TSUNAMI CHAPTER

What is a tsunami?

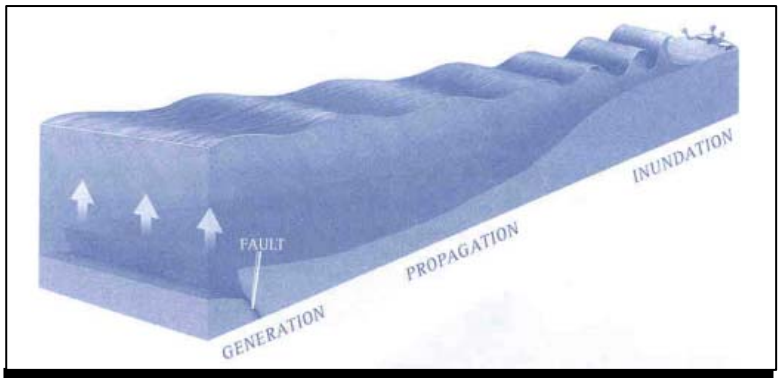


Figure T-1: The evolution of a tsunami from generation to inundation (Source: Washington Military Department, Emergency Management Division)

Tsunamis are a low frequency natural hazard in Oregon and are restricted almost exclusively to coastal areas. However, when they do occur they can be very destructive, especially if the tsunami is generated by a subduction zone earthquake immediately offshore of the coast. The coasts of Washington, Oregon, and northern California are particularly vulnerable to tsunamis from magnitude 9+ earthquakes that occur about every 500 years on the Cascadia Subduction Zone. In additional, smaller tsunamis and earthquakes occur in the subduction zone south of Waldport. Recurrence on the southern coastline for a partial rupture of the Cascadia Subduction Zone is ~240 years.

A tsunami is most commonly caused by deformation (abrupt vertical change) of the sea floor due to an earthquake (Figure T-2). Other important processes that may trigger a tsunami include underwater volcanic eruptions and landslides (includes landslides that start below the water surface and landslides that enter a deep body of water from above the water surface). Principal among these sources are earthquakes that occur at subduction zones (e.g. the Cascadia Subduction Zone), where an ocean plate descends beneath a continental plate.

The initial tsunami surge mimics the shape and size of the sea floor deformation that causes it, but quickly evolves into a series of surges that travel away from the source of disturbance. In rare cases, a tsunami can be generated by asteroid or comet impacts and can be catastrophic to an entire ocean basin.

The surgelength of a tsunami generated by sea floor deformation may be 100 miles or more in the deep ocean, with a surge height of only a few feet or less. These surges may reach speeds of 300 - 600 mph (~150 - 250 meters per second in the open ocean).

As tsunamis approach land where the water depth decreases, the forward speed of the tsunami will slow, and the height of the surges increase dramatically, and may reach heights of as much as 100 feet.

Tsunamis are potentially more destructive than the earthquake that caused them. Loss of lives from the tsunami can often be many times the loss from the earthquake ground shaking. This was highlighted by the December 26, 2004 tsunami, associated with a magnitude 9.3 earthquake, which occurred offshore from the Indonesian island of Sumatra. The tsunami impacted almost every

county located around the Indian Ocean rim and claimed the lives of approximately 350,000 people. The greatest loss of life occurred along the coast of Sumatra, close to the earthquake epicenter. The event displaced some 2 to 3 million people and its economic impact continues to be felt to the present. The Sumatra event is a direct analogue for what can be expected to occur along the Oregon Coast due to its close proximity to the Cascadia Subduction Zone.

