Tsunami

A large tsunami with a wave of approximately 50 feet impacts the Pacific Coast of the United States.

Data Summary

In the following table, note that the low and high likelihoods do not correspond to the low and high impacts. In addition, low and high impacts are not necessarily correlated with each other between different impact categories.

Category	Description	Metric	Low	Best	High
Health and Safety	Fatalities	Number of Fatalities	1	300	1,000
	Injuries and Illnesses	Number of Injuries or Illnesses	1	300	1,000
Economic	Direct Economic Loss[1]	U.S. Dollars (2011)	$705 Million	$1.53 Billion	$3.32 Billion
Social	Social Displacement	People Displaced from Home ≥ 2 Days	8,600	14,700	N/A[2]
Psychological	Psychological Distress	Qualitative Bins	See text		
Environmental	Environmental Impact	Qualitative Bins[3]	Moderate[4]		

LIKELIHOOD	Frequency of Events	Number of Events per Year	0.26%[5]	0.57%[6]	0.92%[7]

Event Background

A tsunami event could present a significant risk to the west coast of the United States. The Pacific Northwest is an area of increased risk due to the Cascadian Subduction Zone, which is where the Juan de Fuca Plate meets and is forced under the North American Plate.[8] These subduction zones are associated with volcanism, earthquakes, and orogenic uplift, commonly referred to as mountain building. Earthquakes produced in these areas have the potential to be

[1] The economic damage numbers reported here include property damage and business interruption costs. The SNRA measure of direct economic damage additionally includes medical costs, and one year's lost demand due to fatalities ($42,500 per fatality): the SNRA project team made the assumption that these contributions would be negligible in comparison to the property damage and business interruption costs, in particular the property damage estimates calculated by HAZUS.

[2] Since variations of scenario parameters in HAZUS did not produce social displacement estimates substantially higher than the best estimate of 14,700, the SNRA does not report a separate high estimate.

[3] The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental impacts for this event. The comments and rankings presented in this Risk Summary Sheet have not undergone review by the EPA and only represent the opinions of the group. Estimates pertain to the potential for adverse effects on living organisms associated with pollution of the environment; they are grouped into high, moderate, low, and de minimus (none) categories.

[4] Experts provided both first and second choice categories, allowing the experts to express uncertainty in their judgments as well as reflect the range of potential effects that might result depending on the specifics of the event. The first choice represents the 'Best' estimate.

[5] One-year frequency corresponding to 12% probability within the next 50 years of a 9.0 magnitude earthquake causing a tsunami inundating coastal communities across the U.S. Pacific Northwest and Northern California. 12% was taken as the midpoint of the 10-15% range estimate cited by geologists (see Additional Relevant Information).

[6] One-year frequency corresponding to a 25% probability of a tsunami within 50 years. The SNRA project team averaged the low and high probability estimates reported in the literature to obtain this best estimate.

[7] One-year frequency corresponding to a 37% probability within the next 50 years of an 8.2 magnitude earthquake causing a tsunami impacting a portion of the U.S. Pacific Northwest and/or Northern California (see Additional Relevant Information).

[8] Local Tsunami Hazards in the Pacific Northwest from Cascadia Subduction Zone Earthquakes, http://pubs.usgs.gov/pp/pp1661b/pp1661b.pdf.

incredibly powerful, with nine of the ten largest quakes over the last 100 years occurring in these areas, including the 2004 Indian Ocean earthquake and the 2011 Tohoku, Japan, earthquake, both of which caused massive tsunamis. This is the same risk posed to the Pacific Northwest as a result of the Cascadian Subduction Zone.

