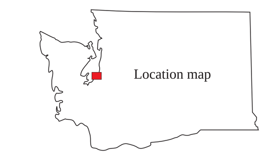
[The Seattle Fault modeling portion of this publication has been superseded by Map Series 2022-03]

WASHINGTON STATE DEPARTMENT OF Natural Resources
Peter Goldmark · Commissioner of Public Lands
Division of Geology and Earth Resources
David K. Norman · State Geologist

NOAA Center for Tsunami Research
Pacific Marine Environmental Laboratory



WASHINGTON DIVISION OF GEOLOGY AND EARTH RESOURCES
OPEN FILE REPORT 2009-9

Tsunami Hazard Map of Tacoma, Washington
July 2009

Tsunami Hazard Map of Tacoma, Washington: Model Results for Seattle Fault and Tacoma Fault Earthquake Tsunamis

by
Timothy J. Walsh[1], Diego Arcas[2], Angie J. Venturato[2], Vasily V. Titov[2], Harold O. Mofjeld[2], Chris C. Chamberlin[2], and Frank I. González[2]

[1]Washington Division of Geology and Earth Resources, PO Box 47007, Olympia, WA 98504-47007; tim.walsh@dnr.wa.gov
[2]NOAA Center for Tsunami Research, NOAA/PMEL-UW/JISAO, 7600 Sand Point Way NE, Seattle, WA 98115

[The Seattle Fault modeling below is superseded by Map Series 2022-03]

Modeled Inundation from a Seattle Fault Tsunami

Photo from the National Agriculture Imagery Program (NAIP)

Inundation depth (m)

- <0.5
- 0.5–2
- 2–5
- >5

1:36,000

0 0.5 1 2 3 mi
0 1 2 3 4 km

[The Tacoma fault modeling and Tacoma-Rosedale fault modeling below is NOT superseded]

Modeled Inundation from a Tacoma Fault (left) and a Tacoma–Rosedale Fault (right) Tsunami

Photo from the National Agriculture Imagery Program (NAIP)

1:62,500

0 0.5 1 2 3 4 mi
0 1 2 3 4 5 6 km

Inundation depth (m)

- <0.5
- 0.5–2
- >2

Suggested citation: Walsh, T. J.; Arcas, Diego; Venturato, A. J.; Titov, V. V.; Mofjeld, H. O.; Chamberlin, C. C.; González, F. I., 2009, Tsunami hazard map of Tacoma, Washington—Model results for Seattle fault and Tacoma fault earthquake tsunamis: Washington Division of Geology and Earth Resources Open File Report 2009-9, partially superseded by Map Sheet 2022-03, 1 sheet, scales 1:36,000 and 1:62,500. [http://www.dnr.wa.gov/ Publications/ ger_ofr2009-9_tacoma_tsunami.pdf]

ABSTRACT

Numerical modeling of tsunamis generated by earthquakes on the Seattle fault and the Tacoma fault show that Tacoma would be subjected to larger and more damaging waves from a Seattle fault earthquake, even though the Seattle fault is considerably more distant. This is because the Seattle fault traverses Puget Sound in much deeper water and can therefore displace more water. The results show that a repeat of the Seattle fault earthquake of about A.D. 935 would generate inundation depths of more than 2 m in much of the Puyallup delta. Although the Port of Tacoma has experienced substantial dredging and filling, there is still natural ground along the main stem of the Puyallup River in Fife and in Hylebos Waterway. Both of these channels have significant areas with modeled inundation depths of more than 5 m for a Seattle fault event and more than 4 m from a Tacoma fault event. These models will provide useful guidance for paleoseismology investigations of A.D. 935 tsunami deposits and perhaps also tsunami deposits from the last Tacoma fault earthquake, which was also about 1000 years ago but is less well constrained.

INTRODUCTION

In 1995, Congress directed the National Oceanic and Atmospheric Administration (NOAA) to develop a plan to protect the West Coast from tsunamis generated locally. A panel of representatives from NOAA, the Federal Emergency Management Agency (FEMA), the U.S. Geological Survey (USGS) and the five Pacific Coast states wrote the plan and submitted it to Congress, which created the National Tsunami Hazard Mitigation Program (NTHMP) in October of 1996. The NTHMP is designed to reduce the impact of tsunamis through warning guidance, hazard assessment, and mitigation. A key component of the hazard assessment for tsunamis is delineation of areas subject to tsunami inundation. This map is part of a series of tsunami inundation maps produced by the Washington Department of Natural Resources, Division of Geology and Earth Resources, in cooperation with the Washington Emergency Management Division, as a contribution of the NTHMP. These maps are produced using computer models of earthquake-generated tsunamis from nearby seismic sources. The modeling for this map was done by the NOAA Center for Tsunami Research (NCTR) at NOAA's Pacific Marine Environmental Laboratory in Seattle.