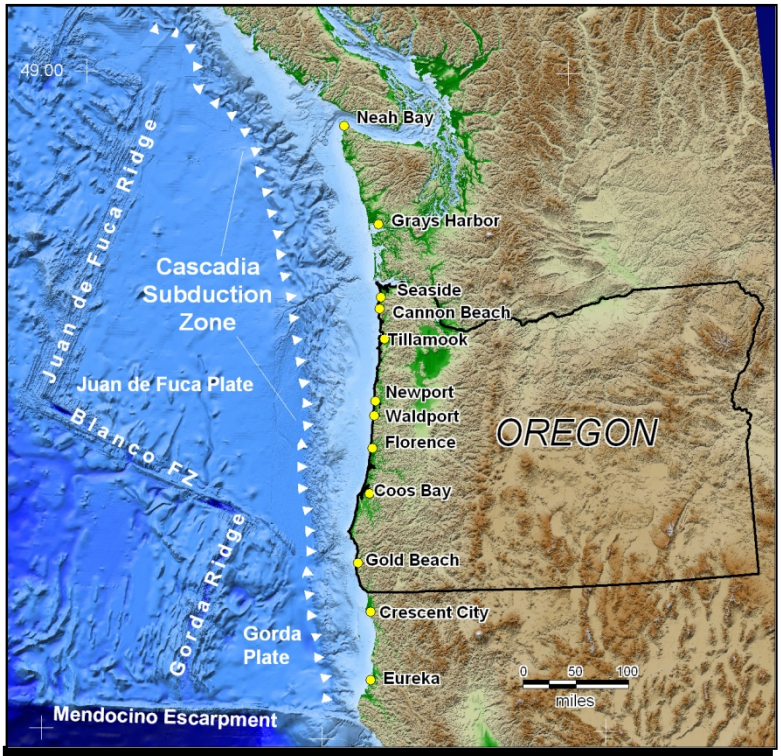


Figure T-2. Map of the surface trace of the Cascadia Subduction Zone active fault. The fault is the contact where the Juan de Fuca Plate plunges beneath the North American continental plate. (Source:USGS)

Damage from a tsunami comes not only from the tsunami surge itself. The rapid retreat of water prior to arrival of the tsunami surge and the debris carried by the tsunami surges add to the destructive potential.

In addition, fires started by the preceding earthquake are often spread by the tsunami surges. As was seen in the Sumatra 2004 tsunami, flood inundation from a tsunami may be extensive, as tsunamis can travel up rivers and streams that lead to the ocean. Delineating the inland extent of flooding, or inundation, is an important aspect of preparing for tsunamis.

A full list of acronyms used in this chapter is provided in Appendix 8-B.

Oregon Tsunami Hazard Analysis & Characterization

In March 1964, a tsunami struck southeastern Alaska following an earthquake beneath Prince William Sound and arrived along the Alaska coastline between 20 and 30 minutes after the quake, devastating villages. Damages were estimated to be over $100 million. Approximately 120 people drowned. The tsunami spread across the Pacific Ocean and caused damage and fatalities in other coastal areas, including Oregon. The tsunami killed five people in Oregon and caused an estimated $750,000 to $1 million in damage. In Crescent City, California, there were 10 fatalities, while damage to property and infrastructure was estimated to range from $11 to 16 million.

In March 2011, a 9.0 earthquake struck off the east coast of Japan. This caused a massive tsunami that inundated much of the eastern coastline of Japan, and reached the west coast of the U.S. many hours later. There was one death and millions of dollars of damage to ports and harbors in Oregon and California. Japan suffered many thousands of dead and missing as well as a nuclear catastrophe which will continue to be a hazard far into the future.

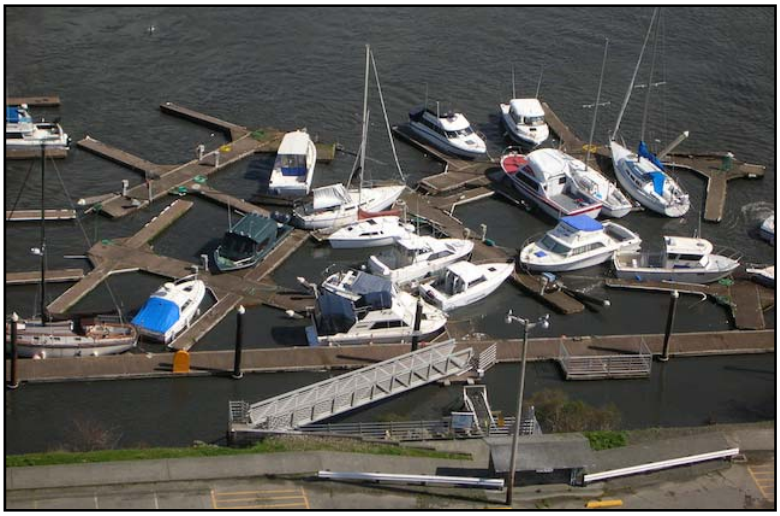


Figure T- 3 : Tsunami damage on the Chetco River, Oregon from March 11, 2011 tsunami. (Source: USGC)

Oregon received a Presidential Declaration of Disaster (DR-1964) which brought millions of dollars of financial aid to repair and mitigate future tsunami damage. Debris from tsunami-damaged buildings in Japan floated across the great extent of the Pacific Ocean and began arriving on the Canadian and US West Coast in December 2011. This is just the leading edge of the floating debris field that will arrive more significantly in Oregon in 2012.