A report for Seaside, Oregon, involved running more than 25 models including both near field (local) and far field (distant) generated tsunamis with estimated return periods.[9] A modeled 100-year tsunami event showed similar impacts to the 1964 Alaska earthquake, which represented a distant event. The local event looked at Cascadian-type events, which tended to follow a 500-year return period event, although the historical evidence shows that these are rarer than every 500 years. The models generated from this project showed tsunami depths ranging from 22 to 38 meters (72 to 124 feet), although the highest of these depths occurred at the shoreline, with the depths of the land areas seeing highs around 14 to 16 meters (45 to 52 feet). A study was performed to develop a method for Probabilistic Tsunami Hazard Analysis based on traditional Probabilistic Seismic Hazard Analysis.[10] While the study did not focus on the Pacific Northwest, this area was included in the discussion, and the findings showed a maximum expected height from a 975-year return period event would be in the range of 10 to 15 meters.

The Seaside area of the Oregon Coast was chosen to model the risk of such an event because it is typical of many coastal communities in the section of the Pacific Coast from Cape Mendocino to the Strait of Juan de Fuca, and because State agencies and local stakeholders expressed considerable interest in mapping the tsunami threat to this area.[11] Looking at possible events with catastrophic consequences, the Cascadian Subduction Zone is one that has a likelihood of occurring and would result in major damages. Oregon has detailed modeling and analysis of tsunamis that would be generated by an earthquake along this zone, including an inundation boundary that extends the entire length of the coastline.

To perform this scenario analysis, ground digital elevation models (DEM) were used for the entire study area as well as the mapped tsunami inundation line from the State of Oregon GIS Clearinghouse.[12,13] The inundation line was converted to a 3D feature with the DEM as the elevation source. This line was copied and placed parallel to the west, offset by approximately 1,000 meters. This outer line was generalized to remove the inlets and river areas that were represented in the original inundation line feature. The lines were used to create a tin that represented a constant ground surface from the actual inundation line, extending west beyond the coast. This tin was converted into a grid, which allowed for a raster calculation to be performed where the ground surface DEM was subtracted from the inundation grid. The output from the calculation produced the depth grid. Potential losses in the seven coastal counties in Oregon were

[9] Wong, F.L., Venturato, A.J., and Geist, E.L., 2006, Seaside, Oregon, tsunami pilot study—Modernization of FEMA flood hazard maps: GIS Data: USGS Data Series 236: http://pubs.usgs.gov/ds/2006/236/.

[10] Thio, H. K., Ichinose, G. A.; Somerville, P. G.; Polet, J, 2006. Probabilistic Tsunami Hazard Analysis. Presentation, American Geophysical Union Fall Meeting, December 2006; abstract at http://adsabs.harvard.edu/abs/2006AGUFM.S31C..08T. See also Thio et al 2007, Probabilistic tsunami hazard analysis for ports and harbors, Proceedings of the American Society of Civil Engineers, Ports 2007, pp 1-10, abstract http://ascelibrary.org/doi/abs/10.1061/40834%28238%29103; and Thio, H. K., Probabilistic Tsunami Hazard Analysis, presentation, National Tsunami Hazard Mitigation Program 2012 Tsunami Hazard/Risk Analysis Workshop, July 2012, full deck http://nthmp.tsunami.gov/2012tsuhazworkshop/presentations/Thio_presentation.pdf (accessed March 2013).

