



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 sites 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. Ruptures take place in places, and unrelieved stress builds up in the plate interface. When the stress is released in the form of a megathrust earthquake rupture, where the North American Plate suddenly slips westward on 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. For example, zones off the coast of Japan in 1944 and 1963, and off the coast of Sumatra in 2004, and offshore Japan in March 2011.

CS Frequency. Comprehensive research of the offshore geologic record indicates that at least 19 major ruptures of the full length of the CSZ have occurred in the past 10,000 years (Figure 3a). The 19 events include 14 CSZ events over the past 500 years (Figure 3a) and 5 pre-Holocene events (CSZ and/or WVCZ) (Figure 3a). The 19 earthquakes (Waters and others, 2013). The most recent CSZ event was the 1906 San Francisco earthquake (M_w 7.9) which caused 100 km of CSZ rupture and the 1700 event which caused 112 miles inland, off tsunami sand deposits have also been discovered in the CSZ (Waters and others, 2013). The 19 events include 19 events within 10,000 to 11,500 years, with a median time interval of 490 years. In the United States Geological Survey (USGS) National Earthquake Information Center (NEIC) catalog, a magnitude 8.9 CSZ earthquake occurring over the next 500 years is 30% and that such earthquakes occur about every 300 years (WGCEP, 2013).

CS2 Model 'Qualifications': 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 slips westward over the Juan de Fuca Plate during a CS2 event. DGGMI has modeled a wide range of slip distributions along the Cascadia subduction zone, and the resulting fault geometries that could amplify the amount of seawater displacement and increase tsunami inundation. Seismic geophysical profiles show that there may be a step along slip fault running nearly parallel to the CS2 but closer to the Oregon coastline (Figure 1). The effect of this step is moving during a full-slip event would be to displace the entire Cascadia subduction zone by 10 to 15 m, resulting in an increase of the tsunami inundation on the order of 100 to 200 ft. Figure 1 shows the step along the Cascadia subduction zone. The time series graphs and wave elevation profiles: In addition to the time-series scenarios, the computer model produces time series data for "gates" locations in the area. These points are simulated gate stations that record the time, in seconds, of the tsunami wave arrival and the wave elevation, in feet, at the gate station. The wave elevation is the wave height and velocity observed and not necessarily associated with the first tsunami to arrive on the Oregon shore. Therefore waves could 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 displays the time series for the Oregon gateway gate station. Figure 6 displays the profile along the Oregon coast and in the mouth of the Willamette River as the tsunami height and inundation spread.

A cross-sectional diagram showing the Juan de Fuca Plate subducting beneath the North American Plate. The Pacific Plate is shown to the west, with the Juan de Fuca Plate extending from it. The Juan de Fuca Plate is labeled with 'Juan de Fuca Plate' and 'Juan de Fuca Ridge'. The North American Plate is labeled 'NORTH AMERICAN PLATE' and 'NORTH AMERICAN PLATE'. The subducting plate is labeled 'Juan de Fuca Plate' and 'Juan de Fuca Ridge'. The diagram also shows 'Magma' rising from the subducting plate and 'Locked zone' at the interface between the plates. The topography includes 'OCEANIC TRENCH' and 'MOUNTAIN RANGE'.

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.

A

The North American Plate rides over the descending Juan de Fuca Plate at a rate of approximately 1.5 inches per year.

B

Because the two plates are stuck in place at the "locked zone," strain builds up over time, and the North American Plate bulges up.

C

Eventually the locked zone ruptures, and causes a great subquake. The sudden slip of the two plates displaces Pacific Ocean water upward and creates a tsunami.

D

Displaced and uplifted Pacific Ocean water rushes in all directions.

E

Along the Oregon coast, tsunami waves run up onto the beach for several hours.

Figure 3: This chart depicts the timing, frequency, and magnitude of the last 10 great Canada Subduction Zone events over the past 10,000 years. The most recent event occurred in January 1700. The 1700 event is considered to be a "median 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 larger the turbidite, the bigger the earthquake.