There is scientific consensus that the Pacific Northwest experienced a subduction zone earthquake estimated at magnitude 9 on January 26, 1700. Data suggests it was comparable to the 2011 earthquake and tsunami in Japan. The earthquake generated a tsunami that caused death and damage as far away as Japan, where it was well-documented in the literature of the time. It is also physically evident in Oregon in the marine organism-bearing sand deposits and in the drowned cedar forests that died during rapid submergence into salt water. The widespread and large body of oral traditional history of the Thunderbird and Whale stories passed down by First Nations people depict both strong ground shaking and marine flooding.

Tsunamis can travel thousands of miles across ocean basins, so that a particular coastal area may be susceptible to two different types of tsunami hazard caused by:

1) distant sources across the ocean basin, and

2) local events like Cascadia tsunamis that occur immediately adjacent to a coast.

Distant tsunamis that may threaten the Oregon Coast are usually generated by a subduction zone earthquake elsewhere in the Pacific and would take several hours to reach the Oregon coastline; the 1964 Alaska tsunami reached the Oregon Coast in four to five hours after the earthquake that generated it. In contrast, a local tsunami generated by a Cascadia subduction earthquake, would take about ~10 to 30 minutes to reach the coast.

A tsunami generated locally will probably be stronger (contain more energy), higher and travel farther inland (overland and up river) than a distant tsunami. By the time the tsunami surge hits the coastline, it may be traveling at 30 mph (~13 meters per second) and have heights of 20 to 60 feet, potentially higher depending on the local coastal bathymetry (water depths) and geometry of the shore. The tsunami surge from a nearby earthquake will break up into a series of surges that will continue to strike the coast over an 8 to 10 hour period, and can continue even longer for a major Pacific-wide tsunami. Furthermore, as was seen in the 2004 Sumatra tsunami, the first surge to strike the coast is not always the most destructive. This was again evident during the 2011 tsunami.

Deep ocean trenches mark the surface trace of subduction zones offshore from the coasts of Alaska, Japan, Russia and South America and are known for generating earthquakes capable of producing a catastrophic tsunami.

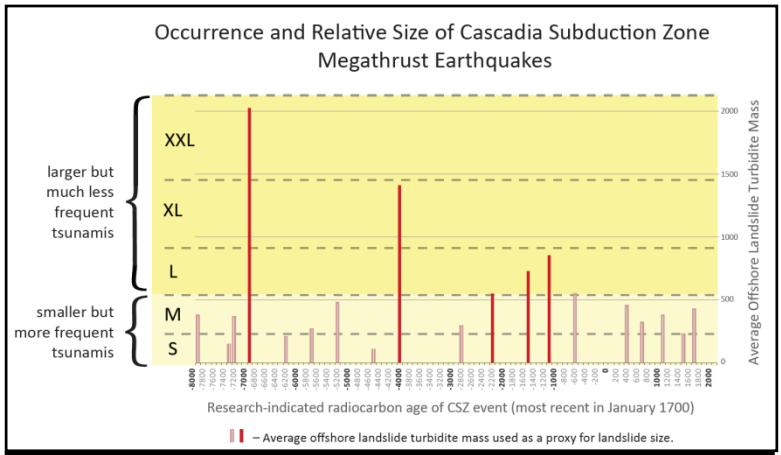


Figure T-4: Occurrence and Relative Size of Cascadia Subduction Zone Megathrust Earthquakes (source: DOGAMI)

Tsunami destruction can come from both the tsunami surge and from the rapid retreat of the water from the coastline, which sometimes occurs prior to the arrival of the tsunami. The tsunami surge tends to be a fast moving rising surge of water. As the tsunami enters coastal bays and rivers, it may move as a high velocity current or a breaking surge that travels up an estuary as a bore (wall of turbulent water like the surges at the coast after they break). This inland surge of water can often cause most or all of the damage. For example, in Seaside the damage from the 1964 Alaskan tsunami occurred along the Necanicum River and Neawanna Creek, well inland from the coast. In addition, storm surges may ride on top of the tsunami surges and may further compound the level of destruction.