THE SEATTLE FAULT

Geographic features now known to be associated with the Seattle fault have been noted for many years. Vancouver (1798) noted that the fault-uplifted bedrock wavecut platform at Restoration Point (Fig. 1, Location 1) on Bainbridge Island "did not possess that beautiful variety of landscape, being an almost impenetrable wilderness of lofty trees" that characterized the rest of his explorations in Puget Sound. Kimball (1897) also noted the uplifted wavecut platform at Restoration Point, measured the uplift, and identified the marine fossils found there. He also described the Newcastle Hills, part of the hanging wall of the fault, as a "postglacial eruption". Daneš and others (1965) interpreted the large gravity and magnetic anomalies through central Puget Sound and the associated abrupt change in the sedimentary section thickness as an active fault with about 11 km of displacement. Rogers (1970) collected additional gravity and magnetic data across the structure and named it the Seattle–Bremerton fault. Gower (1978) demonstrated that the uplift at Restoration Point was Holocene in age and Bucknam and others (1992) showed that the uplift produced 7 m of uplift on the fault about 1000 years ago. In 1996, the first of a series of lidar (light detection and ranging) surveys was flown on Bainbridge Island. This and subsequent lidar missions have enabled scientists to accurately locate the fault in a number of places and dig trenches (Bucknam and others, 1999; Nelson and others, 2002). At about the same time, the U.S. Geological Survey began several large-scale geophysical studies. An aeromagnetic study of Puget Sound (Blakely and others, 1999, 2002) enabled more accurate location of the fault along its entire length. Seismic studies, such as SHIPS (Seismic Hazards Investigations in Puget Sound), and other geophysical studies in Puget Sound have greatly increased our understanding of the fault at depth (Pratt and others, 1997; Johnson and others, 1999; ten Brink and others, 2002).

There also is substantial evidence that earthquakes on the Seattle fault can generate tsunamis. Atwater and Moore (1992) showed that tsunamis inundated part of Whidbey Island and West Point about 1000 years ago, and Jacoby and others (1992) showed that a tree in the tsunami deposit at West Point died in the same season of the same year as a drowned forest carried into Lake Washington by a huge landslide from Mercer Island, strongly implicating the large A.D. ~935 earthquake on the Seattle fault. A discontinuous sand layer along Snohomish delta distributaries—Ebey Slough, Steamboat Slough, Union Slough, and Snohomish River—was also probably deposited by the tsunami from this event (Bourgeois and Johnson, 2001).

THE TACOMA FAULT

Daneš and others (1965) interpreted the large gravity and magnetic anomalies south of the Seattle fault as an active fault as well, although less so than the Seattle fault. Rogers (1970) collected additional gravity and magnetic data across the structure and named it the Tacoma–Gig Harbor fault. Brocher and others (2001) refined its location on the basis of gravity, aeromagnetics, and seismic tomography and renamed it the Tacoma fault. Lidar imagery enabled Sherrod and others (2004) to locate and trench the fault, demonstrating that it ruptured about 1,000 years ago. Johnson and others (2004) proposed structural models for the Tacoma fault that either put surface displacement along the main trace of the fault or partitioning some slip along the Rosedale monocline. No paleotsunami deposits have been attributed to the Tacoma fault.

MODELING

The model of Titov and Synolakis (1998), also known as the Method of Splitting Tsunami (MOST) model (Titov and González, 1997) was used by NCTR modelers. It uses a grid of topographic and bathymetric elevations and calculates a wave elevation and velocity at each gridpoint at specified time intervals to simulate the generation, propagation, and inundation of tsunamis in the Tacoma area.

In this MOST model study, the tsunami generated by a Seattle fault deformation model (Figs. 1 and 2) simulates the ~1100 yr B.P. event as a credible worst-case scenario of magnitude 7.3. Details of the Seattle fault scenario are given in Titov and others (2003) and Walsh and others (2003c). Two deformation models for the Tacoma fault were used in the tsunami simulations, following Johnson and others (2004). The fault parameters (Figs. 1 and 2) were derived in a workshop convened by Walsh and attended by T. M. Brocher, T. L. Pratt, B. L. Sherrod, and C. S. Weaver of the USGS and Diego Arcas, F. I. González, H. O. Mofjeld, V. V. Titov, and A. J. Venturato of NOAA. Details of the Tacoma fault models are given in Venturato and others (2007). These scenarios were modeled separately, although Brocher and others (2004) and Sherrod and others (2004) suggest that the two faults may have ruptured at the same time. If both ruptures were part of the same event, however, reproducing the kinematics of the combined event would be beyond the scope of this study.