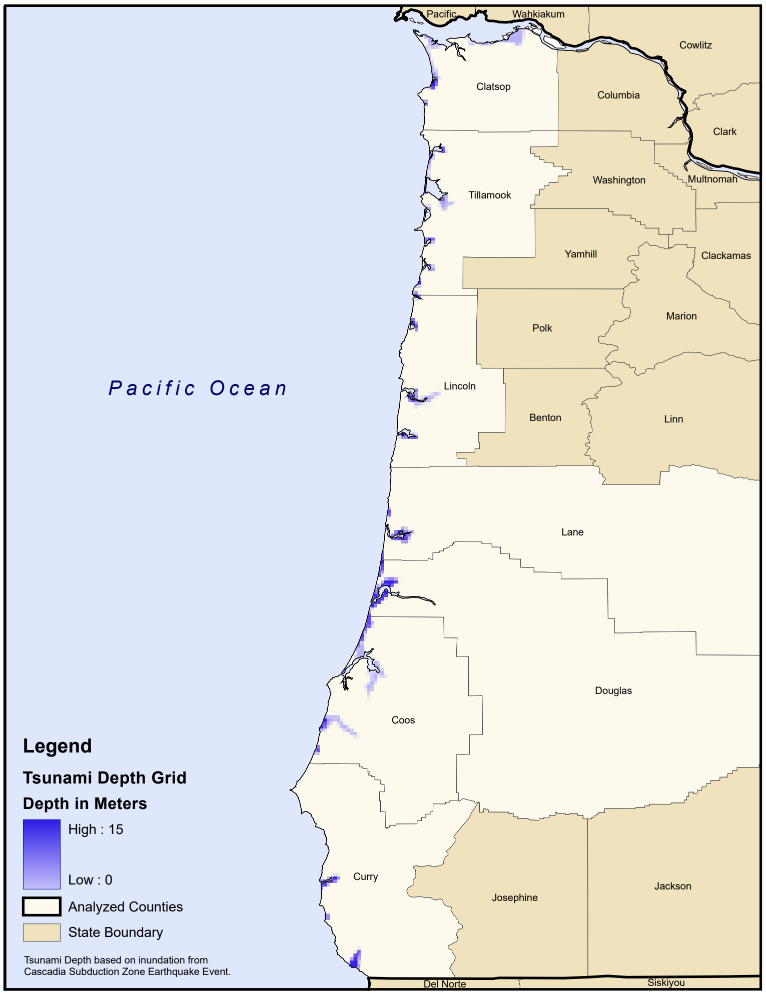
[11] Wong, *op cit*.

[12] Oregon GIS Data Clearinghouse, http://spatialdata.oregonexplorer.info/GPT9/catalog/main/home.page.

[13] The inundation line matched well with the near field event boundary from the USGS project, and it was determined that this was an acceptable line upon which to base scenario depths.

estimated using HAZUS-MH to model the scenario defined by these modeling inputs.[14] Figure 1 shows the scenario area and the inundation zones.

Figure 1. Tsunami Scenario Location Map[15]



Assumptions

Based on previously conducted research, it is reasonable to assume that modeling a tsunami with the maximum height of 15 meters (approximately 50 feet) is appropriate for analyzing a potential Cascadian event generated tsunami along the Oregon Coast.[16],[17] Additionally, the depth damage functions were adjusted to reflect the velocity losses associated with the tsunami phenomenon. The damage function used assumes a linearly increasing damage from 0 to 100 percent for flood depth, with wave action ranging from 0 feet to 4 feet and 100 percent damage at 4 feet and beyond.

[14] HAZUS-MH: multihazard loss estimation software. Federal Emergency Management Agency (FEMA), U.S. Department of Homeland Security (1997-2011): http://www.fema.gov/hazus. See FEMA 433 (2004, August), Using HAZUS-MH for Risk Assessment, http://www.fema.gov/pdf/plan/prevent/hazus/fema433.pdf .
[15] Source: GIS Analysis using Hazus-MH and Oregon GIS Data Clearinghouse data. See Discussion.
[16] Thio et al 2006, *op cit*.
[17] Wong, op cit.

Fatalities and Injuries

The HAZUS-MH flood model used to model the Tsunami scenario does not provide direct estimates of fatalities and injuries. The SNRA project team used the following assumptions to estimate health and safety impacts caused by a tsunami event:

- In terms of fatalities, minimal impact is assumed except:
  - In areas that do not receive the warning in time (may include possible malfunction of warning equipment)
  - In communities not trained in evacuation
  - In flat areas where no evacuation routes exist
  - For persons who do not obey orders or who happen to be in vulnerable areas with no warning systems
- Based on these exceptions, it is reasonable to assume the possible range of fatalities to be between 1 and 1,000 and injuries to be between 1 and 1,000. The timing of a tsunami (impact during day versus night) could potentially impact the ability of the population to receive warnings; therefore, a tsunami at 2 a.m. when people are sleeping could potentially cause more deaths and injuries than a daytime tsunami.
- The population information used for estimating the health and safety impacts is 2000 U.S. Census data.
- Given the effort Oregon has put into training, warning systems, evacuation route planning, as well as other mitigation techniques, professional engineering judgment based on experience suggests that it would be reasonable to expect that approximately 1% of the exposed population would be injured or killed as a result of this event. The result was then split evenly with 50% counted as injured and 50% counted as being killed by the event.
- If a similar scenario were to occur along other areas of the U.S. coastline, higher casualty rates may be more likely because the West Coast (as well as Alaska and Hawaii) is better prepared for tsunami impacts than the East Coast and Gulf Coast (in terms of evacuation plans, drills, and warning systems), and the exceptions listed above would be more likely to be the case in non-West Coast areas.