During the largest CSZ earthquakes there is also the added effect of coastal subsidence, or the downward displacement of the land relative to the sea level, during the earthquake. This is due to the release of the accumulated strain that caused the western edge of the North American Plate to distort and bulge. The new digital models of earthquake geometries indicate that portions of the Oregon coast could drop by several feet.

While Cascadia Subduction Zone earthquakes and associated tsunamis have occurred on average every 300 to 500 years over the last 10,000 years, the time interval between events has been as short as decades and as long as 1000 years. The documented history of the past 19 CSZ earthquakes and offshore tsunami deposits is displayed on figure T-4. All 19 of these full-rupture CSZ events were likely magnitude 8.9 to 9.2 earthquakes. This

chart presents the synthesis of scientific data drawn from work by DOGAMI, OSU, USGS and others.

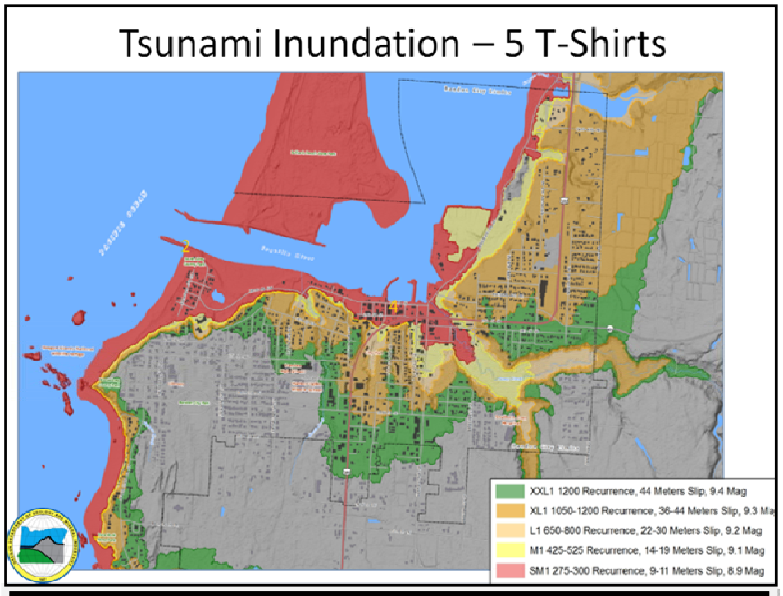


Figure T-5: Relative sizes of Cascadia Subduction Zone earthquakes and the resulting tsunami inundation, City of Bandon area. (source: DOGAMI)

For ease of remembering the different scenarios and to enhance the educational aspects of hazard mitigation and response, DOGAMI has labeled the five scenarios as "T-shirt sizes" ranging from Small, Medium, Large and Extra Large to Extra-Extra Large (S, M, L, XL, XXL). The XXL scenario line is what is used for tsunami evacuation brochures for life safety planning and preparation. Each scenario assumed a Mean Higher High Water (MHHW) Tide and includes the effects of local subsidence. An important aspect of this data is that the amount of time that has taken place since the last earthquake and tsunami is not a useful indicator of the size of the next tsunami. Therefore, although a Small or Medium CSZ tsunami occurs 74% of the time, there are no data that can rule out the next great earthquake and tsunami from being an Extra Extra Large event. In April 200,8 the USGS wrote that for the next 30 years there is a 10% probability of a magnitude 8 to 9 quake somewhere along the 750-mile-long Cascadia Subduction Zone.

These five local CSZ-sourced inundation scenarios involve greater and greater amounts of slip in the plane of the zone, ranging from 30 to 144 feet, with variable vertical seafloor displacement based upon a splay fault rupture geometric model for each scenario.