The Seattle fault, which traverses much deeper water, produces significantly more inundation than either Tacoma fault scenario because it displaces much more water. This scenario is therefore shown at a larger scale.

The computed tsunami inundation is shown on the map in three color-coded depth ranges for the Tacoma fault scenarios: 0–0.5 m, 0.5–2 m, and greater than 2 m. These depth ranges were chosen because they are approximately knee-high or less, knee-high to head-high, and more than head-high. The model for the Seattle fault additionally shows a >5 m inundation depth. Figure 3 shows wave heights and arrival times for all three scenarios at key locations throughout the map area.

The limit of tsunami inundation is the landward edge of the green zone. In previous maps, we have shown only the edge of inundation. Figure 4 also shows current velocities in two zones—less than or greater than 1.5 m/sec (~3 mi/hr), which is the current speed at which it would be difficult to stand. Computed velocities locally exceed 30 m/sec (~60 mi/hr).

Initial flooding in the Tacoma area occurs 15 to 20 minutes after tsunami generation for both the Seattle and Rosedale scenarios and about 5 minutes after generation for the Tacoma fault scenario (Fig. 3; Venturato and others, 2007).

DISCUSSION

There have been no investigations that have identified paleotsunami deposits in the Tacoma area. Model data that show significant depth of flow and velocity may be useful to select appropriate areas of study. The map of fill at the Port of Tacoma (Fig. 5) shows areas where tsunami deposits would not be accessible and areas, such as the mouth of Hylebos Waterway or along the Puyallup River, that may be suitable for paleoseismic studies. Distinguishing the source of a paleotsunami deposit would be difficult, though, because the last major earthquake on each fault was at approximately the same time.

LIMITATIONS OF THE MAP

Because the nature of the tsunami depends on the initial deformation of the earthquake, which is poorly understood, the largest source of uncertainty is the input earthquake. The earthquake scenarios used in this modeling were selected to honor the paleoseismic constraints, but the next Seattle or Tacoma fault earthquake may be substantially different from these. Sherrod and others (2000) show that an uplift event at Restoration Point predating the A.D. 900–930 event was smaller. Trenching of subsidiary structures to the Seattle fault that are thought to be coseimic with the main fault trace (Nelson and others, 2002) indicates that there were at least two earthquakes in the 1500 years before the A.D. 900–930 event. These, however, did not produce prominent uplifted wavecut platforms similar to the one made by the A.D. 900–930 event, suggesting that significant earthquakes have occurred on the fault that had different and smaller uplifts in central Puget Sound. Another significant limitation is that the resolution of the modeling is no greater or more accurate than the bathymetric and topographic data used. This can be up to 50 m horizontally, although high-resolution multibeam data (Gardner and others, 2001) is available for Commencement Bay.

The model runs do not include the influences of changes in tides and are referred to mean high water. The tide stage and tidal currents can amplify or reduce the impact of a tsunami on a specific community. At the Port of Tacoma, the diurnal range (the difference in height between mean higher high water and mean lower low water) is about 12 ft (http://www.tidesandcurrents.noaa.gov, accessed March 23, 2009). This means that, while the modeling can be a useful tool to guide evacuation planning, it is not of sufficient resolution to be useful for land-use planning.

ACKNOWLEDGMENTS

This project was supported by the National Tsunami Hazards Mitigation Program (NTHMP) in cooperation with the Washington Emergency Management Division (WAEMD). Information about NTHMP is available at http://nthmp.tsunami.gov/. During the study, NCTR maintained close communication with WAEMD and the Washington Department of Natural Resources (WADNR), and upon completion of the study, a suite of model-derived mapping products were delivered to both agencies in the form of electronic files and, where appropriate, hard-copy representations.

This map is part of a series of tsunami hazard maps for Washington State. Maps completed to date are the southern Washington coast (Walsh and others, 2000), Port Angeles (Walsh and others, 2002a), Port Townsend (Walsh and others, 2002b), Neah Bay (Walsh and others, 2003a), Quileute area (Walsh and others, 2003b), Seattle (Walsh and others, 2003c), Bellingham (Walsh and others, 2004), and Anacortes–Whidbey Island (Walsh and others, 2005).