Economic Loss

The SNRA project team used the following assumptions to estimate economic impacts caused by a tsunami event:

- More than 1,700 buildings were estimated as being destroyed in the modeled event. Building losses would likely exceed $1.5 billion. The event would also cause business disruption, which is estimated to be nearly $13 million. The area incurring the most severe impacts would be Clatsup County, accounting for nearly half of the destroyed buildings and economic losses which would occur.
- If a similar scenario were to occur along other areas of the U.S. coastline, higher economic losses may be expected resulting from the proximity of more development to the coast, lack of warning, and panic.

Social Displacement

- The SNRA project team used the following assumptions to estimate social impacts caused by a tsunami event:
- Displacement estimates assume those affected would require accommodations in temporary public shelters. The results estimate that approximately 14,737 persons would seek temporary refuge in public shelters, which was used as the best estimate.
- Range estimates for social displacement were calculated by running the same scenario using inundation level as a variation parameter, decreasing the inundation by 2 feet to estimate the lower bound and increasing the inundation by 2 feet to estimate the higher bound. The lower bound of 8,600 was used as the low estimate.
- Since increasing inundation level did not substantially vary the displacement numbers, the SNRA does not report a high estimate for the tsunami event.[18]

Psychological Distress

Psychological impacts for the SNRA focus on significant distress and prolonged distress, which can encompass a variety of outcomes serious enough to impair daily role functioning and quality of life. To reflect empirical findings that the scope and severity of an event is more important than the type of event, the SNRA psychological distress metric is constructed from the fatalities, injuries, and displacement associated with an event as primary inputs, weighted by a secondary factor elicited from subject matter experts for differing psychological impact based on the type of event.[19]

Environmental Impact

The United States Environmental Protection Agency (EPA) convened an ad hoc group of environmental experts representing the fields of environmental science, ecological risk, toxicology, and disaster field operations management to estimate environmental impacts for this event. Estimates are based on the following assumptions:

- Experts were elicited to provide estimates in the environmental impact category based on assumptions. Actual environmental/ecological harm that occurs as a result of the events described in a given scenario may vary considerably, and will depend on numerous variables (e.g., chemical or biological agent, contamination extent, persistence, toxicity—both chronic and acute toxicity—and infectivity).

[18] Because the inundation boundary line would not likely extend further due to topography as well as other contributing factors, the number or displaced persons is not expected to change from the original scenario calculation even when inundation was assumed to increase by two feet of water.

[19] A Significant Distress Index is calculated from these inputs using a formula proposed by subject matter experts consulted for the SNRA project: $N_{SD} = C_{EF} \times (5\ Fat + Inj + ½\ D)$, where N_{SD} represents the number of persons significantly distressed, C_{EF} is an expert assessed Event Familiarity Factor, *Fat* is the number of fatalities, *Inj* is the number of injuries and/or illnesses, and *D* is the number of persons displaced (Social Displacement). In words, this formula suggests that there are 5 significantly distressed persons for each life lost; 1 for each person injured; and 1 for each 2 people displaced. This formula was constructed to reflect the empirical finding that the most severe stressor of a disaster is losing a loved one, followed by injury, followed by displacement. Uncertainty was captured by applying the index formula to the low, best, and high estimates of these three human impact metrics. The familiarity factor, intended to capture the extent to which the event entails an ongoing threat with uncertainty regarding long term effects, is unfamiliar, or that people dread, exacerbating psychological impacts, was assessed as 1.0 for Tsunami on a scale of 1.0 for familiar events to 1.3 for unfamiliar events.