Existing Strategies and Programs

National Tsunami Hazard Mitigation Program (NTHMP)

The National Tsunami Hazard Mitigation Program (NTHMP) is a state/federal partnership and currently provides both monetary support and program guidance to Oregon. The program's Coordinating Committee includes emergency management and geoscience representatives from the original five Pacific states (Alaska, California, Hawaii, Oregon, and Washington), emergency management representatives from the Atlantic and Gulf Coast states, the United States Geological Survey (USGS), the Federal Emergency Management Agency (FEMA), National Oceanographic and Atmospheric Administration (NOAA), and the National Science Foundation (NSF). Funds to administer the Oregon state program are provided by NOAA and have been available every fiscal year since federal FY 1997.

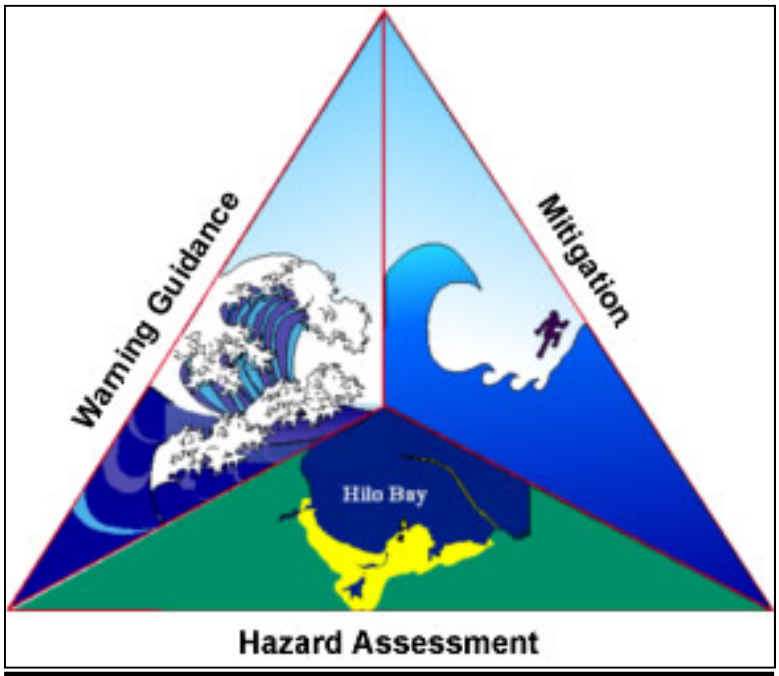


Figure T-6: Logo of the National Tsunami Hazard Mitigation Program (Source: NTHMP)

The 2006 *Tsunami Warning and Education Act* (PL 109-424) called for a Forecasting and Warning Program, a Tsunami Hazard Mitigation Program, and a Tsunami Research Program. These programs include the upgrade of seismic networks and installation of open ocean tsunami detection equipment designed to reduce the number of false alarms; development of tsunami inundation models and maps; and education, preparedness and mitigation work, including an implementation plan to insure that the goals of the program were met. Federal and state partners are in the midst of formulating and implementing this plan. This bill is currently being discussed for reauthorization in 2012. Failure to reauthorize this bill could have devastating effects on the ability to mitigate tsunami hazards on U.S. coastlines.

Oregon is represented on the NTHMP by OEM for emergency management and DOGAMI for geoscience. Oregon has a strong history in participation with the NTHMP by serving on subcommittees as both members and co-chairs. Annual meetings in January are held in order to assess project status, as well as semi-annual reports which are reviewed by subcommittee chairs. Oregon generally gets high marks, but improvements in mitigation and warning capabilities have been suggested in reviewer's comments.

As a key component of Tsunami preparedness outreach, DOGAMI and OEM have crafted a program named *Tsunami Outreach Oregon*. This program was

envisioned as a locally-driven education and outreach program, giving each community the ability to design how best to achieve agreed upon objectives. Based on successful components of the 2005 Seaside tsunami outreach project, priorities for each community included active support of the Tsunami Outreach Oregon program by county and local governments, targeted neighborhood campaigns in evacuation zones; the distribution of tsunami evacuation and preparedness information on a community-wide basis; the engagement of local schools in the participating communities, and; conducting a community-wide tsunami evacuation drill. The identification and/ or recruitment of local volunteers and community groups to foster self-sustaining, volunteer based outreach teams were essential and an integral part of the program.

An additional long-term goal of the program is to increase the number of National Weather Service *TsunamiReady* communities on the coast.