REFERENCES

Atwater, B. F.; Moore, A. L., 1992, A tsunami about 1000 years ago in Puget Sound, Washington: Science, v. 258, no. 5088, p. 1614-1617.

Blakely, R. J.; Wells, R. E.; Weaver, C. S., 1999, Puget Sound aeromagnetic maps and data: U.S. Geological Survey Open-File Report 99-514, version 1.0. [http://pubs.usgs.gov/of/1999/of99-514/]

Blakely, R. J.; Wells, R. E.; Weaver, C. S.; Johnson, S. Y., 2002, Location, structure, and seismicity of the Seattle fault zone, Washington—Evidence from aeromagnetic anomalies, geologic mapping, and seismic-reflection data: Geological Society of America Bulletin, v. 114, no. 2, p. 169-177.

Bourgeois, Joanne; Johnson, S. Y., 2001, Geologic evidence of earthquakes at the Snohomish delta, Washington, in the past 1200 yr: Geological Society of America Bulletin, v. 113, no. 4, p. 482-494.

Brocher, T. M.; Blakely, R. J.; Wells, R. E., 2004, Interpretation of the Seattle uplift, Washington, as a passive-roof duplex: Seismological Society of America Bulletin, v. 94, no. 4, p. 1379-1401.

Brocher, T. M.; Parsons, T. E.; Blakely, R. J.; Christensen, N. I.; Fisher, M. A.; Wells, R. E.; SHIPS Working Group, 2001, Upper crustal structure in Puget Lowland, Washington—Results from the 1998 Seismic Hazards Investigations in Puget Sound: Journal of Geophysical Research, v. 106, no. B7, p. 13,541-13,564.

Bucknam, R. C.; Hemphill-Haley, Eileen; Leopold, E. B., 1992, Abrupt uplift within the past 1700 years at southern Puget Sound, Washington: Science, v. 258, no. 5088, p. 1611-1614.

Bucknam, R. C.; Sherrod, B. L.; Elfendahl, G. W., 1999, A fault scarp of probable Holocene age in the Seattle fault zone, Bainbridge Island, Washington [abstract]: Seismological Research Letters, v. 70, no. 2, p. 233.

Daneš, Z. F.; Bonno, M.; Brau, J. E.; Gilham, W. D.; Hoffman, T. F.; Johansen, D.; Jones, M. H.; Malfait, Bruce; Masten, J.; Teague, G. O., 1965, Geophysical investigation of the southern Puget Sound area, Washington: Journal of Geophysical Research, v. 70, no. 22, p. 5573-5580.

Gardner, J. V.; van den Ameele, E. J.; Gelfenbaum, Guy; Barnhardt, W. A.; Lee, H. J.; Palmer, S. P., 2001, Mapping southern Puget Sound delta fronts after the 2001 Nisqually earthquake. *In* Gardner, J. V.; van den Ameele, E. J.; Dartnell, Peter, Multibeam mapping of the major deltas of southern Puget Sound, Washington: U.S. Geological Survey Open-File Report 01-266, 1 v. [http://geopubs.wr.usgs.gov/open-file/of01-266/]

González, F. I., compiler, 2003, Puget Sound tsunami sources—2002 workshop report: NOAA/Pacific Marine Environmental Laboratory Contribution No. 2526, 36 p.

Gower, H. D., 1978, Tectonic map of the Puget Sound region, Washington, showing locations of faults, principal folds, and large-scale Quaternary deformation: U.S. Geological Survey Open-File Report 78-426, 22 p., 1 plate, scale 1:250,000.

Hart-Crowser and Associates, Inc., 1974, Geology of the Port of Tacoma: Hart-Crowser and Associates, Inc. [Seattle, Wash.], 40 p.

Jacoby, G. C.; Williams, P. L.; Buckley, B. M., 1992, Tree ring correlation between prehistoric landslides and abrupt tectonic events in Seattle, Washington: Science, v. 258, no. 5088, p. 1621-1623.

Johnson, S. Y.; Blakely, R. J.; Stephenson, W. J.; Dadisman, S. V.; Fisher, M. A., 2004, Active shortening of the Cascadia forearc and implications for seismic hazards of the Puget Lowland: Tectonics, v. 23, TC1011, doi:10.1029/2003TC001507, 2004, 27 p.

Johnson, S. Y.; Dadisman, S. V.; Childs, J. R.; Stanley, W. D., 1999, Active tectonics of the Seattle fault and central Puget Sound, Washington—Implications for earthquake hazards: Geological Society of America Bulletin, v. 111, no. 7, p. 1042-1053, 1 plate.