	Entire Map Area	City of Gearhart	City of Seaside	Unincorporated Areas
Total Buildings	6,620	1,729	4,611	280
Buildings within Tuumasi Zones*				
Small	3,885	310	3,573	7
Medium	5,006	832	4,177	41
Large	5,759	1,406	4,225	128
Extra Large	6,217	1,729	4,343	155
Extra Extra Large	6,287	1,729	4,350	208
Percent of Buildings within Tuumasi Zones				
Small	58.7%	17.9%	73.5%	6.7%
Medium	75.6%	48.1%	89.5%	16.8%
Large	87.0%	81.3%	91.6%	45.7%
Extra Large	94.1%	100.0%	94.2%	55.4%
Extra Extra Large	95.0%	100.0%	94.2%	74.3%

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

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

137 Seaside at 12th Ave Bridge (Station 137)

Legend:

- XXL
- XL
- L
- M
- S

Y-axis: Elevation, feet (NAVD83)

X-axis: 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 all 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. Any absence of data indicates periods for which tsunami inundation has not yet reached or has receded from the station location and dry land is exposed.

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.

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-amplifying effects of the local bathymetry. The map shows the predicted inundation depth of the Higher Hange Wave (MHW-H); MHW-H is defined as the average height of the higher high tides observed over an 18-year period at the Astoria tide gauge (NOAA Station 4930040). To make it easier to understand the map, the predicted inundation depth is divided into five aspects of hazard mitigation and response; the five scenarios are labelled as "d-7-hour size": ranging from Small, Medium, Large, Extra Large, and Extra Extra Large (S, M, L, XL, XXL). The map legend depicts the respective amounts of size, the frequency of occurrence, and the respective inundation depth. The map also displays the predicted cumulative number of buildings injured within the map area.

The computer simulation model output is provided to DODGAM and the results of points with values that indicate whether the location of each point is wet or dry. Those 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 WDR (Dry Zone), which equates to the amount of error in the model when determining the inundation depth for each scenario. Only the XXL (Extra Extra Large) 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 (1995) 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 (Priest, 1995).

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 onshore. 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.

2013

Tsunami Inundation Maps for Gearhart - Seaside,
Clatsop County, Oregon

Earthquake Size	Average Slip Range (ft)	Maximum Slip Range (ft)	Time to Accumulate Slip (yrs)	Earthquake Magnitude
	XXL 50 to 72	118 to 144	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
	XXXL 100 to 200			

Clat-01 Clatsop Joint
 Clat-02 Warrenton North
 Clat-03 Warrenton South - Tillamook
 Clat-04 Astoria
 Clat-05 Youngs River North
 Clat-06 Youngs River South
 Clat-07 Del Rio Beach
 Clat-08 Cannon Beach
 Clat-09 Cannon Beach
 Clat-10 Arch Cape - Falcon Cove

Source Data:
This map is based on hydrodynamic tsunami modeling by Joseph Zhang, Oregon Health and Science University, Portland, Oregon. Model data input were provided by John T. English and George R. Priest, Department of Geology and Mineral Industries (DOGAMI), Portland, Oregon.

Hydrology data, contours, critical facilities, and building footprints were created by DOGAMI. Senate Bill 379 line data were redigitized by Rachel L. Smith and Sean G. Pickner, DOGAMI, in 2011 (GIS file set, in press, 2012).

Urban growth boundaries (2011) were provided by the Oregon Department of Land Conservation and Development (DLCD).

Transportation data (2011) provided by Clatsop County were edited by DOGAMI to improve the spatial accuracy of the features or to add newly

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2007 Working Group on California Earthquake Probabilities (WGCEP) 2008, The Uniform California Earthquake Rupture Forecast, Version (UCERF 2): U.S. Geological Survey Open-File Report 2007-1437 and California Geological Survey Special Report 203
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earthquake scenarios. Oregon Department of Geology and Mineral Industries Special Paper 43, 57 p.

Software: Esri ArcGIS® 10.1, Microsoft® Excel®, and Adobe® Illustrator®.

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