State Agency Roles and Responsibilities

Department of Consumer and Business Services (DCBS), Building Codes Division (BCD)

The Department of Consumer and Business Services shall consult with the Seismic Safety Policy Advisory Commission and the State Department of Geology and Mineral Industries prior to adopting rules. Thereafter, the Department of Consumer and Business Services may adopt rules as set forth in ORS 183.325 to 183.410 to amend the state building code to:

(a) Require new building sites for essential facilities, hazardous facilities, major structures and special occupancy structures to be evaluated on a site specific basis for vulnerability to seismic geologic hazards.

(b) Require a program for the installation of strong motion accelerometers in or near selected major buildings.

(c) Provide for the review of geologic and engineering reports for seismic design of new buildings of large size, high occupancy or critical use.

(d) Provide for filing of non-interpretive seismic data from site evaluation in a manner accessible to the public. (ORS 455.447)

The Building Codes Division has implemented the requirements of ORS 455.446 and .447 by amending in 1995 the *State Building Code* to address the location of new buildings in tsunami zones. ORS 455.446 and .447 restrict the location in the tsunami inundation zone of essential and special occupancy structures. The BCD shares information with local building officials and ensures, during program review, that they are aware of available information and their code responsibilities relating to tsunami inundation zones. The division also sponsors training for building officials that may include information relating to tsunami zones.

Department of Geology and Mineral Industries (DOGAMI)

The Department of Geology and Mineral Industries has statutory authority to initiate, carry out or administer studies and programs that will, in cooperation with universities, federal, state and local government agencies, reduce the loss of life and property by understanding and mitigating geologic hazards (ORS 516.030). DOGAMI assists the BCD in administering ORS 455.446 and .447.

Tsunamis can potentially cause the most loss of life of any geologic hazard in the state, so mitigation and assessment of these hazards has a high priority in the agency. DOGAMI, in collaboration with the Oregon Health and Science University and NOAA, has developed detailed tsunami inundation maps for several areas on the coast, including;

- Gold Beach,
- Coos Bay,
- Siletz Bay (southern Lincoln City),
- Alsea Bay (Waldport),
- Yaquina Bay (Newport),
- Cannon Beach,
- Seaside-Gearhart,
- Warrenton/Astoria.

A Tsunami Evacuation Brochure template that presents just two tsunami scenarios: one for the worst case local event displayed in yellow (the XXL splay fault CSZ event) and one for the worst case distant event displayed in orange (worst case Alaska).

Department of Land Conservation and Development (DLCD)

The Department of Land Conservation and Development shall carry out their planning duties, powers and responsibilities and take actions that are authorized by law with respect to programs affecting land use (ORS 197.180).

The Department of Land Conservation and Development contracted with the University of Oregon Community Planning Workgroup to develop *Planning for Natural Hazards - Oregon Technical Resource Guide*. The manual includes a section on coastal hazards, including tsunamis. The Oregon Coastal Management Program (OCMP) is a division of DLCD and is developing Littoral Cell Management Planning inventories for areas in Clatsop, Tillamook, Lincoln, Coos, and Curry counties. Littoral cells are strips of coastline bounded by headlands. The inventories incorporate both chronic (cliff erosion) and catastrophic (tsunamis) hazards, and include NOAA LIDAR data, coastal geology, DOGAMI tsunami inundation maps, FEMA flood map insurance zones, etc., as well as cultural and jurisdictional data. The OCMP is developing a *Coastal Atlas*, a GIS based information system, and web-based interactive mapping, tool and data archive site for coastal planners and managers.

Figure T-7: Tsunami Hazard Zone Sign

Office of Emergency Management, Oregon Military Department (OEM)

Oregon Emergency Management has statutory authority to (a) coordinate and facilitate private sector and governmental efforts to prevent, prepare for, respond to and recover from emergencies; and (b) coordinate exercises and training, planning, preparedness, response, mitigation and recovery activities with state and local emergency services agencies and organizations. (ORS 401.257**).** OEM assists DOGAMI with development of tsunami evacuation maps by coordination with local emergency program managers and review of maps and emergency response information on the maps. OEM also assists local government in hazard mitigation planning, evacuation route planning and mitigation project technical assistance, identification of safe sites where evacuees can gather, and other emergency preparedness and hazard mitigation measures.