Kimball, J. P., 1897, Physiographic geology of the Puget Sound basin [in 2 parts]: American Geologist, v. 19, no. 4, p. 225-237 [part 1]; v. 19, no. 5, p. 304-322 [part 2].

Nelson, A. R.; Johnson, S. Y.; Wells, R. E.; Pezzopane, S. K.; Kelsey, H. M.; Sherrod, B. L.; Bradley, L.-A.; Koehler, R. D., III; Bucknam, R. C.; Haugerud, R. A.; Laprade, W. T., 2002, Field and laboratory data from an earthquake history study of the Toe Jam Hill fault, Bainbridge Island, Washington: U.S. Geological Survey Open-File Report 02-60, 1 v., 2 plates, version 1. [http://pubs.usgs.gov/of/2002/ofr-02-0060/]

Pratt, T. L.; Johnson, S. Y.; Potter, C. J.; Stephenson, W. J.; Finn, C. A., 1997, Seismic reflection images beneath Puget Sound, western Washington State—The Puget Lowland thrust sheet hypothesis: Journal of Geophysical Research, v. 102, no. B12, p. 27,469-27,489.

Rogers, W. P., 1970, A geological and geophysical study of the central Puget Sound lowland: University of Washington Doctor of Philosophy thesis, 123 p., 9 plates.

Sherrod, B. L.; Brocher, T. M.; Weaver, C. S.; Bucknam, R. C.; Blakely, R. J.; Kelsey, H. M.; Nelson, A. R.; Haugerud, Ralph, 2004, Holocene fault scarps near Tacoma, Washington, USA: Geology, v. 32, no. 1, p. 9-12.

Sherrod, B. L.; Bucknam, R. C.; Leopold, E. B., 2000, Holocene relative sea level changes along the Seattle fault at Restoration Point, Washington: Quaternary Research, v. 54, no. 3, p. 384-393.

ten Brink, U. S.; Molzer, P. C.; Fisher, M. A.; Blakely, R. J.; Bucknam, R. C.; Parsons, T. E.; Crosson, R. S.; Creager, K. C., 2002, Subsurface geometry and evolution of the Seattle fault zone and the Seattle basin, Washington: Seismological Society of America Bulletin, v. 92, no. 5, p. 1737-1753.

Titov, V. V.; González, F. I., 1997, Implementation and testing of the method of splitting tsunami (MOST) model: NOAA Technical Memorandum ERL PMEL-112; NOAA Pacific Marine Environmental Laboratory Contribution 1927, 11 p. [http://www.pmel.noaa.gov/pubs/PDF/tito1927/tito1927.pdf]

Titov, V. V.; González, F. I.; Mofjeld, H. O.; Venturato, A. J., 2003, NOAA TIME Seattle tsunami mapping project—Procedures, data sources, and products: NOAA Technical Memorandum OAR PMEL-124, 21 p. [http://www.pmel.noaa.gov/pubs/PDF/tito2572/tito2572.pdf]

Titov, V. V.; Synolakis, C. E., 1998, Numerical modeling of tidal wave runup: Journal of Waterway, Port, Coastal and Ocean Engineering, v. 124, no. 4, p. 157–171.

Vancouver, George, 1798, repr. 1992, A voyage of discovery to the north Pacific Ocean, and round the world; in which the coast of north-west American has been carefully examined and accurately surveyed—Undertaken by His Majesty's command, principally with a view to ascertain the existence of any navigable communication between the north Pacific and north Atlantic Oceans; and performed in the years 1790, 1791, 1792, 1793, 1794, and 1795: G. G. and J. Robinson [London], 3 v.

Venturato, A. J.; Arcas, Diego; Titov, V. V.; Mofjeld, H. O.; Chamberlin, C. C.; González, F. I., 2007, Tacoma, Washington, tsunami hazard mapping project—Modeling tsunami inundation from Tacoma and Seattle fault earthquakes: National Oceanic and Atmospheric Administration, Pacific Marine Environmental Laboratory Technical Memorandum OAR-PMEL-132, 23 p. [http://www.pmel.noaa.gov/pubs/PDF/vent2981/vent2981.pdf]

