



The Oregon Department of Geology and Mineral Industries (DOGAMI) has been identifying and mapping the tsunami inundation hazard along the Oregon coast since 1994. In Oregon, DOGAMI manages the National Tsunami Hazard Mitigation Program, which has been administered by the National Oceanic and Atmospheric Administration (NOAA) since 1995. DOGAMI's work is designed to help cities, counties, and other states in coastal areas reduce the potential for disastrous tsunami-related consequences by understanding and mitigating this geologic hazard. Using federal funding awarded by NOAA, DOGAMI has developed a new generation of tsunami inundation maps to help residents and visitors along the entire Oregon coast prepare for the next Cascadia Subduction Zone (CSZ) earthquake and tsunami.

The CSZ is the tectonic plate boundary between the North American Plate and the Juan de Fuca Plate (Figure 1). These plates are converging at a rate of about 1.5 inches per year but the movement is not smooth and continuous. Rather, the plates lock in place, and unreleased energy builds over time. At intervals, this accumulated energy is violently released in the form of a megathrust earthquake rupture, where the North American Plate suddenly slips westward over the Juan de Fuca Plate. This rupture causes a vertical displacement of water that creates a tsunami (Figure 2). Similar rupture processes and tsunamis have occurred elsewhere on the planet where subduction zones exist: for example offshore Chile in 1960 and 2010, offshore Alaska in 1964, near Sumatra in 2004, and offshore Japan in March 2011.

CSZ Frequency: Comprehensive research of the offshore geologic record indicates that at least 19 major ruptures of the full length of the CSZ have occurred off the Oregon coast over the past 10,000 years (Figure 3). All of these 19-rupture CSZ events were likely magnitude 8.9 to 9.2 earthquakes (Witter and others, 2011). The most recent CSZ event happened approximately 300 years ago on January 26, 1700. Sand deposits carried offshore and left by the 1700 event have been found 12 miles inland; older tsunami sand deposits have also been discovered in estuaries 6 miles inland. As shown in Figure 3, the ranges in time between these 19 events varies from 110 to 1,150 years, with a median time interval of 490 years. In 2008 the United States Geological Survey (USGS) released the results of a study announcing that the probability of a magnitude 8.9-9.2 earthquake occurring over the next 30 years is 10% and that such earthquakes occur about every 500 years (WGCEP 2008).

CSZ Model Specifications: The sizes of the earthquake and its resultant tsunami are primarily driven by the amount and geometry of the slip that takes place when the North American Plate snaps westward over the Juan de Fuca Plate during a CSZ event. DOGAMI has modeled a wide range of earthquake and tsunami sizes that take into account different fault geometries that could amplify the amount of seawater displacement and increase tsunami inundation. Seismic geophysical profiles show that there may be a steep splay fault running nearly parallel to the CSZ but closer to the Oregon coastline (Figure 1). The effect of this splay fault moving during a full-rupture CSZ event would be an increase in the amount of vertical displacement of the Pacific Ocean, resulting in an increase of the tsunami inundation onshore in

A cross-sectional diagram of the Juan de Fuca Plate subducting under the North American Plate. The Pacific Plate is shown to the left, with the Juan de Fuca Plate extending from it. The Juan de Fuca Plate is shown descending into the mantle beneath the North American Plate. The diagram labels the 'Pacific Plate', 'Juan de Fuca Plate', 'North American Plate', 'Juan de Fuca Ridge', 'Juan de Fuca Trench', 'Locked Zone', and 'Magma'. Arrows indicate the direction of plate movement and magma flow.

Figure 1: This block diagram depicts the tectonic setting of the region. See Figure 2 for the sequence of events that occur during a Cascadia Subduction Zone megathrust earthquake and tsunami.

The figure consists of five panels, A through E, showing a cross-section of the Juan de Fuca Plate subducting under the North American Plate.

- Panel A:** Shows the initial state where the North American Plate is moving to the right over the Juan de Fuca Plate. The plates are locked together at the interface.
- Panel B:** As the North American Plate continues to move, stress builds up at the locked zone. The North American Plate begins to bulge upward.
- Panel C:** The locked zone eventually ruptures. The North American Plate slips forward and downward, while the Juan de Fuca Plate is displaced upward. A large tsunami wave is shown forming at the rupture site.
- Panel D:** Following the rupture, the plates are displaced in opposite directions. The North American Plate has moved forward and down, while the Juan de Fuca Plate has moved back and up.
- Panel E:** The plates are now locked again, but the North American Plate has shifted its position relative to the Juan de Fuca Plate. A tsunami wave is shown traveling along the coast of Oregon.