OEM has been active in developing a program for mitigation projects to improve life safety on the Oregon coast. Tsunami hazard zone, evacuation route and evacuation site signs have been distributed to all coastal counties by OEM and DOGAMI and have been installed in many locations on the coast. OEM has been actively involved in tsunami warning systems and procedures with the creation of the Distant Tsunami Working Group. OEM also prepared a five-state *Tsunami Warning Systems and Procedures* guidance document for the NTHMP.

Oregon Department of Transportation

The Oregon Department of Transportation (ODOT) collaborated with DOGAMI, OEM, and coastal counties to develop signs denoting tsunami hazard zones, evacuation routes, and evacuation sites. ODOT manufactures the signs and makes them available to local governments at cost. The signs also have been used in California, Washington, Alaska, The Philippines, and Japan.

A project started in 2003 with OEM, DOGAMI, and coastal counties involved the development of signs that tell motorists when they are entering or leaving a tsunami hazard zone. The new signs have been placed on U.S. 101, the Pacific Coast Highway, when local communities establish the locations of their tsunami evacuation routes.

As local tsunami evacuation plans are developed, ODOT will work with communities to develop corresponding alternate route plans for U.S. 101 and other state highways.

Tsunami Inundation Maps

Using the latest in geologic mapping, DOGAMI is producing new and improved inundation maps to help in mitigation and public education efforts.

Pre-2012 Oregon NHMP Action Met: T-LT-2

Lead Agencies: DOGAMI, OEM

Project Type: education/public awareness

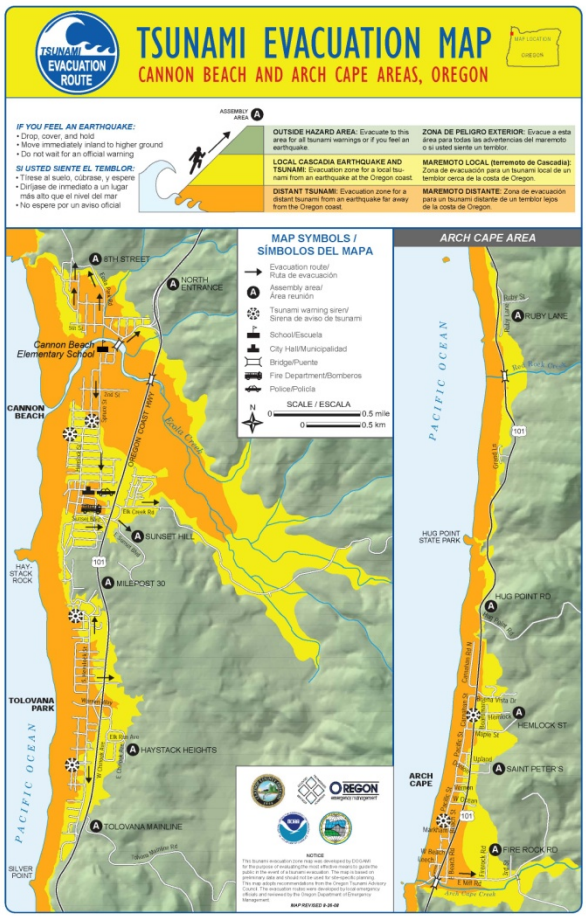
Project Start Date: 2008

Project End Date: 2015

Funding Sources: state funds, others

Project Benefits:

Provides valuable resources to both the general public and local government officials to prevent loss of life and to minimize the destruction of property



Tsunami Public Education

Public education efforts help to create a culture of awareness in areas at risk from geologic hazards.

Pre-2012 Oregon NHMP Action Met: T-ST-6

Lead Agencies: DOGAMI, OEM

Project Type: public education

Project Start Date: 2005

Project End Date: 2015

Funding Sources: state funds, others

Project Benefits: prevention of loss of life by educating the public and policy makers about planning and mitigation

Appendix T-1: Warning Systems for Public Safety

The National Weather Service (NWS) operates two tsunami warning centers: The West Coast/Alaska Tsunami Warning Center (WC/ATWC) and the Pacific Tsunami Warning Center (PTWC) in Hawaii. The WC/ATWC, located in Palmer, Alaska, is the regional center for British Columbia, Washington, Oregon, and California. The PTWC, located in Ewa Beach, Hawaii is the regional center for Hawaii, the national center for the Pacific Island Territories and Commonwealth's of the United States and the international center for other Pacific nations. The role of the tsunami warning centers is to rapidly locate, size, and otherwise characterize major earthquakes, determine their potential for generating a tsunami, predict tsunami arrival times, predict coastal runup when possible, and disseminate appropriate warning and informational products based on this information to coastal populations and emergency management within the area-of-responsibility.