Walsh, T. J.; Caruthers, C. G.; Heinitz, A. C.; Myers, E. P., III; Baptista, A. M.; Erdakos, G. B.; Kamphaus, R. A., 2000, Tsunami hazard map of the southern Washington coast—Modeled tsunami inundation from a Cascadia subduction zone earthquake: Washington Division of Geology and Earth Resources Geologic Map GM-49, 1 sheet, scale 1:100,000, with 12 p. text. [http://www.dnr.wa.gov/Publications/ger_gm49_tsunami_hazard_southern_coast.zip]

Walsh, T. J.; Myers, E. P., III; Baptista, A. M., 2002a, Tsunami inundation map of the Port Angeles, Washington area: Washington Division of Geology and Earth Resources Open File Report 2002-1, 1 sheet, scale 1:24,000. [http://www.dnr.wa.gov/Publications/ger_ofr2002-1_tsunami_hazard_portangeles.pdf]

Walsh, T. J.; Myers, E. P., III; Baptista, A. M., 2002b, Tsunami inundation map of the Port Townsend, Washington area: Washington Division of Geology and Earth Resources Open File Report 2002-2, 1 sheet, scale 1:24,000. [http://www.dnr.wa.gov/Publications/ger_ofr2002-2_tsunami_hazard_porttownsend.pdf]

Walsh, T. J.; Myers, E. P., III; Baptista, A. M., 2003a, Tsunami inundation map of the Neah Bay, Washington, area: Washington Division of Geology and Earth Resources Open File Report 2003-2, 1 sheet, scale 1:24,000. [http://www.dnr.wa.gov/Publications/ger_ofr2003-2_tsunami_hazard_neahbay.pdf]

Walsh, T. J.; Myers, E. P., III; Baptista, A. M., 2003b, Tsunami inundation map of the Quileute, Washington, area: Washington Division of Geology and Earth Resources Open File Report 2003-1, 1 sheet, scale 1:24,000. [http://www.dnr.wa.gov/Publications/ger_ofr2003-1_tsunami_hazard_quileute.pdf]

Walsh, T. J.; Titov, V. V.; Venturato, A. J.; Mofjeld, H. O.; González, F. I., 2003c, Tsunami hazard map of the Elliott Bay area, Seattle, Washington—Modeled tsunami inundation from a Seattle fault earthquake: Washington Division of Geology and Earth Resources Open File Report 2003-14, 1 sheet, scale 1:50,000. [http://www.dnr.wa.gov/Publications/ger_ofr2003-14_tsunami_hazard_elliottbay.pdf]

Walsh, T. J.; Titov, V. V.; Venturato, A. J.; Mofjeld, H. O.; González, F. I., 2004, Tsunami hazard map of the Bellingham area, Washington—Modeled tsunami inundation from a Cascadia subduction zone earthquake: Washington Division of Geology and Earth Resources Open File Report 2004-15, 1 sheet, scale 1:50,000. [http://www.dnr.wa.gov/Publications/ger_ofr2004-15_tsunami_hazard_bellingham.pdf]

Walsh, T. J.; Titov, V. V.; Venturato, A. J.; Mofjeld, H. O.; González, F. I., 2005, Tsunami hazard map of the Anacortes–Whidbey Island area, Washington—Modeled tsunami inundation from a Cascadia subduction zone earthquake: Washington Division of Geology and Earth Resources Open File Report 2005-1, 1 sheet, scale 1:62,500. [http://www.dnr.wa.gov/Publications/ger_ofr2005-1_tsunami_hazard_anacortes_whidbey.pdf]

