message stating that automated evacuation routes are not currently modeled for this area. When that happens, it can help to select an area closer to a residential area. As shown here, modeled locations will provide estimated walk, jog, and run times to safety from that location, turn-by-turn directions, and allow you to print a custom map of that location.

ASCE Tsunami Hazard Tool

The American Society of Civil Engineers (ASCE) offers the ASCE Tsunami Hazard Tool. Entering a location in the search bar, shown on the left of this screen snip below, will provide data for that location. By clicking on the **round red dots**, the tool will allow users to view **ground elevation** and **Inundation Depth**. Clicking on a **red triangle** within the tool allows the user to view potential earthquake-induced regional **ground subsidence** and **tsunami runup elevations**.

Hazus P-2426 Tsunami Loss Viewer

To complement FEMA's *Estimated Average Annualized Tsunami Losses for the United States* report (see Appendix A), FEMA has developed a GIS-based Tsunami Loss Viewer.

NCEI Tsunami Travel Times to Coastal Locations Viewer

The National Oceanic and Atmospheric Administration's National Centers for Environmental Information provides tsunami travel times to coastal location viewers. Per the website, "This map displays estimated pre-computed tsunami travel times ***to*** select coastal locations ***from*** any point in the ocean."

O-Help

Oregon State University offers the Oregon Hazard Explorer for Lifelines Program (O-Help), with site-specific ground motion, landslide, liquefaction, bridge damage assessment, fault rupture, subsidence and tsunami overlays. Printable reports are also generated.

Tsunami.Gov: US Tsunami Warning System

The Tsunami.gov homepage provides real-time tsunami warnings, advisories, watches and threats. Dropdown menus within the website provide a wealth of information, including links to TsunamiReady, the National Tsunami Hazard Mitigation Program (NTHMP), tsunami warning centers, exercises, and more.

NOAA Tsunami Events (1850 to Present) Timelapse Animation

Tsunamis, particularly large ones, are less frequent than atmospheric hazards like hurricanes and floods; however, they do occur more frequently around the world than most realize. To view tsunami events generated by earthquakes, volcanoes, landslides, and even a few from unknown sources, visit NOAA's 1850 to present timelapse animation.

USGS M9 Project

The University of Washington and the USGS ran 50 simulations for a magnitude 9 earthquake, known as the M9 Project. It allows viewers to examine shaking intensity potential in a given location. Many aspects, such as rupture width, determine shaking in a givin location.

Rupture width (down-dip extent): Earthquakes are often thought of as a zipper, traveling in a line; however, earthquake magnitude is impacted by both the length and width of the fault that ruptures. “A [Cascadia] earthquake where the rupture extends deep and partially inland is weighted at 30%, a shallow rupture that is entirely offshore is weighted at 20%, and a mid-depth rupture that extends approximately to the coastline is weighted at 50%,” (Wirth and others, 2019). Each variation impacts shaking intensities across the region. **Due, in part, to these complexities, it is imperative to conduct site-specific modeling for each VES location.**

Rupture width is just one variable that was taken into consideration when the maps were created. Hypocenter location, slip distribution, and localized soil types are also examples of variables that went into the models.

“Overall, the results confirm that coastal areas would be hardest hit, and locations in sediment-filled basins like downtown Seattle would shake more than hard, rocky mountaintops. But within that general framework, the picture can vary a lot; depending on the scenario, the intensity of shaking [at a given location] can vary by a factor of 10,” (Hickey, 2017)

From the original 50 simulations, a set of 30 was selected, “designed to exhibit a range of possible ground-shaking outcomes by varying properties such as the hypocenter location, down-dip rupture limit, slip distribution,” (Wirth and others, 2020).

The results of the set of 30 simulations were then used to develop ShakeMap products displaying potential ground shaking intensity in any given location at the 2nd, 16th, 50th, 84th, and 98th percentiles.

To view the maps, click the grey “View all ShakeMap Products (5 Total)” bar. Select the ground motion potential you are interested in. A map below the options will update to match your selections. Click the map to open it in a new screen, zoom into a location, and click that location to view expected shaking intensity.

Appendix D: A Quick Tsunami Song

It can be hard for community members to remember the difference between a tsunami watch, advisory, and warning. Catchy songs or familiar tunes can help with memorization. Here is an example and we encourage you to make more for your communities! Get the kids to write songs at school. Make it a competition. Make it fun!

♪ Tsunami Bells ♪

(to the tune of Jingle Bells)

Tsunami watch, oh my gosh,
A quake has rocked the sea,
It's far away but stay alert—
There *might* be waves coming!

No need to run just yet,
But keep track of alerts
Tsunamis hit with major force
Be ready just in case!

(Verse 2)
Advisory's next, please take care,
The waves might pull you in,
Stay off the beach and out the surf—
Strong currents could begin!

Warnings are most dire,
You *must* not delay!
Evacuate, don't hesitate—
The wave is on its way! Hey!

Image Credit: https://www.weather.gov/safety/tsunami-alerts