The specificity of the tsunami event to a single geographic scenario precluded comparative judgments of risk on the psychological or other impact metrics with other events. This limitation will be addressed in a future national risk assessment.

- EPA defined environmental consequence (impact)[20] as the potential for adverse effects on living organisms associated with pollution of the environment by effluents, emissions, wastes, or accidental chemical releases; energy use; or the depletion of natural resources.
- Experts identified the best estimate for environmental impacts as "Moderate." Experts indicated that this is the best estimate, but that impacts could be higher or lower depending on the precise location, barrier channels, and ecosystem impacts.

Potential Mitigating Factors

The consequences caused by a tsunami can be mitigated through several preparedness strategies. Warning and monitoring systems can assist in alerting population areas that may be impacted by a tsunami. Periodically testing these systems will ensure that they are functioning when a tsunami event occurs. Identifying evacuation routes and training communities in how to use them during an event will improve the ability for the population to egress vulnerable areas. Finally, the importance of evacuating during a potential event should be communicated to individuals living or working in vulnerable areas.

Additional Relevant Information

In 1700, a major earthquake occurred along this zone, rupturing a 620-mile section of the fault line. The estimated magnitude was between 8.7 and 9.2 and caused a tsunami that impacted the Oregon coastline and was recorded in Japan. More recently, geologists have studied this fault and concluded there is a 37 percent chance of an 8.2 or larger event in the next 50 years and a 10 to 15 percent chance for a rupture along the entire fault from a 9.0 or larger event.[21,22,23] A tsunami generated from this magnitude event could reach heights of 20 to 30 meters (65 to 100 feet) along the Pacific Northwest coast and have catastrophic results.[24] All oceanic regions of the world can experience tsunamis, but in the Pacific Ocean there is a much more frequent occurrence of large, destructive tsunamis because of the many large earthquakes along the margins of the Pacific Ocean.

It is reasonable to expect that a tsunami impacting the U.S. could potentially experience similar consequences to this scenario, regardless of coastal location. The range of potential loss could be broad depending upon many factors including but not limited to the population density of low-lying coastal areas, presence of agricultural assets such as crops and livestock, and location of nearby drinking water supplies. Long-term impacts could also be experienced and would depend on the level of contamination caused in the area.

[20] The 2011 SNRA referred to impacts as 'consequences' because of prior usage in quantitative risk assessment (Kaplan and Garrick [1981, March], On the quantitative definition of risk: *Risk Analysis* 1(1) 11-32). Except where it will cause confusion, 'impact' is used synonymously in this document because of pre-existing connotations of the word 'consequence' within FEMA.

[21] Odds are 1-in-3 that a huge quake will hit Northwest in next 50 years. Oregon State University press release, 24 May 2010, announcing preliminary results later published as reference [23]; at http://oregonstate.edu/ua/ncs/node/13426 (accessed 3/17/2013).

[22] Risk of giant quake off American west coast goes up. *Nature News*, 31 May 2010, citing results later published as reference [23]; at http://www.nature.com/news/2010/100531/full/news.2010.270.html.

[23] Goldfinger et al, 2012. Turbidite event history – Methods and implications for Holocene paleoseismicity of the Cascadia Subduction Zone. USGS p 1661-F, 7/17/2012: http://pubs.usgs.gov/pp/pp1661f/ (accessed 3/17/13).

[24] Recent findings concluded the Cascadia subduction zone was more hazardous than previously suggested. The feared next major earthquake has some geologists predicting a 10% to 14% probability that the Cascadia Subduction Zone will produce an event of magnitude 9 or higher in the next 50 years; however, the most recent studies suggest that this risk could be as high as 37% for earthquakes of magnitude 8 or higher. Geologists have also determined the Pacific Northwest is not prepared for such a colossal earthquake. The tsunami produced may reach heights of approximately 30 meters (100 ft).