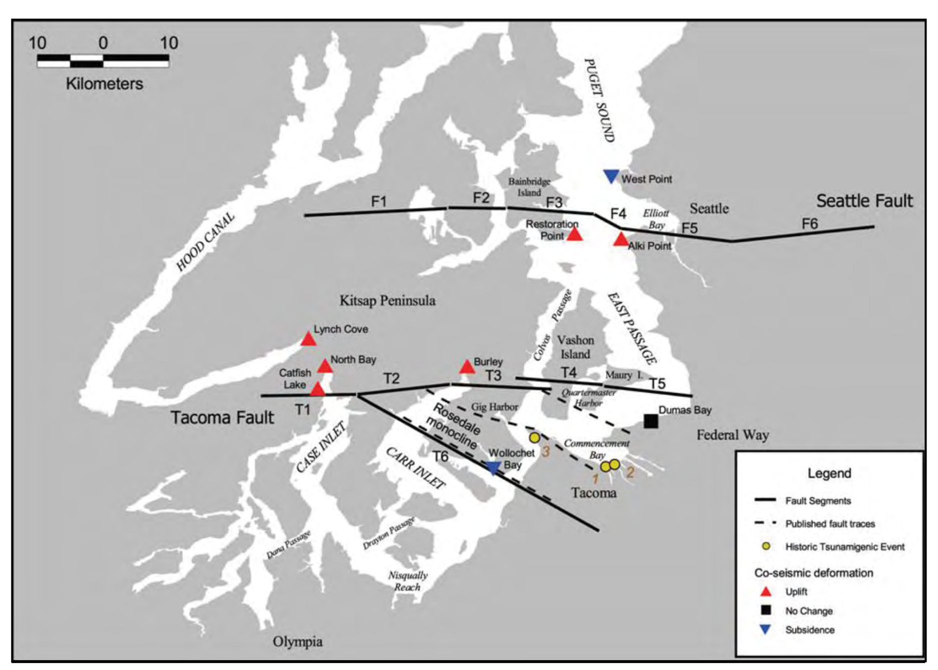


Figure 1. Seattle and Tacoma fault segments used for the study (Brocher and others, 2004). Published fault traces, coseismic deformation, and known historic tsunami events are also displayed (Sherrod and others, 2004; Johnson and others, 1999, 2004; González, 2003; Gardner and others, 2001). From Venturato and others (2007).

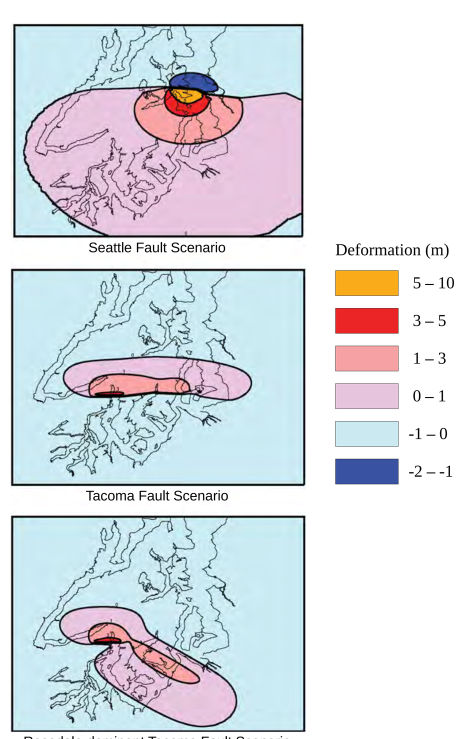


Figure 2. Deformation models for the three scenarios used in this study. From Venturato and others (2007).

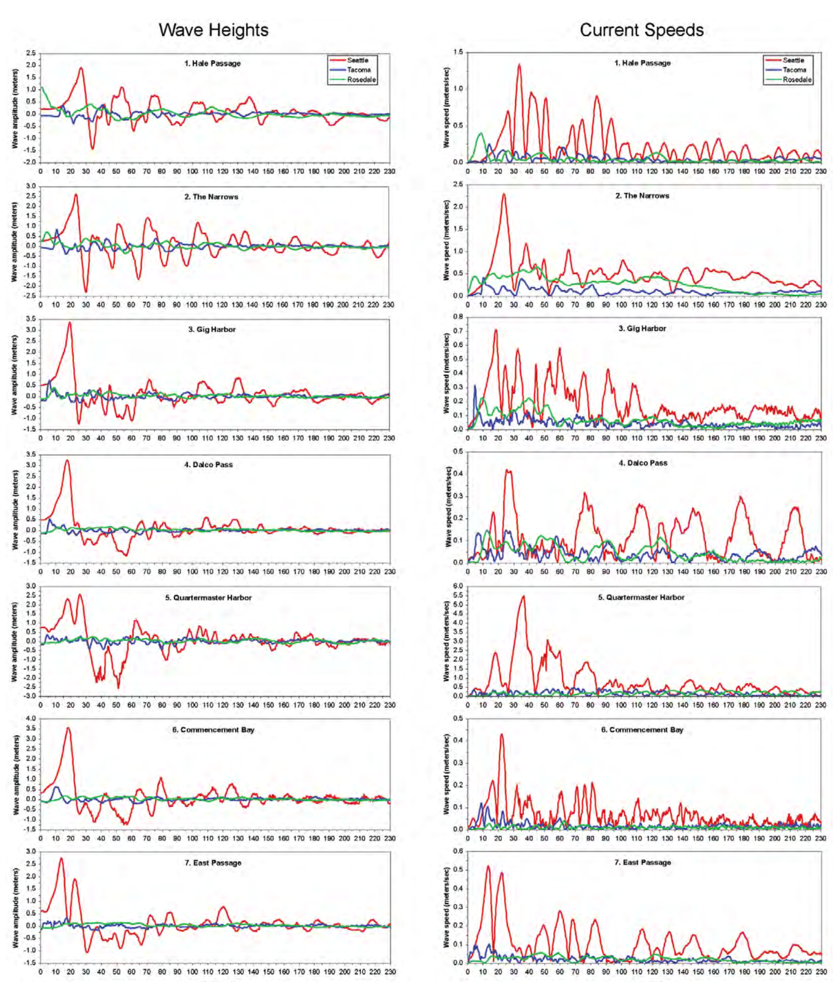
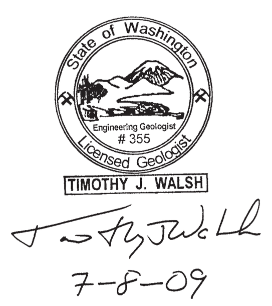