Figure 2: The North American Plate rides over the descending Juan de Fuca Plate at a rate of approximately 1.5 inches per year. Because the two plates are stuck in place at the "locked zone," strain builds up over time and the North American Plate bulges up. Eventually the locked zone ruptures, causing a great earthquake. The sudden slip of the two plates displaces Pacific Ocean water upward and creates a tsunami.

Figure 3. This chart depicts the timing, frequency and magnitude of the last great Cascadia subduction zone events over the past 15000 years. The most recent event occurred on January 26, 1700. The 1700 event is considered to be a "medium sized" event. The data used to create this chart came from research that examined the many sedimentary landforms, or "buried ridges", that are triggered only by these great earthquakes (Witter and others, 2011). The lines correlation is the bigger the tsunamis, the bigger the "buried ridges."

Figure 3: This chart depicts the timing, frequency, and magnitude of the last 19 great Cascadia Subduction Zone events over the past 10,000 years. The most recent event occurred on January 26, 1700. The 1700 event is considered to be a "medium sized" event. The data used to create this chart came from research that examined the many submarine landslides, known as "turbidites," that are triggered only by these great earthquakes (Witter and others, 2011). The loose correlation is "the bigger the turbidite, the bigger the earthquake."

		Entire Map Area	Unincorporated Areas
Total Buildings		33	33
Buildings within Tsunami Zones*			
	Small	9	9
	Medium	15	15
	Large	20	20
	Extra Large	30	30
	Extra Extra Large	30	30

Small	27.3%	27.3%
Medium	45.5%	45.5%
Large	60.6%	60.6%
Extra Large	90.9%	90.9%
Extra Extra Large	90.9%	90.9%

*Building counts shown are based on polygon centroids and are cumulative within the map area.

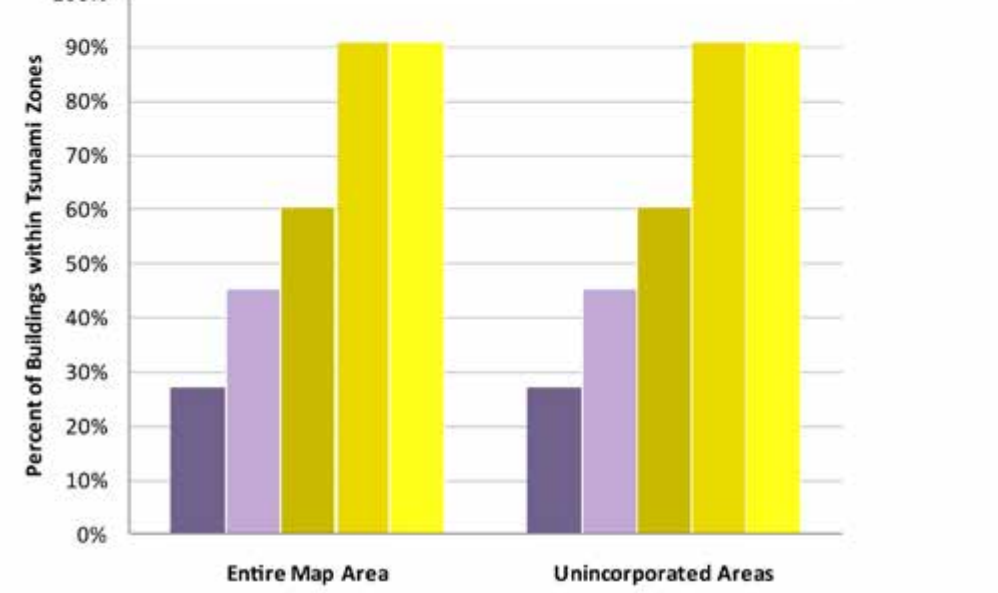


Figure 4: The table and chart show the number of buildings inundated for each "tsunami T-shirt scenario" in cities and unincorporated portions of the map.

Oregon. DOGAMI has also incorporated physical evidence that suggests that portions of the coast may drop 4 to 10 feet during the earthquake. This effect is known as subsidence. Detailed information on fault geometries, subsidence, computer models, and the methodology used to create the tsunami scenarios presented on this map can be found in DOGAMI Special Papers 41 (Priest and others, 2009) and 43 (Witter and others, 2011).