In response to an earthquake, the tsunami warning centers will release one of four messages:

tsunami warning: A tsunami warning is issued when a potential tsunami with significant widespread inundation is imminent or expected. Warnings alert the public that widespread, dangerous coastal flooding accompanied by powerful currents is possible, and may continue for several hours after arrival of the initial surge. Warnings also alert emergency management officials to take action for the entire tsunami hazard zone. Appropriate actions to be taken by local officials may include the evacuation of low-lying coastal areas and repositioning ships to deep waters when there is time to safely do so. Warnings may be updated, adjusted geographically, downgraded, or canceled. To provide the earliest possible alert, initial warnings are normally based only on seismic information.

tsunami watch: A tsunami watch is issued to alert emergency management officials and the public of an event that may later impact the watch area. The watch area may be upgraded to a warning or advisory, or canceled, based on updated information and analysis. Therefore emergency management officials and the public should prepare to take action. Watches are normally issued based on seismic information without confirmation that a destructive tsunami is underway.

tsunami advisory: A tsunami advisory is issued for the threat of a potential tsunami that may produce strong currents or surges dangerous to those in or near the water. Coastal regions historically prone to damage due to strong currents induced by tsunamis are at the greatest risk. The threat may continue for several hours after the arrival of the initial surge, but significant widespread inundation is not expected for areas under an advisory. Appropriate actions to be taken by local officials may include closing beaches, evacuating harbors and marinas, and repositioning ships to deep waters when there is time to safely do so. Advisories are normally updated to continue the advisory, expand or contract affected areas, upgrade to a warning, or cancel the advisory.

tsunami information statement: A tsunami information statement is issued to inform emergency management officials and the public that an earthquake has

occurred, or that a tsunami warning, watch, or advisory has been issued for another section of the ocean. In most cases information statements are issued to indicate there is no threat of a destructive tsunami and to prevent unnecessary evacuations because the earthquake may have been felt in coastal areas. An information statement may, in appropriate situations, caution about the possibility of destructive local tsunamis. Information statements may be reissued with additional information though normally these messages are not updated. However, a watch, advisory or warning may be issued for the area, if necessary, after analysis and/or updated information becomes available.

The International Tsunami Information Centre (ITIC), run jointly by the National Weather Service (NWS) and the Intergovernmental Oceanographic Commission, is the primary source for non-operational tsunami information:

http://ioc3.unesco.org/itic/

Appendix T-2: Additional Resources

Bernard, E.N. (ed.) (2005): Developing Tsunami-Resilient Communities: The National Tsunami Hazard Mitigation Program. (Reprinted from Natural Hazards, 35(1), 2005), Springer, The Netherlands, 184 pp.

California Office of Emergency Services (OES), Findings and Recommendations for Mitigating the Risks of Tsunamis in California, Sacramento, California, 1997

Cascadia Regional Earthquake Workgroup (CREW), Cascadia Subduction Zone Earthquakes: A Magnitude 9.0 Earthquake Scenario, Seattle, Washington, 2005.

Coastal Natural Hazards Policy Working Group, Improving Natural Hazards Management on the Oregon Coast, Oregon Sea Grant, Corvallis, Oregon, 1994

National Tsunami Hazard Mitigation Program, 1997-1999 Activities of the Tsunami Mitigation Subcommittee, Bothell, Washington, 1999

National Tsunami Hazard Mitigation Program, Designing for Tsunamis: Seven Principles for Planning and Designing for Tsunami Hazards, Oakland, California, March, 2001

National Tsunami Hazard Mitigation Program, TsuInfo Alert, Olympia, Washington.

Nature of the Northwest Information Center, 800 NE Oregon Street #5, Portland, Oregon, 97232

Oregon Seismic Safety Policy Advisory Commission (OSSPAC), Oregon At Risk, Salem, Oregon, 2000

Urban Regional Research, Comprehensive Planning for Tsunami Hazard Areas, Seattle, WA, 1998