Figure 3. Time series of tsunami wave heights and current speeds at select sites of the study region. Positive peak elevations are wave crests; negative elevations are wave troughs or times when water is flowing out to sea. From Venturato and others (2007). Note that at all locations, the Seattle fault tsunami is much larger.



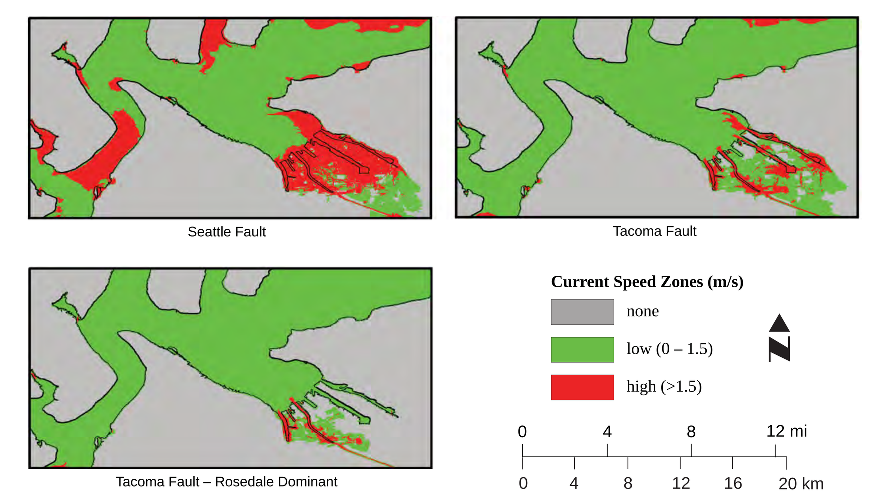


Figure 4. Current velocities modeled for each of the three scenarios. From Venturato and others (2007).

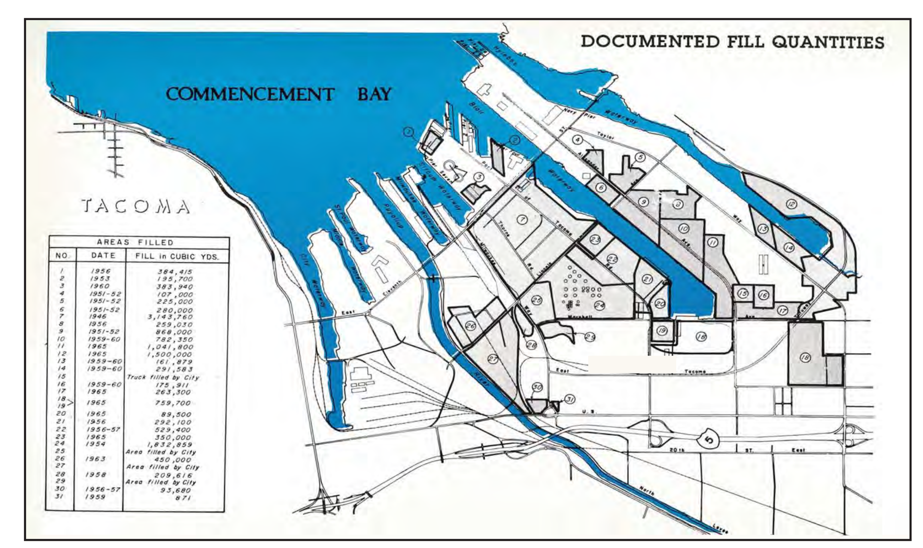


Figure 5. Known fill quantities and dates of emplacement at the Port of Tacoma. From Hart-Crowser, and Associates, Inc. (1974).