This tsunami inundation map displays the output of computer models representing five selected tsunami scenarios, all of which include the earthquake-produced subsidence and the tsunami-implying effects of the spillway flood. Each scenario assumes that a tsunami occurs at Mean Higher High Water (MHHW) tide; MHHW is defined as the average height of the higher high tides observed over an 18-year period at the Garibaldi tide gauge. To make it easier to understand this scientific material and to enhance the educational aspects of hazard mitigation and response, the five scenarios are labeled as "T-shirt sizes" ranging from Small, Medium, Large, Extra Large, to Extra Extra Large (S, M, L, XL, XXL). The map legend depicts the respective amounts of sea level, frequency of occurrence, and the earthquake magnitude for these five scenarios. Figure 4 shows the cumulative number of buildings inundated within the map areas.

The computer simulation model output is provided to DOGAMI as millions of points with values that indicate whether the location of each point is wet or dry. These points are converted to wet and dry contour lines that form the extent of inundation. The transition area between the wet and dry contour lines is termed the Wet/Dry Zone, which equates to the amount of error in the model when determining the maximum inundation for the each scenario. Only the XXL Wet/Dry Zone is shown on this map.

This map also shows the regulatory tsunami inundation line (Oregon Revised Statutes 455.446 and 455.447), commonly known as the Senate Bill 379 line. Senate Bill 379 (1996) instructed DOGAMI to establish the area of expected tsunami inundation based on scientific evidence and tsunami modeling in order to prohibit the construction of new essential and special occupancy structures in this tsunami inundation zone (Pries

Time Series Graphs and Wave Elevation Profiles: In addition to the tsunami scenarios, the computer model produces time series data for "gauge" locations in the area. These points are simulated gauge stations that record the time, in seconds, of the tsunami wave arrival and the wave height observed. It is especially noteworthy that the greatest wave height and velocity observed are not necessarily associated with the first tsunami wave to arrive offshore. Therefore evacuees should not assume that the tsunami event is over until the proper authorities have sounded the all-clear signal at the end of the evacuation. Figure 5 depicts the tsunami waves as they arrive at a simulated gauge station. Figure 6 depicts the overall wave height and inundation extent for all five scenarios at the profile locations shown on this map.

Change in water level for five tsunami scenarios at the simulated gauge station shown on the map

XXL
XL
L
M
S

Cape Lookout State Park - offshore (Station 32)

Elevation, feet (NAVD83)

Time since Earthquake (hours)

Figure 5: This chart depicts the tsunami waves as they arrive at the selected reference point (simulated gauge station). It shows the change in wave heights for five tsunami scenarios over an 8-hour period. The starting water elevation (0.0 hour) takes into account the local land subsidence or uplift caused by the earthquake. Wave heights vary through time, and the first wave will not necessarily be the largest as waves interfere and reflect off local topography and bathymetry.

Figure 6: These profiles depict the expected maximum tsunami wave elevation for the five "tsunami T-shirt" scenarios along lines A-A' and B-B'. The tsunami scenarios are modeled to occur at high tide and to account for local subsidence or uplift of the ground surface.

Map of Oregon showing 14 numbered locations for bird sightings. The locations are: 01 Clatsop, 02 Tillamook, 03 Clatsop, 04 Tillamook, 05 Clatsop, 06 Tillamook, 07 Clatsop, 08 Tillamook, 09 Clatsop, 10 Clatsop, 11 Clatsop, 12 Clatsop, 13 Clatsop, 14 Clatsop. The map also shows the locations of Cape Meares, Tillamook, Lincoln, Yamhill, and Astoria.

Till-01	Aspen Cape - Falcon Cove	Till-08	Cape Meares
Till-02	Marionville - Nahalem	Till-09	Marionville - Oceanside
Till-03	Nahalem East	Till-10	Cape Lookout
Till-04	Rockaway Beach	Till-11	Sand Lake
Till-05	Garibaldi - Bay City	Till-12	Pacific City
Till-06	Tillamook North	Till-13	Nerissa Bay
Till-07	Tillamook South	Till-14	Neskowin

Earthquake Size	Average Slip Range (ft)	Maximum Slip Range (ft)	Accumulate Slip (mm)	Time to Slip (yrs)	Earthquake Magnitude
XXL	59 to 72	118 to 144	1,050 to 1,200		-9.1
XL	56 to 72	115 to 144	1,050 to 1,200		-9.1
L	36 to 49	72 to 98	650 to 800		-9.0
M	23 to 30	46 to 62	425 to 525		-8.9
S	13 to 16	30 to 36	300		-8.7
XXL Vbt/Dry Zone					

	Urban Growth Boundary		Fire Station
	Building Footprint		Police Station
	Simulated Gauge Station		School
	Profile Location		Hospital/Urgent Care Clinic
	Senate Bill 379 Line		U.S. Highway
	State Park		State Highway
	Elevation Contour (25 ft intervals up to 200 ft)		Improved Road

[illegible]